TOTAL

ELECTRICAL MAINTENANCE

BATTERIES

TRAINING MANUAL
Course EXP-MN-SE080
Revision 0.1

ELECTRICAL MAINTENANCE

BATTERIES

CONTENTS

1. OBJECTIVES

Can explain, by an understanding of the fundamentals, the basic operating and maintenance principles of the different batteries found on an industrial site. It includes the indispensable battery complement: the DC Power Supply Systems, *and the basic understanding of UPS, converter part DC to AC.*

The student will be able to:

- Explain the fundamental principle of a battery
- Distinguish the different types of batteries
- Describe the application of different types of batteries e.g. lead acid, Ni-Cad etc.
- Explain the choice of a type of battery for a specific use
- Test batteries safely
- Explain why there are different charging rates
- Explain the different types of charging – equalizing, trickle, rapid
- Differentiate the maintenance schedule of each type of battery
- Explain the hazard associated with storage, handling and charging of batteries
- Differentiate and list the different terms describing the "batteries"
- Associate the current generator theories with batteries
- Explain the principle of generating electricity by photovoltaic cells (also known as solar cells)
- List the applications of photovoltaic cells
- List the operations to be carried out on the batteries in a maintenance programme
- Be ready to follow, install and recommend a centralised maintenance management system for battery cells.
- Respect the safety instructions and regulations applicable to the batteries and to the zones, rooms and housings containing batteries
- Ensure that these same safety instructions and regulations are respected by others

2. GENERALITIES

2.1. WHAT IS A BATTERY?

Immediately we think of this battery *or these batteries ("pile" in French)*

Battery type 'A' *Batteries type 'B'*

Figure 1: Different types of batteries

These also exist with other forms and dimensions of course.

And what else, I would say…..?

'A' is the battery, I use in my car

'B' are the batteries, I use in my day to day applications

Figure 2: Different uses of batteries

And I am maybe (and most probably) right, but maybe wrong!

'A' and 'B' are of different made, different principles, different categories, different voltages and using a non adapted battery could result in serious damages to my "application".

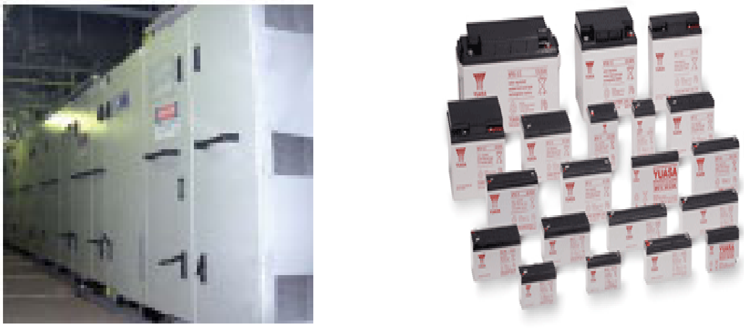
2.1.1. What have all the batteries in common?

- Storage of energy
- Producing DC current under DC voltage
- The same basic principle: the “+” (anode) and the “-“(cathode)
- An electrolyte inside
- Care when disposing of (environmental precautions)
- Can be in series or parallel

2.1.2. What differentiate batteries?

- Dimension and volume
- Form
- Capacity of energy storage: so many Ah under a certain voltage (rated current & peak current)
- The materiel of anode and cathode
- The material of the casing
- The type of electrolyte
- Rechargeable or non rechargeable
- With Maintenance or “*without maintenance”* for ‘A’ type
- No maintenance for ‘B’ type

We are going to see the combinations of the different factors for having batteries to be used on site in our main applications for the ‘A’ type



UPS cubicles with batteries integrated (or apart)

Number, dimensions of batteries as per power requirement

Figure 3: UPS cubicles

Battery charger + battery bank

Distribution of DC voltage / current in unit

Figure 4: Battery charger and battery bank

Figure 5: Set of batteries

Set of batteries to start **Diesel Engine** for generator (EDG), Fire Pump, …etc. and your vehicle (on site), one 12V battery being sufficient…

If something like that happens in one battery bank, it means « something » was missed in the survey and/or the maintenance of « your » batteries

It already occurred on sites, reason of happening is (nearly) always said to be the "low quality of manufacturing", but it is a too easy excuse (even if it is not totally wrong). The 'real' reason is rather the "poor quality" of the operator/technician who has to survey the parameter in control or electrical room and/or some inertia, lack of knowledge in the maintenance…..

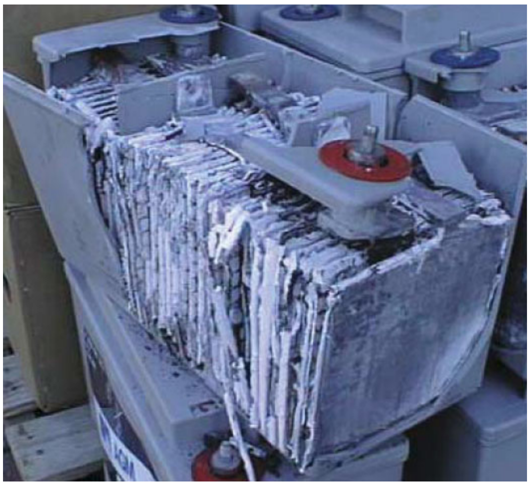


Figure 6: Battery problem

2.1.3. What do we do?

Consequently we shall detail mainly the 'A' type battery which needs care and maintenance. For 'B' batteries, we are going to see only the different types and principles.

In fact, the characteristics of manufacturing are defined within a ***cell***. A ***cell*** alone can be a battery (pile in French) and a battery, in general, is an ***association of cells*** to have the desired voltage and capacity in Ah. To study the characteristics and technology of a cell, we need to know how the current can be generated, subject of following paragraph

2.2. INTER-LANGUAGE

We are using words which can be confusing when trying to translate from French to English and vice-versa. Below you will find a table with the French and English words and expressions commonly used when speaking of batteries. At least this last word is common to both languages, although with a different meaning.

As you can see in the following table, things are not very clear and the expressions we use in either language are not always those we should use.

Mot en français	**Traduction**	**Translation**	**Word in English**
Pile		**?**	*No direct translation*
Le français pense à la pile ronde ou “carrée” qu’il met dans son appareil photo, son baladeur, ou à la batterie plate de la montre. “On” ne sait pas avec ce terme seul si çà se recharge ou non.		French speakers think of the round (or square) dry cell battery used in cameras, radio sets or button types in watches. There is no differentiation as to whether or not the battery is rechargeable.	
	?		**Cell**
La traduction devrait être “élément” (implicitement de batterie). L’anglo-saxon emploie volontiers ce terme pour désigner une “pile” un peu comme en français (toutefois il dira plutôt une “battery”		The element which provides the basic voltage as per the chemical reaction between two metals (in dry and wet electrolyte). English-speakers, like French speakers, commonly use the term “pile”.	
Pile non rechargeable		***Primary Cell***	
L’on pense toujours à la pile “sèche” utilisée comme au-dessus, non rechargeable, soit celle que l’on jette (attention, pas n’importe où…)		Still the same type as above, for non rechargeable ones.	
Dire pile non rechargeable est en fait un pléonasme, le mot “pile” seul devrait désigner l’élément non rechargeable		In fact, in French the word “pile” used alone would mean “primary cell” for non-rechargeable batteries, but non-rechargeable or rechargeable is commonly specified.	
Pas vraiment traduisible	**?**		**Primary Cell**
Ce devrait être “pile non rechargeable”, si l’on admet que dans le langage vulgarise l’on puisse employer ce pléonasme…..		A battery which is not rechargeable, meaning essentially the dry cell types. *Some wet cells are also primary cells (and non rechargeable).*	

Mot en français	**Traduction**	**Translation**	**Word in English**
Pile rechargeable		**?**	*No formal translation*
L'on pense toujours aux "petites piles" de nos appareils électroniques, celles que l'on met à recharger dans un "chargeur", les "piles" du type Cd-Ni / Ni-MH / ….		With "pile", the French still means the dry cell, but when "rechargeable" is specified, it becomes a ***secondary cell.*** The latter term means "a cell that can be recharged" (Type Cd-Ni / Ni-MH /...)	
Le terme à employer devrait être "accumulateur" (pour pile rechargeable) mais accumulateur est interprété autrement…..		Same as in French, the term to use should be "accumulator" which is the equivalent of secondary cell.	
	?		**Secondary cell**
Tout ce qui se recharge, que ce soit pile, batterie, accumulateur		All types of batteries (dry or wet) which are rechargeable	
Accumulateur		***Accumulator***	
La définition devrait être pour tout ce qui est rechargeable que l'on parle de pile ou de batterie de voiture, de batterie d'ASI. *Dans la langue courante, en disant accumulateur ou "accu", l'on pense à la batterie de voiture, seule*		For French speakers, this word is systematically associated with their car battery and more generally with wet batteries. This is not incorrect, but it is a narrow view of the word accumulator which applies to all types of batteries that are rechargeable. It is equivalent to a "secondary cell".	
	Accumulateur		**Accumulator**
Peu employé dans la langue anglo-saxonne. Mais ce mot (accumulateur) peut aussi bien désigner la "batterie rechargeable", que l'accu, faites vous préciser de quoi on parle…		By definition it is *"a voltaic battery that stores an electric charge"*. The term is not frequently used; instead it should be ***Storage Battery*** when speaking about car batteries or a UPS battery bank. In fact, it should be any type of rechargeable battery (dry or wet).	
Batterie		***Battery***	
L'on pense à la batterie de voiture ou aux jeux de batteries des armoires chargeurs et alimentations secourues. C'est systématiquement une "batterie" rechargeable avec électrolyte. La encore c'est un pléonasme de rajouter rechargeable à batterie		With this term, French speakers only "think of" their car battery or the battery used in a UPS.	

	Batterie	**Battery**	
C'est le terme général utilisé par les anglo-saxons pour tout ce qui fournit du courant continu à partir d'une réaction chimique. Faites vous préciser le type de "batterie".		Used as general term for "anything" that produces DC current from a chemical reaction (dry, wet, small, big…). When speaking with French speakers, specify the type of battery you mean.	
Élément (de batterie)		***Cell***	
C'est "l'unité" de" base (2V pour l'élément plomb/acide – 1,25V pour le nickel/cadmium et potassium). Même si l'on ne pense qu'à la "grosse" batterie, l'élément s'applique aux "batteries" qui peuvent être composées d'un ou plusieurs éléments		With the term "element", French speakers mean the cell in a wet battery. In fact it should the equivalent of "cell" for any type of battery.	
Jeu de batteries / rack de batteries		**Battery bank / battery rack**	
Pour terminer, avec un terme pour lequel il n'y a pas de problème de traduction/compréhension L'ensemble des batteries (avec électrolyte) équipant un rack de chargeur et/ou d'armoire onduleur		This is the last term with a common interpretation. A set or bank of wet batteries equipping a UPS system (with inverter), a DC supply system with battery charger.	
Comment on dit en anglais ?		**How to translate to French?**	
En disant "batterie" vous êtes sur de ne pas vous tromper, ça couvre toute la gamme. Par la suite il faudra préciser le type de "batterie"	***Battery***	***Pile / batterie***	You need to differentiate. A "pile" cannot be in a battery bank or in a car and a "batterie" cannot be installed in a camera…

Table 1: Words and expressions used in French and English when speaking of batteries

2.3. ORIGIN AND HISTORY OF BATTERIES

But prior to go to “serious” explanations, let us see some ‘story’ or history.

There are some clues that batteries may have been used in the ancient world, particularly in Baghdad around two thousand years ago. There have also been some finds in Egypt dating back to the ancient period, but none of these have been categorically proven to be batteries.

The first documented battery of the modern era is attributed to the American ***Benjamin Franklin*** in the middle of the 18th Century. He made capacitor out of charged glass plates that was able to produce powerful electric shocks hence the word “Battery” as in “Assault and Battery “came into general use.

Some 50 years later at the very beginning of the 19th Century the Italian ***Alessandro Volta*** made the first chemical battery using copper and zinc discs in brine. This discovery sparked off all sorts of new scientific advances across Europe during the early 19th century as it was now possible to produce electricity reliably.

Volta was followed by ***William Cruickshank*** who created the first battery in 1802. He aligned several squared sheets of copper, soldered them together at one end with a connector, intercalated sheets of zinc of same dimensions and immersed the all in an diluted acid (or salted) aqueous solution and in a wooden waterproof rectangular box.

He created the **first battery** (non rechargeable).

The next major advance came when the Frenchman ***Georges Leclanché*** produced an entirely new form of cell using carbon / zinc. This proved to be the basic technology behind non rechargeable or Primary batteries still in use today.

Another Frenchman, Raymond ***Gaston Planté*** made the **first rechargeable battery** or Secondary Battery using lead plates in a mild solution of sulphuric acid in the 1860’s. This invention has continued in use for nearly 150 years has gone on to be the type of battery still used in cars today.

In the last 120 years the pace of new inventions hoted up. All the various types of battery we now use were developed during this period. It is an intriguing thought that the technology needed to develop these new types of cells depended on the advances in chemistry and physics which had happened after Volta’s cell of 1800.

This allowed for the discovery of the new metals and materials necessary for the designs of these new

The Milestones are:

Year	**Inventor**	**Invention**
1600	Gilbert (England)	First studies on electrochemistry
1791	Galvani (Italy)	The so called "animal electricity"
1800	Volta (Italy)	Discovery of the "voltaic battery"
1802	Cruickshank (England)	First production in series of an electrical battery
1820	Ampère (France)	Magnetism produces electricity
1833	Faraday (England)	Announcement of the Faraday Law
1836	Daniell (England)	Discovery of "Daniell battery"
1859	Planté (France)	Battery lead / Lead - Acid
1868	Leclanché (France)	Battery "Leclanché"
1881	Emile Faure (France)	Lead oxide battery
1888	Gassner (USA)	The dry cell
1897	Tesla (Serbia / USA)	Oxygen Hydrogen
1899	Jungner (Sweden)	The Nickel Cadmium battery
1900	Edison (USA)	The nickel storage
1905	Edison (USA)	The nickel Iron battery
1942	Ruben & Mallory	The Mercury cell
1947	Neumann (France)	First practical Nickel Cadmium cells
1959	Urry (USA)	Patents for primary alkaline battery
1960	--	Development of Lithium battery
70'	--	Development of VRLA Vale Regulated Lead Acid battery
1990		First Ni-MH battery on sale
1992	Kordesh (Canada)	Sale of the first alkaline battery rechargeable
1999		First Li-ion battery
2002		First limited production of 'pile à combustible'

Table 2: Some battery milestones

2.4. CHEMISTRY OF A CELL

A battery consists of one or more electro-chemical ***cells***. Although the terms battery and cell are often used interchangeably cells are the building blocks of which batteries are constructed.

Batteries consist of one or more cells that are electrically connected.
Term ‘battery’ has not disappeared but the real denomination of this source of energy is ‘cell’ or ***battery cell***.

The production of energy within a cell is based on a chemical reaction; we just need to see a minimum of chemistry to explain what is going on inside this cell.

2.4.1. Cells

A cell normally consists of the four principal components shown under.

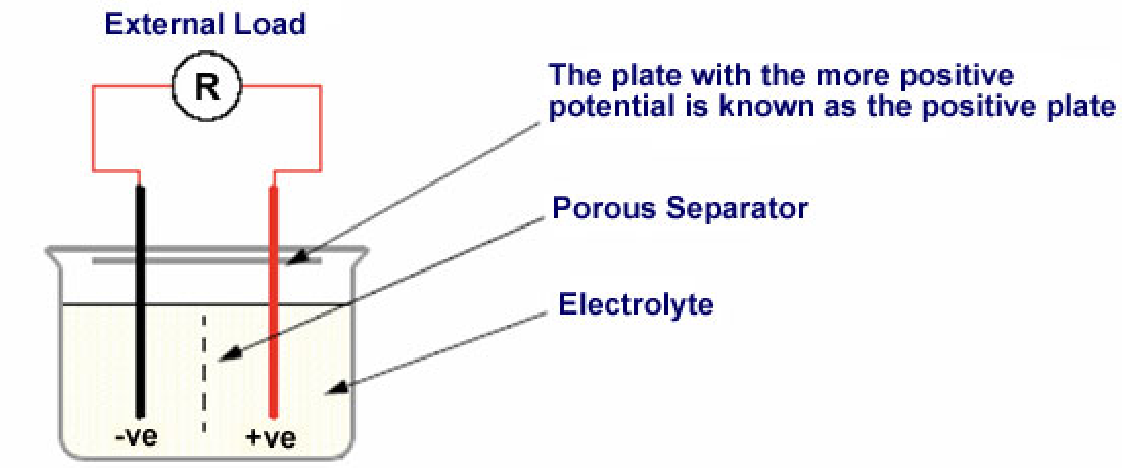


Figure 7: Composition of a battery cell

These are:

- A ***positive electrode or cathode*** (the oxidising electrode) that receives electrons from the external circuit when the cell is discharged, and is reduced during the electrochemical (discharge) reaction. It is usually a metallic oxide or a sulphide but oxygen is also used. The cathodic process is the reduction of the oxide to leave the metal. (GER: Gain Electrons - Reduction). Remember the mnemonic of the lion growling.

- A ***negative electrode or anode*** (the reducing or fuel electrode) that donates electrons to the external circuit as the cell discharges and is oxidised during the electrochemical (discharge) reaction. It is generally a metal or an alloy but hydrogen is also used. The anodic process is the oxidation of the metal to form metal ions. (LEO: Lose Electrons - Oxidation)

- ***Electrolyte*** (the ionic conductor) which provides the medium for transfer of charge as ions inside the cell between the anode and cathode. The electrolyte is typically a solvent containing dissolved chemicals providing ionic conductivity. It should be a non-conductor of electrons (or ions) to avoid self discharge of the cell.

- A ***separator*** which electrically isolates the positive and negative electrodes.

In some designs, physical distance between the electrodes provides the electrical isolation and the separator is not needed.

In addition to the critical elements listed above, cells intended for commercial batteries normally require a variety of packaging and current collection apparatus to be complete.

All Metals have natural ‘voltage’, and different metals immersed in an electrolyte have different electromotive force potentials, as the examples in the following table show:

Metal	Emf (volts)	Metal	Emf (volts
Magnesium	Mg : -2.37	Lead	Pb : - 0.13
Aluminium	Al : -1.66	Hydrogen	H : 0
Zinc	Zn : -0.76	Copper	Cu : +0.34 to +0.52
Iron	Fe : - 0.44	Mercury	Hg : + 0.80
Cadmium	Cd : - 0.40	Silver	Ag : + 0.80
Nickel	Ni : - 0.23	Gold	Au : +1.58 to +1.68

Table 3: "Natural voltage" of metals

Association of these different metals under the form of rod, plate (alone or several in series) will decide the value of the “emf” or voltage of the cell.

2.4.2. How a Cell Works

When a battery or cell is inserted into a circuit, it completes a loop which allows charge to flow uniformly around the circuit.

In the external part of the circuit, the charge flow is electrons resulting in electrical current.

Within the cell, the charge flows in the form of ions that are transported from one electrode to the other.

The positive electrode receives electrons from the external circuit on discharge. These electrons then react with the active materials of the positive electrode in "reduction" reactions that continue the flow of charge through the electrolyte to the negative electrode.

At the negative electrode, "oxidation" reactions between the active materials of the negative electrode and the charge flowing through the electrolyte results in surplus electrons that can be donated to the external circuit.

It is important to remember that the system is closed. For every electron generated in an oxidation reaction at the negative electrode, there is an electron consumed in a reduction reaction at the positive.

As the process continues, the active materials become depleted and the reactions slow down until the battery is no longer capable of supplying electrons. At this point the battery is discharged

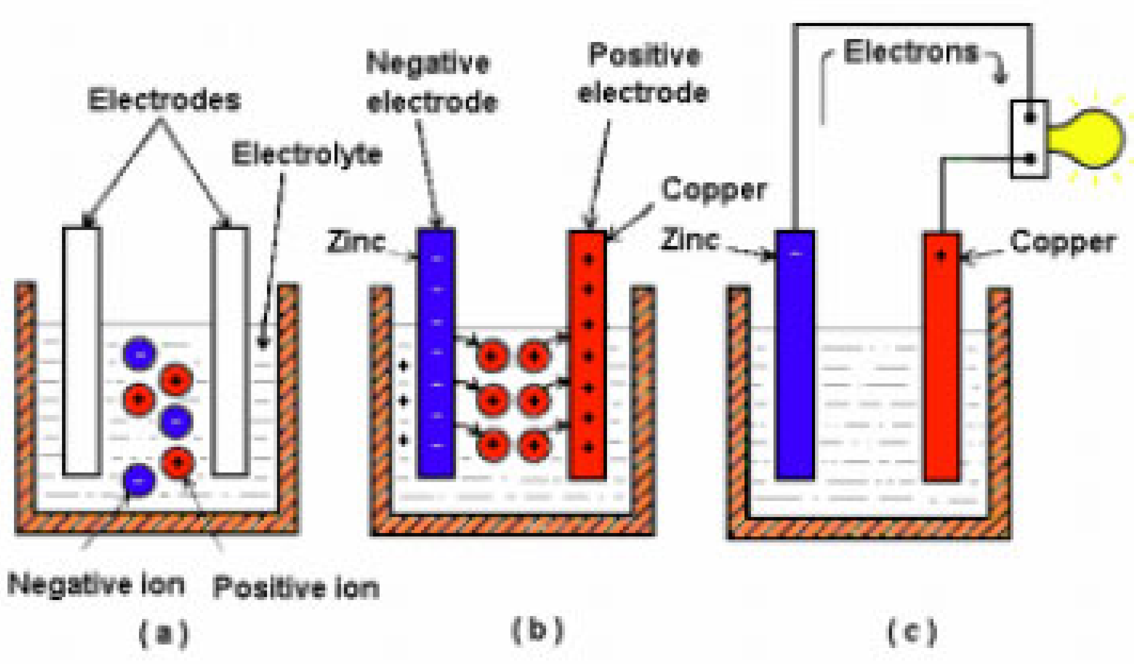


Figure 8: Process in a battery cell

A *voltaic chemical cell* is a combination of materials used to convert chemical energy into electric energy. The chemical cell consists of two electrodes made of different kinds of metals or metallic compounds, and an electrolyte, which is a solution capable of conducting an electric current (Fig. above). A battery is formed when two or more cells are connected

An excellent example of a pair of electrodes is *zinc* and *copper.* Zinc contains an abundance of negatively charged atoms, while copper has an abundance of positively charged atoms. When plates of these metals are immersed in an electrolyte, chemical action between the two begins. The zinc electrode accumulates a much larger negative charge since it gradually dissolves into the electrolyte.

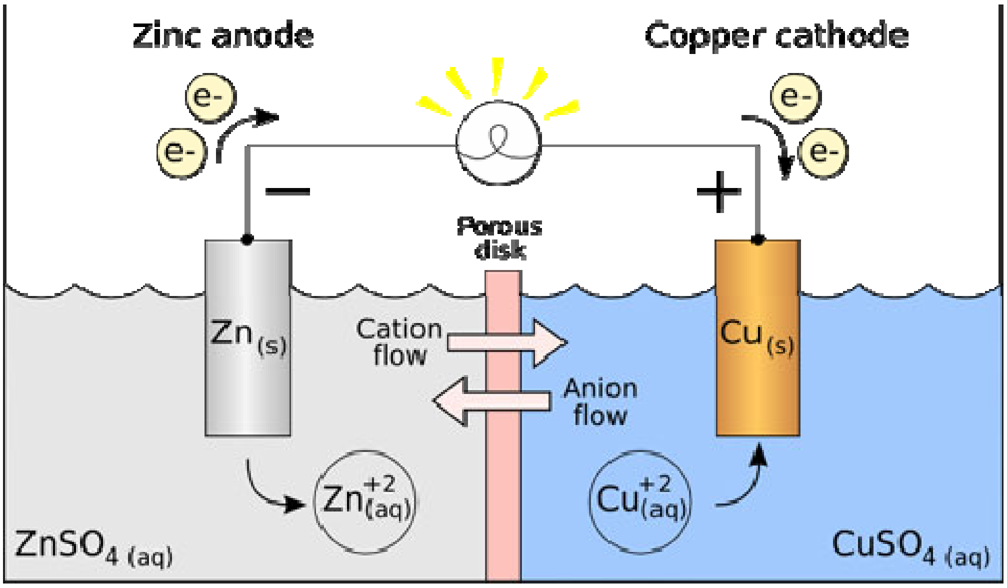
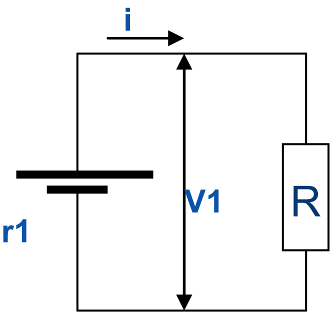


Figure 9: Voltaic chemical cell

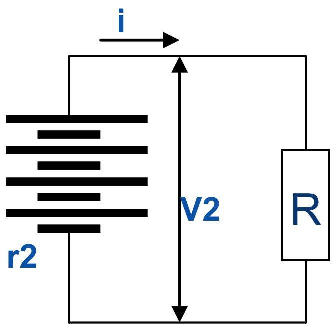
The atoms which leave the zinc electrode are positively charged. They are attracted by the negatively charged ions (-) of the electrolyte, while they repel the positively charged ions (+) of the electrolyte toward the copper electrode. This causes electrons to be removed from the copper, leaving it with an excess of positive charge.

If a load such as a light bulb is connected across the terminals on the electrodes, the forces of attraction and repulsion will cause free electrons in the negative zinc electrode, connecting wires, and light bulb filament to move toward the positively charged copper electrode.

The potential difference that results permits the cell to function as a source of applied voltage.



Question: which potential is (theoretically) higher?
☐ V1 ☐ V2
On which schematic is a cell?
☐ Left ☐ Right ☐ Both
On which schematic can be a battery?
☐ Left ☐ Right ☐ Both



So, ***batteries are devices for converting chemical energy into electrical energy whose voltage is function of the metals used in electrodes.***

Inside the battery itself, a chemical reaction produces the electrons.
The speed of electron production by this chemical reaction (the battery's **internal resistance**) controls how many electrons can flow between the terminals.

When the **Electrons** flow from the battery into a cable, they must travel from the negative to the positive terminal for the chemical reaction to take place.

That is why a battery can sit on a shelf for a year and still have plenty of power unless electrons are flowing from the negative to the positive terminal, the chemical reaction does not take place.

Once you connect a battery to a load, the reaction starts.

2.4.3. The Discharge Process

When the battery is fully charged there is a surplus of electrons on the anode giving it a negative charge and a deficit on the cathode giving it a positive charge resulting in a potential difference across the cell.

When the circuit is completed the surplus electrons flow in the external circuit from
The negatively charged anode which loses all its charge to the positively charged Cathode which accepts it, neutralising its positive charge. This action reduces the potential difference across the cell to zero. The circuit is completed or balanced by the flow of positive ions in the electrolyte from the anode to the cathode.

Since the electrons are negatively charged the electrical current they represent flows in the opposite direction, from the cathode (positive terminal) to the anode (negative terminal).

2.4.4. Recharging or not recharging

The world of batteries divides into two major classes:

- ***Primary*** Cells (or batteries)
  In primary cells this electrochemical reaction is not reversible. During discharging the chemical compounds are permanently changed and electrical energy is released until the original compounds are completely exhausted. Thus the cells can be used only once.
- ***Secondary*** Cells (or batteries).

In secondary cells this electrochemical reaction is reversible and the original chemical compounds can be reconstituted by the application of an electrical potential between the electrodes injecting energy into the cell. Such cells can be discharged and recharged many times.

Figure 10: Primary batteries

Primary batteries (or cells) such as the common torch battery are used once and replaced. The chemical reactions that supply current in them are irreversible, they ***cannot be recharged***

Secondary batteries (or cells) can be ***recharged and discharged*** many times. They use reversible chemical reactions. By reversing the flow of electricity i.e. putting current in rather than taking it out, the chemical reactions are reversed to restore active material that had been depleted.

Figure 11: Secondary batteries

Secondary batteries are also known as **rechargeable batteries**, ***storage batteries*** or ***Accumulators***. (Accumulator = rechargeable battery)

In Chapter 4, we see the different types of batteries diversifying the primary and the secondary ones.

2.4.5. Choice of Active Chemicals

The voltage and current generated by a galvanic cell is directly related to the types of materials used in the electrodes and electrolyte.

The propensity of an individual metal or metal compound to gain or lose electrons in relation to another material is known as its electrode potential. Thus the strengths of oxidizing and reducing agents are indicated by their standard electrode potentials.

Compounds with a positive electrode potential are used for anodes and those with a negative electrode potential for cathodes.

The larger the difference between the electrode potentials of the anode and cathode, the greater the EMF of the cell and the greater the amount of energy that can be produced by the cell.

Note: larger EMF is one reason for greater energy, other parameters are involved as well in the battery capacity

Electrochemical Series is a list or table of metallic elements or ions arranged according to their electrode potentials. The order shows the tendency of one metal to reduce the ions of any other metal below it in the series.

A sample from the table of standard potentials shows the extremes of the table.

Strengths of Oxidizing and Reducing Agents	
Cathode (Reduction) Half-Reaction	Standard Potential E ° (volts)
Li + (aq) + e - -> Li(s)	-3.04
K + (aq) + e - -> K(s)	-2.92
Ca_2+ (aq) + 2e - -> Ca(s)	-2.76
Na + (aq) + e - -> Na(s)	-2.71
Zn_2+ (aq) + 2e - -> Zn(s)	-0.76
Cu_2+ (aq) + 2e - -> Cu(s)	0.34
O_3 (g) + 2H + (aq) + 2e - -> O_2 (g) + H_2O(l)	2.07
F_2 (g) + 2e - -> 2F - (aq)	2.87

Table 4: Samples from the table of standard potentials

The values for the table entries are reduction potentials, so lithium at the top of the list has the most negative number, indicating that it is the strongest reducing agent. The strongest oxidizing agent is fluorine with the largest positive number for standard electrode potential.

The table below shows some common chemicals used for battery electrodes arranged in order of their relative electrode potentials.

Anode Materials	**Cathode Materials**
(Negative Terminals)	(Positive Terminals)
BEST - Most Negative	BEST - Most Positive
Lithium	Ferrate
Magnesium	Iron Oxide
Aluminium	Cuprous Oxide
Zinc	Iodate
Chromium	Cupric Oxide
Iron	Mercuric Oxide
Nickel	Cobaltic Oxide
Tin	Manganese Dioxide
Lead	Lead Dioxide
Hydrogen	Silver Oxide
Copper	Oxygen
Silver	Nickel Oxyhydroxide
Palladium	Nickel Dioxide
Mercury	Silver Peroxide
Platinum	Permanganate
Gold	Bromate
WORST - Least Negative	WORST - Least Positive

Table 5: Some common chemicals used for battery electrodes

Cells using aqueous (containing water) electrolytes are limited in voltage to about 2 Volts because the oxygen and hydrogen in water dissociate in the presence of voltages above this voltage. Lithium batteries which use non-aqueous electrolytes do not have this problem and are available in voltages between 2.7 and 3.7 Volts.

However the use of non-aqueous electrolytes results in those cells having relatively high internal impedance.

2.5. BASIC BATTERY CONCEPT

There are two parameters that measure battery performance: voltage and capacity. In very simple terms, the voltage is the force propelling each of the electrons coming out of a battery and the capacity is the number of electrons that can be obtained from a battery.

How these parameters relate to batteries is explained below.

2.5.1. Voltage

All batteries work on the same set of reactions and use the same active materials.

Let's take the lead-Lead /Acid battery as a base of demonstration

At the positive electrode, lead dioxide (PbO_2) is converted to lead sulphate ($PbSO_4$) and at the negative electrode, sponge metallic lead (Pb) is also converted to lead sulphate ($PbSO_4$). The electrolyte is a dilute mixture of sulphuric acid that provides the sulphation for the discharge reactions.

The reduction and oxidation reactions each produce a fixed potential. The sum of the reduction and oxidation potential is the voltage of the cell. For example, the discharge reaction at the positive electrode for a lead-acid cell is $PbO_2 + SO_4\ -2 + 4H+ + 2e- \rightarrow PbSO_4 + 2H_2O$.

This has a potential of 1.685 volts.

The reaction at the negative electrode is $Pb + SO_4-2 \rightarrow PbSO_4 + 2e$

This has a potential of 0.356 volts. This means that the overall ***voltage of a lead-acid cell is 2.04 volts.***

This value is known as the standard electrode potential. Other factors, such as the acid concentration can also affect the voltage of a lead-acid cell. The typical open circuit voltage of ***commercial lead-acid cells is around 2.15 volts***. Depending the manufacturer

Thus the voltage of any battery cell is established depending on the cell chemistry.

- Nickel-cadmium cells are about 1.2 volts,
- Lead-acid cells are about 2.0 volts, and
- Lithium cells may be as high as nearly 4 volts. (3,6 – 3,7V)

Cells can be connected together so that their voltages accumulate. This means lead-acid batteries with nominal voltages of 2v, 4v, 6v, etc. are available.

2.5.2. Capacity

While the voltage of a cell is fixed by its chemistry, cell capacity is variable depending on the quantity of active materials it contains. Individual cells may range in capacity from fractions of an ampere-hour to many thousands of ampere-hours.

The capacity of a battery is rated in *ampere-hours* (Ah). The capacity of a storage battery determines how long it will operate at a given discharge rate.
For example, a 90Ah battery must be recharged after 9h of an average 10A discharge.

A cell of a lead-acid automobile battery, when fully charged, has an initial voltage of 2.1V at no load, but discharges rapidly. The battery is *dead* after about 2 h of discharging under load condition (2 hours as example if you leave your headlights on without engine running). However, in normal use, the alternator in the automobile constantly recharges this battery type

Question/Exercise:

A car is equipped with a 50Ah battery, fully charged. I leave the lights on; having a power of 60W during 2 hours discharging the battery (we assume the voltage stay constant at 12V). How long it will take to recharge this battery with a loading current of 0.1 time the capacity of battery (C/10 A or 0.1 C A)

☐ 0.5 hour ☐ 1 hour ☐ 2 hours ☐ 5 hours ☐ 10 hours

Even having not seen the charging of batteries (chapter 4) you can find the solution

2.5.3. Voltage and Capacity

Batteries normally consist of multiple cells that are electrically connected. The way that the electrical connections are made determines the voltage and capacity of the battery.

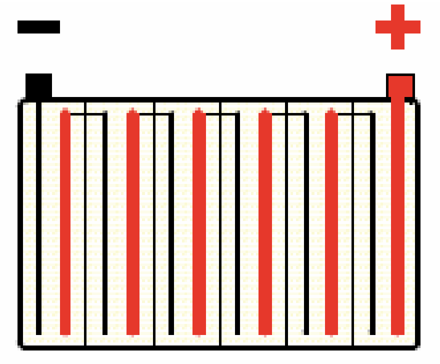


Figure 12: Voltage and capacity

If the positive terminal of one cell is connected to the negative terminal of the next and so on through the battery the result, as illustrated in side figure, is called a series connected battery. The voltage of this type of battery is the sum of the individual cell voltages.

For example, a 12-volt battery consists of 6 x 2-volt lead-acid cells connected in series. Although the voltages add, the cell capacity is fixed at the value for the individual

Let’s see the voltage and capacity in the next paragraph

2.6. SERIES AND PARALLEL CELLS

Any type of battery can be associated, connected either in series or parallel

Here for carbon-zinc primary cells the “natural” voltage is 1,5V by cell

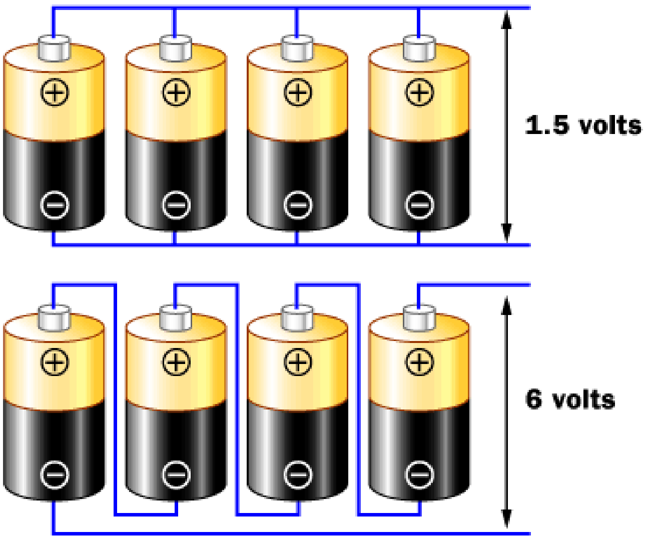


Figure 13: Series and parallel cells

Question: with several cells

In parallel, I increase ☐ Capacity ☐ Voltage ☐ Both Voltage and Capacity

In series, I increase ☐ Capacity ☐ Voltage ☐ Both Voltage and Capacity

2.6.1. Series String

When ***cells are connected in series***, the total voltage across the battery of cells is equal to the sum of the voltage of each of the individual cells.

In the figure, the four 1.5 V cells in series provide a total battery voltage of 6 V.

When the cells are placed in series, the positive terminal of one cell is connected to the negative terminal of the other cell.

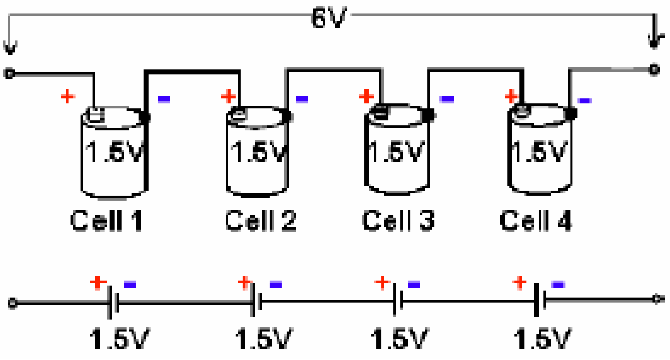


Figure 14: Cells connected in series

The current flowing through such a battery of series cells is the same as for one cell because the same current flows through all the series cells.

Note: In any battery configuration, all of the cells used in a series string must be identical to each other.

A series string is a single series of blocks connected ‘end-to-end’ to form the battery.

The positive terminal of the first block is connected to the negative terminal of the second block; the positive terminal of the second is connected to the negative of the third, etc.

The *overall voltage* of the battery is the sum of the individual block voltages and *must be arranged to match the float voltage setting of the UPS or charger circuit (this in anticipation of following chapter)*.

The capacity of the battery is unchanged with this arrangement, being the same as each individual block.

For example:

If 12 x 12V 10Ah blocks are connected in series, the resulting battery is 144V with a 10Ah capacity.

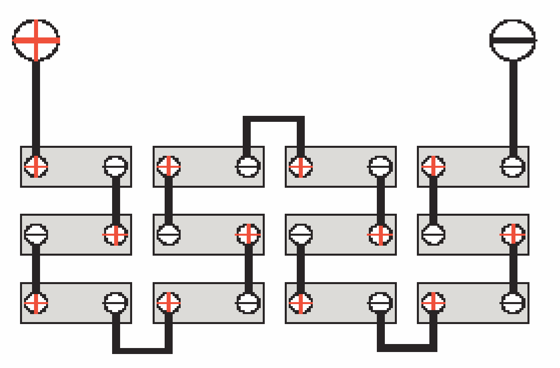
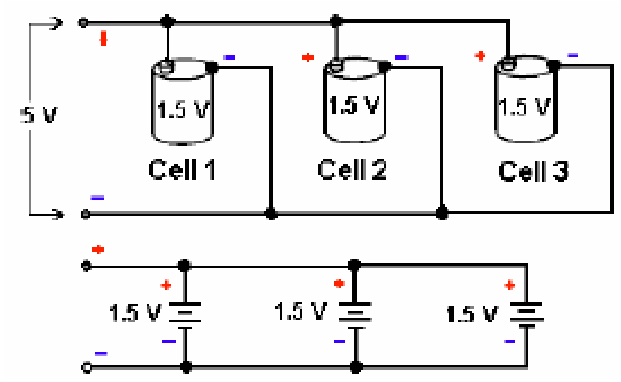


Figure 15: 12 blocks connected in series

2.6.2. Parallel Strings

To obtain a greater current, the battery has cells in parallel



When cells are placed in parallel, all the positive terminals are connected together and all the negative terminals are connected together.

Any point on the positive side can serve as the positive terminal of the battery and any point on the negative side can be the negative terminal.

Figure 16: Parallel strings

The total voltage output of a battery of three parallel cells is the same as that for a single cell, but the available current is three times that of one cell. The parallel connection has the same effect of increasing the size of the electrodes and electrolyte in a single cell, which increases the current capacity.

Identical cells in parallel all supply equal parts of the current to the load.

For example, of three identical parallel cells producing a load current of 270mA, each cell contributes 90mA.

And in “our” industrial application: the series/parallel

A parallel string is a ***combination of two or more series strings***, and ***each string must contain the same number of blocks***. Batteries are paralleled for two main reasons. The primary reason is to increase the capacity (Ah rating) of the battery bank. The other reason is to increase the resilience of the battery bank so that a single faulty battery will not cause all of the batteries to be unavailable to the supported load.

The positive terminal of the first battery series string is connected to the positive terminal of the second battery series string; the positive terminal of the second is connected to the positive of the third, etc.

The negative terminal of the first battery series string is connected to the negative terminal of the second battery series string; the negative terminal of the second is connected to the negative of the third, etc.

The overall voltage of the battery is the same as the voltage of each series string.

The capacity of the battery is the sum of the capacities of the individual series strings.

For example:

If 3 strings of 12 x 12V 10Ah batteries are connected in parallel, the resulting battery is 144V with a 30 Ah capacity.

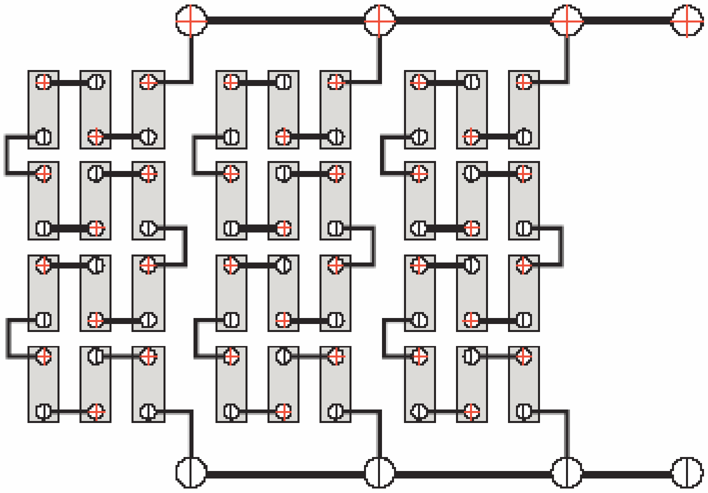


Figure 17: 3 parallel connected strings of 12 blocks

It is unusual for more than six battery series strings to be paralleled.

Questions:

To obtain a greater current, the battery has cells in

☐ parallel ☐ series

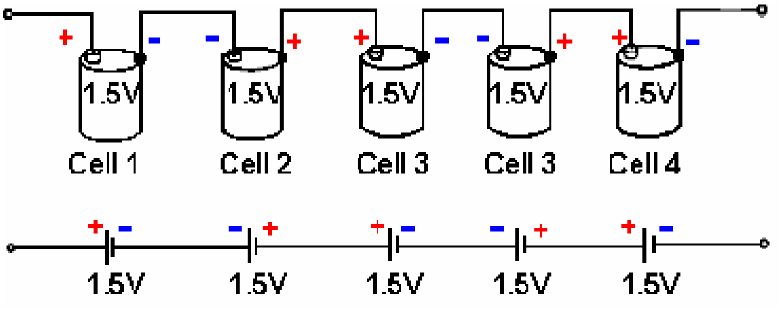
Three identical parallel cells (90mA) produce a load current of

☐ 270 mA ☐ 90mA ☐ 30 mA

The total voltage output of a battery of three parallel cells is

☐ The same as that for a single cell ☐ different

Calculate the “theoretical” voltage of this series assembly



Is this configuration possible (polarities mixed?)

☐ Yes ☐ No

2.7. INTERNAL RESISTANCE OF A BATTERY

A battery is a dc voltage generator. All generators have internal resistance, R_1.

In a chemical cell, the resistance of the electrolyte between electrodes is responsible for most of the cell's internal resistance

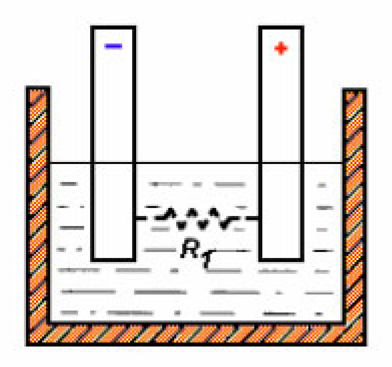
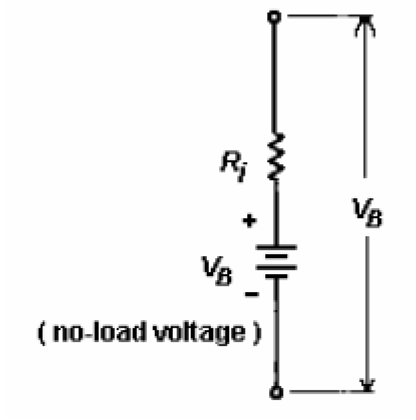


Figure 18: Internal resistance of a battery



Since any current in the battery must flow through the internal resistance, R_1 is in series with the generated voltage V_B
With no current, the voltage drop across R_1 is zero so that the full generated voltage V_B develops across the output terminals.

This is the *open-circuit voltage*, or *no-load voltage*.

Figure 19: No-load voltage

If a load resistance R_L is connected across the battery, R_L is in series with R_1.

When current I_L flows in this circuit, the internal voltage drop, $I_L R_1$, decreases the terminal voltage V_L of the battery so that:

$V_L = V_B – I_L R_1$

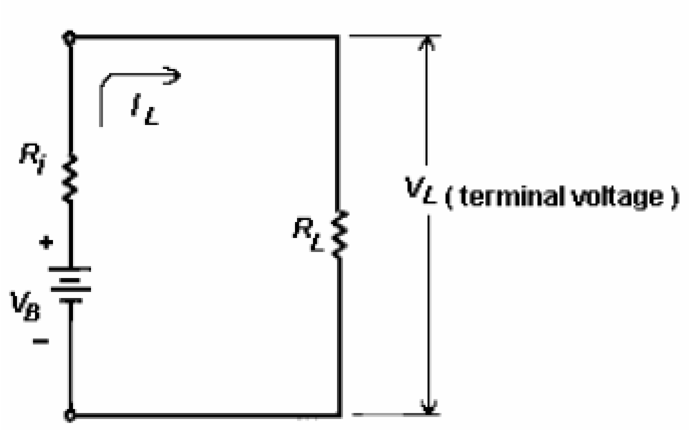


Figure 20: Terminal voltage

The voltage measured between '+' and '-'of an open battery is systematically higher than the voltage measured between the same points but with the battery on load.

The internal resistance of a cell can be calculated using the circuit shown below:

If we measure the cell voltage with the switch open and let this be 'E', now close the switch and measure the current (i) and cell voltage again which is now U.

If E = 2.2V, U = 2.0V and i = 10A, then the cell internal resistance (R_1) can be calculated.

The cell internal voltage drop (V_C) due to the resistance is :

$V_C = E – U = 2.2V – 2.0V = 0.2V = V_C$

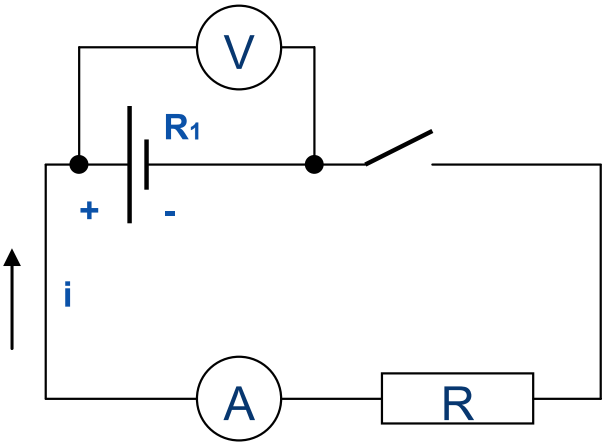


Figure 21: Calculation of internal resistance

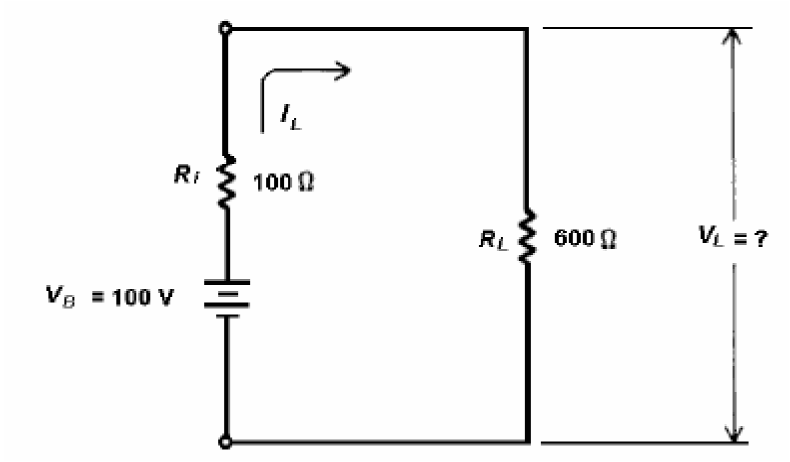
Then,

$$R_1 = \frac{V_c}{i} = \frac{0,2}{1} = 0,02\Omega = R_1$$

Exercise:

It is your turn now to find the ‘real’ voltage on a load

A dry battery has an open-circuit, or no-load, voltage of 100V. If the internal resistance is 100 Ω and the load resistance is 600 Ω, find the voltage V_L across the output terminals.



The battery is marked 100V because 100V is its open-circuit voltage. With no load, the load current is zero.

When load resistance R_L is added, there is a closed circuit, and the load current is calculated by Ohm’s law.

V_L = ??

2.8. ELECTROLYTE

The electrolyte of a cell may be liquid or paste.

- If the electrolyte is a ***liquid***, the cell is often called a ***wet*** cell.
- If the electrolyte is in a **paste** form, the cell is referred to as a ***dry*** cell.

Paste is also called ‘Gel’

The electrolyte is ***the ionic conductor*** which provides the medium for transfer of charge as ions inside the cell between the anode and cathode.

The electrolyte is typically a solvent containing dissolved chemicals providing ionic conductivity. It should be a non-conductor of electrons to avoid self discharge of the cell.

Cells using aqueous (containing water) electrolytes (the wet ones) are limited in voltage to less than 2 Volts because the oxygen and hydrogen in water dissociate in the presence of voltages above this voltage. Lithium batteries which use non-aqueous electrolytes do not have this problem and are available in voltages between 2.7 and 3.7 Volts.

However the use of non-aqueous electrolytes results in those cells having relatively high internal impedance.

2.8.1. The two electrolytes in the Daniell Battery

(and review of how it works)

The principles of the Galvanic cell can be demonstrated by the workings of the Daniell cell, a ***two electrolyte*** system.

Two electrolyte primary cell systems have been around since 1836 when the Daniell cell was invented to overcome the problems of polarisation. This arrangement illustrates that there are effectively two **half cells** at which the chemical actions take place. Each electrode is immersed in a different electrolyte with which it reacts.

The **electrode potential**, either positive or negative, is the voltage developed by the single electrode. The electrolytes are separated from each other by a **salt bridge** or **porous membrane** which is neutral and takes no part in the reaction.

By the process of osmosis, it allows the sulphate ions to pass but blocks the metallic ions.

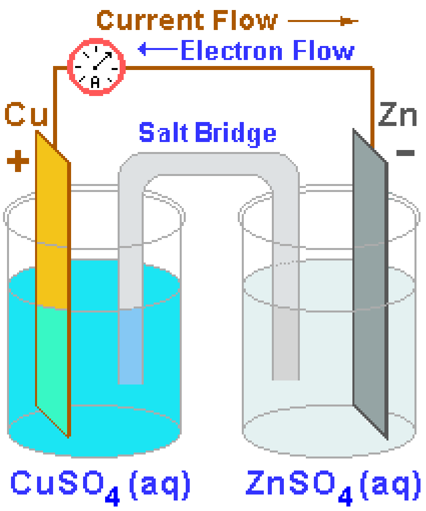
THE CATHODE	**DANIELL CELL**	**THE ANODE**
The **positive** pole of the battery		The **negative** pole of the battery Zinc loses electrons more readily than copper
Accepts electrons from the external circuit		**Supplies electrons** to the external circuit
Copper metal deposits on the cathode		Zinc goes into aqueous solution
The site of **Reduction**		The site of **Oxidation**
The half-cell with the **highest** electrode potential		The half-cell with the **lowest** electrode potential
GER		**LEO**

Figure 22: Daniell cell

This two electrolyte scheme allows more degrees of freedom or control over the chemical process.

Although more complex these cells enabled longer life cells to be constructed by optimising the electrolyte/electrode combination separately at each electrode.

More recently they have been employed as the basis for Flow Batteries, in which the electrolytes are pumped through the battery, providing almost unlimited capacity.

Zinc is a very popular anode material and the chemical action above causes it to dissolve in the electrolyte.

The Daniell cell shown can be said to "burn zinc and deposit copper

Note- The simple, single electrolyte cell can also be represented by two half cells. It can be considered a special case of a Daniell cell with the two electrolytes being the same.

2.8.2. Specific Gravity of liquid electrolyte (wet cell)

Of course, it cannot be 'dry' cell for which the electrolyte is not accessible
If we check the specific gravity, it is for rechargeable batteries and only those having wet electrolyte in our application it will be for lead-acid and Ni-cad Acid (or potassium) batteries

The *specific gravity* of any liquid is a ratio comparing its weight with the weight of an equal volume of water. Pure *sulphuric acid* has a specific gravity of 1.835 since it weighs 1.835 times as much as water per unit volume.

The specific gravity of the *electrolyte* solution in a lead-acid cell ranges from 1.210 to 1.300 for new, fully charged batteries. The higher the specific gravity, the less internal resistance of the cell and the higher the possible load current. As the cell discharges, the water formed dilutes the acid and the specific gravity gradually decreases to about 1150, at which time the cell is considered to be fully discharged.

Specific gravity is measured with a *hydrometer* of the *syringe* type, which has a compressible rubber bulb at the top, a glass barrel, and a rubber hose at the bottom of the barrel. In taking readings with a hydrometer, the decimal point is usually omitted. For example, a specific gravity of 1.270 (Lead-Acid) is read simply as *twelve-seventy*. A hydrometer reading of 1210 to 1300 indicates full charge; about 1250 is half-charge; and 1150 to 1200 is complete discharge.

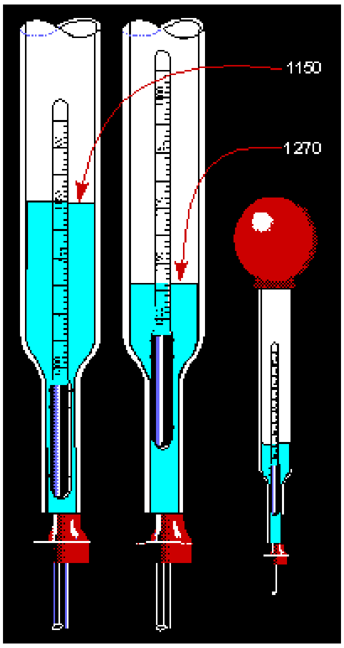
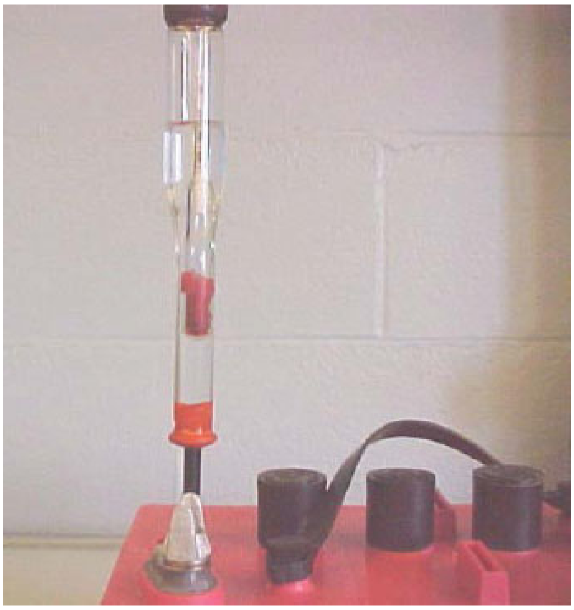


Figure 23: Hydrometer

We see hereafter, the use of a hydrometer, it is part of a maintenance program, we see it again in maintenance paragraph; it applies for our two 'wet' applications: lead-acid and Ni-Cad Potassium (or acid).



The hydrometer, shown, is a glass syringe with a float inside it.

The float is a hollow glass tube sealed at both ends and weighted at the bottom end, with a scale calibrated in specific gravity marked on its side.

To test an electrolyte, draw it into the hydrometer using the suction bulb. Draw enough electrolyte into the hydrometer to make the float rise.

Figure 24: Example of a hydrometer

Do not draw in so much electrolyte that the float rises into the suction bulb. The float will rise to a point determined by the specific gravity of the electrolyte.

If the electrolyte contains a large amount of active ingredient, its specific gravity will be relatively high.

The float will rise higher than it would if the electrolyte contained only a small amount of active ingredient.

2.8.3. Advices when working with electrolyte

Follow these simple steps to test your battery with a hydrometer:

- Have the battery fully charged and disconnected
- Do not add water to any of the cells even if they seem empty.
- Fill and drain the hydrometer two to three times before drawing a sample for reading.
- Fill the hydrometer with electrolyte. Have enough sample fluid of electrolytes in the hydrometer to completely support the float
- Check the reading and ***put back the electrolyte in the same cell***.
- Check all the cells in the battery, repeating the steps above.
- Replace vent caps and wipe of any electrolyte that may have spilled

When working with acid electrolyte (preparation): (safety on batteries)

- Ensure neutralising solutions are available for immediate use
- Add concentrated acid slowly and carefully to the water (Adding water to acid causes acid projections and violent heat generation)
- Stir the mixture with a glass or plastic (Teflon) rod
- Ensure stored electrolyte is put into an appropriate container (E.g. a glass, polyethylene or polypropylene container)
- Do not allow metal (except lead) to come in contact with acid or electrolyte
- Allow the electrolyte to cool before checking its specific gravity

Electrolyte Spill: (safety on batteries)

Consult the appropriate MSDS for spill containment, clean up and disposal details.

If electrolyte is spilt:

- Water shower fully clothed if electrolyte comes into contact with any part of the body or if contact is suspected
- Throw diatomaceous earth or sand (but NOT sawdust) over the contaminated area. (Diatomaceous means it is a non-toxic, safe substance made up from crushed fossils of freshwater organisms and marine life. Crushed to a fine powder and observed through a microscope, the particles resemble bits of broken glass.)
- Remove the earth or sand once it has soaked up the acid/electrolyte.
- Wash down the area with a solution of common washing soda.
- Dispose of any contaminated material safely

2.9. BATTERY TERMS

IDENTIFICATION OF A BATTERY

By the name of metals in anode and cathode followed (when necessary to specify) by the type of electrolyte.

When saying ‘Lead acid’ battery, it should be said: lead-lead –acid but the making of both electrodes in lead in implicitly understood.

Accumulator:
Rechargeable electrochemical generator

Air depolarized battery (Saft):
Battery composed of a zinc electrode. These batteries have high capacity and require little or no maintenance, and are primarily used in traditional applications such as railway signalling, electric gates and buoys used in harbours.

Amperage/Amp Hours (Capacity)
(Ah) (mAh = Milliamp hours, or 1/1000 amp per hour)
Represents the amount of energy a battery can hold at the rated voltage. This measurement helps determine how long the battery will power the equipment it is used in. Generally speaking, the more 'Ah's' the longer the **run time**. A device which consumes 100mAh per hour will run about 10 hours on a 1000mAh (or 1Ah) battery.

Battery:
The totality of electrochemical generators, consisting either of non-rechargeable batteries or rechargeable accumulators.

Cell
A single battery canister. Usually grouped together with other cells to form battery packs of different voltages. Example: six 1.2 volt cells group together in series in a battery pack results in a 7.2 volt battery.

Charge
The process of putting energy into a battery. Required when battery voltage falls below an allowable threshold.

Conditioning
The process of repeatedly charging and deep discharging a battery for the purpose of preventing voltage depression or "memory effect" or to otherwise restore lost capacity.

Cycle
The process of charging and discharging a battery, either through normal use of by a conditioner.

Discharge
The release of energy by the battery.

Energy density:
A battery's energy density (or volume) measured in watt hours per kilogram (WH/Kg), or watt hours per litre (WH/L), corresponding to the amount of energy stored per unit of mass (or volume) of a battery.

Memory Effect (voltage depression)
The term used to describe the capacity loss and subsequent voltage drop in a battery due to constant or repetitious charging and incomplete discharging. This results in a loss of run time.

Shell Life
The *shelf life* of a cell is that period of time during which the cell can be stored without losing more than approximately 10 percent of its original capacity. The *capacity* of a cell is its ability to deliver a given amount of current to the circuit in which it is used.

The loss of capacity of a stored cell is due primarily to the drying out of its electrolyte (wet cell) and to chemical actions, which change the materials within the cell. Since heat stimulates both these actions, the shelf life of a cell can be extended by keeping it in a cool, dry place. Some manufacturers provide now dry loaded cells which can be stored for a relatively long period (to be checked with specific manufacturer data's

And for more detailed glossary of terms used with batteries, see the MPower Battery Technology Glossary: *Source Eurobat*

2.10. ENERGY DENSITY

The energy density is a measure of the amount of energy per unit weight or per unit volume which can be stored in a battery. Thus for a given weight or volume a higher energy density cell chemistry will store more energy or alternatively for a given storage capacity a higher energy density cell will be smaller and lighter. The chart below shows some typical examples.

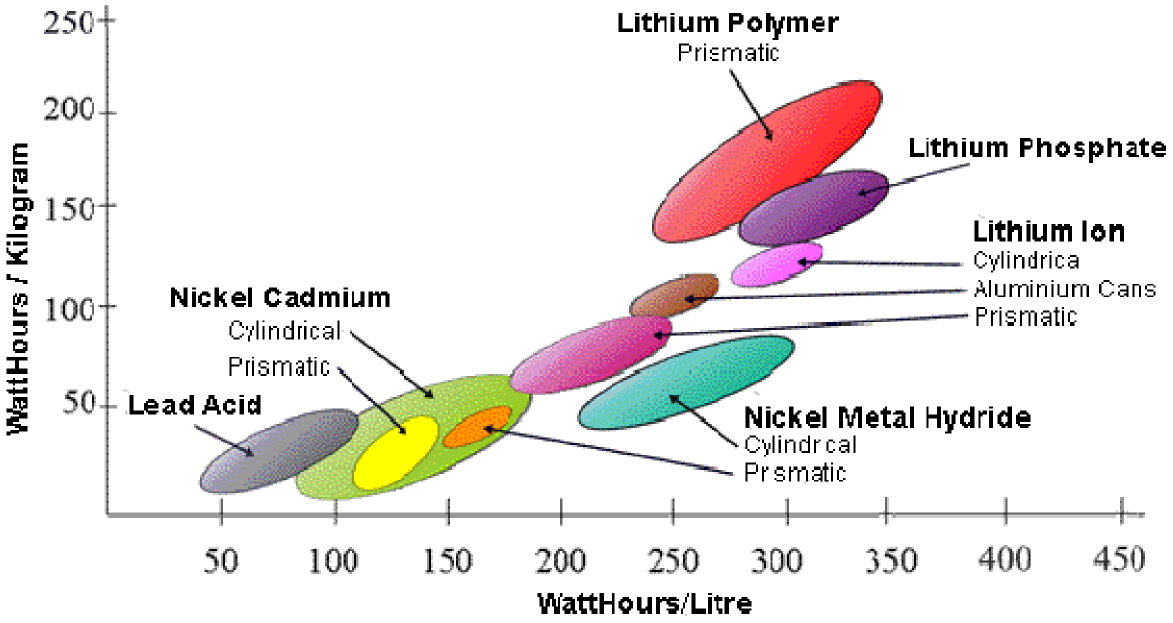


Figure 25: Relative Energy Density of Some Common Secondary Cell Chemistries

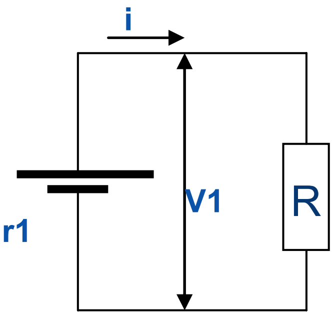
In general higher energy densities are obtained by using more reactive chemicals. The downside is that more reactive chemicals tend to be unstable and may require special safety precautions. The energy density is also dependent on the quality of the active materials used in cell construction with impurities limiting the cell capacities which can be achieved.

This is why cells from different manufacturers with similar cell chemistries and similar construction may have a different energy content and discharge performance.

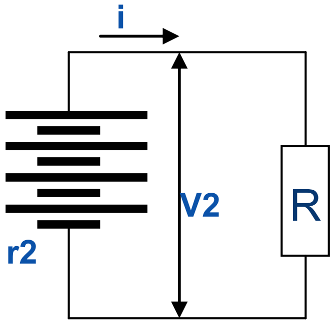
Note that there is often a difference between cylindrical and prismatic cells. This is because the quoted energy density does not usually refer to the chemicals alone but to the whole cell, taking into account the cell casing materials and the connections.

Energy density is thus influenced or limited by the practicalities of cell construction. , hereafter

2.11. EXERCICES



A



B

1. Which potential is (theoretically) higher?

☐ V1

☐ V2

2. Which schema represents a cell?

☐ A

☐ B

☐ Both

3. Which schema represents a battery?

☐ A

☐ B

☐ Both

4. A car is equipped with a 50Ah battery, fully charged. I leave the lights on; having a power of 60W during 2 hours discharging the battery (we assume the voltage stay constant at 12V). How long it will take to recharge this battery with a loading current of 0.1 time the capacity of battery (C/10 A or 0.1 C A)?

☐ 0.5 hour

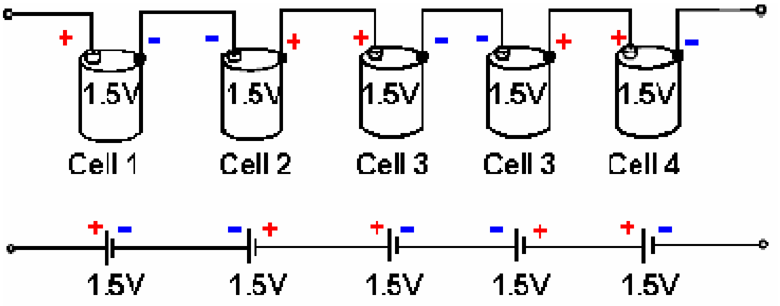
☐ 1 hour

☐ 2 hours

☐ 5 hours

☐ 10 hours

5. Calculate the “theoretical” voltage of this series assembly



= …………… V

6. With several cells in parallel, I increase

☐ Capacity

☐ Voltage

☐ Both Voltage and Capacity

7. With several cells in series, I increase

☐ Capacity

☐ Voltage

☐ Both Voltage and Capacity

8. To obtain a greater current, the battery has cells in

☐ parallel

☐ series

9. Three identical parallel cells (90mA) produce a load current of

☐ 270 mA

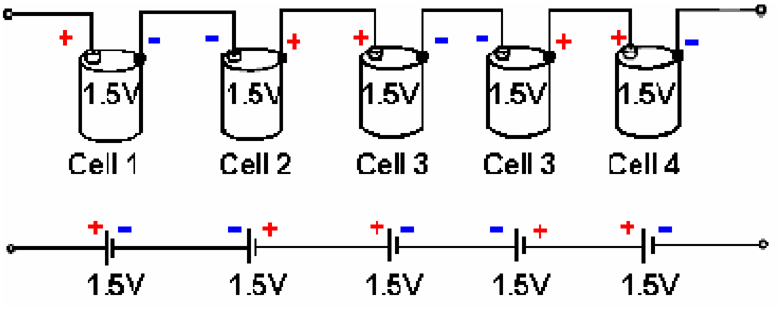
☐ 90mA

☐ 30 mA

10. The total voltage output of a battery of three parallel cells is

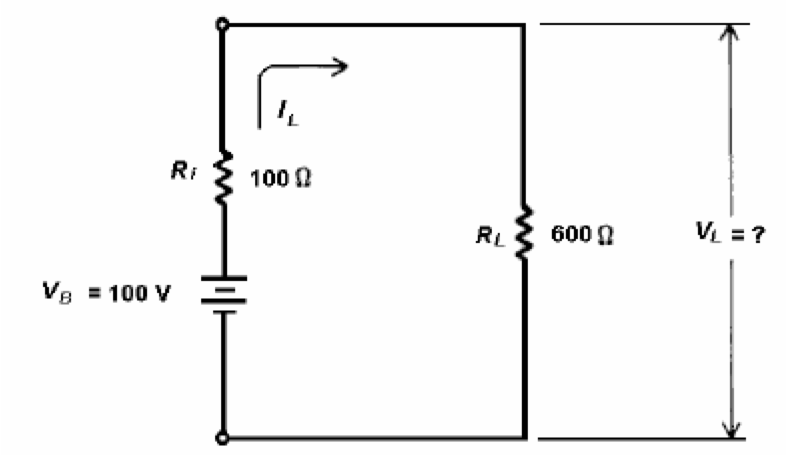
- ☐ The same as that for a single cell
- ☐ Different

11. Is this configuration possible (polarities mixed?)



- ☐ Yes
- ☐ No

12. A dry battery has an open-circuit, or no-load, voltage of 100V. If the internal resistance is 100Ωand the load resistance is 600Ω, find the voltage VL across the output terminals.



The battery is marked 100V because 100V is its open-circuit voltage. With no load, the load current is zero.

When load resistance RL is added, there is a closed circuit, and the load current is calculated by Ohm’s law.

V$_L$ = …………

3. DC VOLTAGE AND DC CURRENT GENERATORS

We have already covered a great deal of theory but let us now look at voltage generation by a DC source from another aspect, by (re)establishing the fundamentals.

3.1. INTRODUCTION

As explained in other courses, the basic elements each have only one well-determined electrical property. This can be a voltage or current source, or a resistance (or even a capacitance or an inductance, but they obey the same laws of analysis).

When we model real physical systems, we use combinations of these basic elements. Therefore, an electric cell or an electric battery can be represented by placing an ideal voltage source and a resistor in series.

3.2. VOLTAGE SOURCE

An ***ideal voltage source*** *is any electrical energy source which delivers a voltage independent of the current it produces, and therefore it is independent of the load which is connected to its terminals.*

By definition, *U0* is the source voltage or **no-load voltage** (at zero current). For an ideal source, the voltage *u* across the terminals is always equal to *U0*, whatever the current *i*.

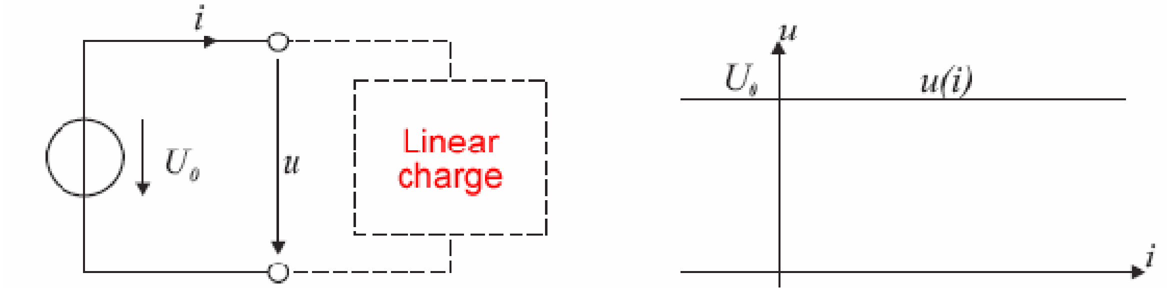


Figure 26: Ideal voltage source

Writing convention: The current *i* and the voltage *u* may vary according to time. However, in this case we use the notation *u(i)* to indicate that the voltage supplied by the source can vary according to the load current.

NB: An ideal voltage source will always deliver a voltage *u(i)* = *U0* even for a current *i* which is infinitely great. This corresponds to an infinite electrical power. Of course, such sources do not exist in reality. However, the ideal voltage source concept is very useful. We just have to limit ourselves to its operating zone where the linearity hypotheses are valid.

Special case: An ideal source which imposes a zero voltage is a **short circuit**.
Like resistors, several ideal voltage sources can be connected in series. In this case, we can model all these sources by a single equivalent source.

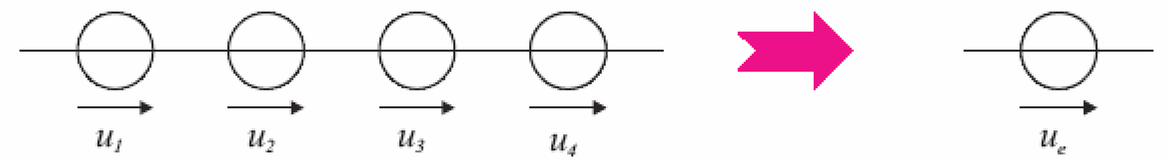


Figure 27: Several ideal voltage sources in series

$$U_e = U_1 + U_2 + U_3 + U_4 + \ldots = \sum_{k=1}^{n} U_k \quad \textit{Unit V (Volts)}$$

It must be noted that there is no sense in placing several voltage sources in parallel: The voltage must be the same in each of these sources (Kirchhoff 's law on mesh analysis).

For most voltage sources, such as batteries for example, we note that the voltage across the terminals *u(i)* tends to vary according to the load current *i*. This is why the model can be improved by defining the **real voltage source**:

*A **real voltage source** is represented here by the combination of an ideal voltage source and a resistor in series. This resistor represents the **internal resistance**.*

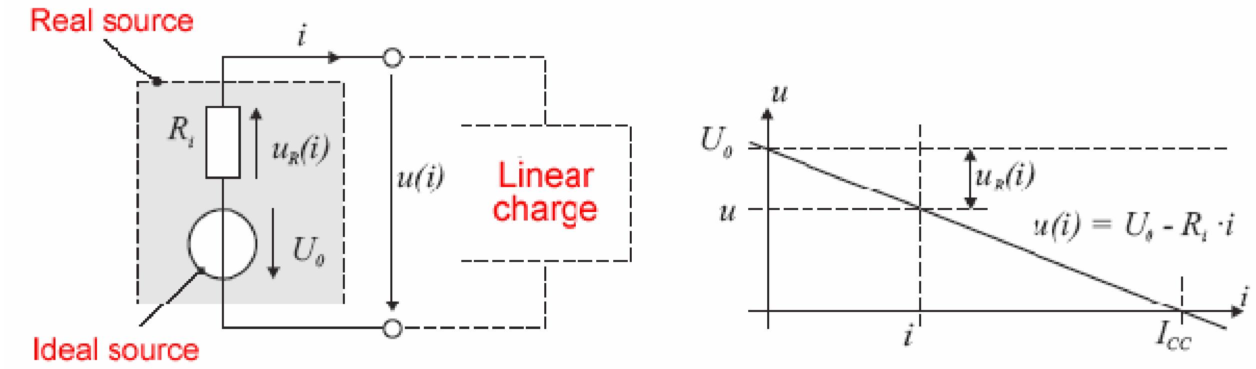


Figure 28: Real voltage source

The internal resistance is used to model a voltage drop proportional to the current supplied.

$$u(i) = U_0 - u_R(i) = U_0 - R_i \,.\, i \quad \textit{(Unit V – Volt)}$$

*The **no-load** voltage U_0 of a real voltage source is the voltage which appears at the terminals of this source when the current supplied is zero.*

The no-load voltage U_0 corresponds to the point of intersection between the straight line representing the load and the Y-axis.

*The **short circuit current Isc** of a real voltage source is the value which the current takes when the source is short circuited, i.e. when the voltage across its terminals is zero.*

The short circuit current I_{sc} corresponds to the point of intersection between the straight line representing the load and the X-axis. We deduce from this that:

$$\mathbf{I_{sc} = U_0 / R_i}$$

The internal resistance R_i is generally very low, and the real source becomes more like an ideal voltage source. Therefore, in practice, the 230 V mains power outlets are more or less ideal voltage sources.

In some places, however, the electricity supply is not very "solid", and the lights go dim when big consumers (cooker, fridge) are switched on nearby. We will assimilate these power outlets to real voltage sources.

In spite of its name, we must always keep in mind that the real voltage source is still only a model.

Therefore, in reality, the variation in the voltage drop across the terminals of a battery is not completely linear, according to the current. In spite of its imperfections, this model is still very useful.

3.3. OPERATING POINT OF A CIRCUIT

*The **operating point** of the circuit is the pair of values (uAB; iA) which simultaneously satisfy the equations for the components on the left of points A and B, and the equations for the components on the right of these two points.*

If we consider a circuit consisting of a real voltage source (on the left in the Figure, characterised by U_0 and R_i) and a load resistor (on the right, characterised by its resistance value R_L), the operating point [*u(i)* and *i*] can be obtained graphically, as shown in this same figure.

The straight line representing the source load is the locus of the pairs of values (*u*; *i*) which satisfy the operating equation for the left-hand part of the circuit. The straight line representing the resistor load is the locus of the pairs of values which satisfy the operating equation for the right-hand part of the circuit. The point of intersection of these two straight lines simultaneously satisfies the operating equations for both parts of the circuit. This is the operating point we are looking for.

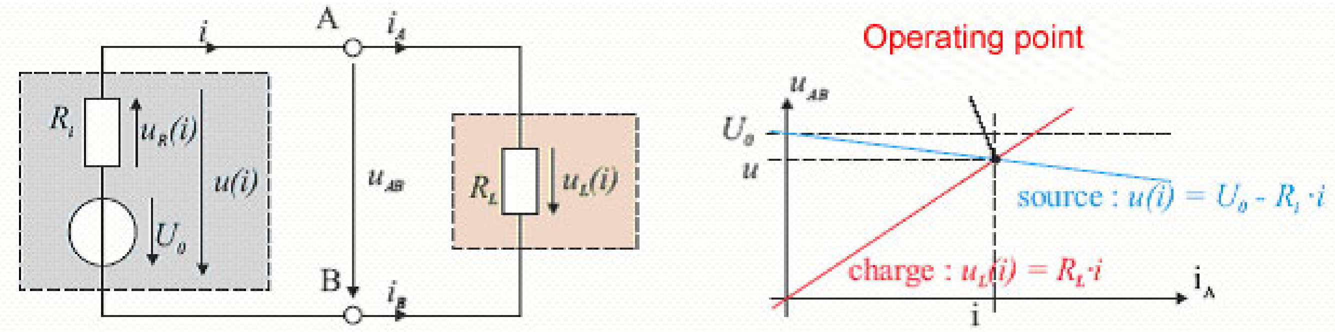


Figure 29: Determining the operating point of a real source graphically

The operating point can also be obtained by calculation:

- for the real voltage source: $u(i) = U_0 - R_i \cdot i$ *(in Volts)*
- for the resistance (Ohm's law): $u(i) = R_L \cdot i$ *(in Volts)*

From this we easily obtain: $u(i) = U_0 \dfrac{R_L}{R_i + R_L}$

This relationship is identical to the formula relating to the voltage divider (also known as potential divider).

3.4. CURRENT SOURCE

*An **ideal current source** is any electrical energy source which supplies an electric current which is independent of the voltage across its terminals, and therefore which is independent of the load connected to its terminals.*

By definition, I_0 is the source current or **short circuit current** (that output from the source when its terminals are short circuited). For an ideal source, the current supplied *i* is always equal to I_0, whatever the voltage *u*.

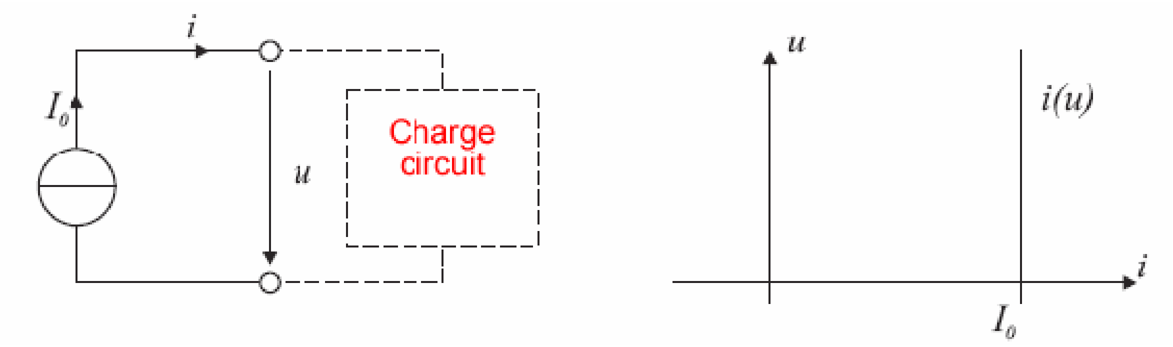


Figure 30: Ideal current source

NB: A ideal current source will always supply the current $i(u) = I_0$ even for a voltage *U* which is infinitely great. This corresponds to an infinite electric power. Of course, such sources do not exist in reality. However, the concept of ideal current source is very useful, for example in association with platinum resistors for temperature measurement (instrumentation). We just have to limit ourselves to the source's operating zone, where the linearity hypotheses are valid.

Special case: When it imposes a zero current, an ideal current source is an **open circuit**, similar to an **open switch**.

Like resistors, several ideal current sources can be connected in parallel. In this case, all of these sources can be modelled by an equivalent single source.

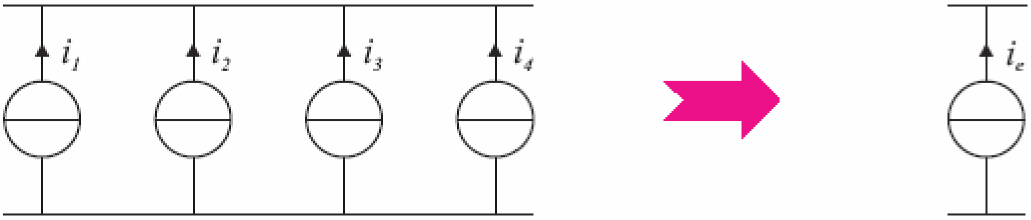


Figure 31: Several ideal current sources in parallel

$$i_e = i_1 + i_2 + i_3 + \ldots = \sum_{k=1}^{n} i_k \quad \text{Unit A (Amp)}$$

It must be noted that there is no sense in placing several current sources in series: The current must be the same in each of these sources (Kirchhoff's law on nodes).

In reality, the current sources are electronic devices which are not always perfect. If the circuit modelling requires more precise knowledge of this current, we use the **real current** source model.

*A **real current source** is represented here by the combination of an ideal current source and a resistor placed in parallel. This resistor is called the **shunt**.*

$$i(u) = I_0 - i_{sh}(u) = I_0 - \frac{u}{R_{sh}}$$ Unit A (Amp)

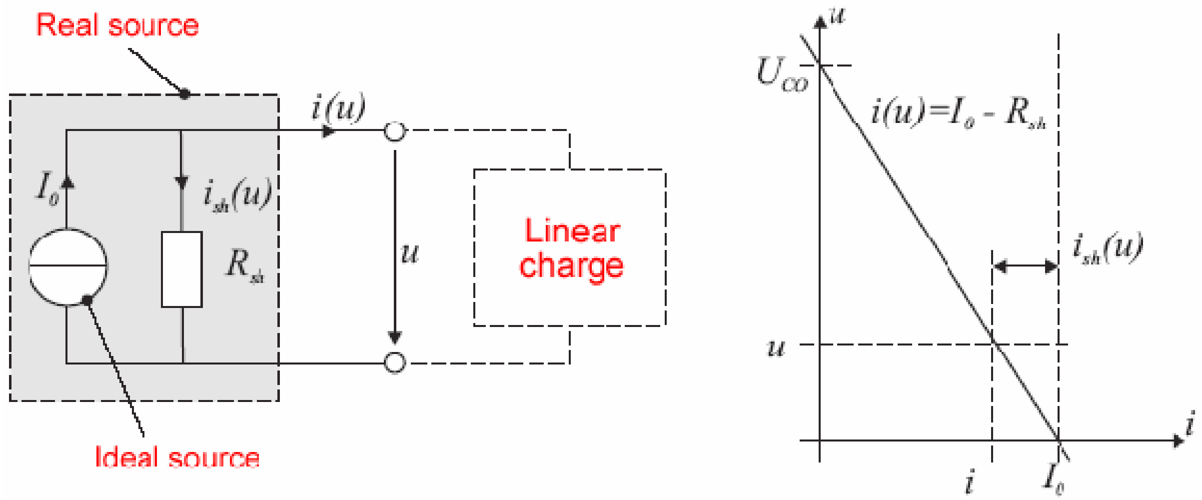


Figure 32: Real current source

*The **no-load** current **I_0** of a real current source is the current delivered by this source when the applied voltage is zero.*

The no-load current I_0 corresponds to the point of intersection between the straight line representing the load and the X-axis.

*The **open circuit** voltage **U_{OC}** of a real current source is the value which the voltage takes when this source is not connected, i.e. when the current supplied is zero.*

The open circuit voltage U_{OC} corresponds to the point of intersection between straight line representing the load and the Y-axis. From this we deduce that:

$$U_{OC} = R_{sh} \cdot I_0$$

*The **leakage** current **$i_{sh}(u)$** of a real current source is the portion of the current which flows through the shunt resistance, and which is therefore not supplied to the load. Its is proportional to the applied voltage.*

A real current source can be compared to a cutting torch: The short circuit current I_0 corresponds to the heating power obtained by burning the acetylene.

The output current *I* corresponds to the heating power transmitted to the sheet metal which is being cut. The current I_{sh} corresponds to the heating power transmitted to the ambient air and thus lost.

The shunt resistance R_{sh} is generally very high. The current source sometimes moves outside of its domain of linearity well before it has reached its open circuit condition voltage U_{OC}. In certain cases, the current source may even be irreversibly damaged.

NB: If we compare the "*Real voltage source*" figure with the "*Real current source"* figure, we observe that if their characteristics are carefully chosen, the straight line representing a real voltage source load is identical to that of a real current source. Therefore, a real current source can be replaced by a real voltage source, and vice versa, on condition that $U_0 = U_{OC} = R_{sh} . I_0$ *and* $R_0 = R_{sh-1}$, *respectively* $I_0 = I_{SC} = U_0 / R_0$ *and* $R_{sh} = R_0$

3.5. THEVENIN'S THEOREM

This theorem was not covered in the other theoretical courses, so let us examine it now.

In electrical circuits, it is rare that we want to know the current and voltage changes simultaneously at all points. Instead, we try to establish a relationship between voltage and current at certain points only.

This method is based on Thévenin's theorem:

Thévenin's theorem:

Each linear circuit seen at two points A and B is equivalent to a real voltage source characterised as follows:

- *the no-load voltage of the equivalent source is equal to the voltage which appears between points A and B when there is an open circuit;*
- *the internal resistance of the equivalent source is equal to that measured between points A and B when all the ideal voltage and current sources have been made passive.*

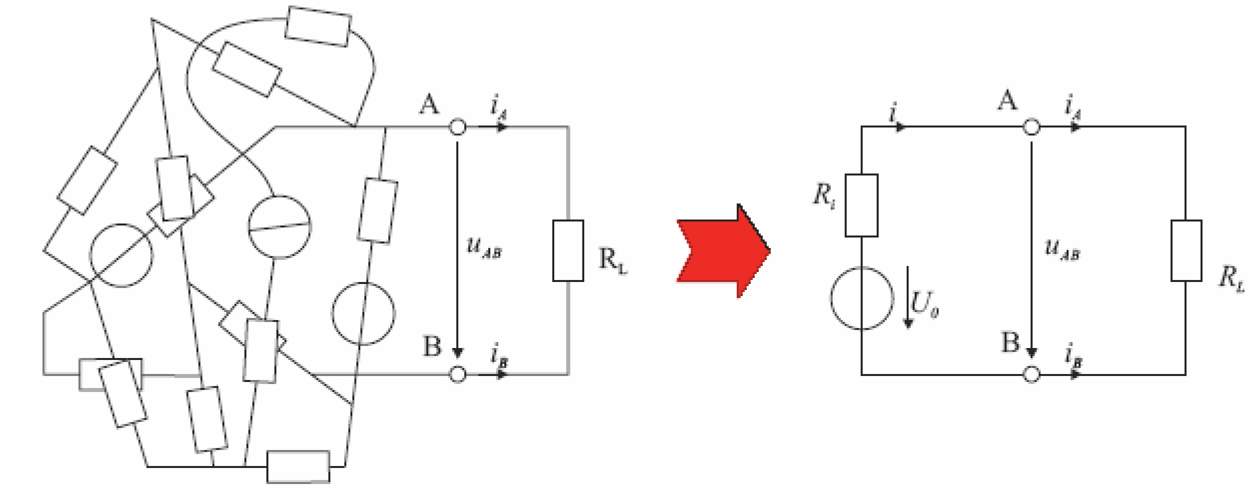


Figure 33: Thévenin's theorem

This theorem is only valid for linear circuits. It is also used for non-linear circuits and systems but care must be taken due to the errors and uncertainties with this approximation.

3.6. DC VOLTAGE SUPPLIES

3.6.1. Definitions

*A **DC voltage** is a voltage whose value remains constant over time. Similarly, a **DC current** is a current which remains constant over time.*

It is common practice to use these terms whereas we should rather talk about constant voltage and constant current. This terminology creates an unfortunate confusion with the concept of continuity introduced in mathematics, which is associated with the uninterrupted nature of a function. In electrical engineering, DC current is opposed to sinusoidal current, the sinusoidal function of the mathematicians is in fact a continuous function!

The abbreviation "DC" is used for *Direct Current* and "AC" for *Alternating Current* to differentiate the DC voltage supplies from the AC voltage supplies.
The abbreviation "CC" for direct current is sometimes used in French technical literature.
The symbols " - " and " = " are also used.

In general, the following expression must be used (example for a 24 V DC voltage source and a 0.5 A DC current):

$U_{DC} = 24\ \text{V} \qquad I_{DC} = 0.5\ \text{A}$

Sometimes (and even fairly often) we also encounter the following formulation, although it is not recognised by the IEC standards:

$U = 24\ \text{V}_{\text{DC}} \qquad I = 0.5\ \text{A}_{\text{DC}}$

3.6.2. Batteries and accumulators

Batteries, accumulators and fuel cells directly convert chemical energy into electrical energy.

The invention of the **electric cell** by the Italian Alessandro Volta in 1800 is one of the most important discoveries in the field of electricity. It allowed an uninterrupted source of electric current to be obtained for the first time. Before this period the only known electricity was was the instantaneous discharges produced by static electricity and thunderstorms.

When two different conductors called **electrodes** are immersed in an acid water solution or an alkali water solution, called an **electrolyte**, a potential difference appears between the two electrodes. If we connect a resistor between the positive electrode called the **anode** and the negative electrode called the **cathode**, a current flows.

The current flow gradually transforms the composition of the electrolyte and of the two electrodes. Electrical energy is released due to this reaction. When one of the electrodes or the electrolyte is more or less completely transformed, the potential difference disappears and the current stops flowing. The cell is then exhausted or discharged, and is no longer usable.

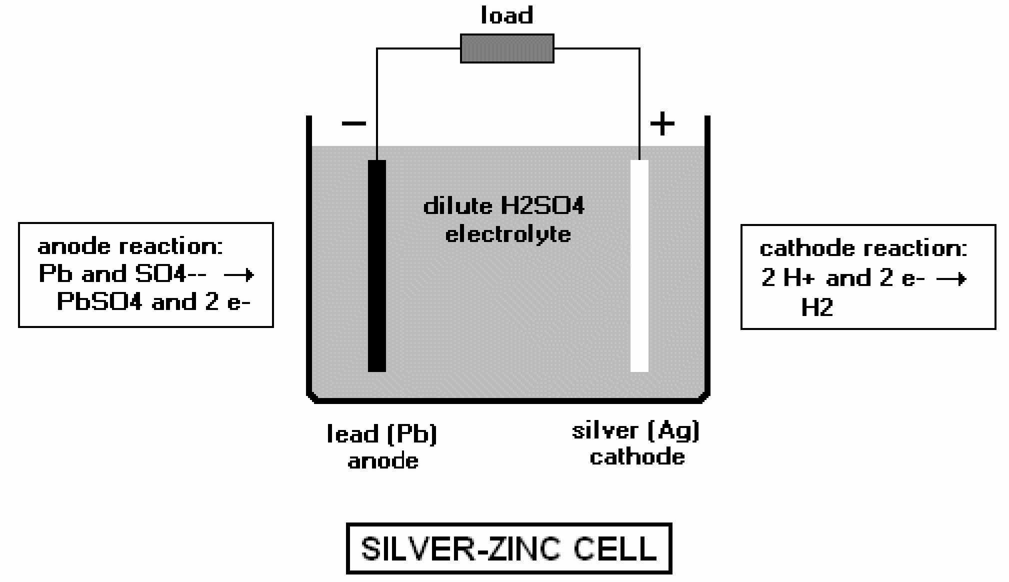


Figure 34: Silver-zinc cell operating principle

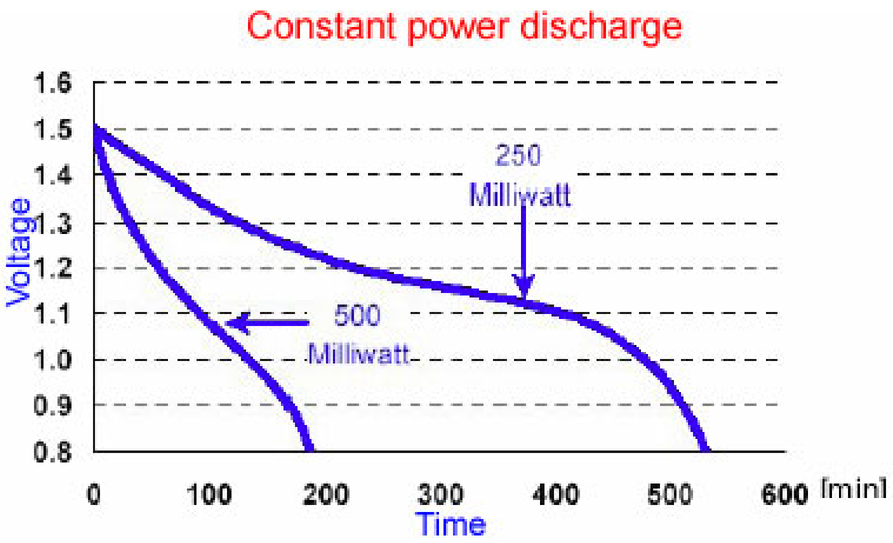
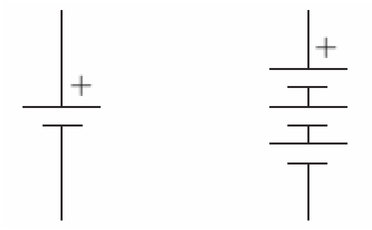


Figure 35: Discharge characteristic of an alkaline cell

However, in **accumulators**, the chemical transformation is reversible. They can be recharged by passing a current in the opposite direction, and the electrodes and electrolyte get back the chemical composition they had before the discharging process.

Therefore a battery is not rechargeable, only an accumulator can be recharged!

To analyse the behaviour of a battery or an accumulator in an electric circuit, the real voltage source model (see above) is very often used, even if the characteristics U_0 and R_i are not quite constant and vary, for example, according to the state of charge and the temperature. The voltages they develop are between 1.3 and 2 V depending on the technology used. This modelling is generally sufficient when we are basically interested in how charging works.



To represent a battery or an accumulator in a circuit diagram we normally use the symbols show in the figure. These symbols clearly indicate that these are electrochemical voltages sources

Figure 36: Symbols representing a battery (or accumulator) cell and a 3-cell battery

3.6.3. Battery charge

*A battery's **charge** is the quantity of electricity it can deliver before the voltage across its terminals begins to fall sharply. It is expressed in Ampere-hours or Amp-hours [Ah].*

EXAMPLE

If a battery operates for 8 hours delivering a constant current of 50 mA before its voltage drops and it becomes unusable, its load is calculated as follows:

$C = 50\ mA\ .\ 8h = 0.4\ Ah$

We saw that the SI unit of charge Q is the coulomb [C]. However, it is the Amp-hour [Ah] which is normally used to describe battery and accumulator charge. The relationship between these two units is by definition:

$$1\ Ah = 1A\ .\ 1h = 1A\ .\ 3600s = 3600\ C$$

A 30 Ah battery can therefore deliver a current of 1 A for 30 h, or 10 mA for 3000 h.

However, it normally cannot deliver 300 A for 0.1 h since the operation of the batteries does not allow high currents to be generated without causing a sharp voltage drop.

Important: Do not confuse a battery's charge with the energy it can supply. The charge only depends on the current delivered, whereas the energy also depends on the voltage.

$$E = P\ .\ \Delta t = U\ .\ I\ .\ \Delta t = U\ .\ Q \qquad (J) = (W).\ (s) = (V)\ .\ (A)\ .\ (s) = (V)\ .\ (C)$$

Where the charge Q is expressed in coulomb (C), and not in Amp-hours (Ah)

EXAMPLE

The battery in the previous example delivers its 50 mA current at a voltage of 4.5 V.

The power delivered by the battery is: P = 4.5 V . 50 mA = 225 mW

Since this battery can deliver this current for 8 h, the available energy is:

E = 225 mW . 8 h . 3600 / 1 h = 6480 J

We would have obtained the same result by applying the above formula, after conversion of the charge in (C):

C = 0.4 Ah . 3600s / 1 h = 1440 C

E = 4.5 V . 1440 C = 6480 J

3.6.4. Technologies, parallel and series configurations

Several cell technologies have been developed since the time of Volta. They are differentiated by the choice of materials (electrolyte, anode, cathode), by their size and by the number of cells in series. Their performance is often described in terms of **volume energy** (expressed in joules per unit of volume – J/m³) or **mass energy** (expressed in joules per unit of mass – J/kg).

Because the energy and the voltage of the cells are relatively low, we couple several of them together to form electric **batteries**:

- Configuring the cells in series gives a higher voltage.
- Configuring the cells in parallel gives a higher current.

In both cases it is very important to group together only cells of the same type and same state of charge in the above configurations.

3.6.5. The photoelectric cell

"Solar" cells *(it is better to say: "light energy" cells)* are a product based on semiconductor technology. Their operation is based on the photoelectric effect: Free electrons are placed in movement due to the effect of the light.

This effect was known since around 1900 but it is only recently that photovoltaic cells can be produced at acceptable costs, and provide competitive performance and reliability levels.

The efficiency of photovoltaic (or photoelectric) cells is still relatively low (barely 20%). They have no moving parts, operate without noise or wear and produce no waste… apart from that produced during their manufacture.

See the chapter on photovoltaic cells later on in this course.

3.6.6. The fuel cell

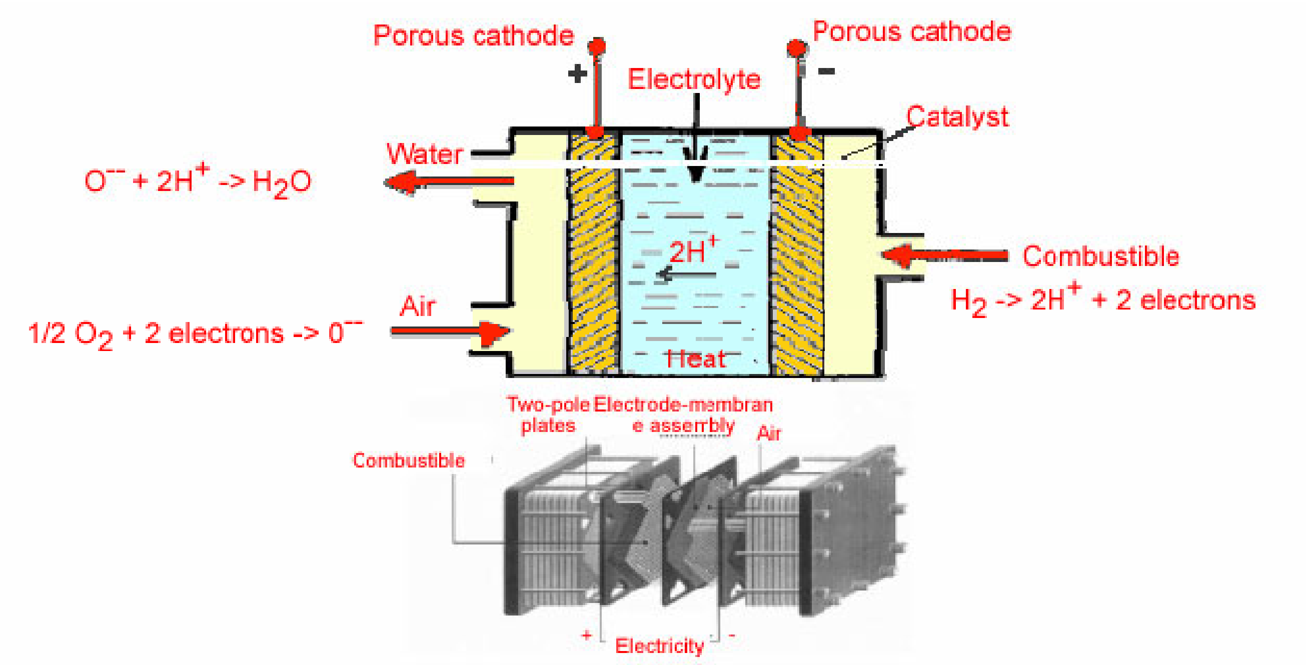


Figure 37: Proton exchange membrane fuel cell (PEMFC)

A **fuel cell** is basically a cell in which the electrochemical agents are constantly supplied to a suitable chamber, and whose residual products are constantly evacuated.

Such a cell thus never becomes discharged because the active products are replaced as they are used up.

In theory, the electric power supplied by a fuel cell is equal to the thermal power which would be released if we burned the fuel. In practice, there are losses, but the efficiency can reach 90%. It is far greater than that of the turboalternators and the Diesel-electric generator sets. This technology is developing fast. The efficiencies are improving and the prices constantly falling.

In addition, the fuel cell produces no noise or pollution apart from that during its manufacture. Prototype cars and buses are already equipped with these cells, prefiguring the alternative to internal combustion engines which will sooner or later be imposed by the falling oil stocks.

3.6.7. Usage and limits DC voltage supplies

In industry, DC voltage supplies are mainly used to operate electronic equipment. In general, they have a low power and are designed for control and measurement circuits. The machine control circuits operate at a DC voltage of 24 V (sometimes 3.3 V, 5 V, 12 V, 48 V, 60 V or 110 V).

These voltages are obtained by rectifying the electricity network's AC voltage by an electronic circuit.

Batteries and accumulators are not powerful enough to operate most machines and installations. They are reserved for portable systems and for backup power sources, with stand-alone operation.

The high-power DC sources are limited to very specific applications: electrolysis, transporting electrical energy over very long distances.

When the power electronics did not reach today's performances, the DC motors were commonly used for electric traction and for variable speed drives on machines.

The use of DC voltage for high-power circuits has several disadvantages:

- It is not easy to modify the source voltage,
- If the source supplies a circuit containing a coil (inductor), if the circuit is interrupted an electric arc is produced which may damage the contacts,
- DC dynamos and motors are expensive and require regular maintenance.

In machines and installations, the DC voltage sources are generally **earthed** (we also say "**grounded**"). This means that one of the terminals of the source, usually the negative terminal, is connected to the machine frame and is thus at the earth potential.

Exception: The DC voltage for portable equipment is supplied by batteries or accumulators. These supplies are not earthed. We say that they are **floating**. This can also be the case for certain DC current distributions from a charger / rectifier (with buffer batteries).

4. CELL CONSTRUCTION AND TECHNOLOGY

4.1. COMPONENTS

The basic components of a battery are the electrodes with terminals to connect to the external circuit, a separator to keep the electrodes apart and prevent them from shorting, the electrolyte which carries the charged ions between the electrodes and a case to contain the active chemicals and hold the electrodes in place.

4.1.1. Case

The case may simply be a robust container made from glass, plastic or metal, insulated from the electrodes, which does not form part of the current path through the battery. Lead acid batteries typically have such containers. A metallic case however can be used as one of the electrodes, saving materials, as in the case of Leclanché (Zinc- Carbon) cells.

4.1.2. Electrodes

The electrodes material may be a rigid metallic grids as in Lead acid batteries or the active electrode material may impregnated into or coated onto a spiral rolled metallic foil which simply acts as a current collector as in many Nickel and Lithium based cells.

4.1.3. Separator

The separator may be a mechanical spacer, fibreglass cloth or a flexible plastic film made from nylon, polyethylene or polypropylene. It must be porous and very thin to permit the charged ions to pass without impediment and it should take up the minimum of space to allow for the maximum use of the available space for the active chemicals.

At the same time it must be resistant to penetration by burrs or dendrite growths on the electrode plates or from contamination of the electrode coating to prevent the possibility of short circuits between the electrodes.

These characteristics should be maintained at high operating temperature when softening of the plastic material could clog the pores or reduce its resistance to penetration. The breakdown or penetration of the separator is a potential area of weakness in high power cells and special separator materials have been developed to overcome this problem.

4.1.4. Terminals

There are many ways of connecting to the electrodes ranging from spring contacts, through wires or tags to mechanical studs. The main requirement is that the terminals should be able to handle the maximum current without overheating, either the terminal itself or the electrode connected to it. This needs careful design of the connection to the electrodes to take off the current through the maximum possible area of electrode material so as not to cause any hot spots.

For industrial batteries (for the UPS), tightening lugs, bolts on electrodes terminal and on inter connections has to be done carefully with dynamometric type wrench. On maintenance vendor booklet, clear instructions on that subject should exist.

4.1.5. Electrolyte

For many years all electrolytes were in aqueous or gel form (we see in maintenance chapter how to take care of those electrolytes), solid polymer electrolytes have been developed which do not suffer from leakage or spillage. They are considered as being safer in case of an accident and they also bring new degrees of freedom to cell design allowing mechanical designs to be shaped to fit into odd shaped cavities. Polymer electrolytes are typically used in Lithium batteries.

4.2. INTERNAL CONSTRUCTION

Broadly speaking

- the cell voltage is controlled by the cell chemistry and nature of metals,
- the capacity is governed by the weight of the active chemicals
- and the current carrying capacity (or power) is governed by the area of the electrodes.

To a lesser extent all three of the above parameters as well as the thermal properties are affected by the internal impedance of the cell and this depends on the conductivity of the electrolyte and the layout and resistance of the components in the current path.

Thus the size shape and materials used in its construction all affect the ultimate electrical performance of a cell.

4.2.1. Electrodes (Energy/Power Trade-Offs)

For a given cell chemistry and within the space available inside a given cell case, the cell performance can be optimised for capacity or power.

- Increasing the surface area of the electrodes increases the cell's current handling capability. Thus the cell can both deliver more power and it can be charged more quickly.
- Increasing the volume of electrolyte in the cell increases the cell's energy storage capacity.

The prime trade off is between the **area of the electrodes** and the **volume of the electrolyte** which can be contained within the volume available in the cell case.

High power cells require **electrodes with a large surface** area as well as enlarged current collectors which take up more of the available space within a given cell, displacing the electrolyte and reducing the cell capacity.

The effective **surface area of an electrode** can be increased without increasing its physical size by making its **surface porous** and using materials with very fine particle size. This can increase the effective surface area of the electrodes by 1000 to 100,000 times enabling higher current rates to be achieved.

High capacity cells require **large volumes of electrolyte** which must be accommodated between the electrodes. This has a double effect in reducing the cell power handling capability. First, the electrodes must be smaller and further apart to make space for the extra electrolyte and hence they can carry less current. Secondly, because of the increased volume of the electrolyte, it takes longer for the chemical actions associated with charging and discharging to propagate completely through the electrolyte to complete the chemical conversion process.

As an example - Lithium Ion cells optimised for capacity may typically handle peak currents of 2C or 3C for short periods, whereas Lithium Ion cells optimised for power could possibly deliver pulsed currents of 30C to 40C.

Four of the most common constructions are shown below. Over the years there have been many thousands of variants of these basic types used for many different cell chemistries.

High power cells usually incorporate special safety devices. (See Safety Chapter)

4.2.2. Bobbin Electrodes

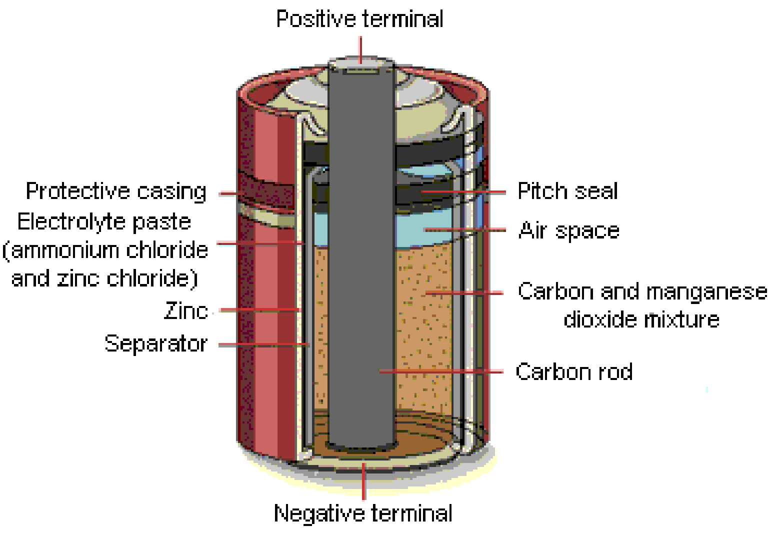


Figure 38: Zinc - Carbon (Leclanché) Cell – 1.5Volt

And now the application with alkaline 'batteries' type AAA or LR 03 / AA or LR06 / C or LR14 / …etc…., all 1.5V

The bobbin construction has been used for over a century since the introduction of the Zinc- Carbon (Leclanché) Cell and a more recently with the newer Alkaline cells which use a more complex version of this type. It is a cylindrical construction utilizing an internal cylindrical electrode usually in the form of a rod which is immersed in the electrolyte which is in turn contained in an external electrode in the form of a cylindrical cup arranged as a sleeve inside the cell container. A separator sheath prevents contact between the electrodes.

Its advantage is that **it is simple**, it stores a large amount of electrolyte which gives it a high capacity and hence long life but the electrode surfaces are very small which results in a high internal resistance and limits the currents it can deliver. However, this small area also results in a low rate of self discharge and these batteries therefore have a long shelf life. It is ideal for many applications requiring **primary cells** and is manufactured in very large quantities.

4.2.3. Flat Plate Electrodes

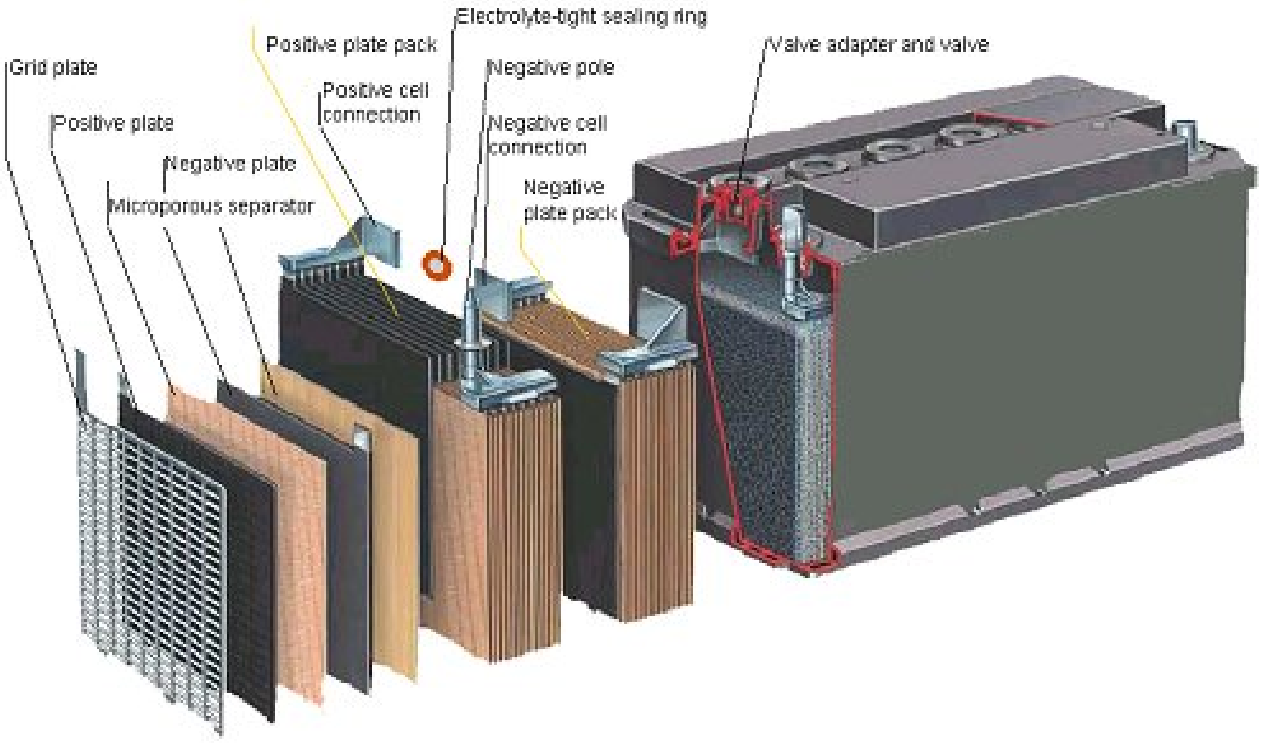


Figure 39: Cells Used in Lead Acid Battery

Flat plate cells typically used in Lead Acid batteries also have over a hundred years of history and development. The electrodes are made in the form of flat plates suspended in the electrolyte which is held in a suitable container which does not usually take part in the chemical reaction.

A separator between the plates prevents them from touching each other and short circuiting. This is another simple construction which is also used by many different cell chemistries. Its main advantage is that it can be scaled up to very large sizes, larger plates providing for higher currents and larger containers allowing high storage capacities.

4.2.4. Spiral Wound Electrodes (Jelly-roll or Swiss-roll construction)

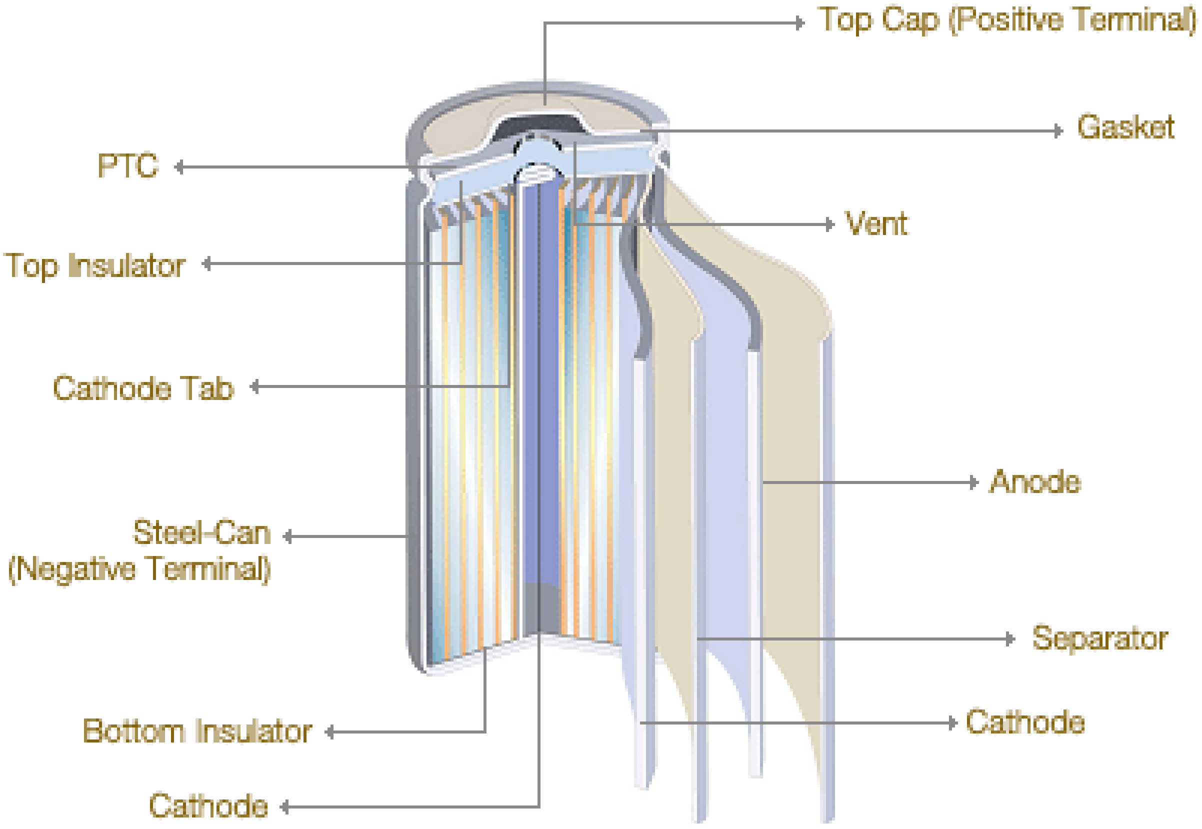


Figure 40: LG Spiral Wound Cylindrical Cell

In the quest for higher current carrying capacity, it is necessary to increase the active surface area of the electrodes; however the cell case size sets limits on the size of electrodes which can be accommodated. One way of increasing the electrode surface area is to make the electrodes and the separator from long strips of foil and roll them into a spiral or cylindrical jelly-roll shape. This provides very low internal resistance cells.

The downside is that since the electrodes take up more space within the can there is less room for the electrolyte and so the potential energy storage capacity of the cell is reduced.

This construction is used extensively for secondary cells.

The example above shows a Lithium-Ion cell but this technology is also used for Ni-Cad's, Ni-MH and even some Lead acid secondary cells designed for high rate applications. Spiral wound construction not limited to cylindrical shapes. The electrodes can be wound onto a flat mandrel to provide a flattened shape which can fit inside a prismatic case. The cases may be made from aluminium or steel.

This construction is ideally suited for production automation.

4.2.5. Button Cells and Coin Cells

Most button and coin cells follow the same basic layout in their construction as shown in the diagram above. They are used where small size is required.

As with bobbin cells they have a relatively high capacity but deliver low power.

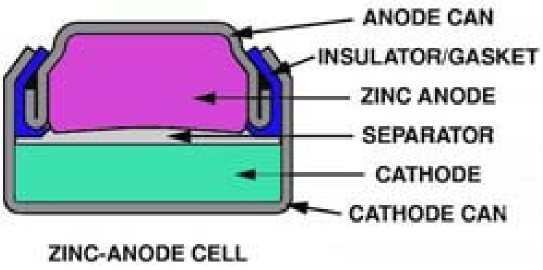


Figure 41: Button cell

4.2.6. Multiple Electrode Cells

4.2.6.1. Monopolar configuration

In this configuration the battery is constructed form individual cells with external connections joining the cells to form series and parallel chains.

This is an example of monopolar configuration. Reminiscent of Volta's pile, the positive and negative plates are sandwiched together in layers with separators between them, inserted into the case, and sealed.

This construction provides an energy efficient form factor and is typically used in high power Lithium Polymer cells with the solid polymer electrolyte separating the cells.

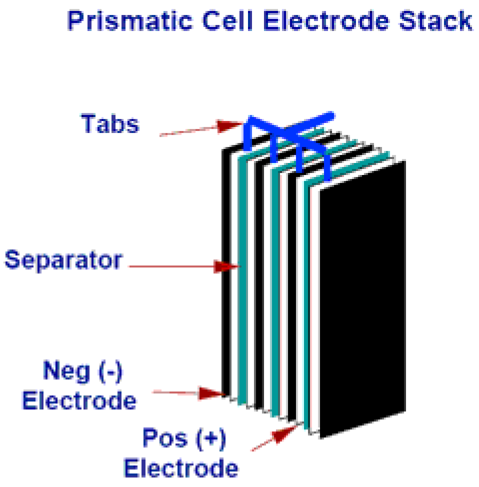


Figure 42: Stacked Electrodes

4.2.6.2. Bipolar configuration

In bipolar batteries the cells are stacked in a sandwich construction so that the negative plate of one cell becomes the positive plate of the next cell. Electrodes, often called duplex electrodes, are shared by two series-coupled electrochemical cells in such a way that one side of the electrode acts as an anode in one cell and the other side acts as a cathode in the next cell. The anode and cathode sections of the common electrodes are separated by an electron-conducting membrane which does not allow any flow of ions between the cells and serves as both a partition and series connection.

This is an efficient design which reduces the number of plates and eliminates external connections, reduces the weight of the battery, increases the energy density and reduces costs.

The current pathway is also shorter and resistance losses will be less enabling the battery to handle higher power. Bipolar construction is usually adopted for Fuel Cells (*) and Flow Batteries in which the electrolyte flows over, or is pumped through the cells, but the technique has recently been trialled on much simpler, smaller scale automotive and portable batteries with several other cell chemistries using single electrolytes.

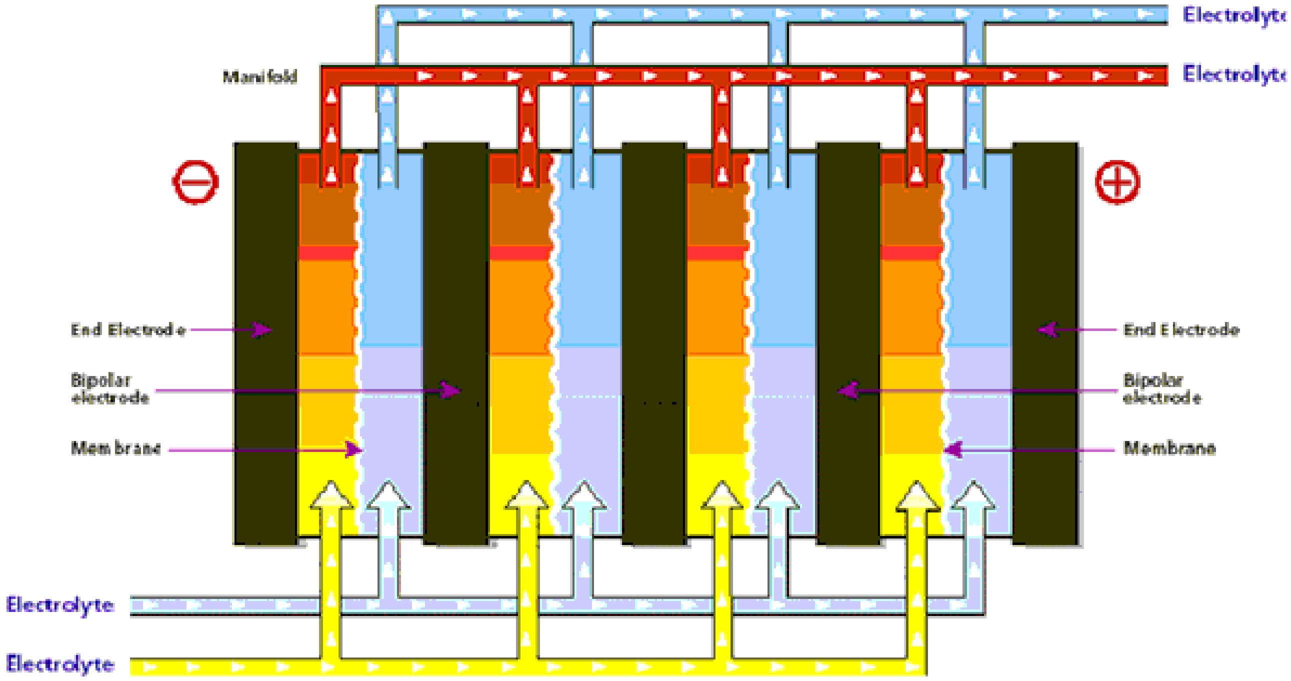


Figure 43: Bipolar Cell Construction in a Flow Battery

Bipolar cells suffer from higher self discharge due the shunt current which occurs through the electrolyte manifold because the electrodes of the same polarity are at different potentials.

Bipolar batteries are also called "Layer Cells" and "Stacked Wafer Cells"

(*) a fuel cell is an electrochemical energy conversion device. A fuel cell converts the chemicals hydrogen and oxygen into water, and in the process it produces electricity.

The proton exchange membrane fuel cell (PEMFC) is one of the most promising technologies. This is the type of fuel cell that will end up powering cars, buses and maybe even your house

As this principle is (not yet) used on our sites, it is not presented here. Go on the net for information

4.3. ELECTRODES INTERCONNECTIONS

The internal resistance of the cell and the distribution of the currents and potentials within the cell are affected by the cell geometry which must be optimised to provide robust connections, minimum length current paths, and even distribution of currents to avoid local hot spots and uneven potentials which could give rise to unbalanced, damaging chemical reactions at different parts of the electrodes.

Anyway, you are not going to design the set of batteries on ‘your’ plant, but you could be in charge of maintenance. Refer to the Maintenance paragraph referring to verification of batteries connections and interconnections.

For your private use (wet batteries on your car and dry ones on your camera), be sure that connections are firm and secured. No hot point should occur.

4.4. SEALED CELLS AND RECOMBINANT CELLS

Most batteries these days seal the electrolyte into the cell case. This is to prevent leakage of electrolyte and to prevent any gaseous products of charging and discharging from escaping into the atmosphere. The cell may also include a catalyst to promote recombination of these gaseous products. Such cells are called recombinant cells.

For our application for Lead and Ni-Cad batteries, see next chapter, the different types of batteries with manufacturer comment/description about the principle of recombination.

4.4.1. Electrolyte of sealed cells

All dry cell cells either primary or secondary do not allow any control, any maintenance.

In “wet cells” (all secondary type) with aqueous electrolyte, the recombination cannot be 100% effective. When the level of electrolyte becomes too low, these cells can be topped with water as per a ‘classic’ vented battery.

Of course, each cell must be equipped with ‘safety vent’ removable (and allowing check for cleaning).

For “semi-wet cells” (Lead or Ni-Cad in our applications on site) with electrolyte in form of gel or paste, no topping can be done. Nevertheless, the recombination cannot be (as well) 100% and those cells have to be vented. It is for example the denomination VRLA for Valve Regulated Lead Acid.

4.4.2. Safety Vents for sealed cells

When a cell is sealed, high internal pressures may build up due to the release of gases and due to expansion caused by high temperatures.

As a safety precaution sealed cells usually incorporate a safety vent to allow excess pressure to be reduced in a controlled way.

There is the possibility of explosion if a sealed cell is encased in such a way that it cannot vent. The vents are often tiny and usually go unnoticed. Standard battery holders won't block the vents, but encapsulating the battery in epoxy resin to make a solid power module certainly will;

And on our site, considering that there is no need of maintenance on those types of batteries, leaving the safety vents dirty and plugged conducts inevitably to the build up of pressure and explosion.

That is what happened already on several sites on sealed batteries, mainly on gel type which are (a lot) more 'sensitive'.

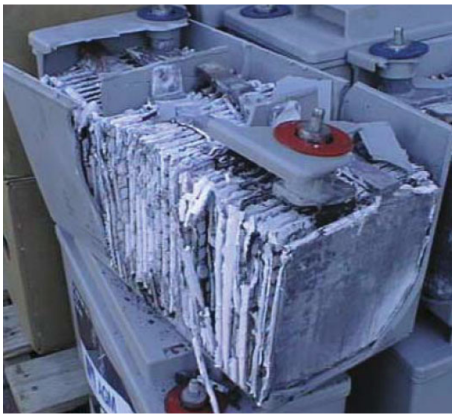


Figure 44: Exploded battery

Unfortunately there is no simple way of monitoring the internal pressure of standard cells to facilitate the implementation of suitable pressure control mechanisms and the product designer is dependent on the efficacy of the safety vent and the use of systems based on temperature monitoring to provide protection from excessive pressure build up within the cells.

It is the Pressure Effects.

We'll try (nevertheless) to see what to do (and to not do) in the charging and maintenance paragraph

4.5. CELL CASING

As with the internal cell construction there are many variants of case designs. Some standard, low power packages are shown below.

4.5.1. Cylindrical Cells

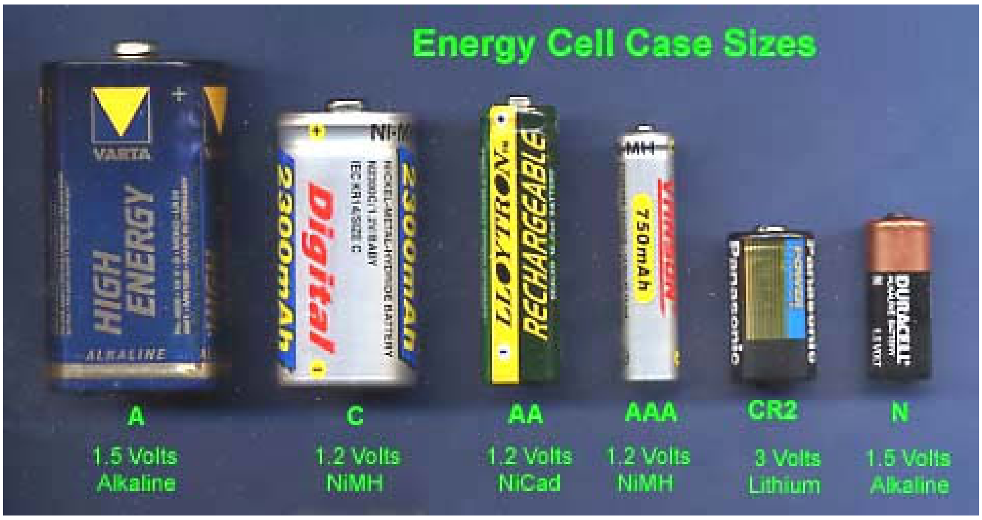


Figure 45: Common cylindrical cell cases

The picture above shows the most common cylindrical cell sizes from a range of manufacturers. The shapes may be standardized but the voltages and chemistries are not.

The four largest sizes can each house Leclanché, Alkaline, Ni-Cad, Ni-MH and Lithium chemistries with voltages ranging from 1.2 to 3.7 Volts. The first two chemistries are used for primary cells and are based on a bobbin construction.

The remaining chemistries are used for secondary cells with spiral wound electrodes. Care is needed to match the chargers to the appropriate cells.

Cylindrical cells provide strong mechanical stability, good energy density and low costs.
It is estimated that 90% of portable, battery-operated devices require AA, C, or D battery sizes.

4.5.2. Multi-cell Batteries

The two batteries shown aside are actually made up from groups of cylindrical cells.

The type 23A contains eight 1.5 Volt cells and the PP3 contains six 1.5 Volt cells.

Figure 46: Multi-cell batteries

4.5.3. Common Household-Battery Sizes

Size	Shape and Dimensions
D	Cylindrical, 61.5 mm tall, 34.2 mm diameter.
C	Cylindrical, 50.0 mm tall, 26.2 mm diameter.
AA	Cylindrical, 50.5 mm tall, 14.5 mm diameter.
AAA	Cylindrical, 44.5 mm tall, 10.5 mm diameter.
PP3	Rectangular, 48.5 mm tall, 26.5 mm wide, 17.5 mm deep.

Voltage is according to type of electrodes, it will be

- 1.5V for Carbon-Zinc (Leclanché) or Alkaline* cell in AA, AAA, C, D shapes which are primary cells
- 1.2V for Ni-Cad, Ni-Mh, secondary in the same ranges of shapes
- PP3 is 9V either in primary or secondary
- With Lithium, voltage would be 3 to 3.6V according to the manufacturing
- Etc…, in other shapes, voltage and dimensions are not yet 'well' standardised…

* With the present new technology, some alkaline cells are rechargeable, alkaline cell has become a secondary cell. (Check the packaging to know if it is a primary or a secondary one)

4.5.4. Button Cells and Coin Cells

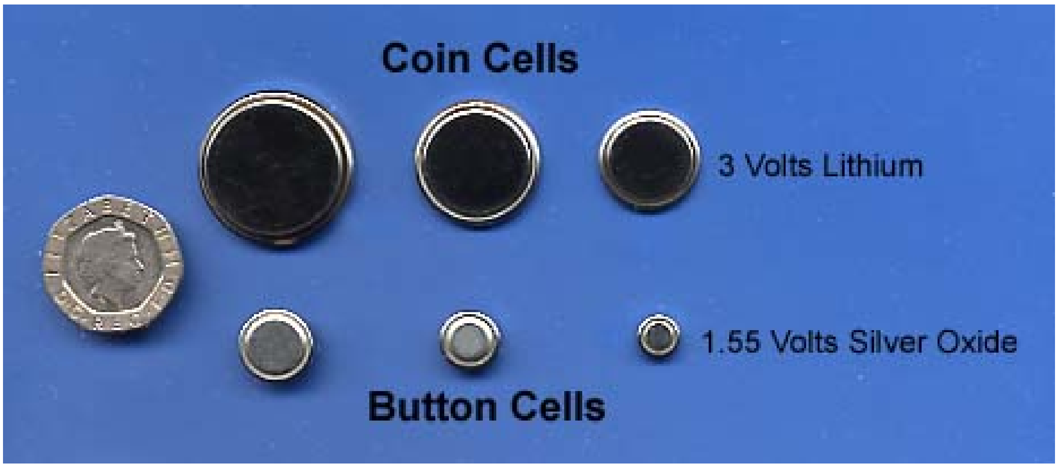


Figure 47: Button and coin cells

Button and coin cells are available in a range of sizes, voltages and cell chemistries. (Zinc -Air cells are also available but not shown)

4.5.5. Pouch Cells

Figure 48: Valence pouch cells

Pouch casings are typically used for Lithium Polymer cells with solid electrolytes, providing a low cost "flexible" (sometimes in unintended ways) construction. The electrodes and the solid electrolyte are usually stacked in layers or laminations and enclosed in a foil envelope. The solid electrolyte permits safer, leak-proof cells.

The foil construction allows very thin and light weight cell designs suitable for high power applications but because of the lack of rigidity of the casing the cells are prone to swelling as the cell temperature rises. Allowance must be made for the possibility of swelling when choosing cells to fit a particular cavity specified for the battery compartment.

The cells are also vulnerable to external mechanical damage and battery pack designs should be designed to prevent such possibilities.

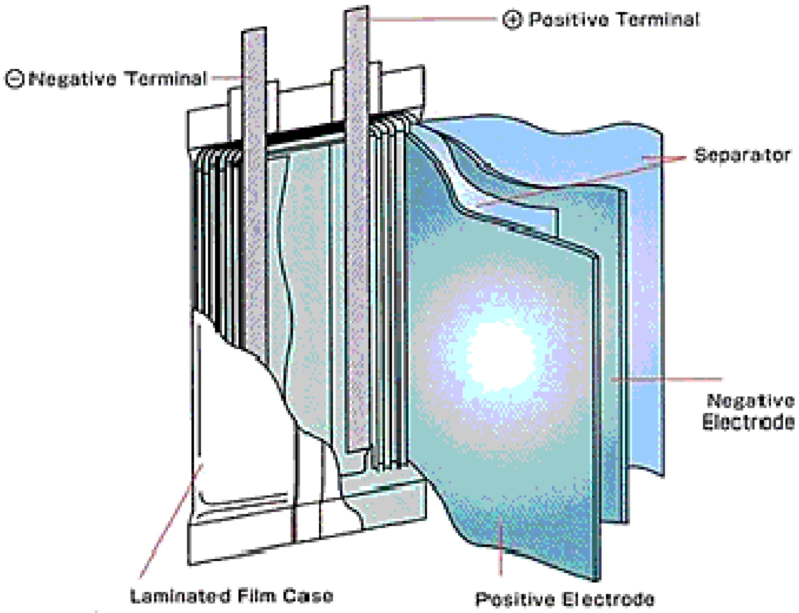


Figure 49: Aluminium laminate package

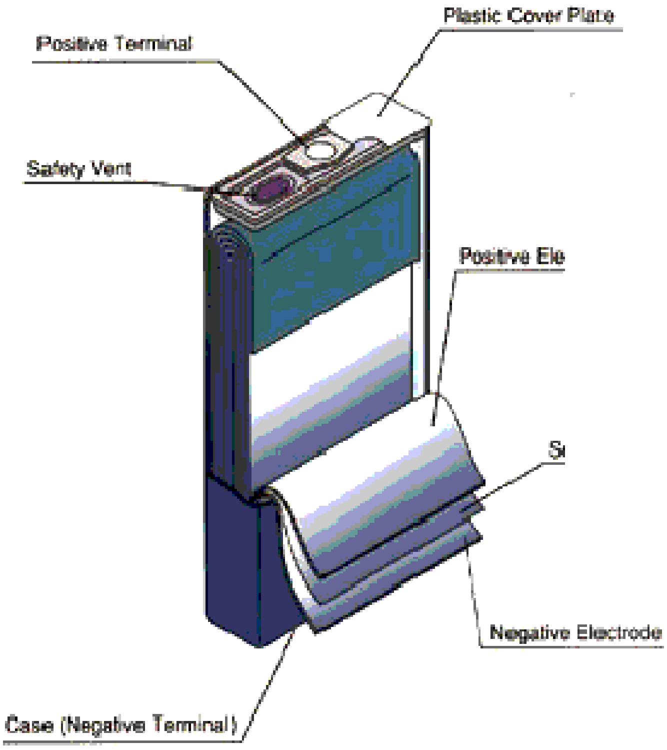
The GS-Melcotec example illustrated uses spiral wound electrodes and a solid polymer electrolyte.

This construction, using stacked electrodes is suitable for making odd shaped cells but few applications make use of this opportunity.

- Accumulator Lithium Polymer
- Voltage 8.4v
- Capacity 850 mAh
- Length: 51 mm
- Width: 35 mm
- Thickness: 11mn

Figure 50: Lithium polymer accumulator

4.5.6. Prismatic Cells



Prismatic cells are contained in a rectangular can. The electrodes are either stacked or in the form of a flattened spiral. They are usually designed to have a very thin profile for use in small electronic devices such as mobile phones.

Prismatic cells provide better space utilisation at the expense of slightly higher manufacturing costs, lower energy density and more vulnerability to swelling, but these are minor effects which don't constitute a major disadvantage.

This example from GS-Melcotec has a steel can with spiral wound electrodes and a liquid electrolyte.

Figure 51: Prismatic Fe case

Battery PMR ALCATEL-TAIT Ni-CD 12V 1400 MAH

- Battery Ni-Cd PMR
- Voltage: 12 V
- Capacity: 1400 mAh
- Weight: 375 g
- Length: 99 mm
- Width: 67 mm
- Height: 38 mm

Figure 52: Example of Ni-Cd battery

Battery PMR MOTOROLA Li-Ion 7.5V 1500 MAH GPNM4024R for GP344

- Battery Li-ion PMR
- Voltage: 7.2 V
- Capacity: 1500 mAh
- Weight: 225 g

Figure 53: Example of Li-ion battery

Batterie PMR ASCOM-AUTOPHON-BOSH Ni-Cd 7.2V - 1200 MAH for SE140

- Battery Ni/Cd PMR
- Voltage: 7.2 V
- Capacity: 1200 mAh
- Weight: 208 g
- Length: 76 mm
- Width: 66 mm
- Height: 31 mm

Figure 54: Example of Ni-Cd battery

4.5.7. Thin Film Batteries

Thin film printing technology is now being used to apply solid state Lithium polymer chemistry to a variety of substrates to create unique batteries for specialist applications.

Thin film batteries can be deposited directly onto chips or chip packages in any shape or size, and flexible batteries can be made by printing on to plastics, thin metal foil or even paper. Because of their small size, the energy storage and current carrying capacity of thin film batteries is low but they have unique properties which distinguish them from conventional batteries including:

- All solid state construction
- The battery can be integrated into the circuit for which it provides the power Bendable batteries are possible
- Can be made in any shape or size
- Long cycle life and operating life
- Operate over wide temperature range
- High energy and power densities
- Cost and capacity are proportional to the area
- No safety problems

Figure 55: Example of thin film battery

Thin film batteries have a wide range of uses as power sources for consumer products and for micro-sized applications.
The example from Oak Ridge Micro-Energy is designed for use in implantable medical devices.

Other applications include non-volatile memory backup and sensors.

Flexible film batteries like that shown on the left from Infinite Power Solutions are suitable for powering smart cards and radio frequency identification (RFID) tags.

Figure 56: Example of flexible film battery

Under development for ten years, thin film batteries are just recently becoming available in commercial quantities.

4.5.8. High Power Batteries

While there is at least some standardisation with low power cells, the same can not be said for high power cells which are made in a wide range of sizes using many different construction techniques. These include foil pouches, plastic or glass box like structures and cylindrical steel tubes.

The large cells on the picture are 3.7 Volt Lithium cells. The cylindrical cell has a capacity of 60 Ah, while the prismatic cell has a 200 Ah capacity. The small cells in the foreground for comparison purposes are AAA size.

Low internal resistance is an important requirement of these cells and this in turn requires thick current carriers and low contact resistances between the electrodes and the interconnections. Because these cells are designed to carry high currents which cause them to heat up, the cells usually incorporate features to allow for expansion of the contents and to avoid swelling.

There may be voids inside the cell or there could be special clamps around the outside of the cells to constrain expansion to a particular direction.

Figure 57: Example of high power battery

4.5.9. Power Batteries

It concerns all the lead-lead and Ni-Cad batteries with electrolyte acid or potassium based in aqueous or paste/gel form, vented or sealed. Those batteries are used in our cars, trucks, but also in batteries banks associated with UPS and Battery Chargers.

Like the High Power Batteries, sizing is not standardised and manufacturers propose theirs products as per their “own” standards

Hereafter, some examples

Sealed Lead Battery with GEL - Europa 12 Volt

Figure 58: Sealed Lead Battery with Gel

- Voltage: 12v
- Capacity: 7.5 Ah 26 Ah, 33 Ah, 44 Ah
- Dimensions: 166*175*125
- Weight: 9kg - 15Kg - 15Kg

Battery Enersol 100 - 12 Volts - 97Ah - 353 x 175 x 190 mm for solar application

- Voltage: 12 Volts
- Capacity: from 52 to 250 Ah
- Weight 25.2kg
- Delivery in dry state with acid electrolyte apart in 5 litres cans

Figure 59: Classic ENERSOL Lead vented

Lead-Gel (acid) Battery sealed SONNENCHEIN

Figure 60: Lead-Gel (acid) Battery

- From 1,2 to10 Ah for 4, 6, 8, 10, 12V
- Performing batteries, life time: 6 years under normal ambient conditions and in « Floating » use.
- No maintenance
- Application: Alarms, Safety, Fire & Gas Telephone, emergency lighting,…etc

Lead sealed Battery 'Saphir' electrolyte: not specified

- 6 and 12 Volts from 1.3 to 120 Ah
- From 0.6 to 16 Kg weight
- Same applications as above

Figure 61: Lead sealed battery "Saphir"

Lead sealed Battery 'Cyclon' electrolyte: not specified

Figure 62: Lead sealed battery "Cyclon"

- 2, 6 and 12 Volts from 2.5 to 25Ah
- Temperature 'utilisation -40°c to +65°c
- Same applications as above

The 'Saft' (or other manufacturer) Batteries in « our » site applications

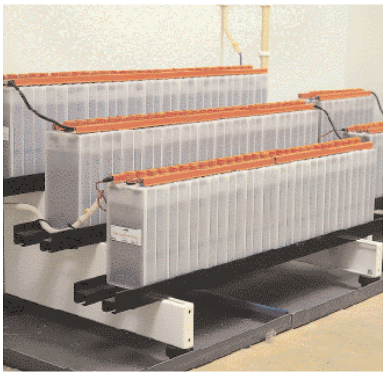


Figure 63: "Saft" batteries

In Ni-Cad (like the figure "Saft" batteries), 1.25V per cell, with either acid or potassium electrolyte itself aqueous or gel; vented or sealed with safety vents (which should be removable for maintenance)

Or in Lead-Lead, 2 to 2.2V per cell, same as above for electrolyte and sealed or vented.

5. THE DIFFERENT TYPES OF BATTERIES

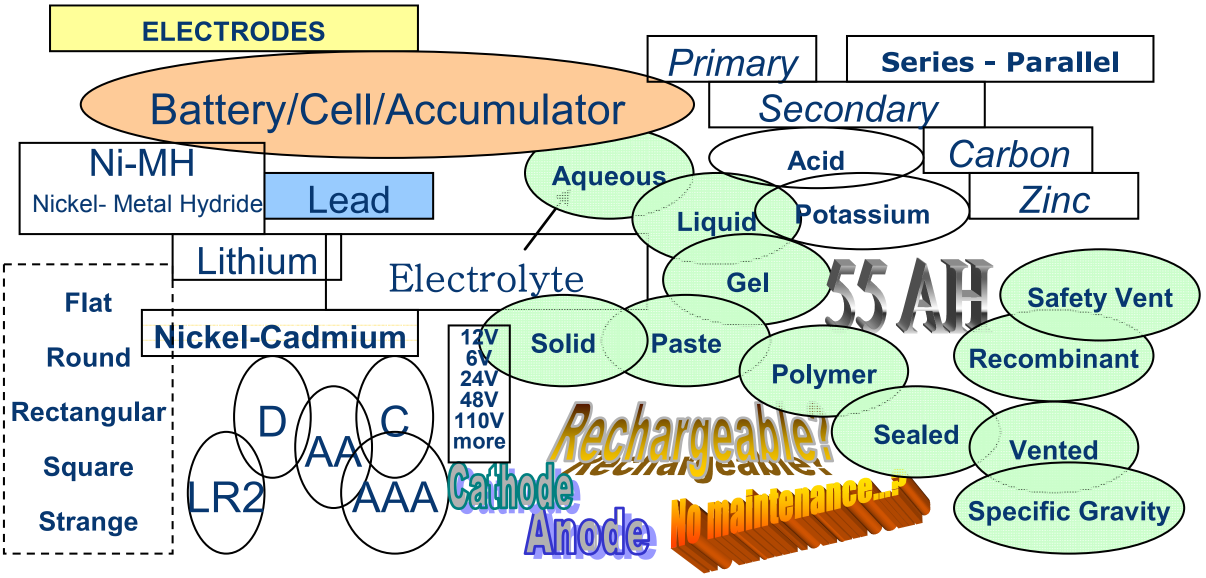


Figure 64: Panic on batteries

With what we have seen up to now, you should know (a bit) more about batteries, but it is (probably) still confusing… Let's continue

5.1. NOMENCLATURE

5.1.1. Cell identification.

There is considerable confusion about naming standards for cells with different systems used in Europe, the USA and Japan as well as manufacturers ' own standards.

One convention is two letters followed by a series of numbers.

The first letter represents the cell chemistry. The second letter represents the shape of the cell.

The numbers represent the dimensions of the cell in millimetres. For cylindrical cells the first two digits are the diameter and the remaining digits the length. For prismatic cells the first two digits represent the thickness, the second pair the height and the last pair the width.

Because of the plethora of "standards" the only safe course in identifying a cell is to consult the manufacturers' data sheets.

5.1.2. Examples

5.1.2.1. Common Primary Cells

See Battery Case Sizes hereunder for dimensions of common primary cells.

COMMON BATTERY CASE SIZES			
CELL TYPE	SHAPE	HEIGHT (mm)	DIAMETER (mm)
AAAA	Cylindrical	42.5	8.3
AAA	Cylindrical	44.5	10.5
AA	Cylindrical	50.5	14.5
A	Cylindrical	50.0	17.0
C	Cylindrical	50.0	26.2
D	Cylindrical	61.5	34.2
F	Cylindrical	87.0	32.0
G	Cylindrical	105.0	32.0
J	Rectangular	48.5	33.5 x 9.22
N	Cylindrical	29.35	11.95
PP3 (9 Volt)	Rectangular	48.5	26.5 x 17.5
PP9 (9 Volt)	Rectangular	80.2	65.1 x 51.6
Lantern (6 Volt)	Rectangular	115.0	68.0 x 68.0

Table 6: Battery case sizes

5.1.2.2. Low Power Cylindrical Cells

See Cylindrical Cell Sizes hereunder for a listing of typical cylindrical cell sizes and capacities

Low Power Cylindrical Cell Sizes and Capacities				
Model	Dimensions (mm)		Capacity	Voltage
	Diameter	Length	(mAh)	(V)
14500	14	500	720	3.7
14650	14	650	940	3.7
18500	18	500	1100	3.7
18500F	18	500	1600	3.7
18650	18	650	1700	3.7
18650F	18	650	2300	3.7
18650H	18	650	1900	3.7

Table 7: Cylindrical cell sizes

As example, LC18650 is a common Li-ion cell in a Cylindrical can with a diameter of 18mm and a height of 65.0mm

5.1.2.3. Prismatic Cells

See “Low Power Prismatic Cell Sizes” hereunder for a listing of typical prismatic cell sizes and capacities.

Low Power Prismatic Cell Sizes and Capacities								
Model	Thickness (mm)	Width (mm)	Height (mm)	Capacity (mAh)	Impedance (mΩ)	Voltage (V)	Weight (g)	Casing
053048	5.5	30.0	48.0	650.0	30-70	3.7	20.5	Steel
063048	6.3	30.0	48.0	750.0	30-70	3.7	25.5	Steel
063448	6.5	34.0	48.0	950.0	20-60	3.7	29.0	Steel

LOW POWER PRISMATIC CELL SIZES AND CAPACITIES								
MODEL	THICKNESS (mm)	WIDTH (mm)	HEIGHT (mm)	CAPACITY (mAh)	IMPEDANCE (mΩ)	VOLTAGE (V)	WEIGHT (g)	CASING
073048	7.5	30.0	48.0	900.0	30-70	3.7	28.0	Steel
073448	7.5	34.0	48.0	1000.0	30-70	3.7	32.0	Steel
083448	8.5	34.0	48.0	1050.0	30-70	3.7	35.0	Steel
103447	10.0	34.0	47.0	1400.0	30-70	3.7	40.0	Steel
123582	12.1	35.1	82.0	3000.0	20-60	3.7	90.0	Steel
143447	14.0	34.0	47.0	1800.0	20-60	3.7	56.0	Steel
033450	3.9	34.0	50.0	600.0	40-80	3.7	14.8	Aluminium
043048	4.4	30.0	48.0	600.0	30-80	3.7	14.5	Aluminium
043450	4.4	34.0	50.0	720.0	40-80	3.7	16.5	Aluminium
052246	5.6	22.0	46.0	450.0	40-80	3.7	12.3	Aluminium
052248	5.8	22.0	48.0	500.0	40-80	3.7	13.5	Aluminium
053048	5.4	30.2	48.0	700.0	30-70	3.7	17.5	Aluminium
053048L	5.4	30.2	48.0	680.0	30-70	3.7	17.5	Aluminium
053450	5.4	34.0	50.0	850.0	30-80	3.7	19.5	Aluminium
063048	6.4	30.0	48.0	850.0	30-70	3.7	19.0	Aluminium
063048L	6.4	30.0	48.0	780.0	30-70	3.7	19.0	Aluminium
063448	6.4	34.0	48.0	950.0	30-70	3.7	23.5	Aluminium
063450	6.4	34.0	50.0	950.0	30-70	3.7	23.0	Aluminium
073048	7.5	30.0	48.0	950.0	30-70	3.7	23.1	Aluminium
073448	7.6	34.0	48.0	1100.0	30-70	3.7	27.3	Aluminium
083448	8.5	34.0	48.0	1200.0	30-70	3.7	28.0	Aluminium
103450	10.0	34.0	50.0	1650.0	30-70	3.7	36.2	Aluminium

Table 8: Low power prismatic cell sizes

As example, LP083448 is a Li-ion cell in a Prismatic can with a thickness of 8.mm, a height of 48mm and a width of 34 mm

See “High Power Prismatic Cell Sizes” hereunder for examples of high power prismatic cells. (High power cylindrical cells are also available)

HIGH POWER PRISMATIC CELL SIZES AND CAPACITIES								
DIMENSIONS (mm)				CAPACITY	MAX CURRENT	VOLTAGE	IMPEDANCE	WEIGHT
MODEL	THICKNESS	WIDTH	HEIGHT	(Ah)	(A)	(V)	(mΩ)	(Kg)
6163A	46	116	190	50	100	3.6	0.8-1.5	1.2
90A	61	115	215	90	180	3.6	0.5-1.5	2.4
8581A	61	145	220	100	200	3.6	0.5-1.5	3.0
9393A	71	182	285	200	400	3.6	0.2-0.8	5.5
5453B	71	280	560	500	800	3.6	< 2.0	15.0
6168B	71	280	560	700	1200	3.6	< 2.0	17.0
7171B	71	280	560	700	1100	3.6	< 2.0	19.0
1313B	85	280	560	1000	1500	3.6	< 2.0	26.0

Table 9: High power prismatic cell sizes

5.2. PRIMARY CELLS

Disposable Primary Batteries Résumé of the most used:

Type	Advantages	Disadvantages	Typical application	GP Product
Carbon/Zinc	Cheapest of all Reliable	Relatively Low Power	Torches Toys Doorbells.	Super Alkaline
Alkaline Alkaline button	Cheap, higher power and longer life than Carbon/Zinc. Longer shelf life	Medium power	Motorised toys Photo flash	Ultra Alkaline Alkaline button
Zinc Air	High output from a small size Long storage life until opened Low environmental impact	Once exposed to air the shelf life is quite short.	Hearing aids	ZA10 ZA13 etc
Silver Oxide	High power in a small size	Relatively high cost	Photographic Equipment Watches	Wide range e.g. 301 329 399
Lithium Primary Cells	Very high power for low weight. Durable, small cells.	High Cost	Medical implants Computer memory, Car Fobs	Wide range e.g. CR2016, CR2032, CR123A

Table 10: Disposable primary cells

We see hereafter, in detail, the different primary (non rechargeable) cells or batteries available on the market, they are the

- "Leclanché" Cells (or Carbon-Zinc)

- Alkaline Cells
- Silver Oxide Cells
- Zinc Air Cells
- Lithium Primary Cells
- Water Activated Batteries
- Thermal Batteries

5.2.1. Leclanché Cells (Carbon-Zinc)

5.2.1.1. Characteristics

Primary cell with a nominal open circuit voltage of 1.5 Volts produced in very high volumes.

Chemistry based on a zinc anode and a cathode/depolariser of manganese dioxide which absorbs the liberated hydrogen bubbles which would otherwise insulate the electrode from the electrolyte. It uses a carbon rod as the cathode current collector with an electrolyte of ammonium chloride. Its variants have been in use for over a century. The performance of Leclanché cells improved by 700% between 1920 and 1990.

Also referred to as Zinc- Carbon Cells or Dry Cells (not to be confused with Solid State Cells) despite having an aqueous electrolyte since in modern cells the electrolyte of ammonium chloride and zinc chloride is produced in gel form or held in porous separators to reduce potential leakage if the cell becomes punctured.

Variants include:

- Zinc carbon (Carbon cathode)
- Zinc chloride (Ammonium chloride electrolyte replaced by zinc chloride)
- Alkaline manganese (Ammonium chloride electrode replaced by potassium hydroxide)

5.2.1.2. Advantages

- Inexpensive materials
- Low cost

- Available in a wide range of sizes including AAA, AA, C, D and 9Volt sizes.
- Suitable for a wide range of consumer applications
- Interchangeable with alkaline batteries

5.2.1.3. Shortcomings

- Propensity to leak
- The basic zinc carbon battery has a lower energy density than the competing - alkaline batteries
- Poor low temperature performance. Do not function well in sub-zero temperatures.
- The use of naturally occurring manganese dioxide from different sources can lead to wide performance variations due to the presence of small quantities of impurities such as nickel, copper, arsenic, and cobalt.
- Not rechargeable

5.2.1.4. Applications

- General purpose, low cost applications
- Toys / Remote controls / Flashlights / Clocks / Consumer applications
- Losing market share to alkaline cells and newer technologies

5.2.1.5. Costs

- Lowest cost primary batteries

5.2.2. Alkaline Cells

5.2.2.1. Characteristics

- 1.5 Volt primary cell
- Most popular premium general purpose battery.
- In an alkaline cell the electrical energy is essentially derived from the reaction of a metal with oxygen.
- The alkaline manganese battery is a variant on the Leclanché cell. As with the Leclanché Cell the electrodes are zinc and manganese dioxide but the electrolyte is potassium hydroxide.

Recently rechargeable cells using this chemistry have become available. Known as (RAM) Rechargeable Alkaline Manganese batteries they offer all the features and benefits of Alkaline primary cells, with the added benefit of being rechargeable, but without the disadvantage of "memory effect" (see chapter charging batteries for this term).

Examples:

Figure 65: Alkaline Cell GP25A

9v capacity 18 mAh
Dimensions:
h: 21.4mn dia 7.7mn
Weight: 3.5grams

Figure 66: Alkaline Cell 186 LR43

1.5v capacity 70mAh
Dimensions:
h 4.2mn diam 11.6mn
Weight: 1.60gr

Figure 67: Alkaline Cells Duracell Procell PC915 ECOLI V 6V 13AH or 4LR25

6V capacity 13Ah
Dimensions :
h 110mn
W 68 * 68
Weight : 612 grams

And all “classic” shapes, use between -20 and +70°C

5.2.2.2. Advantages

- Similar to, and interchangeable with, zinc carbon Leclanché cells but with as much as double the energy density.
- Four times the capacity of an equivalent size rechargeable Nickel Cadmium or Nickel Metal Hydride cells.
- Four to nine times longer life than the equivalent Leclanché cell.
- Constant capacity over a wide range of current drains.
- Suitable for high drain rate applications.
- Good shelf life
- Better low temperature performance than zinc carbon. Continue to function in sub-zero temperatures.
- Less leakage than Leclanché cells
- Available in a wide range of sizes including AAA, AA, C, D and 9Volt sizes.
- Suitable for a wide range of consumer applications
- Made from non toxic chemicals

5.2.2.3. Shortcomings

- Higher cost than the basic competing zinc carbon Leclanché cells
- Normally not rechargeable
- 25% heavier than Leclanché cells
- RAM cells have limited cycle life of about 100 cycles and are only available in AA and AAA sizes

5.2.2.4. Applications

Premium products / Toys / Remote controls / Flashlights / Clocks / Consumer applications
RAM cells can be interchanged with standard alkaline cells (but not mixed in the same application).

5.2.2.5. Costs

Low cost but about 50% higher than zinc carbon, however these cells are more cost effective because of the longer life

5.2.3. Silver Oxide Cells

5.2.3.1. Characteristics

Commonly called Silver Oxide batteries they are primary cells with an open circuit voltage of 1.6 Volts.

Because of the high cost of sliver they are available in either very small sizes as button cells where the amount of silver used is small and not a significant contributor to the overall product costs or they are available in very large sizes where the superior performance characteristics of the silver oxide chemistry outweigh any cost considerations.

5.2.3.2. Advantages

- High capacity per unit weight.
- Long operating life. A tiny button cell will keep a watch running 24 hours per day for 3 to 5 years!!
- Low self discharge and hence long shelf life (better than zinc air)
- Better low temperature performance than zinc air
- Flat discharge characteristics
- Higher voltage than zinc mercury cells.

5.2.3.3. Shortcomings

- Uses expensive materials
- Lower energy density than zinc air
- Poor low temperature performance.
- Limited cycle life.

5.2.3.4. Applications

- A major contribution to miniature power sources.
- As a button cell it is well suited for hearing aids, instruments, photographic applications, electronic watches and other low power devices.
- Larger size Silver Zinc batteries are used in submarines, missiles, underwater and aerospace applications

5.2.3.5. Costs

- More expensive than zinc air
- Very expensive for high power applications

5.2.4. Zinc Air Cells

5.2.4.1. Characteristics

An example of Metal Air batteries, cells using zinc-air technology are energized only when atmospheric oxygen is absorbed into the electrolyte through a gas-permeable, liquid-tight membrane. With the removal of a sealing tab, oxygen from the air is introduced into the cell. A zinc-air battery usually reaches full operating voltage within 5 seconds of being unsealed.

The zinc air cell is basically a primary battery however rechargeable designs for high power applications are possible by physically replacing the zinc electrodes.

They use the oxygen content of the air as active mass. The positive electrode is a porous body made of carbon with air access. Atmospheric oxygen is reduced at this electrode. The active mass is thus not contained in the electrode but is taken from the surrounding air as it is needed. The initial weight of the battery is reduced accordingly. The negative electrode consists of zinc. An aqueous solution of potassium hydroxide serves as the electrolyte.

The cell voltage for the chemistry is theoretically capable 1.65 Volts however almost all designs are optimised for less than 1.4 or 1.3 Volts in order to achieve longer lifetimes.

RENATA N°	DIMENSIONS	NOMINAL VOLTAGE	NOMINAL CAPACITY
	(mm)	(V)	(mAh)
ZA 675	11.6 x 5.4	1.4	610
ZA 13	7.9 x 5.4	1.4	270
ZA 312	7.9 x 3.6	1.4	150
ZA 10	5.8 x 3.6	1.4	80
ZA 5	5.8 x 2.1	1.4	35

Figure 68: Example of 'Renata' Cells for hearing devices

5.2.4.2. Advantages

- High energy density but low power
- Inexpensive materials
- The zinc-air system, when sealed, has excellent shelf life, with a self-discharge rate of only 2 percent per year.
- In relation to their physical size, Zinc/Air batteries store more energy per unit of weight (in terms of 220 Wh/kg) than almost any other primary type.
- Primary cells available in a range of button and coin cell sizes.
- Rechargeable high power cells available for traction applications.

5.2.4.3. Shortcomings

- Sensitive to extreme temperature and humid conditions.
- Carbon dioxide from the air forms carbonate which reduces conductivity.

- High self discharge.
- After activation, chemicals tend to dry out and the batteries have to be used quickly.
- Although recharging is possible it is also inconvenient and is only suitable for high power types.
- High internal resistance which means zinc air batteries must be huge to satisfy high current needs.
- High power batteries such as those designed for traction applications use mechanical charging in which discharged zinc cartridges are replaced by fresh zinc cartridges. The used cartridges are subsequently recycled

5.2.4.4. Applications

- The system is well known as a primary battery.
- Zinc air button cells are commonly used for watches and hearing aids.
- Larger types are employed as prismatic or cylindrical cells for telecoms and railway remote signalling, safety lamps at road and rail construction sites or as power sources for electric fences.
- Possible traction applications where "Mechanical Charging" cuts down on recharging time but little take up so far.

5.2.4.5. Costs

- Low cost

5.2.5. Lithium Primary Cells

5.2.5.1. Characteristics

Voltage: 3 V
Dimensions: H: 2.5 mm Dia: 10 mm
Temperature of use: -40°C to + 60°C

Figure 69: Button battery lithium CR1025

Voltage: 3 V
Capacity 1500mAh
Dimensions: H: 60mm Dia:12mm
Weight: 15g
Applications: Memory Back up (MBU)

Figure 70: Lithium battery 3V CR12600SE

Lithium is the lightest of metals and it floats on water. It also has the greatest electrochemical potential which makes it one of the most reactive of metals. These properties give Lithium the potential to achieve very high energy and power densities permitting batteries with very long useful life and small cell packages.

Because lithium reacts violently with water, as well as nitrogen in air, this requires sealed cells. High-rate lithium cells build up temperature and pressure if they are short circuited or abused. Thus, the cell design needs to include safety vents, which release the pressure or rupture to prevent uncontrolled explosion.

Typical chemistries are lithium manganese dioxide, lithium sulphur dioxide and lithium thionyl chloride (see below) but other variants are available.

Available cell voltages range between 3 and 4 Volts

Cell packaging includes coin cell and cylindrical packages.

Thin film cells based on ceramic or flexible substrates are also available.

5.2.5.2. Advantages

- High energy density, double that of premium alkaline batteries
- Low weight

- High cell voltage
- Flat discharge characteristic
- Low self discharge
- Very long shelf life
- Very long operating life (15 to 20 years for lithium thionyl chloride)
- Wide operating temperature range (-60 ° C to +85 ° C for lithium sulphur dioxide)
- Excellent durability
- Small cell size

5.2.5.3. Shortcomings

- High cost

5.2.5.4. Applications

- Computer memory protection
- Medical implants
- Heart pacemakers
- Defibrillators
- Utility meters
- Watches
- Cameras
- Calculators
- Car keys
- Security transmitters
- Smoke alarms
- Aerospace applications

Because of its superior performance characteristics Lithium technology is replacing older, traditional technologies in an ever widening range of applications.

5.2.5.5. Costs

More expensive than common consumer primary Leclanché and alkaline batteries

Lithium-Manganese Dioxide Cell: anode: lithium foil cathode: manganese dioxide electrolyte: separator sheet impregnated with electrolytic salts cell voltage: 3 volts The most common non-rechargeable lithium cell.

Lithium Iron Disulphide Cell: anode: lithium foil cathode: iron disulfide with aluminium cathode contact electrolyte: separator sheet impregnated with electrolytic salts. Designed to be a drop in replacement for zinc carbon or alkaline batteries the cell voltage: 1.5 volts. Often called the "Voltage compatible" lithium cell, they have a higher energy density than the cells they replace and tailored to high current applications.

Lithium Thionyl Chloride Cell: The highest energy density of all Lithium type cells have a service life of 15 to 20 years.

Lithium Iodine Cell: Provides excellent safety and long life. Uses only solid components and the separator is self healing if cracks occur. High internal impedance limits its use to low drain applications. Used for the majority of implanted cardiac pacemakers

5.2.6. Water Activated Batteries

5.2.6.1. Characteristics

These are single use primary cells often called "reserve batteries" with a long shelf life used mainly for emergency applications.

Stored in the dry condition and activated at the time of use by adding or immersing in water or adding an aqueous electrolyte.

Seawater-activated types also available.

Magnesium is generally used as the anode material with various chlorides being used for the cathode cost being traded off for performance, silver chloride having superior energy and current density while cuprous chloride has lower costs.

Aluminium anodes are also widely used with seawater-activated batteries.

Very high current densities possible.

5.2.6.2. Advantages

- Reliable
- Rugged
- Safe
- Light weight without the need to carry the electrolyte.
- High power and energy densities
- Good response to pulse loading
- Instantaneous activation
- Long inactivated shelf life
- No maintenance

5.2.6.3. Shortcomings

- High self discharge rate after activation
- Once activated they must be replaced

5.2.6.4. Applications

- Military applications
- Marine use for sonobuoys, life jackets, Air Sea rescue equipment, emergency lighting, weather balloons.
- Forced flow types used for powering torpedoes can deliver over 300kW for 10 minutes

5.2.6.5. Costs

- Silver cathode types have high material costs
- Non-silver cathode types have low material costs

5.2.7. Thermal Batteries

5.2.7.1. Characteristics

These are single use High Temperature galvanic primary cells also called Reserve Batteries.

They contain a metallic salt electrolyte which is non-conducting when solid at ambient temperature but which is an excellent ionic conductor when molten.

Activated by a pyrotechnic charge, they provide a high burst of power for a short period. (A few tens of seconds to 20 minutes or more)

They are rugged and safe with an indefinite shelf life in storage which makes them ideal for military applications.

Typical chemistry is Lithium Iron disulphide. The electrolyte is normally a eutectic mixture of lithium and potassium chlorides.

Power output ranges from a few watts to several kilowatts.

5.2.7.2. Advantages

- Able to withstand severe mechanical stresses of acceleration, shock, vibration and spin
- Rugged
- Reliable
- Safe
- High power and energy densities
- Instantaneous activation
- Active chemicals are inert until activated
- Long inactivated shelf life - Up to 20 years
- No maintenance
- Design can be optimised for power or capacity.

5.2.7.3. Shortcomings

Operating temperature of 400 to 700°C must be maintained by the pyrotechnic charge throughout the duration of the application. Need insulation to conserve heat once activated

5.2.7.4. Applications

- Military applications
- Missiles
- Weapons systems

5.2.7.5. Costs

- Expensive

Biothermal Battery

- Low temperature, low power devices using nano scale materials and semiconductor technology to convert thermal energy produced by the human body into electrical energy.
- Resulting power can be used to trickle charge batteries for medium power devices or to drive low drain applications such as heart pacemakers.
- Long life.
- Can be implanted.
- Low energy conversion efficiency due to low operating temperature.
- Use limited to low power applications

5.3. SECONDARY CELLS

Disposable Primary Batteries Résumé of the most used and those used on site, they are the Rechargeable battery

Type	Advantages	Disadvantages	Typical Application	GP Product
Lead / Acid	Low cost Reliable. High Current	Bulky Heavy May leak	Car Batteries Golf trolleys	Not Available
Nickel / Cadmium (Ni-Cd)	High Rate of charge Life cycle approx 400-600 times Relatively cheap.	Memory Effect reduces useable capacity Being phased out on environmental grounds because of Cadmium content.	Motorised toys Power tools Razors	Being discontinued
Nickel Metal Hydride (Ni-Mh)	High power in a small size. No memory effect. Rapid Charging possible Low environmental impact. Long shelf life.	Self discharge quite quickly. Get hot whilst charging	Motorised toys Power tools Medical equipment Toothbrushes Razors	Ni-MH Rechargeable
Lithium Rechargeable	Very high density High voltage per cell. Low weight Fast charge. Very low self discharge. No memory effect. Long life	Relatively high cost. Some care should be taken not to damage the cell as the contents could be hazardous.	Laptop computers Camcorders, Cameras. Portable TV. Medical equipment	Specialist Applications

Table 11: Primary batteries

5.3.1. Lead Acid

5.3.1.1. Characteristics

Car battery 12V - open vented Flooded/Wet cell batteries

Sealed with gel (UPS) – 12V

4V Sealed Lead Gel (Alarm, Telephone,…)

Figure 71: Examples of lead acid batteries

Lead acid batteries were invented in 1859 by French physicist Gaston Planté, and first demonstrated to the French Academy of Sciences in 1860. They remain the technology of choice for automotive SLI (Starting, Lighting and Ignition) applications because they are robust, tolerant to abuse, tried and tested and because of their low cost. For higher power applications with intermittent loads however, Lead acid batteries are generally too big and heavy and they suffer from a shorter cycle life and typical usable power down to only 50% Depth of Discharge (DOD). Despite these shortcomings

Battery chemistry

Lead-acid car batteries for a '12 volt' system consist of six cells of 2.1 V nominal voltage. Each cell contains (in the charged state) electrodes of lead metal (Pb) and lead (IV) oxide (PbO_2) in an electrolyte of about 37% (or 6-12M) *w/w* sulphuric acid (H_2SO_4). In the discharged state both electrodes turn into lead (II) sulfate ($PbSO_4$) and the electrolyte loses its dissolved sulfuric acid and becomes primarily water.

Due to the freezing-point depression of water, as the battery discharges and the concentration of sulfuric acid increases, the electrolyte (including the more modern jellified electrolyte of the gel battery) is more likely to freeze.

Many vendors sell chemical additives (solid compounds as well as liquid solutions) that supposedly reduce sulfate build up and improve battery condition when added to the electrolyte of a vented lead-acid battery. Such treatments are rarely, if ever, effective.

The following are general voltage ranges for six-cell lead-acid batteries:

- Open-circuit (Quiescent) at full charge: 12.6 - 12.8 V
- Open-circuit at full discharge: 11.8 - 12.0 V
- Loaded at full discharge: 10.5 V
- Continuous-preservation (float) charging: 13 - 13.2 V
- Typical (daily) charging: 13.2 - 14.4 V
- Equalization charging (for flooded lead acids): 15 - 16 V
- Gassing threshold: 14.4 V
- After full charge the terminal voltage will drop quickly to 13.2 V and then slowly to 12.6 V.

The chemical reactions are (charged to discharged):

Anode (oxidation):

$$Pb(s) + SO_4^{2-}(aq) \leftrightarrow PbSO_4(s) + 2e^- \quad \varepsilon^\circ = 0{,}356V$$

Cathode (reduction):

$$PbO_2(s) + SO_4^{2-}(aq) + 4H^+ + 2e^- \leftrightarrow PbSO_4(s) + 2H_2O(l) \quad \varepsilon^\circ = 1{,}685V$$

Because of the open cells with liquid electrolyte in most lead-acid batteries, overcharging with excessive charging voltages will generate oxygen and hydrogen gas by electrolysis of water, forming an extremely explosive mix. This should be avoided. Caution must also be observed because of the extremely corrosive nature of sulfuric acid.

Antimony is one of the best hardeners for lead batteries.

5.3.1.2. Advantages

- Low cost.
- Reliable. Over 140 years of development.
- Robust. Tolerant to abuse.
- Tolerant to overcharging.

- Low internal impedance.
- Can deliver very high currents.
- Indefinite shelf life if stored without electrolyte.
- Can be left on trickle or float charge for prolonged periods.
- Wide range of sizes and capacities available.
- Many suppliers world wide.
- The world's most recycled product.

5.3.1.3. Shortcomings

- Very heavy and bulky.
- Typical coulombic charge efficiency only 70% but can be as high as 85% to 90% for special designs.
- Danger of overheating during charging
- Not suitable for fast charging
- Typical cycle life 300 to 500 cycles.
- Must be stored in a charged state once the electrolyte has been introduced to avoid deterioration of the active chemicals.

Gassing is the production and release of bubbles of hydrogen and oxygen in the electrolyte during the charging process, particularly due to excessive charging, causing loss of electrolyte. In large battery installations this can cause an explosive atmosphere in the battery room. Sealed batteries are designed to retain and recombine these gases. (See VRLA below)

Sulphation may occur if a battery is stored for prolonged periods in a completely discharged state or very low state of charge, or if it is never fully charged, or if electrolyte has become abnormally low due to excessive water loss from overcharging and/or evaporation. Sulphation is the increase in internal resistance of the battery due to the formation of large lead sulphate crystals which are not readily reconverted back to lead, lead dioxide and sulphuric acid during re-charging. In extreme cases the large crystals may cause distortion and shorting of the plates. Sometimes sulphation can be corrected by charging very slowly (at low current) at a higher than normal voltage.

Completely discharging the battery may cause irreparable damage.

Shedding or loss of material from the plates may occur due to excessive charge rates or excessive cycling. The result is chunks of lead on the bottom of the cell, and actual holes in the plates for which there is no cure. This is more likely to occur in SLI batteries whose plates are composed of a Lead "sponge", similar in appearance to a very fine foam sponge. This gives a very large surface area enabling high power handling, but if deep cycled, this sponge will quickly be consumed and fall to the bottom of the cells.

Toxic chemicals

Very heavy and bulky

Lower temperature limit -15 °C

Decomposition of the Electrolyte Cells with gelled electrolyte are prone to deterioration of the electrolyte and unexpected failure. Such cells are commonly used for emergency applications such as UPS back up in case of loss of mains power. So as not to be caught unawares by an unreliable battery in an emergency situation, it is advisable to incorporate some form of regular self test into the battery.

5.3.1.4. Charging

- Charge immediately after use.
- Lasts longer with partial discharges.
- Charging method: constant voltage followed by float charge.
- Fast charge not possible but charging time can be reduced using the V Taper charge control method.

5.3.1.5. Applications

- Automotive and traction applications.
- Standby/Back-up/Emergency power for electrical installations.
- Submarines
- UPS (Uninterruptible Power Supplies)
- Lighting
- High current drain applications.
- Sealed battery types available for use in portable equipment.

5.3.1.6. Costs

- Low cost
- Flooded lead acid cells are one of the least expensive sources of battery power available.
- Deep cycle cells may cost up to double the price of the equivalent flooded cells

5.3.1.7. Varieties of Lead Acid Batteries

Lead Calcium Batteries

Lead acid batteries with electrodes modified by the addition of Calcium providing the following advantages:

More resistant to corrosion, overcharging, gassing, water usage, and self-discharge, all of which shorten battery life.

Larger electrolyte reserve area above the plates.

Higher Cold Cranking Amp ratings.

Little or No maintenance.

Lead Antimony Batteries

Lead acid batteries with electrodes modified by the addition of Antimony providing the following advantages:

Improved mechanical strength of electrodes - important for EV and deep discharge applications

Reduced internal heat and water loss.

Longer service life than Calcium batteries.

Easier to recharge when completely discharged.

Lower cost.

Lead Antimony batteries have a higher self discharge rate of 2% to 10% per week compared with the 1% to 5% per month for Lead Calcium batteries.

Valve Regulated Lead Acid (VRLA) Batteries

Also called Sealed Lead Acid (**SLA**) batteries.

This construction is designed to prevent electrolyte loss through evaporation, spillage and gassing and this in turn prolongs the life of the battery and eases maintenance. Instead of simple vent caps on the cells to let gas escape, VRLA have pressure valves that open only under extreme conditions (like PSV’s).

Valve-regulated batteries also need an electrolyte design that reduces gassing by impeding the release to the atmosphere of the oxygen and hydrogen generated by the galvanic action of the battery during charging. This usually involves a catalyst that causes the ***hydrogen and oxygen to recombine*** into water and is called a recombinant system. Because spillage of the acid electrolyte is eliminated the batteries are also safer.

AGM Absorbed Glass Mat Battery

Also known as Absorptive Glass Micro-Fibre

Used in VRLA batteries the Boron Silicate fibreglass mat which acts as the separator between the electrodes and absorbs the free electrolyte acting like a sponge. Its purpose is to promote recombination of the hydrogen and oxygen given off during the charging process. No silica gel is necessary. The fibreglass matt absorbs and immobilises the acid in the matt but keeps it in a liquid rather than a gel form. In this way the acid is more readily available to the plates allowing faster reactions between the acid and the plate material allowing higher charge/discharge rates as well as deep cycling.

This construction is very robust and able to withstand severe shock and vibration and the cells will not leak even if the case is cracked.

AGM batteries are also sometimes called "starved electrolyte" or "dry", because the fibreglass mat is only 95% saturated with Sulfuric acid and there is no excess liquid.

Nearly all AGM batteries are sealed valve regulated "VRLA".

AGM's have a very low self-discharge rate of from 1% to 3% per month

Gel Cell - Gel battery

This is an alternative recombinant technology also used in VRLA batteries to promote recombination of the gases produced during charging. It also reduces the possibility of spillage of the electrolyte. Prone to damage if gassing is allowed to occur, hence charging rates may be limited.

They must be charged at a slower rate (C/20) to prevent excess gas from damaging the cells. They cannot be fast charged on a conventional automotive charger or they may be permanently damaged.

Used for UPS applications.

SLI Batteries (Starting Lighting and Ignition)

This is the typical automotive battery application. Automotive batteries are designed to be fully charged when starting the car; after starting the vehicle, the lost charge, typically 2% to 5% of the charge is replaced by the alternator and the battery remains fully charged. These batteries are not designed to be discharged below 50% Depth of Discharge (DOD) and discharging below these levels can damage the plates and shorten battery life.

Deep Cycle Batteries

Marine applications, golf buggies, fork lift trucks and electric vehicles use deep cycle batteries which are designed to be completely discharged before recharging. Because charging causes excessive heat which can warp the plates, thicker and stronger or solid plate grids are used for deep cycling applications.

Normal automotive batteries are not designed for repeated deep cycling and use thinner plates with a greater surface area to achieve high current carrying capacity.

Automotive batteries will generally fail after 30-150 deep cycles if deep cycled, while they may last for thousands of cycles in normal starting use (2-5% discharge).
If batteries designed for deep cycling are used for automotive applications they must be "oversized" by about 20% to compensate for their lower current carrying capacity.

5.3.2. Nickel Iron

5.3.2.1. Characteristics

This rechargeable battery was introduced in 1900 by Thomas Edison. It is a very robust battery which is tolerant of abuse and can have very long life even if so treated. It is often used in backup situations where it can be continuously charged and can last for 20 years.

Also called Nickel Alkaline of NiFe batteries.

The open circuit voltage of these cells is 1.4 V, and the discharge voltage is about 1.2 V.

5.3.2.2. Advantages

- Very robust.
- Withstands overcharge and over-discharge
- Accepts high depth of discharge - deep cycling.
- Can remain discharged for long periods without damage, whereas a Lead Acid battery needs to be stored in a charged state.
- The ability of this system to survive frequent cycling is due to the low solubility of the reactants in the electrolyte - potassium hydroxide.
- Lifetime of 30 years possible

5.3.2.3. Shortcomings

- Low cell voltage.
- Very heavy and bulky.
- The low reactivity of the active components limits the high rate performance of the cells. They take a charge slowly, and give it up slowly.
- Low coulombic efficiency, typically less than 65%
- Steep voltage drop off with state of charge
- Low energy density.
- High self discharge rate.

5.3.2.4. Applications

- Traction applications
- Fork lift trucks

5.3.3. Nickel Cadmium

The widest use: dry cells in your radio set, hundreds of wet cells in the site UPS and as well with all form of electrolyte (gel, paste, aqueous, polymer,…) and also either vented or sealed.

5.3.3.1. Characteristics dry cells

1.2 Volt secondary cells using an alkaline chemistry with energy density about double that of lead acid batteries.

Invented in 1899 but only introduced in volume in the early 1960's

They use nickel hydroxide Ni(OH)2 for the positive electrode (cathode), cadmium Cd as the negative electrode (anode) and an alkaline potassium hydroxide KOH electrolyte.

Their small size and high rate discharge capacity made portable tools and other consumer applications practical for the first time.

Figure 72: Examples of dry cells

The cells are sealed and utilise a recombinant system to prevent electrolyte loss and extend the useful life.

Once the battery of choice for low power portable products they have lost (partially) market share to the newer Nickel Metal Hydride batteries. (Ni-Mh)

5.3.3.2. Characteristics of industrial cells

The nickel-cadmium battery uses nickel hydroxide as the active material for the positive plate, and cadmium hydroxide for the negative plate. (same as for dry)

The electrolyte is an aqueous solution of potassium hydroxide containing small quantities of lithium hydroxide to improve cycle life and high temperature operation.

The electrolyte is only used for ion transfer; it is not chemically changed or degraded during the charge/ discharge cycle. In the case of the lead acid battery, the positive and negative active materials chemically react with the sulphuric acid electrolyte resulting in an ageing process.

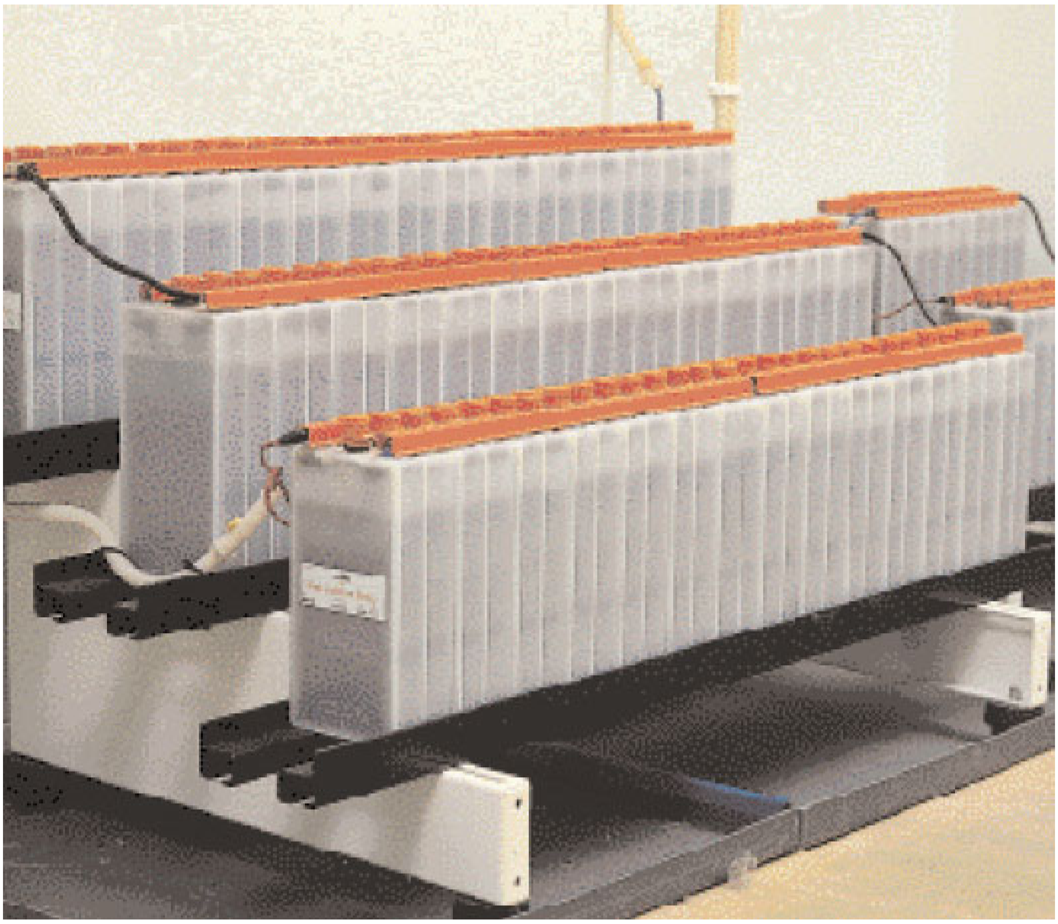


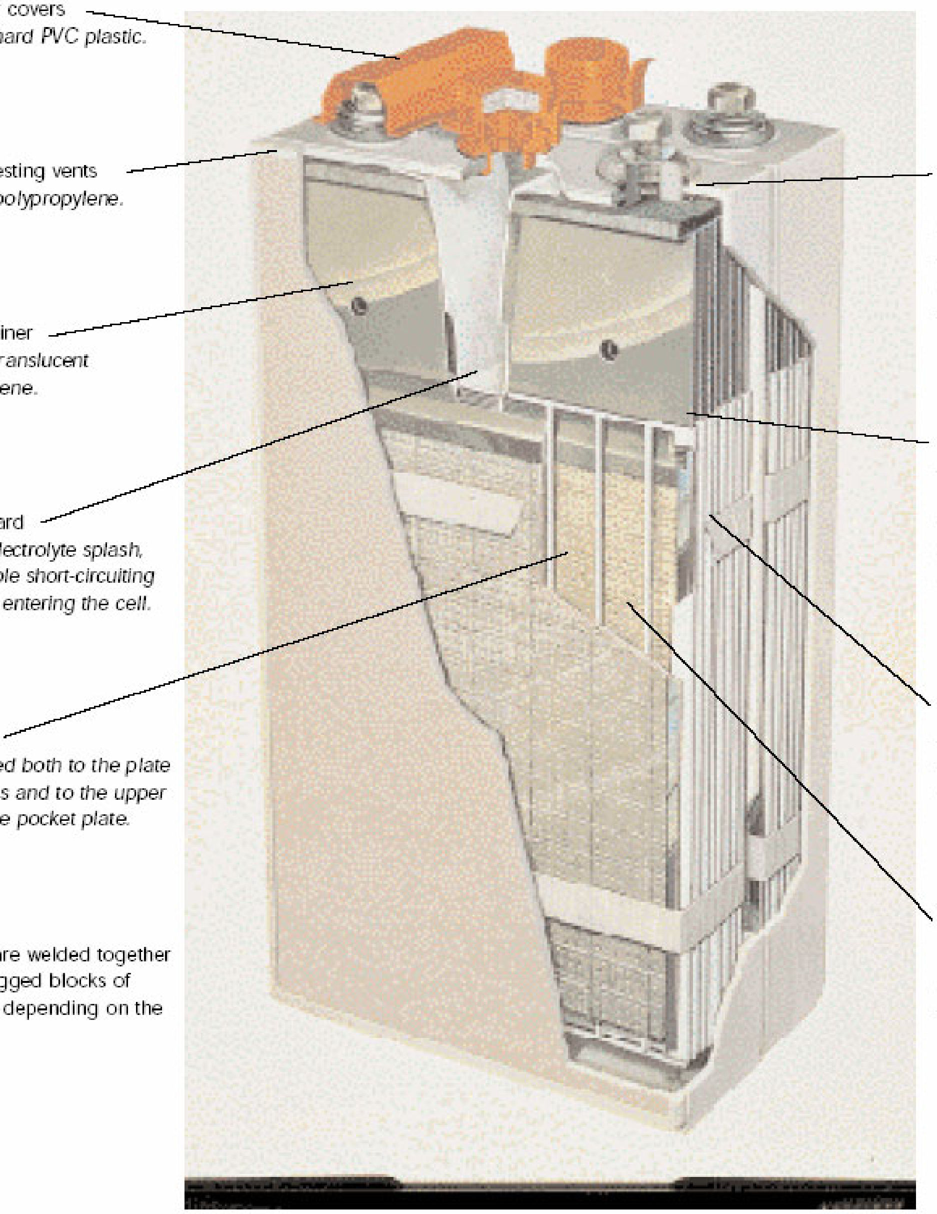
Figure 73: Sealed or vented, aqueous or gel, the SAFT type

The support structure of both plates is steel. This is unaffected by the electrochemistry, and retains its characteristics throughout the life of the cell. In the case of the lead acid battery, the basic structure of both plates are lead and lead oxide which play a part in the electrochemistry of the process and are naturally corroded during the life of the battery.

During discharge the trivalent nickel hydroxide is reduced to divalent nickel hydroxide, and the cadmium at the negative plate forms cadmium hydroxide.
On charge, the reverse reaction takes place until the cell potential rises to a level where hydrogen is evolved at the negative plate and oxygen at the positive plate which results in water loss.

Unlike the lead acid battery, there is little change in the electrolyte density during charge and discharge. This allows large reserves of electrolyte to be used without inconvenience to the electrochemistry of the couple.

Thus, through its electrochemistry, the nickel-cadmium battery has a more stable behaviour than the lead acid battery, giving it a longer life, superior characteristics and a greater resistance against abusive conditions. Nickel-cadmium cells have a nominal voltage of 1.2 volts.



Connector covers
Material: hard PVC plastic.

Flame arresting vents
Material: polypropylene.

Cell container
Material: translucent polypropylene.

Splash guard
Prevents electrolyte splash, and possible short-circuiting by objects entering the cell.

Plate tab
Spot-welded both to the plate side-frames and to the upper edge of the pocket plate.

The cells are welded together to form rugged blocks of 1-10 cells depending on the cell size.

6

Plate group bus
Connects the plate tabs with the terminal post. Plate tabs and terminal post are projection welded to the plate group bus.

Separating grids
Separate the plates and insulate the plate frames from each other. The grids allow free circulation of electrolyte between the plates.

Plate frame
Seals the place pockets and serves as a current collector.

Plate
Horizontal pockets of double-perforated steel strips.

Saft Nife battery cells fulfill all requirements specified by IEC, publication 623.

Figure 74: Composition Saft battery

The battery is built up using well proven block battery construction. The tough polypropylene containers (like nearly for all manufactures) are welded together by heat sealing.

See maintenance paragraph for the ‘general checks’ and the specific works according to the type of electrolyte

5.3.3.3. Advantages

- Low internal resistance
- High rate charge and discharge rate possible
- Up to 10C discharge rates for short periods typical
- Flat discharge characteristic (but falls off rapidly at the end of the cycle)
- Tolerates deep discharges - can be deep cycled.
- Wide temperature range (Up to 70°C)
- Typical cycle life is over 500 cycles.
- Charging process is strongly endothermic-the battery cools during charging. This makes it possible to charge very quickly, as the I^2R heating and endothermic chemical reactions counteract each other.
- Rapid charge typically 2 hours, but can be as low as 10 to 15 minutes.
- The coulombic efficiency of nickel cadmium is over 80% for a fast charge but can drop to below 50% for slow charging.
- The sealed nickel-cadmium cell can be stored in the charged or discharged state without damage. It can be restored for service by recharging several charge/discharge cycles.
- Available in a large variety of sizes and capacities

5.3.3.4. Shortcomings

A major drawback of this technology is its susceptibility to memory effect: arrived at a certain point of discharge (in voltage), the battery stops discharging and looks like fully discharged when it is not (really) the case.

Originally, the terms memory effect or memory problem was coined to describe a cyclic memory problem where the NiCad battery would "remember" the amount of discharge for previous discharges and limit the recharge life of the battery. The problem is less prevalent with modern Ni-Cd batteries, which are designed to avoid cyclic memory issues.

The memory effect is caused by a change in crystalline formation from the desirable small size to a large size which occurs when a NiCad battery is recharged before it is fully discharged. The growth of large crystals increases the cell impedance and can eventually prevent the battery from discharging beyond that point and/or cause rapid self-discharge of the battery.

The growth of large crystals can be avoided by either completely discharging it each time it is used or by using a NiCad battery charger which has a built-in discharge circuit.

Memory effect can sometimes be reversed by putting the battery through *several complete discharge and recharge cycles* which helps to recover the smaller crystal formations. This is called reconditioning.

NiCad batteries are also prone to damage by overcharging.

Low cell voltage of 1.2 Volts compared with primary alkaline cells 1.5 Volts and only quarter of the capacity of the alkaline cells.

Self re-sealing safety vents must be incorporated to prevent damage due to overheating and pressure build up.

The use of Cadmium in consumer products is now deprecated on environmental grounds.

Gradually being phased out in favour of Nickel metal hydride and Lithium technologies which have superior energy density characteristics and performance characteristics.

5.3.3.5. Charging

- Run down fully once per month to avoid memory effect.
- Do not leave battery in charger.
- Slow charging method: Constant current followed by trickle charge.
- Rapid charging method uses Negative delta V (NDV) charge termination.

5.3.3.6. Applications

- Motorised equipment
- Power tools
- Two way radios
- Electric razors
- Commercial and industrial portable products

- Medical instrumentation
- Emergency lighting
- Toys
- Battery banks supply with Battery Charger
- UPS

5.3.3.7. Costs

Relatively inexpensive for low power applications but between three and four times more expensive than lead acid for the same capacity.

5.3.4. Nickel Metal Hydride

5.3.4.1. Characteristics

Nickel-metal-hydride batteries are related to sealed nickel-cadmium batteries and only differ from them in that instead of cadmium, hydrogen is used as the active element at a hydrogen-absorbing negative electrode (anode).

This electrode is made from a metal hydride usually alloys of lanthanum and rare earths that serve as a solid source of reduced hydrogen that can be oxidized to form protons. The electrolyte is alkaline potassium hydroxide. Cell voltage is 1.2 Volts

The Ni-MH battery was patented in 1986 by Stanford Ovshinsky, founder of Ovonics.

The basic concept of the nickel-metal hydride cell negative electrode emanated from research on the storage of hydrogen for use as an alternative energy source in the 1970s.

Certain metallic alloys were observed to form hydrides that could capture (and release) hydrogen in volumes up to nearly a thousand times their own volume. By careful selection of the alloy constituents and proportions, the thermodynamics could be balanced to permit the absorption and release process to proceed at room temperatures and pressures.

Now that the technology is reasonably mature, Ni-MH batteries have begun to find use in high voltage automotive applications. The energy density is more than double that of Lead acid and 40% higher than that of Ni-Cads

They accept both higher charge and discharge rates and micro-cycles thus enabling applications which were previously not practical. The components of Ni-MH batteries include a cathode of Nickel-hydroxide, an anode of Hydrogen absorbing alloys and a

Potassium-hydroxide electrolyte. Like NiCd batteries, Nickel-metal Hydride batteries are susceptible to a "memory effect" although to a lesser extent.

They are more expensive than Lead-acid and NiCd batteries, but they are considered better for the environment.

5.3.4.2. Advantages

- High energy density
- Typical cycle life is 500 cycles (less than Ni-cads).
- Can be deep cycled.
- Using Ni-MH batteries, up to 3000 cycles at 100 % Depth of Discharge (DOD) have been demonstrated. At lower depths of discharge, for example at 4 % DOD, more than 350.000 cycles can be expected.
- Robust – Ni-MH batteries also tolerate over charge and over discharge conditions and this simplifies the battery management requirements.
- Low internal impedance
- Flat discharge characteristic (but falls off rapidly at the end of the cycle)
- Wide operating temperature range
- Rapid charge possible in 1 hour
- Trickle charging can not normally be used with Ni-MH batteries since overcharging can cause deterioration of the battery. Chargers should therefore incorporate a timer to prevent overcharging.
- Because of potential pressure build up due to gassing they usually incorporate a re-sealable vent valve
- Reconditioning is possible.
- Environmentally friendly (No cadmium mercury or lead)

5.3.4.3. Shortcomings

- Very high self discharge rate, nearly ten times worse than lead acid or Lithium batteries.

- Can be stored indefinitely either fully charged or fully discharged.
- Suffers from memory effect though not as pronounced as with NiCad batteries
- Battery deteriorates during long time storage. This problem can be solved by charging and discharging the battery several times before reuse. This reconditioning also serves to overcome the problems of the "memory" effect.
- High rate discharge not as good as Ni-Cads
- Less tolerant of overcharging than Ni-Cads
- As with Ni-Cads the cells must incorporate safety vents to protect the cell in case of gas generation.
- The coulombic efficiency of nickel metal hydride batteries is typically only about 66% and diminishes the faster the charge.
- While the battery may have a high capacity it is not necessarily all available since it may only deliver full power down to 50% DOD depending on the application.
- Cell voltage is only 1.2 Volts which means that many cells are required to make up high voltage batteries.
- Lower capacity and cell voltage than alkaline primary cells
- Losing market share to Lithium batteries

5.3.4.4. Charging

- Run down fully once per month to avoid memory effect.
- Do not leave battery in charger.
- Slow charging method: Constant current followed by trickle charge.
- Rapid charging method uses dT/dt charge termination.
- Use timer cut off to avoid prolonged trickle charge.

5.3.4.5. Applications

- Low cost consumer applications
- Electric razors

- Toothbrushes
- Cameras
- Camcorders
- Mobile phones
- Pagers
- Medical instruments and equipment
- Automotive batteries

5.3.4.6. Costs

Originally more expensive than NiCad cells but prices are now more in line as Ni-MH volumes increase and the use of toxic Cadmium based cells is deprecated.

5.3.5. Nickel Zinc

5.3.5.1. Characteristics

This rechargeable battery like the Nickel Iron battery uses an alkaline electrolyte.
Cell voltage 1.65 Volts

5.3.5.2. Advantages

- Good cycle life
- Fast recharge capability
- Can be deep cycled down to 100%.
- Uses low cost benign materials.

5.3.5.3. Shortcomings

- Heavy and bulky.

- Low energy density.
- High self discharge rate.

5.3.5.4. Applications

- Traction applications
- Electric Bicycles
- Scooters
- Lawnmowers

5.3.5.5. Costs

- Low cost but higher than Lead acid

5.3.6. Lithium Secondary Cells

5.3.6.1. Characteristics

Lithium is the lightest of metals and it floats on water. It also has the greatest electrochemical potential which makes it one of the most reactive of metals. These properties give Lithium the potential to achieve very high energy and power densities in high power battery applications such as automotive and standby power.

Many variations of the basic Lithium chemistry have been developed to optimise the cells for specific applications or perhaps in some cases to get around the patents on the original technology. Lithium metal reacts violently with water and can ignite into flame.

Early commercial cells with metallic lithium cathodes were considered unsafe in certain circumstances, however modern cells don't use free Lithium but instead the Lithium is combined with other elements into more benign compounds which do not react with water.

The typical lithium-ion cells use carbon for its anode and lithium cobalt dioxide or a lithium manganese compound as the cathode. The electrolyte is usually based on a lithium salt in solution.

Lithium batteries have now taken their place as the rechargeable battery of choice for portable consumer electronics equipment, though they were expensive when introduced.

5.3.6.2. Advantages

In many ways Lithium is almost the perfect cell chemistry and many variants exist. Practical Lithium based rechargeable batteries were first demonstrated in the 1970's, and they are now used in very high volumes in low power applications such as mobile phones, laptops, cameras and other consumer electronic products. They have many attractive performance advantages which make them also ideal for higher power applications such as automotive and standby power.

High cell voltage of 3.6 Volts means fewer cells and associated connections and electronics are needed for high voltage batteries. (One Lithium cell can replace three NiCad or Ni-MH cells which have a cell voltage of only 1.2 Volts)

- No liquid electrolyte means they are immune from leaking.
- Very high energy density (About 4 times better than Lead acid). For example a 3.5 ton electric powered LDV light van uses 750Kg of Lead acid batteries. The same capacity could be provided by less than 200 Kg of Lithium batteries, allowing the van an increased payload of half a ton. Alternatively. The van's range of only 50 miles could be quadrupled by using the same weight of Lithium batteries.
- Very high power density. As above.
- Very small batteries also available. Solid state chemistry can be printed on to ceramic or flexible substrates to form thin film batteries with unique properties.
- Low weight
- Can be optimised for capacity or rate.
- Individual cells up to 1000Ah capacity available.
- Can be discharged at the 40C rate. The high discharge rate means that for automotive use the required cold cranking power or boost power for hybrid vehicles can be provided by a lower capacity battery.
- Fast charge possible.
- Can be deep cycled. The cell maintains a constant voltage for over 80% of its discharge curve. It thus delivers full power down to 80% DOD versus 50% for Lead acid. This means that in practice, for a given capacity, more of the stored energy is usable or that the battery will accept more starting attempts or boost power requests before becoming effectively discharged.
- Very low self discharge rate. Can retain charge for up to ten years.
- Very high coulombic efficiency (Capacity discharged over Capacity charged) of almost 100%. Thus very little power is lost during the charge/discharge cycles.

- No memory effect. Does not need reconditioning as do nickel based batteries.
- Tolerates micro cycles
- Long cycle life. Cycle life can be extended significantly by using protective circuits to limit the permissible DOD of the battery. This mitigates against the high initial costs of the battery.
- Variants of the basic cell chemistry allow the performance to be tuned for specific applications.
- Available in a wide range of cell constructions with capacities from less than 500 mAh to 1000 Ah from a large number (over 100) of suppliers world-wide.
- Volume production has brought the prices down

5.3.6.3. Shortcomings

- Internal impedance higher than equivalent Ni-Cads
- For high power applications which require large high cost batteries the price premium of Lithium batteries over the older Lead Acid batteries becomes a significant factor, impeding widespread acceptance of the technology. This in turn has discouraged investment in high volume production facilities keeping prices high and has for some time discouraged take up of the new technology. This is gradually changing and Lithium is also becoming cost competitive for high power applications.
- Stability of the chemicals has been a concern in the past. Because Lithium is more chemically reactive special safety precautions are needed to prevent physical or electrical abuse and to maintain the cell within its design operating limits. Lithium polymer cells with their solid electrolyte overcome some of these problems.
- Stricter regulations on shipping methods than for other cell chemistries.
- Degrades at high temperatures.
- Capacity loss or thermal runaway when overcharged.
- Degradation when discharged below 2 Volts.
- Venting and possible thermal runaway when crushed.
- Need for protective circuitry.

- Measurement of the state of charge of the cell is more complex than for most common cell chemistries. The state of charge is normally extrapolated from a simple measurement of the cell voltage, but the flat discharge characteristic of lithium cells, so desirable for applications, renders it unsuitable as a measure of the state of charge and other more costly techniques such as coulomb counting have to be employed.

- Although Lithium cell technology has been used in low power applications for some time now, there is still not a lot of field data available about long term performance in high power applications. Reliability predictions based on accelerated life testing however shows that the cycle life matches or exceeds that of the most common technologies currently in use.

These drawbacks are far out weighed by the advantages of Lithium cells and are now being used in an ever widening range of applications.

5.3.6.4. Charging

- Should be charged regularly.

- Battery lasts longer with partial charges rather than full charges.

- Can not tolerate overcharging and hence should not be trickle charged.

- Charging method: Constant Current - Constant Voltage

5.3.6.5. Applications

Rechargeable Lithium cells are used a wide range of consumer products including cameras, camcorders, electric razors, toothbrushes, calculators, medical equipment, communications equipment, instruments, portable radios and TVs, pagers and PDA's.

They are fast replacing Nickel Metal Hydride cells as the preferred power in mobile phones. Laptop computers almost exclusively use Lithium batteries.

Now high power versions of up to 1000Ah capacity and more are becoming available for use in traction applications in electric and hybrid vehicles as well as for standby power.

5.3.6.6. Costs

The price of Lithium cells continues to fall as the technology gains more acceptance. The target price for high power cells is around $300/kWh but cell makers are still quite some way from achieving that.

5.3.6.7. Other varieties of lithium rechargeable cells

Lithium Cell Chemistry Variants

Lithium's unique properties have been used as a basis of numerous battery chemistries both for primary and secondary cells. Using nano - electrode materials provides a bigger active surface area and hence a higher current carrying capacity.

Lithium-ion

Lithium-ion batteries were designed to overcome the safety problems associated with the highly reactive properties of Lithium metal.

The essential feature of the Lithium ion battery is that at no stage in the charge-discharge cycle should there be any Lithium metal present. Rather, Lithium ions are intercalated into the positive electrode in the discharged state and into the negative electrode in the charged state and move from one to the other across the electrolyte.

Lithium-ion batteries thus operate based on what is sometimes called the "rocking chair" or "swing" effect. This involves the transfer of Lithium ions back and forth between the two electrodes. The anode of a Lithium-ion battery is composed of Lithium, dissolved as ions, into a carbon or in some cases metallic Lithium. The cathode material is made up from Lithium liberating compounds, typically the three electro-active oxide materials, Lithium Cobalt-oxide $LiCoO_2$, Lithium Manganese-oxide $LiMn_2 O_4$, and Lithium Nickel-oxide $LiNiO_2$

Lithium salt constitutes the electrolyte.

The origin of the cell voltage is then the difference in free energy between Li^+ ions in the crystal structures of the two electrode materials.

Lithium-ion cells have no memory effect and have long cycle life and excellent discharge performance. For safety reasons, charge control circuitry is required for virtually all Lithium-ion applications.

Lithium-ion technology uses a liquid or gel type electrolyte. This cell chemistry and construction permits very thin separators between the electrodes which can consequently be made with very high surface areas. This in turn enables the cells to handle very high current rates making them ideal for use in high power applications. Some early cells used flammable active ingredients which required substantial secondary packaging to safely contain these potentially hazardous chemicals. This additional packaging not only increased the weight and cost, but it also limited the size flexibility. Modern cell chemistries and additives have essentially eliminated these problems

Lithium-ion Polymer

Lithium-ion polymer batteries use liquid Lithium-ion electrochemistry in a matrix of ion conductive polymers that eliminate free electrolyte within the cell. The electrolyte thus plasticizes the polymer, producing a solid electrolyte that is safe and leak resistant. Lithium polymer cells are often called Solid State cells.

Because there's no liquid, the solid polymer cell does not require the heavy protective cases of conventional batteries. The cells can be formed into flat sheets or prismatic (rectangular) packages or they can be made in odd shapes to fit whatever space is available. As a result, manufacturing is simplified and batteries can be packaged in a foil. This provides added cost and weight benefits and design flexibility. Additionally, the absence of free liquid makes Lithium-ion polymer batteries more stable and less vulnerable to problems caused by overcharge, damage or abuse.

Solid electrolyte cells have long storage lives, but low discharge rates.

There are some limitations on the cell construction imposed by the thicker solid electrolyte separator which limits the effective surface area of the electrodes and hence the current carrying capacity of the cell, but at the same time the added volume of electrolyte provides increased energy storage. This makes them ideal for use in high capacity low power applications.

Despite the above comments there are some manufacturers who make cells designated as Lithium polymer which actually contain a liquid or a gel. Such cells are more prone to swelling than genuine solid polymer cells.

Other Lithium Cathode Chemistry Variants

Numerous variants of the basic Lithium-ion cell chemistry have been developed but only Lithium Cobalt and Lithium Manganese are currently being produced in commercial quantities. The rest are either at various stages of development or they are awaiting investment decisions to launch volume production.

While the basic technology is well known, there is a lack of operating experience and hence system design data with some of the newer developments which also hampers their adoption. At the same time patents for these different chemistries tend to be held by rival companies undertaking competitive developments with no signs of industry standardisation or adoption of a common product. (The original patent on Lithium Cobalt technology has now expired which is perhaps one explanation for its popularity

Lithium Cobalt $LiCoO_2$

Lithium Cobalt is a mature, proven, industry-standard battery technology that provides long cycle life and very high energy density. The polymer design makes the cells inherently safer than "canned" construction cells that can leak acidic electrolyte fluid under abusive conditions. The cell voltage is typically 3.7 Volts. Cells using this chemistry are available from a wide range of manufacturers.

The use of Cobalt is unfortunately associated with environmental and toxic hazards.

Lithium Manganese $LiMn_2O_4$

Lithium Manganese provides a higher cell voltage than Cobalt based chemistries at 3.8 to 4 Volts but the energy density is about 20% less. It also provides additional benefits to Lithium-ion chemistry, including lower cost and higher temperature performance. This chemistry is more stable than Lithium Cobalt technology and thus inherently safer but the trade off is lower potential energy densities. Lithium Manganese cells are also widely available but they are not yet as common as Lithium Cobalt cells.
Manganese, unlike Cobalt, is a safe and more environmentally benign cathode material.

Lithium Nickel $LiNiO_2$

Lithium Nickel based cells provide up to 30% higher energy density than Cobalt but the cell voltage is lower at 3.6 Volts. They also have the highest exothermic reaction which could give rise to cooling problems in high power applications. Cells using this chemistry are therefore not generally available.

Lithium Metal Polymer

Developed specifically for automotive applications employing 3M polymer technology and independently in Europe with technology from the Fraunhofer Institute, they have been trialled successfully in PNGV project demonstrators in the USA. They use metallic Lithium anodes rather than the more common Lithium Carbon based anodes and metal oxide (Cobalt) cathodes.

Some versions need to work at temperatures between 80 and 120ºC for optimum results although it is possible to operate at reduced power at ambient temperature. The Fraunhofer technology uses an organic electrolyte and the cell voltage is 4 Volts. It is claimed that their cell chemistry is more tolerant to abuse.

These products are not yet in volume production.

Lithium Sulphur Li_2S_8

Lithium Sulphur is a high energy density chemistry, significantly higher than Lithium-ion metal oxide chemistries. This chemistry is under joint development by several companies but it is not yet commercially available. Lithium Sulphur cells are tolerant of over-voltages. The cell voltage is 2.1 Volts

Alternative Anode Chemistry

The anodes of most Lithium based secondary cells are based on some form of carbon (graphite or coke). Recently Lithium Titanate Spinel ($Li_4Ti_5O_{12}$) has been introduced for use as an anode material providing high power thermally stable cells with improved cycle life

5.3.7. Sodium Sulphur

HIGH TEMPERATURE BATTERY

Since the mid 1960s much development work has been undertaken on batteries using Sodium for the negative electrodes. Sodium is attractive because of its high reduction potential of -2.71 Volts, its low weight, its non toxic nature, its relative abundance and ready availability and its low cost. All these factors offer the prospect of batteries with very high power and energy densities.

Unfortunately in order to construct practical batteries using sodium electrodes, the sodium must be used in liquid form. Since the melting point of sodium is 98 °C this means that sodium based batteries must operate at high temperatures, typically in excess of 270 °C. This in turn brings problems of thermal management and safety and places more stringent requirements on the rest of the battery components.

The first commercial battery produced was the Sodium/Sulphur battery which used liquid sulphur for the positive electrode and a ceramic tube of beta-alumina for the electrolyte. Corrosion of the insulators can be a problem in the harsh chemical environment since they gradually become conductive and the battery self-discharge rate increases.

Later developments included the Zebra Battery which used a solid metal positive electrode of Nickel Chloride. This was intrinsically safer and allowed larger cells to be made.

The special safety precautions and complex thermal management required for these batteries conspire to prevent the achievement of the very high energy densities theoretically possible. With the advent of the newer Lithium technologies enthusiasm for these high temperature batteries is beginning to wane.

High temperature technology is also used in Thermal Batteries . These batteries use an electrolyte which is solid and inactive at normal ambient temperatures. The batteries only become active at high temperatures by the application of heat from an external source to liquefy the electrolyte. These batteries are use almost exclusively for military applications

5.3.8. Flow Cells (Redox)

5.3.8.1. Characteristics

The Redox battery is an example of both a Flow Battery and a two electrolyte system. In this case, it depends on two different active aqueous electrolytes of vanadium dissolved in sulfuric acid separated by a membrane at which ionic interchange takes place. The chemical reactions take place on inert graphite electrodes stacked in a bipolar configuration. The electrolytes are stored externally from the battery and must be pumped through the cell for the chemical action to take place.(See fig 31 in paragraph 3.2.6.2.)

Sloping discharge characteristic with output voltage varying from 1.5 to 1.0 Volts

The name Redox is a contraction of the terms "Reduction" and "Oxidation". Although these particular batteries are named after this chemical reaction, the Redox action is common to most all Galvanic cells.

5.3.8.2. Advantages

- Very high power output (Tens of kilowatts)
- Fast recharge by replacing spent electrolyte
- Capable of long life due to replacement of electrolyte.
- Can be fully discharged
- Use non toxic materials

5.3.8.3. Shortcomings

- Complex.
- Low energy density
- Little commercial take up to date

5.3.8.4. Applications

- Suitable for high power rechargeable storage systems in applications such as load levelling.

5.3.8.5. Costs

- High costs since little progress from experimental systems to high volume applications

5.3.9. Zebra Cells

5.3.9.1. Characteristics

- High power, high capacity cells suitable for electric traction applications.
- High Temperature Battery operating at over 270°C
- Sodium Nickel Chloride (NaNCl) chemistry giving a nominal operation cell voltage of 2.58 Volts

5.3.9.2. Advantages

- High energy density (5 times higher than Lead acid)
- Large cells (up to 500Ah) possible
- Cycle life better than 1000 cycles
- Tolerant of short circuits
- Safer than Sodium Sulphur cells
- Typical cell failure is short circuit which does not cause complete failure of the battery.
- Low cost materials

5.3.9.3. Shortcomings

- Suitable for large capacity batteries only (> 20KWh)
- Limited range of available sizes and capacities. (Large multi-cell blocks)
- Only one factory in the world produces these batteries.
- High internal resistance
- Molten sodium electrode
- High operating temperature.
- Preheating needed to get battery up to the 270°C operating temperature. (Up to 24 hours from cold)
- Uses 14% of its own capacity per day to maintain temperature when not in use.
- Thermal management needed

5.3.9.4. Applications

- Traction applications, EVs, HEV, and Railway

5.3.9.5. Costs

- Expensive

5.3.10. Other Galvanic Cells

5.3.10.1. Solid State Cells

These are cells using solid electrolytes. They offer the advantages of no leakage or gassing, long shelf life, excellent packaging efficiency, no separators and miniature designs. they depend on electrolyte materials with high ionic conductivity and negligible electronic mobility. The former provides low internal resistance while the latter prevents self discharge providing long life. The Lithium Iodine primary cell used in heart pacemakers is an example of such a cell.

5.3.10.2. Nanotechnology

Nano-materials (nano-crystalline materials) are currently being used for electrodes and separator plates in experimental Ni-MH and Lithium ion batteries where their foam-like microstructure provides a very large porous active surface area which can hold and deliver considerably more energy than their conventional counterparts. C rates of 10 to 100 times higher have been claimed. (This implies charging the battery in one minute!)

These cells are not yet commercially available.

5.3.10.3. Mercury Cells

The original technology for primary button cells was the mercury cell, which had a mercuric oxide cathode, an anode made of an amalgam of mercury and zinc, and an electrolyte consisting of potassium hydroxide mixed with zinc hydroxide. It is essentially an alkaline cell with a different and more efficient cathode. It provided an open circuit voltage of 1.35 Volts.

Designed as a replacement for the carbon-zinc cell, this battery could not only resist high temperatures and high humidity, but also had better discharge characteristics, longer shelf life, and greater efficiency.

As mercury is toxic, mercury cells are now banned in the US and some other countries and *they are now only a curiosity.*

Silver-Oxide or Zinc-Air cells make good or superior alternatives.

5.3.10.4. Nickel Hydrogen (Ni-H2) Batteries

Hybrid batteries combining NiCad battery and fuel cell technologies, using pressurised hydrogen in place of the cadmium electrode. Not to be confused with Nickel Metal Hydride cells. They are robust, maintenance free with high energy and power density. They have a very long cycle life of 40,000 cycles and a lifetime of up to 15 years. They are also very expensive.

Used in satellite and spacecraft applications.

5.3.10.5. Metal Air Cells

A very practical way to obtain high energy density in a galvanic cell is to utilize the oxygen in air as a "liquid" cathode. A metal, such as zinc or aluminium, is used as the anode. (See below) The oxygen cathode is reduced in a portion of the cell that is physically isolated from the anode. By using a gaseous cathode, more room is available for the anode and electrolyte, so the cell size can be very small while providing good energy output.

5.3.10.6. Rechargeable Aluminium-Air Cells

They have long shelf-life and high energy density but are complex and have low efficiency.

Aluminium-air batteries obtain their energy from the interaction of aluminium with air. The incoming air must be filtered, scrubbed of CO_2, and dehumidified; the water and electrolyte must be pumped and maintained within a narrow temperature range - hence the complexity of the battery.

The batteries are not electrically recharged but are "refuelled" by replacing the aluminium anodes and the water supply.

Special versions which use seawater electrolytes have also been developed.

A new generation of Aluminium-Air cells recently patented in Finland using nanotechnology have overcome the problems associated with recharging aluminium cells and promise very high energy and power densities.

Still under evaluation and not yet available in production quantities

5.4. UNUSUAL BATTERIES

5.4.1. Urine Battery

No it’s not a joke

2005 Korean bioengineer Ki Bang Lee working at Singapore's Institute of Bioengineering and Nanotechnology developed a paper battery powered by urine for use as a simple, cheap and disposable power source for home health tests for diabetes and other ailments.

It is composed of paper, soaked in copper chloride, sandwiched between layers of magnesium and copper and laminated in plastic. The test kit including the battery is about half the size of a credit card, 6cm by 3cm and 1mm thick. Typically the battery will provide around 1.5 Volts, with a maximum power output of 1.5 milli-Watts with 0.2 millilitres of urine.

A range of medical test kits incorporating biosensors or biochips is envisaged which use the body fluid being tested as the source of power and a variety of geometries and materials depending on the requirements of the test.

5.4.2. Ampoule Batteries

Ampoule batteries store the electrolyte in a separate ampoule which is incorporated into the battery case. When the battery is needed, the ampoule is broken open allowing the electrolyte to enter the cell. This technique has been used for military fuses as well as marine applications.

5.4.3. Homebrew Battery

For many years, before batteries were mass produced, electrical experimenters had to make their own batteries and many concoctions were tried.

You "can" try this at home yourself with materials commonly found around the house.

Figure 75: Home-made DIY battery

Recipe for making a DIY Battery

Ingredients

1 Lemon or lime
1 Galvanised roofing nail or galvanised screw
1 Piece of heavy copper wire (Mains cable without the insulation) or a shiny copper coin.

Equipment needed

1 Voltmeter

Checking the Ingredients (Optional)

You could try the old fashioned "Tongue Test" (First make sure the parts are clean. See 2 below)
As with wine tasting: Taste - Don't swallow.
(**Note:** This is an experiment in electronics, not electric cooking. We recommend that you **do not eat the fruit** used in your battery)

Preparation

1. Squeeze the lemon gently without breaking the peel to release the juices inside.
2. Thoroughly clean the nail and the copper wire until they are bright. Use steel wool if necessary and rinse well in water.
3. Insert the nail and the copper wire deeply into two separate points on the lemon taking care that the wire does not touch the nail.
4. Check the potential between your two improvised skewers with the voltmeter.

Brewing time

Ready immediately

Serves up

About half a Volt

Hungry for Power?

Don't expect to start your car with this battery - The internal resistance is rather high.
By connecting 3 or 4 batteries in series however you should be able to light up an LED (Light Emitting Diode) or a small flashlight.

Flavours

The lemon may be replaced by other fruits or vegetables. You could try an Electric Potato for starters. The electric effect is the same.
Using a paper clip instead of the nail reduces the output to one third of a Volt.
If you can't find a galvanised nail, an alternative (and better) source of zinc is to cut a strip from the case of an old flashlight zinc carbon battery (D Cell).

Chef's notes

The lemon acts as a battery case holding the lemon juice (citric acid) which acts as the electrolyte.
The copper **P**enny is the **P**ositive electrode and the zinc galvanised coating on the **N**ail is the **N**egative electrode.
A series connection is a chain of cells, the positive electrode of each cell connected to the negative electrode of the next cell, to form a battery of higher voltage.

Alternatives

A passable replica of **Volta's pile** can be constructed from a stack of alternately placed copper and nickel coins separated by discs cut from a paper towel and soaked in lemon juice or vinegar.
(Make sure the surfaces of the coins are not oxidised)

5.5. RECAPITULATIVE TABLE – SECONDARY CELLS

Type	Commercialisation	Cell Voltage Volts	Energy by Weight Wh / Kg	Specific Power W / Kg	Energy by volume Wh / L	Max discharge rate	Recharge Time Hours	Cycle Life Cycles	Self Discharge per month	Temp range °C	Preferred charge method	Average energy cost $2005 : kWh
Lead Acid	1881	2.0	30 / 40	180	60 / 75	10C	>10	500/ 800	3% / 4%		Const Volt.	150
Ni Cad	1956	1.2	40 / 60	150	50 / 150		8	2000	20%	-40°C +60°C	Const Current	400 / 800
Ni MH	1990	1.2	30/ 80	250 / 1000	140 / 300	20C	6	1500	30%	-20°C +60°C	Df/dt	250
Zinc Air	1997	1.15	200	30 / 140	220			200			NA	80
Al Air		1.5	220	30.							NA	
Ni Iron	1901	1.2	50	100					20% 40%			150 / 200
Ni Zinc	1920	1.5	60	300	100			600	<20%			150 / 200
Sodium Sulphur	1960	2.1	110	150				1000				
Zebra NaNiCl	1982	2.58	100	150	160			1000	Zero			300
LiCo0$_2$	1992	3.7	90 / 140	760	220 / 350	40C	< 3	1200	5% / 10%	-20°C +60°C	Const. Volt. Const. Curr.	300
LiMn$_2$O$_4$	1999	3.6	160	1800	270	40C	< 3	1200	5% / 10%	-20°C +60°C		300
Li Ph		3.2	150	??	250							600
LiNiCoO$_2$												
LiNiO$_2$												
LI$_2$S$_8$	2003	2.1	300		400				<5%			
Lithium Metal	2003	3.0	150	250								
Lithium Metal	2003	4.0	200		400							

Table 12: Recapitulative table - secondary cells

Type	Comments
Lead Acid	Deteriorate with micro cycles. Dry or Wet / aqueous (vented) or gel electrolyte (sealed)
Ni Cad	Memory Effect; Dry or Wet / aqueous (vented) or gel electrolyte (sealed)
Ni MH	High self discharge rate. Useful power down to 50% DOD
Zinc Air	Primary cell cannot accept Regeneration Loads. Uses replaceable electrodes
Al Air	Primary cell cannot accept Regeneration Loads. Needs booster due to low specific power
Ni Iron	Corrosion problems
Ni Zinc	Dendrite growth. Causes short cycle life
Sodium Sulphur	High Temperature 350°C. Damaged if Temp < 200°C. Discontinued
Zebra NaNiCl	High temperature 270°C
$LiCo0_2$	Expensive. Toxic material. Useful power down to 80% DOD
$LiMn_2O_4$	Useful power down to 80% DOD
Li Ph	No Field experience
$LiNiCoO_2$	No Field experience
$LiNiO_2$	No Field experience
LI_2S_8	No Field experience
Lithium Metal	No Field experience
Lithium Metal	No Field experience

Table 13: Summary secondary cells

6. CHARGING BATTERIES (BATTERY CHARGER)

More batteries are damaged by bad charging techniques than all other causes combined.

Batteries are generally destroyed by "overcharging" which is in fact an over current. By monitoring and limiting the current, once the batteries are charged, no problem should occur.

Maintenance and operating instructions refer to "Floating voltage" for charging batteries, but the value of this voltage fluctuates with time as the batteries are ageing.

What is important is the "Floating current" which must be minimum as per manufacturer recommendations; anyway never more than 1/100C (*).

Of course this "floating current" is determined and adjusted by the voltage which is the "Floating Voltage".

(*) C is the capacity of the battery or set of batteries in series; as example, for100 Ah, the "floating current" must be no more than 1 ampere. Again, value to check on batteries data sheet, it would be (most probably) less.
Temperature is the other 'obvious' factor to check. If the battery is heating, there is a problem.

More details are given in the section on Charging Times.

6.1. HOW CHARGING ACCUMULATORS OR BATTERIES

We are going to see the most important part of this course, the 'charging'

3 main methods of charge have to be distinguished, they are for the 3 main technologies in use:

- Lead Batteries
- Nickel Batteries
- Lithium Batteries

We see hereafter the charging methods for:

- Lead Technology
- NI-Cd Technology.
- Ni-MH Technology.
- Lithium Technology
- Other Technologies

And we see as well specific subject such as

- Delta Peak -dV/dt -DV what is that?
- Real Capacity: the capacity of an accumulator changes according to its use. What is the meaning, in that case of the capacity indicated on the name plate?

6.1.1. Charging Lead Acid Batteries

This is a common part for vented or sealed, aqueous or gel types batteries

Theories to remember:

With Lead accumulators, all the reference values (of end of charge and discharge) are in voltage. It is said to be 2V as per the reference value of a lead/lead cell but it is not exactly this ‘2Volts’.

All values hereunder noted, can be used, even if not really ‘optimised’ in regard to manufacturer indications and recommendations. This values apply for all types of lead/lead batteries with electrolytes either VRLA, AGM, aqueous, gel,….etc. vented or sealed.

Reference Voltage:

Voltage of a charged cell in open circuit, at 25°C: ***2.1V*** and for the ‘classic’ 12V battery, it should be 12.6V. This is the value you should read on a voltmeter between the electrode of a battery charged over the night and not connected to the load

Floating Voltage:

Voltage which can be applied permanently on electrodes to be sure that the battery is always fully charged: 2.25 to 2.28V per cell at 25°C. Value to be corrected 0.005V by degree Celsius in plus or minus as per the ambient temperature.

Example: at +10°C, floating voltage per cell is at 2.36V (2.28 + 0.005x15) and 2.21V (2.28 + 0.005x15) at +40°C, These values have to be checked on manufacturer data sheets.)

For the « 12V » battery, it will be consequently :14.2V at +10°C and 13.2V at +40°C

Charging Voltage :

Maximum Voltage which can be applied on battery electrodes but not permanently : 2.3 to 2.4V per cell at 25°C and with still the same correcting coefficient (0.005C/°C). It is 13.8V to 14.4V for the "12V" battery at 25°C.

Caution: this charging voltage value is the maximum value in DC voltage, and if the charger is of poor (even average) quality, some harmonics or 'waves' could be added due to bad filtration. The peak voltage is then "seen" by the battery and it does not like it.

Charging Current :

An easy value to remember is 1/5 of the nominal Capacity in 20 Hours.

Consequently, for 12V/7Ah battery, this (maximum) current is 1.4 Ampere. In fact, checking the manufacturer data sheet, it is generally said 1.7A for a 7Ah and 20A for a 85Ah, slightly above the 1/5 C.

But, in doubt, stick to the 1/5, the battery would not be under charged, it would need (may be) a little time more.

And in practice:

You can deduct that your Battery Charger will need to deal with 2 parameters: the maximum 'charging current' and the 'end of charge voltage'. 2 methods of charging are therefore possible: charging in 2 steps or in 3 steps

6.1.1.1. Charging Lead Battery in 2 steps

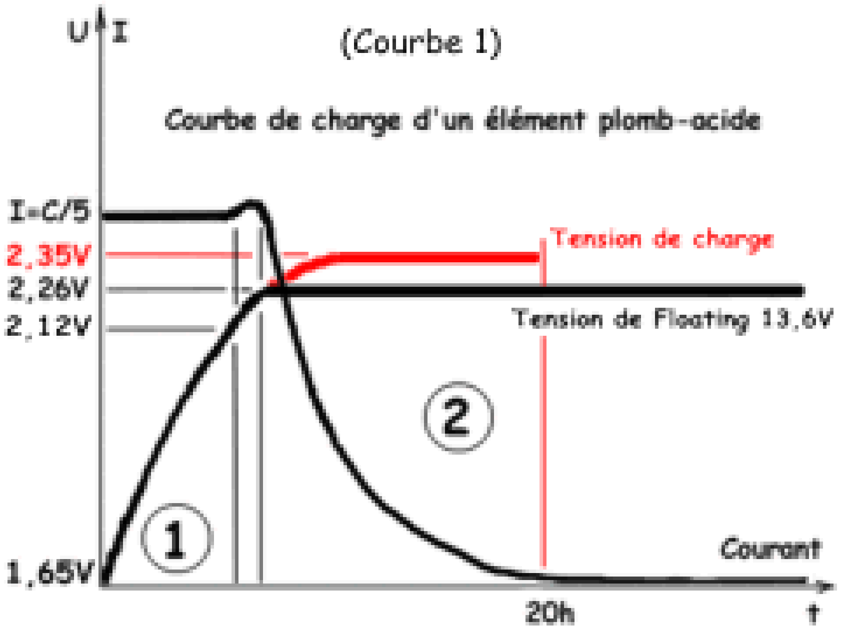


Figure 76: Charging lead batteries in 2 steps

In part ‘1’, current is limited to the maximum charging current, C/5 (or manufacturer value)

Once the voltage arrives at 2.12V (12.7V for the 12V Battery), the charge switches to the voltage limitation.

There are 2 solutions:

- The Battery is permanently connected to the charger (UPS system) and the limited voltage is the ‘Floating Voltage’: 2.26V (13.6V for the 12V Battery), allowing the Capacity to be at about 95% after the 20 hoursof charge

- The Battery is to be used apart immediately, the voltage needs to be at the ‘Charging Voltage’ value: 2.35V (14.1V for the 12V Battery). The Battery will be fully charged, after; of course the ‘normal’ delay of 20 hours.

In both case, after the 20 hours, the charging current must be limited at 1/100 of the Capacity.

6.1.1.2. Charging Lead Battery in 3 step

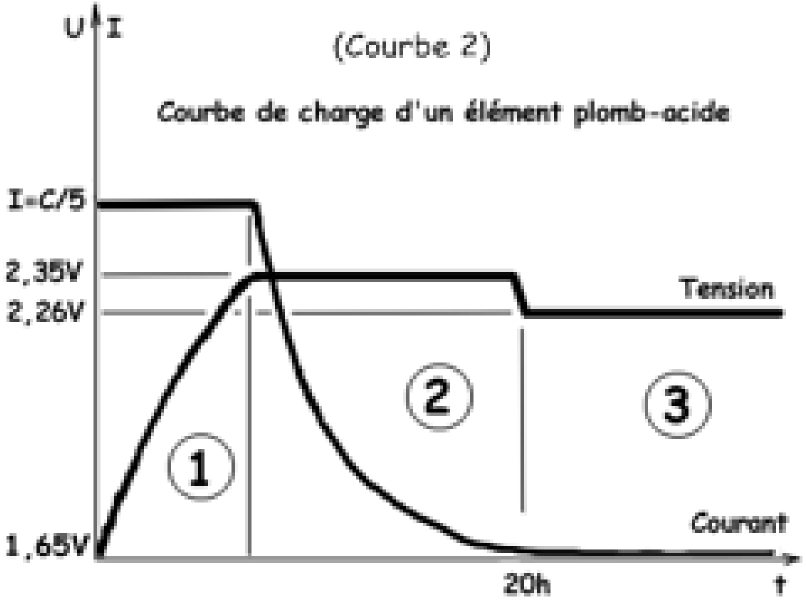


Figure 77: Charging lead batteries in 3 steps

In part ‘1’, current is limited to the maximum charging current, C/5 (or manufacturer value)

In part ‘2’, It is the Charging Voltage which is ‘operational’

In part ‘3’, the voltage switch to the ‘Floating Voltage’ value

This method in 3 steps allow the Battery to be charged at 100% in the ‘normal’ charging delay of 20 hours and then to maintain the full Capacity in ‘Floating’.

This is the type of charge used in UPS / Inverters systems.

Advice: the ‘cheap’ battery charger bought in Supermarket (at 15 Euros!) are going to kill your car battery and accessorily (may be) charge it.

This “thing” is made with a transformer and a diode bridge only. Adjusting voltage/current is done by commutating some of the transformer coils. There is no filter, the peak voltage is far above the maximum charging value

On site: just add the number of cells in series to have the values of ‘Charging Voltage’ and ‘Floating Voltage’ not forgetting to discount the dead cells somewhere in the middle (those you have discovered during the maintenance and short-circuited them).

In all cases, once the batteries have been in charge for a couple of days, the **“floating current”** must be < 0.01C.

6.1.2. Charging Nickel-Cadmium Batteries

As per for the Lead batteries, this applies for all types of Ni-Cd Batteries, dry or wet, sealed or vented, aqueous, or gel electrolyte

6.1.2.1. Normal Charging

Done with a ***constant current*** of ***1/10 of Capacity*** under a voltage at least equal to ***1.45V per cell***. Current must be maintained for at least ***14 hours*** when the Battery was fully discharged at the beginning of the charge.

During charge, the voltage is increasing first rapidly, after slowly to reach the value of ***1.4V per cell. Charge is then completed***.

If the Battery stays under charge with the same current, there will be overcharge. The voltage starts to decrease, the battery does not take more energy but gives out some heat, and Battery produces then Hydrogen and Oxygen. After 14 hours of (normal) charge and still at 0.1 In, the Battery begins destroying itself.

The best way to know the end of charge is to detect the “dV/dt” (see in following paragraph), meaning the instant at which the Battery has reached its maximum voltage, this one in turn starting to decrease. This detection of the dV/dt is mandatory for the other methods of ‘rapid charge’ and ‘accelerated charge’, hereafter. Other practical solution: detection of the ‘theoretical’ end of charge voltage of 1.4V per cell

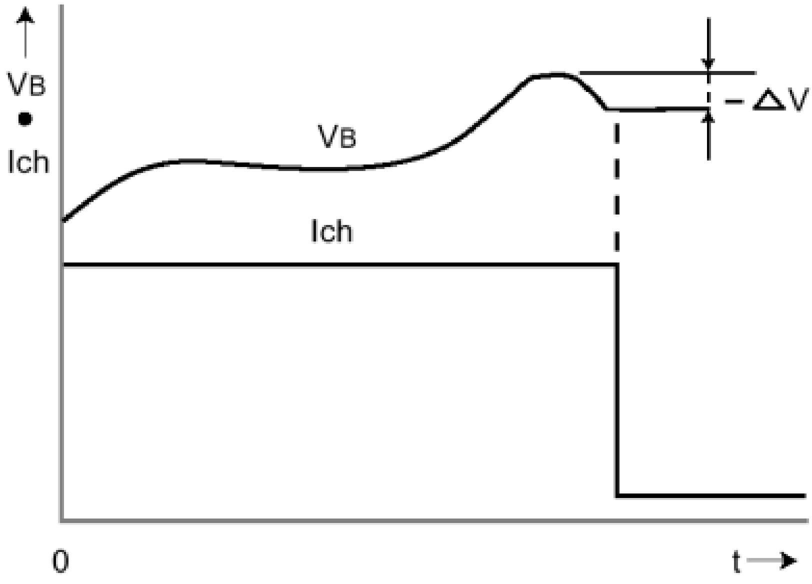


Figure 78: Normal charging of nickel-cadmium batteries

6.1.2.2. Accelerated Charging

Done at *1/5 of the Capacity* during *6 to 7 hours* maximum.

Overcharging must not exceed 40 mn, Battery starting to destroy itself after this delay.

This is a ‘good’ quality charging but, of course, less efficient than the ‘normal charging’.

6.1.2.3. Rapid Charging

Done at the Capacity of the Battery during 1 hour maximum; Overcharging is strictly ‘forbidden’ at this charging rate

Caution: not all the Ni-Cad Batteries allow this type of charge.

In ‘Rapid Charging’ (and as well in ‘Accelerated Charging’), the charger must be equipped with end of charge detector (dV/Dt system) which see the instant when the voltage starts to decrease, and the Battery must be fully discharged at the beginning of charge.

6.1.2.4. Permanent Charging

Done at 1/20 of the Capacity with limitation of time (but not up to a week!).

The Battery charges but not heats after end of charge due to lower current.

6.1.2.5. Maintaining Current

Or *“Floating Current”*

Once the charge is completed, applying a current of 1/100 of Capacity (same as for Lead Battery) maintain the Battery at its full Capacity indefinitely.

This current does not charge the Battery, it simply compensate the natural loss of energy which are (without this 0.01C current) of 99% of Capacity after 10 days and 90% after one month.

Voltage to be adjusted and regulated to have this 0.01C (maximum) current.

6.1.2.6. Industrial charging method

Which is the method used in site UPS and Battery Chargers

It is a combination of ‘Rapid’ or ‘Accelerated’ charge with a permanent charging at end of cycle. Detection of dV/dt (point 3 of the curve under) triggers the charging current to 1/20 of Capacity during few hours.

The industrial chargers are equipped with all the required safety devices in detection of Voltage, Current, Temperature, and timing.

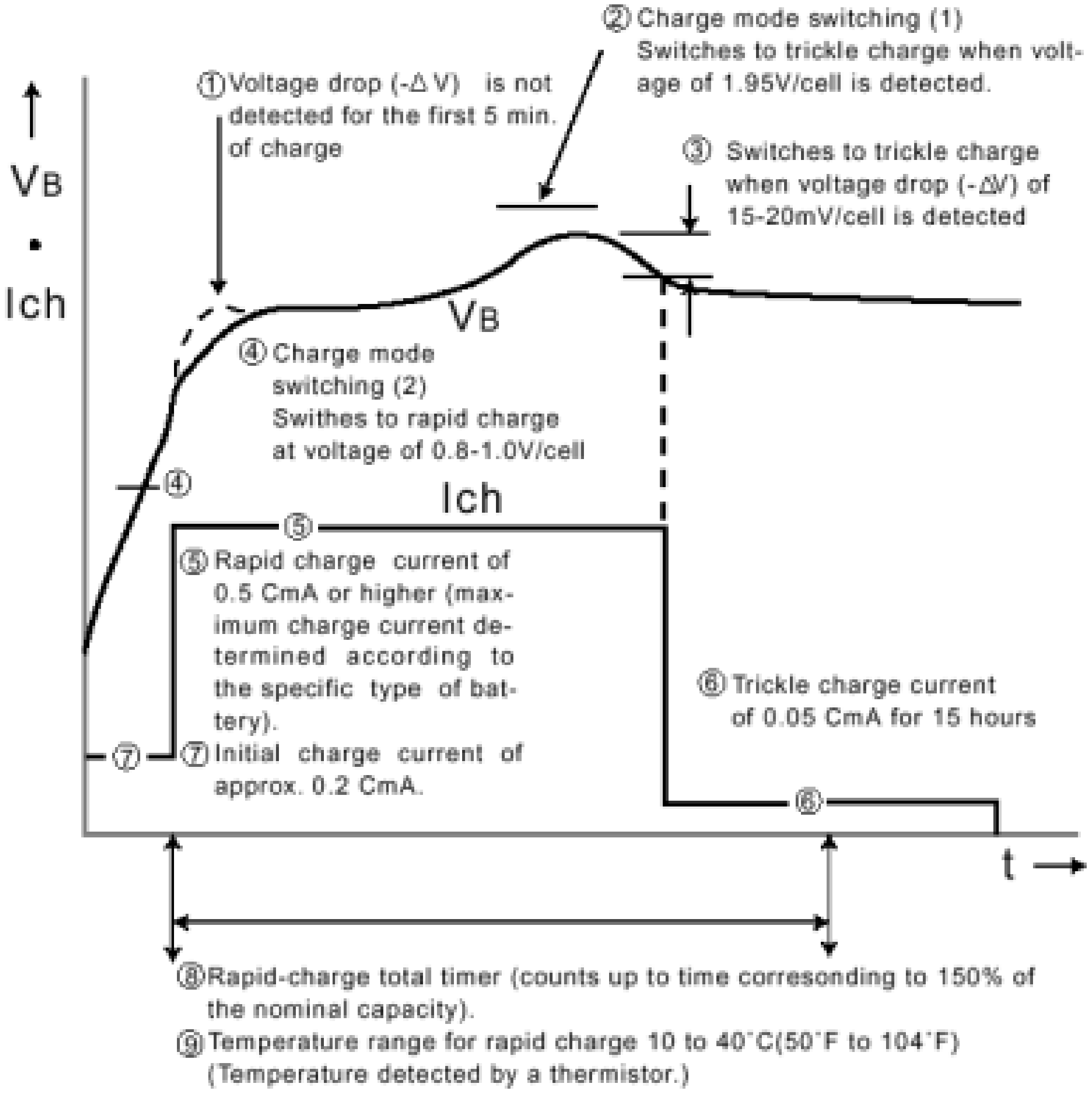


Figure 79: Combined charging curve

(1) Time delay on end of charge detection to avoid triggering at the beginning of charge
(2) Detection of 1.95V max per cell
(4) Limitation of charging current if voltage is under 0.8V per cell
(8) Time delay limiting rapid or accelerated charge at 150% of Capacity
(9) Temperature sensor for check of cell temperature. Cell to be equipped with these devices.

And on site: same remark as per Lead Batteries, check the current charging your UPS of Battery Charger Sets. The current in normal, stabilised conditions must be < 0.01 C of the Batteries. For the 'Floating voltage', it is 1.4V per cell and you need to know the number of cell (in good conditions) in series.

The charging current is available on the ampere-metre on the door of the unit…

6.1.3. Charging Nickel-Metal Hydride Batteries

Like the Ni-Cad accumulator, the Ni-MH is charge at constant current. The difference is in the variations of Voltages at end of charge. Ni-MH has far less amplitude variations in such a way that the dV/dt detection at 0.1 C is nearly impossible.

The detection of dV_2/dt_2 (inflexion of charging curve at end of charge) is required. No way to detect the voltage, it has not enough accuracy, the charge at 0.1C is not easy to realise due to this particularity of 'smooth' end of charge

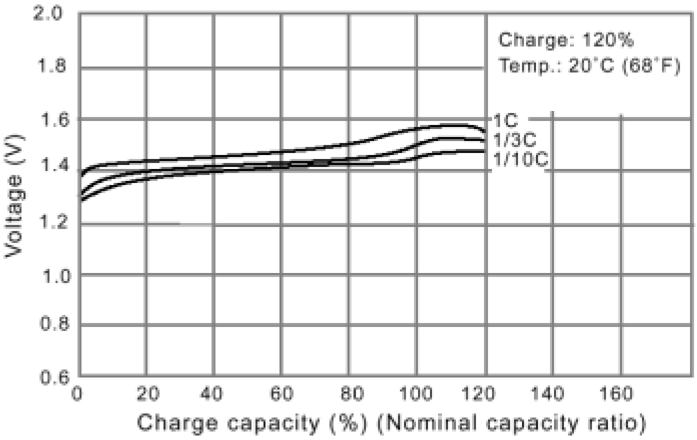


Figure 80: Charging curve Nickel-Metal Hydride batteries

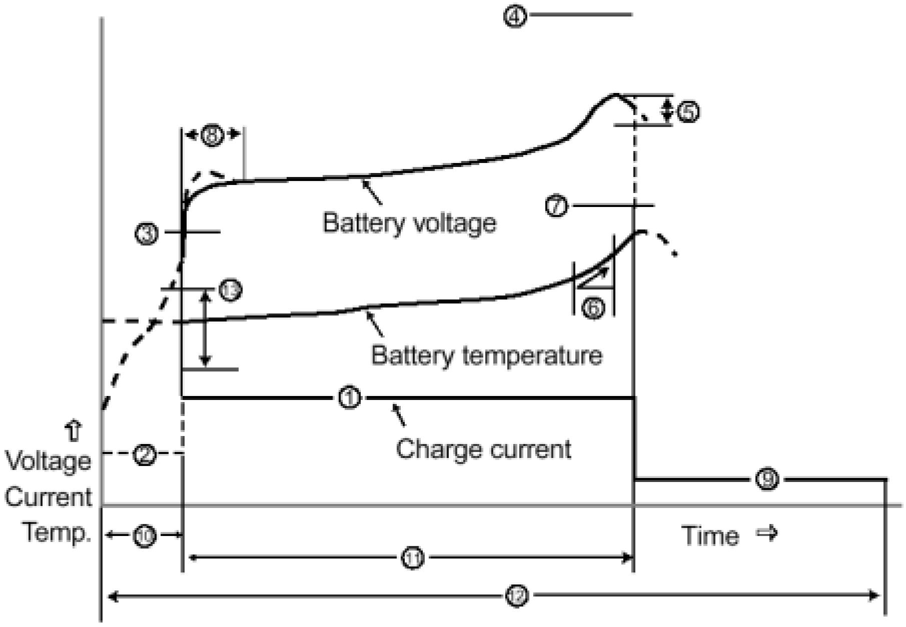


Figure 81: Example of a rapid charge system for Ni-MH

(1) Rapid Charge current: must be between 0.5 and 1 C (or In). Above In, there will be overheating and gassing.
(2) Pre-charge current: 0.2 to 0.3 In, in case of voltage being under 0.8V per cell
(3) Start of a Rapid Charge when voltage reach 0.8V
(4) Detection of maximum voltage at 1.8V per cell
(5) Detection of dV/dt for switching to permanent charging current: 5 mV < -dV < 10 mV per cell
(6) Detection of dT/dt for switch to permanent charging current: 1 to 2°C/mn
(7) Detection of maximal temperature, 50 to 60°C according to manufacturer.
(8) Time delay of 10 mn to inhibit detection dV/dt at beginning of charge
(9) Permanent charging current at 1/30 to 1/20 of In
(10) Time delay for pre-charge: 60 mn
(11) Time delay for 'Rapid' charge: 90 mn
(12) Time delay total: 10 to 20 hours

The manufactures of Ni-MH chargers have adopted a specific method using several steps in charging. It starts by a 'Rapid Charge' at 0.5 to 1 C. With such a current, the charging curve gives at end of charge a slight inflexion which allows consequently the detection of the dV/dt

Once this instant is detected, current is decreased to 1/30 of C to complete the charge by a 'Maintaining Charge'

Caution, the Ni-MH batteries do not like overcharging and detection of end of charge is very important. It is mostly advised to incorporate a time delay limiting the charge at 90 mn and a temperature monitoring to avoid overheating.

6.1.4. Charging Lithium Batteries

The voltage of lithium accumulators is 3.6V for the Li-ion old technology and 3.7V for the Li-Po and Li-ion new technology

Whatever the technology (Li-ion, Li-Po, …) the charging principle is identical:

- The ***charge is at constant voltage and limited current.***

Particularity of charging Lithium cells is based on 2 main ^points:

- **They do not support overcharging, even a small one**
- **Voltage value for charging must be respected otherwise it does not charge!**

The gap of voltage is very thin to charge the Lithium batteries, it requires a very strict value

The 2 technologies Li-ion (old) and Li-Po + Li-ion (new) have closed reference voltages but they are different and the charger of one will not work on the second!

Charging Voltage:

- **Reference Voltage: 3.6V - Charging Voltage: 4.1V per cell**
- **Reference Voltage: 3.7V - Charging Voltage: 4.2V per cell**
- Tolerance is +/- 0.05V per cell

Charging Current limited between C/2 and 1C, charging time between 2 and 3 hours

Some manufactures pretend charging Lithium cells in 1 hour but in one hour, the charge is only at 75% of the Capacity

Charging Curve (under):

- At the beginning of the charge, the current is limited and voltage increases slowly up the maximum charging voltage (4.1 or 4.2V)
- Then occur the second phase (the filling, voltage stays perfectly stable and current decreases
- Charge is completed once the current comes under 0.03 C

Then charge must be stopped, otherwise cell are destroyed

An overcharged Lithium battery generates Hydrogen, thus Pressure and Temperature increase, and it can go up to the explosion.
Li-ion batteries are generally protected by inside devices, but the Li-Po's are not, and if they are not subject to explosion, they can burst into flames….

If you see overheating, cut the power!!

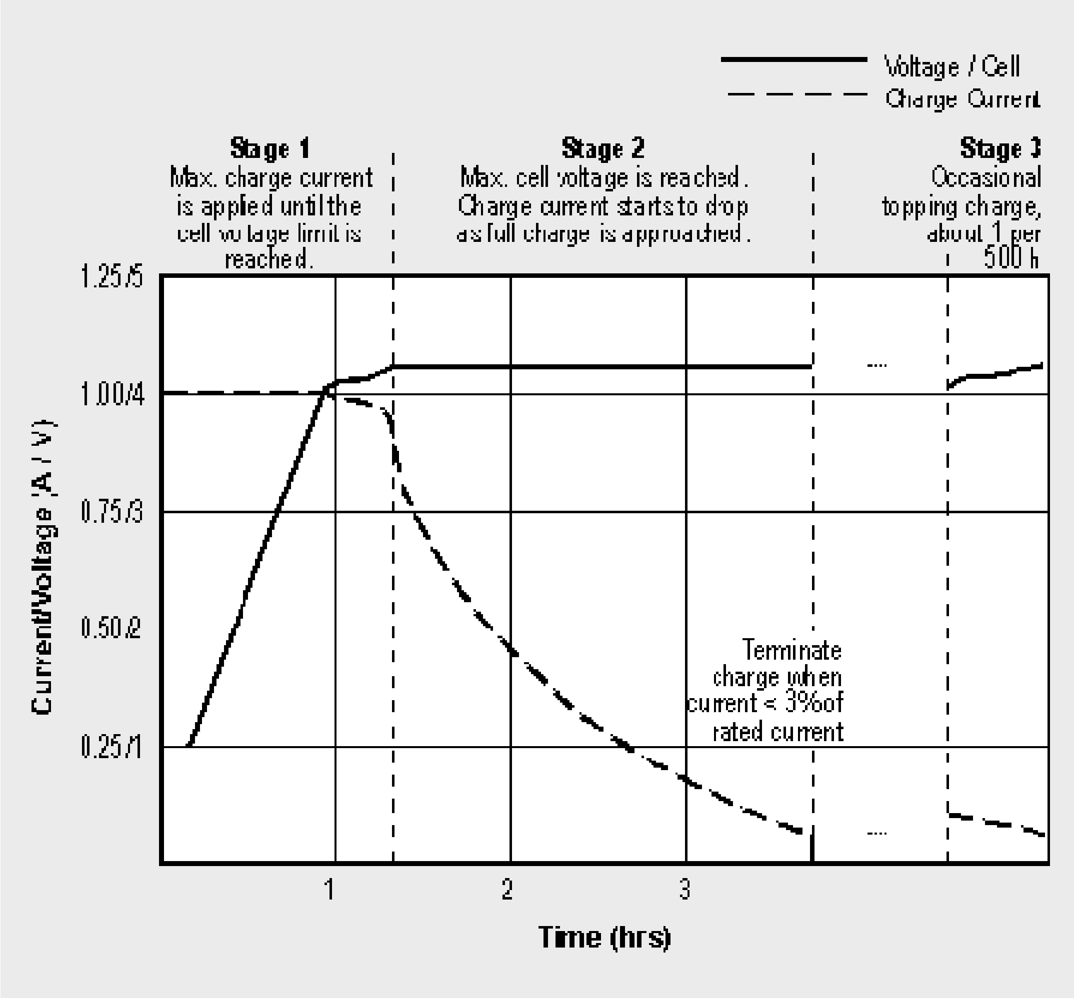


Figure 82: Charging curve Lithium batteries

Last Charging Advises

- Do not increase the charging current to decrease the charging time. If it allows going faster to step 2, the “filling” phase will require more time and high charging current will hamper the life time of the battery. It is more advisable to stand at a charging rate of C/2.

- Do not apply low charging current (or maintain current). It creates a deposit of Lithium on electrodes conducting to unstable conditions. To compensate the ‘auto-discharge’, it is recommended to charge briefly the battery every 500 hours. This recharge should be as well stopped at 0.03C

- Risks charging Li-Po in series. These types of cells could have not exactly the same voltage and one cell in a middle of a series block could be reactive to a non-adapted charging voltage

- **No Maintaining current,**

- **No Floating voltage (or current)**

- **Charged = disconnected**

6.1.5. Charging Alkaline Batteries

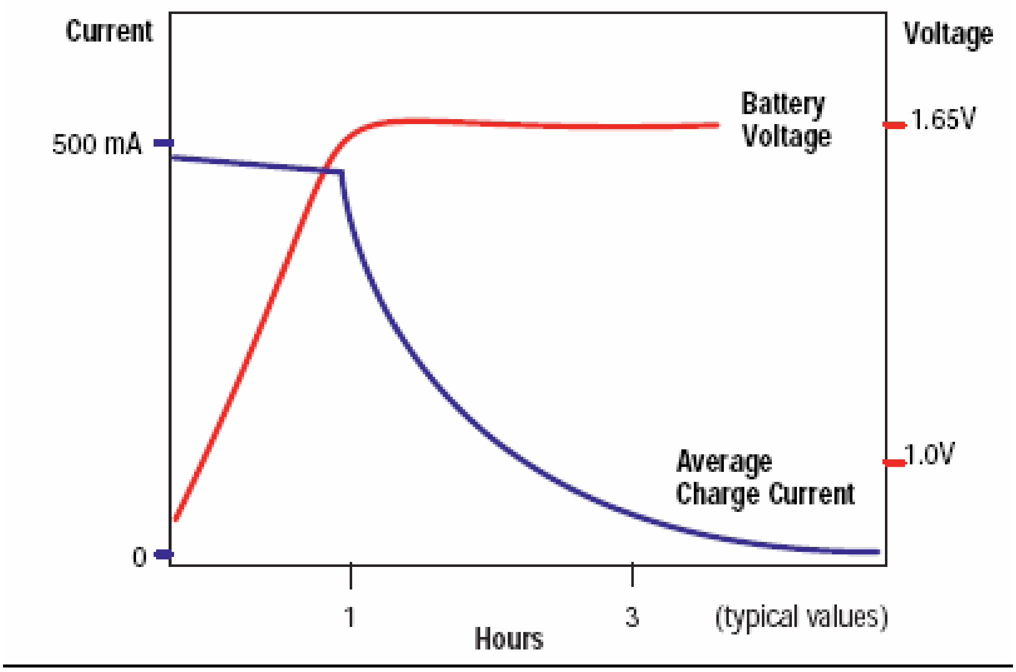


Figure 83: Typical current/voltage profile for rechargeable alkaline batteries

- Charging Voltage limited at 1.7V
- Charging Current limited at C/15
- Charging time of about 10 hours
- Discharge voltage minimum: 1.25V

See manufacturer documentation Rayovac on this subject

Figure 84: Examples of alkaline batteries

6.1.6. Delta Peak –dV/dt - dV

This phenomena concerns only Ni-Cd and Ni-MH Batteries

A Ni-Cd or Ni-MH cell is charged when the derivative value of the voltage goes to zero (the derivative of a curve is the tangent of the same curve at a given point)

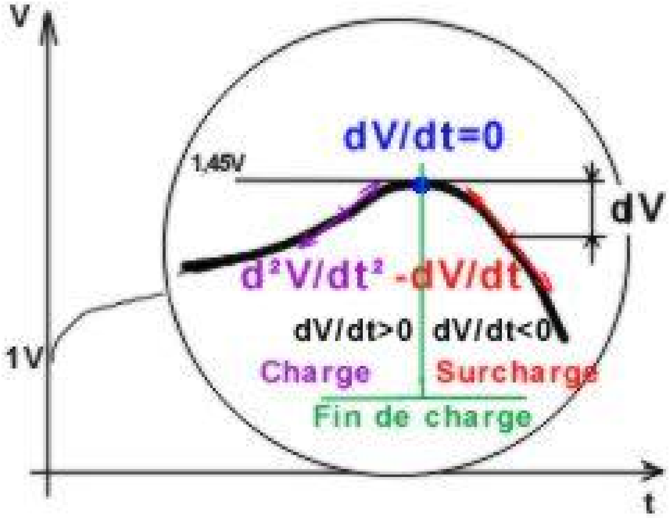


Figure 85: Derivative value of voltage

Before end of charge the voltage increases, derivative is positive

Once cell is charged, voltage does not increase, derivative becomes zero

After the full charge, voltage decreases and derivative becomes negative

The principle is to detect this change from positive to negative, detecting at zero being the "ideal" control.

The 3 terms "Delta Peak", "-dV/dt" and "dV" are the mathematical interpretation of the change of status in the curve direction.

6.1.7. Real Capacity of Batteries

International Standard for accumulators are

? For Lead Batteries

CEI 61951-1 for Ni-Cad Batteries

CEI 61951-2 for Ni-MH Batteries

Extracted from the Standards, it is well said that the manufacturer must indicate on the name plate the *"assigned capacity"*

The 'assigned Capacity" should be tested and controlled (and is anyway part of Maintenance in a battery bank) according to "article '" of those standards

Capacity Test:

Charge must be done at +20°C +/-5°C at a constant current of 0.1C during 16 hours, the cell (or battery) having been discharged initially et the same temperature at 0.2In down to 1.0V.
The battery must be kept charged, not touched at least 1 hour and at maximum 4 hours

Discharge allowing the measurement of the Capacity must then be done at 0.2 In at 20°C +/-5°C up to the final voltage of 1.0V.

Capacity must at least correspond to the manufacturer indication. Example: for a 100Ah battery, discharge at 20 Amperes must last at least 5 hours before reaching the 'critical' voltage of 1.0Volt

6.2. THE BATTERY CHARGER

6.2.1. Description and principle of operation

This is the basic and general technology. Of course “simple” battery chargers exist on the market, we consider hereafter, “our” devices used on site.

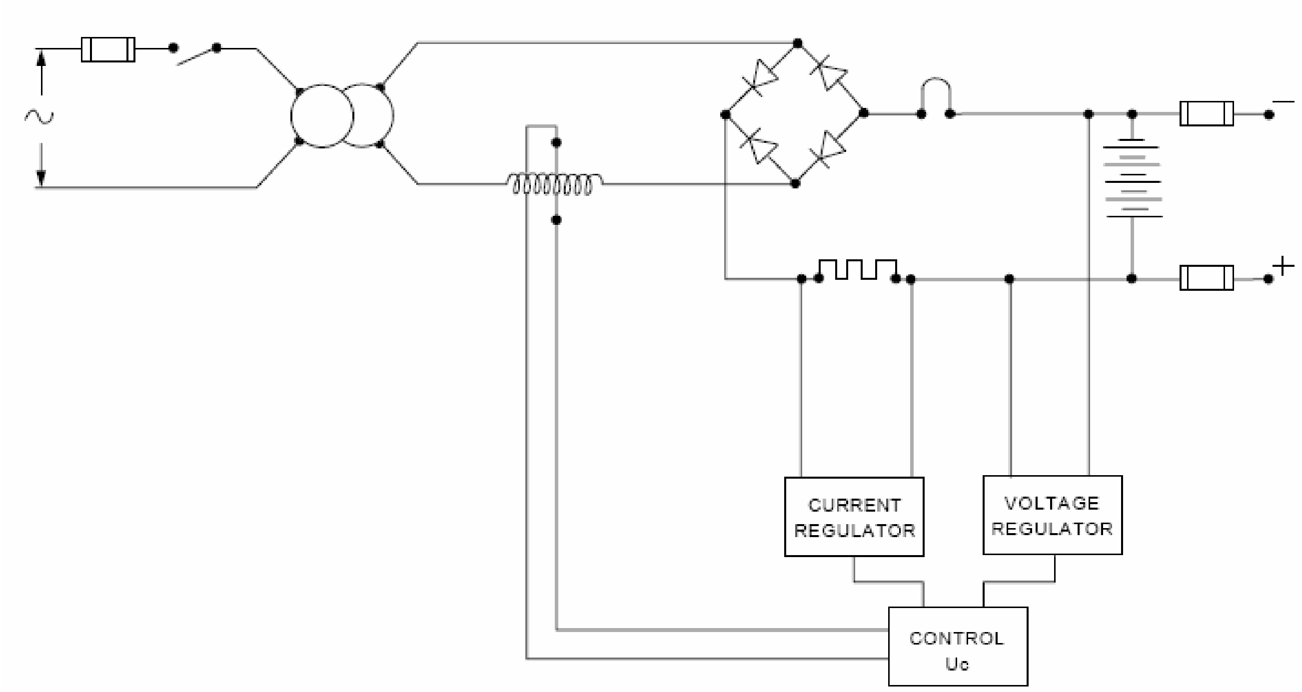


Figure 86: Battery charger

The power circuit includes:

- A main transformer
- A transducer whose control the flow of the charger according to a “weak” D.C. current of control
- A single-phase bridge of diode
- A battery or a set of cells in series and parallel

The regulating circuit includes:

- A voltage controller with transistor which regulates the charging voltage with ±1 % (at least) of the nominal value.
- A current controller with transistors which limits the current of the charger and its nominal current.

The **voltage controller** works in such a way that for an increase of the battery voltage, the flow of the charger decreases to lower the voltage of the battery, by decreasing the control current circulating in the transducer.

The **transducer** consists of two magnetic circuits

- One AC winding (called: work)
- One DC winding (called: control)

Their operation is based on the principle: we can act on the impedance of a coil by superposing to the alternative flux a continuous flux of control.

The current controller works when the flow of the charger exceeds its nominal value. An increase of the flow limit the control current of the transducer

Automatic Check of the Battery charger:

The automatic check of the battery charger is carried out on the following points:

- Loss of the Load voltage: 24 or 48 or 60 or 110 or xxx Volts
- Breakdown of the fuses of the protective DC circuit
- Loss of the AC
- Ground fault either on AC or DC sides

6.2.2. Dual system

Dual System means: the load (or charge) downstream of the 'block Battery Charger + Battery Bank have to be supplied either by the battery charger alone or by the battery bank alone.

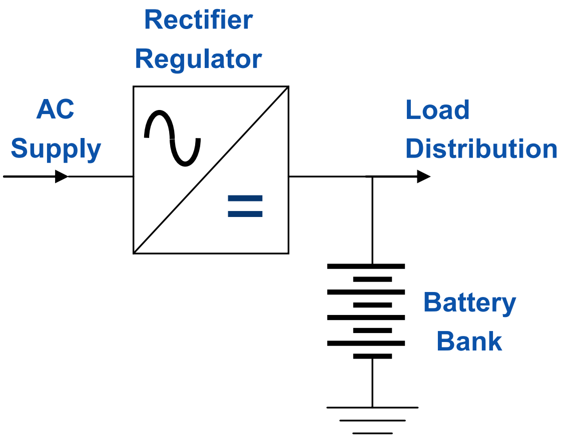


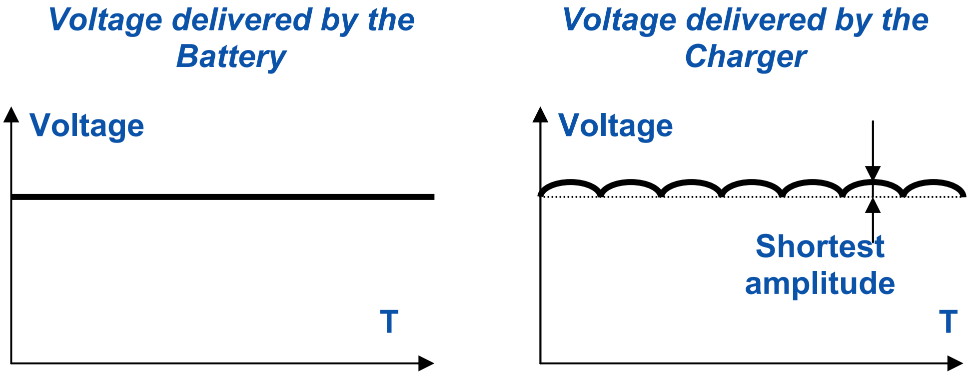
Figure 87: Dual system

Description:

This DC Power System is designed to supply DC electric power (Load Distribution) that is protected from abnormal occurrence on the public or 'normal AC supply. The AC supply is used to power a rectifier in order to store energy in a battery to be used during a power cut. T

The equipment consists of two independent systems, AC supply and DC Load Distribution with (generally) a common distribution board.

Each half system consists of two major parts; see Figure above Block Diagram, the Rectifier/ Charger and the Battery.


Voltage delivered by the Battery

Voltage delivered by the Charger

Figure 88: Voltage delivered by the battery and by the charger

The DC supply from the charger "tries" to be a pure quality DC, depending the quality of the rectifier / filters, when the voltage/Current delivered by the Battery itself is in a "pure" DC form.

Rectifier/Charger:
It converts the Primary AC supply to a regulated DC voltage, which charges the battery, powers the Load (or inverter in a UPS system).

The Battery Charger must be calculated to be able to supply the full Load alone + Charge the Battery

It operates as per the charging methods seen in the previous paragraph regarding the charge of the batteries, and in same time supply the Load.

On some site (where Load have been added), after a shutdown, the Capacity of the Battery Charger is "borderline" and it has 'difficulties' to assume these dual functions

6.2.3. Operating Modes

It operates in three possible modes:

- Float mode
- AC supply failed mode
- Charge and supply load mode

6.2.3.1. Float Mode

Again, whatever strict warning said by the manufacturer, or the convinced practices done by the electrician, it is not the "Floating Voltage" which is important; it is the "Floating Current".

It concerns the batteries used on site ***(Lead/Lead and Ni-Cad),*** and remember what was said above, the lithium batteries do not need 'Floating'. See paragraph 5.1.4., overcharging destroys lithium batteries
Nowadays, the control system of the battery charger is adapted for the type of Batteries and regulates accordingly, but….

The 'Float mode is the normal mode. It is a constant-voltage/current charge mode so battery charge current will tend to taper off to near zero as the battery becomes fully charged.

The voltage chosen is that value at which the internal losses are compensated by the charge current into a charged battery. The battery is maintained fully charged with a "maintaining current" which remains below gassing values so that the rate of loss of electrolyte is negligible.

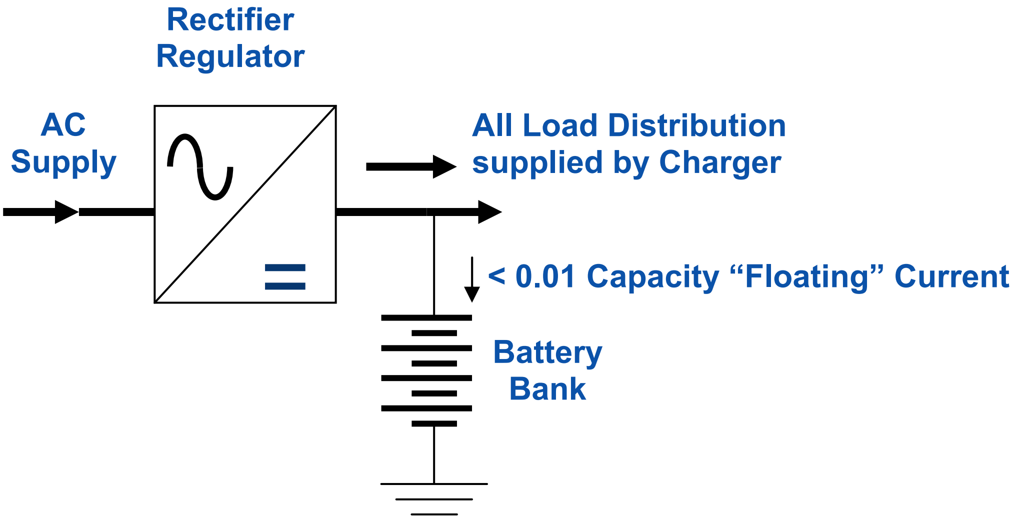


Figure 89: Float mode

6.2.3.2. AC supply failed Mode

When the power to the charger is interrupted the charger stops and without any switching taking place or operator intervention the battery supplies the load.

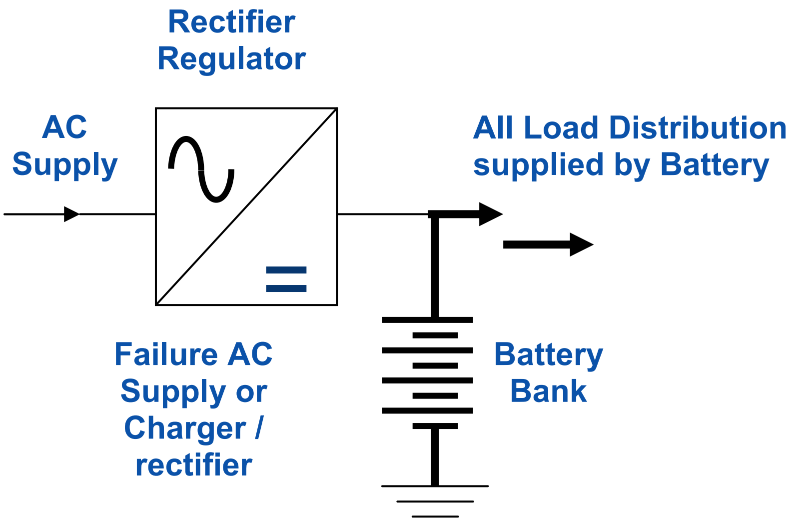


Figure 90: AC supply failed mode

6.2.3.3. Charge and load supply Mode

Automatically selected when the AC supply is restored. Slightly higher constant voltage charge to recharge tile battery as per the principle seen in the previous paragraph (Rapid, Accelerated, Constant Current, Constant Voltage,….etc) and in same time supply the Load.
It is why, you need an “intelligent” charger able to monitor voltage, current and timing for the Load and the type of charging required by the Battery

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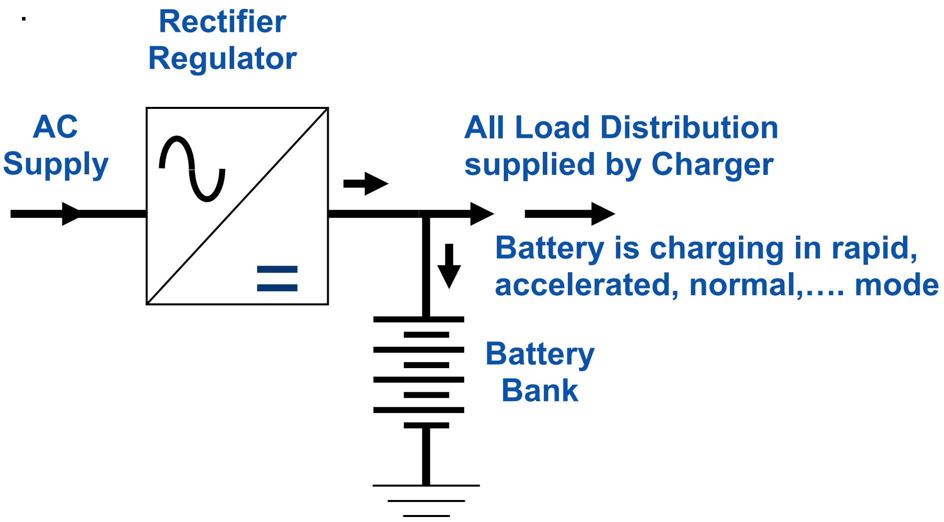


Figure 91: Charge and load supply mode

6.2.3.4. Battery Bank

This stores energy from the charger to be used during a power cut when it will discharge to power the load.

The autonomy of the system during a mains fail depends on the amp-hour capacity of the installed battery.

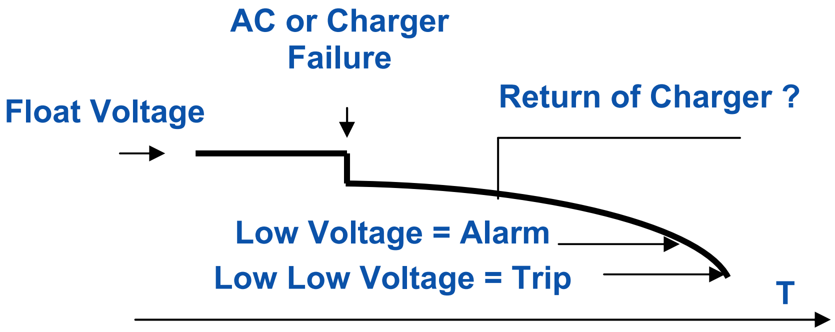


Figure 92: Battery bank

6.2.3.5. Ventilation and Extraction

Either for the Charger devices and for the Battery Bank, temperature is controlled by ventilation / extraction

On the Charger/batteries cubicles all ventilation apertures must be kept free and clean. These systems can work (normally) in a continuous environment within 0 to 40°C temperature range, although, ideally the ambient temperature should be below 25°C.

This value of 20/25°C is even more than recommended for sealed gel batteries which are very sensitive to high temperature (loosing Capacity).

The heat can be removed from the equipment room by a forced cooling ventilation system or, alternatively, an air conditioning system. It is why you can find “heavy duty” Air Conditioning system in Battery Charger and UPS rooms

The required air changes per hour will depend on the system rating, the heat loss and the cooling air temperature.

6.3. THE UPS FOR AC SUPPLY

Just to know few "tricks" about it. It is a battery Charger completed by an Inverter and an automatic commutation system. The Load is an AC distribution towards mainly Instrumentation devices.

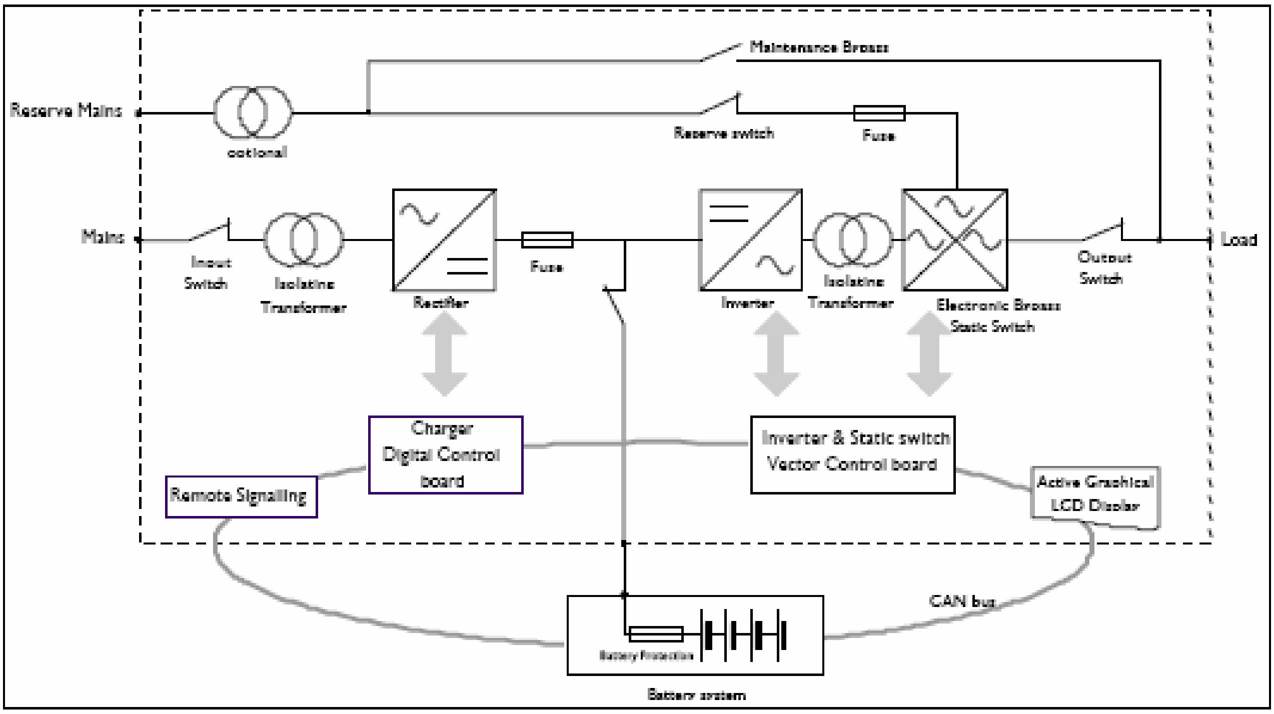


Figure 93: Example of site application the 'Chloride' EXCOR Apodys single block system

The EXCOR Apodys range shall include **1-phase** or **3-phase output** models

The UPS shall automatically provide continuity of electrical power, within the defined limits and without interruption, upon failure or degradation of the AC source. The length of the backup time, i.e. autonomy time in the event of network failure, shall be determined by the battery capacity.

6.3.1. UPS Synchronisation

A panel operator often sees in his alarm list: "UPS out of synchronisation". This has become a common alarm which is 'always' inhibited and even deleted….!!

When putting in service (or return to normal supply), according to distribution configuration, either:

UPS and network: UPS taking over in case of power failure

UPS and other UPS: load supplied by UPS only and permanently

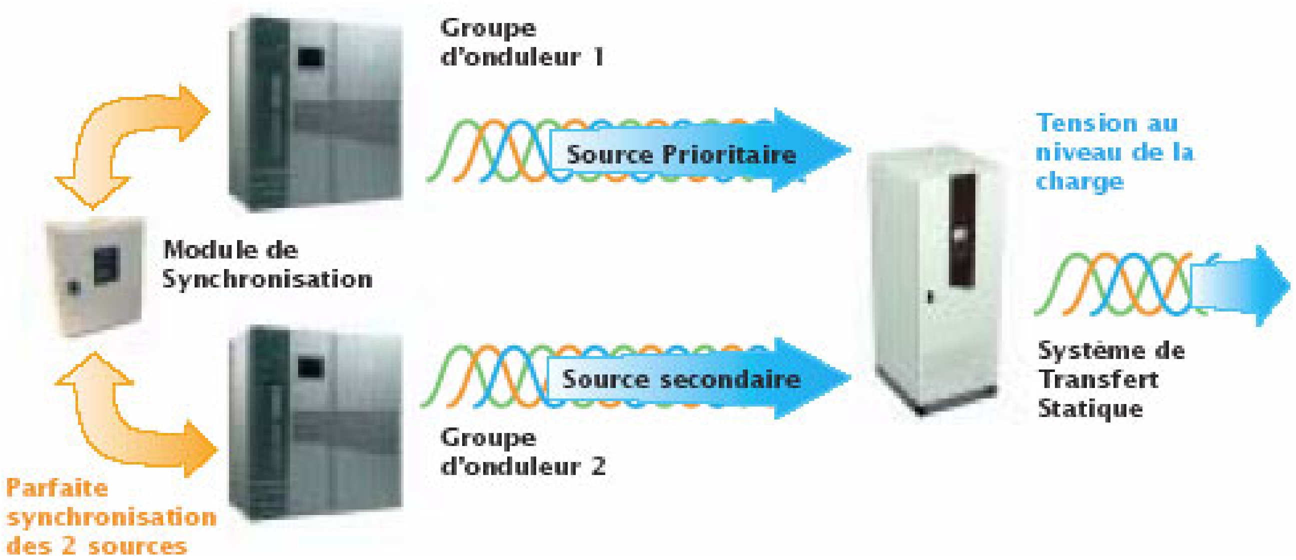


Figure 94: UPS Synchronisation

All UPS are equipped with a synchronisation module which acts with the same principle as for synchronisation of 2 generators. The only difference is that the AC out an inverter is a "reformatted" wave when the AC out an alternator is a perfect sinusoid. The UPS is watching permanently the network AC to adapt its own output to be exactly in phase, ready to take over without any "time break"

Synchronising 2 Inverters does not give (generally) problem; when it comes to synchronise Network and one Inverter, some 'slight' discrepancies occur in the shape of wave form or in frequencies.

This is why the alarm "out of synchronism" appears (relatively) frequently.

6.3.2. Back-up principle

The equipment consists of four major parts (see. Block Diagram):

- The Rectifier/ Charger
- The Battery
- The Inverter
- The Static Switch (with the reserve AC supply and its by-pass).

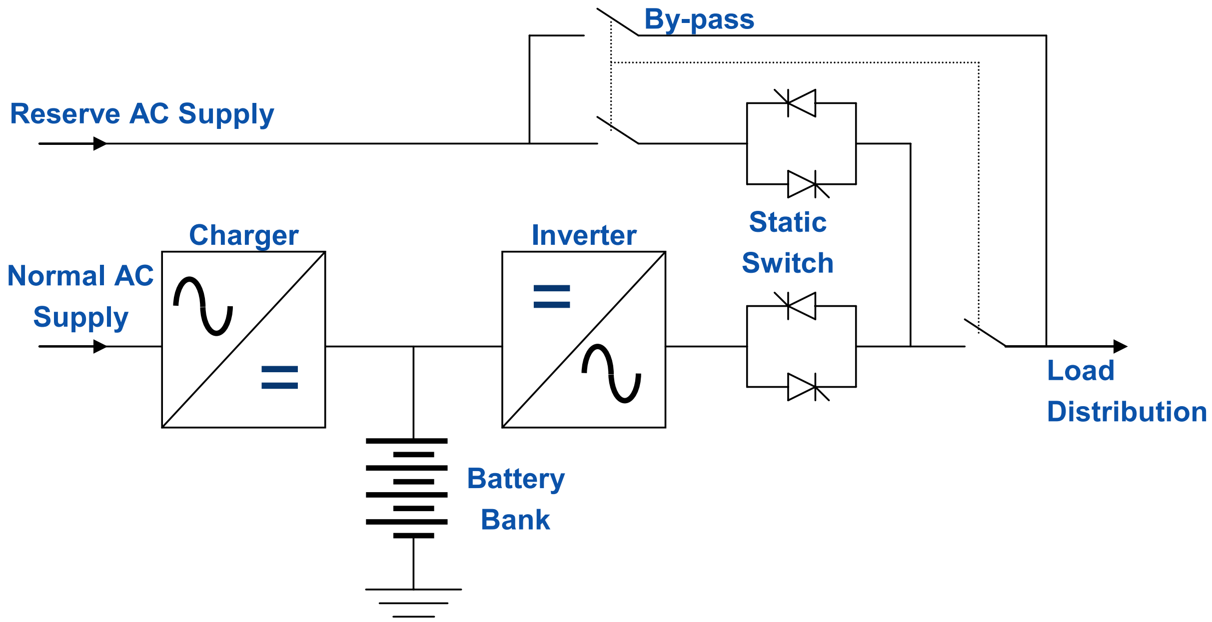


Figure 95: Back-up principle

In our application, UPS is used alone or doubled, one train of together the charger/inverter/battery being able to take the full Load

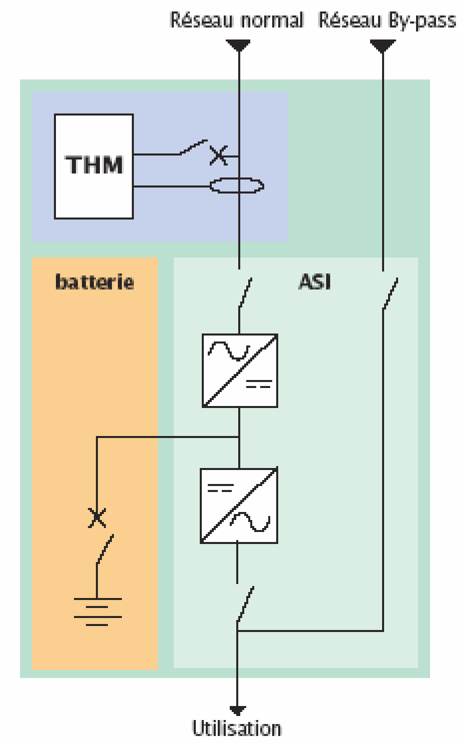


Figure 96: Single UPS

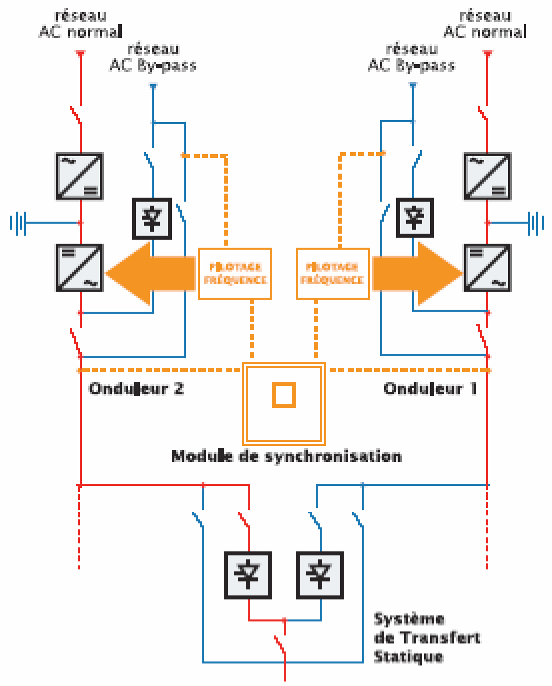


Figure 97: Double UPS

6.3.2.1. Normal Operation

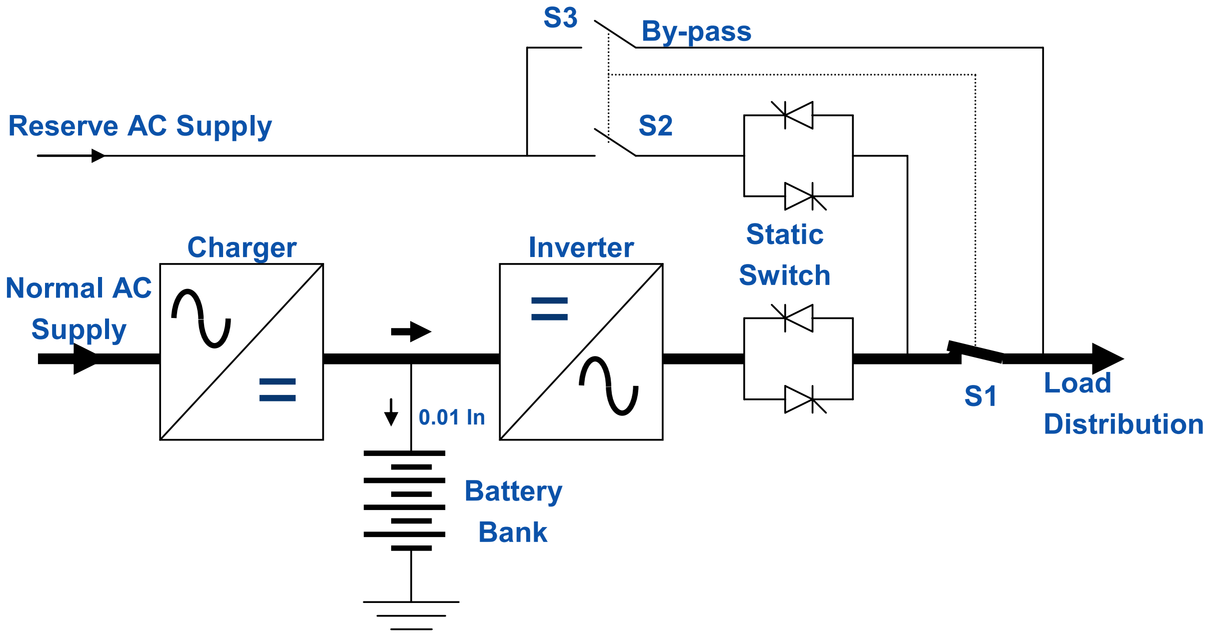


Figure 98: Normal back-up operations

Load is supplied through the Charger, the Inverter, the Static Switch, S1 is closed

6.3.2.2. Primary (Normal) AC supply failure

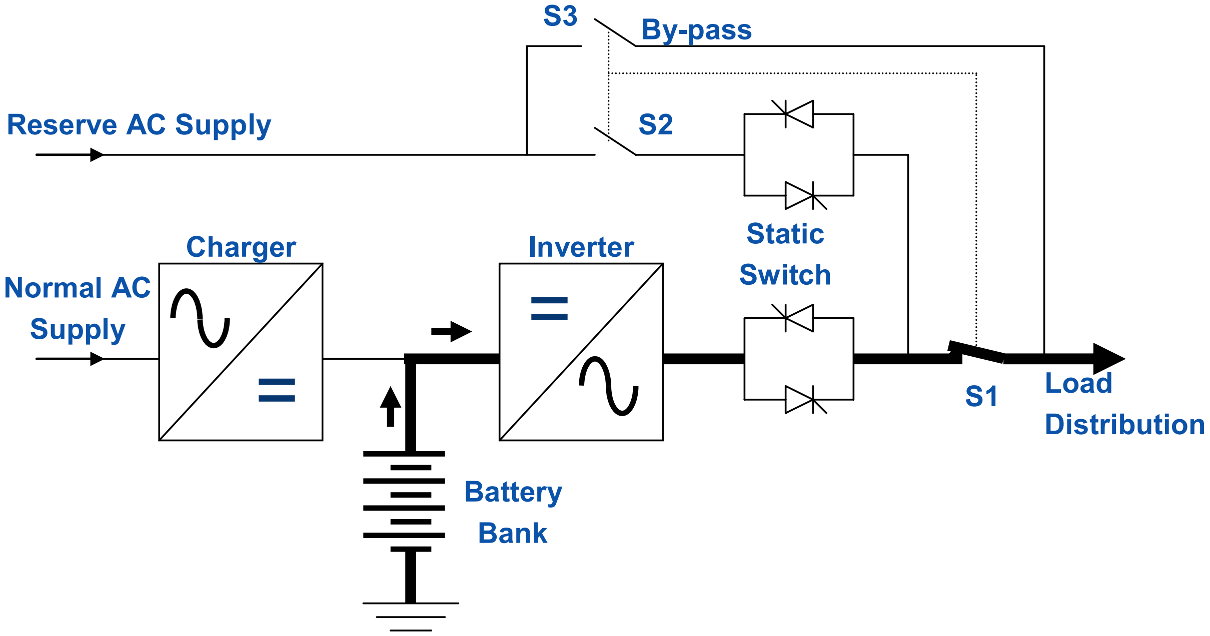


Figure 99: Primary AC supply failure

The reserve supply may or may not be available depending on the configuration of supplies into the UPS. The charger stops and the battery powers the inverter and hence the load. In this mode, the duration of operations depends upon the Capacity of the Batteries

6.3.2.3. Reserve supply to Load mode

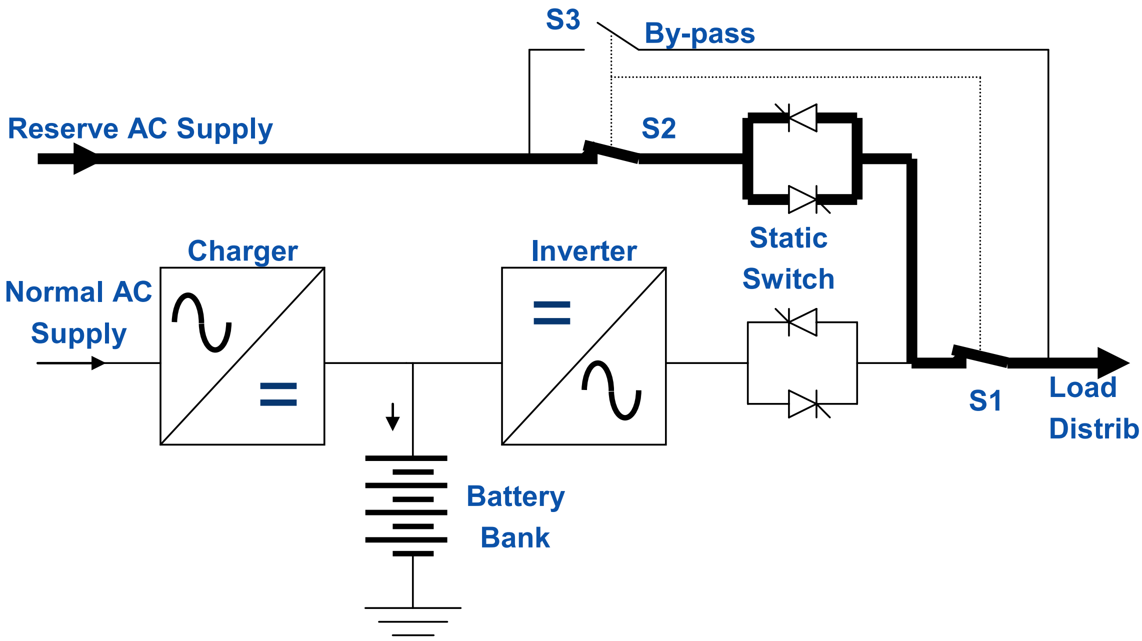


Figure 100: Reserve Supply to load mode

Could have failed: the normal supply, the charger, the inverter, the Static Switch (partially); S1 and S2 are closed. The switching occurs automatically, it is the purpose (and the principle) of an UPS.

If the failure comes from the inverter, the charger can still be on line charging the batteries in floating.

Back to “Normal Operation” should occur also automatically, with all components in duty and in operation. Needs for reset or not, depending the configuration of the inverter.

6.3.2.4. Maintenance By-pass mode

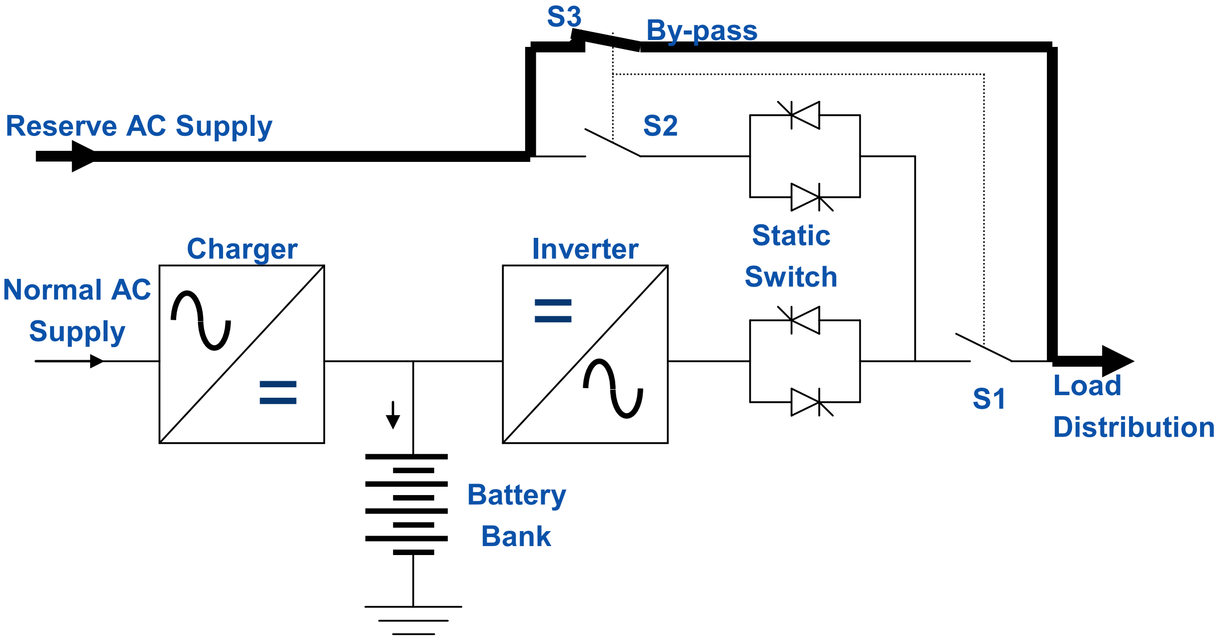


Figure 101: Maintenance by-pass mode

Load is supplied by the reserve supply directly through S3 switch. This operation is (generally) made manually for maintenance works.

Back to normal operation requires as well manual intervention with step by step sub-operation and synchronisation through S2 and S1 switches.

7. MAINTENANCE OPERATIONS

The purpose of this section is to outline the duties and responsibilities for routine operation and care of all types of secondary set/rack of batteries

It concerns the Battery Packs and Banks used on site, namely the Lead/Lead and Ni-Cad, sealed or vented, electrolyte acid or potassium, aqueous or gel batteries.

7.1. MAINTENANCE OBJECTIVES

There are three main objectives common to all ***Battery Management Systems (BMS).***

This is a general term which has to be interpreted as either a “manual” BMS using log book to record information or a “built-in” automatic history record in the battery charger/inverter system.

- Protect the cells or the battery from damage
- Prolong the life of the battery
- Maintain the battery in a state in which it can fulfil the functional requirements of the application for which it was specified.

To achieve these objectives the BMS may incorporate one or more of the following functions. (Follow the links to see how these functions are implemented.)

7.1.1. Cell Protection

Protecting the battery from out of tolerance operating conditions is fundamental to all BMS applications. In practice the BMS must provide full cell protection to cover almost any eventuality. Operating a battery outside of its specified design limits will inevitably lead to failure of the battery.

Apart from the inconvenience, the cost of replacing the battery can be prohibitive. This is particularly true for high voltage and high power automotive batteries which must operate in hostile environments and which at the same time are subject to abuse by the user.

7.1.2. Charge control

This is an essential feature of BMS. More batteries are damaged by inappropriate charging than by any other cause. Refer to the previous chapter and remember that ***charging methods are different when batteries are different.***

7.1.3. Demand Management

While not directly related to the operation of the battery itself, demand management refers to the application in which the battery is used. Its objective is to minimise the current drain on the battery by designing power saving techniques into the applications circuitry and thus prolong the time between battery charges.

For all our site applications, the Battery charger must be designed to supply the full load permanently regardless the charging/discharging of the batteries.

7.1.4. SOC Determination

Many applications require knowledge of the State of Charge (SOC) of the battery or of the individual cells in the battery chain. This may simply be for providing the user with an indication of the capacity left in the battery, or it could be needed in a control circuit to ensure optimum control of the charging process. It is why discharge tests are performed (also for SOH hereafter).

7.1.5. SOH Determination

The State of Health (SOH) is a measure of a battery's capability to deliver its specified output. This is vital for assessing the readiness of emergency power equipment and is an indicator of whether maintenance actions are needed.

7.1.6. Cell Balancing

In multi-cell battery chains small differences between cells due to production tolerances or operating conditions tend to be magnified with each charge / discharge cycle. Weaker cells become overstressed during charging causing them to become even weaker, until they eventually fail causing premature failure of the battery. Cell balancing is a way of compensating for weaker cells by equalising the charge on all the cells in the chain and thus extending battery life.

The maintenance includes individual cell verification of voltage and SOH at least once a year

7.1.7. History - (Log Book Function)

Monitoring and storing the battery's history is another possible function of the BMS. This is needed in order to estimate the State of Health of the battery, but also to determine whether it has been subject to abuse. Parameters such as number of cycles, maximum and minimum voltages and temperatures and maximum charging and discharging currents can be recorded for subsequent evaluation. This can be an important tool in assessing warranty claims.

On site maintenance technician records all interventions, all checks / tests made on each set of batteries. Be sure that the values and information's recorded on he log books are properly read and interpreted for action……

7.1.8. Authentication and Identification

The BMS also allows the possibility to record information about the cell such as the manufacturer's type designation and the cell chemistry which can facilitate automatic testing and the batch or serial number and the date of manufacture which enables traceability in case of cell failures.

7.1.9. Communications

Most BMS systems incorporate some form of communications between the battery and the charger or test equipment. Some have links to other systems interfacing with the battery for monitoring its condition or its history. Communications interfaces are also needed to allow the user access to the battery for modifying the BMS control parameters or for diagnostics and test.

7.2. GENERAL COMMON MAINTENANCE

For the Lead-Lead and the Ni-Cad battery banks of our site (of all types)
Each manufacturer gives its own maintenance recommendations but generally they do not include the hereafter operations.

7.2.1. Cleanliness of battery bank

Monthly: check for general cleanliness of the batteries, mounting rack and battery room or battery cubicles.

Check for electrolyte leaks, cracks in cells and cover integrity and take corrective actions if needed.

Check for corrosion at terminals, connectors, racks and cabinets.

When checking Specific Gravity in the schedule of vented cells, clean the “breathing” orifice of each plug with a tiny diameter adapted steel wire. Clean as well the plugs

For VRLA cells with Safety plugs removable, this breathing orifice is on the downstream side of the ‘PSV’ type plug and should be cleared and clean.

7.2.2. Inter-cells connections tightening and Resistance verification

As per the site schedule, type of Cells and vendor recommendation (3, 6 or 12 month).
See the specific schedule in the following paragraphs

A) Numerate each Cell and each Inter-connection as per example hereunder

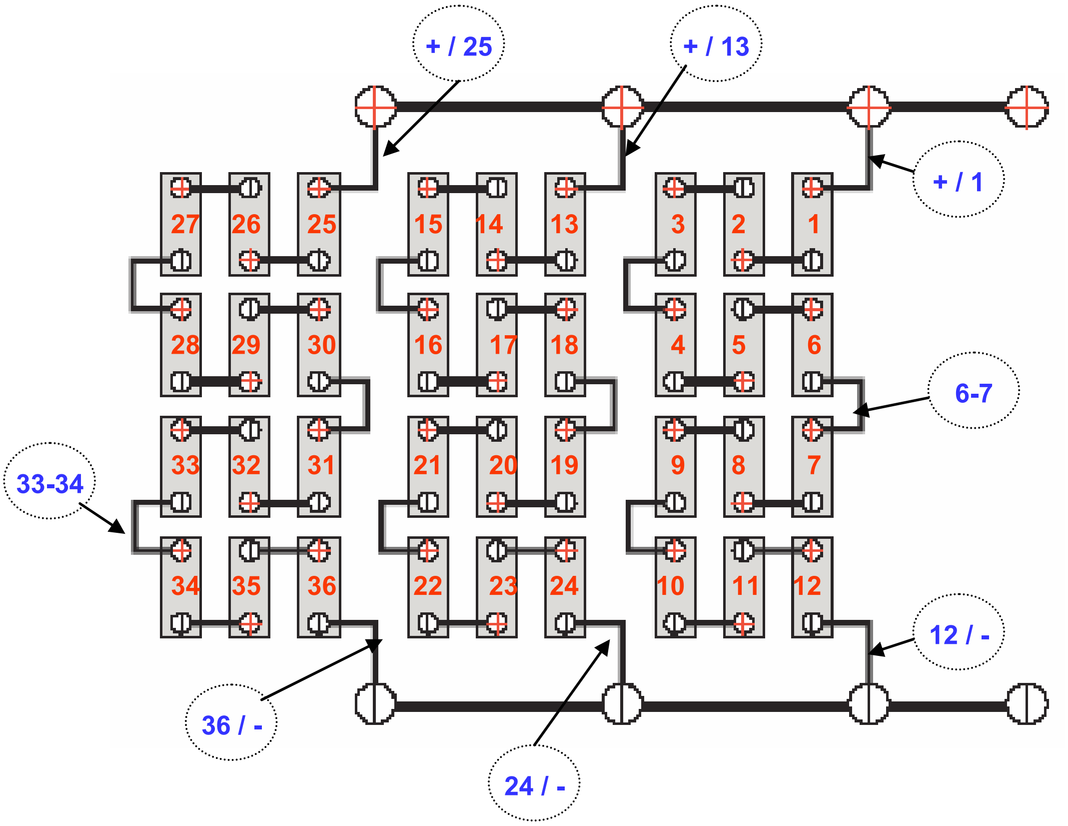


Figure 102: Numeration of cells

B) Measurement

1st Check (recorded in “As left Micro-ohms” column): using an accurate micro-ohmmeter, record the resistance of each connection on a form as per example under.

The readings should be on the order of a few micro-ohms (less than 100).

Schedule re-check: repeat resistance checks of the connections checked in step above and compare values. If any connection resistance has increased more than 20 percent, clean, apply no-ox grease, retorque the connections, and retest.

Fill out both "as found" and "as left" columns on form under

BATTERY BANK TAG N°		**CONNECTION RESISTANCE REPORT**			
Date:		**Location:**		**Battery Type**	
Note: Take the first reading between the connector (lug) and the cell post, then take readings between adjacent opposite polarity cell posts. Take the last reading between the last post and the connector lug					
Meter Probes between	**As Found Micro-ohms**	**As left Micro-Ohms**	**Meter Probes between**	**As Found Micro-ohms**	**As left Micro-Ohms**
Lug + & post 1			18-19		
Post cells 1.2			19-20		
Dito 2.3			20-21		
3-4			21-22		
4-5			22-23		
5-6			23-24		
6-7			24 & Lug-		
7-8			Lug+ & 25		
8-9			25-26		
9-10			26-27		
10-11			27-28		
11-12			28-29		
12 & Lug -			29-30		
Lug+ & 13			30-31		
13-14			31-32		
14-15			32-33		
15-16			33-34		
16-17			34-35		
17-18			35-36		
			36 & Lug-		

Table 14: Record Table (connection resistance) for the battery bank example above

Up to the “*verificator*” or his Supervisor to edit the proper table

C) Recommended Method for Taking Annual Micro-Ohmmeter Readings across Battery Connections.

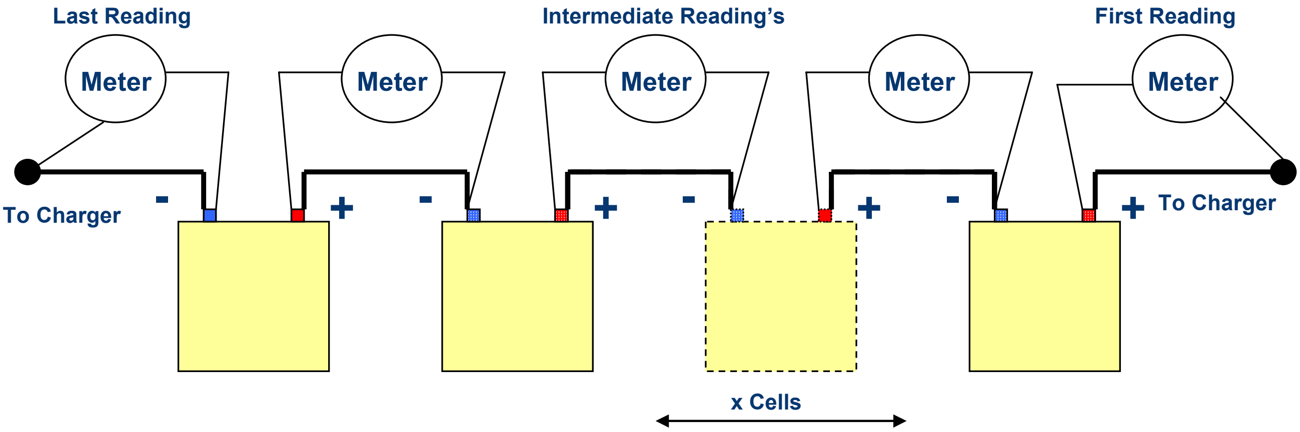


Figure 103:Placement of meter probes for connection resistance measurements.

Caution: Never place probes across a cell or cells (between positive and negative posts), with the meter set on ohms. The meter may be destroyed and arcing may occur at the battery.

1. Make sure the battery is on float charge before beginning the readings. Obtain an accurate digital micro-ohmmeter, and set it to the lowest scale.

2. On cell No. 1 take the first reading between the connector lug and the first post (see fig.). This reading will be the resistance between the post and connector lug 1and will be about one-half the middle readings. Record all readings on form

.

3. Take the second reading between *opposite* polarity posts (not connectors) of cells No. 1 and No. 2. Following readings will be between positive and negative posts of adjacent cells. These middle readings will include the resistance of two connections (one on each post) and the inter-cell lead (see fig.). These readings will be about double the first and last.

4. Take the remaining middle readings as in step 4, proceeding from cell to cell.

5. Take the last reading between the last post on the last cell and the connector lug as shown.

6. If high resistance is found, take readings from each post to its connector to determine which of the two connections is bad. Mark this and all high-resistance connections for later repair.

7. After readings are complete, disconnect the charger and loads from the battery.

Caution: *do not remove or make connections while current is flowing.* Clean problem connections, retorque to manufacturer's specifications, and apply no-ox grease. Retest the repaired connections and record the resistance in the "as-left" column on form

7.2.3. Measurement of each cell voltage

Voltage readings should be taken in accordance with the following instructions.

Note: Accurate voltmeters are critical for extending battery life. Provide a digital voltmeter accurate to 0.01 volt reserved only for station battery duty and calibrate it or send it out for calibration at least once a year. This voltmeter must be treated with extra care; do not use a shop meter or electrician's general-use meter for battery voltages.

A) Each Shift (Attended Stations) or During Routine Inspections (Unattended Stations)

Check the voltmeter on the control panel to determine if the battery is being charged at the proper voltage. Adjust the battery charging voltage if necessary.

B) Monthly

With the charger in service, check the overall float voltage across the battery terminals with an accurate digital meter and record on form (example under

Check the “designated pilot cell float voltage with an accurate digital voltmeter and record on form

F) 3 or 6 Month

Check the float voltage on all individual cells to the nearest 0.01 volt with an accurate digital voltmeter.

Take these readings as rapidly as possible and record them on form. At the end of the yearly cycle, use these readings to determine the pilot cells for the next year.

BATTERY BANK TAG N° **CELL VOLTAGE REPORT**

Date:

Location:

Battery Type

Note: all readings are to be taken with the battery stabilised on float. For wet cells, do not add water prior to take readings. Specific Gravity measurement is added on this report form for wet cells, as the measurement should be done in same time

Cell	**Volts**	**Sp Gr**	**Cell**	**Volts**	**Sp Gr**
1			19		
2			Pilot 20		
3			21		
4			22		
5			23		
Pilot 6			24		
7			25		
8			26		
9			27		
10			28		
11			29		
12			30		
13			31		
14			Pilot 32		
15			33		
16			34		
17			35		
18			36		

Table 15: Record Table (cell voltage) for the battery bank example above

7.2.4. Measurement of each cell internal resistance

Internal resistance is a good indication of the state of charge and substitutes for specific gravity readings taken on flooded, wet cells.

Measuring the internal resistance of a module monitors the two main failure modes-grid corrosion and dry out. The manufacturer's literature will list the normal expected values. This test should not be done until after the connection resistances of the cells are checked and repaired as in above paragraph. Elevated connection resistance will appear as internal resistance and make cells appear faulty. Internal resistance can be checked as follows:

1. While the battery is fully charged and operating on float (nearly no current) or disconnected, check and record voltage and for the cell being tested. (V_B)

2. Apply a normal load across the cell.

3. Again check and record the voltage and current. V_L & I_L

5. The internal resistance can then be calculated by dividing the change in voltage by the change in current.

$$\mathbf{V_L = V_B - I_L R_1}$$

Commercial test sets are available to measure internal resistance, which saves time and effort. Consider purchasing a test set if maintaining more than one VRLA battery.

Perform the internal resistance check on each cell as per the specific maintenance schedule and compare the results with the initial records (at installation). Changes in the internal resistance of 20 percent or greater should be considered significant. Contact the battery manufacturer

BATTERY BANK TAG N°	**CELL RESISTANCE REPORT**				
Date:		**Location:**		**Battery Type:**	
Note: all readings are to be taken with the battery stabilised on float. For wet cells, do not add water prior to take readings.					
Cell	**V_B**	**V_L**	**V_L**	**I_L**	**Ri = $(V_B-V_L) / I_L$**
1					
2					
3					
4					
5					
6					
7					
…					
…					
…					
…					
…					
29					
30					
31					
32					
33					
34					
35					
36					

Table 16: Record Table (cell resistance) for the battery bank example above

7.2.5. Discharge Tests

This is the “Battery Testing” to be done as per the specific maintenance schedule, generally once a year.

7.2.5.1. Upon Installation

Acceptance capacity testing should be performed within 1 week after the battery has reached equilibrium in charge and temperature. Operating temperature of the battery will greatly affect the available capacity, and manufacturer’s data must be consulted for correction factors. Maintain accurate records of tests, including all equipment used and test results. These records can be used as baseline for later comparisons

1. Conduct the test only after a connection resistance test has been performed as in above paragraph.

2. Install an accurate ammeter, voltmeter, and temperature meters, and provide an accurate stopwatch or other means to indicate elapsed time. Minimum test time should be at least 1 hour.

More time is recommended for critical applications and test accuracy, done generally at 0.2C or 0.4C.

3. Provide a variable load resistance so that constant current can be maintained equal to the rating of the battery for the selected test time.

Example: for a 100Ah, 48V battery, I want to make the test at 0.2C. It means 20 Amperes during 5 hours

Resistance needed is $R=U/I = 48 / 20 = 2.4$ ohms

Power of the resistance $P=RI^2 = 2.4 \times 20^2 = 2.4 \times 400 = 960$Watts (or 1kW)

4. Disconnect the charger, connect resistance and meters

5. Read and record individual cell/module voltages and the battery terminal voltage. The readings should be taken after applying the load at the beginning of the test. Repeat the readings at specified intervals and plan the test time long enough in advance to provide a minimum of five sets of readings.

Caution: Take individual cell voltage readings between respective terminals of like polarity (positive to positive) so the voltage drop of the inter-cell connectors will be included.

Record cells voltage values on a form like fro above paragraph.

6 If an individual cell/module is approaching reversal of its polarity (zero volts) or a module voltage is (consequently) lower than the others, but the overall terminal voltage has not reached its test limit, ***bypass*** the cell/module and continue the test. Perform the bypass connection away from the cell/module to avoid arcing. A new minimum voltage based on the remaining cells should be established for the remainder of the test. Consult the manufacturer and prepare to bypass cells in advance. The possibility of weak cells is high, especially as the battery ages.

7. Maintain the discharge rate until the battery terminal voltage decreases to a value equal to the manufacturer's specified minimum voltage per cell (usually 1.75 volts for Lead) times the number of cells.

8. Battery capacity can then be calculated by dividing the actual time to reach specified terminal voltage by the *rated* time to specified terminal voltage and multiplying by 100.

7.2.5.2. Every six months and/or annually

Perform a discharge capacity test with the same set-up and equipment as in step ‘A’ above.

Perform every six months, after the battery falls below 90 percent of its original design capacity on the annual test. Replace the battery as soon as possible after it falls below 80 percent of its original design capacity rating.

7.2.5.3. Continuity Tests

Continuity tests are performed on a non-routine basis, whenever the integrity of the battery is suspect. A VRLA cell typically fails open, and continuity through the cell is lost.

This condition is not readily apparent. A quick check is to turn off both chargers and see if the battery will accept the load of the connected equipment. Another method is to place a test load across the battery and see if it will accept load. If cells/modules are connected in parallel, the load must be placed across individual cells/modules to detect an open circuit. Contact the manufacturer if further information is needed.

7.2.6. Temperature Readings

All cells of a battery should be at the same ambient temperature. Heat sources such as sunlight, portable heaters, etc. must be blocked so they do not raise the temperature of individual cells.

Record the room ambient temperature before cell temperatures are taken.

Note: An accurate infrared (IR) camera may be used for temperatures; however, the camera calibration must be checked at least once each year. If possible, take the annual temperature readings of the cells just after camera calibration. If the temperature spread of the cells exceeds 3 °C (i.e., upper rows are warmer) the room or cubicle ventilation may be inadequate.

A. Monthly

Record the pilot cell temperatures on prepared form

B. Quarterly

Record temperature readings of 10 percent of all the cells; rotate the subject cells each quarter.

C. Annually

If an accurate IR camera is available, take the temperature of the battery connections during a load or discharge test, i.e., while current is flowing. If one or more of the connections are loose or dirty, their temperatures will be higher than the other connections.

7.2.7. Replacement of a cell

If you have one cell faulty in the middle of xx cells in series already in service for months/years; it is far more advisable to just by-pass (and remove) this cell. A set of cells should have the same “age” in a bank.

Once you have removed cells, adjustment of the different voltage (Charge rapid, accelerated, floating,…) have to be adjusted accordingly, not forgetting, once again, that is the maintaining current which is important and to be kept at 0.01C with charged lead, Ni-Cad, Ni-Mh batteries.

Once several cells become faulty, problem is more serious, replacement of all bank cells could be overseen.

7.2.8. Routine Operation Checks

In résumé for all types of our “industrial” batteries.

Daily check:

- Check the “**floating current” or “maintaining current”** which is 0.01C for Lead or Ni-Cad batteries.

- And if the unit is only equipped with a voltmeter showing the ***"Floating Voltage",*** ask for a modification…

Weekly Checks:

- Check all alarm and status indicators.
- Check meter readings are normal.
- Check the cause of any significant changes. For example, change in load, recent discharge
- Record all abnormal occurrences in the service log

Monthly Checks:

- Check ventilation apertures are clean and clear of obstructions.
- Check ambient temperature
- Check for availability of all safety equipment's (battery room) such as neutralising solution, eye-wash facility, fire extinguisher (tested !), insulated tools. See Safety Chapter on that subject.

Trimestrial Checks:

- Check ventilation grilles
- Visual check of electrical connections and component for signs of overheating or corrosion. *Rectify as necessary.*
- Check painted and plated components for signs of damage or corrosion. *Rectify as necessary*

Yearly Checks:

- Carry out a test discharge of the battery for the specified autonomy.

Note: The test should be carried out at a time of low risk and followed immediately by a full recharge. Consult the battery manufacturer's instructions for guidance on frequency of testing, depth of discharge etc.

Extra Checks:

- Fans are rated for a 5 year life. It is recommended that fan failures be pre-empted by renewing them after four years. It concerns Fans in UPS / Battery Charger in cubicles and Extractor Fan of Battery Rooms.

7.3. SPECIFIC BATTERY MAINTENANCE

7.3.1. Lead-Acid vented and aqueous

7.3.1.1. Flooded, Wet Cell Lead Acid Battery – Maintenance Schedule

Maintenance	New Battery	Daily / Shift	Monthly	3 Month	Annual	5 Year
Visual inspection. (6.2.1 & 6.2.8)			As per 6.2.1.above			
Battery Floating conditions		Panel meters	+ Digital meter		Compare Panel meter with digital one	
Cells Floating Conditions. (6.2.3.)	All Cells with digital meter		Pilot cell with digital meter	All Cells with digital meter		
Specific Gravity Readings (under)	All Cells		Pilot Cells	10% of all Cells	All Cells	
Temperature Readings			Pilot Cells	10% of all Cells		
Connections Resistance. (6.2.2.)	All Connections				All Connections	
Battery Testing (6.2.5.)	Acceptance Capacity testing				Annual If 5 Year < 90%	Capacity Discharge Test
Safety Equipment. (Chapter 7)			All safety equipment in room			

Table 17: Maintenance schedule flooded, wet cell lead acid batteries

Refer to the previous chapter ‘Common Maintenance’ for details
Once a month check electrolyte level and top up above the plates with “pure” (or distilled) water.

7.3.1.2. Appearance of normal cell

Edges of positive plates do not give much information. Edges of negative plates should be uniformly grey; they should be examines with a non-metallic flashlight for sparkling from lead sulfate crystals. Correct float charging will cause no lead lead sulfate crystals.

7.3.1.3. Specific Gravity test (every 6 months

Specific gravity readings of vented lead-acid batteries must be taken in accordance with the following instructions. *Note:* All specific gravity readings must be corrected to 25°C before recording (see *).

Do not attempt to take any specific gravity reading after adding water to a cell. The electrolyte takes several hours to mix after water is added.

** Specific gravity of electrolyte must be corrected for temperature. Subtract one point (0.001) from the specific gravity reading for each 3 °F (1.66°C) the temperature is below 77 °F (25°C), and add one point (0.001) for each 3 °F the temperature is above 77 °F (25°C). The recommended specific gravity spread between all cells is 0.010.*

A. Monthly

Take the specific gravity reading of the pilot cell and record it on a form.

B. Quarterly

"Take specific gravity readings of 10 percent of the total number of cells and record them on a form. Rotate these cells so that readings are taken on different cells each quarter.

C. Annually

Take specific gravity readings of every cell and record them on a form.

D. After Equalizing Charge

About 15 minutes after heavy gassing stops, take the specific gravity readings of every cell and record them on a form. If two cells with the lowest specific gravity (checked over the last one-eighth of the charging period) have not stopped rising, continue the equalizing charge.

Method for tagging the Specific Gravity:

(See paragraphs 2.7.2. and 2.7.3.)

The specific gravity of the battery electrolyte (SG) measurement requires the use of a temperature compensating hydrometer.

You must first have the battery fully charged. The charge must be disconnected before testing and the battery must have been sitting for at least several hours, then you may begin testing.

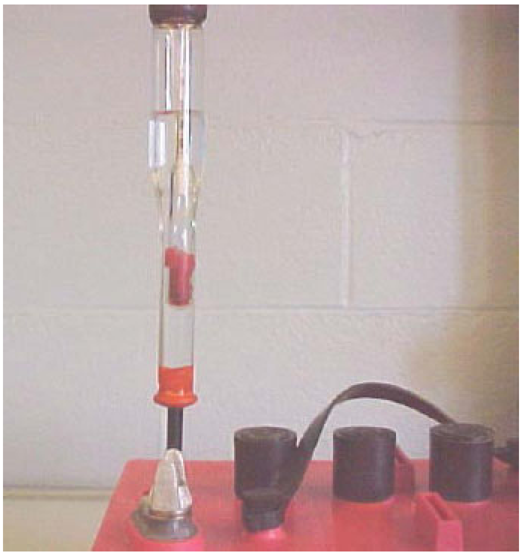


Figure 104: Hydrometer

A fully charged Lead-Sulphuric Acid battery has SG of 1.255 to 1.280. Fully discharged batteries have a SG between 1.110 and 1.130.

Hydrometer SG readings should not vary by more than 0.01 to 0.05 (as per manufacture data's) between cells. Note that the SG of sealed Lead Acid Battery cannot be measured unless the battery has a built in hydrometer.

Most well designed maintenance free batteries have a built in hydrometer that measures the SG of cell 1 of 6. However, it is possible to get a good reading from cell 1 and have a problem with other cells in the battery.

The sulfation of battery grids starts when the specific gravity falls below 1.225 or the voltage measures less than 12.4 (12v Battery) or 6.2 (6 volt battery). Sulfation hardens the surface of the battery plates reducing and eventually the battery's ability to discharge and be recharged.

7.3.2. Lead-Acid sealed VRLA / AGM / GEL

7.3.2.1. General

Valve regulated lead-acid batteries (VRLA) are usually manufactured in multi-cell blocks, (called modules) rather than single cells. The cases are often made of ABS plastic material and ***do not permit visual inspection of plates or electrolyte*** levels.

They are called starved electrolyte or absorbed electrolyte cells and operate under a positive pressure. The hydrogen and oxygen are not expelled but recombined.

Cells are sealed and require no water addition or specific gravity readings. These cells are typically lead calcium pasted-plate type cells with the electrolyte retained in gel or fiberglass mats.

These batteries are normally used for emergency lighting, telecommunications, and other uninterrupted power supply (UPS) service. They are best applied where long slow discharges are needed. Heavy short discharges required for breaker operations are not recommended for this type battery.

The life has been found to be only 18 months to 10 years in actual service.

These cells are not *flooded* and ***do not effectively dissipate heat***. This characteristic can lead to thermal runaway if ambient and battery temperatures are not carefully controlled.

Cases have occurred in which the battery has burst into flame.

Maintaining the cells as close as possible to 25 °C is imperative.

Ambient temperature should be maintained as close as possible to 22°C. Air circulation must be sufficient to eliminate any ambient temperature differences. The maximum cell temperature spread (hottest to coldest cell) should not exceed 3 °C, and the hottest cell should not be more than 3°C above ambient.

Colder temperatures reduce capacity, and higher temperatures greatly reduce service lie. About 50 percent of the service life will be lost for every 10 °C above 25°C

Do not allow sunlight or other heat sources to raise the temperature of individual cells. These cells are not recommended for station service because of these characteristics. VRLA modules/cells are typically shipped fully charged and do not require initial charge.

And do not be surprised if you have problems on site with this type of battery with a non adapted maintenance

7.3.2.2. Valve Regulated Lead Acid Battery / Gel – Maintenance Schedule

Maintenance	New Battery	Daily / Shift	Monthly	3 Month	6 Month	Annual
Visual inspection. (6.2.1 & 6.2.8)			General Inspection			
Battery Floating conditions		Panel meters	+ Digital meter			
Cells Floating Conditions (6.2.3.)	All Cells with digital meter		Pilot cell with digital meter		All Cells with digital meter	
Temperature Reading	All Cells			All Cells		
Connection Resistance. (6.2.2.)	All Cells			All Cells		
Internal Resistance. (6.2.4.)	All Cells			All Cells		
Battery Testing	Acceptance Capacity testing				Capacity (Discharge) Test. 6 month if 1 year< 90%	
Safety Equipment. (Chapter 7)			All safety equipment in room			

Table 18: Maintenance Schedule valve regulated lead acid battery

7.3.3. Nickel-Cadmium vented aqueous (Acid or Potassium)

7.3.3.1. Vented Nickel-Cadmium Battery – Maintenance Schedule

Maintenance	New Battery	Daily / Shift	Monthly	3 Month	6 Month	Annual
Visual inspection.			Electrolyte Level			
Battery Floating conditions		Panel meters	+ Digital meter	Battery Volt & Amp.	All Cells digital meter	
Cells Floating Conditions	All Cells with digital meter			Pilot cell with digital meter		
Specific Gravity Readings (under)*	All Cells		Pilot Cells	10% of all Cells	All Cells	
Temperature Reading				Pilot Cells		
Inter cell Connection.	Torque to spec's all Cells					Re-torque all Cells
Battery Testing	Acceptance Capacity testing after 1 week				Capacity (Discharge) Test. 1 year if 5 year< 90%	
Safety Equipment.			All safety equipment in room			

* **Electrolyte Level:** At lest once a month check electrolyte level and top it.

Table 19: Maintenance schedule vented Nickel-Cadmium batteries

Cells lose water through natural evaporation and when gassing on equalizing charge.

Always keep the plates covered with electrolyte.

Serious damage will occur if the plate tops are exposed to air.

7.3.3.2. Electrolyte of Vented Nickel-Cadmium Battery

The electrolyte solution in nickel-cadmium batteries consists of purified caustic potash (KOH potassium hydroxide) and other salts in distilled water. Liquid electrolyte should be stored in a clean, glass, or porcelain container. The electrolyte will readily absorb carbon dioxide from air to form potassium carbonate. This process will temporarily lower battery capacity. Electrolyte must therefore be stored in airtight containers.

The specific gravity of electrolyte does not change with state of charge but remains almost constant on charge and discharge. The average specific gravity of a normal cell will be about 1.190 at 22 °C; however, in servicing a battery, always refer to the manufacturer's recommended specific gravity range. The specific gravity range for ni-cad cells has limits. Below 1.200, the resistivity begins to increase rapidly, making cells sluggish, and the lowest electrolyte density is usually set at 1.170.

High concentrations are damaging because of the increased solubility of the electrodes, especially at higher temperatures. Concentrations much higher than 1.1.70 also result in increased resistivity. The proper density of the electrolyte is a compromise held within narrow limits.

The freezing point of electrolyte with a specific gravity of 1.190 is about -10 °F, at which the solution forms a slush but will not freeze solid. If the battery will encounter temperatures colder than -10 °F, specific gravity is usually raised to 1.230 for protection to -40 °F. Always consult the manufacturer before attempting to change the specific gravity of electrolyte.

7.3.3.3. Electrolyte Level

Monthly

Check the electrolyte level in every cell during the visual inspection. The level can be observed by looking closely at the cell. Cell cases are typically (normally…) translucent, and the electrolyte level can be seen through the cell case.

When electrolyte level is low, add distilled water to the proper height but do not overfill. If cells are overfilled, the electrolyte may be forced out of vents on charge. This condition can cause electrolysis between the cells, corrosion of the cell containers, and grounds in the electrical circuit. The maximum level of the electrolyte is ***halfway*** between the tops of the plates and the inside of the cell covers.

To retard natural evaporation, pure mineral oil should be floated on the electrolyte in each cell. All cells should be checked annually for adequate oil depth, (about 0.6 mm). See manufacturer's instructions for the recommended oil type and depth.

7.3.3.4. Specific Gravity Readings

Specific gravity readings are only needed every 5 years to determine if the electrolyte needs to be replaced.

When taking a hydrometer reading, squeeze the bulb before inserting, insert the nozzle to the top of the plates, then release the bulb. This procedure will avoid introducing air bubbles and prevent floating oil from being drawn into the barrel. ***The sample should always be returned to the cell from which it was taken***. Wash out the hydrometer thoroughly with distilled water. Electrolyte remaining in the hydrometer absorbs carbon dioxide from the air, forms a coating, and causes false readings.

Specific gravity changes with temperature, and if the electrolyte temperature is different from 25 °C, add 0.001 to the reading for every 2 °C above 25 °C. Subtract 0.001 for every 2 °C below 25 C.

Do not take specific gravity readings when gas bubbles are visible in the electrolyte. False readings will result unless the bubbles are allowed to dissipate. Specific gravity readings cannot be taken on cells just after adding water; the readings should be delayed until mixing has occurred.

Do not try to maintain a single supply of distilled water for serving both Ni-Cad and lead-acid batteries. Water will become contaminated with traces of sulfuric acid from the filler bulb by the transfer between lead-acid cells and the water container.
A separate supply of distilled or approved mineral water, used only for nickel-cadmium batteries, is necessary. Provide a separate hydrometer that is used exclusively for testing nickel-cadmium cells.

7.3.3.5. Electrolyte Renewal

This is the particularity of wet Ni-Cad battery. Each Cell can be drained of its electrolyte and a new one, of same type, same concentration can be refilled. And back to a new (or almost new) battery.

Specific procedure, available in all manufacturers maintenance booklet is to be followed for that purpose.

7.3.4. Nickel-Cadmium sealed VRLA / GEL

Consider the same general and specific maintenance as for the Lead-Acid VLRA / Gel battery as the electrolyte is not accessible.

However the battery is not suitable for fast charging.

7.4. TROUBLESHOOTING BATTERIES

7.4.1. Common Problems

The following problems, most of which can be controlled by the user, are the most common causes of premature system failure,

Post seal leakage.

A leaky post seal allows electrolyte to migrate up to the post/inter-cell connection area and cause a connection problem.

Loose inter-cell connections.

Improperly tightened inter-cell hardware means very high resistance connections.

Low float voltage.

This causes sulphate crystals to form on the plate surfaces. Sulphate crystals that harden over a long period of time go back in solution when proper voltage is applied and therefore cause permanent loss of capacity. This problem shows up as an increase in cell resistance.

High float voltage.

This causes excessive gassing of hydrogen and oxygen, and this leads to loss of water in the flooded cells, causing dry out and potential thermal runaway in VRLA cells. High float voltage also causes shedding of active material from the positive plates. All of these problems increase the internal resistance of the cell.

Low temperature.

Battery capacity is diminished at low temperatures. (At 17°C, capacity is approximately 90%). At low temperatures, a higher float voltage is required to maintain full charge. If the charger is not adjusted properly, cells may be undercharged, leading to the problems described under low voltage.

High temperature.

This causes loss of **battery life**. (Life is cut in half if operated at greater than 92^0 F). High temperature also increases float current, which results in loss of water in flooded cells, and dry out and thermal runaway in VRLA cells. These problems lead to increase of cell resistance.

Discharge without recharge.

A fully discharged or nearly fully discharged cell will be damaged and possibly ruined if not recharged within 24 to 48 hours.

Over discharge.

This causes abnormal expansion of plates, which can lead to permanent damage and recharge problems. This can happen in lightly loaded UPS systems that experience an extended power outage.

Electrochemical resistance increase.

An increase due to the problems in the paste and electrolyte. This failure causes the cell to run out of “fuel” and become incapable of delivering rated capacity.

Metallic resistance increase.

The more serious and dangerous of the two resistance problems. A high metallic resistance means a problem in the conduction path, which leads to a catastrophic failure, such as an explosion or a total loss of the current carrying path. The metallic resistance problems can lead to abrupt failures, causing potential harm to equipment and personnel, not to mention loss of power

7.4.2. Lead Acid Vented Battery Problems

A. Lack of Gassing

Lack of gassing while on charge may indicate an internal short between plates, i.e., the cell discharges internally as fast as it is being charged.

B. Specific Gravity or Voltage

Specific gravity or voltage of a cell lower than other cells is an indication of excessive internal losses and may result from consistent undercharging.

C. Color

Color or appearance of plates or sediment different from other cells is addressed below:

1. Patches of white lead sulfate on either the positive or negative plates: caused by standing idle or undercharging for extended periods.

2. Antimony deposit dark-slate patches on negative plates (usually near the terminal) : caused by charging at too high a rate or an aged cell nearing the end of its service life.

3. Top layer of sediment white: caused by undercharging.

4. Lumpy brown sediment: caused by overcharging.

5. All white sediment no visible layers: caused by overcharging after prolonged low float voltage.

6. Large flaking on the inter-plate collector bar: caused by being on float charge for extended periods at insufficient float voltage without equalizing charging being performed.

D. Plate Problems

If any checks below are excessive, capacity tests must be run to determine if individual cells or the entire battery should be replaced.

1. Cracks on the edges of the positive plate grids.

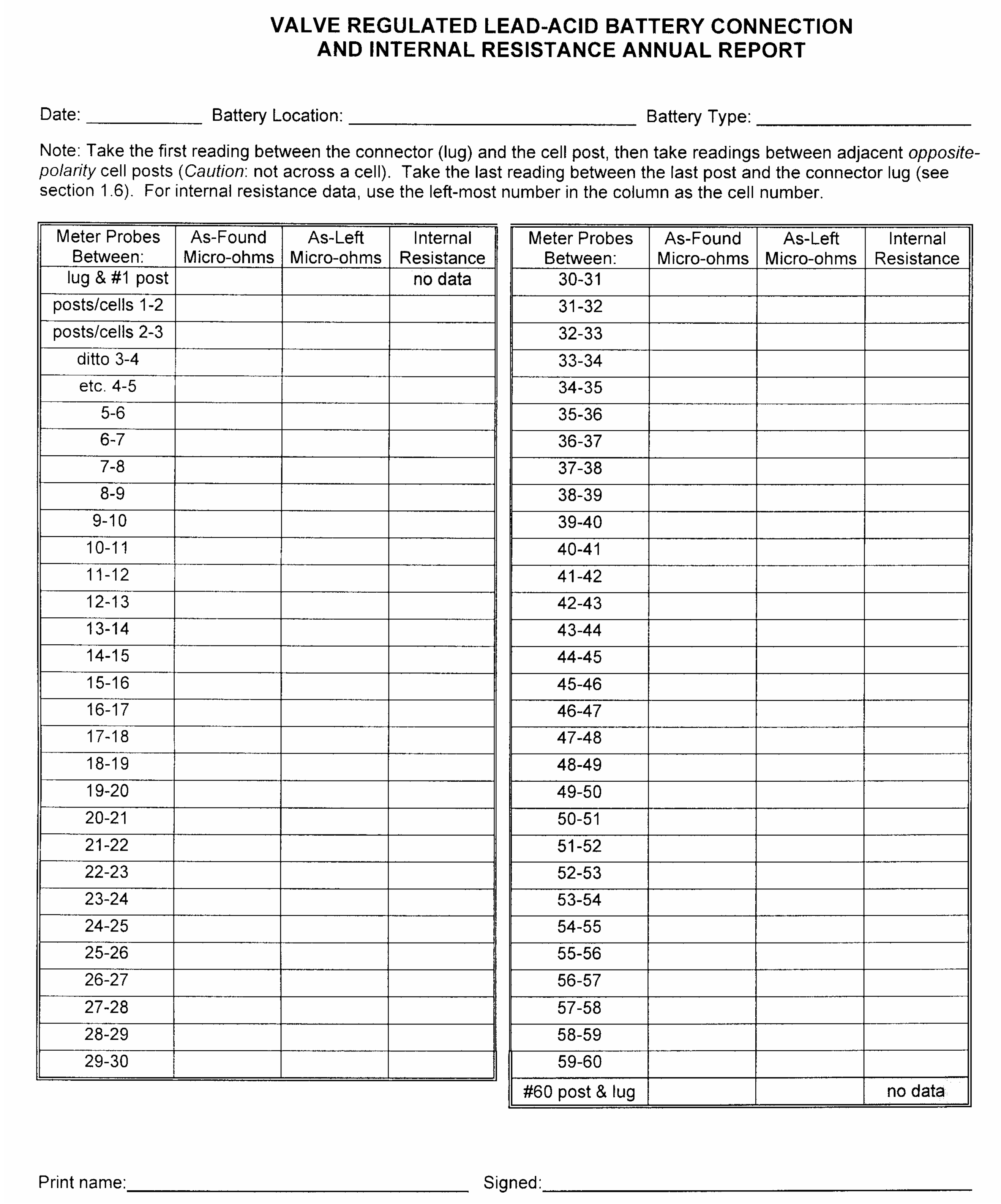
2. Light-colored sulfating spots on edges of plates below cracks mentioned in check No.1 above.

3. Excessive sediment in the bottom of the case.

4. Mossing” or “treeing” on the tops of negative plates.

7.5. MAINTENANCE FORMS

Hereafter, 5 forms as example for “your” Batteries surveys



VALVE REGULATED LEAD-ACID BATTERY CONNECTION AND INTERNAL RESISTANCE ANNUAL REPORT

Date: ____________ Battery Location: ______________________________ Battery Type: ______________________

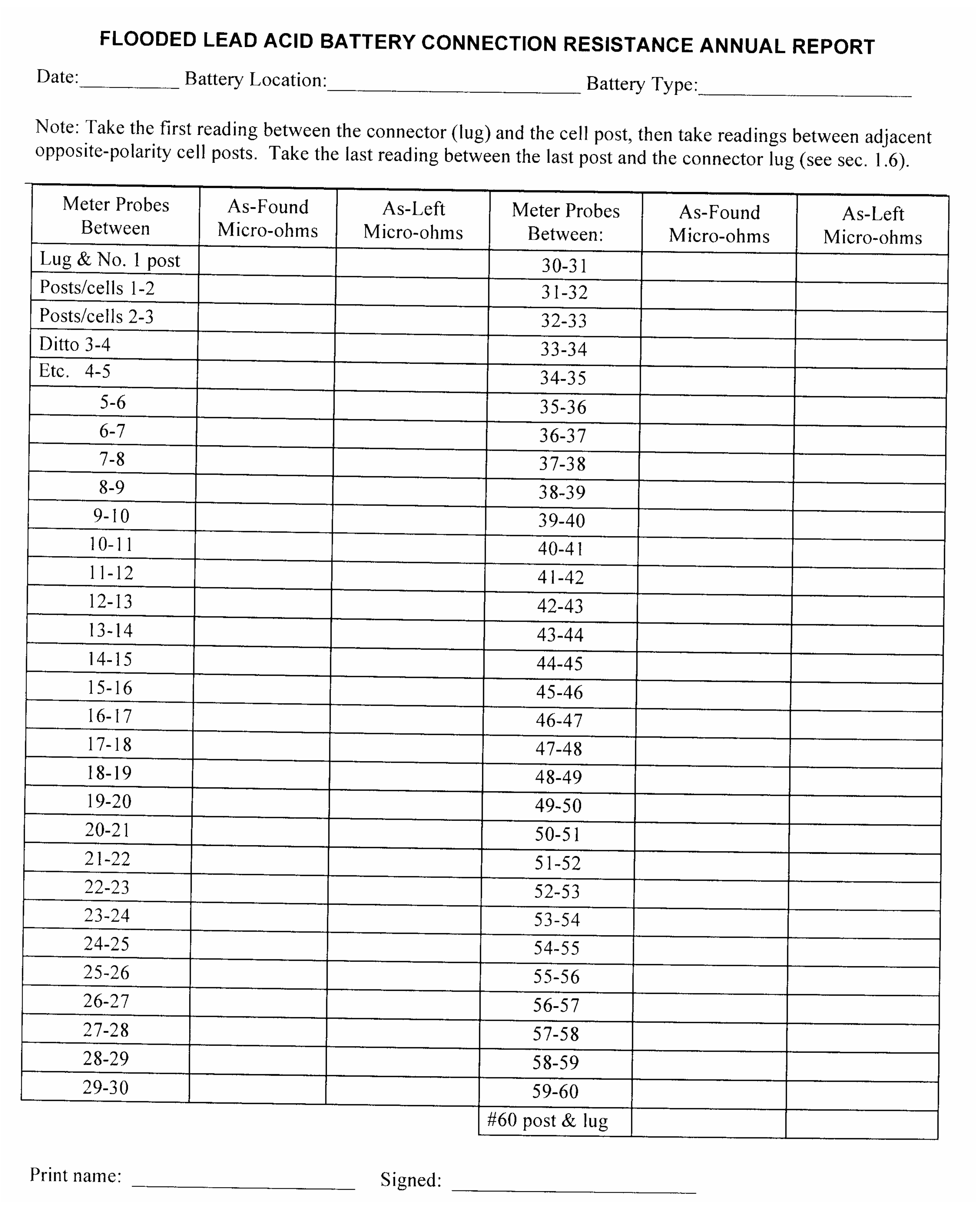
Note: Take the first reading between the connector (lug) and the cell post, then take readings between adjacent *opposite-polarity* cell posts (*Caution*: not across a cell). Take the last reading between the last post and the connector lug (see section 1.6). For internal resistance data, use the left-most number in the column as the cell number.

Meter Probes Between:	As-Found Micro-ohms	As-Left Micro-ohms	Internal Resistance
lug & #1 post			no data
posts/cells 1-2			
posts/cells 2-3			
ditto 3-4			
etc. 4-5			
5-6			
6-7			
7-8			
8-9			
9-10			
10-11			
11-12			
12-13			
13-14			
14-15			
15-16			
16-17			
17-18			
18-19			
19-20			
20-21			
21-22			
22-23			
23-24			
24-25			
25-26			
26-27			
27-28			
28-29			
29-30			

Meter Probes Between:	As-Found Micro-ohms	As-Left Micro-ohms	Internal Resistance
30-31			
31-32			
32-33			
33-34			
34-35			
35-36			
36-37			
37-38			
38-39			
39-40			
40-41			
41-42			
42-43			
43-44			
44-45			
45-46			
46-47			
47-48			
48-49			
49-50			
50-51			
51-52			
52-53			
53-54			
54-55			
55-56			
56-57			
57-58			
58-59			
59-60			
#60 post & lug			no data

Print name:__________________________________ Signed:____

Figure 105: Example of battery survey form (1)



FLOODED LEAD ACID BATTERY CONNECTION RESISTANCE ANNUAL REPORT

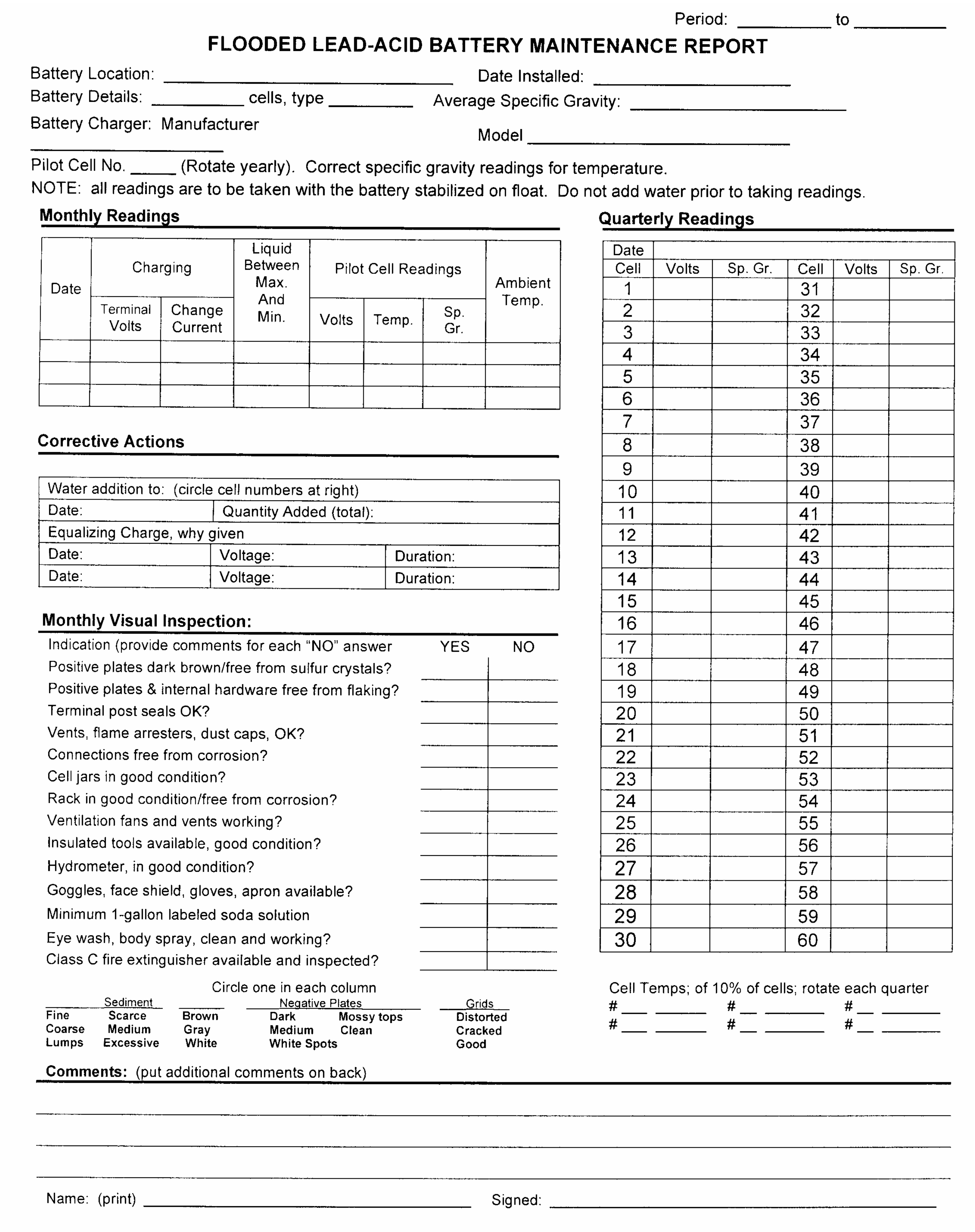
Date:__________ Battery Location:_________________________ Battery Type:_____________________

Note: Take the first reading between the connector (lug) and the cell post, then take readings between adjacent opposite-polarity cell posts. Take the last reading between the last post and the connector lug (see sec. 1.6).

Meter Probes Between	As-Found Micro-ohms	As-Left Micro-ohms	Meter Probes Between:	As-Found Micro-ohms	As-Left Micro-ohms
Lug & No. 1 post			30-31		
Posts/cells 1-2			31-32		
Posts/cells 2-3			32-33		
Ditto 3-4			33-34		
Etc. 4-5			34-35		
5-6			35-36		
6-7			36-37		
7-8			37-38		
8-9			38-39		
9-10			39-40		
10-11			40-41		
11-12			41-42		
12-13			42-43		
13-14			43-44		
14-15			44-45		
15-16			45-46		
16-17			46-47		
17-18			47-48		
18-19			48-49		
19-20			49-50		
20-21			50-51		
21-22			51-52		
22-23			52-53		
23-24			53-54		
24-25			54-55		
25-26			55-56		
26-27			56-57		
27-28			57-58		
28-29			58-59		
29-30			59-60		
			#60 post & lug		

Print name: ______________________ Signed: ________________________

Figure 106: Example of battery survey form (2)



Period: __________ to __________

FLOODED LEAD-ACID BATTERY MAINTENANCE REPORT

Battery Location: ________________________________ Date Installed: ______________________

Battery Details: __________ cells, type _________ Average Specific Gravity: ________________________

Battery Charger: Manufacturer ____________________ Model _____________________________

Pilot Cell No. _____ (Rotate yearly). Correct specific gravity readings for temperature.

NOTE: all readings are to be taken with the battery stabilized on float. Do not add water prior to taking readings.

Monthly Readings

Date	Charging		Liquid Between Max. And Min.	Pilot Cell Readings			Ambient Temp.
	Terminal Volts	Change Current		Volts	Temp.	Sp. Gr.	

Corrective Actions

Water addition to: (circle cell numbers at right)

Date: Quantity Added (total):

Equalizing Charge, why given

Date: Voltage: Duration:

Date: Voltage: Duration:

Monthly Visual Inspection:

Indication (provide comments for each "NO" answer	YES	NO
Positive plates dark brown/free from sulfur crystals?		
Positive plates & internal hardware free from flaking?		
Terminal post seals OK?		
Vents, flame arresters, dust caps, OK?		
Connections free from corrosion?		
Cell jars in good condition?		
Rack in good condition/free from corrosion?		
Ventilation fans and vents working?		
Insulated tools available, good condition?		
Hydrometer, in good condition?		
Goggles, face shield, gloves, apron available?		
Minimum 1-gallon labeled soda solution		
Eye wash, body spray, clean and working?		
Class C fire extinguisher available and inspected?		

Circle one in each column

	Sediment		Negative Plates		Grids
Fine	Scarce	Brown	Dark	Mossy tops	Distorted
Coarse	Medium	Gray	Medium	Clean	Cracked
Lumps	Excessive	White	White Spots		Good

Quarterly Readings

Date					
Cell	Volts	Sp. Gr.	Cell	Volts	Sp. Gr.
1			31		
2			32		
3			33		
4			34		
5			35		
6			36		
7			37		
8			38		
9			39		
10			40		
11			41		
12			42		
13			43		
14			44		
15			45		
16			46		
17			47		
18			48		
19			49		
20			50		
21			51		
22			52		
23			53		
24			54		
25			55		
26			56		
27			57		
28			58		
29			59		
30			60		

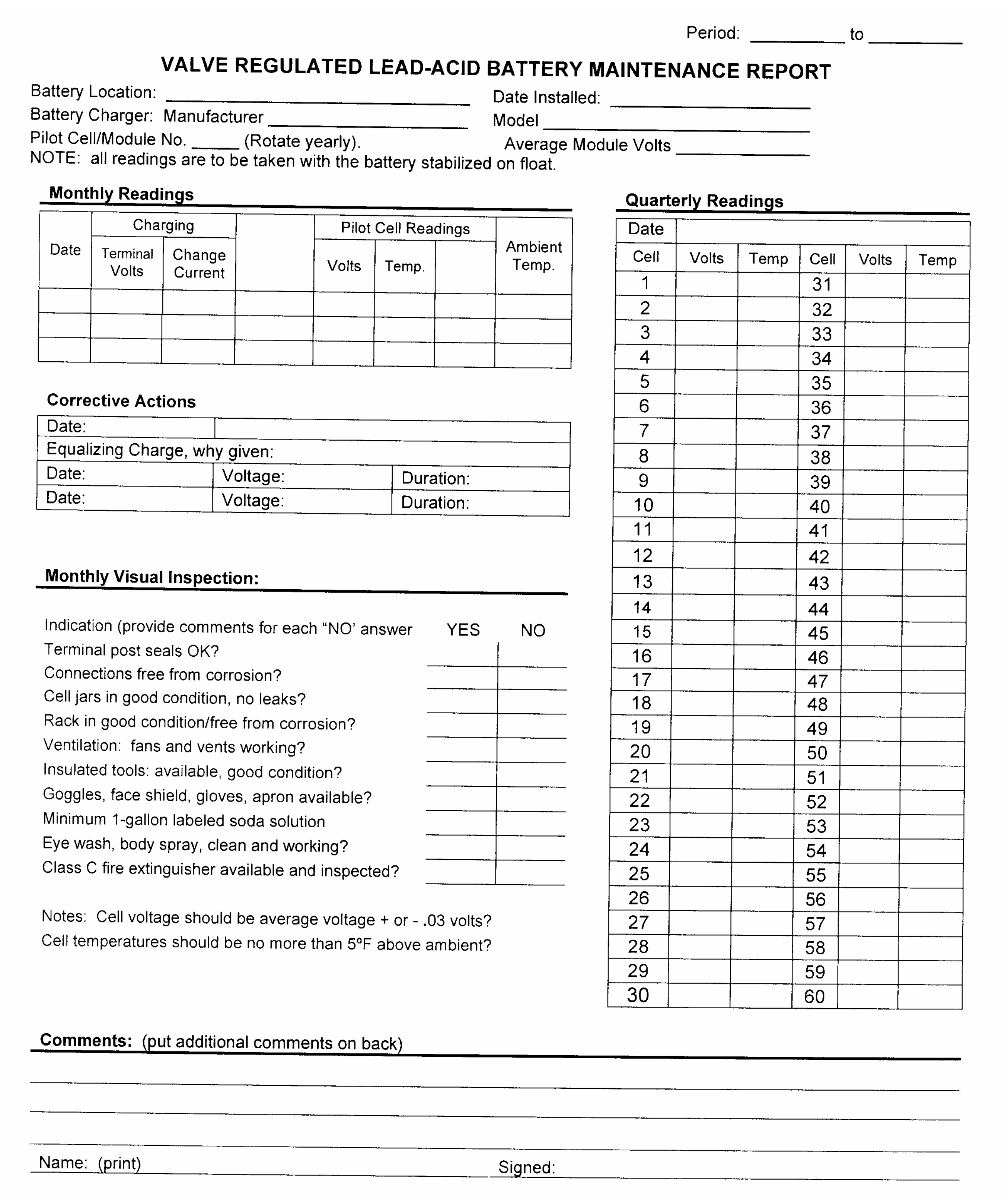
Cell Temps; of 10% of cells; rotate each quarter

___ ______ # __ _______ # __ _______
___ ______ # __ _______ # __ _______

Comments: (put additional comments on back)

Name: (print) ______________________________ Signed: ___________________________________

Figure 107: Example of battery survey form (3)



Period: __________ to __________

VALVE REGULATED LEAD-ACID BATTERY MAINTENANCE REPORT

Battery Location: ______________________________ Date Installed: ____________________

Battery Charger: Manufacturer __________________ Model ______________________________

Pilot Cell/Module No. _____ (Rotate yearly). Average Module Volts ______________

NOTE: all readings are to be taken with the battery stabilized on float.

Monthly Readings

Date	Charging			Pilot Cell Readings			Ambient Temp.
	Terminal Volts	Change Current		Volts	Temp.		

Corrective Actions

Date:		
Equalizing Charge, why given:		
Date:	Voltage:	Duration:
Date:	Voltage:	Duration:

Monthly Visual Inspection:

Indication (provide comments for each "NO' answer	YES	NO
Terminal post seals OK?		
Connections free from corrosion?		
Cell jars in good condition, no leaks?		
Rack in good condition/free from corrosion?		
Ventilation: fans and vents working?		
Insulated tools: available, good condition?		
Goggles, face shield, gloves, apron available?		
Minimum 1-gallon labeled soda solution		
Eye wash, body spray, clean and working?		
Class C fire extinguisher available and inspected?		

Notes: Cell voltage should be average voltage + or - .03 volts?
Cell temperatures should be no more than 5°F above ambient?

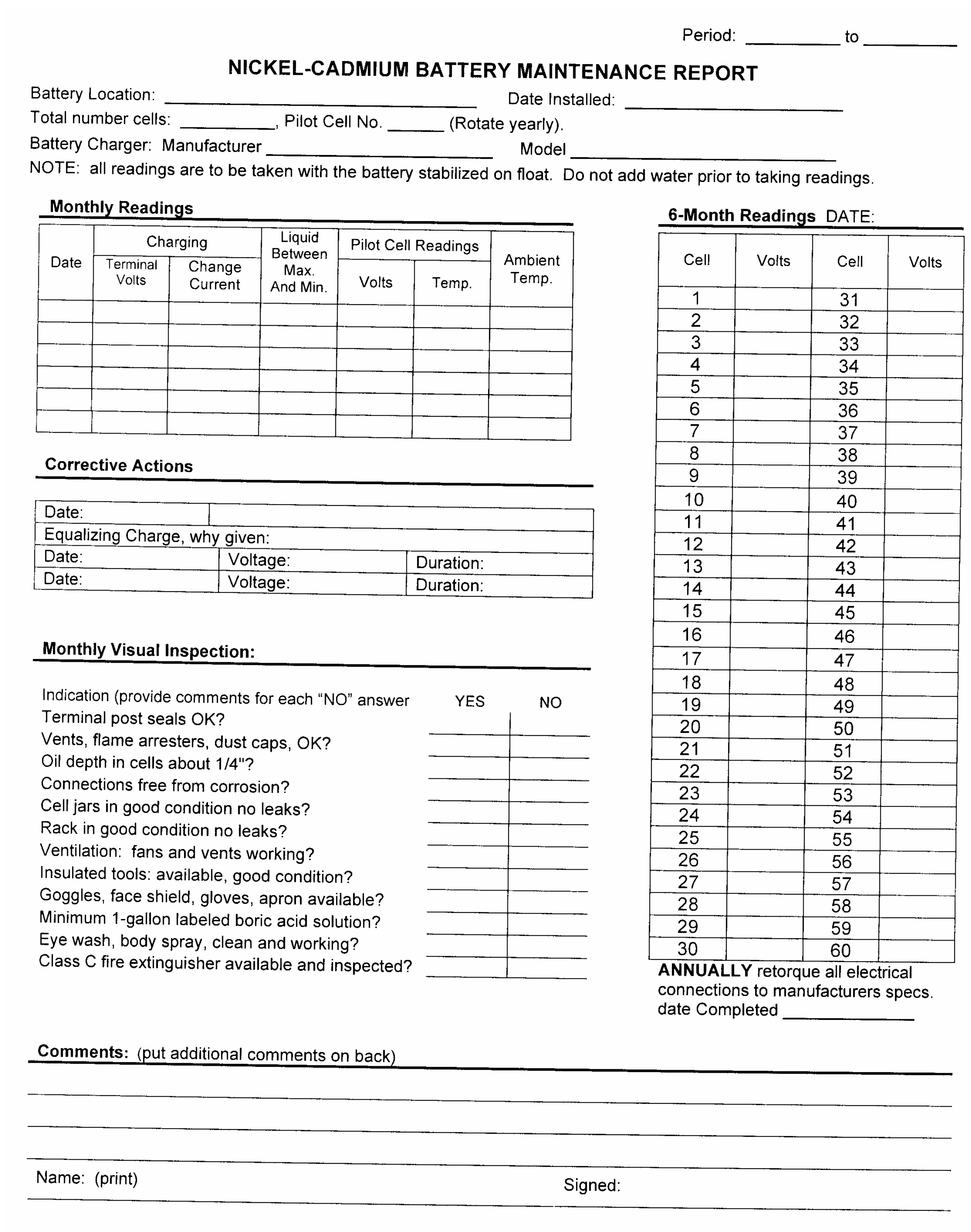
Quarterly Readings

Date					
Cell	Volts	Temp	Cell	Volts	Temp
1			31		
2			32		
3			33		
4			34		
5			35		
6			36		
7			37		
8			38		
9			39		
10			40		
11			41		
12			42		
13			43		
14			44		
15			45		
16			46		
17			47		
18			48		
19			49		
20			50		
21			51		
22			52		
23			53		
24			54		
25			55		
26			56		
27			57		
28			58		
29			59		
30			60		

Comments: (put additional comments on back)

Name: (print) ______________________________ Signed: ______________________________

Figure 108: Example of battery survey form (4)



Period: __________ to __________

NICKEL-CADMIUM BATTERY MAINTENANCE REPORT

Battery Location: ______________________________ Date Installed: ______________________

Total number cells: __________, Pilot Cell No. ______ (Rotate yearly).

Battery Charger: Manufacturer ______________________ Model __________________________

NOTE: all readings are to be taken with the battery stabilized on float. Do not add water prior to taking readings.

Monthly Readings

Date	Charging		Liquid Between Max. And Min.	Pilot Cell Readings		Ambient Temp.
	Terminal Volts	Change Current		Volts	Temp.	

6-Month Readings DATE:

Cell	Volts	Cell	Volts
1		31	
2		32	
3		33	
4		34	
5		35	
6		36	
7		37	
8		38	
9		39	
10		40	
11		41	
12		42	
13		43	
14		44	
15		45	
16		46	
17		47	
18		48	
19		49	
20		50	
21		51	
22		52	
23		53	
24		54	
25		55	
26		56	
27		57	
28		58	
29		59	
30		60	

ANNUALLY retorque all electrical connections to manufacturers specs.
date Completed ____________

Corrective Actions

Date:		
Equalizing Charge, why given:		
Date:	Voltage:	Duration:
Date:	Voltage:	Duration:

Monthly Visual Inspection:

Indication (provide comments for each "NO" answer	YES	NO
Terminal post seals OK?		
Vents, flame arresters, dust caps, OK?		
Oil depth in cells about 1/4"?		
Connections free from corrosion?		
Cell jars in good condition no leaks?		
Rack in good condition no leaks?		
Ventilation: fans and vents working?		
Insulated tools: available, good condition?		
Goggles, face shield, gloves, apron available?		
Minimum 1-gallon labeled boric acid solution?		
Eye wash, body spray, clean and working?		
Class C fire extinguisher available and inspected?		

Comments: (put additional comments on back)

Name: (print) Signed:

Figure 109: Example of battery survey form (5)

8. BATTERY CELL MANAGEMENT

As we saw in operator course, EQ-160, how to maintain and operate the different types of batteries installed on production sites, maintenance teams thoroughly perform (we are sure of that…) the tasks scheduled in the preventive/routine maintenance programs. Nevertheless incidents and accidents do occur on the battery banks, especially with sealed type batteries.

In chapter 6 of EQ-160, we introduced the notion of BMS for Battery Management System. What about a complete automatic system managing each individual component (each cell) of a battery bank?

It does exist, but not on our sites (I never seen it up to now). But computer monitoring of all the cells in all of the batteries on the site is a relatively simple and relatively low-cost operation. It can be installed either at the time of construction or subsequently on an existing installation.

Below is a report from a U.S. plant where such a monitoring system was installed on a rack of 58 elements. In my opinion it is very convincing, it is worth considering installing “that” on our plants, to save a lot of trouble, misinterpretations and “bad” operations (by maintenance teams…).

Here is this report

8.1. DECISION FOR INSTALLATION OF MANAGEMENT SYSTEM

Regardless of the type of battery, it must be maintained to function properly.

We typically maintain our batteries on a weekly, monthly, and yearly schedule.

- On a weekly cycle, the battery is inspected, several cell voltages are read, and the respective specific gravities are checked.
- On a monthly basis, all the cell voltages are read and all the specific gravity readings are taken.
- Annually, all the inter cell connections are removed, cleaned, lubricated and reinstalled.

Doing all of the recommended maintenance requires many man-hours. we spent about 8 hours per month doing maintenance on the batteries (the concerned bank), and a full day doing the yearly maintenance. This amounts to about 104 man-hours, or 13 man-days a year or about $5,200 per year.

Compared to other equipment in the plant, this makes the battery a relative inexpensive maintenance item; however, it is a significant cost when compared to the cost of a battery.

After 20 years and $104,000 worth of maintenance, we could have replaced the battery several times.

After we do all the maintenance on the battery do we really know how well the battery will perform under actual operating conditions? As we found out at our Plant, we may have actually been creating problems. On our site (a power plant), a new battery was installed four years ago. The battery is a 58 cell, 420 Amp-hour unit that was operated on float-only charge at 130.5 VDC (2.25 V per cell, for lead /acid battery). The battery was installed according to the manufacturer's instructions and put in service. About two months later we installed a battery condition monitoring system.

Choice was according to external recommendation. It was new on the market and had been developed by a local US enterprise. The system was chosen because of the features it has and its ability to give long-term trends on the individual battery parameters. We felt that any system we installed had to have the following minimum features:

- Be non-intrusive to the battery case.
- Software and hardware compatible with Windows operating system.
- Be able to provide the following readings:
    - Cell voltage.
    - Cell Specific Gravity.
    - Test the integrity of the cell-to-cell connections.
    - Monitor the amount of cell float current necessary to maintain a uniform charge on each cells
    - Give the direction and magnitude of the bank current.
    - Bank voltage.
    - Automatic monitoring of the bank during discharge.

The installation of the monitoring system consisted of installing 2 sensing modules to the side of each battery jar. These are attached with a self-adhering tape that is an integral part of each cell module. In addition, it was decided to install a wire gutter to contain the cell-to-cell data link and other wire. This made for a neat installation. See Figure .

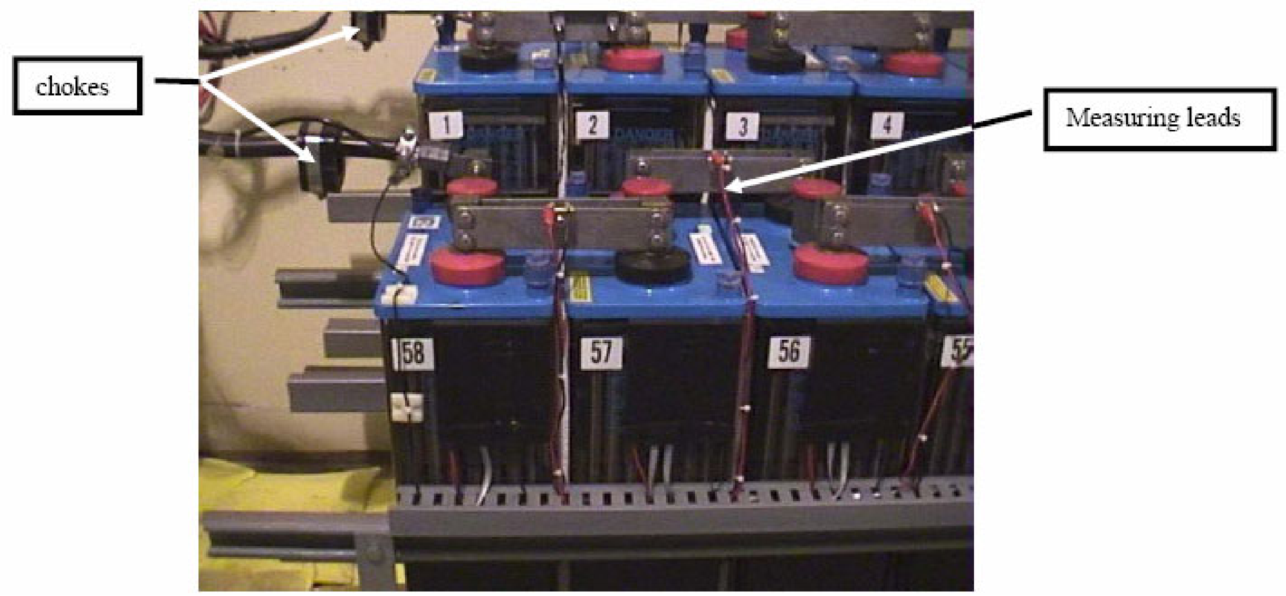


Figure 110: Installation of sensing device on each cell

Figure shows the sensing modules and wire gutter attached to the jars. Also shown are the measuring leads attached to the bus bars, and the chokes attached to the main battery leads.

Next, connections were installed to each bus between the battery posts. These connections are used to measure cell voltage and voltage drop across the cell when a one-millisecond bank load is applied for the current path integrity test. A choke (isolation inductor) is installed around each main battery lead.

The installation of all the equipment took two days and consisted of mounting modules on each cell, installing power cabling, and mounting the bank monitor and communications interface equipment.

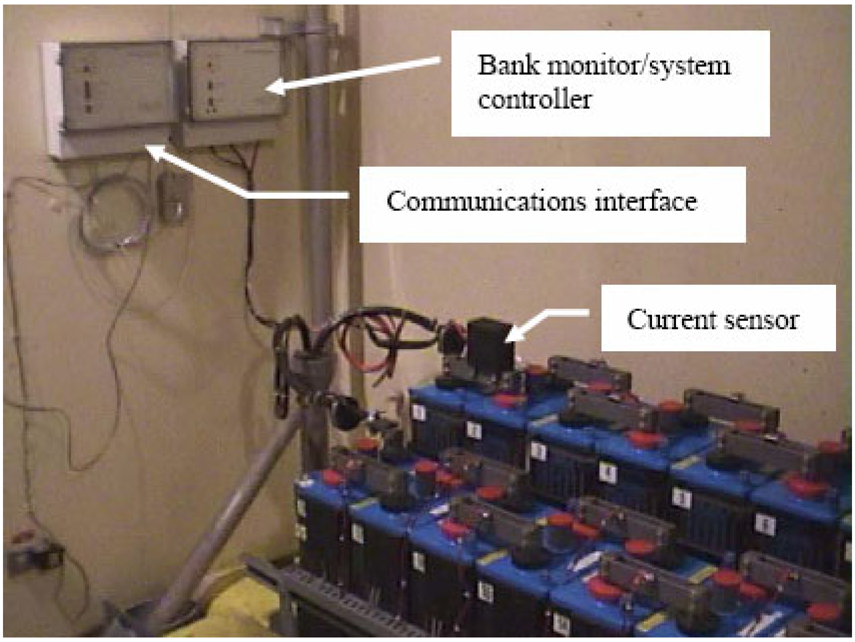


Figure 111: Connections of sensing devices

Figure shows the communication interface (with built in modem) and the bank monitor/controller mounted on the wall, the current sensor mounted at cell #1, and the rest of the hardware.

The overall system is shown schematically hereunder.

The data links between the cell monitoring modules are optically isolated to eliminate the possibility for a current path to exist between modules.

The isolation inductors (chokes) provide test isolation for approximately one millisecond during the connection resistance test (current path integrity test).

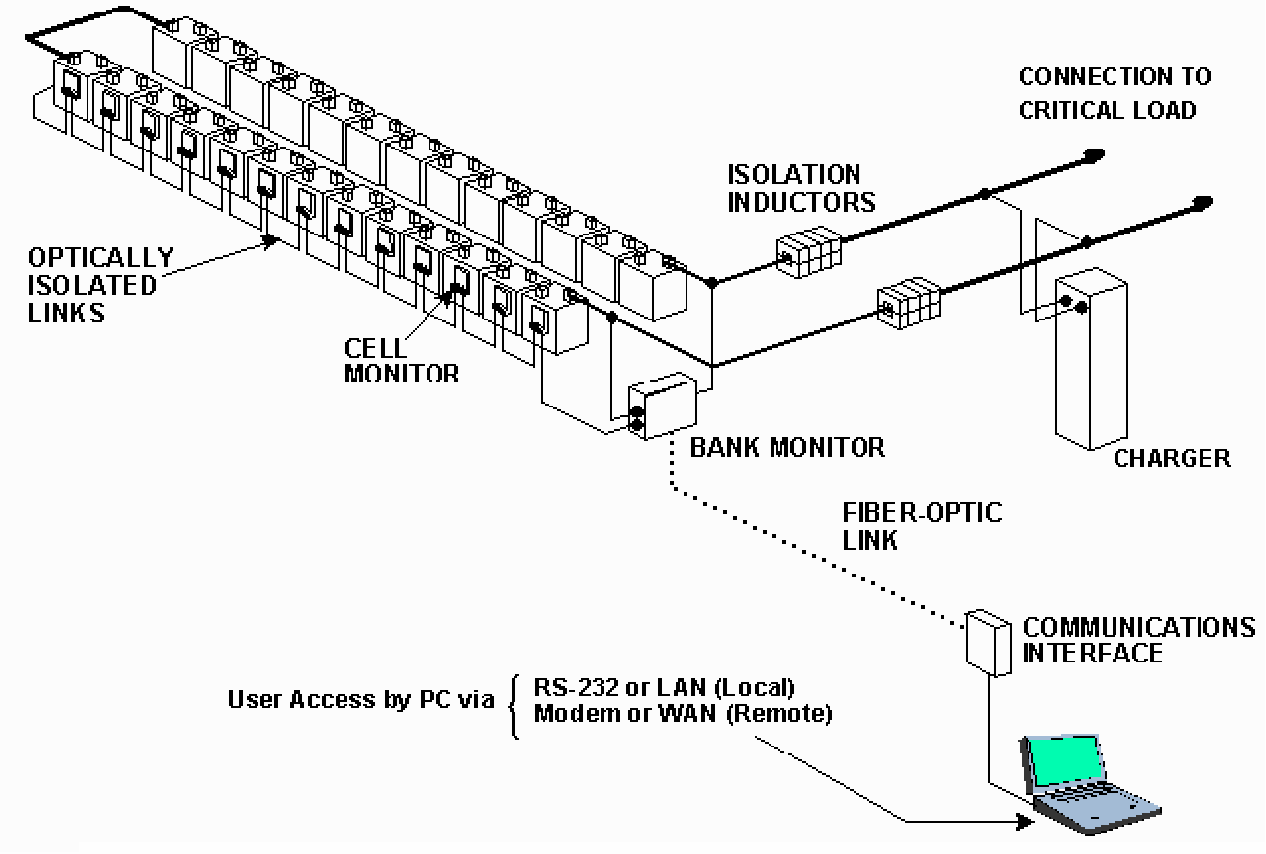


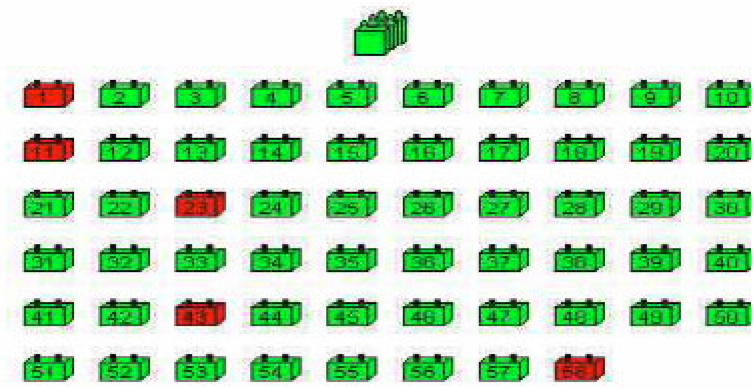
Figure 112: Overall configuration of a non-invasive battery monitoring system

8.2. USE OF THE MONITORING

Once the equipment was installed the system was set up and calibrated. A complete set of readings was taken on the battery and the data entered into the software as the starting point for monitoring. Much to our surprise, within days of putting it in service, the monitoring system started to report problems with the battery. The first deficiency it found was high resistance at several inter-cell link and battery post connections. We had taken resistance readings on the connections and not found any problems.

However, the monitor takes connection voltage-drop readings while a load of about 400 amps is applied to the battery for one millisecond (current path integrity test).

This method found poor connections that we had missed.



All the cells in question had high resistance connections.

Figure 113: View of the opening page showing cells with problems in red

The current path integrity is measured by employing the four-wire resistance technique (Wheatstone bridge).

To prepare for the measurement, the bank monitor simultaneously instructs all cell monitors to measure their cell's voltage and store the result in memory.

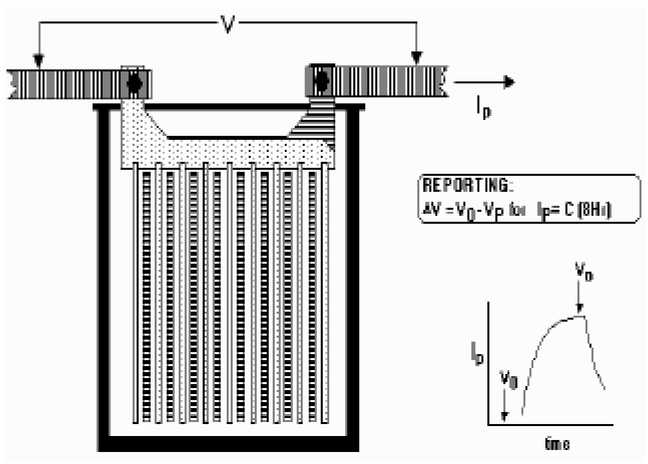
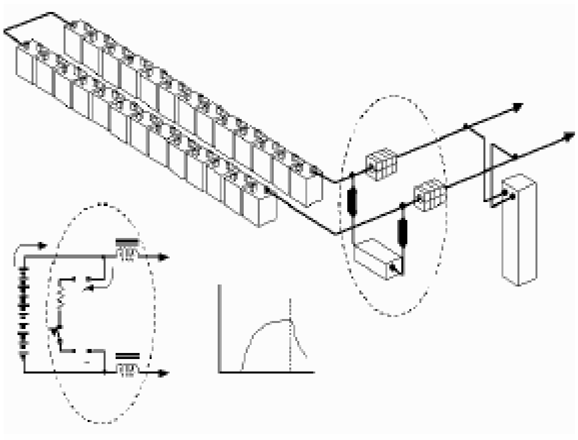
	
Voltage-current relationship for measuring the voltage drop across connection resistance in the series circuit.	The load is electronically inserted across the battery for one milisecond. The chokes provide test isolation

Figure 114: Process for automatically measuring current path integrity

The bank monitor next, switches an electronic load across the bank that draws current for approximately one millisecond. At the peak of the bank current, which is arranged to be roughly equal to the amp-hour capacity of the bank, the bank monitor again simultaneously instructs all cell monitors to re-measure cell voltage and subtract the results from the zero-current values of voltage already stored in memory.

The difference voltage for each cell, reported as “delta V” is proportional to the resistance of the current path including both the cell and strap/post connections. Figure (*measuring current path integrity*) shows the relationship of the voltages and currents during this test.

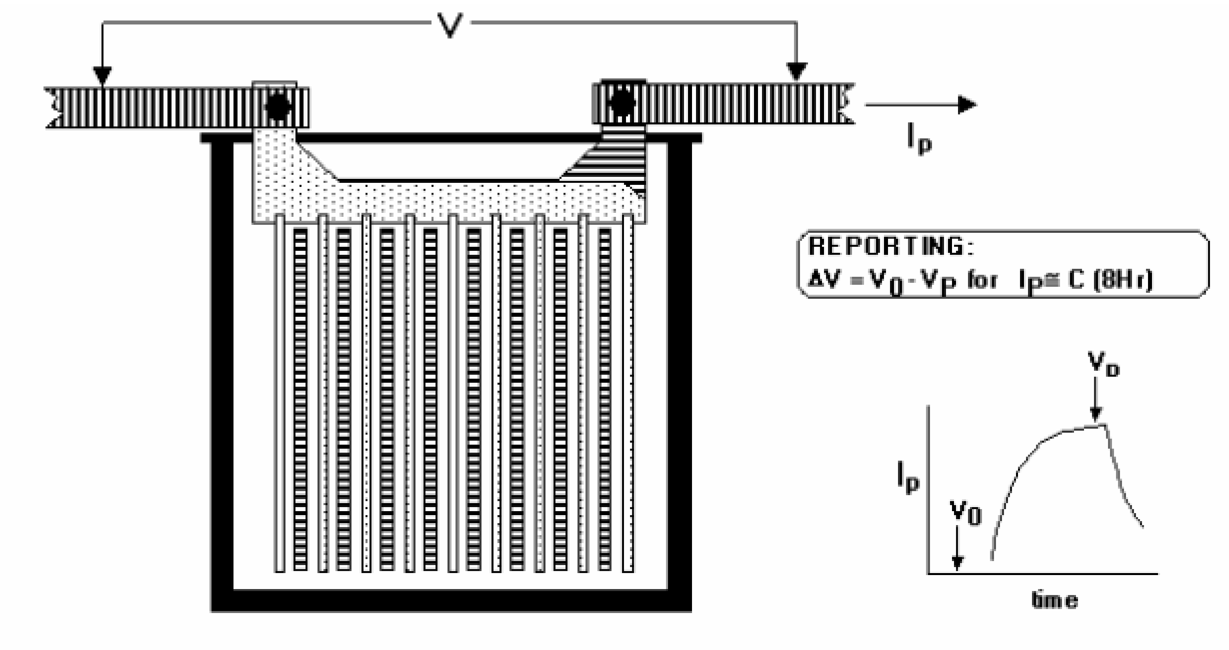


Figure 115: Cell resistance sensing – enlarged view of figure 114

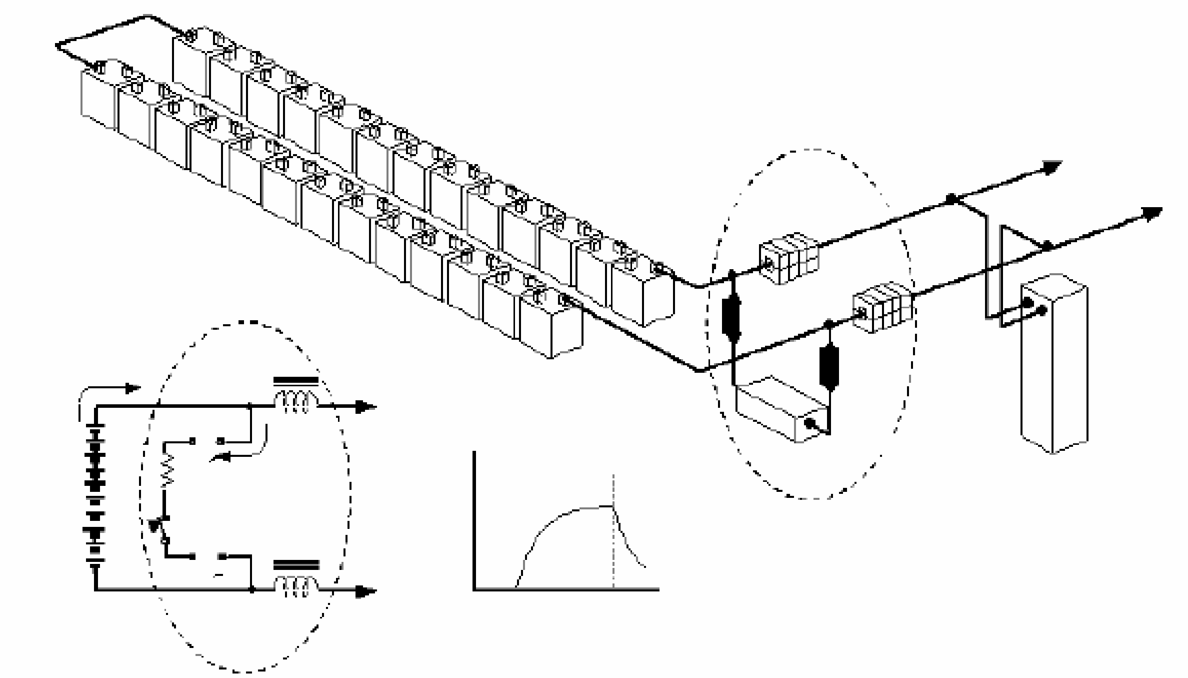


Figure 116: Bank surge current loading – enlarged view of figure 114

8.3. SOFTWARE READINGS / INTERPRETATION

Upon opening the software up to the individual cells, one can get either a cell-by-cell view of the battery or a view that shows the average cell, the high cell, and the low cell in each category. In looking at Figure you can see the trends of cell #1 over a period of time. Of interest is the gradual rise in the voltage drop across the connection of this cell.

With every voltage drop alarm, our electricians reported that the connecting bolts did tighten before the torque wrench reached the desired value. It was also interesting to note that just prior to developing a high resistance connection the battery underwent a load cycle as indicated by the downward spike in the readings, shown in the Figure below:

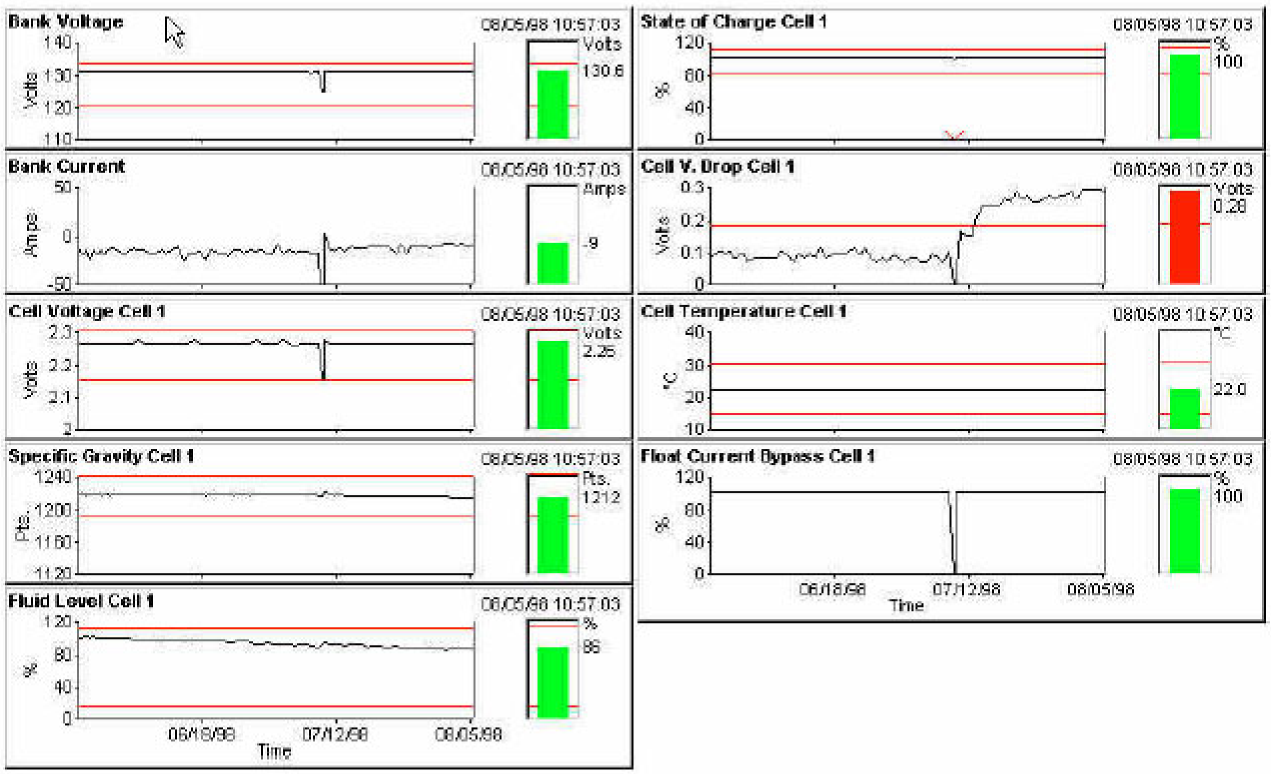


Figure 117: View of the screen giving trends on individual cells (cell 1 here)

After some months of operation “batteries specialists” reviewed the data that was being taken. They noticed that the water consumption of the battery was fairly high. From the Float Current Bypass cell readings it was noted that all the cells were bypassing 100% of the float current. In essence this indicated that the battery was being over charged, making it use more water. We started lowering the float voltage until most of the cells read in the 80% bypass range.

This reduced water consumption in the battery. See Figure (screen survey of cell. Note that the fluid levels move down. The straight line shows where water was added. Note place where the bank voltage is lowered you also notice that the slope of the water curve changes, and the cell current bypass currents drop.

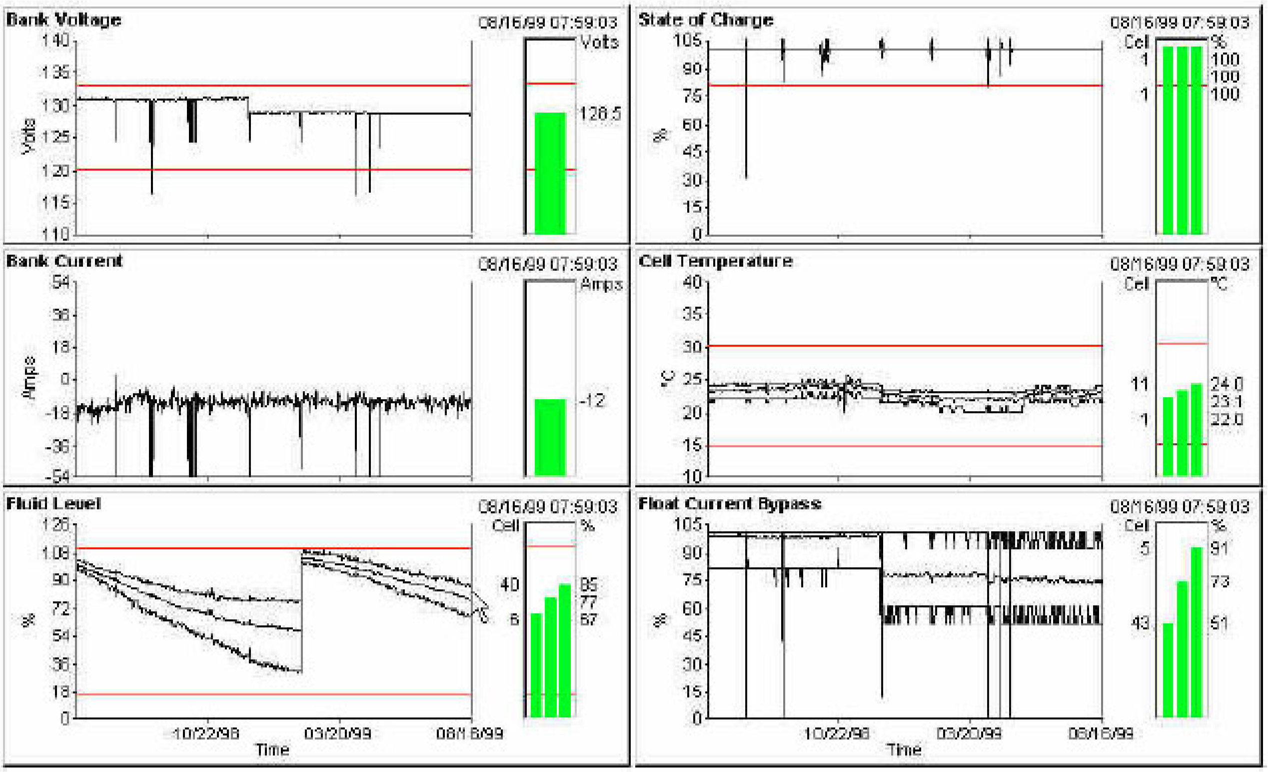


Figure 118: Screen survey of cells

8.4. TOWARDS FUTURE – USING MONITORING SYSTEM

The system allows the user to look at many conditions in each cell, and the battery bank at a whole. In addition, it will record bank discharges, showing the overall bank and each cell's performance during the discharges. This information goes a long way to assuring the quality and integrity of the battery.

The monitoring system performs a test on the battery however often the user desires. The monitoring system is set up to automatically do a test and collect data every 24 hours (for the example here). This gives us good data without building a huge database. However, during a load test on the battery or during an actual emergency event, the battery monitoring system steps up its data measurement rate to capture the performance of the battery, during the event.

The data is downloaded to a computer in the plant once a week, reviewed, and any necessary actions taken. This test sequence yields the data that we have looked at above. This system has been in use for almost two years, and has successfully found serious problems; it has also minimized the required battery maintenance.

The cost of this system approaches the cost of a battery. In order to justify this cost we must take a close look at what our battery does, and how important it is in the overall scheme of things.

The main purpose of the battery is to provide critical power to control and protection equipment when it most needs it. Failure of the battery system during these periods of time can have consequences that range into the millions of dollars for the equipment they protect. Thus it must be argued that the justification for the monitoring system should be based on the cost of these consequences rather than the ratio of the cost of the battery versus the monitoring system.

The bottom line for the monitoring system on our site is that it has drastically cut our man-hours of maintenance. Since the monitor's installation, several bad connections have been corrected, and the battery bank has had water added only twice. Then since system has been in service; a set of readings was manually taken after one year to verify the readings of the monitoring system, and they proved to be identical.

The Maintenance crew has decided that a lot of the maintenance that was done previously was probably causing as many problems as they solved. Redoing the jumper bar connections probably loosened more connections than it did to repair possible corrosion and tightness problems.

The need to be assured that your battery will operate as designed when it is needed most has been assured. This along with the reduced maintenance makes the cost of the system easily justifiable.

Conclusion:

“Manual” maintenance, however good it might be, can never reach the same level of performance as this “automatic” monitoring of each cell in a battery bank. Simple defects are automatically detected, corrective action can be immediately initiated, what more do we need?

And if not convinced here are some other arguments giving advantages to computerized survey / maintenance versus “manual” maintenance.

8.4.1. Factors that threaten battery reliability

Several factors threaten battery reliability:

- Overcharging and Undercharging of Individual Cells
- High Resistance Current Path (cells & connections)
- Excessive Temperature and Rippthe current
- Overfilling, Underfilling, and Leaking (flooded cells)
- Electrolyte Contamination (flooded cells)
- Unreliable Testing

8.4.2. Cell parameters

Cell parameters archived & trended (<u>with cell management</u>)

VRLA & Flooded

- Cell Voltage Regulation (bypass/maintenance current)
- Individual Cell Resistance (strap-to-post, post-to-plate)
- Voltage (regulated, discharge, recharge, peak load)
- Internal Temperature (plate pack mid-plane)
- Positive Post Temperature (VRLA)

Flooded

- Fluid Level (electrolyte depth between fill marks)
- Specific Gravity (plate pack mid-plane)

8.4.3. Bank parameters

Bank parameters archived & trended (<u>with cell management)</u>

- Voltage (regulated, discharge, recharge, peak load)
- Current (bipolar)
- AC Current (peak-to-peak ripple)
- Temperature (ambient)

8.4.4. Cell voltage regulation

Why Cell voltage regulation ?

- Operational and Environmental Stresses Shorten Cell Life
- Internal Resistance is Variable from Cell-to-Cell
- Cells in Series Result in Cell-to-Cell Voltage Variability
- Cell-to-Cell Voltage Variability Causes Charge Variability
- Charge Variability Results in Both Over and Under Charging
- Present Practice is to Force Equalize
- Force Equalization Highly Stresses Fully Charged Cells
- Cell Voltage Regulation Circumvents the Variability Problem Minimizing Cell Stress and Cell Aging

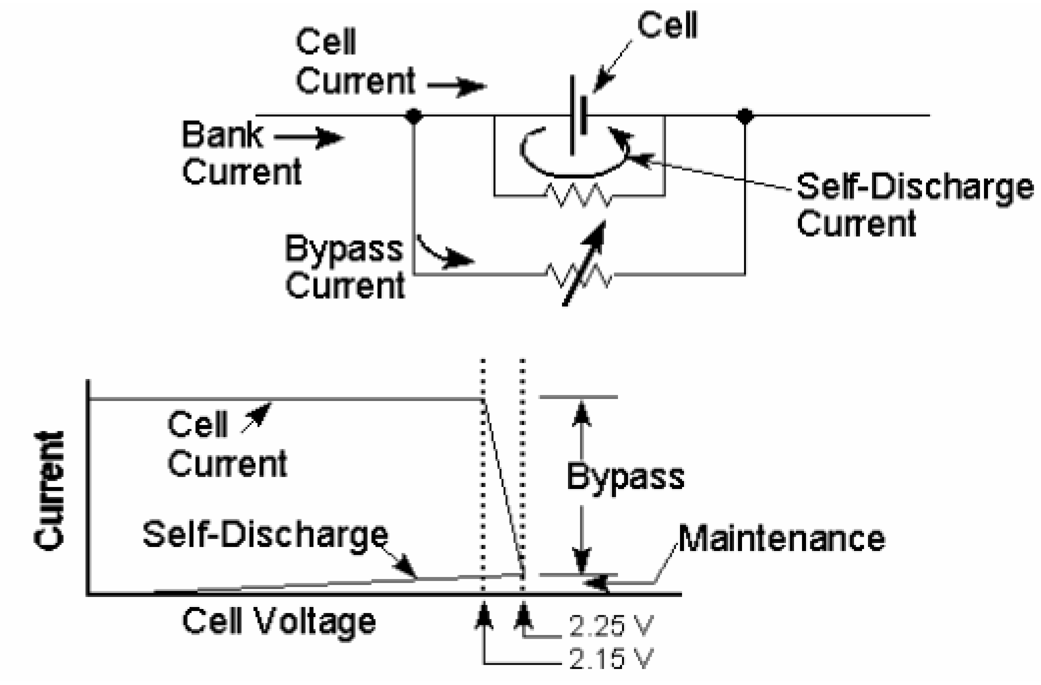


Figure 119: Using Cell Voltage to regulate Cell Charge

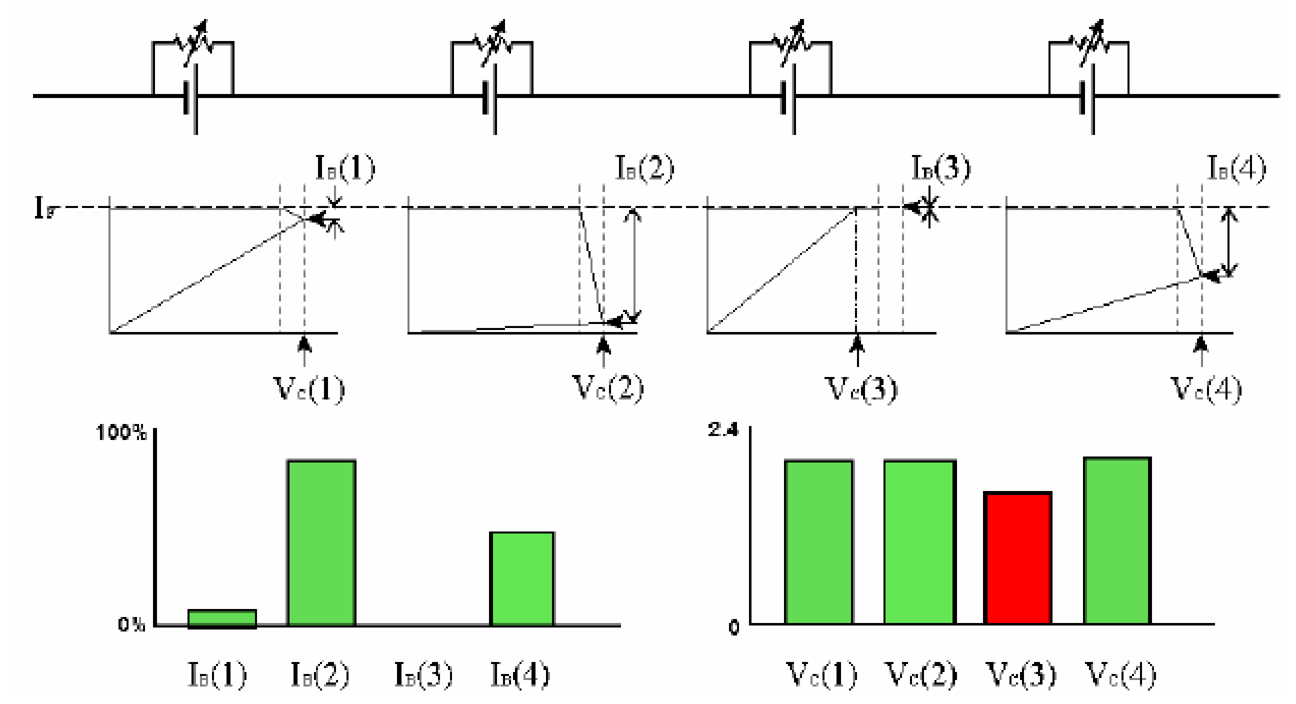


Figure 120: Cell-to-Cell Discharge Variability

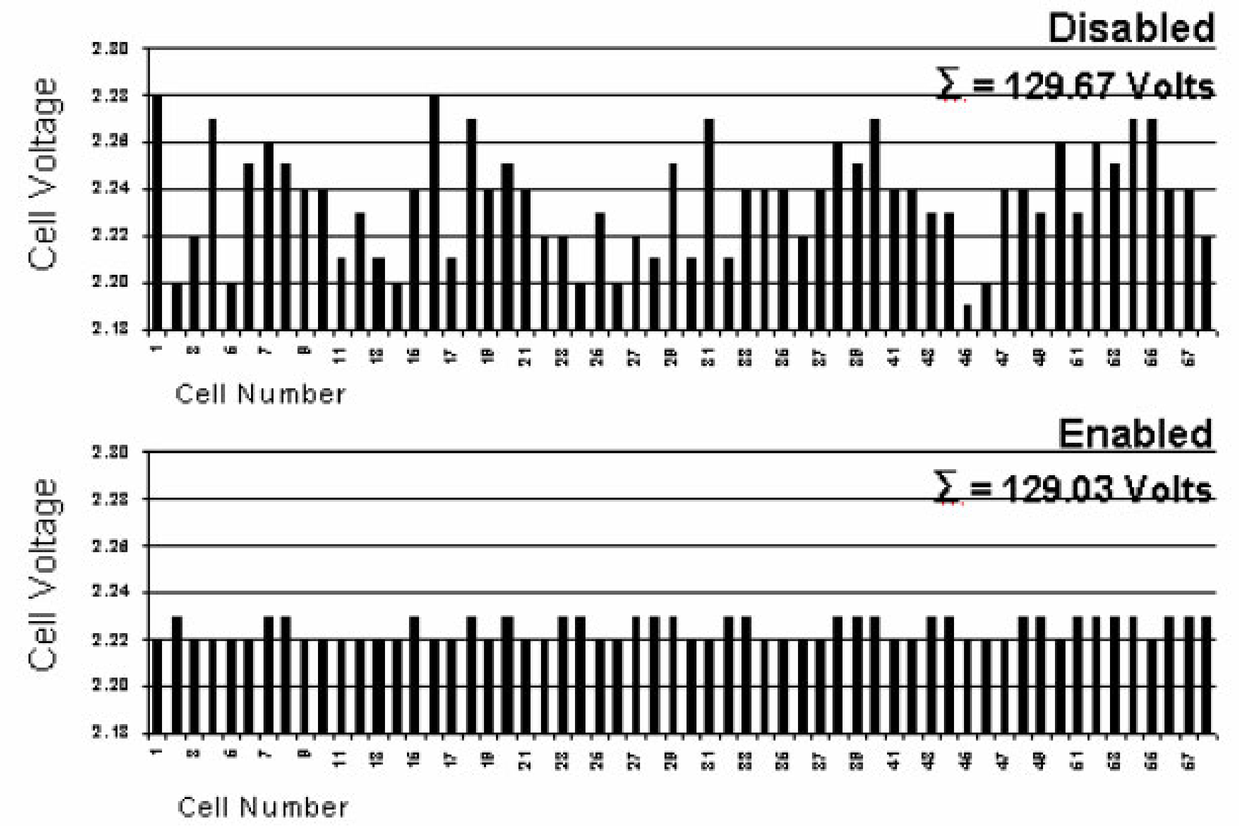


Figure 121: Bank Levelisation resulting from Cell Voltage Regulation Monitoring

8.4.5. Cell resistance sensing

Why cell resistance sensing ?

- Bank Voltage Sag Depends on Bank Total Internal Resistance
- Total Internal Resistance is the Sum of All Resistances along Current Path Including Cables, Joints, and Internal Cell Defects
- Resistive Defects **Both** Drop Voltage and Dissipate Heat
- Dissipation at a Defect Increases Resistance and May Result in Run-Away Heating
- Run-Away Heating Will Cause Melting and Circuit Interruption
- Circuit Interruption and Circuit Inductance Will Cause Arcing
- Potential Consequences are Loss of Service, Explosion, & Fire
- Cell Resistance Sensing Discloses All Resistive Defects

8.4.6. Non-invasive electrolyte sensors with cell management

- **Cell Fluid Level**
  - Measures Electrolyte Level between Fill Marks
  - Alarms for High and Low Levels

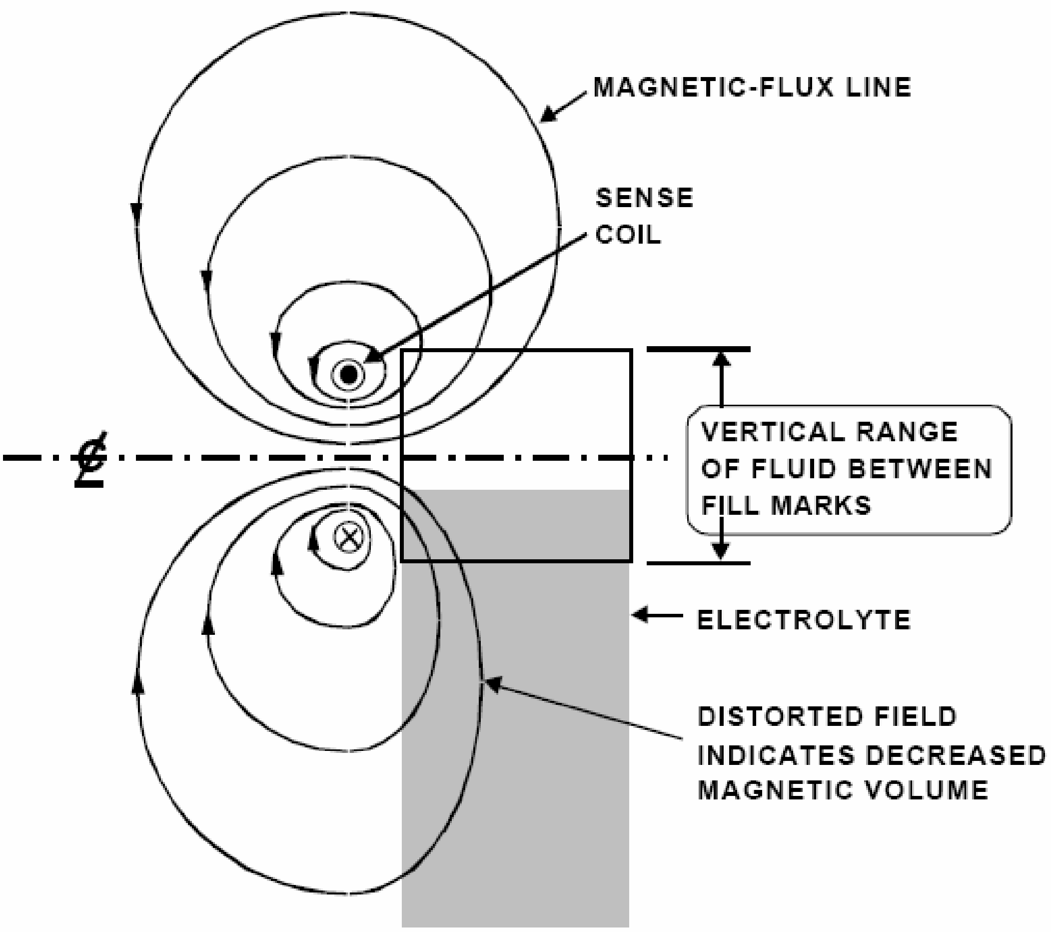


Figure 122: Fluid Level Sensing using Magnetic Flux Exclusion

- **Specific Gravity**
  - Measures Electrolyte Specific Gravity
  - Alarms for High and Low Levels

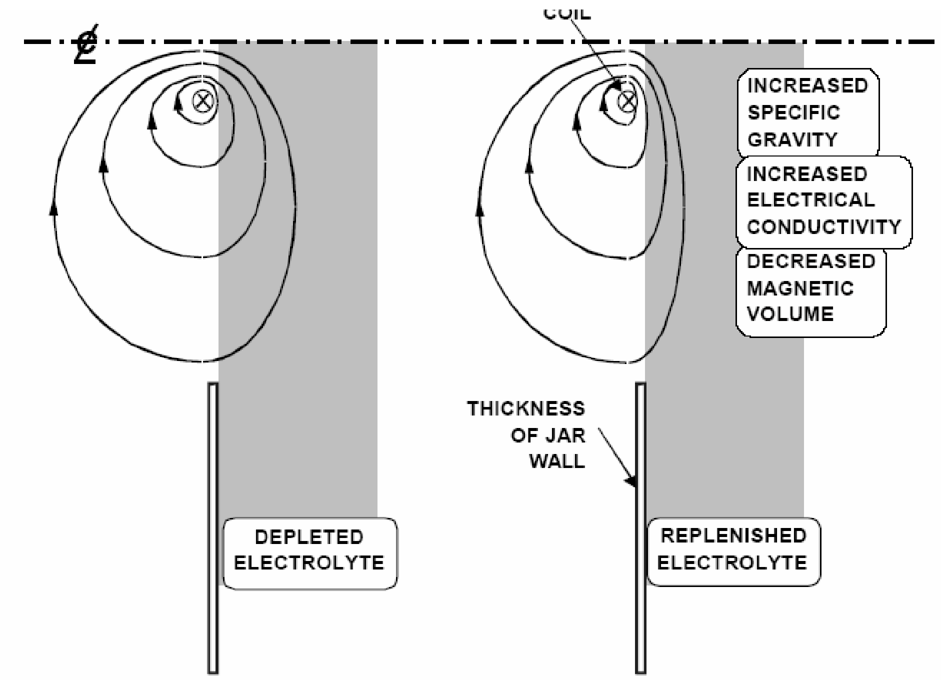


Figure 123: Specific Gravity Sensing using Magnetic Field Exclusion

8.4.7. Exemples of problems found

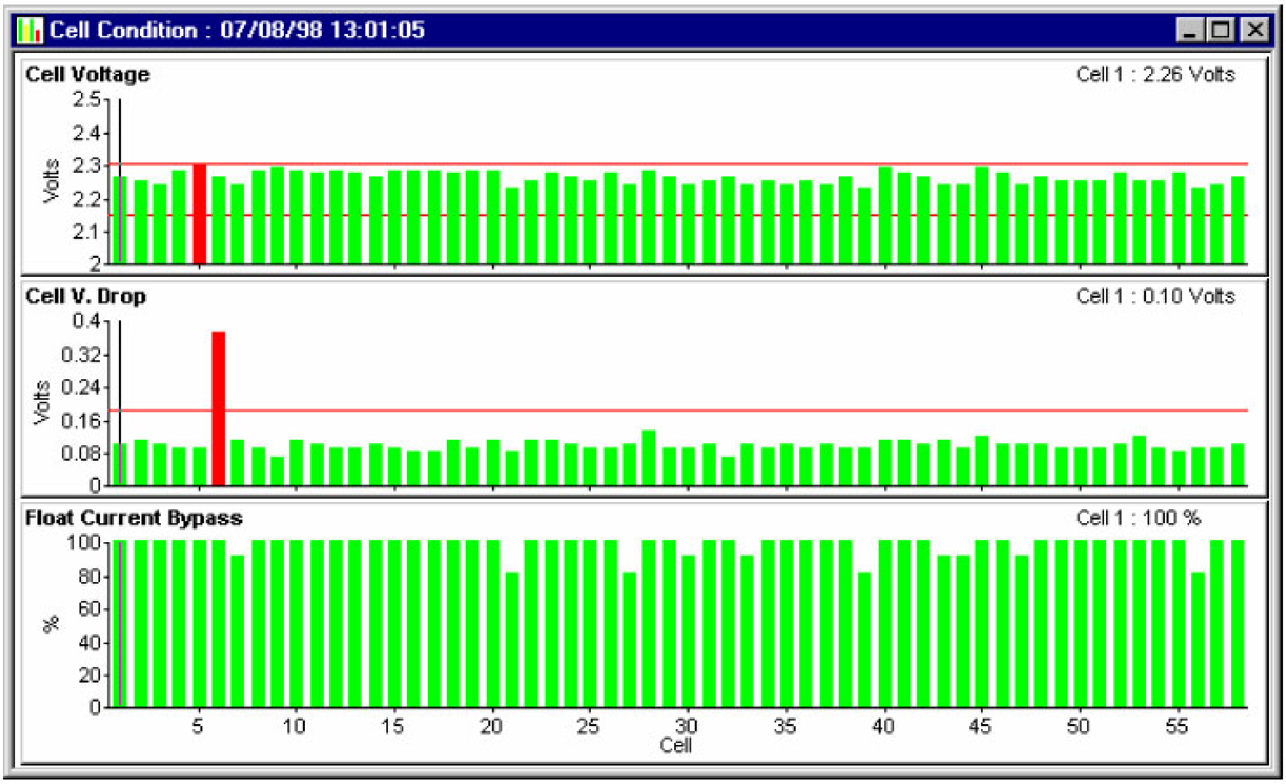


Figure 124: Voltage Problem in Cell 6

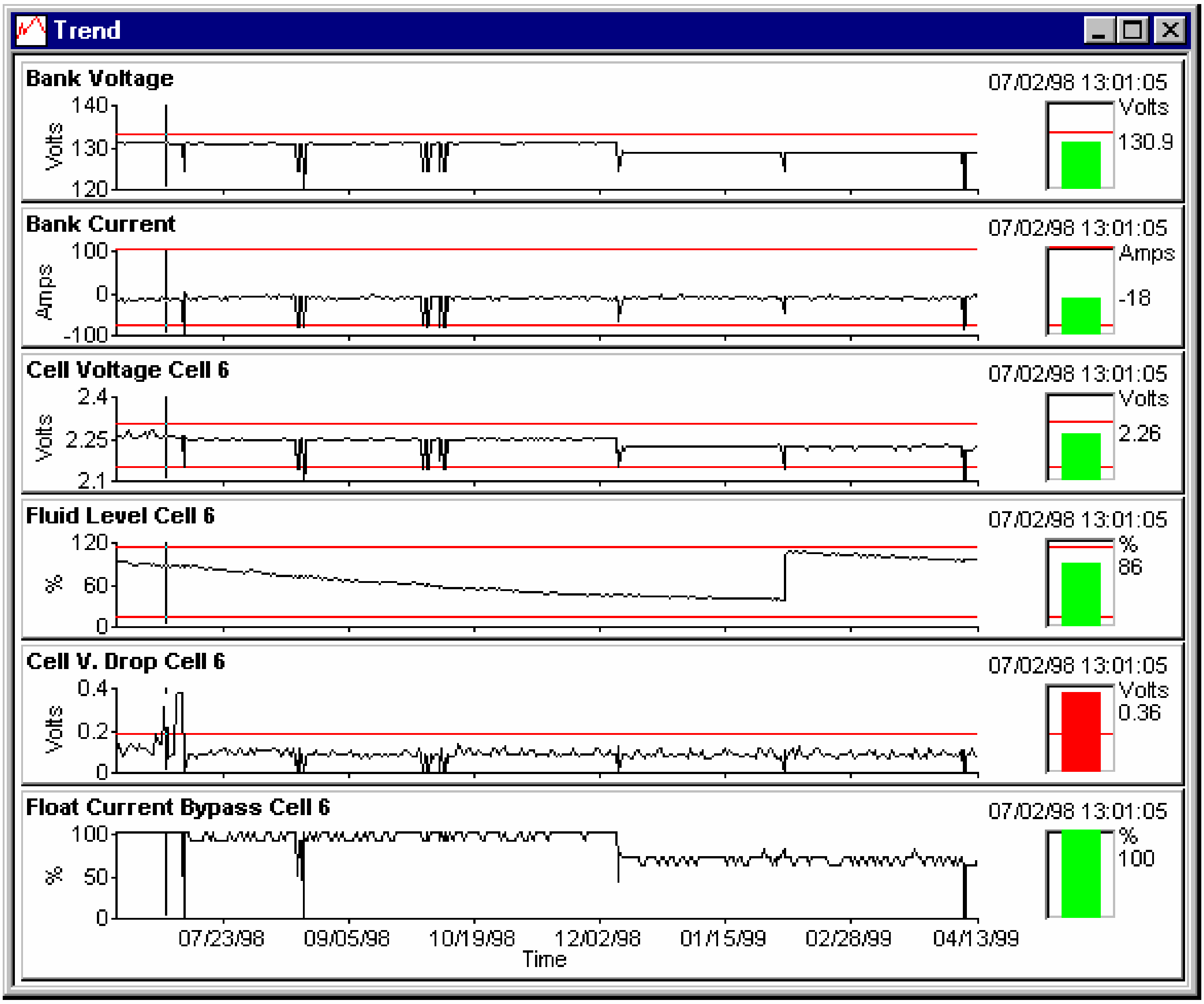


Figure 125: Voltage Problem in Cell 6 – other View

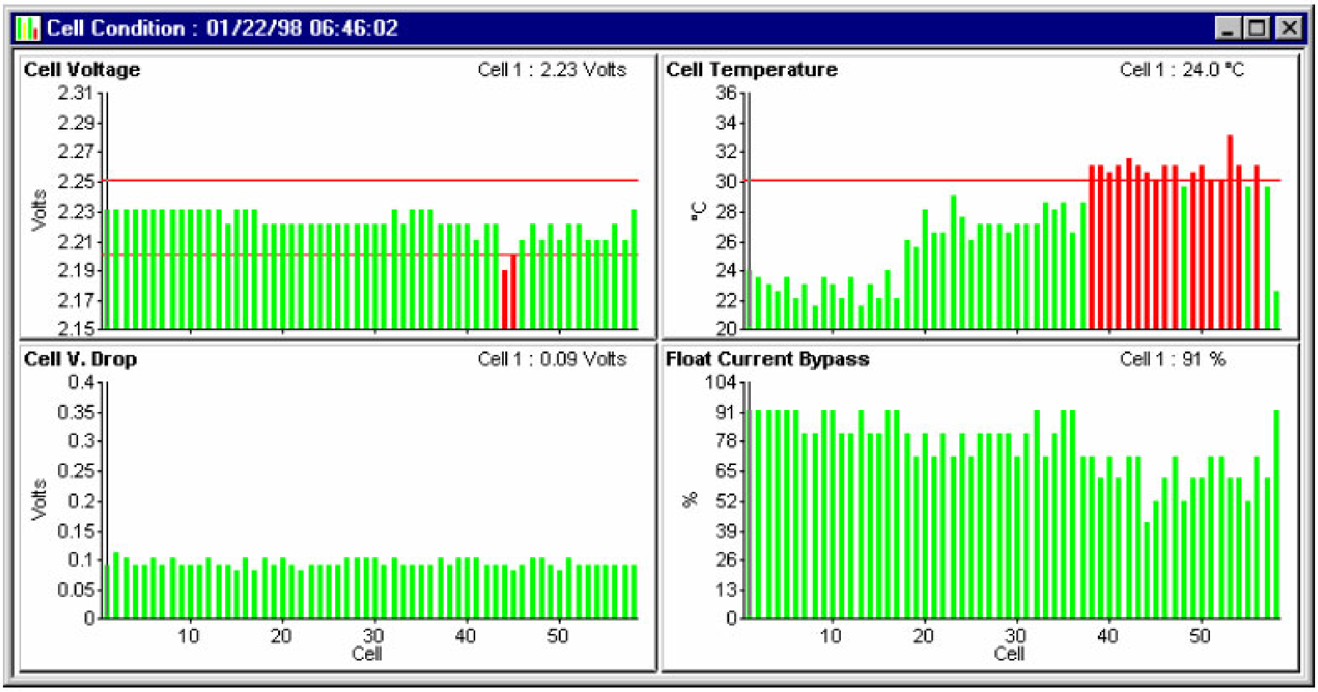


Figure 126: Other 58 Cells Bank – Temperature effect

And, of course, once you get such a monitoring system installed, you need someone to follow the records and to initiate the corrective actions immediately…, and with decision-making authorisation as well….

9. PHOTOVOLTAIC CELLS

Platforms and remote sites are now equipped with more and more "solar panels", *we should say "light energy panels" because they can operate even without sunlight and with artificial light*.

Figure 127: A “bank” of photovoltaic cells on a platform

A photovoltaic cell is a DC energy source in the same way as an electrochemical battery.

The problem is that it can only provide energy during half of the day, therefore solar panels are always combined with "conventional" batteries to provide a continuous electrical supply both day and night.

Solar panel maintenance:

Solar panels require very little maintenance, the "big job" is the **cleaning**. *It seems that on the platforms the seagulls (and all the other seabirds) are particularly fond of this type of landing strip to "answer the call of nature" (even though there is enough space around about!)*

Please don't use seawater to clean these cells. Unless you wish to transform them into the equivalent of "salt pans" and have to scrape off the salt during your next visit... *However, you can use seawater (it is of course more practical offshore), but carefully wipe them dry immediately! And follow the manufacturer's instructions...*

For the maintenance of the "ancillaries":

- Batteries: see the Operator course on batteries. The type of battery recommended is sealed Nickel - Cadmium but lead VRLA batteries may be encountered

- Charger / controller: see the specific course on chargers and also the manufacturer's instructions which specify the charging and floating voltages and currents.

Since we have not yet looked at the "PVCs" or "PV" cells (which are DC generators), their technology is explained below.

9.1. GENERAL FEATURES OF PVCs

PVC stands for Photovoltaic Cell

A photovoltaic cell consists of a semiconductor material which absorbs light energy and transforms it directly into electric current.

9.1.1. Types of cells

We generally make the distinction between three types of photovoltaic cells according to the technological developments.

9.1.1.1. 1st generation PVC

The first generation cells are based on a single P-N junction and generally use crystalline silicon as the semiconductive material.

Figure 128: First generation PVC

The production method based on silicon wafers requires a great deal of energy and is therefore very expensive.

It also requires highly pure silicon. We also make the difference between monocrystalline silicon-based cells and polycrystalline silicon-based cells. The polycrystalline cells are less efficient than the monocrystalline cells but are cheaper to produce.

9.1.1.2. 2nd generation PVC

The second generation photovoltaic technology uses thin films. With this generation, we make the distinction between amorphous silicon (a-Si), copper-indium selenide (CIS) and "cadmium telluride" (CdTe), among others.

Figure 129: Second generation PVC

In the case of thin films, the semi-conductor layer is directly deposited on a substrate (e.g. glass). This type of cell is cheaper to produce than the first generation cells because it uses less semi-conductor material and the step to transform the silicon into wafers is no longer required.

The problem with the second generation cells is that they have a low efficiency (6-7% and 14% in the laboratory) and the toxicity of certain elements (cadmium) to produce them.

However, this second generation has many advantages because they can be used in flexible modules, with low illuminations or with high temperatures.
The copper-Indium selenide (CIS) which is now at the industrial production stage gives 10 to 12 % efficiency for its commercial modules and does not have the cadmium toxicity problems.

Therefore the expected cost reductions in the medium term for this technology are very promising.

9.1.1.3. 3rd generation PVC

The third generation aims to reach the maximum efficiency limit for the present cells, which is approximately 30%.

Figure 130: Third generation PVC

Several concepts are envisaged to reach this objective:

- superimposing multiple cells (using different energy bands)
- concentration cells
- using low energy photons which are not normally absorbed by the cell
- hot electron cells producing more electron/hole pairs for energies greater than the energy band
- conversion of the photons to adjust the solar light spectrum to the characteristics of the semi-conductor.

9.1.2. Cell efficiency

A cell's efficiency is the ratio between the light energy received on the surface of the cell and the electrical energy produced by this same cell.

The efficiency of a photovoltaic cell would be approximately 85% if each photon could transfer all its energy to an electron.

However, this is not the case because the energy transfer can only take place in the energy band specific to each semi-conductor. Therefore, the photons with a lower energy than this standard value cannot contribute to the photovoltaic effect and their energy will be converted into heat. In addition, the photons with more energy can only transmit the energy specific to the semi-conductor and all excess is then lost.

In the present cells, these two effects limit the theoretical efficiency of the cells to 50%.

Type	**Cell efficiency (in lab)**	**Module (in lab)**	**Module (commercial)**	**Development level**
1st generation				
Monocrystalline silicon	24.70%	22.70%	12-20%	Industrial production
Polycrystalline silicon	20.30%	16.20%	11-15%	Industrial production
2nd generation				
Amorphous silicone	13.40%	10.40%	5-9%	Industrial production
Thin layer crystalline silicon		9.40%	7%	Industrial production
CIS	19.30%	13.50%	9-11 %	Industrial production
CdTe	16.70%		6-9%	Ready for production
3rd generation				
Organic cell	5.70%			In the research phase
Grätzel cell	11%	8.40%		In the research phase
Multi junction cells	39%	25-30%*	In the research phase, production exclusively for space applications	

Table 20: Efficiency of the different types of photovoltaic cells

*Triple junction GaInP/AsGa/G/Ge module

9.2. PVC OR PV TECHNOLOGY

9.2.1. Photovoltaic effect

When a material is exposed to the sunlight, the atoms exposed to the rays are "bombarded" by the photons forming the light; due to this bombardment the electrons in the outer electron shells of the atoms (called valence shell electrons) tend to be torn off:

If the electron returns to its initial state, the electron's agitation heats up the material. The photon's kinetic energy is converted into heat energy. However, in photovoltaic cells, part of the electrons do not return to their initial state. The electrons "torn off" create a low continuous electric voltage.

Part of the kinetic energy of the photons is thus directly converted into electric energy: this is the photovoltaic effect.

The photovoltaic effect is the direct conversion of the energy from the solar rays into electric energy. The term photovoltaic comes from the Greek "phos, photos" which means light and from "voltaic", which is a word derived from the name of the Italian physicist Alessandro VOLTA, well-known for his work on electricity.

9.2.2. Operating principle of a silicon photovoltaic cell

When it is illuminated, a photovoltaic cell (also called a photocell) generates a continuous electric current across its terminals, at an electric voltage. Its operating principle (shown below) is simple: it consists of converting the kinetic energy of the photons (light particles forming the sun's rays for example) into electric energy.

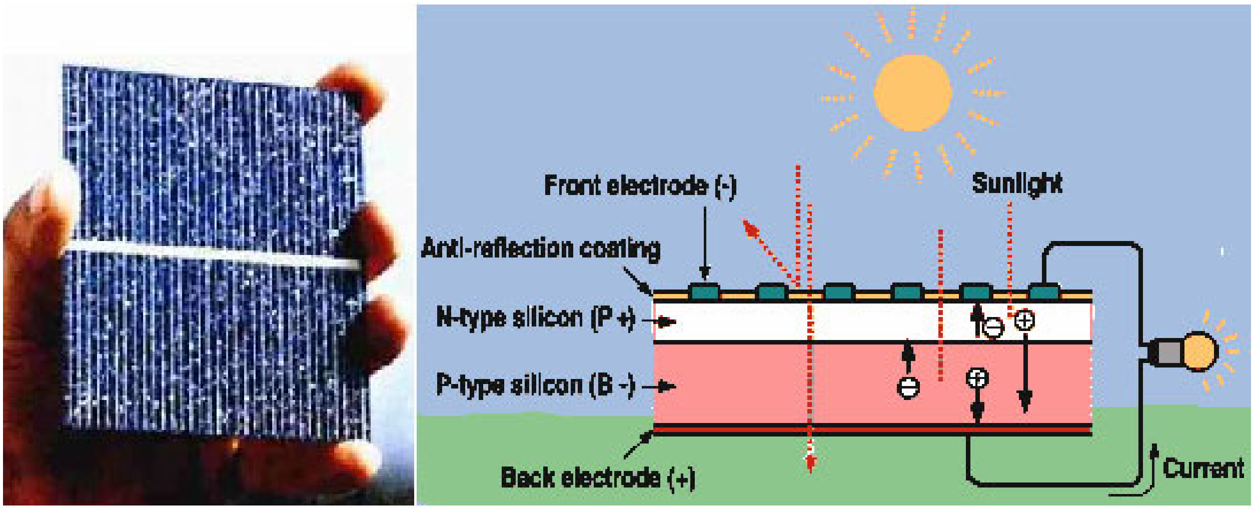
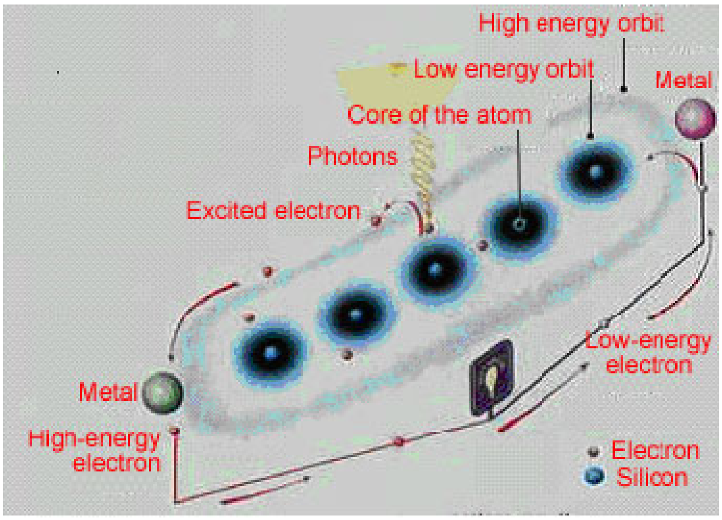


Figure 131: Silicon PV and operating principle

As a first approximation this system can be considered to be a DC generator. It must be noted that this generator has no moving parts.

Photovoltaic (PV) cells are produced from semi-conductor materials, particularly silicon, and most PV cells are manufactured from this element (99 % of cells manufactured in 2001)



In a semi-conductor material the electrical situation is between that of an electric insulator and an electric conductor: the valence electrons can only flow if they are provided with energy to free them from their atoms (e.g. solar energy), i.e. the semi-conductor material becomes conductive only if it receives energy.

Figure 132: Representation of a perfect silicon photocell

The electrons rotate around the nuclei in the photovoltaic cell. Under the effect of the light the electrons in the outer layer of the atoms are "torn off" due to the impact of a photon of light.

The electrons "torn off" the atoms thus create a DC current which is directly usable at the terminals of the cell, under a DC voltage (open circuit voltage of the order of 0.4 to 0.6 Volts for monocrystalline silicon photovoltaic cells in standard operating conditions (STC).

The operation of the silicon photovoltaic cells is based on the electronic properties of this material. Its atoms are perfectly aligned in rows and columns and linked together by four pairs of outer electrons: the silicon is said to be tetravalent.

We can also improve its conduction properties by doping this crystal, i.e. by adding a small number of foreign atoms (impurities) of the same size to the crystalline network. These atoms must have a number of outer electrons just less or just greater than the silicon's 4 valence electrons.

9.2.3. Description of a PV cell

The technologies used by the different manufacturers vary but the basic characteristics of a cell's components are the same.

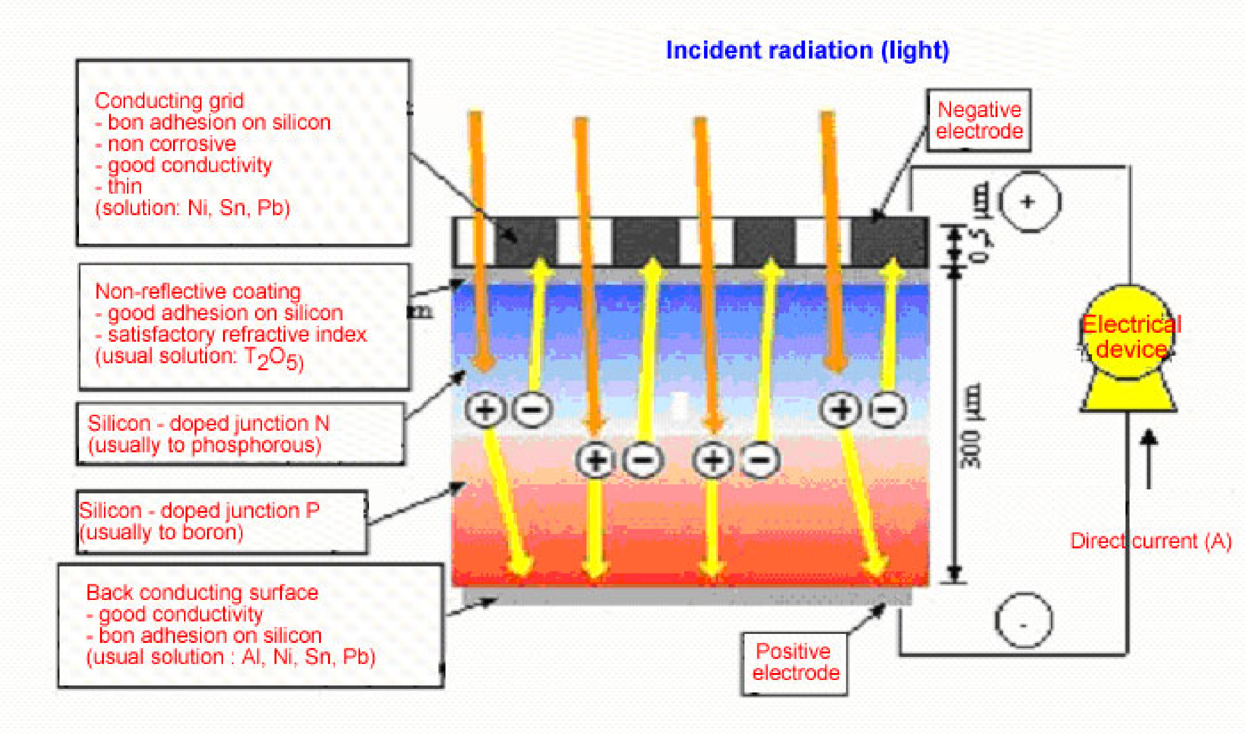


Figure 133: Diagram describing a photovoltaic cell

In practice, the PV cell consists of several thin films (see diagram describing a photovoltaic cell) i.e.:

- an "anti-reflection" layer on the front, the aim of which is to facilitate to the maximum the penetration of a maximum amount of photons through the surface and to reduce the losses due to reflection;
- a front "electron collector" conductive grid which must also be linked to the silicon and must not be corrosion-sensitive;
- a doped N-layer with negative free charge carriers (electrons);
- a doped P-layer with positive charge carriers (holes);
- an "electron collector" metal conductive contact surface with a good conductivity and a good attachment on the silicon;

Notes:

For the best possible collection of the electrons, the "front collector grid" on the N-layer must be as dense as possible. The effect of this will be to cover the receiving layer and therefore reduce the area of the N-layer, thus reducing the quantity of photons hitting the PV cell by the same amount, and therefore the electricity production. The best compromise between the two constraints is to allow the light to pass through by arranging the front electrode in the form of a comb which is as close together as possible.

9.3. PHOTOVOLTAIC MODULES

A "bare" cell is often of little use as it is: it is very thin and therefore both very fragile and its voltage and current are very low meaning that it cannot be directly used in normal electrical applications.

The operating voltages of the electrical equipment are standardised (12, 24, 48V, etc.) and a single PV cell is not sufficient to supply this equipment directly. Therefore to increase the available power and the energy produced by PV cells the manufacturers assemble the PV cells in series and in parallel.

The desired voltage is reached by connecting several cells in series. To obtain the desired power, several of these series of cells can be installed in parallel.

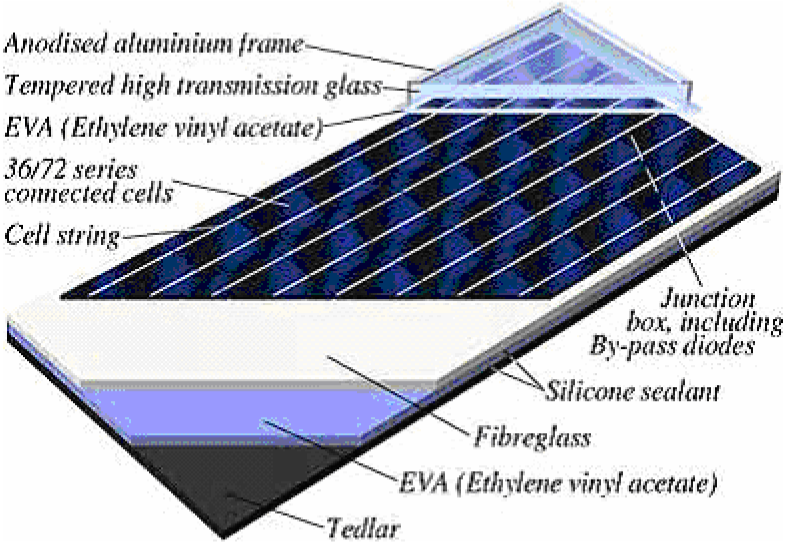
These configurations are then protected in a "packaging" which gives the whole assembly a good mechanical strength and efficiently protects it against external aggressions.

The rectangular panels thus obtained are called "**photovoltaic modules**".

9.3.1. Technology

9.3.1.1. PV modules

Since a single photovoltaic cell is virtually unusable it must therefore be encapsulated and protected against external aggressions.



The encapsulation operation consists of covering the side exposed to the sun with glass or resin (materials which must withstand high temperatures and guarantee high transmission coefficients); the rear of the module is covered with glass or Tedlar (glass + organic material).

Figure 134: Cross section of a PV module

The cells assembled in series/parallel are "embedded" in a transparent organic material, generally EVA (Ethylene Vinyl Acetate); the whole assembly is sealed by a lateral silicon seal and the two ends of the module are connected to a terminal box which is necessary to connect the module to the application, and the whole unit is then crimped in a frame (otherwise they are said to be "laminated").

These operations are essential because in space applications (satellites) the module has to withstand extreme temperatures, a vacuum and meteorite impacts; for outdoor applications back on earth (installations producing energy from solar energy), the modules must withstand the following aggressions: atmospheric, temperature, wind, rain, hail, weight of snow, erosion due to sand in suspension in the wind and marine corrosion.

In spite of these precautions, imbalances generated by spurious blackouts of certain cells may occur within a module. To overcome this, protection diodes have been inserted in the system.

The recommended electrical protections will only be valid if the parallel diodes can withstand the current of the whole branch likely to deliver electricity in the branch.

9.3.1.2. Concentration PV modules

The modules we have just seen are the most common, they are called "flat PV solar modules" or simply "flat PV solar panels".

To improve the productivity of the photovoltaic cells (kWh of electricity produced / per m² of cells) or (kWh of electricity produced / by unit cost of the cells) different approaches are being explored.

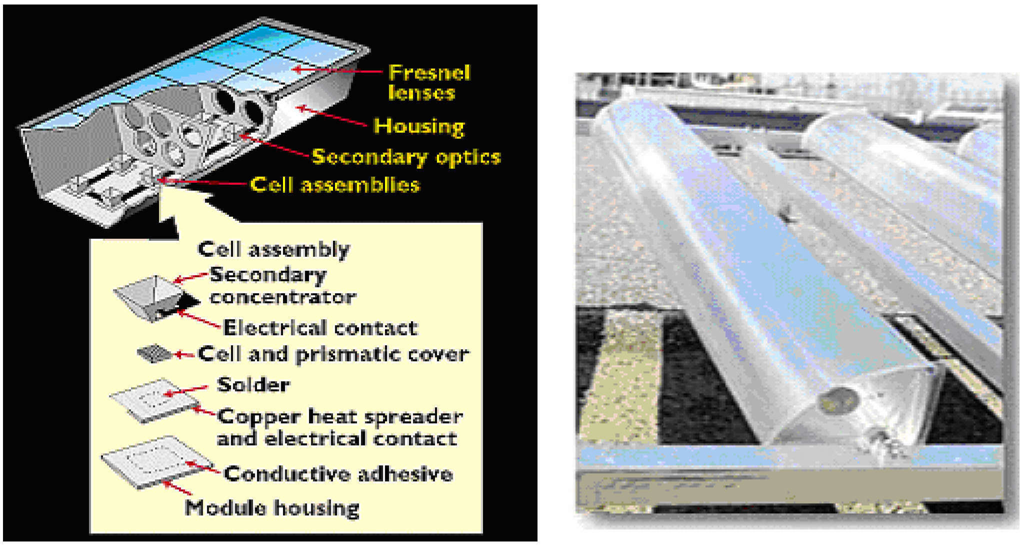


Figure 135: Cross section of concentration PV modules

The ***first*** consists of trying to produce ***cheaper cells***, this is the theme of the developments of new semiconductor materials, however, the principle, the fundamental physics of converting solar radiation into electricity limits this process.

The ***second*** approach consists of ***increasing the efficiency*** by reducing the losses in the photovoltaic cells by reducing either the losses due to the reflection of the incident rays (using antireflective layers), or by reducing the losses due to convection (by insulating the cell, by allowing it to operate at a lower temperature by cooling it, by placing it in a collector under a vacuum, etc.). However, these approaches are very limited...

The ***third*** approach consists of ***increasing the incident rays*** on the cell by a concentrator (optical lenses, Fresnel lenses, etc.). For example, by using lenses *doubling* the incident rays on the cells the power delivered at the terminals of the photovoltaic cell is almost doubled. The cost of these lenses *doubling* the rays is far less than the cost of doubling the surface area of the photovoltaic cells which produce the power!!!

There are two major disadvantages to this process, on the one hand the concentrators only operate with diffused solar rays (diffused from the sky and diffused from the ground) and these solar rays often represent 40 to 60 % of the total solar rays, and on the other hand the concentrator must be equipped with a tracking system to ensure that the solar rays are correctly focused directly on the cell (and not in front of it or to the side of it) and, finally, using these concentrators the temperatures reached by the cells can be high (think of a magnifying glass) and it will often be necessary to provide cooling systems which can be more costly than the gain in energy produced.

9.3.1.3. Double-sided PV modules

Some manufacturers propose solar panels **which have solar cells on both sides, on the front exposed to the sun and on the rear of the panel**.

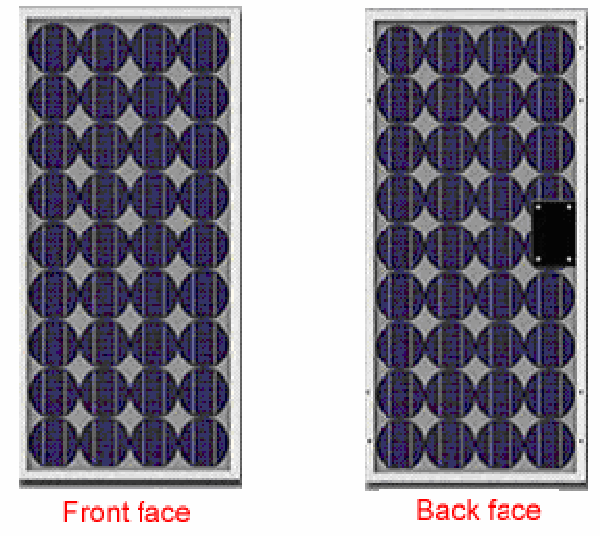


Figure 136: Front and rear of a 36 Vdc double-sided PV module

The cells are generally mounted on a glass panel, encapsulated in an aluminium frame. These panels are adapted to sites with a high albedo (also called reflectance) such as lakes, seas, deserts and snowy regions.

Tests in Krasnoe Znamya have shown that the energy produced was 10 % greater than the energy produced by a single-sided solar panel.

This is not surprising because the albedo of snow, or of water surfaces is around 0.75 to 0.90. It is an interesting idea but the 10 % gain is certainly low in comparison to the extra cost with respect to a single-sided panel.

The power of the double-sided module is twice that of the same single-sided module but the average annual energy produced by the double-sided module is only 10 % higher (however, the investment cost is almost doubled!!). This is a good example of the necessity to optimise the techno-economic aspects and the need to know if the purpose of a photovoltaic solar installation is to obtain an instantaneous power (which is rarely the case when the installation has an electrical storage system such as electrochemical batteries).

Would it not be more financially advantageous to place a reflective surface in front of the panels (e.g. a sheet of mylar with a 90% reflective factor) which would reflect part of the solar flux, thus increasing the incident flux on the panels and therefore the energy produced? The cost of such a mirror is negligible compared to increasing the surface areas of panels or of equipping the rear of the panels with cells.

All these ideas are being explored and a number of experiments have been carried out.

9.3.2. Nominal specifications of PV modules

The manufacturer accompanies his module with:

- a sheet indicating the inspections it has undergone,
- a sheet indicating the module's specifications, in particular:
    - the specifications of the module (weight, dimensions, surface area, attachment points, etc.),
    - the current characteristic curves = f (voltage) in the standard operating conditions (STC),
    - some electrical specifications:
        - the open-circuit voltage measured across the terminals of the PV cell in standard operating conditions, VOC (V) Volts,
        - the short circuit current measured across the terminals of the PV cell in standard operating conditions, ISC (A) Amps,
        - the rated power, the maximum power measured across the terminals of the PV cell in standard operating conditions (STC) Pmax rated (W) Watts,
        - the rated power voltage, the maximum power measured across the terminals of the PV cell in standard operating condition, V Pmax rated OC (V) Volts,
        - the rated power current, the maximum power measured across the terminals of the PV cell in standard operating conditions (STC), I Pmax rated (A) Amps.

By extension and for simplification, the professionals characterise a PV module simply by:

- *The rated power* in the standard operating conditions (STC); $P_{rated} = P_{max}$ (W) Watts,
- *The rated voltage* of the PV module (generally 12, 24, 48 V DC; V_{rated} (V) Volts).

Notes:

The specifications of the modules are often expressed in the standard test conditions (STC) in the laboratory, i.e. with a solar ray distribution AM = 1.5, normal incident ray on the PV cell of 1000 W / m², and a cell temperature of + 25 °C plus or minus 2°C, the speed of the air circulating around the cell - approximately 2 m / s - is not specified since it is taken into account in the cell temperature.

The nominal operating cell temperature (NOCT) is the temperature of the cellule (or of the module) operating under rays producing 800 W / m², an ambient temperature of + 20 °C and an ambient surrounding air circulation of 1 m / s.

There are a lot more technical specifications, descriptions, power calculations, etc., but that is not the (main) aim here, so let us now move on to the applications (the assembly consisting of the PV + Batteries + Controller = system on site) .

9.4. APPLICATIONS

Our PV installations on the sites are self-contained, i.e. they are not connected together or to a network but when they are an installation's only energy source they are (relatively) small systems.

9.4.1. Description of the installation

These installations consist of:

- photovoltaic (PV) panels,
- electricity storage batteries,
- a charge and discharge controller providing the electrical protection for the installations and controlling the battery's charge and discharge,
- one or more DC / AC converters also called inverters
- and possibly one or more makeup supplies.

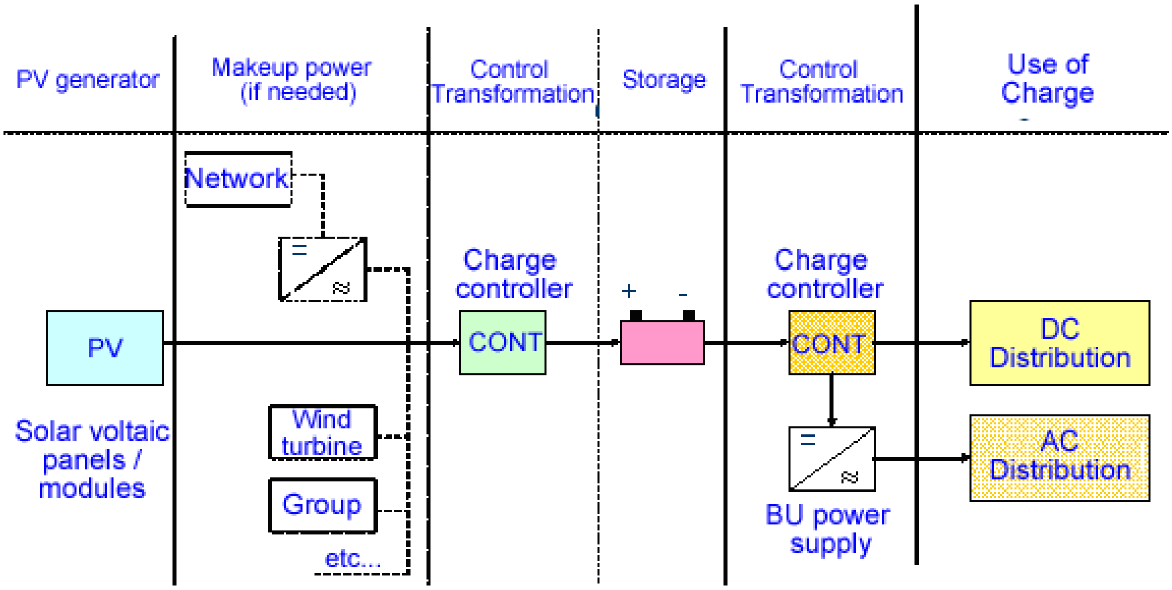


Figure 137: Typical self-contained PV supply / distribution arrangement

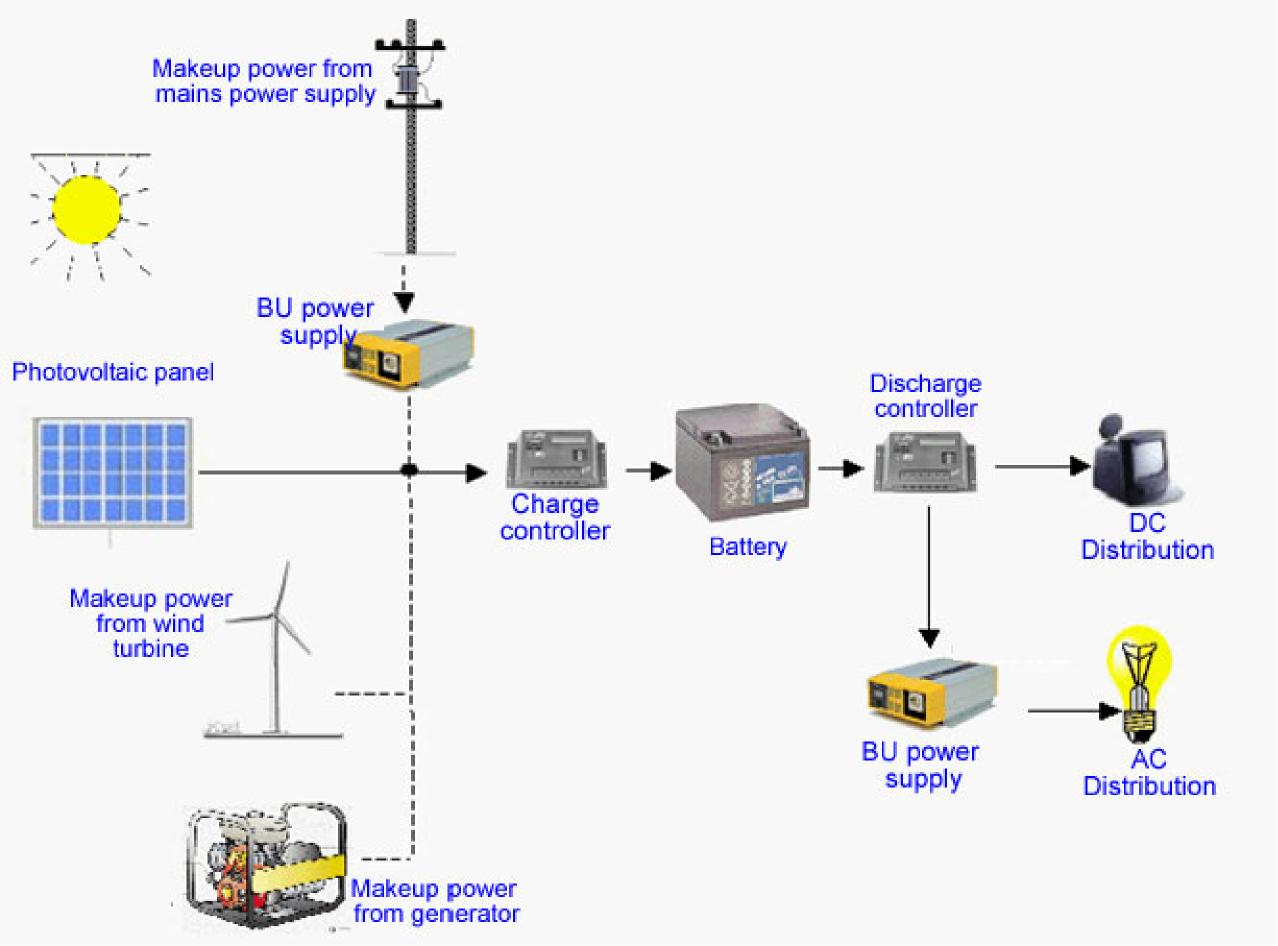


Figure 138: Typical self-contained PV supply / distribution arrangement - illustrated graphically

9.4.2. Field of application

- **Vehicles**

Figure 139: The LA PESCA solar car

Produced in 1987, battery range: 216 Km at low speed (30 - 40 km/h).

- **Self-contained housing**

Figure 140: PV application, self-contained house

Mountain chalet exclusively powered by the electricity produced by the photovoltaic solar panels (Sare, Pyrénées-Atlantiques (64), France – installed in 2004)

- **Pumping station**

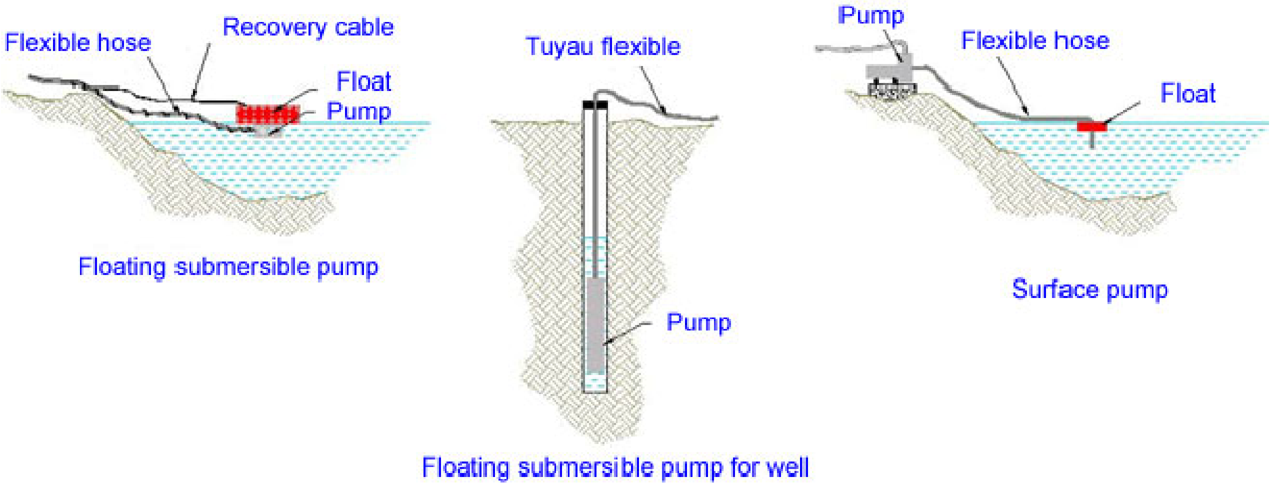


Figure 141: Supplying an (isolated) pump, in a well, on the surface, submersible, etc.

Figure 142: Photovoltaic system for surface pumping

Note the PV panels on the bank and pump on the surface of the pond

- **Lighting**
- **Signalling**

- **Isolated production site**

Figure 143: PV generation in the Béarn countryside (France)

- **Boat**

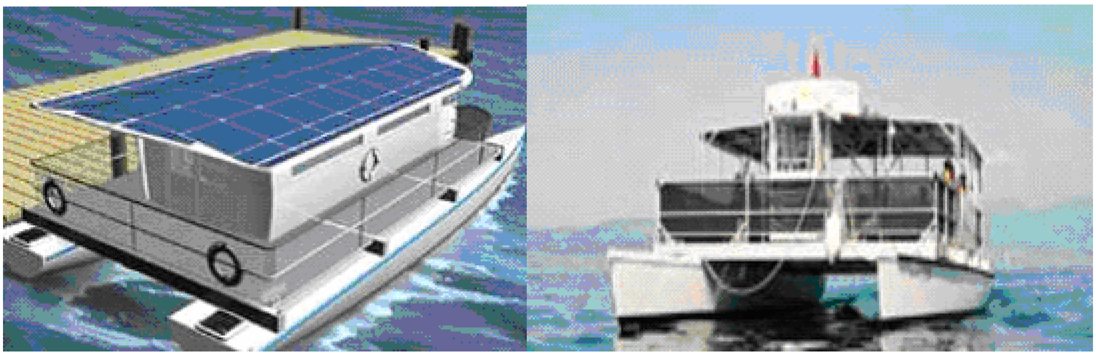


Figure 144: 3D representation and photo of the "Aquabus" solar powered electric boat

- **Solar calculator / solar charger**
- etc.

*These applications are a development of the PVs and **a development of the battery technology** with the desire to increase capacity while reducing the weight of these same batteries (main handicap).*

- **PV power plants**

Figure 145: Power plant in Holland

Large capacity photovoltaic power plants can be installed on roofs instead of in fields.

In the photo, the solar panel roof of the building in Floriade in the Haarlemmermeer polder in Holland is a 2.3 MWc solar power plant connected to the Dutch national electricity grid.

The 19,000 Siemens photovoltaic panels cover an exposure zone of approximately 3 hectares.

We (Total) can also install PV power plants.

Figure 146: PV power plant in Chambéry (France)

Entry into service: inaugurated in June 2005

Installer: Total Énergie

Supplier: Photowatt

Total PV panel area: 1000 m²

Expected performance: The electricity production of around 120,000 kWh/year will be partly used to supply the drinking water reservoir pumps (20% approx.), the surplus will be sold to EDF. The supplement necessary to operate the pumps (night, on overcast days, etc.) is bought from the EDF network.

This type of plant is diurnal, i.e. it functions in the daytime only and of course does not have a set of batteries…

9.5. SPECIFICATIONS

Pour installation, commissioning, reception, specifications, etc., see Total specification **GS EP EL 261** "Solar Power System", latest issue, October 2005.

Some extracts of this document are given below.

Paragraph 3.4: Typical installation/distribution diagram

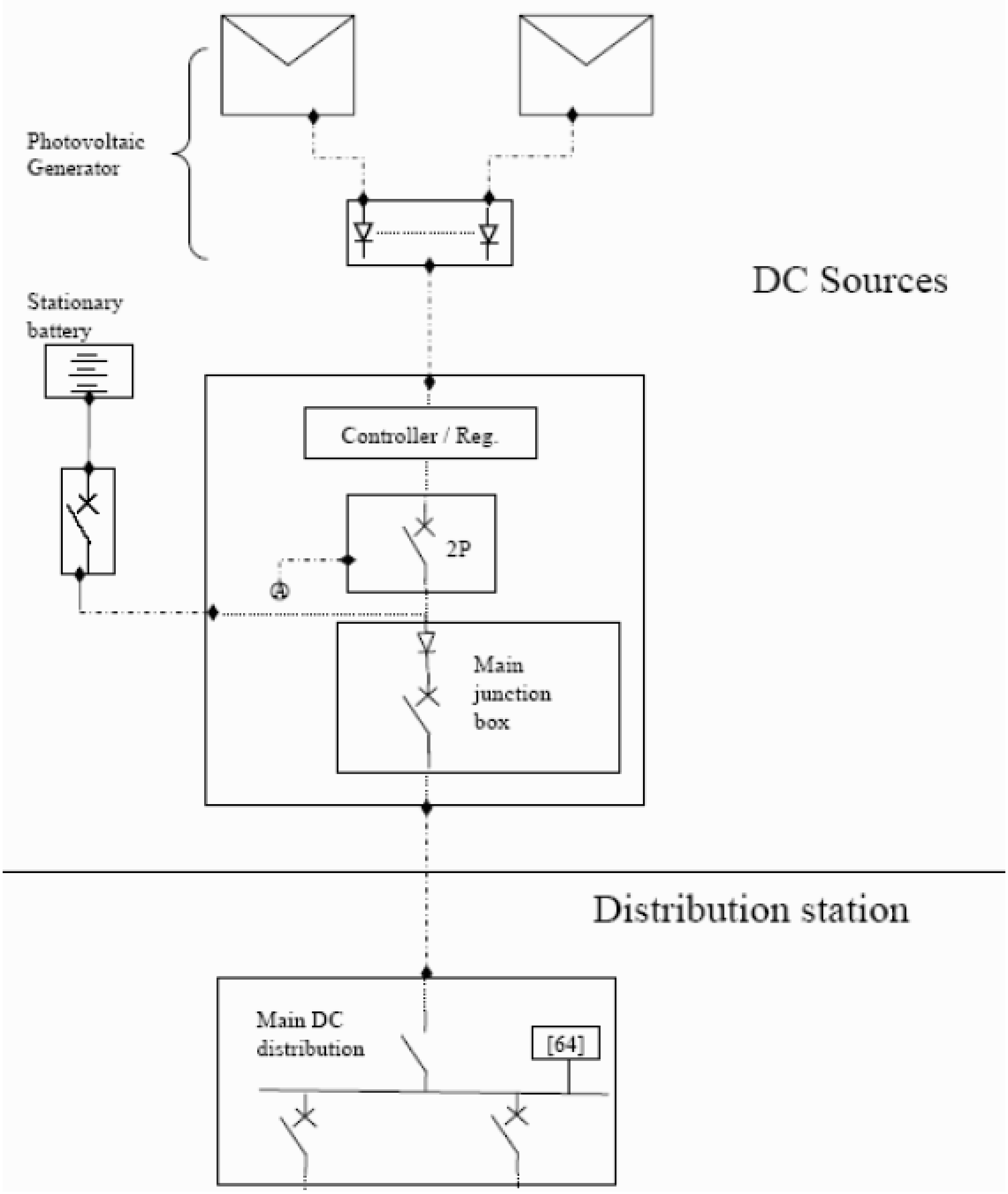


Figure 147: Solar Power System Typical Single Line Diagram - type 1

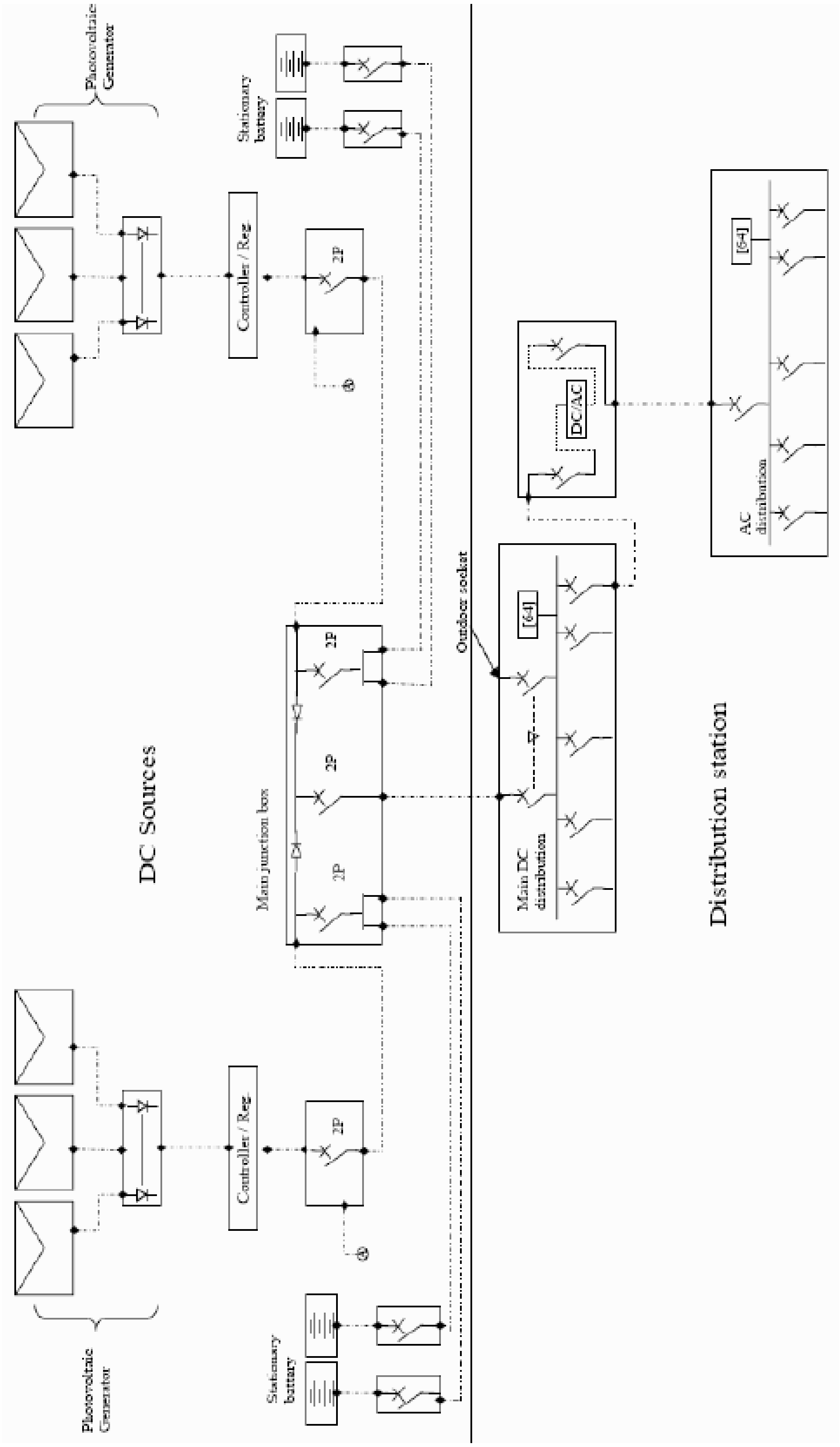
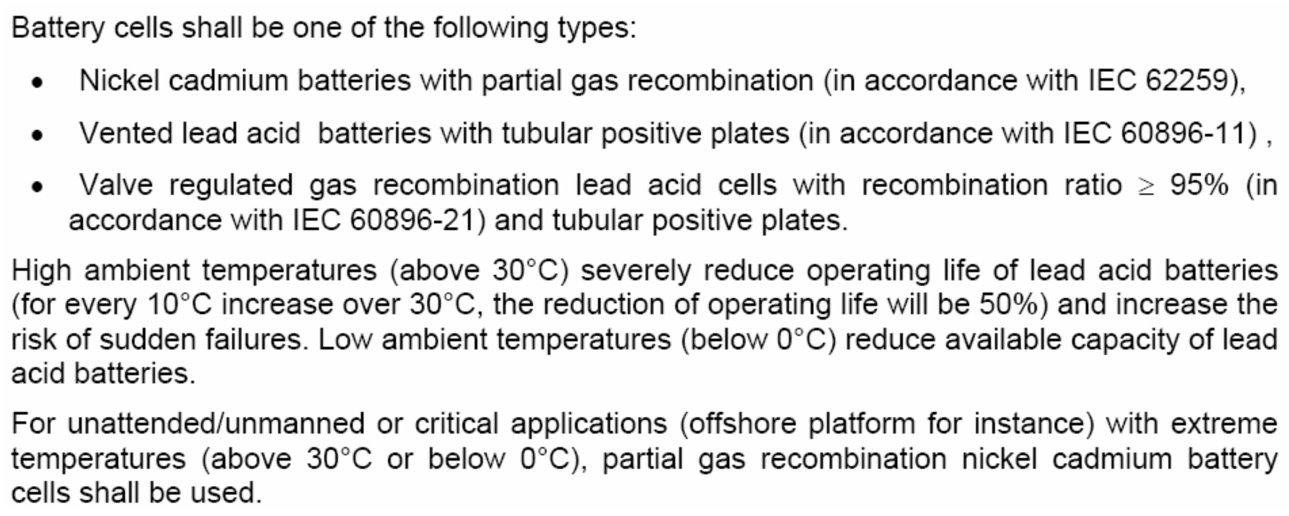


Figure 148: Solar Power System Typical Single Line Diagram - type 2

Paragraph 3.5: Battery types:



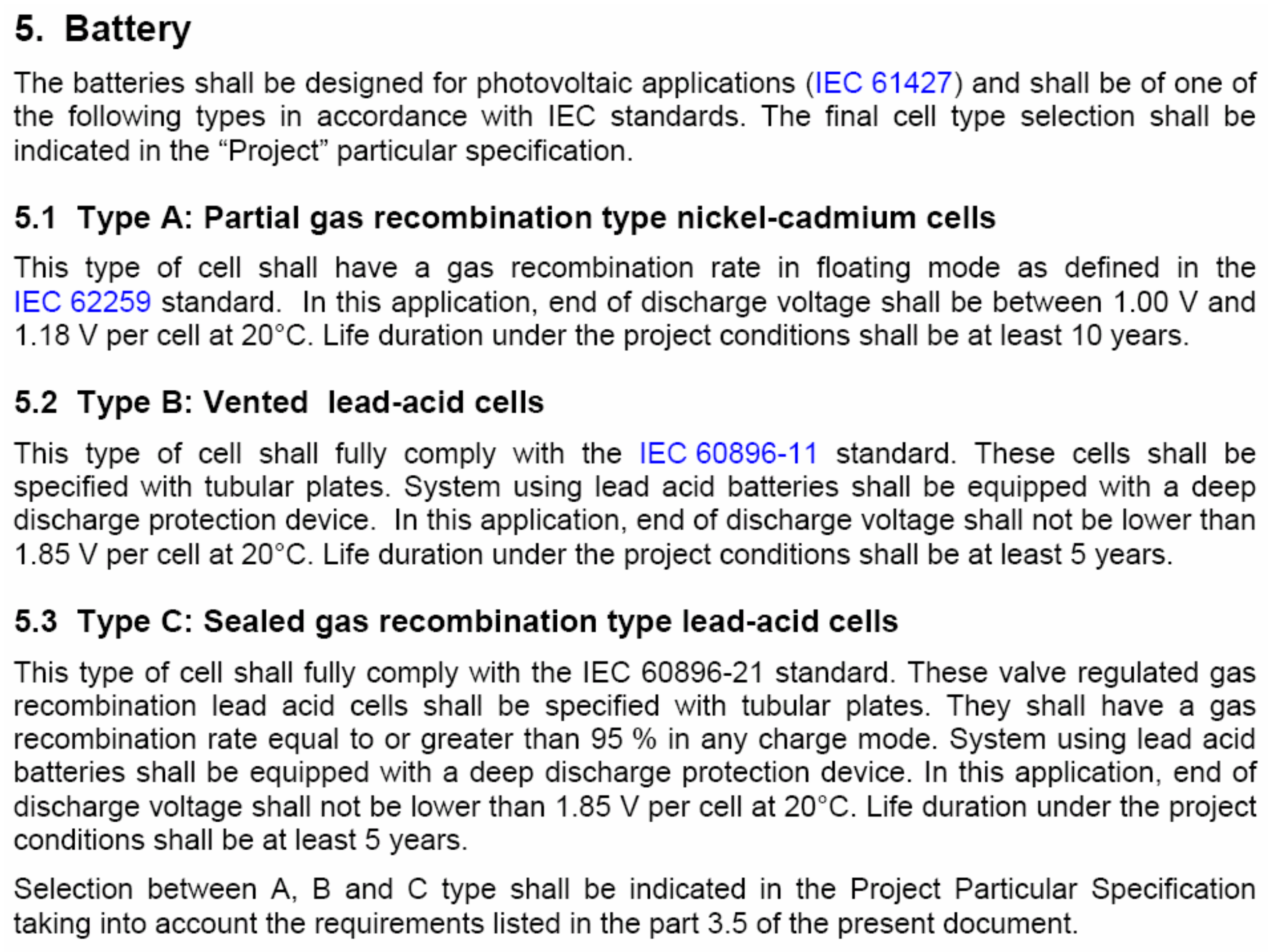
Battery cells shall be one of the following types:

- Nickel cadmium batteries with partial gas recombination (in accordance with IEC 62259),
- Vented lead acid batteries with tubular positive plates (in accordance with IEC 60896-11) ,
- Valve regulated gas recombination lead acid cells with recombination ratio ≥ 95% (in accordance with IEC 60896-21) and tubular positive plates.

High ambient temperatures (above 30°C) severely reduce operating life of lead acid batteries (for every 10°C increase over 30°C, the reduction of operating life will be 50%) and increase the risk of sudden failures. Low ambient temperatures (below 0°C) reduce available capacity of lead acid batteries.

For unattended/unmanned or critical applications (offshore platform for instance) with extreme temperatures (above 30°C or below 0°C), partial gas recombination nickel cadmium battery cells shall be used.

+ Paragraph 5: "Battery" on battery specifications and installation regulations.



5. Battery

The batteries shall be designed for photovoltaic applications (IEC 61427) and shall be of one of the following types in accordance with IEC standards. The final cell type selection shall be indicated in the "Project" particular specification.

5.1 Type A: Partial gas recombination type nickel-cadmium cells

This type of cell shall have a gas recombination rate in floating mode as defined in the IEC 62259 standard. In this application, end of discharge voltage shall be between 1.00 V and 1.18 V per cell at 20°C. Life duration under the project conditions shall be at least 10 years.

5.2 Type B: Vented lead-acid cells

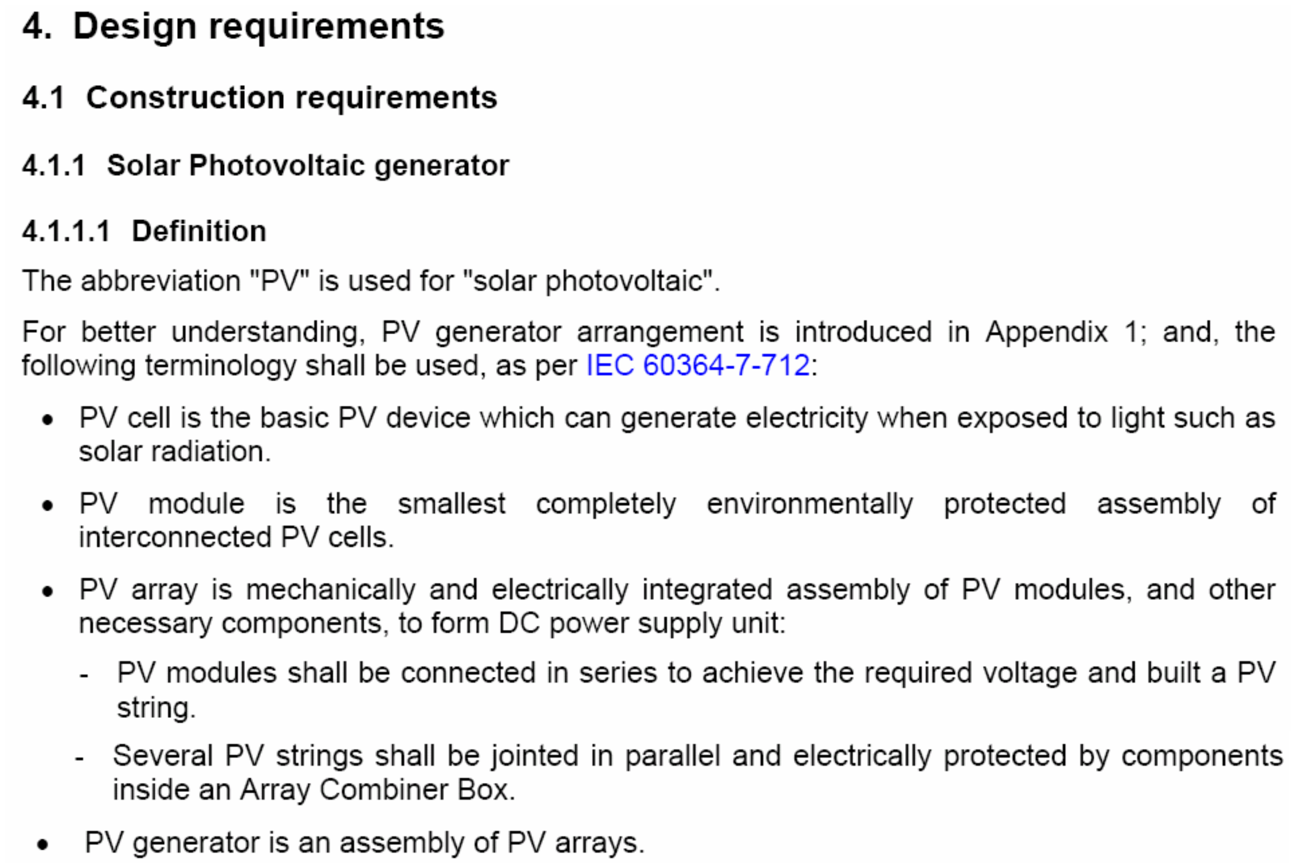
This type of cell shall fully comply with the IEC 60896-11 standard. These cells shall be specified with tubular plates. System using lead acid batteries shall be equipped with a deep discharge protection device. In this application, end of discharge voltage shall not be lower than 1.85 V per cell at 20°C. Life duration under the project conditions shall be at least 5 years.

5.3 Type C: Sealed gas recombination type lead-acid cells

This type of cell shall fully comply with the IEC 60896-21 standard. These valve regulated gas recombination lead acid cells shall be specified with tubular plates. They shall have a gas recombination rate equal to or greater than 95 % in any charge mode. System using lead acid batteries shall be equipped with a deep discharge protection device. In this application, end of discharge voltage shall not be lower than 1.85 V per cell at 20°C. Life duration under the project conditions shall be at least 5 years.

Selection between A, B and C type shall be indicated in the Project Particular Specification taking into account the requirements listed in the part 3.5 of the present document.

Paragraph 4.1.1.1. Definition of installations with solar generators



4. Design requirements

4.1 Construction requirements

4.1.1 Solar Photovoltaic generator

4.1.1.1 Definition

The abbreviation "PV" is used for "solar photovoltaic".

For better understanding, PV generator arrangement is introduced in Appendix 1; and, the following terminology shall be used, as per IEC 60364-7-712:

- PV cell is the basic PV device which can generate electricity when exposed to light such as solar radiation.
- PV module is the smallest completely environmentally protected assembly of interconnected PV cells.
- PV array is mechanically and electrically integrated assembly of PV modules, and other necessary components, to form DC power supply unit:
    - PV modules shall be connected in series to achieve the required voltage and built a PV string.
    - Several PV strings shall be jointed in parallel and electrically protected by components inside an Array Combiner Box.
- PV generator is an assembly of PV arrays.

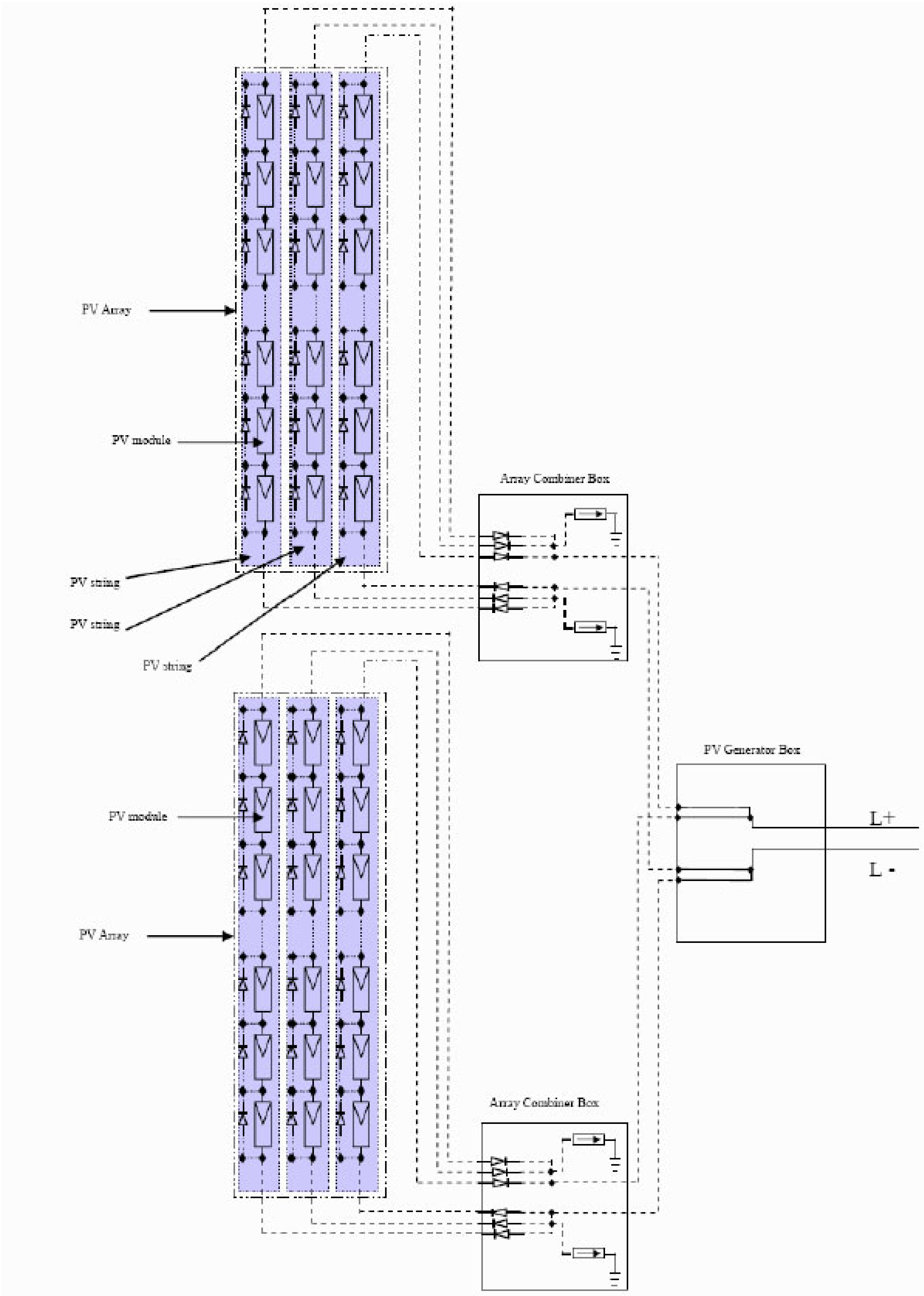


Figure 149: PV Generator arrangement

Paragraph 4.2.2: Size and power of the battery associated with the PVs

The installation is obviously dimensioned according to the load. There is an installed power, the set of batteries must thus have a rating of "x" Amp-hours, the PV generator must be able to supply the whole installation and recharge the batteries at the same time. The batteries must not only "last" the whole night but also during the day if there is no sunshine.

This lack of sunlight or low sunlight may last for some time, i.e. "x" consecutive days. The ELE 261 specification is based on the NASA statistics relating to the minima/maxima conditions and deduces from this a complicated correction factor calculation for the rated power of the batteries.

I didn't understand..., I asked the people around me, nobody had understood either, the paragraph concerned is given below with the example/appendix and "Good Luck" if you need to determine or just check the power of the batteries installed on "your" platform. So ask the Project Team and/or the person writing the specifications.

4.2.2 Stationary battery system

Stationary battery system shall be sized in accordance with the following requirements:

- Autonomy in order to cover (see example in appendix 4):
    - The maximum equivalent number of "NO-SUN" days seen in the consecutive X-day table: the consecutive X-day is the number of consecutive days where the minimum available insolation ratio for each month is higher than 49-50%. Then the maximum equivalent number of "NO-SUN" day is extracted from the "International Available Tables" about Surface Meteorology and Solar Energy (NASA data bases).
    - Appropriate ageing de-rating factor taken into account for maximum ambient temperatures in order to achieve the design life:
        - for lead-acid cells (see part 3.5):

Max. Ambient T°	20°C	30°C	40°C	50°C
Ageing factor	1.2	1.25	1.88	2.85

Note : Above table valid only for lead acid batteries, to achieve a 5 year design life.

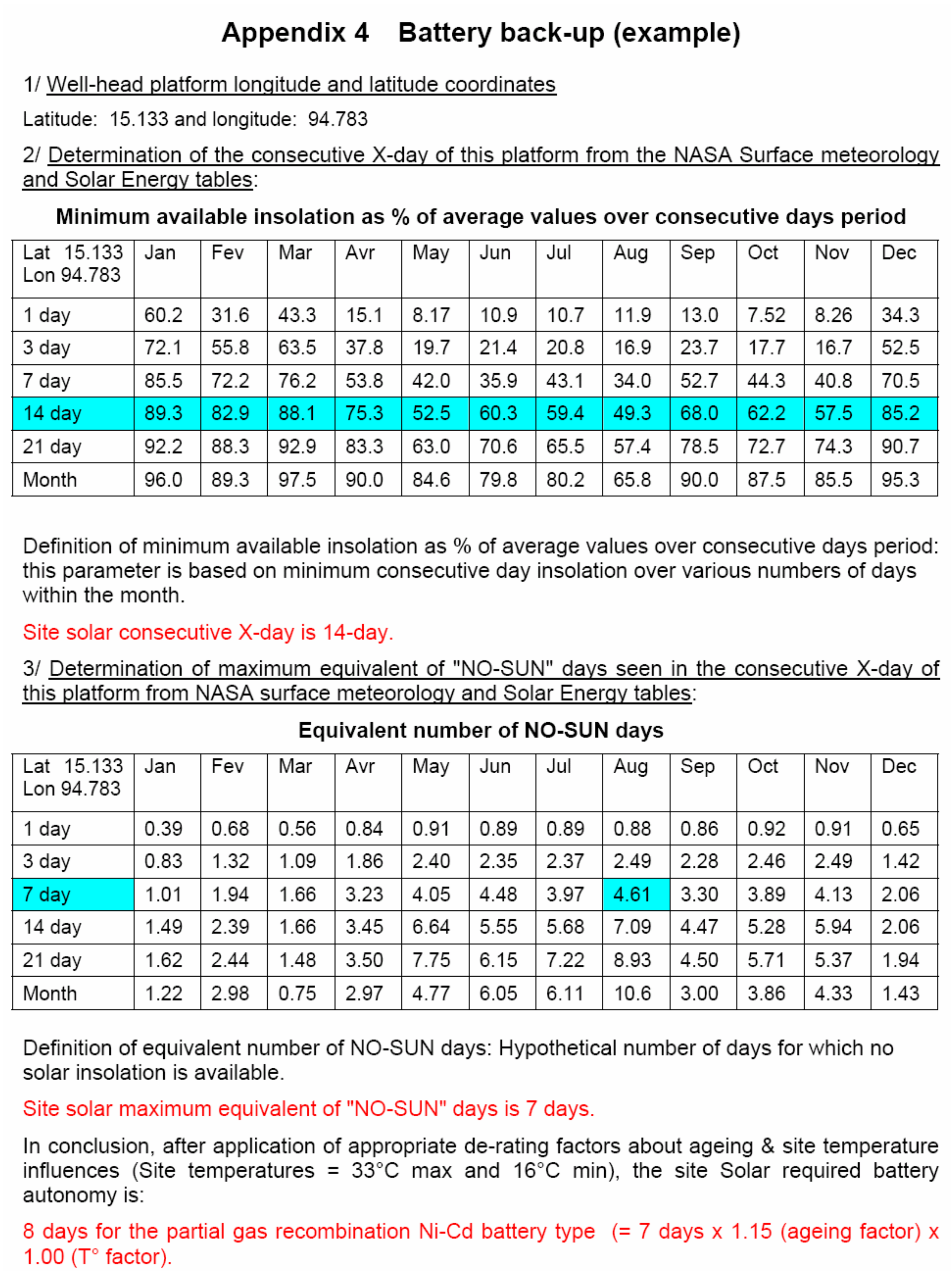
- for Ni-Cd cells (see part 3.5):

Max. Ambient T°	20°C	30°C	40°C	50°C
Ageing factor	1.15	1.15	1.18	1.25

Note : Above table valid only for Ni-Cd batteries, to achieve a 10 year design life.

- Appropriate temperature de-rating factor shall be taken into account for cold/low ambient temperatures (below 0°C) in order to achieve the required battery cell performances. Exact temperature de-rating factors shall be given by the battery MANUFACTURER and shall be for 0°C:
    - for lead-acid cells (see part 3.5): 1/0.80 = 1.25;
    - for Ni-Cd cells (see part 3.5): 1/0.90 = 1.11.

- Power supply of :
    - Maximum continuous electrical consumption increased by 15% for spare capacity,
    - All peak electrical consumptions increased by 15% for spare capacity without decreasing solar power system autonomy;
- End of discharge voltage required in accordance with chosen battery cell type and specified in the chapter 5 of the present document;
- Specified load voltage tolerance on the DC main distribution bus-bar: -15% / +10% without taking into account the voltage drop of the blocking diodes (if any - 0.6V/diode) inside the main junction box, on each DC source.



Appendix 4 Battery back-up (example)

1/ Well-head platform longitude and latitude coordinates

Latitude: 15.133 and longitude: 94.783

2/ Determination of the consecutive X-day of this platform from the NASA Surface meteorology and Solar Energy tables:

Minimum available insolation as % of average values over consecutive days period

Lat 15.133 Lon 94.783	Jan	Fev	Mar	Avr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	60.2	31.6	43.3	15.1	8.17	10.9	10.7	11.9	13.0	7.52	8.26	34.3
3 day	72.1	55.8	63.5	37.8	19.7	21.4	20.8	16.9	23.7	17.7	16.7	52.5
7 day	85.5	72.2	76.2	53.8	42.0	35.9	43.1	34.0	52.7	44.3	40.8	70.5
14 day	89.3	82.9	88.1	75.3	52.5	60.3	59.4	49.3	68.0	62.2	57.5	85.2
21 day	92.2	88.3	92.9	83.3	63.0	70.6	65.5	57.4	78.5	72.7	74.3	90.7
Month	96.0	89.3	97.5	90.0	84.6	79.8	80.2	65.8	90.0	87.5	85.5	95.3

Definition of minimum available insolation as % of average values over consecutive days period: this parameter is based on minimum consecutive day insolation over various numbers of days within the month.

Site solar consecutive X-day is 14-day.

3/ Determination of maximum equivalent of "NO-SUN" days seen in the consecutive X-day of this platform from NASA surface meteorology and Solar Energy tables:

Equivalent number of NO-SUN days

Lat 15.133 Lon 94.783	Jan	Fev	Mar	Avr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	0.39	0.68	0.56	0.84	0.91	0.89	0.89	0.88	0.86	0.92	0.91	0.65
3 day	0.83	1.32	1.09	1.86	2.40	2.35	2.37	2.49	2.28	2.46	2.49	1.42
7 day	1.01	1.94	1.66	3.23	4.05	4.48	3.97	4.61	3.30	3.89	4.13	2.06
14 day	1.49	2.39	1.66	3.45	6.64	5.55	5.68	7.09	4.47	5.28	5.94	2.06
21 day	1.62	2.44	1.48	3.50	7.75	6.15	7.22	8.93	4.50	5.71	5.37	1.94
Month	1.22	2.98	0.75	2.97	4.77	6.05	6.11	10.6	3.00	3.86	4.33	1.43

Definition of equivalent number of NO-SUN days: Hypothetical number of days for which no solar insolation is available.

Site solar maximum equivalent of "NO-SUN" days is 7 days.

In conclusion, after application of appropriate de-rating factors about ageing & site temperature influences (Site temperatures = 33°C max and 16°C min), the site Solar required battery autonomy is:

8 days for the partial gas recombination Ni-Cd battery type (= 7 days x 1.15 (ageing factor) x 1.00 (T° factor).

Figure 150: Battery back-up calculation example for a solar cell generator system

Paragraph 6: Charging control

This depends on the battery type, see Operator course EQ160 chapter 5 dedicated to battery charging and course SE090 on chargers / rectifiers.

Reminder: All the specifications talk about "floating" voltage, but what is important is that a "floating current" must be controlled, it must be a minimum value (or even zero in certain batteries). This is just like for the protection of persons, we always talk about a hazardous voltage but you can touch 220 kV (which you should not do, of course). As long as you are insulated, as long as the current passing through the body remains below a certain "threshold", there is no hazard. The same is true for batteries, too high a charging current "kills" them.

10. SAFETY WHEN WORKING WITH BATTERIES

When working with Batteries in Battery-room or in Uninterruptible Power Supplies (UPS) cubicles, it is important that the Personnel is aware of the inherent dangers that may occur on this type of equipment.

The aim of this chapter is to describe these dangers and the necessary precautions that must be taken to ensure safe working practice.

IMPORTANT NOTE:

Ensure that each section in this chapter has been read and fully understood before carrying out any task on Batteries or UPS / Battery Charger Equipment.

The safety precautions for both batteries and UPS are dealt with, separately

There are two main types of lead-acid batteries which may be used in UPS applications:

- Open - vented
- Sealed or Valve Regulated VRLA

The open vented battery requires regular routine maintenance and is usually sited in a separate battery room. Using older technology, it has a wet cell construction and requires different safety considerations.

Sealed VRLA batteries are self contained more environmentally friendly (apparently) and do not need the same level of maintenance as open vented batteries, however many of the Safety Precautions still apply.

10.1. WORKING WITH BATTERIES

Batteries contain acid and lead. Individually they operate at fairly low voltages, but hold very large amounts of power (high current capacity). When connected in a series and / or parallel string, voltage and current may be substantially increased to dangerous levels.

Battery safety is strait forward but very important. When working around batteries, keep in mind that they can be very dangerous when improperly treated.

10.1.1. Battery hazards

The following hazards have the potential to cause harm or damage to personnel or equipment.

- **High DC Voltage :** Batteries when connected in a series string may have DC voltages in excess of 400V DC.
- **Electric Shock :** Batteries have the potential to give serious electric shocks due to their high voltage and capacity.
- **Short Circuit Terminals :** Connecting the two posts together on one battery, or the wrong posts together on multiple batteries, can cause a short circuit. A short circuit in a battery causes it to try to discharge completely, very quickly. These high current levels can cause serious burns, can cause the battery to rupture or explode, causing severe injury, and possibly death.
- **Electric Arc if short circuit :** It is possible to draw a considerable arc from a battery even if it has a low terminal voltage, if a short circuit is applied. This could result in a serious burn.
- **Acid Spillage :** Although the acid found at the top of the battery will typically not cause immediate damage to unprotected skin, it is best to avoid contact, or if contact occurs, immediately wash the exposed area with soap and running water. Acid spillage is also possible if a battery casing is damaged or cracked.
- **Acid Burns :** Battery acid will eat holes in clothing (only evident after washing), and similar to other household chemicals, can cause blindness or severe eye damage.
- **Hydrogen Gas :** Batteries give off hydrogen gas when they are being charged, and are nearly full. However, it is always possible that a hydrogen gas bubble is trapped between battery plates and is released later.
- **Explosion Risk :** If there is a degradation or failure in the ventilation of the battery area, a build up of hydrogen (a highly volatile gas) could occur. If this situation is allowed to persist there is a risk of explosion.

Figure 151: Exploded battery

10.1.2. Safety Precautions

Always observe the following precautions when working on batteries.

10.1.2.1. General

- Before working on batteries, ensure that the battery string is isolated from the charger usually by removing the fuses or tripping the battery circuit breaker.
- When removing a battery always disconnect the battery positive (Earth) connection first.
- When installing a battery always connect the battery positive (Earth) connection last.
- Do not smoke or have any other flames or sparks near the batteries.
- Ensure that the place of work is kept well ventilated at all times.
- Do not clean batteries with dry cloths.
- Batteries are heavy, observe the correct lifting techniques when handling or transporting batteries. With weights above 24 kilos lifting aids should be used.

10.1.2.2. Safety Clothing

- Wear safety glasses or a safety face screen/shield associated with the helmet. If your personal glasses have metal frames, either wear an elastic glasses retainer strap, or remove the metal framed glasses and substitute plastic framed safety glasses.

Figure 152: Safety face screen

- Always wear appropriate safety clothing, gloves an apron or old clothes.
- When handling electrolyte, wear face shields (face shields should not have metal reinforcing rims, which could cause a battery short if dropped), rubber aprons, and rubber gloves (like in kitchen for dish washing); avoid splashes.
- Remove all watches and other metal jewellery. For avoiding metal contact between batteries poles but as well to avoid spill of acid on your “family gift”.
- Wear electrically certified rubber gloves when making final battery connections.

10.1.2.3. Safety Tools

- Always use insulated tools and never allow terminals to be connected together inadvertently.

Figure 153: Safety tools

Not insulated tools in contact with battery posts could behave like « fuse ». You would be surprised to see it! And it would be (also) better to not have your hands (even with gloves) in the next proximity; the arcing is impressive on high Capacity Batteries.

- Ensure tools are small enough that they cannot easily contact and short battery terminals. Use always adapted tools, ban the adjustable wrench !!

- Always tighten battery terminal bolts with an appropriate torque wrench. Do not over tighten.

10.1.2.4. Acid, Electrolyte Spillage

The electrolyte is injurious to skin and clothing and must therefore always be handled carefully.

Avoid contact with battery acid, or if contact occurs, immediately wash the exposed area with soap and running water. Do not use bicarbonate of soda on the skin, which may aggravate the burn.
The eyes in particular should be guarded. If acid is splashed into the eyes or anywhere on the skin, flood with water for at least 15 minutes and get medical attention.

Ensure that an acid neutralising solution is available at all times.
Sodium Carbonate Anhydrous (Soda Ash) is provided for this purpose.
For neutralization of acid electrolyte spilled on the floor or rack, a bicarbonate of soda solution (120 g per litre of water) is recommended.
When mixing acid always add acid to water and not water to acid.

For neutralization of Ni-Cad battery electrolyte (potassium hydroxide), keep a concentrated solution of 150 g of boric acid powder per litre of water available for neutralizing spills on skin or clothing. Use plain water to wash up spills of potassium hydroxide on the cells or racks.

10.1.3. Battery Hazards

Keep battery terminals clean and covered with petroleum jelly to prevent terminal oxidation.

10.1.3.1. Explosive Hazard

All storage batteries give off a highly explosive mixture of hydrogen and oxygen when gassing.

Therefore, never permit sparks, open flame, lighted cigarettes near a storage battery

Post "No Smoking" signs where they are clearly visible to anyone entering the battery room area.

A non metallic flashlight (Ex type for use in explosive atmosphere) is mandatory for battery inspection.

Use only alcohol thermometers when taking electrolyte temperatures.

Keep all battery connections tight to avoid sparking.

Never lay any metallic object on top of a battery.

A class C, 4.5-kg fire extinguisher should be mounted just inside the battery room door. Carbon dioxide (CO_2) is not recommended because of the potential for thermal shock to the batteries.

Extractor / Ventilation to equip the battery room or the cubicle.

10.1.3.2. Flame arrestors – purpose and cleaning

Each vented battery cell has to be equipped with a flame arrester designed to prevent destruction of the cell attributable to an ignition of gases outside the cell.

The diffuser material of flame arresters can become partially clogged from electrolyte spray if cells are overfilled with water or have been excessively overcharged.

Flame arresters should therefore be inspected annually, and all arresters having clogged pores should be replaced or cleaned as follows:

- Immerse the flame arrester several times in fresh water in a plastic bucket.
- Eject the water after each immersion by vigorous shaking or an air blast.
- Dump and refill the bucket with clean water for every 15 flame arresters that are cleaned.
- Do not use any cleaning or neutralizing agents in the water because any dry residue may clog the pores of the diffuser materials.

10.2. BATTERY ROOM

The batteries in a room create a type 1 risk zone due to the gassing. Even if the batteries are sealed, there may be leaks and therefore flammable gases may be present. Ensure that the battery premises are permanently ventilated, they must be equipped with gas detectors and/or fire detectors.

For battery servicing and maintenance, carry the necessary authorisations and wear the safety equipment, i.e.:

- ***Obtain a Permit to Work (PTW)***. *This is the first thing to do, the isolating procedures, general protection procedures, and other procedures have therefore been carried out and you can start the job in safety…*
- ***Helmet with face mask***. *Goggles alone will not protect you from acid splashes on you nose… And if you have a pockmarked nose, someone may ask you where you stuck it...*
- ***Rubber gloves***. This is the (only) acid-resistant material. *You will look silly wearing fabric gloves which are full of holes… and with hands which are full of holes.*
- ***Rubber protection apron***. *A spurt of acid, or acid spray can fly in any direction, don't be afraid of looking like a butcher or a welder wearing your apron.*
- ***Rubber boots***. *Rubber will resist acid and other "corrosive" liquids, your "Nikes" or 400 euro "Westons" will not be very pleased, nor will you…*
- ***Insulated tools.*** *A spanner can slip, you're only human. An electric arc, or arcing across the battery terminals can damage your eyes and skin (due to the spatter).*
- ***A dose of good sense.*** *Even if it doesn't seem like it, working on batteries can be (very) hazardous. Work calmly and carefully, and avoid continually breathing above the batteries, there are other ways to get a high...*

10.2.1.1. Civil Work

"No Smoking," No Sparks," or "No Open Flame" signs should be posted on the outside of the door.

Metal battery racks shall be grounded.

Concrete floors shall be painted with acid-resistive paint (alkaline resistive) for Ni-cad batteries.

Electrical receptacles and light switches should be located outside of battery areas.

A 10-pound class C fire extinguisher should be located just inside the battery room door. The fire extinguisher should not be a $C0_2$ type to prevent thermal shock to the battery.

Exit from the battery room must be kept clear at all times

A combination eyewash, face, and body spray unit must be located within 7.5 m of each battery room or battery system.

These units can be permanently mounted and connected to the facility's potable water system, or can be of a portable pressurized type.

Keep the area in front of the washing station clear.

Gas detectors to equip the battery room as per standards.

10.2.1.2. Ventilation:

A determination must be made for each battery area as to whether sufficient ventilation is being provided to ensure adequate diffusion of hydrogen gas during maximum gas generating conditions.

In a country or area where HVAC is required, the equipment must be adapted for the specific use of battery room

10.2.1.3. Example of Non Sealed Battery Room Civil Works Arrangement

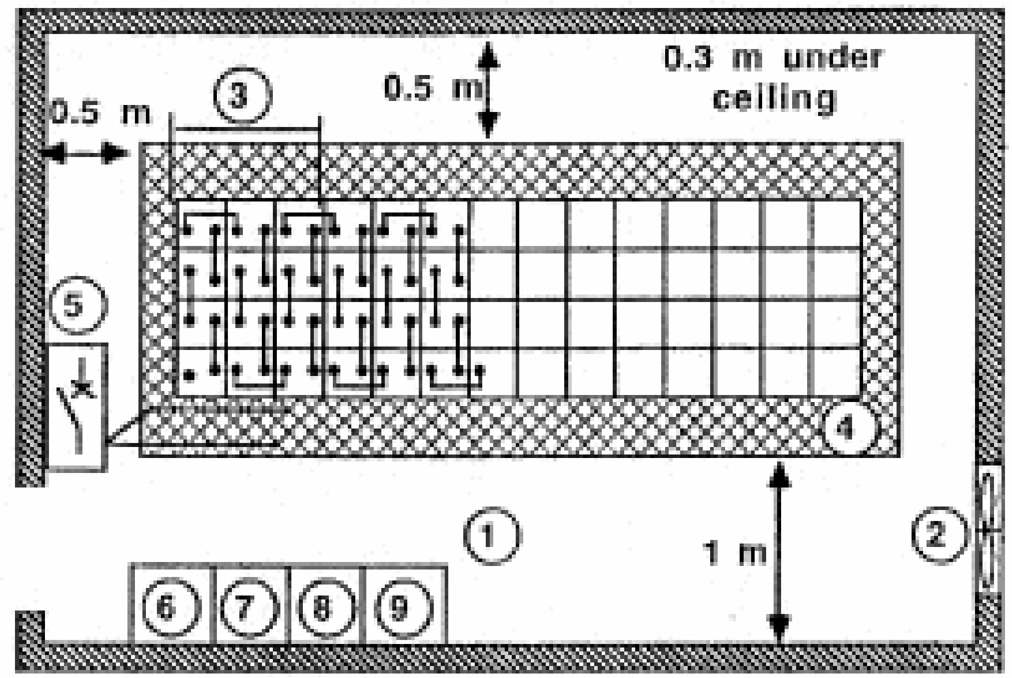


Figure 154: Non sealed battery room civil works arrangement

(1) Floors and walls
- Slope - gutter - retention tank
- Anti-acid coating (asphalt)

(2) Ventilation
- High High aspiration: d = 0.05NI (m3)
- Mains off if break-down

(3) Batteries
- Placed as nobody can touched two denuded pieces with a voltage > 150 v

(4) Maintenance floor
- Non-sliding duckboard - Isolated from floor

(5) Connections
- Connections as short as possible
- Command and circuit-breaker will be non deflagration type

(6) Fire proof materiel
- Powder fire-extinguisher or CO 2

(7) Security equipment
- Security glasses - gloves - shower

(8) Control equipment
- Densimeter -filler -thermometer

(9) Explosion proof security
- Hydrogen detection
- Temperature sensor

10.3. ELECTRICAL ROOM – UPS AND CHARGER CUBICLES

Everything has been planned for (in theory).

The *air must be continuously renewed*. *If the ventilation stops or if there is an air conditioning failure, this probably means that there is a shutdown and that the batteries must perform their discharge functions. Important: in this case beware of the temperature rise and the gassing!*

The battery cubicles are equipped with ***fans / extractors***. *These fans must also operate continuously, you must clean them regularly. Also, plan to systematically replace them. Like all equipment, they have a certain lifetime.*

Voltage and current indicators show the charging conditions. *A daily check must be carried out, a surveillance log must be kept. Here too, beware of the "floating" values where voltage and particularly current is concerned. And if the UPS / charger cubicles are not equipped with indicators, have them installed! And make sure that everybody knows that it is really stupid to make cheeseparing economies… It costs (much) more to replace a complete battery rack (particularly when it has exploded... and it does happen…)*

Electrolyte leaks. *This is not planned. At least, it shouldn't happen, but as you know there is a difference between theory and reality... Check the interior of the cubicles regularly to detect any leaks, a visual check works best in this case, even if the battery rack is equipped with a centralised cell management system (which in any case does not exist on our sites). It may take us a certain amount of time to see the fall in the electrolyte level, if it is just due to a crack in the battery casing.*

10.4. BATTERIES ON THE SITES

These will be the batteries to start the diesel turbo generator set. On platforms, the batteries supply the instrumentation system, the telecommunications system, the navigation aids, etc.

These same circuits/equipment are normally supplied by an auxiliary power source which charges the batteries at the same time (solar cells, motor-generator set, thermo-electric system, etc.).

Here too, you must first obtain a permit to work, you are going to work on a sensitive power source and the safety procedures must be respected.

If you are in zone 1 or 2, beware of sparks when disconnecting the batteries!

For the installation of the batteries and their charging sources, see the installation conditions according to GS EP ELE 079 below.

Equipment	***Risk zone (Ex)***			***No risk***
	Zone 0	**Zone 1**	**Zone 2**	
Batteries	Prohibited	**EEx "e"** Short circuit protection. Insulating housing. Natural ventilation. Certification. Assembly in box + battery box	**EEx "e" or IP23/IK08** minimum	Short circuit protection. Insulating housing. Natural ventilation. **IP22/IK08 minimum**
Control panel	Prohibited	**EEx "e"** **EEx "d"**	**EEx "e"** **EEx "d"**	Industrial type
Solar panels/ Turbogenerator sets/Generator sets.	Prohibited	**EEx "em"**	**EEx "n"**	Industrial type

Table 21: Installation of batteries and accessories in risk zones

And when working on the batteries, follow the same safety instructions as for the battery room.

10.5. CHARGING BATTERIES IN THE WORKSHOP

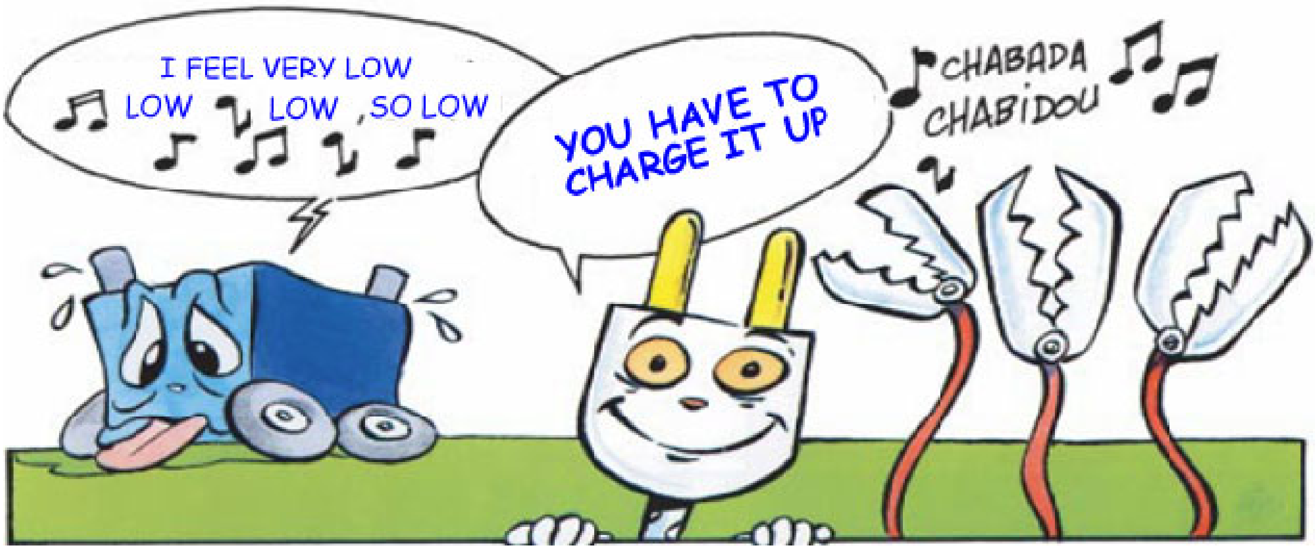
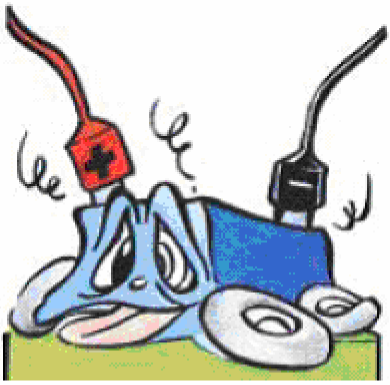


Figure 155: Flat battery – it needs charging

You have replaced one or more batteries on site, you have taken them to the workshop, or you are at home and you have to charge your car battery.

Here are the basic tips and recommendations.

10.5.1. Charging sequence, preparation



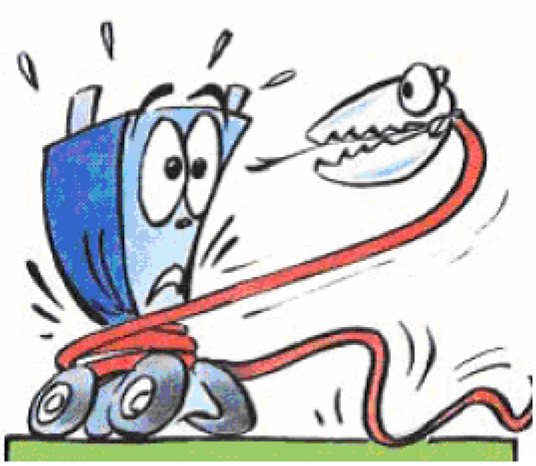
To disconnect a battery, first remove the negative lead

Figure 156: Disconnect to the negative lead first

Check the electrolyte and top up if necessary

Figure 157: Check the electrolyte level

Important: wear the safety equipment. Top up with water only (never add acid). But there may be spills and splashes. Clean up if this is the case.



Avoid using crocodile clips. Instead use terminal clamps tightened by protected screws.

Figure 158: Avoid crocodile clips

Crocodile clips do not necessarily give a good contact or the correct tightening, they may jump off (without warning) and as they normally have a powerful spring, they risk ending up where we do not want them to be (and create a short circuit).

10.5.2. Charging

As shown in the figure:

Connect the battery charger's positive lead to the positive battery terminal and connect the battery charger's negative lead to the negative battery terminal (*it seems obvious and even silly to write this down but it is not necessarily obvious for everyone – think about blondes and about certain film sequences – the "7th Company" among others…).*
Slacken off the battery vent plugs, the battery must be allowed to "breath" during charging.

When the battery is connected, connect the charger or just switch it on.

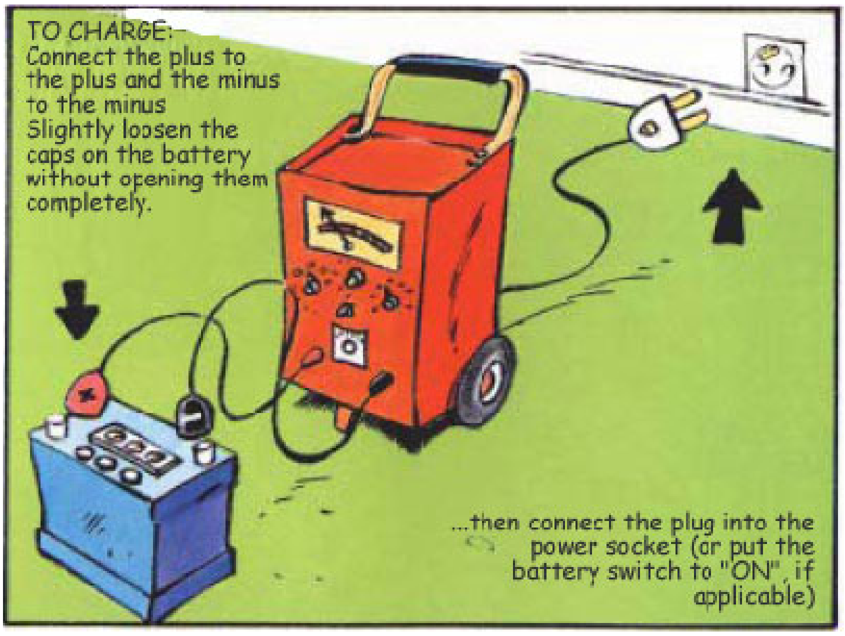
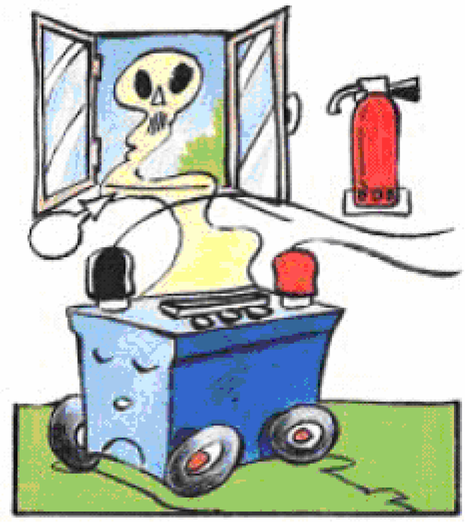


Figure 159: Plug in and switch on the charger



You are applying a current to an electrolyte, which is a mixture of water and acid. This produces electrolysis and gives off gases including hydrogen which is considered to be (highly) explosive. This is why you have to slacken off (and even remove) the vent plugs (where the batteries allow it). Remember to ventilate the area where the batteries are being charged, just as in a battery room.

Figure 160: Ventilate the battery charging area

Sealed batteries which have nonremovable vent plugs are equipped with a system equivalent to a PSV system.

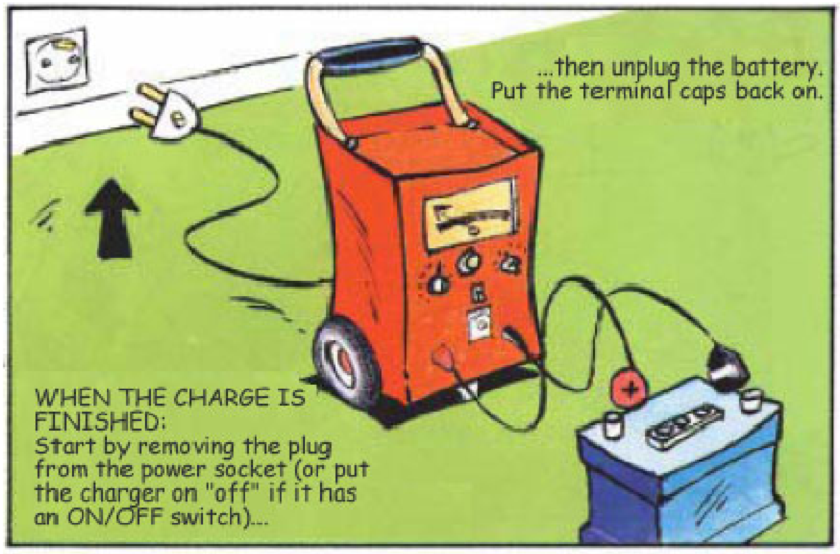
There must obviously be no flames or hot spots in the charging environment. And smoking is strictly prohibited.

NB: each battery vent plug (removable type) has a vent, a "hole" which allows gassing during "normal battery operation". Remember to clean and clear this duct using thin steel wire and also clean these vent plugs.

10.5.3. During charging

Depending on the battery type, the charging is different and the charging method can also be fast, accelerated, boosted, etc. See the Operator course.
Regularly check the charging current and voltage and adjust if necessary.

Figure 161: Check the charge, adjust the charging rate

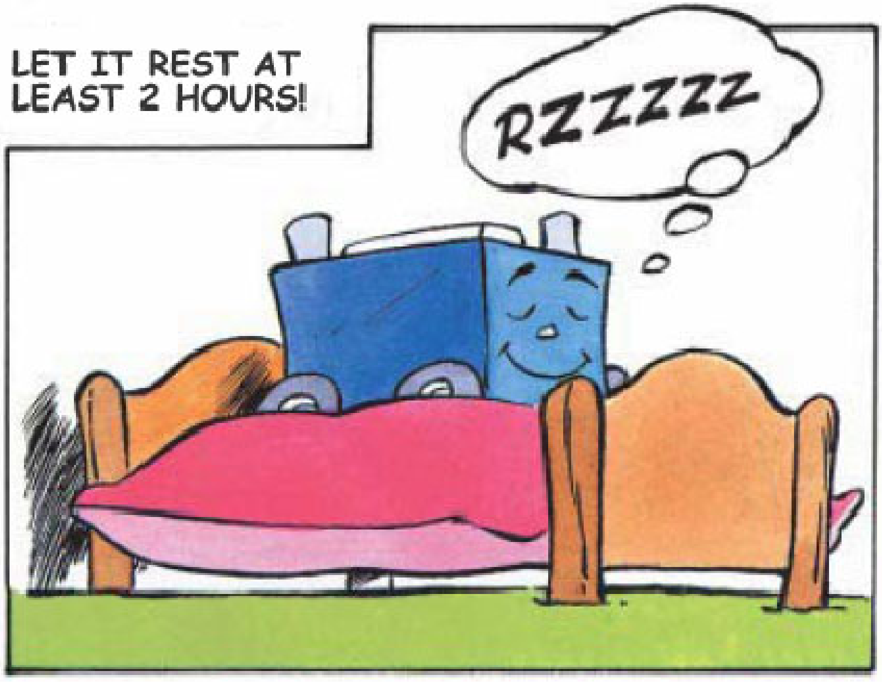


And when the battery is charged, first stop the charger.

Figure 162: Stop the charging

Then disconnect the battery

If your battery has been removed, allow it to stand for a moment before reinstalling it.



You like to have a nap yourself after a big meal, don't you?

Figure 163: Allow the battery to stand after charging

And now: get to work!

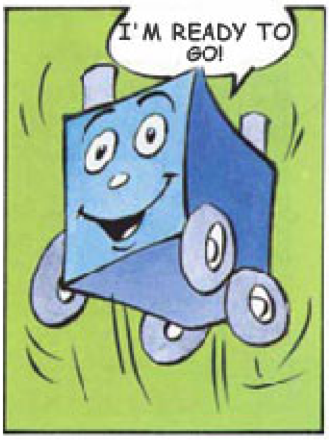


Figure 164: The battery is ready to use

10.5.4. Destruction of batteries

Do not allow worn out batteries (those which get in your way) to "wander". They contain lead, acid and are hazardous for the environment, but they can be recycled!

At home, go and see the local scrap merchant, he will take your old battery... to recover the lead. Important: he does not necessarily know what to do with the other materials and the electrolyte. Take your old battery to a specialist centre or quite simply to your local garage.

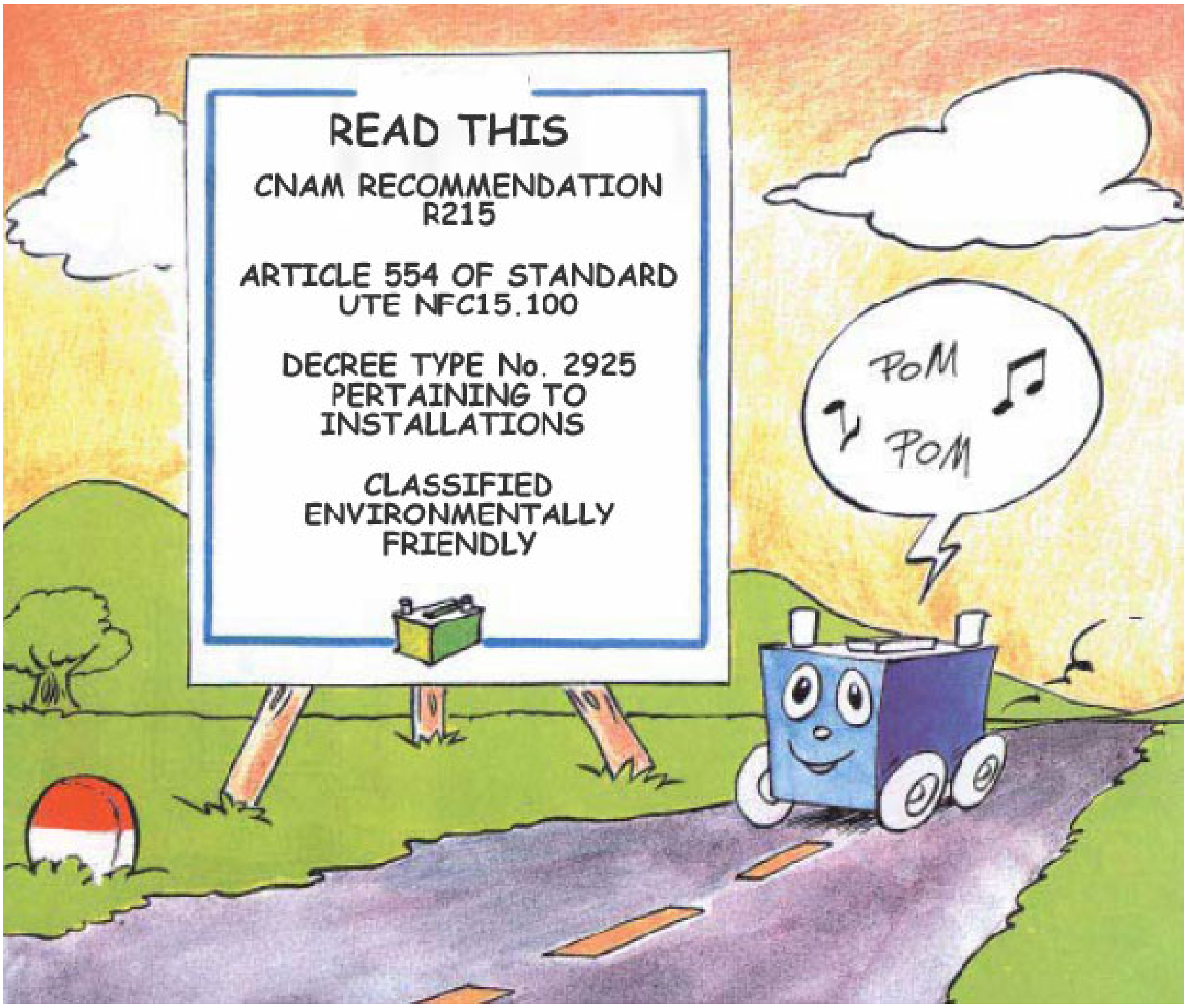


Figure 165: Get rid of your old batteries "intelligently"

10.6. PREVENTING EXPLOSION RISKS

10.6.1. Recommendations

Recommendations adopted by the National Technical Committees for the French Transport and Handling Industries and Metallurgical Industries on 26 November and 2 December 1982.

Many incidents and accidents are caused by explosions due to storage batteries.

These explosions mainly take place:

- When charging and discharging the battery
- When making the connections between the charger and the battery
- When making makeshift connections to the battery terminals
- When connecting the battery to the charger or to the electric circuit it powers

And by decreasing order of importance:

- In the garage (off the vehicle, handling equipment or plant equipment)
- On the vehicle, handling equipment or plant equipment
- In the workshop (off the vehicle, handling equipment or plant equipment)
- At the charging station.

Remember that during battery charging (and to a lesser extent after charging) a certain amount of hydrogen is given off which, when mixed with the ambient air, creates a very large explosive zone: a spark in an environment between 4% and 72% hydrogen will cause an explosion.

Sealed batteries are an explosion hazard because they give off gas if the charging current is too high.

The following recommendations apply to all storage batteries in general and more especially to lead batteries.

In companies where all or part of the personnel charge storage batteries or carry out work on batteries (even as a secondary or occasional activity) the Company Managers must take the following measures or ensure that they are taken in addition to the regulations in force.

10.6.1.1. Connection

Before charging, make the necessary connections starting from the battery: after charging disconnect the connections starting from the mains power supply.

Disconnect the charger when it is no longer used.

Avoid using crocodile clips and instead use protected sockets which differ according to the terminals; in all cases, check that the polarities match: + with + and – with –.

Check the battery before connecting it to its operating circuit.

10.6.1.2. Charging operations

Before charging, remove the battery box cover if there is one. For the vent plugs, check the manufacturer's instructions which will be displayed at the charging stations.

For accessible batteries, isolate the terminals and protect the cell connectors by insulating strips and, for traction batteries, ensure that there is an insulating protective plate between the cover and the battery.

Insulate the battery handling pick-up means.

Check the electrolyte level when this is specified by the supplier, and check that the charger is operating correctly.

Check the charging current value.

Allow the charged battery to stand sufficiently long enough before it is put back into service on a vehicle, handling equipment or plant equipment (e.g. 2 h), this is because degassing may continue for some time after charging.

Regularly check the electronic charge controller on the vehicle, handling equipment or plant equipment.

10.6.1.3. Charging premises

Carry out the charging in suitable, ventilated premises (French NF C 15 100 standard). Calculate the air renewal rate necessary according to the number of batteries.

If the chargers are in the same premises, provide a mechanical protection against possible impacts.

Provide a fixed installation for the charging cables near the battery to be charged.

For the charging rooms:

- Install 0.60m wide insulated floor racking in the alleys.
- Place the batteries on concrete or wood supports covered with a chemically resistant coating.
- Provide a hoist handling system operated by chain, manual or pneumatic means or by electric means which is safe for explosive atmospheres.
- Provide a safety station consisting of a shower and an eye bath.
- In premises containing both lead and alkaline batteries, provide two separate electrolyte transfer systems.
- Clean the premises frequently and remove the dust from the battery trays by a vacuum cleaning system.

10.6.1.4. Battery storage room

Since the layout of this room is not governed by any regulations or standard, the following rules should be applied:

- Store the batteries in appropriate and well-ventilated premises.
- Provide premises which are protected from naked flames and sparks.
- Place extinguishers for electrical fires and sand boxes at accessible and obvious locations.
- Wash the floor regularly.

10.6.1.5. Work on batteries

The work on the batteries must be carried out in appropriate and well-ventilated premises separate from the charging room by personnel qualified and trained for this purpose.

Purge the interior of the components with compressed air and inert where necessary.

Provide the operators with goggles (masks), acid-resistant clothing, safety footwear and rubber gloves.

10.6.1.6. Instructions

In the charging station, display no smoking signs and signs indicating that the battery supplier's instructions must be respected for all operations.

10.6.2. Workshops / charging rooms

Formation of explosive atmospheres: calculating the volume of hydrogen given off

When charging lead batteries and alkaline accumulators, hydrogen is given off due to the electrolysis of the water or the alkaline solution (potassium or sodium). The hydrogen given off in small, closed or badly ventilated premises can, if we are not careful, form an explosive atmosphere. A simple method of approximately evaluating the volume of hydrogen given off is given below (calculation by excess).

10.6.2.1. Evaluation principle

We know that in a battery cell (rated voltage 2 V for a lead accumulator, approximately 1.3 V for an alkaline accumulator – iron/nickel, cadmium/nickel), during charging, the production of one gramme – i.e. 11.2 litres of hydrogen – consume a quantity of 96500 C of electricity; in other words 1 Ah (3600 C) produces 0.42 litres of hydrogen.

We suppose that the total quantity of electricity Q (Ah) supplied during charging is used to replenish the battery's capacity C (Ah) for the rated voltage and to electrolyse the water or the alkaline solution. This is not strictly true but it will be used for safety and simplification (in particular, part of the energy used for the charging is converted into heat due to the battery's internal resistance).

Therefore the volume v of hydrogen produced (in litres), is equivalent to:

$$\mathbf{v \approx 0.42\,(Q - C)\,N}$$

- Q, the quantity of electricity supplied by the charger to the battery, expressed in Ah (Q can be evaluated by the sum of the currents (in Amps); based on readings taken every hour; revised throughout the charging period; or evaluated by excess by the product of the current delivered during the first hour of charging – where it is at its highest – multiplied by the charging time (in hours)).
- C, the battery capacity for the rated voltage
- N, the number of cells in series in the battery

10.6.2.2. Hydrogen given off when charging a lead battery

Calculating the volume given off: two methods of calculation can be used.

Applying the formula which follows from the previous formula

v (litres) ≈ 0.21 (Q – C) U where U is the rated voltage of the battery in V

For example: a lead traction battery rated at 510 Ah 12 V (six 2 V cells in series) is charged for 14 hours, the DC current supplied for the first hour is 60 A.

The volume of hydrogen (in litres) given off during charging is certainly less than:

$v < 0.21 [(14 \times 60) - 510] \times 12$ ***v < 832 litres***

Estimation based on the battery's energy capacity

This is given in Wh and is equal to the product of the capacity (in Ah), multiplied by the voltage (in volts) **W = C.U**

The energy efficiency for charging a lead battery is normally 50 to 75%.

For our evaluation, we will estimate it to be 50%. In this case, the energy dissipated during the electrolysis is equal to that stored in the accumulator again, i.e. equal to its energy capacity.

We can easily calculate that, in more or less normal charging conditions, a maximum quantity of hydrogen is given off: 0.2 1 litres per Wh (i.e. 210 litres per kWh) of battery energy capacity.

For the example in the previous paragraph, we would find:

$v \approx 0.21 \times 510 \times 12$ i.e. approximately ***1285 litres***

Moment when the hydrogen is given off

During normal charging of a lead battery, the hydrogen is given off from the fourth hour.

The hydrogen tends to build up in the high parts of the premises.

10.6.2.3. Hydrogen given off when charging an alkaline battery

Calculation method:

We can either use the formula which follows from the previous paragraph

v (litres) $\approx$ 0.3 (Q – C) U using the same notations / calculations

Or we can use the estimation based on the battery's energy capacity W = C.U

The energy efficiency of the charging is around 50%. In normal charging conditions we must count on a quantity of hydrogen given off of: ***0.300 litres per Wh*** (or 300 litres per kWh)

Moment the hydrogen is given off

Hydrogen is given off throughout the charging period of an alkaline battery.

10.6.2.4. Explosive atmosphere formed with the hydrogen given off

The lower explosion limit concentration for hydrogen in air is 4%. Unventilated battery charging premises would certainly contain an explosive atmosphere if their volume does not exceed 25 times that of the hydrogen given off.

A hydrogen concentration of 1% must not be exceeded. (For safety reasons)

When charging storage batteries, we must:

- Either have premises at least 100 times greater than the volume of hydrogen given off; a moderate ventilation would also be useful.
- If this is not the case, provide sufficient natural ventilation, preferably in the upper part of the premises. A window or an open door can renew the air from 1 to 3 times per hour. It is always desirable to set up a natural circulation of air.
- If the hydrogen given off per hour reaches a few % of the volume of the premises, provide mechanical ventilation with an hourly flow rate of 50 to 100 times the hydrogen production rate. There will also be an urgent necessity for this ventilation due to the droplets of electrolyte vapour given off and which can make the air in the charging premises difficult to breathe.

The ventilation should preferably be by extraction in the upper part of the premises, with a natural air entry in the lower part.

As an example, charging a standard lead car battery rated at 60 Ah 12 V – i.e. 720 Wh energy capacity – gives off, at the maximum:

$$210 \times 0.720 \approx 150 \text{ litres of hydrogen}$$

And should not be carried out in closed premises < 15 $m^{3.}$

10.6.2.5. Accumulator charging workshops

Classified as dangerous, unhealthy and impractical

Accumulator charging workshops are subject to the regulatory measures taken in application of the French Law of 19-7-1976 amended, when the maximum power of the DC current usable for the charging exceeds 2.5 kW.

If the plates are reformed or regenerated, this figure is reduced to 0.5 kW.

11. GLOSSARY

12. SUMMARY OF FIGURES

13. SUMMARY OF TABLES

14. CORRECTIONS FOR EXERCICES