UPS SIZING

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UPS

- UPS (Uninterruptible power supply)
- Used to support critical/sensitive load
- It is typically a battery-backed system which will continue to operate for a specified amount of time after main power supply interruption.
- Used as stable power supplies that provide a reasonably constant voltage and frequency output, independent of voltage input.
- Particularly useful for sensitive electrical equipment on main power supplies that are prone to voltage or frequency fluctuations or instability.

Why do the calculation ?

- UPS sizing calculation will determine the ratings of the main UPS system component :

    - Rectifier

    - battery bank

    - Inverter

In addition, the calculation result will also help determine the indicative dimensions of the equipment (e.g. size of battery banks)for preliminary layout purposes.

When to do calculation ?

The UPS sizing calculation can be done when the following prerequisite information is known :

- UPS load that need to be supported
- Input / output AC voltage
- Autonomy time
- Battery type

Calculation Methodology

The calculation procedure has four main steps :

1. Determine and collect the prospective AC UPS loads
2. Construct a load profile and determine the UPS design load (VA) and design energy (V Ah)
3. Calculate the size of the stationary battery (number of cell in series and Ah capacity)
4. Determine the size of the inverter, rectifier / charger and static switch.

Step 1- Collect the AC UPS loads

- Determine the type and quantity of loads. For example, industrial facilities :
  - The critical instrumentation and control load such as the DCS (Distribution Control System) and ESD processor and marshalling hardware
  - Critical workstations and HMI's
  - Telecommunications equipment and sensitive electronics

- The necessary load data should be available from the instrumentation and control engineers.

Step 2- Load Profile, Design Load, and Design Energy

- Refer to the load profile calculation for detail on how to construct a load profile, calculate design load and design energy.
- The "Autonomy method" for constructing load profile is typically used for AC UPS system. Autonomy method is the number of hours that the load needs to be supported during a power supply interruption
- The autonomy time is often specified by the client (in their standards)
- IEEE 446 "IEEE Recommended Practice for Emergency and Standby Power System for Industrial and Commercial Application" has some guidance for autonomy time. Sometimes a single autonomy time is used for entire UPS load, which obviously makes the construction of the load profile easier to compute.

Calculating the Consumed Load VA

- For each load in VA, this can be calculated as follows:

$$S_l = \frac{P_l}{\cos\phi \times \eta}$$

Where S_l is the consumed load apparent power (VA)

P_l is the consumed load power (W)

$\cos\phi$ is the load power factor (pu)

η is the load efficiency (pu)

Autonomy Method

Tag Number	Description	Load (W)	Power Factor	Load VA	Autonomy (h)	VA Hours
CCTV-001	CCTV Cabinet	450	0.85	529	3	1,588
DCS-001	DCS System Cabinet	1200	0.85	1,412	5	7,059
DCS-002	DCS System Cabinet	1200	0.85	1,412	5	7,059
ESD-001	ESD System Cabinet	1500	0.85	1,765	8	14,118
EWS-001	Engineering Workstation	400	0.85	471	1	471
FG-001	Fire and Gas Cabinet	1500	0.85	1,765	8	14,118
MON-001	CCTV Camera #1	300	0.80	375	3	1,125
MON-002	CCTV Camera #2	300	0.80	375	3	1,125
MON-003	CCTV Camera #3	300	0.80	375	3	1,125
MON-004	CCTV Camera #4	300	0.80	375	3	1,125
OIS-001	Operator Interface Station #1	100	0.85	118	3	353
OIS-002	Operator Interface Station #2	100	0.85	118	3	353
			TOTAL LOAD VA	9,088	TOTAL VAh	49,618

Construct Load Profile

- The load profile is constructed from the load list and is essentially a chart that shows the distribution of the loads over time.

Description	Load (VA)	Autonomy (h)
DCS Cabinet	200	4
ESD Cabinet	200	4
Telecommunications Cabinet	150	6
Computer Console	90	2

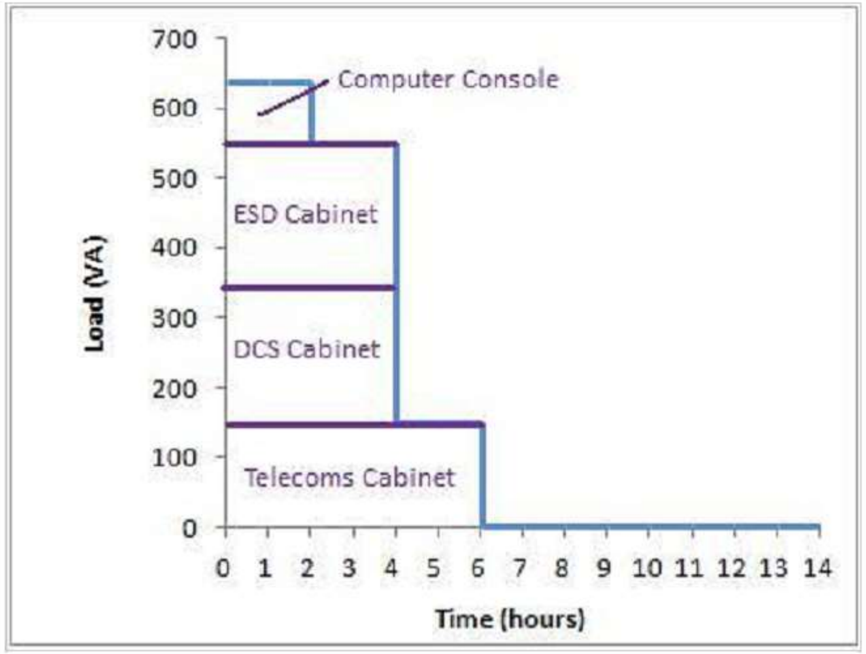

Figure 3. Load profile constructed for this example

Calculate Design Load

The design load is the instantaneous load for which the power conversion, distribution and protection devices should be rated, e.g. rectifiers, inverters, cables, fuses, circuit breakers, etc. The design can be calculated as follows:

$$S_d = S_p(1 + k_g)(1 + k_c)$$

Where S_d is the design load apparent power (VA)

S_p is the peak load apparent power, derived from the load profile (VA)
k_g is a contingency for future load growth (%)
k_c is a design margin (%)

It is common to make considerations for future load growth (typically somewhere between 5 and 20%), to allow future loads to be supported. If no future loads are expected, then this contingency can be ignored. A design margin is used to account for any potential inaccuracies in estimating the loads, less-than-optimum operating conditions due to improper maintenance, etc. Typically, a design margin of 10% to 15% is recommended, but this may also depend on Client preferences.

Design Energy Demand

- The design energy demand is used for sizing energy storage devices. From the load profile, the total energy (in terms of VAh) can be computed by finding the area underneath the load profile curve (i.e. integrating instantaneous power with respect to time over the autonomy or 24h period). The design energy demand (or design VAh) can then be calculated by the following equation:

$$E_d = E_t(1 + k_g)(1 + k_c)$$

Where E_d is the design energy demand (VAh)

E_t is the total load energy, which is the area under the load profile (VAh)
k_g is a contingency for future load growth as defined above (%)
k_c is a design contingency as defined above (%)

Step 3 – Battery Sizing

Selection of type battery should consider the following factor as suggested by IEEE :

- Physical characteristics, e.g. dimensions, weight, container material, intercell connections, terminals
- application design life and expected life of cell
- Frequency and depth of discharge
- Ambient temperature
- Charging characteristics
- Maintenance requirements
- Ventilation requirements
- Cell orientation requirements (sealed lead-acid and NiCd)
- Seismic factors (shock and vibration)

Next, find the characteristics of the battery cells, typically from supplier data sheets. The characteristics that should be collected include:

- Battery cell capacities (Ah)
- Cell temperature
- Electrolyte density at full charge (for lead-acid batteries)
- Cell float voltage
- Cell end-of-discharge voltage (EODV).

Nominal Battery (or DC Link) Voltage

The nominal battery / DC link voltage is often selected by the AC UPS manufacturer. However, if required to be selected, the following factors need to be considered:

- DC output voltage range of the rectifier – the rectifier must be able to output the specified DC link voltage
- DC input voltage range of the inverter – the DC link voltage must be within the input voltage tolerances of the inverter. Note that the battery end of discharge voltage should be within these tolerances.
- Number of battery cells required in series – this will affect the overall dimensions and size of the battery rack. If physical space is a constraint, then less batteries in series would be preferable.
- Total DC link current (at full load) – this will affect the sizing of the DC cables and inter-cell battery links. Obviously the smaller the better.

Number of Cells in Series

The number of battery cells required to be connected in series must be between the two following limits :

(1) $N_{max} = \dfrac{V_{dc}(1 + V_{i,max})}{V_f}$

(2) $N_{min} = \dfrac{V_{dc}(1 - V_{i,min})}{V_{eod}}$

where N_{max} is the maximum number of battery cells

N_{min} is the minimum number of battery cells
V_{dc} is the nominal battery / DC link voltage (Vdc)
$V_{i,max}$ is the inverter maximum input voltage tolerance (%)
$V_{i,min}$ is the inverter minimum input voltage tolerance (%)
V_f is the nominal cell float (or boost) voltage (Vdc)
V_{eod} is the cell end of discharge voltage (Vdc)

The limits are based on the input voltage tolerance of the inverter. As a maximum, the battery at float voltage (or boost if applicable) needs to be within the maximum input voltage range of the inverter. Likewise as a minimum, the battery at its end of discharge voltage must be within the minimum input voltage range of the inverter.

Determine Battery Capacity

The minimum battery capacity required to accommodate the design load over the specified autonomy time can be calculated as follows :

$$C_{min} = \frac{E_d(k_a \times k_t \times k_c)}{V_{dc} \times k_{dod}}$$

where C_{min} is the minimum battery capacity (Ah)

E_d is the design energy over the autonomy time (VAh)

V_{dc} is the nominal battery voltage (Vdc)

k_a is a battery ageing factor (%)

k_t is a temperature correction factor (%)

k_c is a capacity rating factor (%)

k_{dod} is the maximum depth of discharge (%)

Step 4 – UPS Sizing

Overall ups sizing

Most of the time, all you need to provide is the overall UPS kVA rating and the UPS vendor will do the rest. Given the design load calculated in Step 2, select an overall UPS rating that exceeds the design load. Vendors typically have standard UPS ratings, so it is possible to simply select the first standard rating that exceeds the design load. For example, if the design load 12kVA, then the next size unit (e.g. 15kVA UPS) would be selected.

Rectifier / Charger Sizing

The rectifier / charger should be sized to supply the inverter at full load and also charge the batteries (at the maximum charge current). The design DC load current can be calculated by :

$$I_{L,dc} = \frac{S}{V_{dc}}$$

where $I_{L,dc}$ is the design DC load current (full load) (A)

S is the selected UPS rating (kVA)
V_{dc} is the nominal battery / DC link voltage (Vdc)

The maximum battery charging current can be computed as follows:

$$I_c = \frac{Ck_l}{t_c}$$

where I_c is the maximum DC charge current (A)

C is the selected battery capacity (Ah)
k_l is the battery recharge efficiency / loss factor (typically 1.1) (pu)
t_c is the minimum battery recharge time (hours)

The total minimum DC rectifier / charger current is therefore:

$$I_{dc} = I_{L,dc} + I_c$$

Select the next standard rectifier / charger rating that exceeds the total minimum DC current above.

Inverter Sizing

The inverter must be rated to continuously supply the UPS loads. Therefore, the inverter can be sized using the design AC load current (based on the selected UPS kVA rating) :

For a three-phase UPS:

$$I_L = \frac{S}{\sqrt{3}V_o}$$

For a single-phase UPS:

$$I_L = \frac{S}{V_o}$$

where I_L is the design AC load current (full load) (A)

S is the selected UPS rating (kVA)
V_o is the nominal output voltage (line-to-line voltage for a three phase UPS) (Vac)

Select the next standard inverter rating that exceeds the design AC load current.

Static Switch Sizing

Like the inverter, the static switch must be rated to continuously supply the UPS loads. Therefore, the static switch can be sized using the design AC load current (as above for the inverter sizing)

Example case :

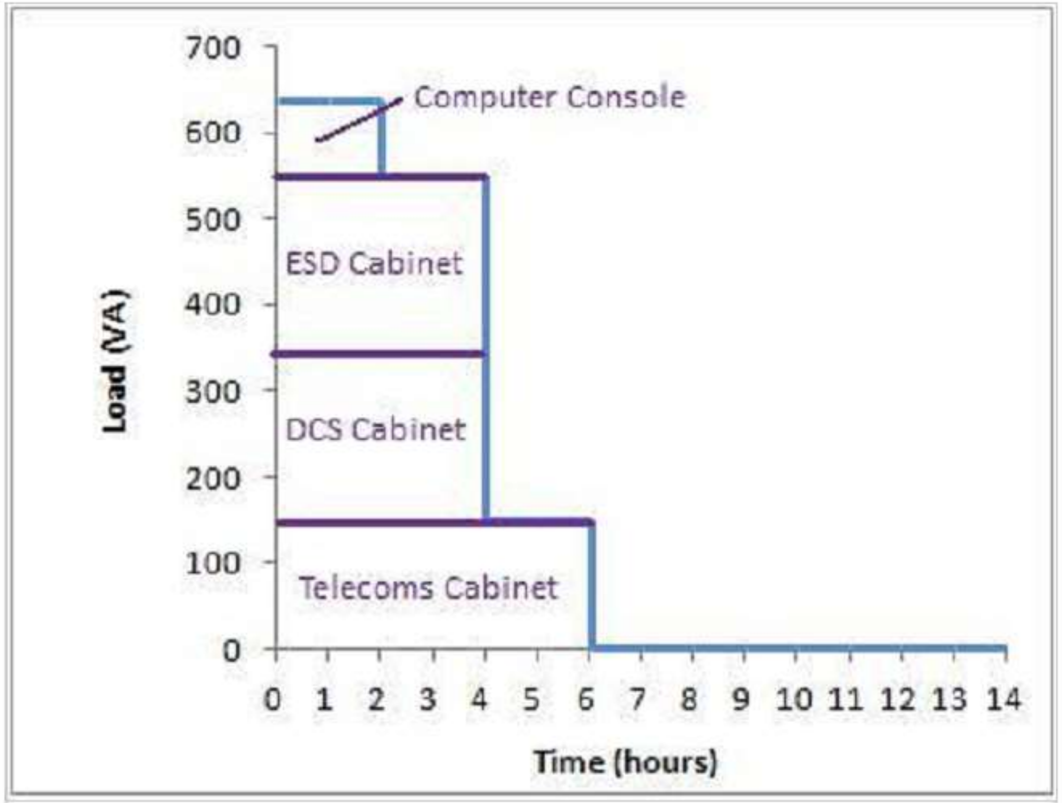

Figure 3. Load profile constructed for this example

Step 1 & 2 :

Peak Load :

S_p=150 + 200 + 200 + 90 = 640 VA

Design Load :

S_d=S_p(1+k_g)(1+k_c)

=640(1+0.1)(1+0.1)= 774.4 VA

Energy demand :

E_t=150.6 + 200.4 + 200.4 + 90.2 = 2680 VAh

Design Energy demand :

E_d=E_t(1+k_g)(1+k_c)

=2680(1+0.1)(1+0.1)= 3242.8 V Ah

Step 3 – Battery Sizing

Suppose that the nominal battery voltage is V_{dc} = 120Vdc, the cell charging voltage is V_c = 2.25Vdc/cell, the end-of-discharge voltage is V_{eod} = 1.8Vdc/cell, and the minimum and maximum load voltage tolerances are$V_{l,min}$ = 10% and $V_{l,max}$ = 20% respectively.

$$N_{max} = \frac{V_{dc}(1 + V_{i,max})}{V_f} = \frac{120(1 + 0.2)}{2.25} = 64\ cell$$

$$N_{min} = \frac{V_{dc}(1 + V_{i,max})}{V_{eod}} = \frac{120(1 - 0.1)}{1.8} = 60\ cell$$

Given a depth of discharge k_{dod} = 80%, battery ageing factor k_a = 25%, temperature correction factor for vented cells at 30 deg C of k_t = 0.956 and a capacity rating factor of k_c = 10%, the minimum battery capacity is:

$$C_{min} = \frac{E_d(k_a x\ k_t x k_c)}{V_{dc}\ x\ k_{dod}} = \frac{3242.8(1.25\ x\ 1.1\ x\ 0.956)}{120\ x\ 0.8} = 44.4\ Ah$$

Step 4 – UPS Sizing

- Overall Sizing

Given the design load of 774.4, then a 1 kVA UPS would be appropriate

- Rectifier Sizing

Given a nominal dc link voltage of 120 Vdc, the design DC load current is :

$$I_{L,dc} = \frac{S}{V_{dc}} = \frac{1000}{120} = 8.33\ A$$

Suppose the minimum battery recharge time is 2 hour and a recharge efficiency factor of 1.1 is used. The maximum battery charging current is :

$$I_c = \frac{C.k_i}{t_c} = \frac{50\ x\ 1.1}{2} = 27.5\ A$$

Therefore the total minimum DC rectifier / charge current is :

$$I_{dc} = I_{L,dc} + I_c = 8.33 + 27.5 = 35.83\ A$$

A DC rectifier rating of 40 A is selected.

Inverter and static switch sizing

Suppose the minimal output voltage is 240 Vac. The design AC load current is :

$$I_c = \frac{S}{\sqrt{3}V_o} = \frac{1000}{\sqrt{3}\ x\ 240} = 2.406\ A$$

An inverted and static switch rating of 5 A is selected.