HANDBOOK FOR INSTALLATION OF MEDIUM VOLTAGE LINES

for Rural Electricity Service Constructors and Operators (RESCO)

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Foreword

This handbook is meant as a reference for those technicians and Rural Electricity Providers in Cambodia who are constructing, operating and maintaining Medium Voltage lines.
The handbook guides the actual installation of MV networks by providing crucial information on all subjects relating to construction, operation and maintenance of each and every part of the electrical network. For actual implementation in the field, more applied and practice based information and training may be needed (for info in www.etc-technicaltraining.org)

The handbook covers important basics of the actual design of networks. Network design is to be done by licensed professionals before a Rural Electricity Entrepreneur (REE) can build the MV network.

In Cambodia, providing access to electricity - in particular to rural area- is a growing need covered mostly by private operators who generate their own electricity for use in Low Voltage networks. At the same time the government extends the High Voltage networks to urban and peri-urban area.
The eventual closing of gaps between the separate Low Voltage and High Voltage networks requires installation of Medium Voltage networks, which are technically compatible with both the LV and HV networks.

Cambodian Government has issued a regulation for small off-grid-electricity entrepreneurs that only those entrepreneurs that are certified will be allowed to build and operate LV and MV electricity networks.

This handbook is thus written in support of a short course to REE's and technicians to familiarize them with high standard construction, operation and maintenance of Medium Voltage networks. It addresses all that an MV constructor/ operator needs to know, providing the basics for certification by the government.
It is also meant for those interested entrepreneurs, for technicians from government and for training institutes that engage in building up Cambodia's electricity staff.

The handbook follows a practical, **hands-on approach** and addresses common situations in Cambodia. It is divided into 12 sections.

The first chapter hints at some design parameters that one needs to know before the total network can be mapped out and materials ordered. Because electricity network design is a professional job, theoretical background information is added in the last chapter for reference to specialists.

The second chapter helps the REE to prepare for construction. It describes all elements in a Medium Voltage network, from generator to household connection. It indicates the various technical and economical options available (in the Cambodian market) for putting together a good network.
This chapter also lists all tools and machineries needed to be ready before construction of the MV network can begin.

The third chapter provides insight in risk and safety issues, both during construction and during operation.

The fourth chapter shows how to construct and connect the different applications within the MV network and shows good and bad examples.

The fifth chapter explains how to install, inspect and indicates trouble shooting of the MV network.

The sixth chapter describes the roles and responsibilities of all those stakeholders in Electricity Provision dealing with Medium Voltage lines: from households, to operators, to technicians up to the National Authority.

This chapter includes reference to current electricity rules and regulations in Cambodia. It gives insight in the current regulations for Rural Electricity Entrepreneurs to embark on MV network construction and operation.

The seventh chapter provides the basic (academic) theory on electricity and serves as background reading and as refresher course for those already familiar with the principles of electricity.

The chapter eight explains functionality of a power transformer commonly used in a MV network construction.

The chapter nine describes the voltage regulation adjustment from theoretical and practical regulation point of view.

The chapter ten describes the operation and maintenance rules to be taken into account for a MV network implementation.

The chapter eleven provides reference to applicable rules and technical specification in Cambodia (2007). This chapter also illustrates one example of calculation of the MV network according to this standard.

Finally, the chapter twelve also provides safety rules through earthlng of the system installation.

We would like to thank to our team work – Mr. Ky Chanthan as co-developer, Mr. Theng Marith from EAC as co-developer, Mrs. Melanie Stallen, project coordinator from ETC/TTP and Mr. Patrick van de Rijt, ETC/TTP's engineer, helping in commenting on developed curriculum in order to finalise it.

Glossary of terms

AC	Alternating Current
Bushing	special connecting piece between main electricity cable and distribution transformer. 'Primary bushing' for incoming and 'secondary bushing' for outgoing cable.
Cable	medium for transport of electricity. Comes in various thicknesses, depending on amount of electricity to be transported.
Cable clearance	height between the ground and the cables crossing a road. Cambodia uses standards for clearance.
Capacitor Bank	electric component in the MV network that can store electric energy
Clamp meter	hand-tool which measures electrical current anywhere in the electrical circuit
Conductor	electrical component in the MV network that contains/ carries the electricity. When over long distance, it is in fact the 'electricity cable'.
Cross arms	horizontal part of the poles that transport electricity
Current transformer	electrical component in the MV network that is used to support measurement of AC current driving on the circuit.
Cutout	electrical component in the MV system that holds the cable connected to the source in normal service, but disconnected from the source when there is fault
Condens	commonly used terms for capacitor bank
DC	Direct Current.
Distribution system	term for the whole MV system, distributing electricity to various places
Distribution transformer	power transformer for transferring electric power from MV side to LV side. It. can also be placed overhead, on electricity pole and is called "pole mounted transformer".
Dry cell	electrical component for DC circuit, DC voltage source
Electromagnetic field	area in which electro-magnetism occurs, usually around a current in conductor
Energy meter	component hooked up to the MV system which measures the amount of energy used by that particular wire extension.
Fuse	electrical component in the electrical network that melt when a big enough current flow through it. This component is used to protect some part of distribution network from damage by fault current.
Generator	electrical component that convert other form of energy (e.g. mechanical energy) into electrical energy.
Grounding system	part of the MV system that connect some elements of the system firmly to the earth. Grounding system is used to protect people against electrical shock or MV system from atmospheric overvoltage.
Impedance	term that expresses complex characteristic of a passive electric component (in electricity theory)
Insulator	device that does not conduct electricity and is hooked up to the electricity system to prevent contact between parts.
Lightning arrester	device connected to the MV network that protects the network from sudden electrical overloads. Usually connected to transformer
Line	see cable
Load	term that is used to express the total consumption of energy at a particular point in the MV network.

MV	Medium Voltage
One phase connection	connection between any phase and neuter
Open type cutout	see Cutout
Overhead line	see cable, carries electricity and is fixed to the poles
Pin spacing	distance between pins that are placed on the poles. Important to prevent sparks between different conductors
Pole	component in the MV network needed to fix the electricity lines for overland transport of electricity from generator to households. Cambodia uses standards for electricity poles.
Pole pin	pins that are used for securing the insulators to the poles
Power loss	difference between the electricity that is generated, then goes into the MV system and then is coming out for use by clients
Raw electricity	main supply of electricity is to be converted before it can be used with electric appliance
REE	Rural Electricity Entrepreneur
RESCO	Rural Electricity Service Constructor and Operator
Sag	distance that a cable bends vertically (base on its own weight) when hung horizontally between 2 poles. Indicative figures for MV cables are available.
Symmetrical load	term used when each 'wire' in a 3-phase electricity system carries the same load of electricity system.
Span	distance between 2 poles that a cable has to cross over
Substation	a place in the MV system where a power transformer is installed in order to transmit electric power from a higher voltage to a lower voltage or versus
Transformer	electric component in the MV network that does step up/down the voltage.
Transformer post	A substation with small capacity, placed in the MV system to convert high voltage to low voltage. The main component of transformer post is a power transformer.
Voltage drop	Difference between magnitude of source voltage and the receiver voltage.
Voltmeter	hand-tool which measures voltage.

Chapter 1: Design of MV network

1 Design parameters

1.1 Load

The location or area covered by distribution network. A precised map of this location is useful and needed for the design. Road, streets, path and other infrastructures such as canal,..etc should be presented.
The designed load is forecasted for 10 to 20 coming years. Therefore, to do this many data are needed, depending on method used in the calculation. For example, total number of families, infrastructures in the location, future vision of the economic and social growth etc; electricity source near or in the location: Power plant, MV feeder, grid substation; existing MV line.
MV network parameters and service parameters: Voltage, Maximum power, power factor (Cos phi)

Note: In design process, some assumptions should be made at the preliminary stage. For example the best scheme should have shortest length. On the reliability of the scheme, the standard of performance is required in the MV distribution network - the outage shall not last longer than 48 hours. The good practice indicates that the total power loss in MV network should in the range of 2-5%. In Cambodia, the MV voltage range is 22[kV] + 10% to 22[kV] - 10%.

Electricity source for the design: MV line or grid substation feeder, stand alone network with own generation.

1.2 Loads

Load of MV distribution network is a concentrating load. The distributed LV load will connect to LV network that has step down transformer as LV source. So, the transformer post centralizes the LV load in some areas on a single position in the MV network. Some big consumers (e.g. Hotel, Rice mils) should connect to MV network via pole mounted transformer. The beginning of another MV line is considered as the MV load.

1.2.1 Load center of LV loads

LV household loads are connected to LV network via LV distribution (meter) box on the pole installed along the road, street or path in the village/town. So, the LV loads are from the pole on the LV line trace. Load from each pole is displayed as a circle with center at the pole and radius proportionally to the load. In each zone on the map all the LV loads are represented by a centralized load located on the load center. This location should be the place for transformer post. However, in reality it is difficult to identify the load center, and the place of transformer is not optimized.
The load center is an equivalent location where the moment is equal to the sum of all moments of all pole considered.

1.2.2 Big consumer

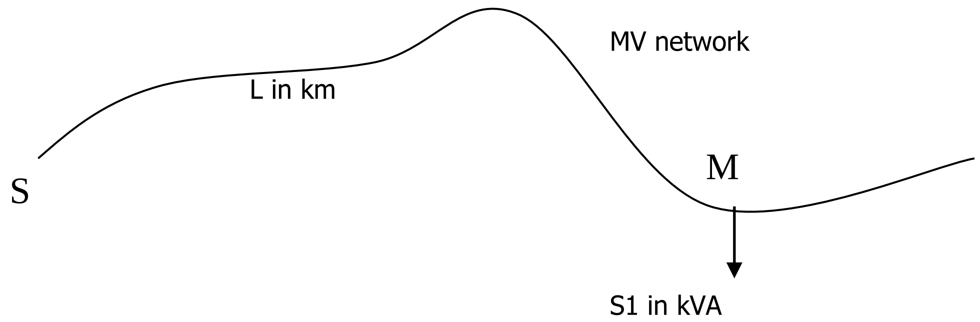
There is not standardized definition of big consumer. In this handbook a consumer is considered as big one if it has good characteristic for connecting from MV network via power transformer. In the connection agreement, for a MV consumer, some parameters are considered as constraints: maximum power demand, energy use factor, minimum consumed energy per month or year, service power factor, load category etc. For example, Hotel, big building, condo etc.

The owner of MV line may sell electricity to other licensed zone via a MV connection. The buyer shall build his own MV line to connect to this main line. This MV line represents a centralized load of the whole licensed zone.

1.3 Load moments of MV network

1.3.1 Load moment

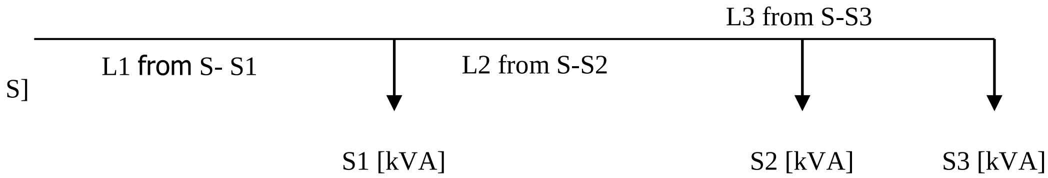
If a load that is on the MV network is located at L meter from the power source and has max apparent power of S1, so its moment is S1xL (in kVA.km). Example: S1 = 500 kVA; L=2 km; the moment will be 1000 kVA.km.



Moment= S1xL in kVA.km

1.3.2 Moment of line compared to a point of power source

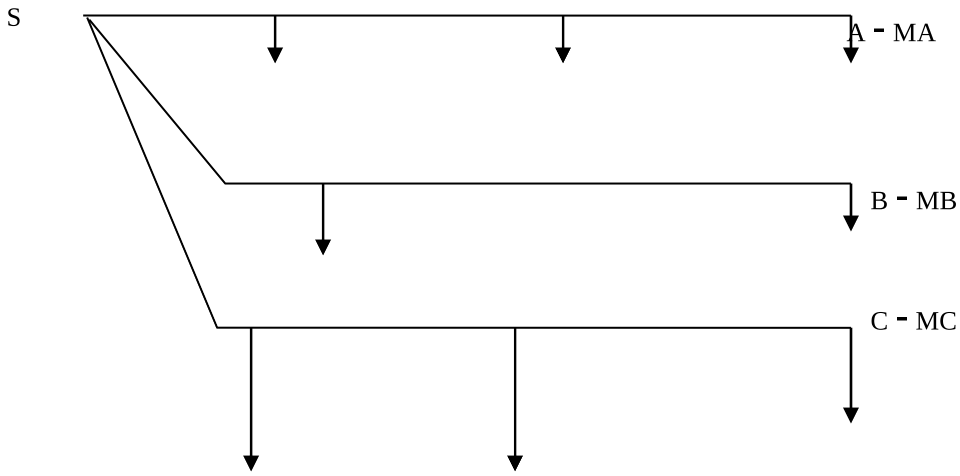
On the line we can identify all MV loads. Each load is characterized by the apparent power or active power (assuming same power factor for all loads) and the distance from the origin of line (or source).
Maximum load moment of radial MV network is the maximum of load moment of MV line from origin to any end pole of network.



Moment; = S1xL1 + S2xL2 + S3xL3

1.3.3 Moment of the network with many branches from the source

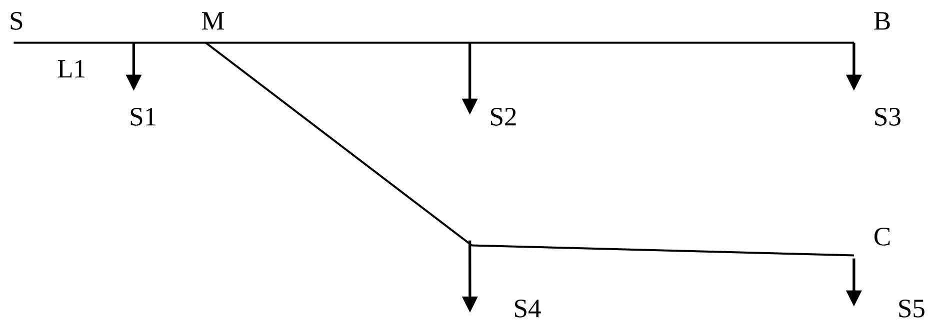
The moment of a network with several branches is equal to the maximum value of moment of each branch that is calculated as 1.3.2. Considering that the network has a power source; there are 3 branches from the ource as Sa, Sb, Sc.
Each branch, we can calculate the moment MA, MB and MC. The maximum value between MA, MB and MC is the moment of the line.



MA, MB and MC can be calculated as 1.3.2.
The maximum moment of the 3 branches is MA,MB,MC

1.3.4 *Moment of the network with branches*

At the point of derivation, we replace all branches by a load equivalent to the sum of all loads on the branch, and the moments are calculated as 1.3.3. then, we calculate the moment of derivation as 1.3.2.



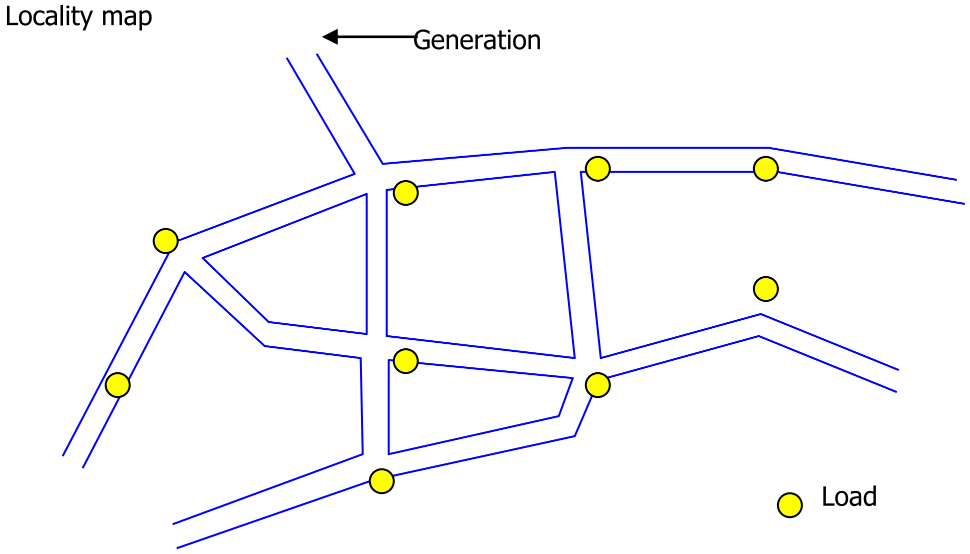
Considered MB = Moment of MB/M and MC/M.
Taking the max between MB and MC, MBC = max (MB, MC)
Branch: MB and MC are replaced by a load = S2+S3+S4+S5 and moment of; MBC
So, the moment of the network is:

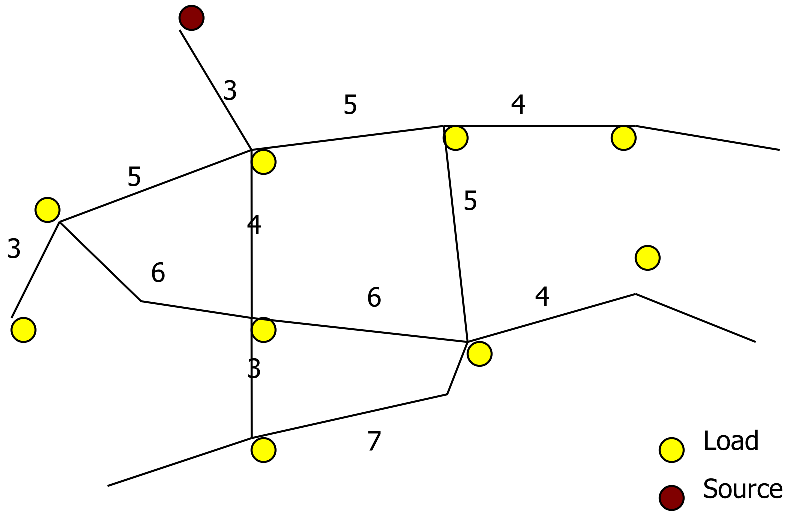
Moment= S1xL1 + (S2+S3+S4+S5)x[SM] + MBC

1.4 Network scheme layout

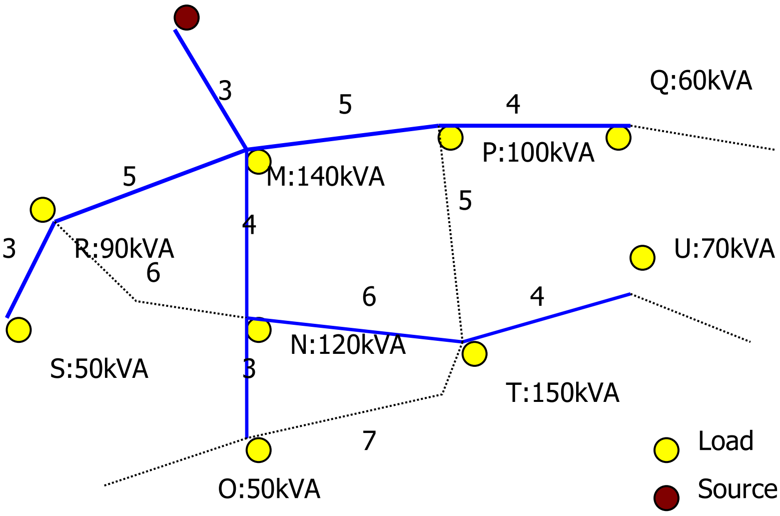
1.4.1 Possible configurations of network

On a map with displayed road, street and path, identify and mark the centralized position and source of electricity. Draw the path from the source to each centralized load as possible, avoiding any loop in the scheme. The path from source to any load shall be along road, street and may pass through another load location. By this way many configurations of network will be obtained.

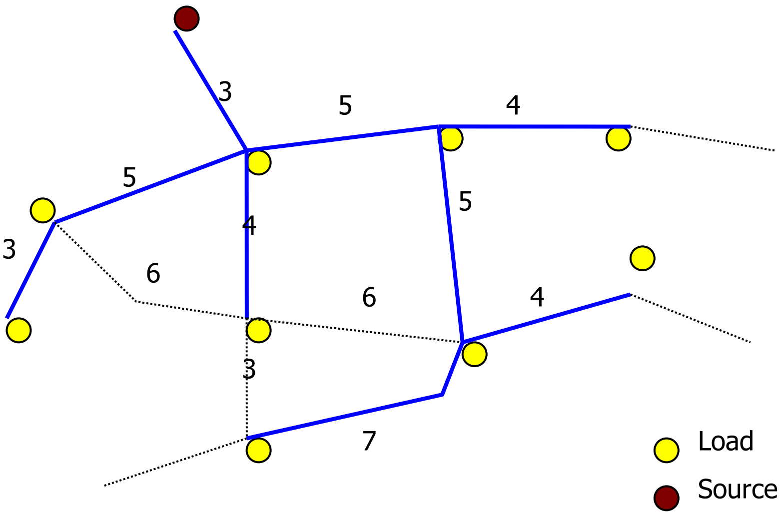




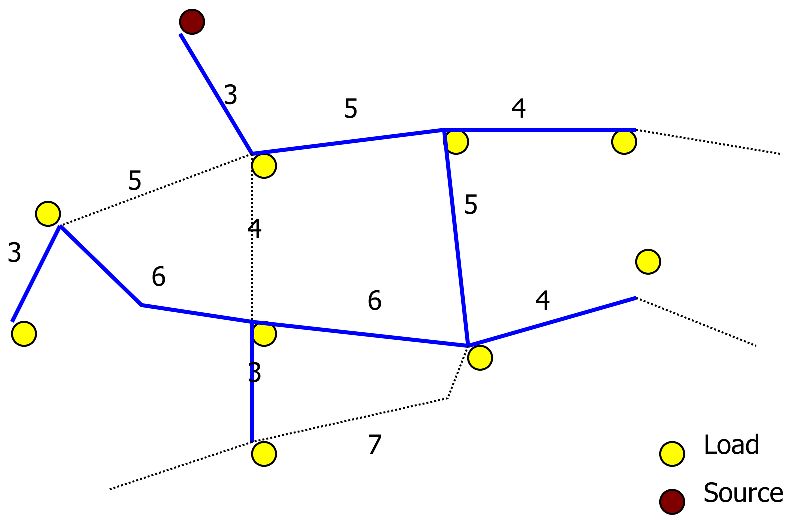
Configuration 1
Alternative A
Total length of line L = 37
Maximum length L max = 17



Configuration 2
Alternative B
Total length L = 41
Maximum length L max = 20



Configuration 3
Alternative C
Total length = 39
Maximum length = 28



The probably best scheme is configuration 1 (Alternative A).

1.4.2 Load moment calculation

In our example, there are 4 end positions for the alternative A, so we can compute load moments

For location- M:

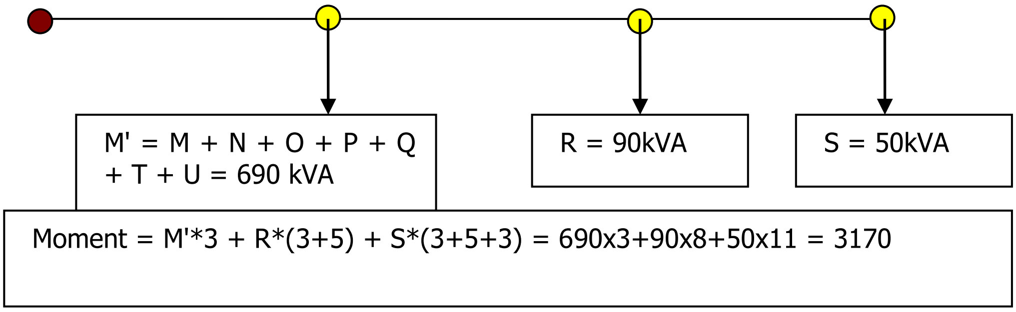
Total load = M+N+O+P+Q+R+S+T+U = 830 kVA
Moment = total load * Source-M = 830 * 3 = 2490 kVA.km

The table below summarizes the computation,

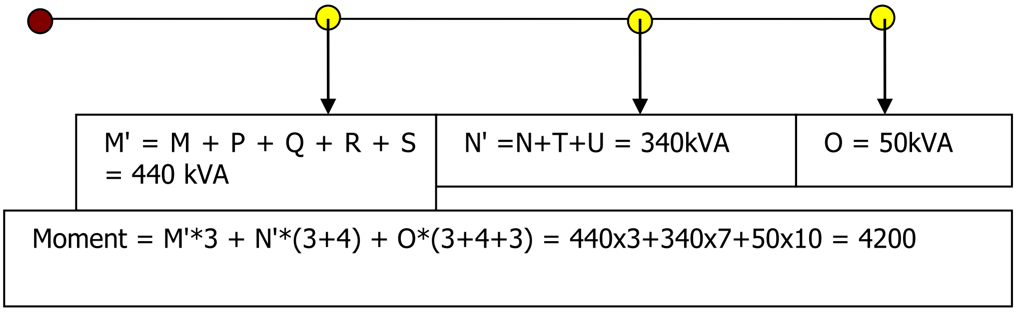
location	total load	distance	moments	
M	830	3	2490	kVA.km
N	390	4	1560	kVA.km
O	50	3	150	kVA.km
P	160	5	800	kVA.km
Q	60	4	240	kVA.km
R	140	5	700	kVA.km
S	50	3	150	kVA.km
T	220	6	1320	kVA.km
U	70	4	280	kVA.km

For line Source-S:

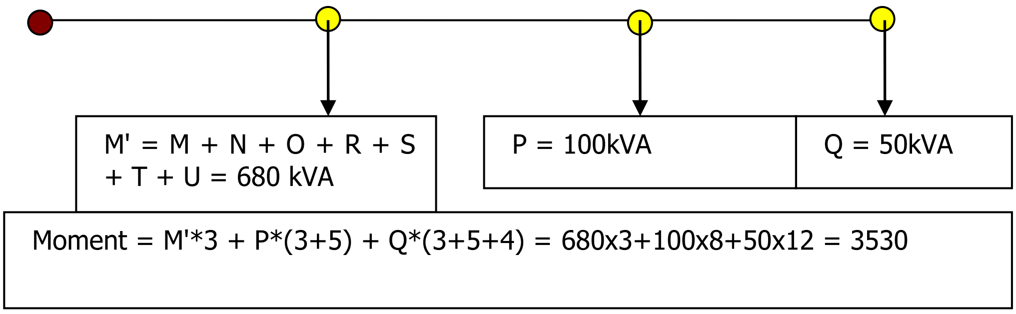
Load moments = moment M + moment R + moment S = 2490 + 700 + 150 = 3340 kVA.km



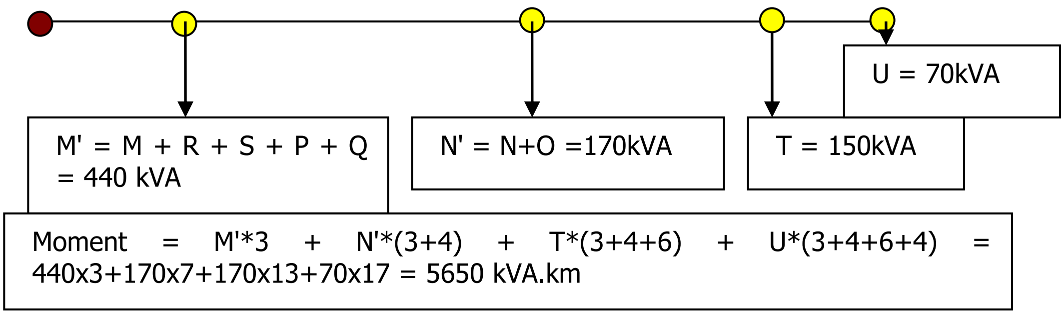
For line source-O: moment = 4200 kVA.km



For line source-Q: moment = 3530 kVA.km



For line source-U: moment = 5650 kVA.km



1.4.3 Selection of conductors by voltage drop criteria

The conductor AAC and ACSR (*see par 2.3 Conductors*) can be chosen for the MV overhead network. Requirement on voltage drop: for example 5% at the end of line.
To determine cross section of conductor, we should select an appropriate value from the below table.

For power factor = 0.8

Cross section mm2	Moment for voltage drop 5% kW.km
35	20,000
50	26,000
70	32,000
95	39,500
120	42,500
150	47,500

In above example, maximum moment in line Source-U is 5650 kVA.km or 4520kW.km if power factor is equal to 0.8. So the cross section for this line is 150mm2.

Recommendations:

You should choose only about 2 cross sections, and if possible only one cross section.
The main line may be double circuit, and this line will be built in two stages; for example: first for the period of first seven years, only one circuit and then after seven years, we build the second circuit.

1.4.4 Verification of the conductors by power loss

The MV network should be designed in the way that the power loss is minimized. The loss in distribution network in practice may be about or less than 10%. This loss is composed of (1) loss on MV network; (2) loss in transformer post; and (3) loss in LV network. For example the loss in MV network is about 2%; that in transformer is about 2.5% and that in LV network is about 6.5%.
After determining the conductor cross section by voltage drop, the power loss is calculated for maximum and minimum service. Sometime the cross section shall be increased to satisfy the power loss requirement.

1.5 MV network scheme

When designing a MV network scheme, we should consider of:

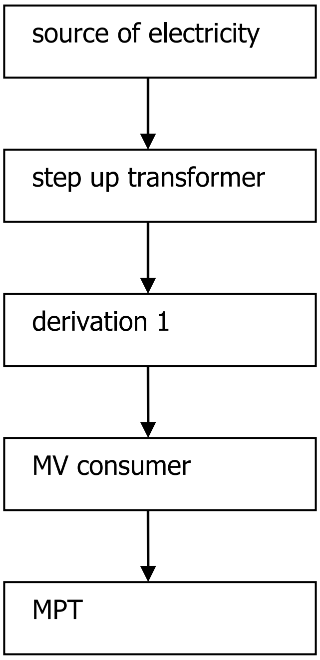
- Reliability of the scheme,
- Easy operation and maintenance of the network.

1.5.1 Steps in designing the scheme

- To draw functioning scheme of the network.
- To design the connection point to satisfy the requirement of each node.
- To design the protection of main line.

For economic reason, the protective device may be fuse cutout. For convenience in operation, the load breaker switch is the preferred one.

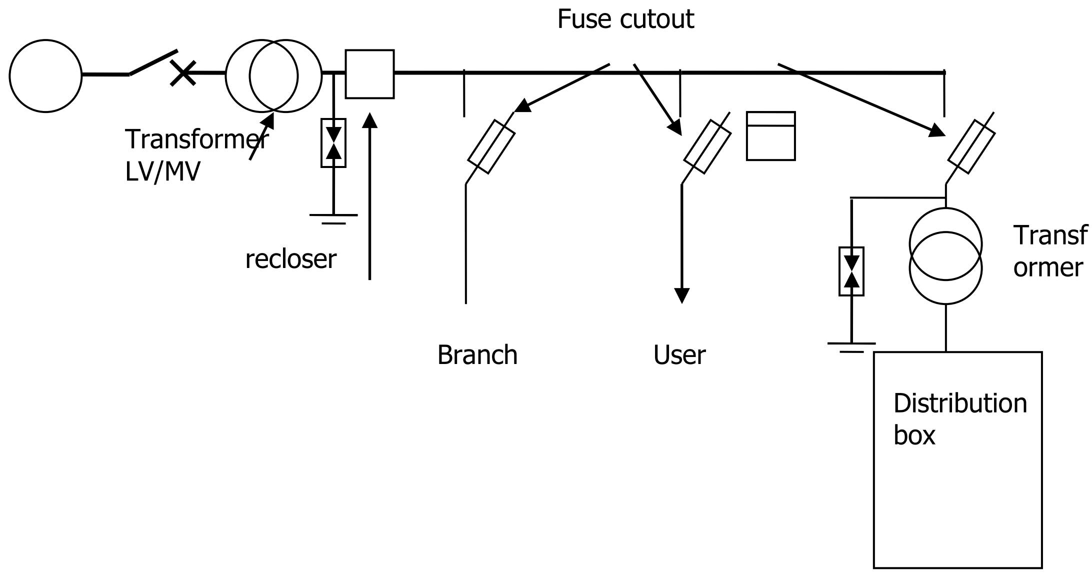
Example of functioning scheme



Prepared schema may consist of branches (or derivations) following the solidity strength needed. According the standard, it must equip with overcurrent protection device, surge arrester for overhead network at the transformer post. at the derivation point, it shall be installed a overcurrent protection device. As in above example, we can prepare a schema as follows.
At the beginning of transformer LV/MV, there is a circuit breaker for preventing alternator.

In Cambodia, there are often short-circuit due to some problems, such as kite flying, birds, squirrel, snake, branch of trees..etc. therefore, if it is economically possible, a recloser should be installed.

at the branch of MV network or at the MV user consumer or at the point of connection to LV, a fuse-cutout should be installed. At the transformer, surge arrester should also be considered for installation to prevent against lighting.



1.6 Design of installation of MV line

The design of MV line installation scheme is a professional job and requires experiences. Experienced people and technicians can refer to the theory in the last chapter of the handbook.

1.6.1 Select the type of support structure

There are many types of MV pole: wooden pole, reinforced concrete pole, steel frame pole etc. The selection of pole type depends mostly on economic point of view. In practice in Cambodia, the optimum type of pole is reinforced concrete one. The height of the 22 kV pole is standardized as 12m and 14m.

1.6.2 Determine the maximum span between supporting structure.

The maximum span for 22 kV line is 70m for reinforced concrete poles (electro technique standard in the Kingdom of Cambodia). For the conductors with cross section greater or equal to 100 mm2, the span of 50m is preferred.

Relationship between pole span and conductor sag (AAC)

Pole span (m)	Conductor sag (m)
50	1.1
55	1.3
60	1.5
70	2.1

1.6.3 Determine the distance from dead end poles

The preferred distance is either 500m or 1000m, depending on pole strength and on cable. EDC uses a 500m span between two dead end poles.

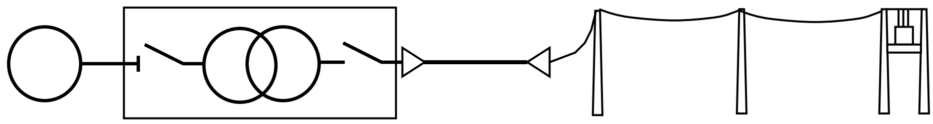
1.6.4 Map of network

Along the line trace, we can identify pole location and pole type. We can select the appropriate strength of pole depending on type and its location on the trace.
On the map, draw the 22 kV line trace on it, mark the pole position and the type of pole. All poles should be enumerated. Special location should be marked by special symbol (e.g. PMT, protective device, etc.).

Chapter 2: Preparation for construction of MV networks

2 Stand alone overhead MV network

Stand alone overhead MV network connects a stand alone generation system to load (LV and MV). Main components of this stand alone system are: generation system, step up substation, MV network, step down transformer post. The MV network can be overhead or underground type. In this handbook only overhead line will be considered further. The figure below shows an example of stand alone system.

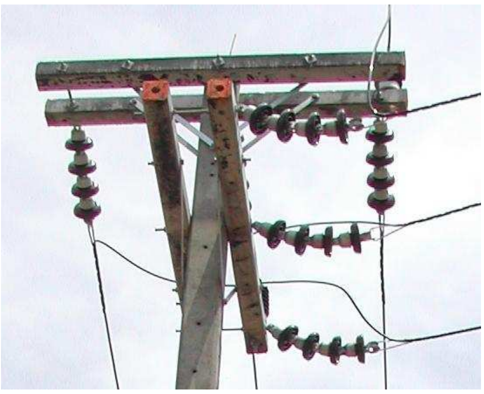


Generator Step up substation MV underground cable MV overhead line Step down transformer post

2.1 MV overhead line is built on supports, where the conductors are to fix on insulator

Supports may be towers, poles, or other structures such as steel, concrete or wood. The choice of a type of support depends on the terrain to be crossed and the size of conductors and equipment to be carried. Availability and economy, as well as atmospheric elements determine the choice of material.
Poles may be wooden, reinforced concrete or steel frame type. In Cambodia, reinforced concrete poles are considered as most economic. As supporting structure, poles are characterized by its length (height) and strength.
Cross sections of reinforced concrete pole are of rectangular or circle types. To comply with the clearance of overhead line in Cambodia, the length of 12m and 14 m are sufficient. The factory produces poles with strength of 3 kN, 5 kN, 8 kN and so on.

2.2 Pole accessories

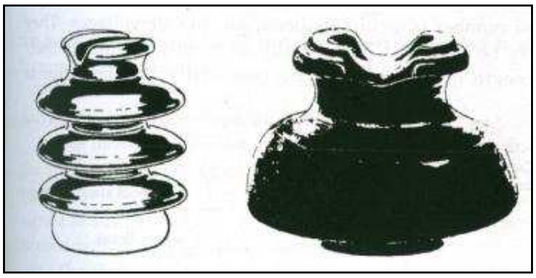


In Cambodia, the crossarms are usually made of galvanized steel. The usual cross-sectional dimensions for distribution crossarms are 0.09m by 0.1m; their length depending on the number and spacing of pins. Heavier arms of varying lengths are used for special purposes, usually holding the heavier transmission conductors and insulators.

When a heavy loading is usually encountered, as at corner or junction poles, double arms, that is, one on each side of the pole, may be required.

Note: For ABC type cable, the fixing structures are very simplified.

2.2.1 Insulators



Line conductors are electrically insulated from each other as well as from pole by non-conductors which are called insulators.

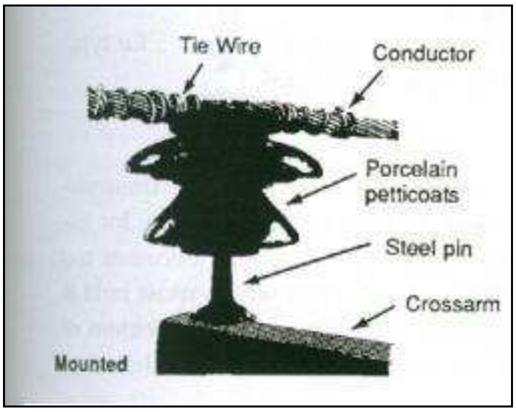
There are two type of insulator: pin insulator and suspension insulator.

To determine whether or not an insulator can be used, both its mechanical strength and electrical properties must be considered. Two practical insulator materials are porcelain and glass – Porcelain can withstand heavy loading in compression, but tears apart easily under tension, that is, when pulled apart. In using a porcelain insulator, therefore, care must be taken to make the forces acting on its compress and not pull apart. The same is generally true of glass.
Although glass insulators are good for lower voltage application, porcelain insulators are much more widely used because they are more practical.
Pin insulators are fixed to crossarm by pin poles. The pole pins are used to attach to the croosarms. They are used to hold pin type insulators. Note that they are threaded so that the insulator can be securely screwed on.

2.2.2 Pin spacing

The spacing of the pins on the crossarms must be such as to provide air space between conductors to prevent electric current from jumping or flashing over from one conductor to another. Also, sufficient spacing is necessary to prevent contact between the wires at locations between poles when the wires sway in the wind. In addition, enough spacing must be provided to enable workers climbing through the wires to work safety. The spacing on a standard threepin arm is 0.7m, (so to say around 2.2m long arm for MV line).

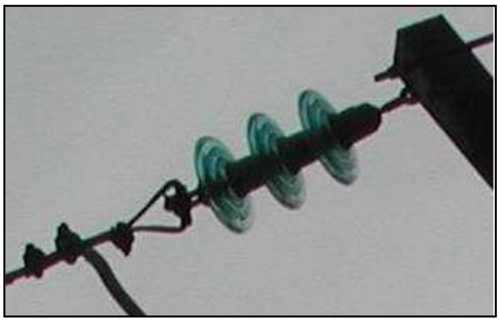
2.2.3 Pin type insulators



Insulators, in compression, supporting conductors may be classified as pin type. The pin type insulator is designed to be mounted on a pin which in turn is installed on the cross arm of the pole. The insulator is screwed on the pin and electrical conductor is mounted on the insulator.

This pin type insulator is applicable for rural and urban distribution circuits, and it is usually constructed as one of solid piece of porcelain or glass.

2.2.4 Suspension type insulator



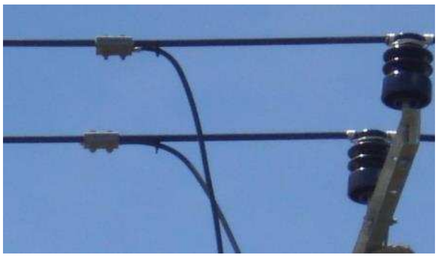
2.3 Conductors

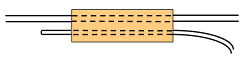
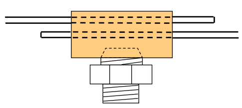
Most conductors are aluminium or copper. We use aluminium for almost all new overhead line installations because aluminium is lighter and less expensive than copper for a given current carrying capability. But aluminium can corrode quickly through electrical contact with copper or steel. To connect it to copper bar or conductor a bimetal connector shall be used to prevent corrosion of aluminium conductor.

There are many types of conductor in usage:
AAC (all aluminium cable) has highest conductivity-to-weight ratio. AAC has enough strength for usage in urban or suburban area
ACSR (aluminium conductor steel reinforced) has high mechanical strength-to-weight ratio. ACSR has about twice the breaking strength of AAC. ACSR is used in the area where you have often to cut or trim tree, or there are strong wind such as in rural area.
AAAC (all aluminium alloy conductor) has strength and equivalent capabilities of AAC or ACSR. It is used for coastal area where ACSR is prohibited.
ACAR (aluminium conductor, alloy reinforced)
ABC aerial bundle cable (for MV). ABC cable should use in the area where the safety clearance is difficult to be ensured, for example in urban area, where there are narrow street, tourist site

2.4 Connectors

Connectors are accessories for connecting cable.



Type	Classification of usage	figure and usage situation	
Straight Sleeve	Connection conductors when tension acts the connection point	 	Twist (applied to Cu conductor) Compression (applied to Cu, Al conductor)
Branch Sleeve	Connection a conductor used as a main line and a conductor used as a branch line or jumper, when tension acts the connection point		Compression (applied to Cu, Al conductor)
Bolt-type Clamp-down Connector	Connection conductors when tension does not act the connection point		Clamp-down (applied to "Cu and Cu" or "Cu and Al")

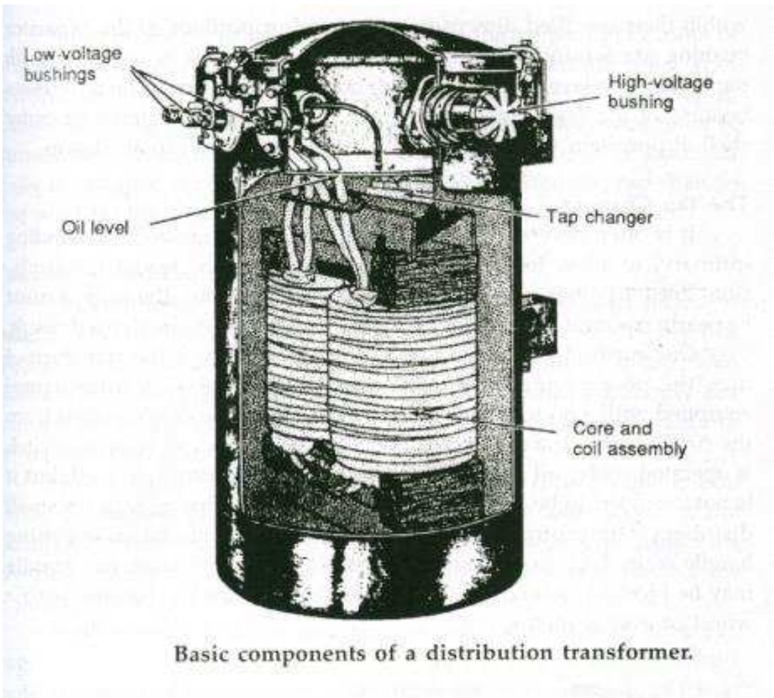
Source: Electrical Standard of Cambodia, llsbG article 41.2.3, table ES41A

2.5 Post of Transformers

They are electric static machines to transfer electrical energy converting from one voltage to another voltage. In MV network distribution, a transformer transferring energy from LV to MV is called step up transformer, and from MV to LV is called step down transformer.

2.5.1 Transformer construction

A transformer has two sets of coils coupled together through a magnetic field. The magnetic field transforms all of the energy. In real transformer
V1/V2 = N1(Number of turns in windings 1)/N2 (Number of turns in windings 2)



Basic components of a distribution transformer.

Loss in transformer:

Power is lost in the core through:

- Hysteresis: as the magnetic dipoles change direction, the core heats up from the friction of the molecules.
- Eddy current in the core material cause resistive loss.
- Power is lost in the windings by ohm effect.

Distribution transformer:

- Distribution transformer has power range from a few kVA to a few MVA. This transformer has function to convert primary voltage to low voltage that customers use.
- Size: Transformer size sometime means the rated power in kVA. Standard rated power may be for single phase transformer 5, 10, 15, 25, 37.5, 50, 75, 100, 167, 250, 333, 500 (kVA). For three phase transformer the rated power may be 30, 45, 75, 112.5, 250, 300, 500 kVA.

Through fault capability of distribution transformer:

- for single phase: 40 pu for 5-25 kVA, 35 pu for 37.5-110 kVA and 25 pu for 167-500 kVA.
- for three phase: 40 pu for 15-75 kVA, 35 pu for 112.5-300 kVA and 25 pu for 500 kVA.

Completely self-protected transformers (CSP):

It is used in single phase distribution transformer with some built-in features: tank mounted arrester, internal weak-link fuse and secondary breaker.

Three phase transformer:

Primary system: on primary side of three phase distribution transformer, utilities have a choice between grounded and ungrounded winding connections. In Cambodia we use ungrounded winding connection.

- Ungrounded primary: there are delta and floating wye primary connections. These connections are suitable for ungrounded and grounded distribution systems.
- Grounded primary: there is only grounded wye connection. It is suitable on four-wire grounded systems.

Secondary system:

Grounded wye secondary (used in Cambodia)
Delta secondary for three wire ungrounded services.

Note: Industrial facilities prefer an ungrounded system, because the system can be operated with line-to-ground faults.

The scheme Delta-Grounded Wye are used in distribution network in Cambodia. Advantages of such system are:

- supply 3 wire or 4-wire system
- supply grounded-wye service, 400 volts
- does not supply ungrounded service
- Ground faults: block zero sequence so upstream ground relays are isolated from line-to-ground faults on the secondary of the customer transformer.
- Harmonics: isolates the primary from zero-sequence harmonics created on the secondary.
- No primary ground service
- Secondary ground source
- No tank heating: no zero-sequence flux in the transformer's core.
- Ferroresonance: highly susceptible.

Loading conditions:

Transformer can deliver its rated kVA without exceeding temperature rise limits when is under some conditions:

- Secondary voltage and the voltage/frequency do not exceed 105% of ratings.
- Power factor greater or equal 80%
- Frequency not less than 95% of rating

Losses:

Distribution transformers account for about 30% of transmission and distribution loss. There are 2 main contributors to losses: No load loss about 85% and load loss about 15%.

- No load losses are the continuous losses of a transformer, regardless of load (from 0.15 to 0.4% of transformer power);
- Load loss (copper or wire losses) are from current through the transformer's windings, generating heat through the winding resistance as I^2R.

Inrush:

When a transformer is switched on, the transformer may draw inrush current from the system due to core magnetisation being out of sync with the voltage. The inrush current may approach short-circuit levels (about 40 times the transformer's full load current). Inrush may cause fuses, reclosers or relays to falsely operate.

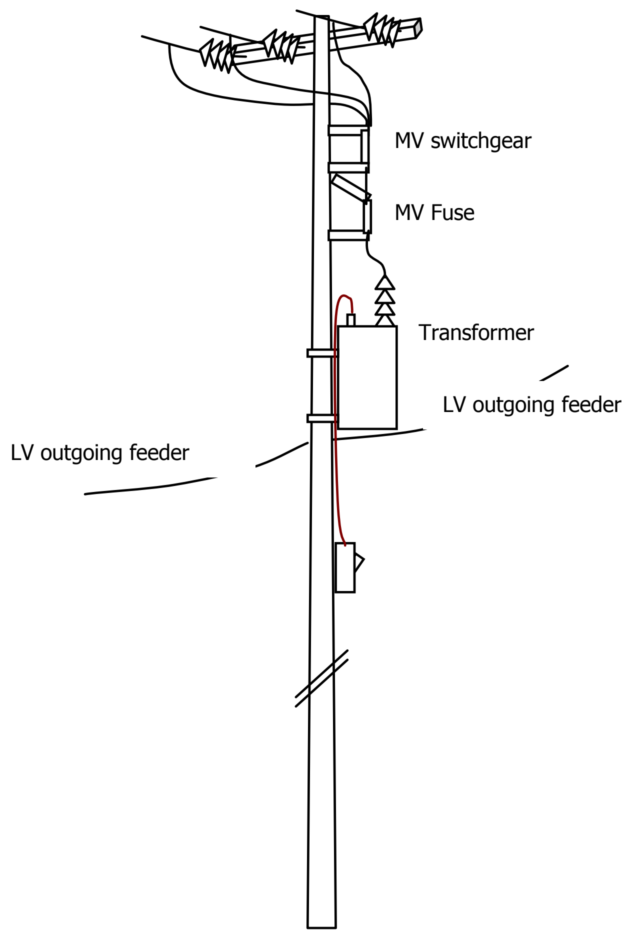
Some voltage disturbances cause inrush in transformer:

- Voltage sags: when there is recovery from voltage sag from a nearby fault, the sudden rise in voltage can drive a transformer into saturation.
- Symmetrical inrush: Energizing a transformer can cause a nearby transformer to also draw inrush.
- Lightning. A flash to the line near the transformer can push the transformer into saturation.

2.6 Protective devices

A distribution system is exposed to overcurrent, overvoltage, and open circuit conditions. Protective equipment is placed to limit and isolate the faults so that the remainder of the system is not affected.

At a distritbution substation, there are normally high-voltage fuses or a circuit breaker on the high-voltage side of the substation transformer and circuit breaker or reclosers on each distribution feeder or the low-voltage side.



Circuit Interrupters, including circuit breakers, fuse and recloser.

The devices interrupt fault current during a zero-crossing. The interrupter creates an arc. Example: Fuse creates an arc when the fuse element melts. Circuit breaker or recloser does it when the contacts mechanically separate.
After the arc is created, the dielectric strength across the arc is increased so that the arc clears at the current zero.

There are 2 types of MV circuit interrupters:

- Interrupter such as disconnect switch, load interrupter is installed to provide operating capability. It can operate with a load-break tool or can interrupt load current or cannot interrupt any load current. But none of this type can interrupt fault current.
- Interrupter such as a circuit breaker, a recloser, a sectionalizer or a fused cutout is installed to provide circuit protection.

Circuit breaker

Circuit breakers are often used in substation on the bus and on each feeder. Circuit breakers are tripped with external relays. They are installed to protect generators, transformers, sub-transmission lines and distribution lines.

Circuit breaker relay

Distribution circuits are almost always protected by overcurrent relays that inverse time overcurrent characteristics.

Main type of relays: electromagnetic relays, static relays (analog electronic circuit) and digital relays (based on micro processor component).

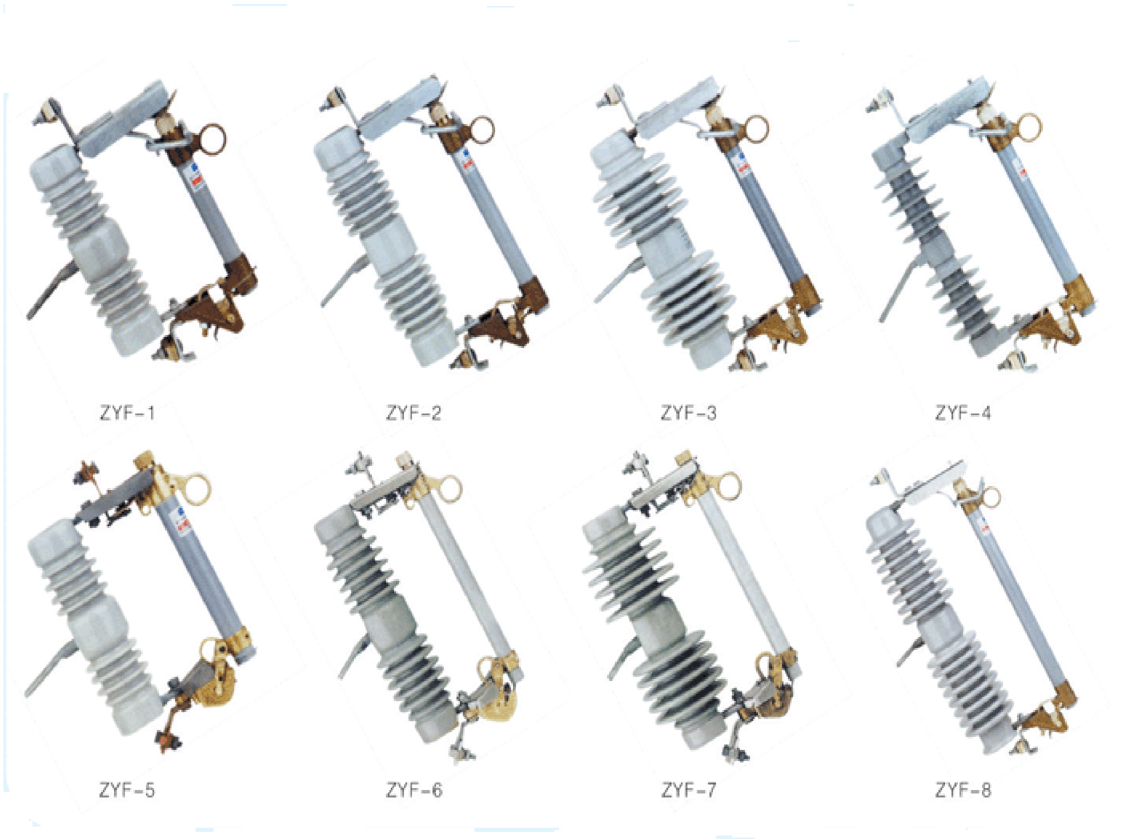
Examples of some of the relays that can be installed to protect a circuit are listed:

- An overcurrent relay detects current when its exceeds some limits
- a thermal relay detects an abnormal rise in the temperature of a generator or transformer.

Expulsion fuses

Fuses are low-cost interrupters that are easily replaced.
Concept: a fuse element made of tin or silver melts under high current. In a fuse tube, after the fuse element melts, an arc remains. The arc, which has considerable energy, can cause a rapid pressure build up. The pressure forces much of ionized gas out of the bottom of the cutout. By this way the electric strength increases with the help of extreme pressure, arc stretching and turbulence of gas.

Fuse cutout

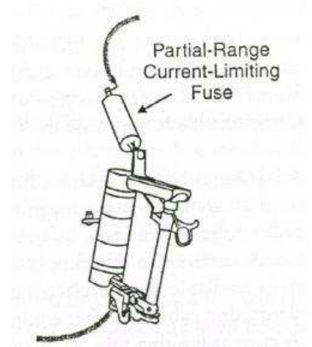


Some varieties of cutout are built with a removable fuse holder. The holder is placed in a cutout with a porcelain bushing type support. These cutouts do not have load break capacity. If the cutout is opened under load, an arc can drew out and will not clear.
When the fuse is in the fuse holder melts, it breaks a mechanical link, which causes the fuse holder to drop open. It provides overcurrent protection and will isolate faultry equipment and circuits automatically.

Whe a cutout is opened with a switch stick, the cutout operated as a regular disconnect switch with no arc-extinguish equipment other than the air gap between the switch terminals. Normally a load-break tool should be used when interrupting load current.

Link-break fused cutout is a cutout that can interrupt load. A link-break hook is pulled down with a switch stick to break the fuse link and safely extinguish any arcing inside the fuse chamber.
If a cutout is closed in on a faulted circuit, it is important not to immediately open the cutout. Let the fuse and fuse holder extinguish the arc.

Current-limiting fuse (CLF)



Current limiting fuse is another interrupter. This fuse has ability to reduce the fault current magnitude and has very high fault-clearing capability. CLFs have symmetrical maximum interrupt ratings up to 50 kA. It will limit the magnitude of the current flow by introducing a high resistance after the fuse element melts.

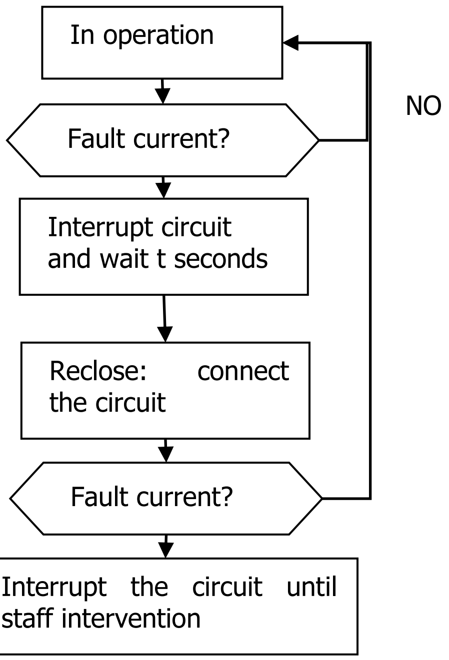
Transformer fusing

It is used to disconnect the transformer from the circuit when it fails. The fuse cannot effectively protect the transformer against overloads.

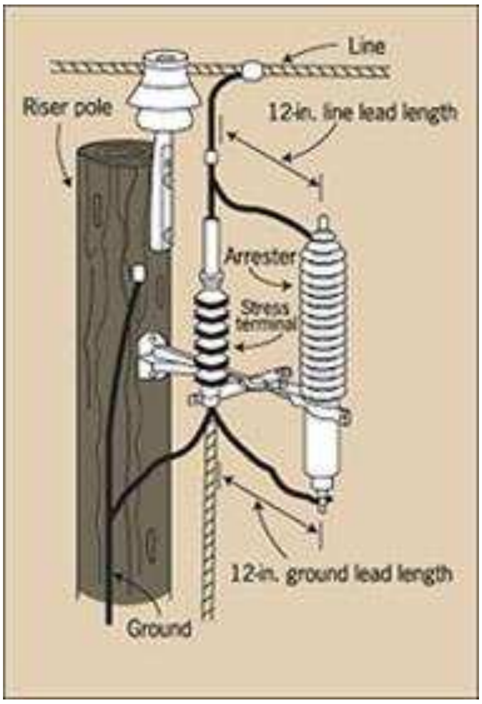
Recloser

A recloser is a distribution protective device capable of interrupting fault current and automatically reclosing. That means automatic circuit recloser is a self-controlled device for automatically interrupting and reclosing an alternating current circuit, with a predetermined sequence of opening and reclosing followed by resetting, hold closed or lock out.

Example of simple sequence of opening and reclosing in a recloser



2.7 Surge arrestors



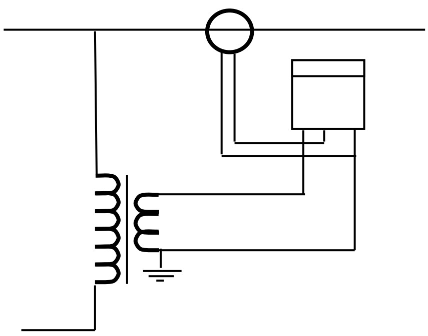
A surge arrester is a device to arrest the surge of lightning. Surge arrester has metal-oxide block. Under normal voltage, a metal-oxide surge arrester is almost an open circuit. When there is an overvoltage, the metal-oxide block responds almost instantly by dropping it current impedance to a few ohms only. After the surge is done (no more overvoltage) the metal-oxide is immediately returns to its normal high impedance.

2.8 Metering system equipment

- Current transformer: a device to transform a big current to a current in the range of 0..5 A that can pass through measurement instrument (e.g. meter)
- Voltage transformer: a transformer for adapting the high voltage to the rated voltage of meter.

Now digital meter is widely used in MV network in Cambodia.

The MV meter is also a type of meter used for LV system, and is connected to the main lines via current and voltage transformers as shown in the figure below.



The meter must be class 1 in accordance with IEC.
Current transformer plays a role of:

- Convert a big current to a current in the range of 1….5A
- Isolate the measurement circuit from MV line for safety.

In general, the meter is often found with the range of 5A in Cambodia. Therefore, the secondary current is also 5A.

Voltage transformer plays a role of:

- Convert a MV voltage to LV voltage (range of 100 or 110V) to allow meter function.
- Isolate the measurement circuit from MV for safety.

Chapter 3 Risk and safety issues

3 Risk and safety issues

3.1 Environment concern

Production activities can have negative impacts on environment. Installation of overhead line should be conducted in such a way to minimize bad impacts on environment. Big impact may be from cutting trees and flora, trimming tree, loss of cultivative soil, bad influence of electromagnetic field on human health.

Overhead line almost damages some interest from agriculture. So overhead line should be laid along a road, path or on border of land use. Luckily the construction of 22 kV line sometime has minimum influence on agriculture.

Strictly follow the safety rule (rule about clearance). See Electrical Technical Standard in Kingdom of Cambodia. In planning, the layout of overhead line should be scheduled for a period with less economic activities.

In transporting material like pole, conductors and construction materials, avoid as possible damaging tree, land surface, road surface. Use truck with lifting hoist with high capacity. Lay the pole parallel to road so that the pole could not obstruct the traffic and cause accident.

The bad influence of electromagnetic field can be reduced by putting the line at s sufficient height (see rule about clearance). The electric field intensity should less than 15 kV/m in no-population area, 5 kV/m in town and 10 kV/m on the road.

To reserve the landscape, the pole should be acceptable in view point of aesthetic. Cylindrical pole is a good example.

Do not allow easy to burn or explodable material near the line trace to prevent any fire case, especially in dry season.

3.2 Organization for safety

To prevent professional sickness, traumas on workers, some rules must be respected:

- Before sending a worker to install overhead line, give him necessary information, rule, measure for remain safety.
- Each team shall have first-aid manual, kit and materials.
- When installation work is conducted far from hospital, health centre, we should reserve a special transport for case of accident.
- Do not allow a worker to execute task alone without survey
- Do not allow a worker to site without training on safety technique and primary safety measures: wear safety clothes, shoes, gloves, helmet,...etc.
- When there is doubt, team leader shall verify the safety knowledge of his workers.

- Do not allow boys or girls less than 18 years old near by the installation area.

3.3 Safety measures

3.3.1 *Cutting tree:*

Two teams shall be separated by a distance larger than 50 m.

- Cut only a tree in one time.
- If necessary trim the tree branch as much as possible
- Do not work when there are strong wind, rain or storm.
- Do not stand in the corner, where the tree should fall down.
- Respect the safety manual when used special cutting machine.

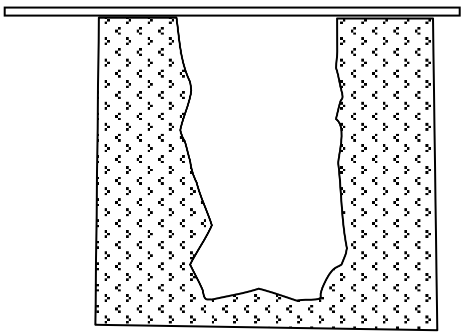
3.3.2 *Earth works:*

- Respect the rule by excavating earth slowly, with small amount a time to avoid damaging underground installations.
- Excavated soil shall be put at least 0.5 m far from the hole mouth.
- Take an appropriate measure to prevent landslide.
- Do not stand inside the area of the excavator arm action
- The hole shall be covered and marked to prevent people fall down.

3.3.3 *Foundation:*

If a worker is inside the hole, do not allow people stand near the hole mouth (at least 1 m far from the mouth). A worker can approach the hole mouth by stepping or standing on a wooden bridge.

When put the concrete mix, do not allow concrete mix touch the hole wall when falling.



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3.3.4 *Using lifting hoist:*

- Check the strength of cable or trolley and the correct work of lifting mechanism.
- Do not allow overweighting the hoist mechanism (over lifting capacity)
- Respect the meaning of control signal
- Allow only one direction of displacement at one time: vertically, horizontally (turning at some angle and at low speed).
- Do not allow people stand under the load when lifting.

3.3.5 *Installing pole:*

Workers shall know their role and responsibility.

- One worker will give control signal, so do not allow him to do other task, when controlling.
- Check every time necessary item before the execution (enlacing the pole, hook the pole, roller mechanism, cable etc.)
- Pole shall be installed completely. If the installation can not be finished, the pole shall be lay down back to the ground.
- Allow to climb up the pole only when the pole can stand strongly alone.

3.3.6 Lifting, handling materials

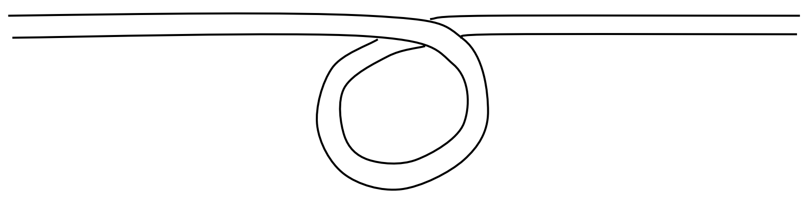
- Lighting the work area, following the norm of lighting.
- Worker shall have self-confidence
- Lifting, handling pole shall be done under the control of a responsible.
- Pole shall be lay on the ground completely and parallel to the road or path.

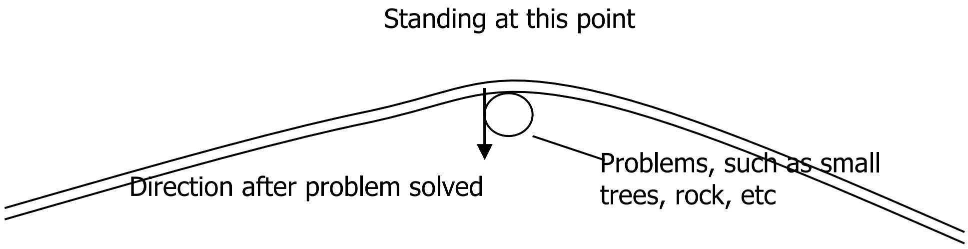
3.3.7 Handling conductor

- Avoid hooking with clothes, conductor rolls fall down to ground
- The conductor rolls shall be put at horizontally smooth and reliable surface
- Turning the conductor rolls in counter direction of the windings
- When stretch the conductor, turn the conductor rolls in the windings direction.

3.3.8 Pulling conductor

- Pulling smoothly. Avoid pulling abruptly the conductor.
- Check stability of conductor rolls
- Do not make ring for pulling.
- Do not pull the conductor to the top of hill, The conductor should be pulled from the hill top down.
- When there is obstacle, to liquidate this obstacle, stand at the side where the conductor will not be moved.
- Do not allow children less than 18 years old climb the pole.
- To climb the pole, worker shall use appropriate tool and safety tool such as climbing ring, scale, safety belt etc.
- Check the pole stability before climbing.
- Bring a light and reliable cable for lifting tool when necessary.
- Use pulley to bring necessary material to top of the pole.
- Do not allow people stand near pole while people work at the top of pole.





Safety when installing conductor:

Conductor of overhead lines may be bare or covered. Such conductors, located in trees, or adjacent to structures where they may come into contact occasionally, may be covered with high density polyethylene or other plastic material resistant to abrasion. This covering is generally not sufficient to withstand the rated voltage at which the line is operating, so these conductors must be mounted on insulators any way. The purpose of covering is mainly to protect the wire from mechanical damage. The wire should be treated as though they were bare.

If installation of conductor is done in the area where there is not electricity, workers shall wear safety tools: helmet, goggles, clothes with tight sleeves and trouser legs, no ring on fingers, no bracelet on arm, no collar on neck, safety shoes.

If installation is conducted in the area where there is electricity supply, workers shall wear over safety tools some special protective tools if necessary. For example wear protective gloves over rubber gloves.
The conductor to be installed shall be connected to earth.

Safety when installing distribution transformer:

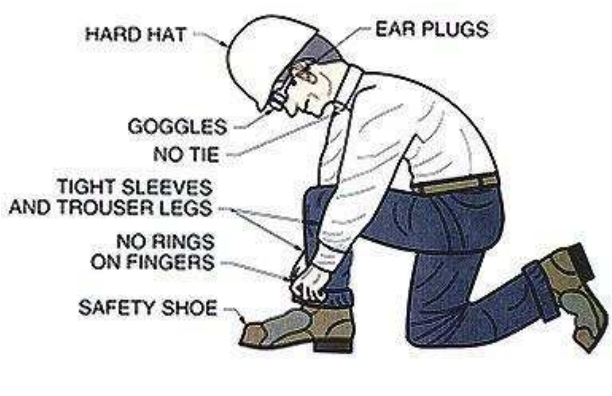
- While working; protect yourself; lift and move transformer with care and mount transformer securely.
- Observe all safety practices and procedure regulations established.
- Wear all protective gear and clothing (boots, helmet, gloves, mask, goggles, safety glasses..) for safety job.
- Before moving the transformer, check the total weight of equipment (see nameplate for example) and check the conditions and capacity of all lifting and hoisting equipment.
- Do not use worn, frayed or damaged hooks, cables, or slings.
- Do not use fork lift or cranes with load capacity less than the weight of the transformer.
- Do not drop the transformer from truck.
- The transformer must be securely fastened to the pole.

When making connection of transformer to network:

- Make sure multiple voltage switches and tap changes are in the proper position.
- Make sure the tank is grounded properly before doing any other works.
- Clean all bushings, terminals and all connection points before making system connection.
- Make sure the insulating fluid is at the proper level before the transformer is energized.

Safety tools and instruments:

- Helmet
- Gloves
- Clothes
- Shoes
- Insulated and indicator rod



- Grounding conductors and temporary earthing system

3.4 Safety issues in operation

3.4.1 Step potentials, touch potentials

- During ground fault, all the ground current returns to the substation transformer through the earth. It can create significant voltage gradient along the ground and between the ground and conducting objects.
- Touch potential is considered a hand-to-foot or hand-to-hand contact. Step potential creates a path through the legs from one foot to another.
- Under normal condition, these voltages are not dangerous but can cause annoying shocks and concerns in farms (slay voltage). But step and touch voltage potentials during faults are more dangerous.

When you feel that you are in the electric field of ground fault:

- Stand by uniting the 2 legs and ask your college to shut down the circuit if possible
- Do not run (avoid bid step voltage, especially when you fall down)
- Do not touch any object around you with bare and non insulated arms.
- Walk by very small step, not lifting your leg from the ground and take care not to fall down.

3.4.2 Slay voltage

Slay voltage is a touch voltage that end-users experience. Possibly causes of slay voltage are:

- improper facility grounding and bonding
- may on secondary system (larger neutral, poor neutral connections...)
- failed equipment insulation (a failure to a bonding frame)

Utility side to slay voltage includes:

- Balancing (reduces earth return current, so reduce neutral to earth voltage)
- Single phase lines: converting single phase sections to 2 or 3 phases to reduce the neutral to earth voltage.
- Neutral: upgrade neutral size to create low impedance path for earth-return current.
- Capacitor banks: check item for blown fuses. If a grounded-wye capacitor has a blown fuse, the unbalance can create excessive neutral current.

3.5 Safety in Maintenance

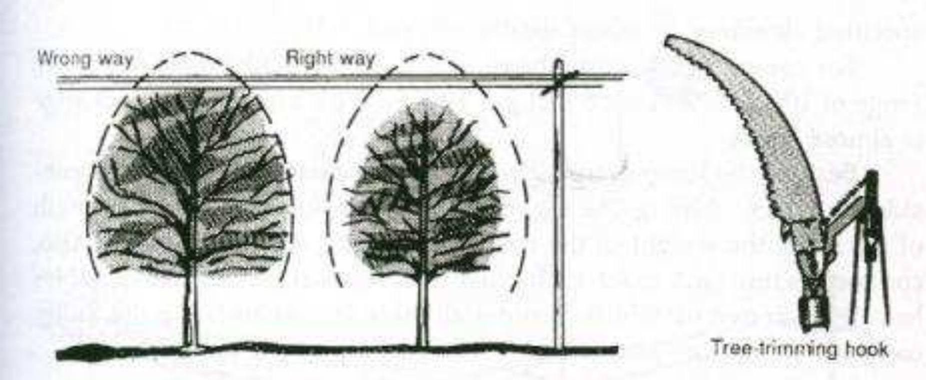
Procedure should be followed when maintaining the system:
Note that working only on deenergized circuit.

- The responsible person, before sending team to do maintenance work, shall:
- Describe clearly the task and the specification of location to do maintenance.
- give special instructions if necessary
- Check list of necessary tool and additional tools, safety labels etc.
- If necessary verify the safety knowledge of the team staff.
- switch off the circuit at maintenance place and put appropriate label on switch ("People working");
- check the voltage on the place and ground the circuit
- Put the label "work here", "pass by here" etc.

- Allow people to do their job.

3.5.1 Tree contact

Tree contact causes possibly dangerous shocking hazard. If a tree is on contact with an energized phase conductor, it may create a touch potential hazard near the ground. The tree will not draw enough current to operate a fuse or other protective devices. But it may create significant touch potentials.



Where possible, trees are trimmed.

In that case, some measures should be considered:
- educate the public on dangers of cutting trees in the vicinity of power lines
- trim tree away from power lines
- train tree trimming crews and ground support crews properly
- use covered wire instead of bare wire.

3.5.2 Protective grounding

Repair, maintenance and installation shall be done with the circuit deenergized. During deenergized work, protective grounds tie the phase conductors to a ground point, in order to:
Prevent the case that circuit accidentally energized
Protect against voltages from magnetic or capacitive coupling and backfeed through transformer or capacitor banks

So some measures have to be considered by the team when doing repair and maintenance work:
1) Test the line voltage before installing jumpers
2) Team work until the team finishes the work
3) Ensure that everyone is clear of the work site
4) Remove the protective grounds
Note: the protective grounding set should be tested periodically.

3.5.3 Procedure to implement the work with safety

1. Remember that safety while carrying out the work should follow the following procedure even though those works are small.

1. <u>Meeting before starting work:</u>

   All concerning people must participate the meeting and then follow the principle below:
   a. Work plan
   b. Schedule
   c. role of each staff
   d. safety tool
   e. check all accessories to be used
   f. inform concerning people

2. <u>Preparing for staring work</u>

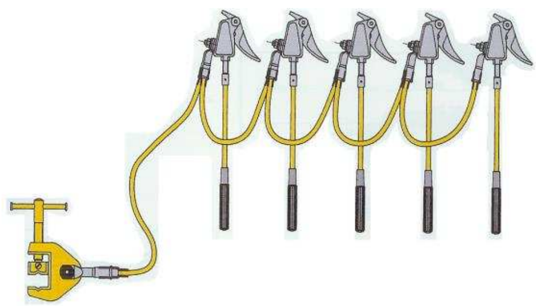
Work on network: disconnect the circuit breaker.

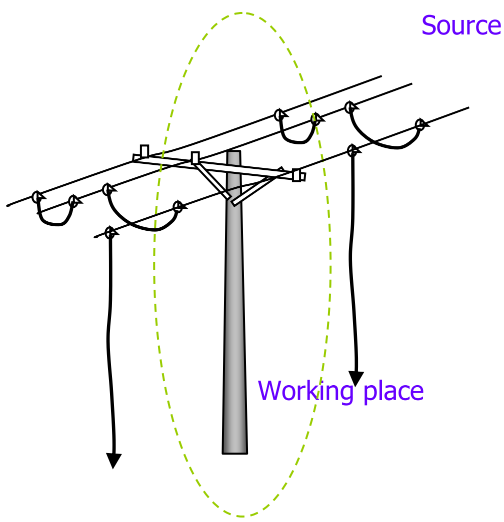
a. Put signal near circuit breaker: "do not switch on the electricity supply while working" ➔ must have a permanent guard.
b. Lock the circuit breaker in case of electricity supply disconnection. Check the voltage using measurement tool for MV/LV voltage.

Voltage Measure tool

Measurement tool of voltage of 1 kV

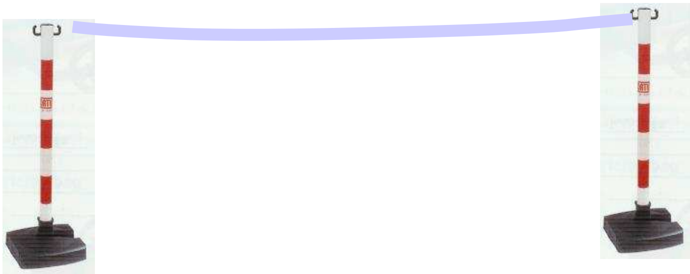
2. Install the grounding system, all phase conductors must be interconnected in case of short-circuit, so it is connected to the ground for:
   a. Finally confirming that one working on one circuit is correctly done with safety.
   b. Obtaining prevention from electrical shock to be generated by return-current due to mal working made by operator, touching with neighboring circuit, lighting…
   c. Obtaining prevention from induction: we need the grounding system to prevent from induction on 2 types: static induction will generate voltage in the circuit and magnetic induction will generate current flow within the conductor connected to the ground.





Connected to the ground while working

To protect those who come inside the working place, the warning board must be installed



Type of warning board

3. Working inside the power house

    a. Stop the generator set and disconnect circuit breaker
    b. measure the voltage using voltmeter of MV or LV
    c. Install grounding system
    d. Insulate a part of wire using PVC or similar insulate element.
    e. Ensure the limit of work to protect a part of working and other live current electric appliances.

4. Working near the living current equipment:

    a. Determine the working space to avoid contact or be nearby the electrical equipment with which the live current operates that may create electrical shock.

Voltage (kV)	Distance (m)
22	1,5
115	2
230	3

5. General measures

    All staff must follow the guidance of supervisor. The chef must supervise all staff, staff must supervise workers for safety purpose.

6. Safety during work

    Nobody takes stair or long accessories to be close with live electrical appliances. Those long accessories shall be tightly held nearby the ground when they are close to the live electric appliances. In order to prevent fall of people working at the top level (pole, building), belt or scaffold shall be applied for safety purpose.

7. After completion of work, do not forget to:

    a. Collect all staff
    b. Check number of tools used

c. clean working place (strong point to communicate with clients)
d. disconnect the grounding system
e. Brainstorm the work performed
f. Discuss the problem happened after work completion and share experiences for later working safety pourpose.

3.5.4 Grounding system and safety

Configuration:

In Cambodia, MV system is ungrounded distribution system. Figure below shows the ungrounded three-wire systems. Whether grounded or ungrounded, three-wire systems have some following advantages: lower cost for three phase loads, lower stray voltage, easier detection of high-impedance faults, lower magnetic fields.

Neutral shift during ground faults

A single line-to-ground fault shifts the ground potential at the fault location. For ungrounded system the full offset occurs because the line-to-ground voltage on the unfaulted phases rises to the line-to line voltage, 1.73 times. Ungrounded systems may have extra-high overvoltages under following conditions:
Resonance - the line-to-ground capacitance can resonate with the system reactance
Arcing ground fault - a restriking ground fault can create significant line-to-ground voltage.

The impact of these overvoltages is stress on insulation and is on arresters (so higher rated arresters are necessary).

Equipment grounding

The electrical technical standard requires grounds on surge arresters, primary, secondary and common neutrals, ungrounded metal or metal-reinforced supporting structures, instrument transformers, most equipments including transformers, capacitors, regulators, reclosers and sectionalizers, uninsulated guy, customer meters.

In MV system, the secondary neutral grounding system is the whole grounding system. If a transformer fails to operate from the primary to secondary (a high-to-low fault), the secondary grounding system must be effective enough to prevent unsafe voltages on customer wiring.

Secondary grounding problems

There are some common problems of secondary grounding: open secondary neutral, neutral and safety ground reversed in the facility, neutral and safety ground connected in the facility.

Soil resistivity

Soil resistivity is primarily affected by:

- Moisture - moisture is one the main factors determining soil resistivity. The dryer the soil is, the higher resistivity is.
- Temperature - above the freezing point of water, temperature does not impact resistivity significantly.
- Salts - the presence of soluble salts significantly impacts the resistivity.

Corrosion issues:

Corrosion is major consideration for grounding electrodes. Ground rods are normally copper-clad steel or galvanized steel. Most grounded wires are copper. Steel and aluminium corrode too quickly for grounding use. But copper is attractive to thieve.

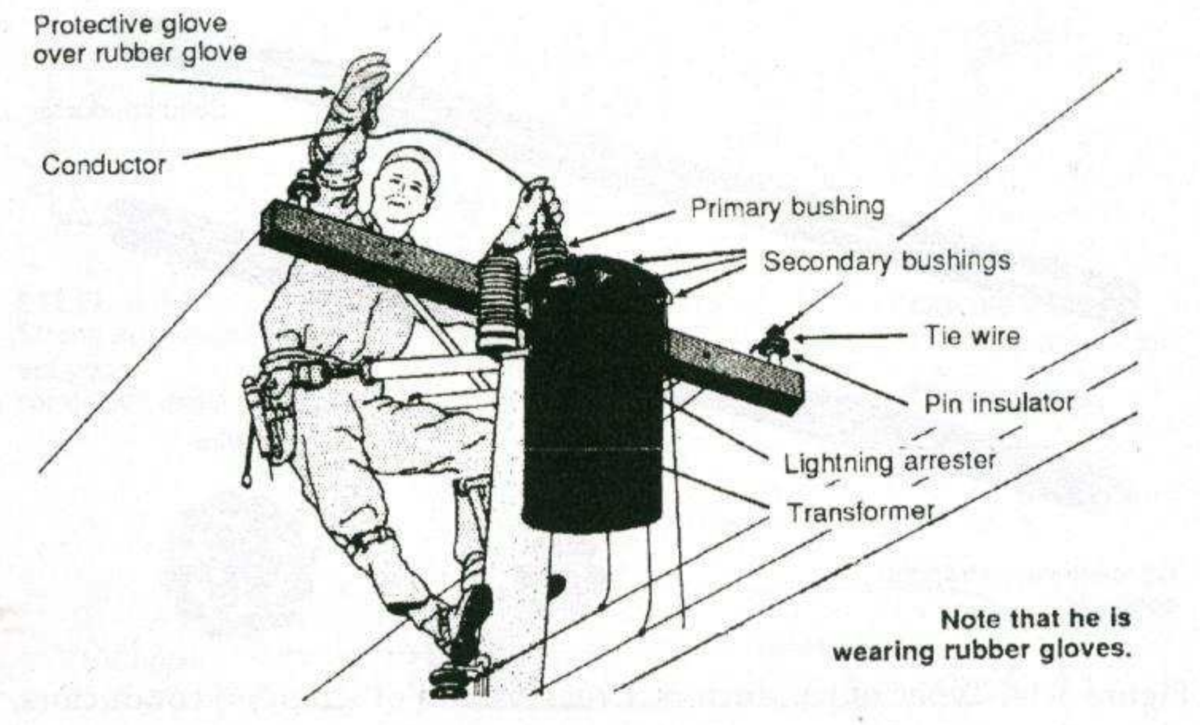
Mixing metals significantly increases corrosion. This is galvanic corrosion, because different metals create an electrochemical battery in the soil. Galvanic corrosion between dissimilar metals can eat up grounding electrodes.

Copper has naturally good properties that limit corrosion. A zinc coating on a steel ground rod (galvanized ground rod) provides corrosion protection for the rod. With lower soil resistivity, grounding electrodes corrodes faster.

To limit excessive corrosion caused by different metals, avoid using different grounding rods or provide as much separation as possible between ground electrodes of different metals. With galvanized steel rods, use steel or aluminium pole ground leads. With copper-clad steel rods, use copper down leads.

Chapter 4 Installation of MV networks

4 Installation of MV network



Lineworker working on line conductor.

4.1 Installation method of overhead 22 kV line

There are 2 methods to install the overhead 22 KV MV line:
1. Make contract with a specialized company for implementing the whole installation project
2. Use internal force: the staff consists of many specialists for dealing with special part of line.

The first method is more efficient in terms of investment efficiency. The second method is good for repairing some parts in the installation.

Generally, the installation of overhead line in Cambodia can be done in four stages:
1. Preparatory works: clear the line trace, pole location, transport etc.
2. construction: earth works, pole foundation, earthing, assembly work, pole installation
3. Installation works: connect conductor, pull conductor along line trace and install accessories and other line equipments.
4. Testing and commissioning works.

The workers in the installation of MV line (stage 2 and 3) are organized by different specialized teams that will accomplish 5 different tasks:
1. for preparing line traces (tree cutting and trimming, mark the pole location...)
2. for transporting materials (distribute the pole along line trace, construction materials ...)
3. for pole foundation
4. for installing pole and assembly accessories

5. for installing conductors.

Machine and tools used in overhead line installation are as follows:
- transport means: truck, crane lorry,
- for earth works: shovel, drilling car
- tools for handling, pulling and lifting: crane, hoist, pulley,

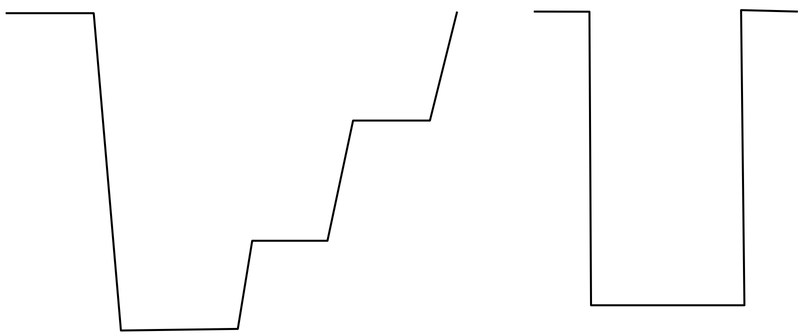
4.2 Construction works

To start construction works when installing overhead line, some preparatory works shall be done as follows:
- Trees must be cut out or trimmed if it is possible.
- prepare place for materials
- if it is necessary, install temporary electrical network from for e.g. an independent generator.
- Rearrange other installations on intersection point.

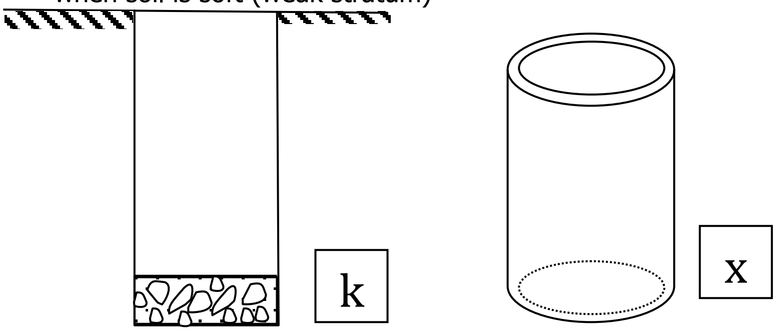
Inspection of materials before sending them to site (e.g. presence of crack on the concrete pole, size and number of accessories, measuring insulator resistance (R >= 3000 Mohms)

4.3 Preparation foundation for pole

a. Earth works:
- may be manual works or with drilling truck
- or may be by excavator
- or using explosive material, air hammer (for rock place)

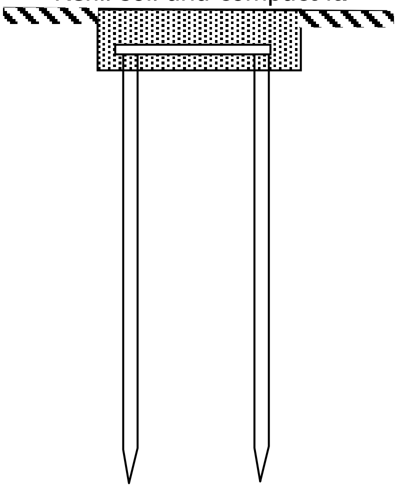


b. Foundation making;
- supporting pole
- dead end pole
- when soil is soft (weak stratum)



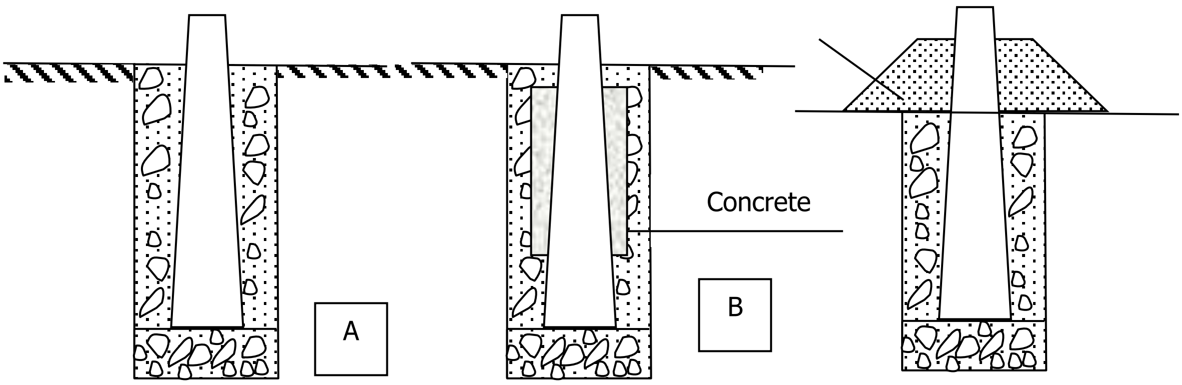
c. Earthing
- Dig soil till 0.5m depth or 0.1m for rock type soil

- Pound the electrodes into earth and bond them together by welding.
- Refill soil and compact it.



d. Pole installation

- lift up the pole using crane,
- put the pole on the mark point on the foundation and rotate the pole as necessary, so the cross arm will perpendicular to line trace
- ensure that the pole is vertical
- fill back the earth hole with construction materials (concrete, mix of sand and gravel, etc)



Note: if the depth of the hole is not enough because of geographical reason, the soil is filled up to reach a sufficient height. After, follow some rules below:

- earthing the pole
- mark the pole
- install accessories
- guying the pole if necessary

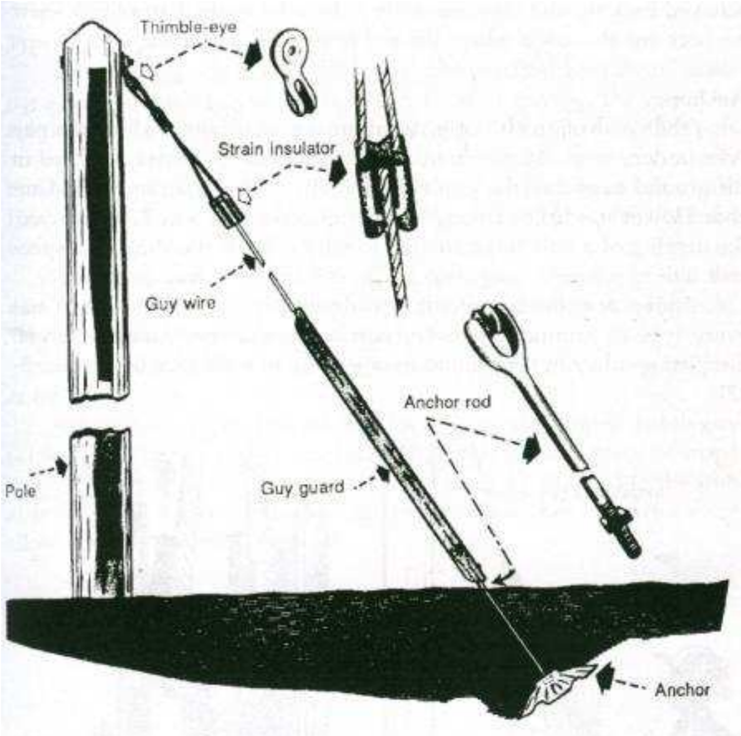
4.4 Guys

Anchor guy is usually to keep poles in position, particularly in case of poles installed on the hill, corners areas, etc.

Components of an anchor guy: wire, clamps, anchors, guy guards and strain insulator. The wire is usually copperweld, galvanized or bethanized steel. The guy is usually firmly attached to the pole by a thimble-eye or by a guy eye bolt and stubbing washer. The wire is held firmly by the clamp while the bolt is being tightened. Strain insulators are not necessary in grounded systems.

Guy guard is located near the ground to serve for:

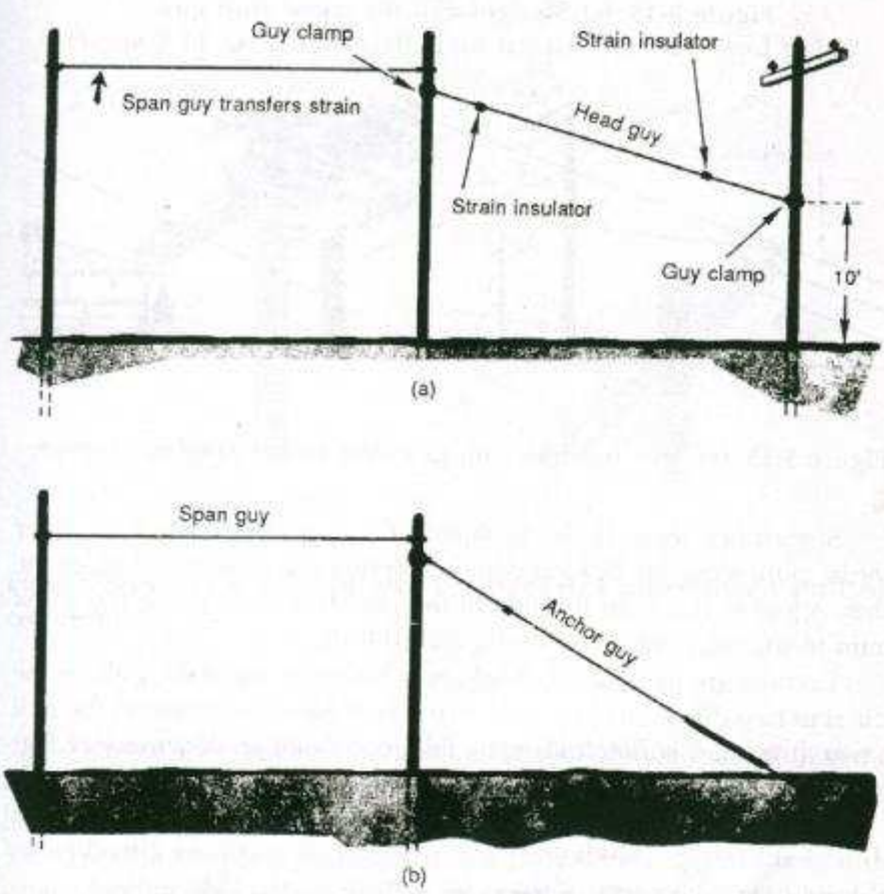
- making wire more visible to prevent pedestrians from tripping
- clearing the chance of being cut by the wire when someone walk into a guy wire
- protecting the guy wire from damages by cars or vandals.



Components of an anchor-guy installation.

4.5 Span guy

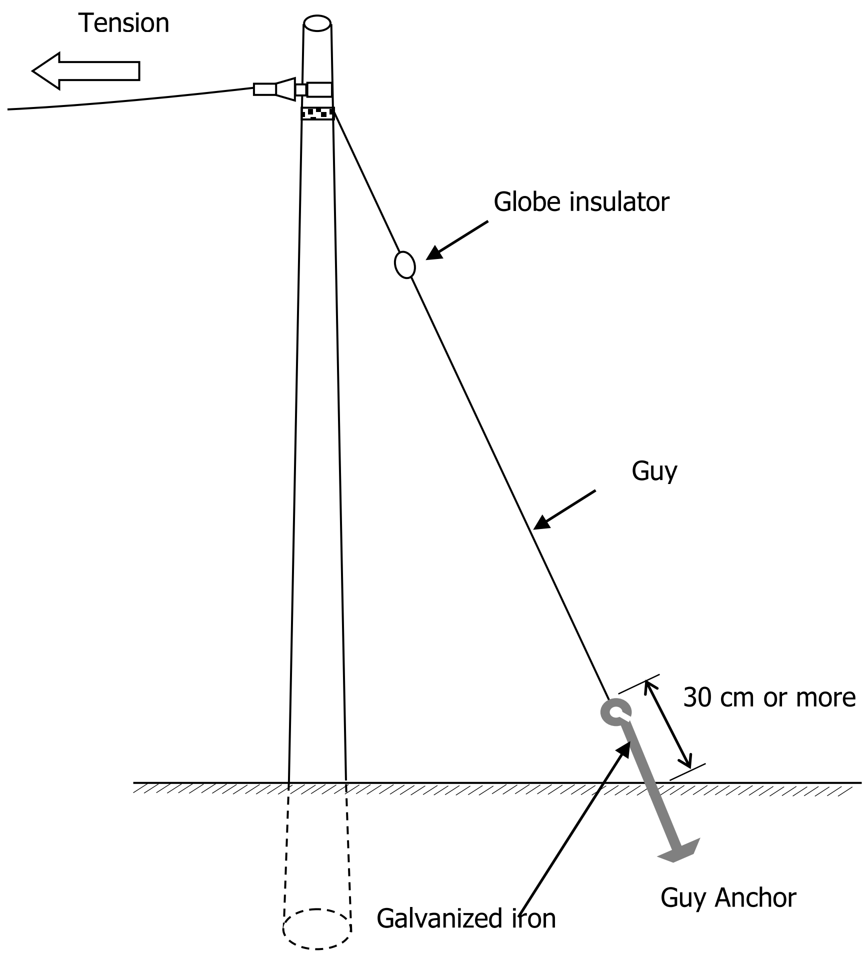
The span guy is usually used in situation where an anchor guy is impractical because of crossing a road. The guy wire will extends from the top of pole to be guyed to the top of another pole across the street.



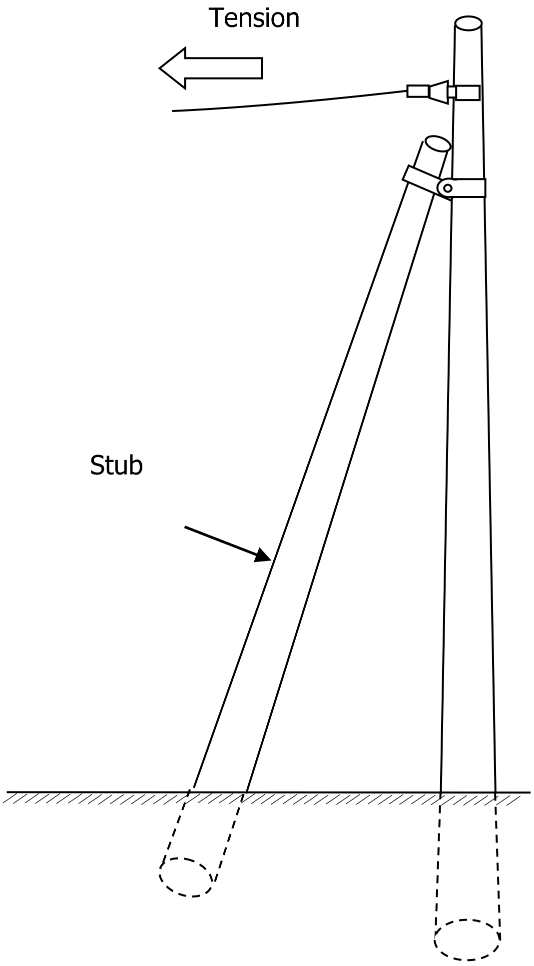
How a span guy is used (a) and (b).

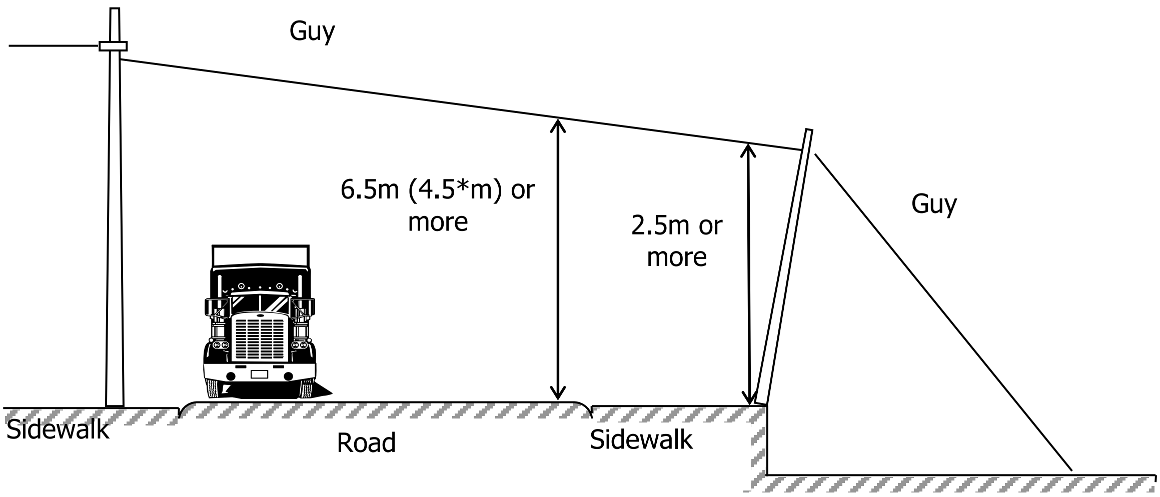
4.6 Stub guy

The stub guy is used to adjust the clearances of cable. It is just a piece of wood to which the guy wire is attached. The stub guy wire must allow enough clearance for traffic.



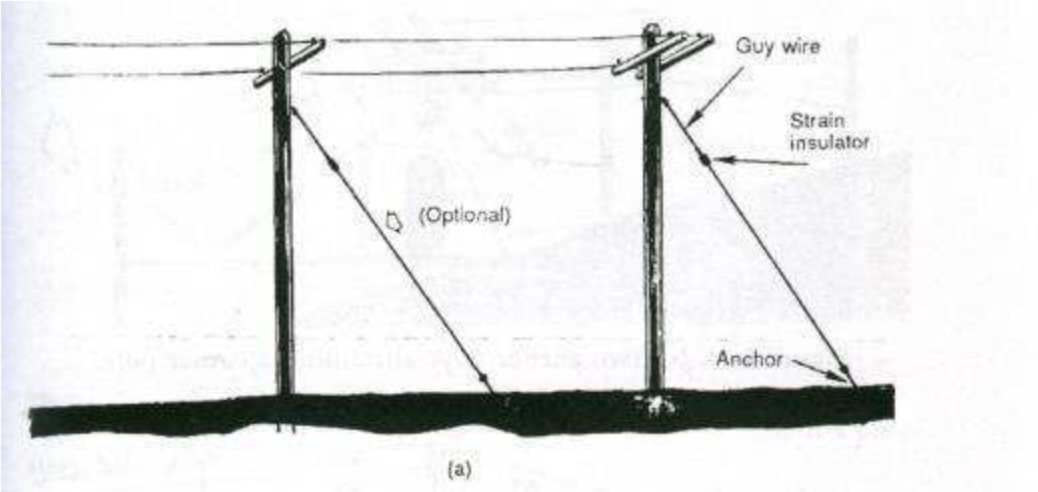
Tension
Globe insulator
Guy
30 cm or more
Guy Anchor
Galvanized iron





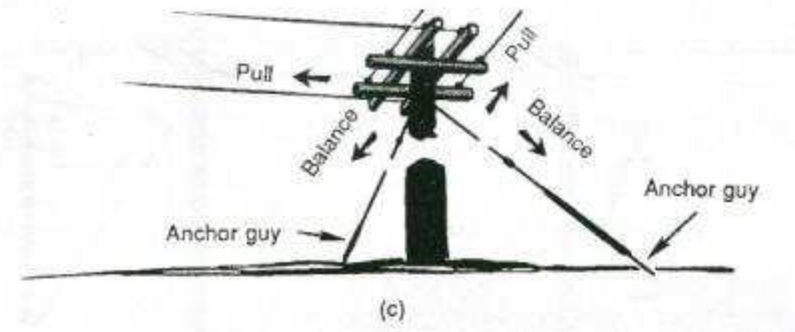
4.7 Different cases of guy used

Dead-end pole: a guy is needed to counteract the pull of the conductors. In case of heavy construction where one guy is inadequate, an additional guy may be used on the pole previous to the last one.



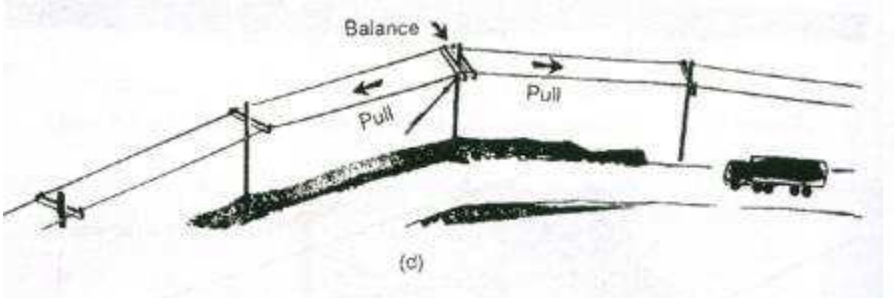
Guy installed on terminal or dead-end pole.

Corners are treated like dead-ends. Two guys should be used to counterbalance the pull of one set of wires each.



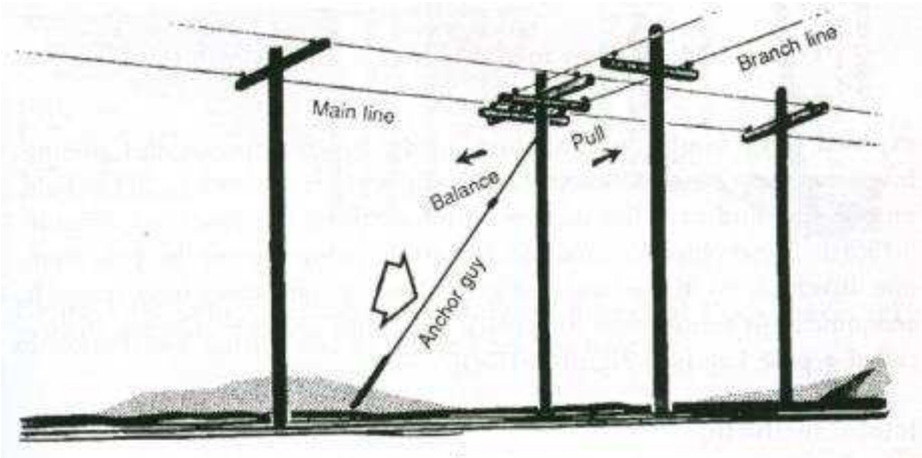
Two anchor guys sustaining a corner pole.

Conductors form an angle: the pole is submitted to an additional stress. Side guys are attached to the pole to balance the side pull forces.



Line making an angle.

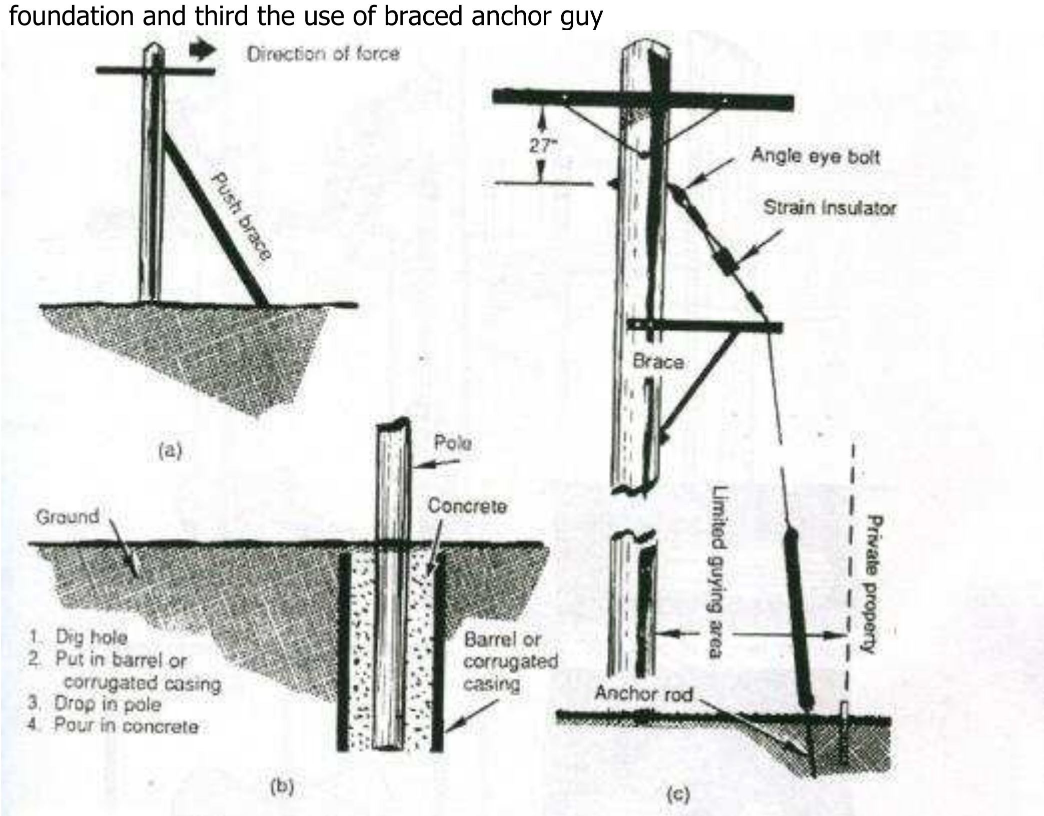
Branch line shoots from the pole: the weight of branch causes a side pull. The side pull is counterbalanced by side guys



(f)

A guy is used to counteract the side pull of a branch line connection.

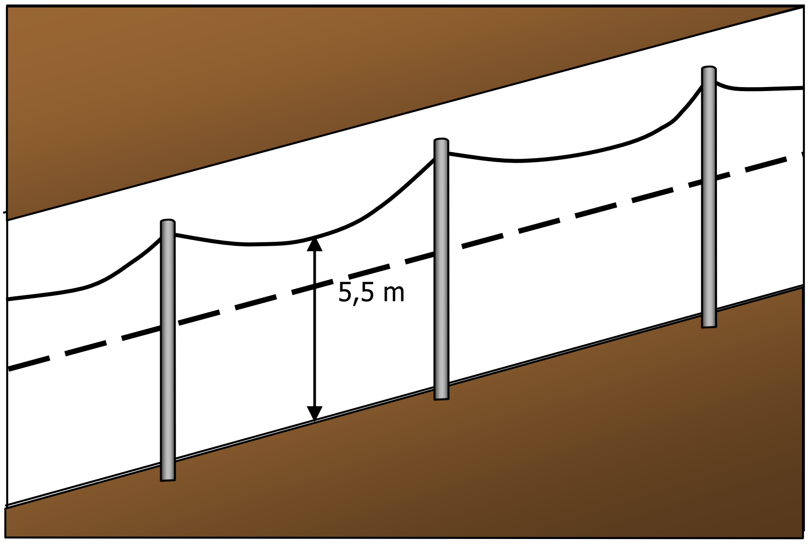
Marshy and swampy land: the guys are impractical or impossible. Three options should be considered. One is the use of push brace, second the use of concrete-filled barrel in the foundation and third the use of braced anchor guy



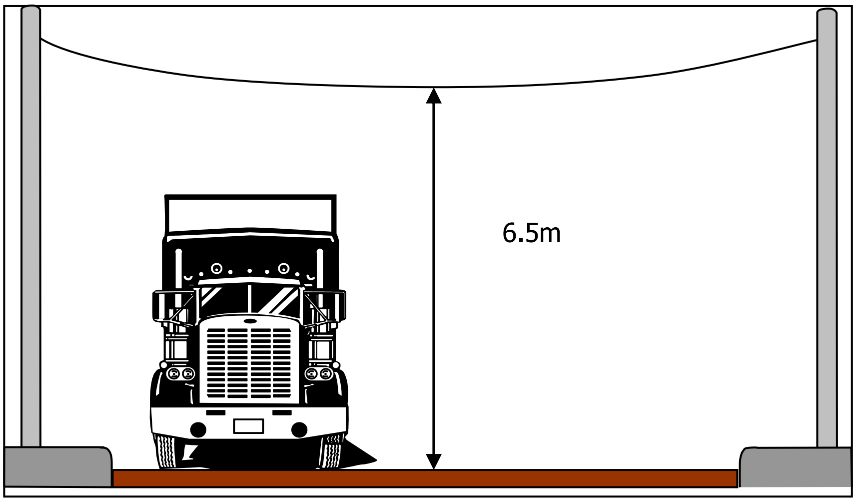
Other methods of sustaining poles. (a) Push brace, (b) concrete-filled barrel, and (c) braced anchor buy.

4.8 Installing conductor

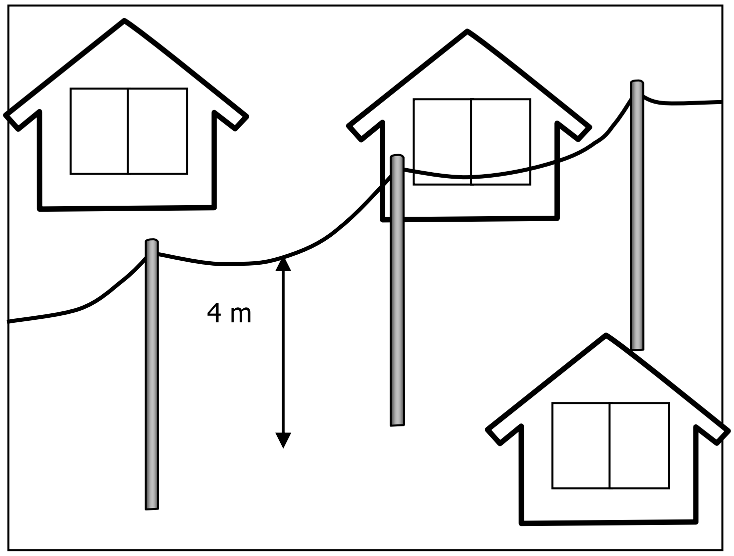
4.8.1 Clearance



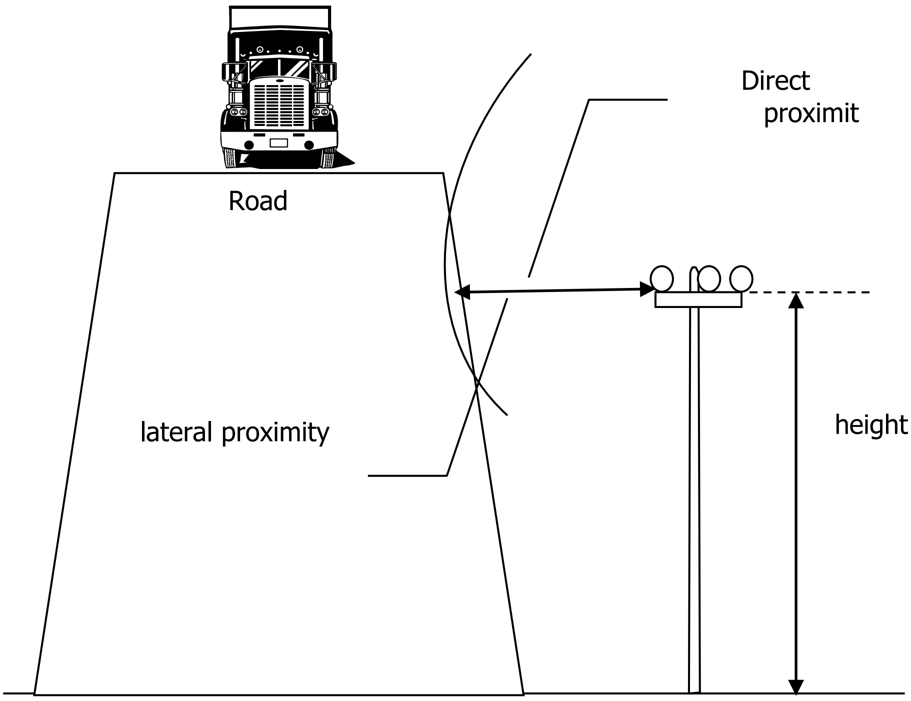
Along the road, street

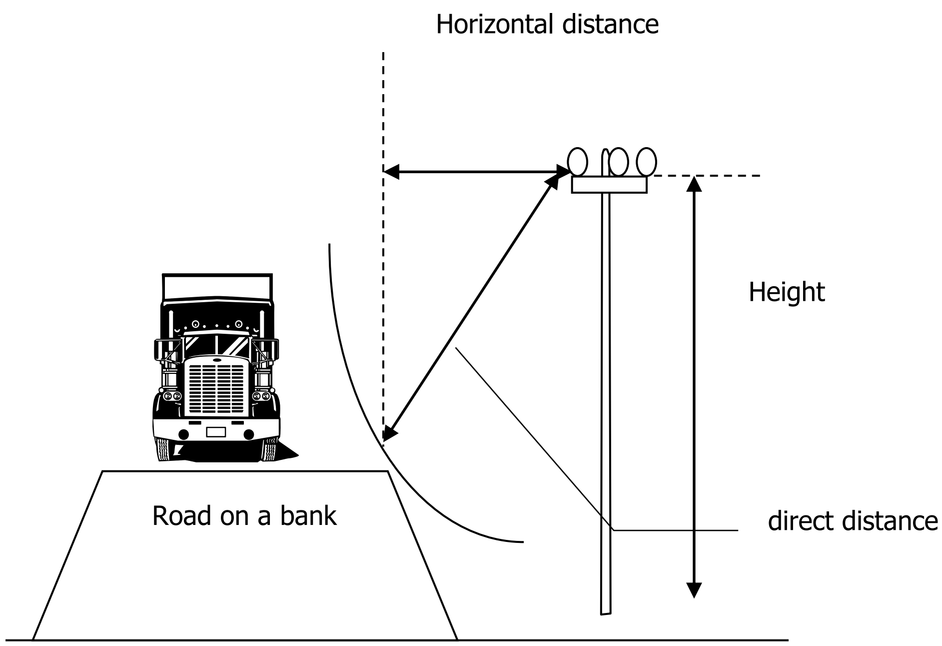


Cross the road or
street

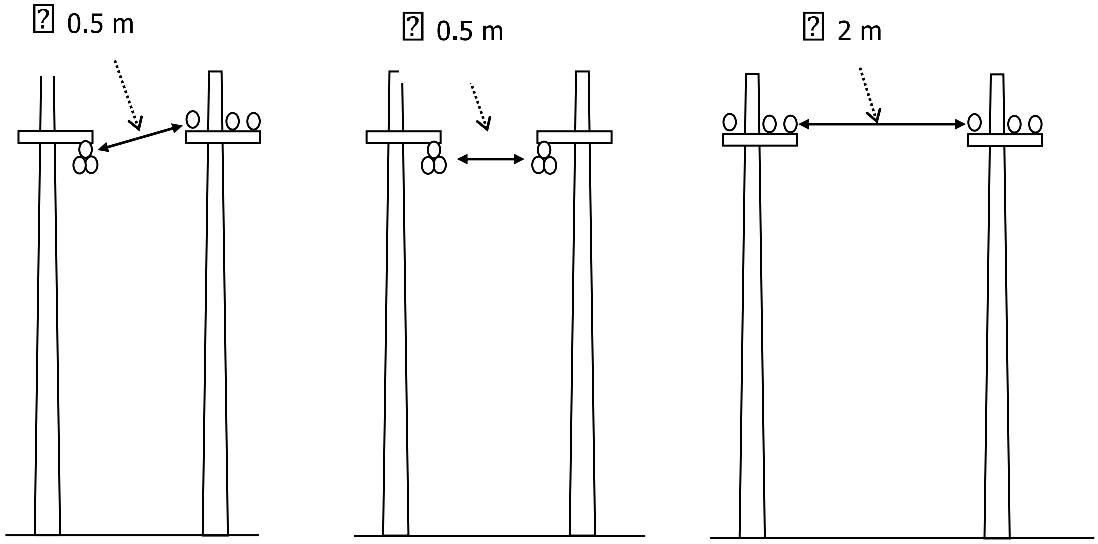


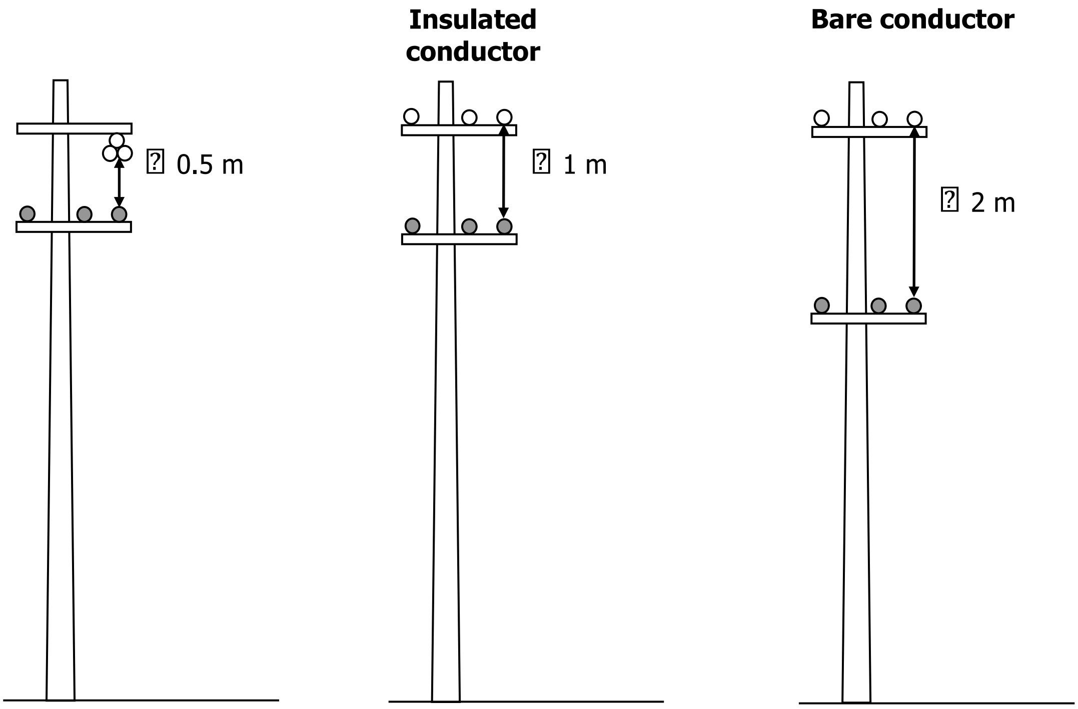
Where there are not roads or streets





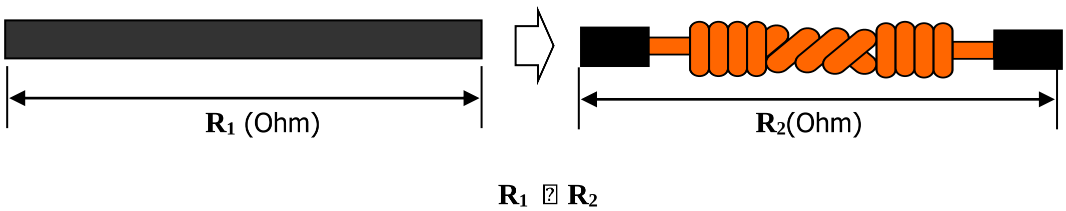
4.8.2 Clearance between two MV lines (ref.7.1)





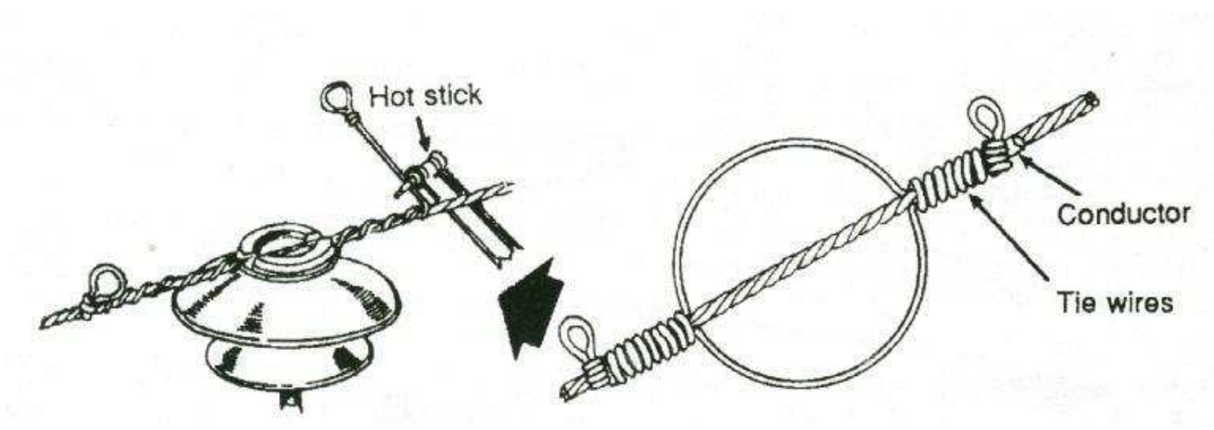
4.9 Connection of conductors

Conductors shall be connected firmly and the resistance of conductors shall not increase. If it is necessary, the connected conductor shall undergo a resistance test.



4.9.1 At insulator level

Usually, the conductor is spliced by overlapping the ends and twisting the ends together, taking three or four turns.



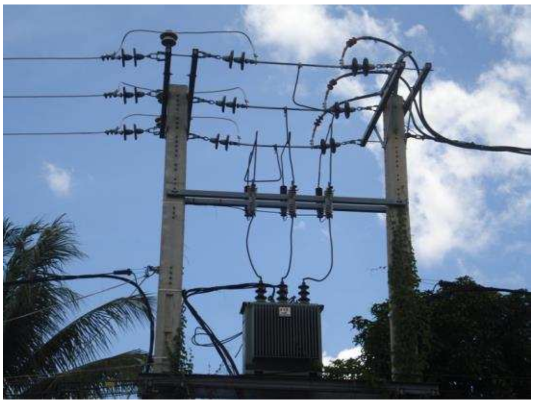
4.9.2 at corner location

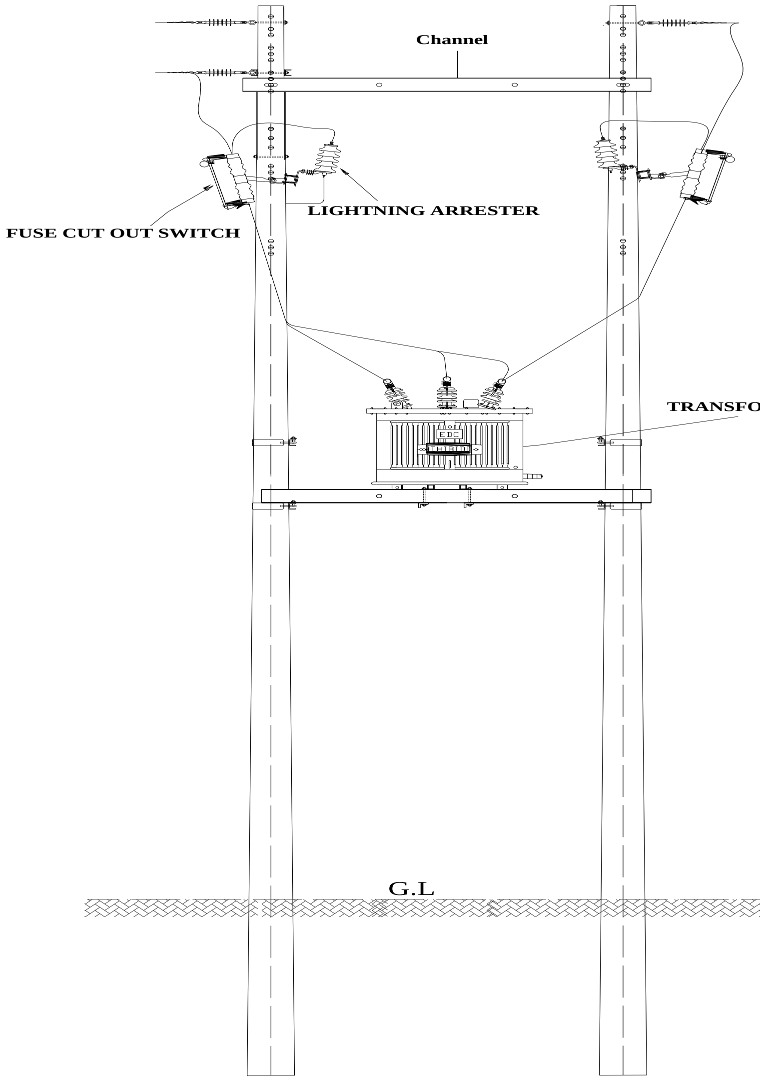
4.9.3 at angle point or deviation point

4.9.4 at the end of pole, to underground cable

Installation of MV equipments
a) Fuse cutout
b) surge arrester
c) LBS
d) transformer (pole mounted transformer)

transformer post on ground





Chapter 5: Operation, maintenance and trouble shooting of MV networks

5 Installation and inspection

Operation of MV networks consists of supply via MV network electricity load to comply with Standard of Performance of Electricity Service in Cambodia (issued by EAC). Operator shall ensure the quality of electricity, the reliable and sustained service, efficiency of MV network.

5.1 Tasks in MV network operation

- switch on/off a transformer post
- switch on/off a MV load
- Do voltage regulation
- optimization of MV network (loss of power, loss of energy)
- Reliability improvement.
- Increase the capacity of MV network. (not consider here)
- liquidation of fault cause or prevent eventual fault

5.2 Organisation of the MV operation unit

Staff working on LV line cannot work with MV line without special training (safety training)
At least 2 people qualified for working on 22 kV line in the MV line unit.

5.3 Operation and maintenance works

5.3.1 Switch off a MV load

No LBS

- Switch off the LV load (so after some MV interrupters, a LV circuit breaker should be used on LV side)
- Switch off the transformer if any.
- Switch off the MV line.

5.3.2 Maintenance and inspection

The best maintenance for MV distribution network is trimming tree (largest expense for the utility)
Beyond tree trimming, the maintenance practice varies widely. Most of distribution equipments are maintenance fee: transformer, capacitors, insulators, wires, cables. Oil filled switches, reclosers and regulators need only occasional maintenance.

Process in maintenance:

- Identify old and failing equipment and targeting it for replacement. Equipment deteriorates over time. Several rural enterprises have increasingly older infrastructures. Equipment fails at varying rates over its lifetime.
- Do restoration (e.g. when storms knock lines and equipment down, and crews put them back.
- Do tracking equipment quality and failures (to help improve the reliability of MV network). For overhead MV line, most failure causes are external but still tracking equipment failure and targeting bad equipment help the operator to maintain the service. It should be noted that failure occurs in clusters: particular manufacturer, particular models, and particular manufacturing years.
- Identify non proper application of equipment to prevent overloading equipment excessively and to apply good surge protection.
- Elaborate inspection program.

Inspection techniques used for distribution line:

- Visual inspections (drive-by): find severely degraded poles, broken conductor strands, and broken insulators.
- infrared thermography
- wood pole test: e.g. hammer test
- operation counts (recloser, regulator tap changer)
- oil test.

Inspection (and monitoring) method:

Inspection and monitoring is a method to find out where a fault could be possible, so REE can prevent this fault.

The measures are as follows:

- periodical inspection of overhead line (one time in six month by a technician and one time in a year by an electrical engineer)
- inspection by an inspector one time in 6 year or by necessity
- inspection when there are incidents or failure: fire case near or along MV line, strong wind or storm, after fault outage, after successful operation of recloser.
- measure insulation resistance: on time in 6 years
- measure the earth resistance: one time in 10 years
- to verify clearance.

5.3.3 Repair method

Pole:

- when pole is declined from vertical line
- when there is crack (concrete pole). Small cracking shall be covered by painting. Serious cracking can lead to pole replacement.

Line:

Line repair include replacement of conductor, connector, surge arrestor, insulator etc.

When do replacement, the materials shall be equivalent or superior to old materials. The conductors should have same brand name, type, size and the strand direction. Put new conductor ready before take out old conductor.

Remark: The repair shall be conducted while the circuit is switched off and by following safety procedure. The replacement of insulator without switching off the circuit requires very high safety and security measures to be taken into account.
About the safety rule, please refer to chapter 3.

5.4 Safety of Third Persons

1. Safety of Third Persons at Power Stations, Substations and Switching Stations.

a. External fences or walls to separate outside from compound. The height of external fences or walls shall not be lower than 1800 mm. Boundary Clearance from these fences or walls to electrical equipment shall not be less than the values described in the following table:

Nominal voltage	Height of wall or fence	Boundary clearances [mm]
22 kV	not less than 1<8m	not less 2.1 m from wall not less 2.6 m from fence

b. Signs to alert third persons to danger shall be installed at the entrances/exits. Moreover, where necessary, signs shall also be displayed on walls and fences.
c. Locking devices or other appropriate devices shall be installed at the entrances/exits.

2. Safety of Third Persons at Electric Supporting Structures.

Appropriate measures shall be taken to prevent third persons from climbing supporting structures of overhead electrical lines. To prevent danger to third persons related the supporting structures of electrical lines the following measures shall be taken into account:

- any metal steps on supporting structures shall be installed more than 1.8m from the ground.
- warning signs to alert the third persons to danger shall be installed at each supporting structure.

5.5 Environmental Protection

Compliance with Environmental Standards

To prevent environmental pollution, the electric power facilities shall be constructed in accordance with the environmental laws and regulations of the Kingdom of Cambodia.

Prohibition of Installation of Electrical Machines or Equipment containing Polychlorinated Biphenyls (PCBs):

The installation of new electrical equipment using insulating oil that contains greater than 0.005 percent (50 ppm) polychlorinated biphenyls (PCBs) shall be prohibited.

Chapter 6 : Roles and responsibilities

6 Roles and responsibilities

The electricity law of Cambodia lay out the legal framework of power sector development. Three important players in this framework are MIME, EAC and EdC.
MIME is responsible in the policy and planning e development. So MIME will not plan the MV line in the distribution area. EdC is a big operator and has right to transport electricity in the Kingdom of Cambodia and has responsibility in planning all subtransmission lines in order to transport electricity (bought by EdC from IPP) to rural area (to sell to EAC licensees). EAC will coordinate the action of rural licensees in building MV line, so there will not conflict of interest between licensees and EdC.

This framework involves many stakeholders of Electricity Supply dealing with Medium Voltage lines:

- household
- MV consumer
- Operator, EAC licensee
- Technicians
- Electricity Authority of Cambodia
- Ministry of Industry, Mines and Energy
- local authority (commune authority, district authority)
- Electricité du Cambodge
- Ministry of Public Works and Transport

Households are the users of electricity. To supply electricity to user, the electricity is transported from source via transmission line, MV distribution network, transformer post and LV line. The household is therefore related to all electrical installation. The household should be aware about clearance of the MV line to the object in his property like gate, tree, house etc. The problem for the investor is cutting tree that some household require compensation. So household should know the regulation about object in their property and the part of public land for developing infrastructure such as road, electrical network, water supply etc. Household must know that in some necessary case the MV line shall cross their property, and in this case household can require compensation.

MV consumers are for example big hotel, rice mild, enterprise etc. MV consumers sign power purchase agreement with operator. If there is not MV line nearby the MV consumer location, MV consumer must build MV line from his facilities to operator MV line. Depending on agreement, MV consumer shall responsible on their transformer post, keep overall power factor not less than some value (e.g. 0.85) and maintain their facilities, so there are not troubleshooting to MV line.

The operator is a licensee, holding distribution license or special purpose transmission license. The operator shall respect the terms and conditions of his license issued by EAC. To obtain this license, the enterprise or company apply for Prakas from MIME to have right to invest in power sector. If enterprise receives right to build sub-transmission 22 kV line, it can start building the main MV line. If enterprise receives right to distribute electricity in some area, he will build the MV network by technical necessity and by economic reason.

The operator is responsible in ensuring normal operation of his MV network or sub-transmission line with respect to EdC's grid code. He cannot sell the infrastructure to anyone. In general MV line may be connected to EdC system via MV line or MV feeder in grid substation.

The operator has responsibility to improve the reliability and increase the capacity of the MV network and expand the network to comply with the load demand.

MIME shall be responsible for setting and administrating the government policies, strategies and planning in power sector. So MIME has right to issue Prakas to investor of MV line following the planning scheme. But because MIME elaborates strategic development plan in power sector, MIME do not plan on developing MV network.
To ensure the quality and safety of infrastructure in power sector, MIME issues electric technical standard.

DIME (provincial department of industry, mines and energy)
DIME play role like MIME but limited to a capacity of 125 kVA of generation and not big area of distribution zone.

Local authority
Coordinate and solve some conflicts of interest arisen between operator and local people in construction phase. Coordinate tree trimming and cutting during construction and maintenance.

EAC (Electricity Authority of Cambodia)
EAC is responsible in coordinating planning work of EdC with the expansion plan of licensee, approving the planning of REE. After construction EAC will inspect the MV infrastructure before the operation. EAC could also assist rural operators in designing the MV network, if they ask for assistance. It should remark that when REE will connect to EdC grid, EdC will test the infrastructure one more.

Chapter 7: Basic Electricity Fundamentals

7 Component of a distribution system

The society must use energy resources in the form such as water, wind, oil, coal etc. to accomplish tasks the societies consider desirable: heating, cooling, lighting etc. To be useful energy must be available at the place where the work is to be done. The electricity via distribution system allows the raw energy resources and the equipments (appliances) to be separated by great distances. Thus electricity must be generated at the power plant and transported to consumer by distribution network at the same time when the societies need.

7.1 System components

- Generation: the production of electricity
- Transmission: the system of lines that transport the electricity from the generating plants to the area in which it will be used. (in our rural system, this refers to sub-transmission 22 kV line). For a stand alone system, there are not transmission lines.
- Distribution: the system of lines that connect the individual customers to the electric power supply system.

The generation has to be located away from heavily populated area when it is possible because land is less expensive and the plants may be closer to the source of fuel they use. Electricity is then transported to the area of use by the transmission lines and distributed to the customers at lower voltages by the distribution lines.

7.1.1 Voltage levels

The transport of electricity is accompanied by losses in conductors. The major losses are proportional to the current squared. As power is the product of current time voltage, thus when the voltage is increased, the current is decreased, so the loss can be reduced dramatically. The electric power technical standard of the Kingdom of Cambodia sets the voltage levels for the distribution line. For the generation there is no setting of voltage level.
In our rural distribution system, there are two voltage levels:0.4 kV and 22 kV.

7.1.2 Frequency

Many different frequencies are used in power systems. But now there are only two frequencies 50Hz and 60 Hz. In Cambodia the rated frequency is 50Hz.

7.1.3 Transmission

The source of losses in transmission system is the same as for transmission and distribution lines.

- Resistance: the series resistance of a conductor depends on the resistivity of the conductor material, its length, temperature and the skin effect.
  DC resistance R is directly proportional to the resistivity rho and length (l) and inversely proportional to the cross section (s):

$R = \int x\ l / s$

Stranded conductors are spiralled. Spiralling typically adds about 2% to the length. Resistance increases almost linearly with temperature.

- Skin effect refers to the fact that as frequency increases current flow shifts toward the surface of a conductor. The skin effect can result in the ac resistance of a large conductor being about 20% higher than the dc resistance.
- Reactance: The magnetic flux produced by the ac current produces series inductive reactance (X_L). The reactance does not dissipate active power but results in voltage drop along the line and reactive power (volt-ampere-reactive). Generator should supply reactive power on the line in addition to the load power.
- Capacitance: Conductors separated by a distance have capacitance. The capacitance of the lines must be charged before a line can transfer power. Some power is shunted to ground from the line through the capacitive reactance.
- Corona: Corona is caused by the breakdown of the air around a transmission line because of high voltage. The effect is most severe around small conductors and at sharp points and corners. Corona absorbs energy from the line.

7.1.4 Distribution

A distribution network is subject to all the losses that a transmission system has. Because of lower voltages bundling of conductors to prevent corona is not necessary.

Simplified line impedance calculations

The impedance of overhead line is:

Z1 = R0 + jk1*log10(GMDph/GMRph)

Where
Ro = resistance of the phase conductor in ohm/distance
k1 = 0.0529f/60 if output in ohm/1000ft
f = frequency in hertz
GMRph = geometric means radius of the phase conductor in mm
GMDph = geometric means distance between the phase conductors in m.

The zero-sequence impedance (3 wire overhead line)
Z0 = Rph + 3Rearth + j3k1*log10 (Dearth/sqrt3(GMRph*GMDph^2)
Where Rearth = resitance of the earth return path
Dearth =equivalent depth of the earth return current in ft = 2160 sqrt(rho/f)
rho = earth resistivity in ohm/m

Major effects:

- Conductor size affects resistance: the larger the conductor is, the lower the resistance. The change in reactance is small.
- Conductor spacing: Increasing spacing increases Z1 but decreases Zo. The effects are modest.
- Earth resistivity: the earth resistivity does not change the earth return resistance because it depends only on frequency. Higher resistivities are raising the reactance.
- Grounding: Z1 stay the same.
  Z2 = Z1

7.2 Conductor sizing

Several electrical and economic characteristics affect conductor sizing:

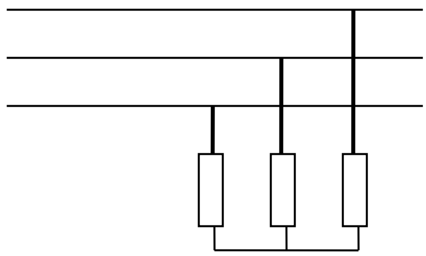
Criteria:

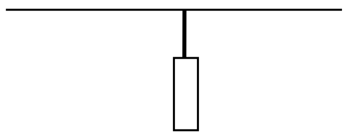
- Ampacity- the peak current-carrying capability of a conductor limits the current carrying capability.
- Economics-If we use larger conductors, the cost will be higher but the loss will be lower and the conductor run cooler. This will leaves room for expansion.
- Mechanical strength-plays an important role in size and type of conductor. Wind loadings must be considered. See chapter 7. Design of overhead LV and MV line.
  Corrosion-this problem limits certain types of conductors in certain applications

7.3 Power flow in radial network, calculation of voltage drop and loss

- Symmetrical load

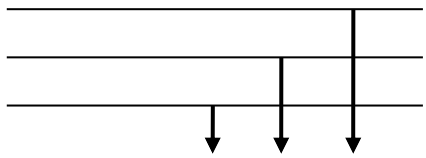
In three phase system the load for each phase should be the same. We call symmetrical load when the load of each phase is equal.

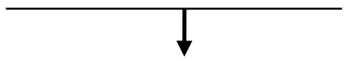




In symmetrical circuit each phase has same configuration, so in drawing we can represent only one phase and omit 2 other phases. The diagram that shows only one line is called single line diagram.

The load of different types has different representations. In the power system the best presentation is power load S = (P, Q)



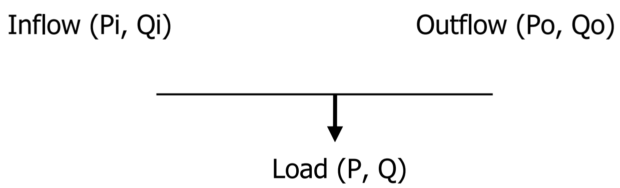


The point to where the load is connected is called node. Ordinary this is may be a feeder, a derivation of MV network, a transformer post. The tension at this point we call node voltage.

- Electrical scheme, single diagram

Suppose the loads are symmetrical. So for phase A the scheme is the same as for phase B or phase C. To show one phase is sufficient.

Note: the power flow around a node



$Pi = Po + P$; $Qi = Qo + Q$

Fig: Power flow around a node

$Po = Pi - P$; $Qo = Qi - Q$

At the beginning node of a branch: node voltage by U1, active power flow from the beginning by P′, reactive power flow by Q′.
At the end node of a branch: node voltage by U2, active power flow to the end node by P″, reactive power flow by Q″.

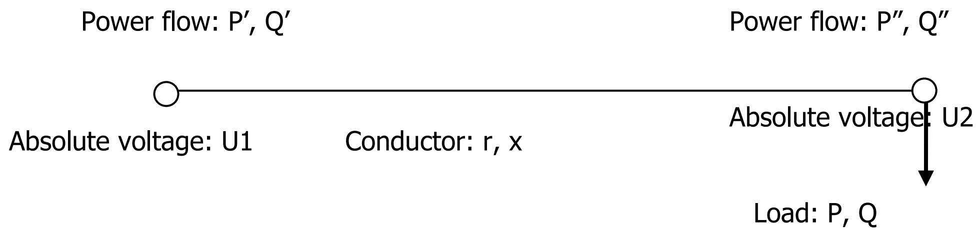


Fig: Representation of a branch

Voltage drop has 2 components, a longitudinal and a transversal component.

$DU2 = (P'' r + Q'' x)/U2$ (longitudinal)

$dU2 = (P'' x - Q'' r)/U2$ (transversal)

$DU1 = (P' r + Q' x)/U1$

$dU1 = (P' x - Q' x)/U1$

In general when the power factor is about 0.8 the transversal component of voltage drop is small compare to the longitudinal one. dU2 can be drop out in calculation.

Node voltage

$U1 = Sqrt((U2 + DU2)^2 + dU2^2)$

$U2 = Sqrt((U1-DU1)^2 + dU1^2)$

In normal case, when power factor is greater than 0.8,

$U1 \approx U2 + DU2$

$U2 \approx U1 - DU1$

Voltage loss

$DU = U1 - U2$

Power loss

$DP = (P''^2 + Q''^2)\, r/U2^2$

$DQ = (P''^2 + Q''^2)\, x/U2^2$

$$DP = (P'^2 + Q'^2)\, r/U1^2$$
$$DQ = (P'^2 + Q'^2)\, x/U1^2$$

Radial network is a network whose configuration does not contain any loop (tree like configuration)

Example:

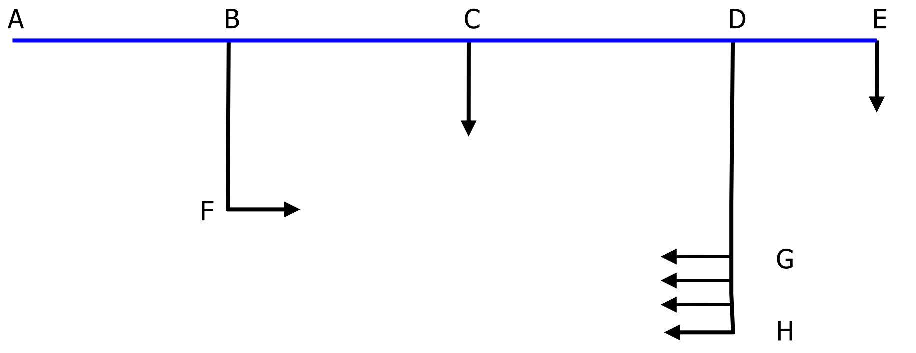


Fig: Radial network

Beginning	Ending	Branch	
A	B	AB	
B	C	BC	
C	D	CD	
D	E	DE	E is last node
B	F	BF	F is last node
D	G	DG	
G	H	GH	H is last node

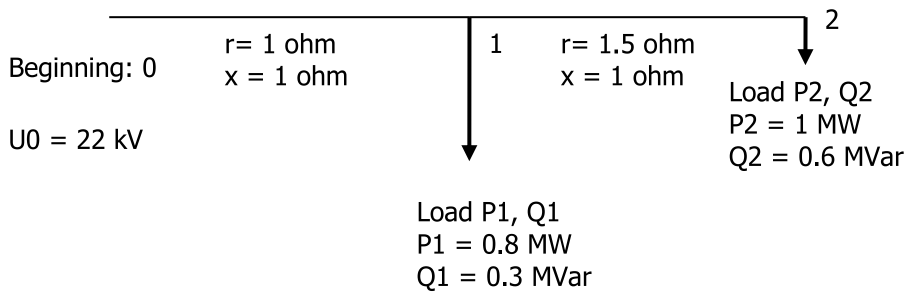
To find out the path from the first node to last node

1- Write down branch of last node, ex: DE
2- Get the previous node to the node D: C so we have CDE
3- Repeat this process until the first node
   BCDE
   ABCDE

For the last node F: ABF
For the last node H: ABCDGH
Compute a radial network (approximately)

1. Find the path to each last node
2. Compute the power flow for each branch
3. From the first to the last node compute all node voltage, voltage drop in each branch and power loss.

Example1:



1. The path is {0, 1, 2}
2. From node 2 the power flows are
   P12 = P2 + 0 = P2 = 1 MW
   Q12 = Q2 + 0 = Q2 = 0.6 MVar
   From node 1 the power flows are
   P01 = P1 + P12 = 0.8 + 1 = 1.8 MW
   Q01 = Q1 + Q12 = 0.3 + 0.6 = 0.9 MVar
3. Compute voltage drop and Power loss
   From node 0 to 1 (branch { 0, 1})
   DU1(01) = (P01.r01 + Q01.x01)/U0 = (1.8 x 1+0.9 x 1)/22 = 0.123 kV
   U1 = U0 – DU1 = 21.877 kV

   From node 1 to node 2 (branch {1, 2})
   DU1(12) = (P12.r12+Q12.x12)/U1 = (1 x 1.5 + 0.6 x 1)/21.877 = 0.096 kV
   U2 = U1 – DU1(12) = 21.877 – 0.096 = 21.781 kV

   Total voltage drop = 22 – 21.781 = 0.219 kv that means 1%.

Chapter 8: Power Transformer

8 Power transformer

A transformer is a static machine that converts electric power from one voltage level to another.

8.1 Construction

A transformer has two sets of coils coupled together through a magnetic field that transfer all of the energy.

8.2 Ideal transformer

In an ideal transformer, the voltages on the input and the output are related by the ratio

$$Vinput/Voutput = Ninput/Noutput$$

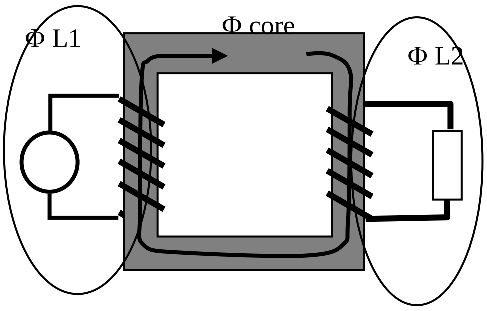
with N the number of windings in each coil.
In real transformer, there is a leakage flux that creates a voltage drop between windings

$$V\ input = Ninput/Noutput * Voutput - XL*Iinput$$

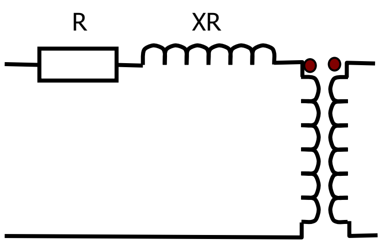
For the current

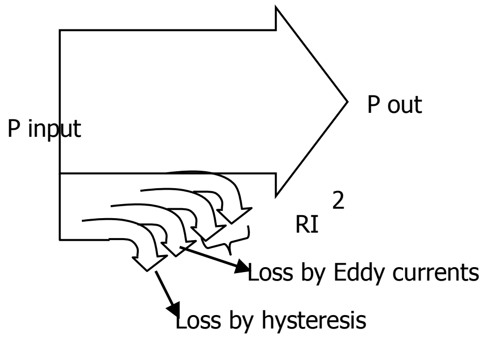
$$Iinput/Ioutput = Noutput/Ninput \text{ or } I\ input * N\ input = I\ output * N\ output$$

The transformer has a iron core. The core can carry large magnetic fields.



Simplified model of a transformer





Power diagram:

$$P\ output = P\ input - P\ loss$$

The loss can result from (1) Power loss in the core by hysteresis and by Eddy currents and (2) by the thermal loss in the windings.

In the simplified model serial impedance is sufficient for calculation including local flows, short-circuit calculation, motor starting or unbalance.
The leakage reactance causes voltage drop on a loaded transformer. Leakage impedance is under control of the designer, so the maker will make transformer with customized impedances. For example, transformer with great capacity has high leakage impedance in order to control the fault current.

8.3 Insulation materials

The mineral oil filled many distribution transformers. The oil has two functions: insulation and conducting heat. Oil is flammable (flash point at 150 degree C). Oil has high dielectric strength (86.6 kV/cm). Oil also protects coils, core and other materials from corrosion.

8.4 Distribution transformer

8.4.1 Single phase transformer

Single phase transformer supplies single phase service. We can use 2 or 3 single phase units in a variety of configuration to supply 3 phase service.

Load current I = S(kVA)/V(kV)
Where S(kVA) = transformer kVA rating
V (kV) = line to ground voltage rating in kV.

Impedance:

R = W cu/ (10*S(kVA))

Where W cu = W tot - Wnl = loss at rated load, W
W tot = total losses estimated at rated load, W
W nl = no-load losses W

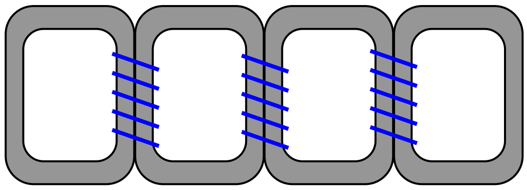
$X = \mathrm{sqrt}(Z^2-R^2)$

Where
Z = name plate impedance magnitude %

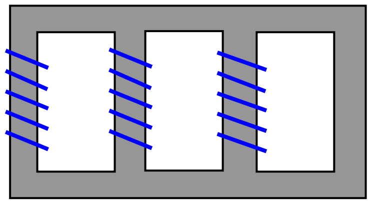
8.4.2 Three phase transformer

Construction:

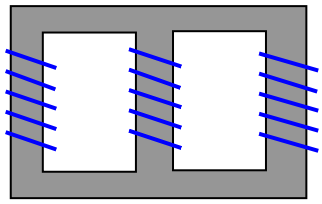
There are five-legged wound core, four legged stacked core, three legged stacked core.



five legged wound core



four legged stacked core



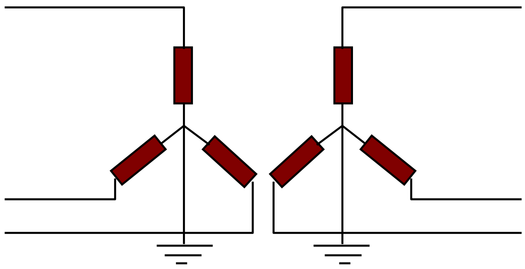
three legged stacked core

Connection scheme of windings:

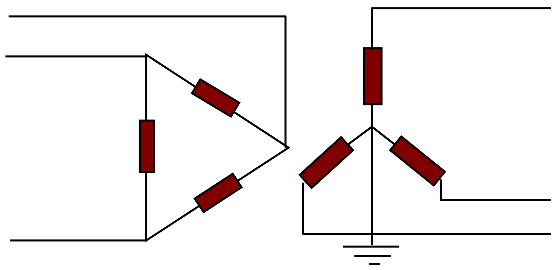
Different ways of windings connection are delta, floating-wye or grounded wye. The windings may be grounded or ungrounded.
Primary winding may be wye-connection or delta connection. On the secondary side the delta configuration and the grounded wye configuration are used.

Grounded wye secondary: We have

- grounded wye - grounded wye



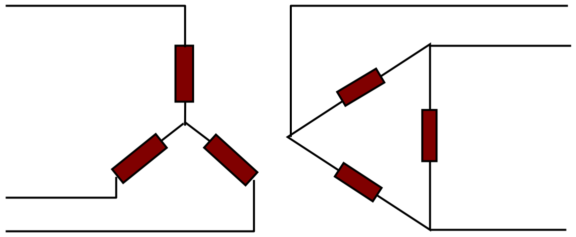
- delta - grounded wye



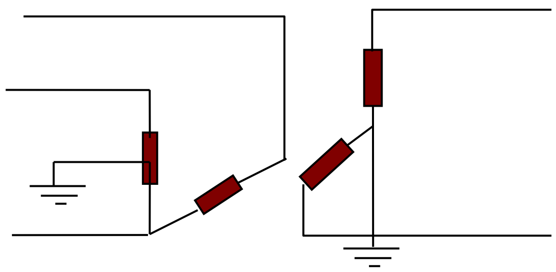
A grounded wye secondary adaptly handle single phase loads on any three phases with less concern about unbalanced.

Delta secondary: supply three wire ungrounded service. We have

- floating wye - delta



- open wye - open delta



If customer requires ungrounded secondary voltage (3 wires or 4 wires), the scheme floating wye - delta is suitable. For customer with four wire grounded system, the scheme grounded wye - grounded wye and delta - grounded wye can be used.

8.4.3 Characteristics of each scheme

Grounded wye - grounded wye:

- Supply: grounded four wire system
- Service: supply grounded wye service and does not supply ungrounded service
- Tank heating: tank heating happen with three-legged core construction under sever service unbalance. But the tank heating is impossible with 3 single-phase units.
- Zero sequence: All zero sequence currents transfer to primary. High impedance ground source to the primary.
- Ferroresonance: There is no chance of ferroresonance with three single-phase or triplex construction, but with four and five-legged core construction.

Coordination: load protective device and larger transformer services should be coordinated with utility ground relays.

Delta-Grounded Wye connection:

Delta windings establish a local grounding reference and blocks zero sequence currents from entering the primary.

- Supply: 3-wire or 4-wire system
- Service: supplies grounded wye service, does not supply ungrounded service
- Ground faulted: blocks zero sequence, upstream are isolated from line to ground fault at secondary
- Harmonics: Zero-sequence harmonics and third harmonics cannot get through to the primary.
- No primary ground source: delta - grounded wye cannot act as a grounding source.
- Secondary ground source: independent of the primary-side grounding configuration
- No tank heating: Delta connection ensures that there are no zero-sequence flux. Three-legged core transformer can be used.
- Ferroresonance: highly susceptible.

Floating-Wye - Delta

- Supply: 3-wire or 4-wire system
- Service: can supply ungrounded service and four-wire service
- Unit failure: can continue to operate if one unit fails if it is rewired as an open wye - open delta.
- Voltage unbalance: secondary-side unbalances are mor likely than with a wye secondary connection.
- Ferroresonance: Highly susceptible.

Note: If one phase is switched off, the delta on the secondary is broken and the primary neuter can shift wildly: possible overload by load unbalance. This scheme is best used for supplying three phase load with a smaller amount of single-phase load.

Delta-Delta:

- Supply: 3-wire or 4-wire system
- Service: Can supply ungrounded service and cannot supply grounded wye four-wire service.
- Ferroresonance: Highly susceptible
- Unit failure: Can continue to operate if one unit fails (as an open delta-open delta)
- Circulating current: high circulating current

Open wye-open delta:

- Supply: 2 phase and the neutral of a 4-wire grounded system
- Service: Can supply ungrounded service, and cannot supply grounded wye four-wire service
- Ferro resonance: no
- Voltage unbalance: may have high secondary voltage unbalance
- Primary ground current: high primary-side current unbalance. High currents are forced into the primary neutral even with balanced loadings.

8.4.4 Neutral stability

Floating wye winding can have an unstable neutral. Unbalanced single-phase loads on the secondary, unequal magnetizing currents, and suppression of third harmonics can shift the neutral.

- Unbalanced loads: Zero sequence currents have no path to flow. Loading one phase drops the voltage on that phases and raises the voltage on the other two phases.

- Unequal magnetizing currents: Difference in the amount of magnetizing current each leg needs can shift the floating neutral.
- Suppression of third harmonics: The suppression of zero sequence currents generates a significant third harmonic voltage in each winding. With the neutral grounded in the floating wye - grounded wye, a significant third-harmonics voltage adds to each phase-to-ground load. If the neutral is floating, the third-harmonic voltage appears between the neutral and ground.
- Grounded wye-Grounded wye on the 3-wire system: the grounded wye on the primary does not have an effective grounding source, so it acts the same as floating wye-grounded wye.

Wye-wye transformer with the primary and secondary neutrals tied together internally but with the neutral left floating: the magnetizing currents and suppression of third harmonics are the problem. These can generate large voltages between the neutral point and ground. The secondary neutral follows the neutral shift of the primary and shifts the secondary phases relative to ground.

Sequence Connections of Three phase Transformers:

The problem is to eliminate the effect of zero sequence, which impacts unbalances and response to line-to-ground faults and zero-sequence harmonics. The three-phase transformers may affect zero-sequence circuits as follows:

- Isolation - a floating wye-delta connection isolates the primary from the secondary in the zero sequence.
- Pass through-The grounding of grounded wye-grounded wye connection is determined by the grounding upstream of the transformer.
- Ground source: A delta-grounded wye connection provides a ground source on the secondary.

8.4.5 Loadings

Distribution transformers are output rated in kVA without exceeding temperature limits in the conditions:

- the secondary voltage and the voltage/frequency do not exceed 105% of rating.
- the load power factor >= 80%
- frequency >=95% of rating.

Distribution transformer is 65 degree C rise units. The hottest spot winding temperature should rise to no more than 80 degree C.

The normal life expectancy is 20 years. But because of daily and seasonal load cycles, the temperature is nowhere near these values (low enough, so not to do any degradation of insulation). We cannot load distribution transformer more heavily when it is hot (>30 degree C).

Transformer Loading Guidelines

		Equivalent Peak Loading Per Unit of Rated kVA with the Percent Preload and Ambient Temperatures Given Below										
Peak Load duration	Extra Loss of Life	50% Load				75% Load				90% Load		
		Ambient Temp, C				Ambient Temp, C				Ambient Temp, C		
Hours	%	20	30	40	50	20	30	40	50	20	30	40
2	Normal	1.91	1.79	1.65	1.50	1.82	1.68	1.52	1.26	1.74	1.57	1.26
		2.13	2.02	1.89	1.77	2.05	1.93	1.80	1.65	1.98	1.85	1.70

4		2.22 2.44 1.61 1.80 1.87 2.06	2.10 2.34 2.50 1.70 1.77 1.97	1.99 2.23 1.38 1.60 1.67 -	1.87 - 1.25 1.48 - -	2.14 2.37 1.56 1.76 1.83 2.02	2.02 2.26 1.44 1.65 1.72 1.93	1.90 2.15 1.30 1.54 1.62 -	1.75 - 1.09 1.40 150 -	2.07 2.31 1.50 1.71 1.79 1.99	1.95 2.20 1.36 1.60 1.68 1.89	1.81 2.08 1.13 1.47 1.56 -

Source ANSI/IEEE C57.91-1981

8.4.6 Power Losses

Load losses, no-load losses, and purchase price are all interrelated. Approaches to reduce load losses tend to increase no-load losses and vice versa. The average load on most transformers is relatively low (25 to 30% of transformer rating), so the importance of no-load losses. The total equivalent losses on a transformer are:

Ltotal = P^2*FlossLload + Lno-load

Where
Ltotal = average losses, kW (to multiply with 8760 hours/year)
P = peak transformer load, per unit
Floss= loss factor, per unit
Lno-load = rated no-load losses, kW
Lload = rated load losses, kW

8.5 Paralleling

When replacing a transformer, paralleling transformer during the changeover eliminates the customer interruption. Criteria for parallel connection of transformers:

- phasing-the high and low voltage must have the same phasing relationship.
- polarity- If the units have different polarity, they should wire accordingly
- voltage-the phase to phase and phase to ground voltages on the outputs should be equal.

Before connection, the technician must ensure that the secondary voltages are all zero or very close to zero. The share of power in each transformer depends on the percent impedance.

8.6 Inrush

Inrush current is the current of magnetizing transformer core when transformer is first energized. The inrush current may approach short-circuit levels. Inrush may cause fuses, reclosers, or relays to falsely operate. Factors which have impact on inrush current.

- Closing point: the point where the circuit closes back in determines how close the core flux can get to maximum. The worst case is when the flux is near its peak.
- Design flux-Transformer that is to operate lower on the saturation curve draws less inrush.
- Transformer size: Larger transformers draw more inrush.
- Source impedance: Higher source impedance relative to the transformer size limits the current that the transformer can pull from the system.

ipeak = io/(1+io*X)

Where
io = peak inrush without source impedance in per unit of the transformer rated current.

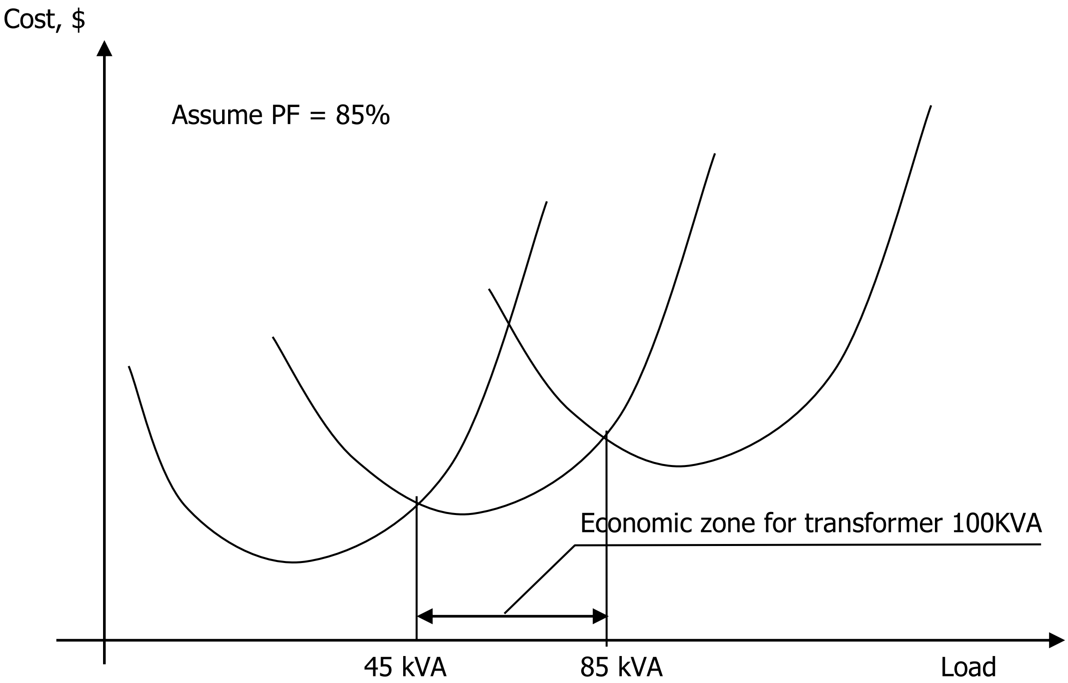
X = source impedance in per unit on the transformer kVA base.

Other cause of inrush:

- Voltage sags: when there is the recovery of voltage sag from a nearby fault, the sudden rise in voltage can drive a transformer into saturation.
- Sympathetic inrush: Energizing a transformer can cause a nearby transformer to also draw inrush.
- Lightning: A flash to the line near the transformer can push the transformer into saturation.

8.7 Sizing a transformer

The cost of a transformer post has 2 components (simplified model). One component is assumed as constant (not depending on load) and second component square proportional to load factor. The transformer works well if the 2 components are equal and this is about 60 to 80% load factor. For each transformer there is so called economic zone of the load. The determination of transformer economic zone is not the scope of this course, but as illustration we give the graphic of economic zone of some transformer capacity.



To choose the capacity of transformer:

S(transformer) >= S (load)

In emergency case, it is allowed to overload transformer is short period in a day, and for some few day only in a year. The overload is determined according to factory specification.

S(load) is in economic zone of transformer.

Chapter 9: Voltage Regulation

9 Voltage Regulation

9.1 Voltage standard (ref 7.1)

Two locations on electric power system:

- Service voltage: is the point where the electrical systems of the supplier and the user are interconnected, normally at the meter.
- Utilization voltage-at the line terminals of utilization equipment. This voltage is the customer responsibility.

The power system technical standard of the Kingdom of Cambodia define the voltage range for MV line: 22 kV +/- 10%

Improper voltage regulation can cause problem for end users, for example:

- Improper or less-efficient equipment operation: light may give incorrect illumination or a machine may run fast or slow.
- Tripping of sensitive loads: uninterruptible power supply may revert to battery storage during high or low voltage.

- Undervoltage can cause overheating of induction motors. Motors draw higher current and have reduced motor starting torque.

9.2 Overvoltage (ref 7.1)

The overvoltage can cause:

- Equipment damage or failure - the insulation can suffer damage. Incandescent light bulbs wear out mush faster at higher voltages.
- Higher no-load losses in transformers because of magnetizing currents are higher at higher voltage.

Voltage drop along a circuit could be approximated by formula:

$$V\ drop = IR.R + Ix.X$$

Where V drop = voltage drop along the feeder, V
R = line resistance in ohm
X = line reactance in ohm
IR = line current due to real power flow in A
Ix = line current due to reactive power flow in A.

2 aspects:

- Resistive load plays a major role in voltage drop because at power factor 0.95 the reactive power factor is 0.31 only.
- Reactive load at moderate to low power factors, the voltage drop depends mainly on the reactance of the conductors. Poor power factor increases dramatically voltage drop.

The main ways to reduce voltage drop are to:

- increase power factor (add capacitors)
- increase size of conductor
- balance circuits
- convert single-phase sections to three-phase sections
- reduce load

- reduce length

9.3 Regulation Technique

Most popular regulation methods include:
- substation load tap-changing transformer (LTCs)
- substation feeder or bus voltage regulators
- Line voltage regulators
- Fixed and switched capacitors.

Operator can use LTCs to regulate the substation bus and supplementary feeder regulators and/or switched capacitor banks where needed.

Voltage drop allocation and primary voltage limits:
The LTC controls the voltage at the source. Voltage drops along primary 22 kV line, step down transformer and secondary low voltage line.

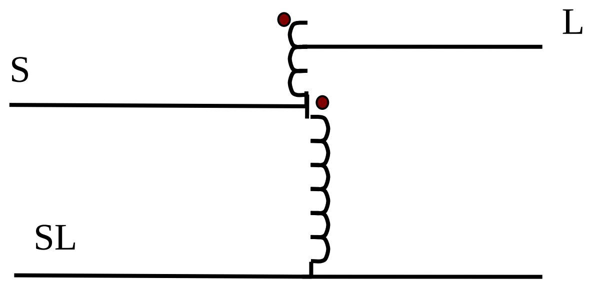
At the start of the circuit, if the line is lightly loaded, operator must ensure that the first customer does not have overvoltages. The operator should allow the voltage drop no more than 10%, and if the terminal voltage is 21 kV, the voltage at the start shall be 21+10% = 23.1kV.
At the heavily loaded end line: low voltages are a concern, so operator considers a heavily loaded transformer and secondary.

For rural area, when there are only household consumers, the voltage drop at MV line may be about 2%[1], on transformer

9.4 Regulators

9.4.1 Voltage regulators

The voltage regulators are autotransformer with automatically adjusting taps with range -10% to +10% 32 steps (1 step = 5/%)
Single-phase regulator has three bushings: source (S), load (L) and source-load (SL)



The regulator controller measures current with a CT at the L bushing and measure the voltage with a PT between L and SL. Regulators have a reversing switch that can flip the services windings around to change back and forth the boost and the buck connection.

[1] 2% as required by Standards

A three phase regulator controls all three phases simultaneously. When using single-phase regulators, we can connect them in several ways: grounded wye connection, open delta connection, and closed delta (leading connection).

- Line to neutral: In four-wire system, 3 single-phase regulators connected line to neutral. Also for 2 phase circuits.
- Open delta: two single-phase regulators are needed, each connected phase to phase.
- Closed delta: regulators are connected phase to phase. This scheme extends the regulation by range by 50% from+/-10%.

Regulators have voltage regulating relay that control tap changes. This relay has three basic setting that control tap change.

- set voltage (band centre) = desired output of the regulator
- Bandwidth: the regulator controls monitor the difference between the measured voltage and the set voltage when the difference exceeds as half of the bandwidth, a tap change will start.
- Time delay: waiting time between the time when the voltage goes out f band and when controller initiates a tap change (about 30 - 60 s).

9.4.2 Line-drop compensation

When there are heavy loads, the controller boosts voltage the most and when light load, voltage is boosted the lead. Line drop compensator uses an internal model of the impedance of the distribution line to match the line impedance. R and X are set to adjust. The controller adjusts 5 taps based on the voltage regulating relay, which is the PT voltage plus the voltage across the line-drop compensation circuit. 2 approach to select settings:

- Load center that means the settings are chosen to regulate the voltage at a given point downstream of the regulator.
- Voltage spread: R and X settings are chosen to keep the voltage within a chosen band when operating from tight to full load. The R and X settings may or may not be proportional to the line's R and X.

9.4.3 .Line loss and Voltage drop relationship

Ways to reduce line loss include:
- use a higher system voltage
- balance circuits
- Convert single-phase circuits to three-phase circuits.
- reduce loads
- increase power factor (capacitors)
- reconductor with a larger size.

If load distribution are **uniform** and the line has length = l. The loss is the same as a single lumped load placed at l/3 from the source end. But a circuit of length l has same voltage drop as a single lumped load placed at a length of l/2 from the source end.

For a **uniformly increasing load**, the equivalent lumped load is at 0.53l of the length from the source end. The MV lines (22 kV) are thermally limited (and not voltage drop limited).
Let L1, L2 the loss on circuit 1 and 2. $L1 = R1 \cdot I^2$, $L2 = I2^2 \cdot R2$.

$L2 = (V1/V2)^2 \cdot L1$ (voltage limited circuit)

$L2 = (V1/V2)^{(2/3)} \cdot L1$ (thermally limited circuit)

On a system-wide basis

$L2 = (V1/V2)^n \cdot L1$ where $n = 2/3 \ldots 2$

System	Capacity, pu	V drop, pu	Line loss
Balance three phase	1	1	1
2 phases	0.5	2.0	2.0
2 phases plus multigrounded neutral	0.67	2.0-3.3	1.2-3.0
2 phases plus unigrounded neutral	0.67	2.5-4.5	2.25
One phase and multigrounded neutral	0.33	3.7-4.5	3.5-4.0
One phase and unigrounded neutral	0.33	6.0	6.0

Loss factor = Average losses/Peak losses = Fls
Peak losses = Power losses at peak demand

$$Fls = 0.5\ Fld + 0.8\ Fld^2 \quad (1)$$
$$Fls = 0.3\ Fld + 0.7\ Fld^2 \quad (2)$$

where Fld = load factor.

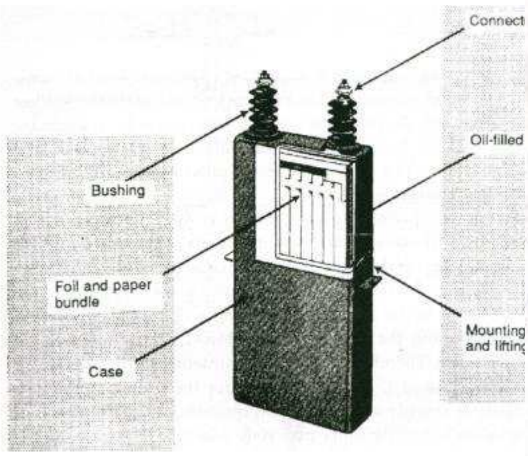
9.5 Capacitor Application

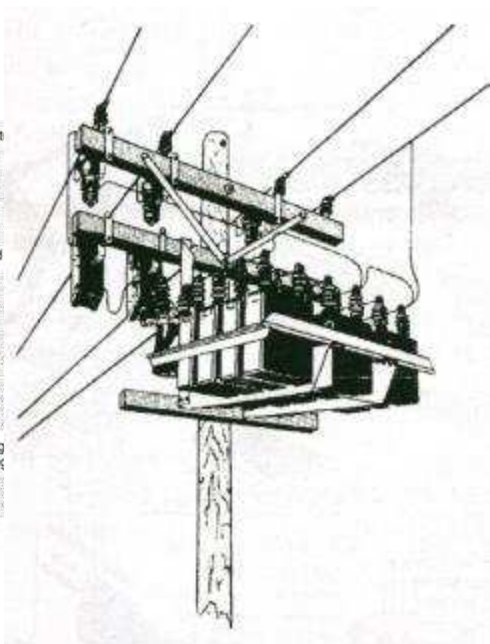
In distribution system, capacitor reduces losses, free up capacity, and reduces voltage drop.

a) Capacitor eliminates reactive power to motors and other reactive loads (with low power factor) and decreases the line current. So it frees up capacity, and the same circuit can provide more load.
b) Voltage drop: when line current is reduced, voltage drop is reduced and causes a voltage boost.

But if not properly applied or controlled, the reactive power from capacitor banks, they can create losses and high voltage (overvoltages occur under light load).

9.5.1 Capacitor component





Capacitor unit are made of series and parallel combinations of capacitor pack or elements put together. Capacitor dielectrics must withstand on the order 78kV/mm.

a) Capacitor installation: Capacitors are often installed at point of distribution feeders. Line capacitor installation has capacitor units and other components (arrester, fuses, control, potential transformer, switches and controller).

b) Ratings:
Capacitor should not be applied if:

- 135% of name plate kVar
- 110% of rated rms voltage and crest voltage not exceeding 1.2 sqrt(2) of rated rms voltage, including harmonics but excluding transients.
- 135% of nominal rms current based on rated kVar and rated voltage.

Capacitor should withstand various peak voltage and current transients. See table.

Probable numbers	Permissible peak transient	Permissible peak transient
of transient per year	current (multiplying factor)	voltage (multiplying factor)
4	1500	5.0
40	1150	4.0
400	800	3.4

c) Capacitance (in microfarad)

$$C\ \mu F = 2.65 QkVar/Vkv^2$$

Where Vkv = capacitor voltage rating kV
QkVar = unit reactive power rating, kVar

d) Resistor

The resistor must be low enough so RC time constant can decay in 300 seconds.

$$50/\mathrm{sqrt}(s)V <= \exp(-300/RC)$$

V = capacitor voltage rating V
R: discharge resistor, ohm
C: capacitance, F

e) Discharged power:

Power discharged by resistor P (watts) = (Q kVAr/113.2)* ln(35.36/V)

f) Environment

Capacitor does not have load cycles; they are always at full load. Capacitor have to operate from 40 to46 degree C with unrestricted ventilation and direct sunlight. Minimum temperature of air is about -40 degree C.

g) Release capacity

Extra capacity as a function of the size of capacitor and original power factor.

$$P\ extra = (-20\ PF\ orig + (PF\ corrected - 0.5)*120)\%$$

h) Voltage support

I = I rated * V pu
Q kVar = Q rated (V pu)^2

i) Reducing line loss

Using capacitor to supply reactive power reduces the amount of current in the line. So reducing the reactive power flow on line significantly reduces losses.

9.6 Sizing and placing capacitor

There is 2/3 rule for sizing and placing capacitor to optimally reduce losses.
For uniformly distributed load, the optimal size of capacitor is 2/3 of the var requirement of the circuit. The optimal placement of this capacitor is 2/3 of the distance from the substation to the end of line.

If using n capacitor, so

Q rated = 2/(2n+1) Q var required
Location at 2/(2n+1).i.L where i is the number of capacitor

Method Gransgel and Lee (1981) using 1/2kVar rule.

1) Pick a size
   Choose a standard size capacitor Q rated 0. If Q rated = 2/3 Q var required, so only 1 bank.

Else Q rated = 1/6 Q var required and then use 5 banks

2) Locate first bank

Start from the end of line.

Find point where Q va = 1/2 Q rated

3) Locate subsequent banks

Reevaluate the var profile. Move upstream until the point where var flow = 1/2 Q rated But under light load check that the capacitors have not raised the voltages above allowable standards If V > Vlimits (V + 10%) reduce the size of the capacitor banks or the number of capacitor banks until voltage limits are not exceeded.

9.6.1 Energy losses

Use the average reactive loading profile to optimally size and place capacitor for energy losses.

For peak load, use 1/2 kVar method.

For average reactive load, use 1/2 kVar method or the 2/3 rule to optimize energy losses.

If we do not have average system case, we can use reactive load factor RLF.

RLF = Average kVar demanded / Peak kVar demanded.

9.6.2 Switched Banks

Benefit of switched banks in situations:

- more loss reduction: we switch banks on and off to track these changes.
- voltage limits: when apply banks under average loading scenario cause excessive voltage under light load, so use switched banks.

9.6.3 Sizing and placing switched banks

We can use 1/2 kVar method and determine the on time and off time and determine the proper sizing based on the average reactive flow between the on and off times.

9.6.4 Combinations of fixed and switched banks

- Apply fixed banks to the circuit with 1/2 kVar rule based on the light load case.
- Check voltage. If undervoltage, so increase the size of capacitor or use more capacitor banks or add regulators.
- Look for location suitable for switched banks. Use average reactive line flows for the time when the capacitor is on. Apply switched capacitors, check the light load case for possible overvoltages, and check peak-load for undervoltage.

9.7 Controls

Several options for controls are available for capacitor banks:

- Time clock: switch capacitor on and off based on the time of the day
- Temperature: switch capacitor on and off depended on the temperature of the capacitor
- Voltage: switch the capacitor on and off based on voltage.
- vars: the capacitor uses var measurement to determine switching
- power factor: similar to var control, the controller switch capacitor on and off based on the measured power factor.
- current: The capacitor switches on and off based on the line current (as measured downstream of the capacitor).

9.8 Failure modes

9.8.1 Low current and progressive failure

The dielectric fails is one of the elements within the capacitor. If one element is shorted, voltage on remaining elements increases, so higher current is. Another element may short out because of more voltage stress. Failure can cascade until the whole string short out. Fuse must be very sensitive.

High current: a low impedance failure develops across the capacitor terminals or from a phase terminal to ground. A broken connection could cause such a fault.

9.8.2 Fusing and protection

- Purpose: clear a fault if a capacitor unit or any of the accessories fail.
- Problem: a fuse is blown, but the capacitors themselves are still functional. So unbalance voltage increases and can also increase stray voltages, and so increase losses.
- Selection of fuse size: 1.25 and 1.35 times rule. 3 factors can contribute to higher than expected current.
- Overvoltage: I capacitor is proportional to capacitor voltage, but Q var is proportional to square V. So upper voltage limit of 110% is normally use.
- Harmonics: Capacitor is a sink for harmonics. Increase the peak and rms of the current through the capacitor. Grounded three-phase banks absorb zero sequence harmonics from the system.
- Capacitor tolerance: +15% above their ratings (so increase current by 15%)

Smallest size of fuse:
Use tight-fusing approach, with tin link

$$I_{min} = 1.35\ I1 / 1.5 = 0.9\ I1$$

where
I1 = capacitor bank current, A
Imin = minimum fuse rating
1.5 is for overload

9.8.3 Nuisance fuse operations

- Lightning: Capacitors are low impedance to the high frequency lightning surge, so they attract lightning current, which can blow fuse. Rule of thumb: fuse should > 20K or 15T
- Outrush to nearby faults: Capacitor may dump its stored charge into a nearby fault, the fuse could blow. Capacitor banks also have inrush every time they are switched in, but this is well below the melt point of the fuse.

  Outrush may be worse with two factors:
  a) Higher system voltage. Higher voltage capacitor bank use smaller fuses with loss I^2 *t capability.
  b) Larger conductors (because conductor has low resistance).

- Sever harmonics. Harmonics increase the current through the fuse.
- Animal or other bushing faults. A fault across a bushing due to an animal, contamination on the bushing or tree contact can blow a fuse. Use animal guards and covered jumpers to reduce these.
- Mechanical damage and deterioration
- Corrosion and vibration can weaken fuse links (not so much problem of this kind)
- Installation errors: Fuses are more likely to blow if crews put in the wrong size fuse or wrong type fuse or do not properly tighten the braid on the fuse.

Chapter 10: Operation and Maintenance

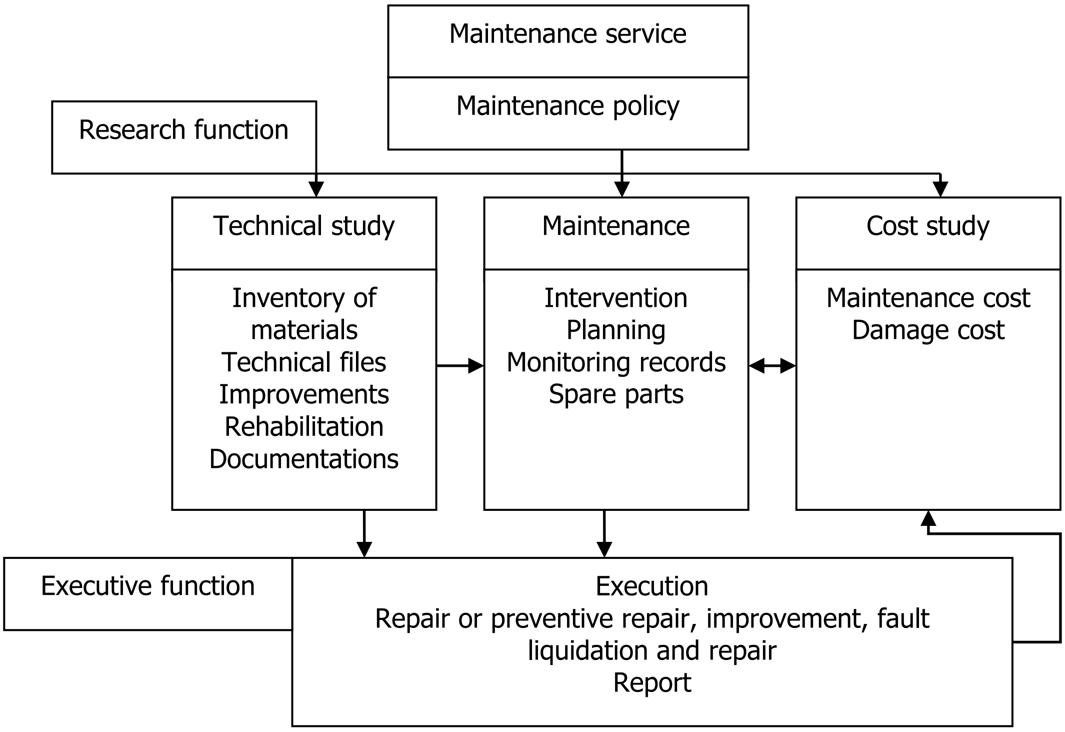
10 Operation and maintenance

10.1 Repair and maintenance

Repair is action aimed to liquidate the cause of a fault and restore the initial state of equipment. Maintenance is preventive action aimed to prevent a cause of fault not to occurs, so the equipment could operate continuously. That means maintenance is activities aimed to maintain the equipment in normal state of operation. The maintenance tends to eliminate the repair activities.

10.2 Maintenance service

The maintenance service is responsible in the prevention of any power outage and prevents any possible accidents.



10.3 Study function

a) Technical study in order to elaborate base of technical documentation of maintenance.
b) Prepare order and instructions: this is the core of maintenance operation.
c) Cost study: study the procurement and analyse maintenance cost and damage cost in order to consider the efficiency of the maintenance service.
d) Executive function

This function is realized by a team of many specialized workers and technicians (mechanical, electrical domain)

e) Methodology

- Preventive maintenance
- Corrective maintenance

f) Maintenance tasks

- Fault liquidation
- major repairs

- Inspection
- Revision
- Standard compliance

g) Maintenance documentations

- Technical documentation
- History
- Monitoring card
- Correction card

h) Conclusion

Chapter 11: Design of an Electrical Network

11 Design of aerial electrical network conforming to Electric Power Technical Standard of the Kingdom of Cambodia

11.1 Formal standards, rules and regulations

All technical designs for MV installation need to comply with:

- The Electrical Power Technical Standards of Cambodia – Charpter 4: Medium and Low voltage distribution facilities - Printed by EAC dated August 2007,

11.2 Basic Calculation

- **The calculation of wind load**

Wind Load

<Wind Load to 1m2>

$$P = C\left(\frac{1}{2}\delta V^2\right) \qquad [N]$$

P : Wind Load to 1m2 [Pa]
C : Resistance coefficient
δ : Density of Air(kg/m3)
V : Wind Speed(m/sec)

V adopted in GREPTS is 32m/sec, that is derived from the observation data in Kingdom of Cambodia.

<Example 1 (for conductor)>
V=32m/sec, C=1.05, $\delta=1.137kg/m^3$
$P=1.05\times1/2\times1.137\times32^2=611(Pa)$
10% margin is taken into consideration
Maximum design wind Load for Conductors
→ 680(Pa)

<Example 2 (for wooden pole)>
V=32m/sec, C=1.2, δ=1.137kg/m3
$P=0.8\times1/2\times1.137\times32^2=466$ Pa
10% margin is taken into consideration
Maximum design wind Load for Wooden Pole
→ 520(Pa)

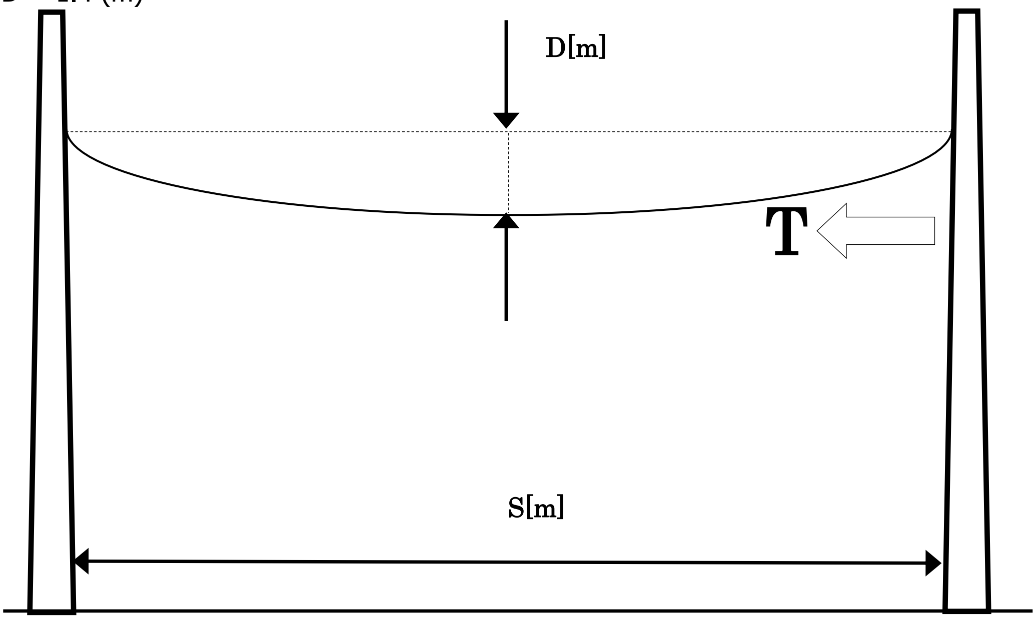
Table : Wind load (to 1m2)

Segment of an object receiving wind pressure			Wind pressure to 1m2 of the vertical projected area (Pa)
Supporting structure	Wooden pole	Columnar pole	520
	Iron-reinforced concrete pole	Columnar pole	520
		Square pole	1,290
Electrical conductor and other strung conductor			680

- **The calculation of tension of overhead distribution conductors**

$$T = \frac{WgS^2}{8D}$$

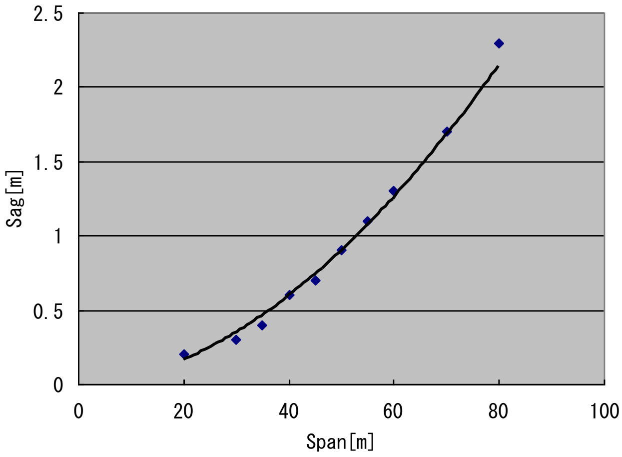
T = Tension in the longitudinal direction (N)
D = Sag for overhead conductor (m)
W = Weight per unit conductor length (kg/m)
g = Gravity acceleration (=9.8m/s2)
S = Span between two poles (m)
[Example]
W = 1.0(kg/m)
g = 9.8 (m/s2)
S = 48 (m)
D = 1.4 (m)



$$T = \frac{WgS^2}{8D} = \frac{1.0 \times 9.8 \times 48^2}{8 \times 1.4} = 2{,}016[N]$$

Sag table – for overhead-Conductor(Sample)

Span[m]	Sag[m]	Span[m]	Sag[m]
20	0.2	20	0.2
30	0.3	30	0.4
35	0.4	35	0.5
40	0.6	40	0.7
45	0.7	45	0.8
50	0.9	50	1.1
55	1.1	55	1.3
60	1.3	60	1.5
70	1.7	70	2.1
80	2.3	80	2.7

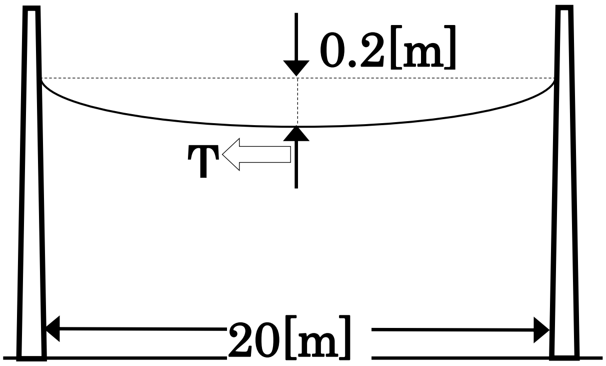


<u>Question 1</u>
Calculate the wind load (to 1m2) for wooden pole
Condition : Wind Velocity 21.36(m/s)
What is the value of wind load (to 1m2) ?
<u>Answer 1</u>
P = 1.2 × ½ ×1.137 × 21.362
= 311.3 (Pa)
311.3 × 1.1 = 342 → 350 (rounded up)

<u>Question 2</u>
Calculate the wind load (to 1m2) for iron-reinforced concrete pole (square pole consisting of steel pipes)
Condition : Wind Velocity 32 (m/s)
What is the value of wind load (to 1m2) ?
<u>Answer 2</u>
P = 1.5 × ½ ×1.137 × 322
= 873.2 (Pa)
311.3 × 1.1 = 961 → 970 (rounded up)

<u>Question 3</u>
Calculate the wind load (to 1m2) for iron-reinforced concrete pole (columnar pole)
Condition : Wind Velocity 32 (m/s)
What is the value of wind load (to 1m2) ?
<u>Answer 3</u>
P = 0.8 × ½ ×1.137 × 322
= 465.7 (Pa)
465.7 × 1.1 = 512 → 520 (rounded up)

<u>Question 4</u>
Calculate the tension in under condition
<Condition>
Weight of wire : 165 (kg/km), Span : 20 (m)
Sag : 0.2 (m)

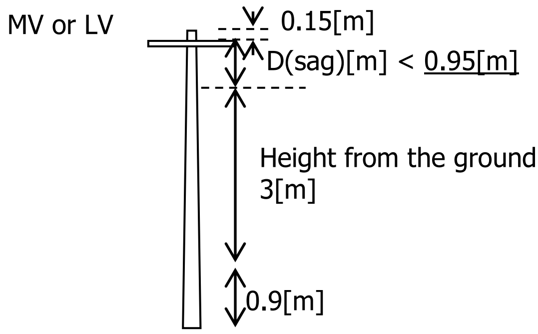


Answer 4
T = (0.165 × 9.8 × 202)/(8 × 0.2)
= 404.3 (N)

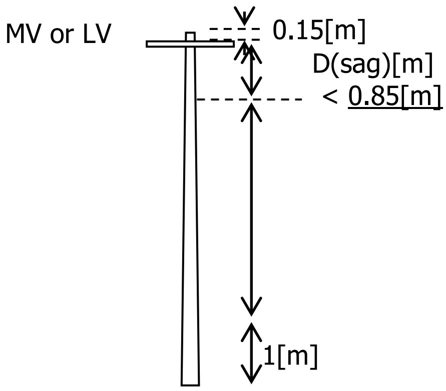
Question 5
Calculate the tension in under condition
<Condition>
Weight of wire : 435 (kg/km), Span : 80 (m)
Sag : 2.7 (m)

Answer 5
T = (0.435 × 9.8 × 802)/(8 × 2.7)
= 1263.1 (N)

6.2Typical Assembling of Distribution Facilities
<Mitigate Case>

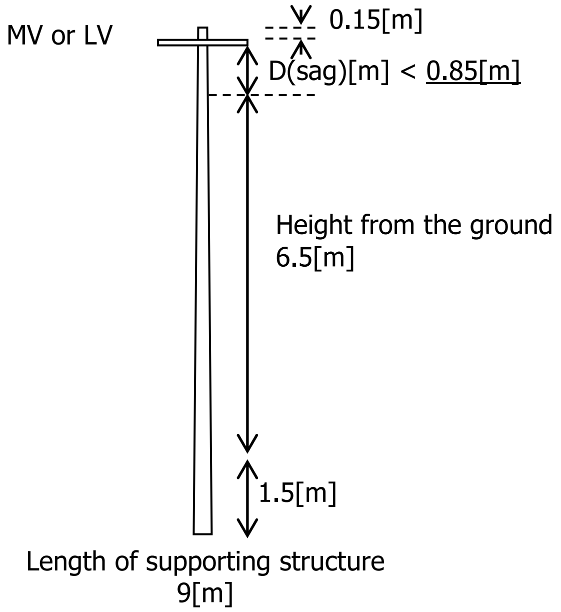


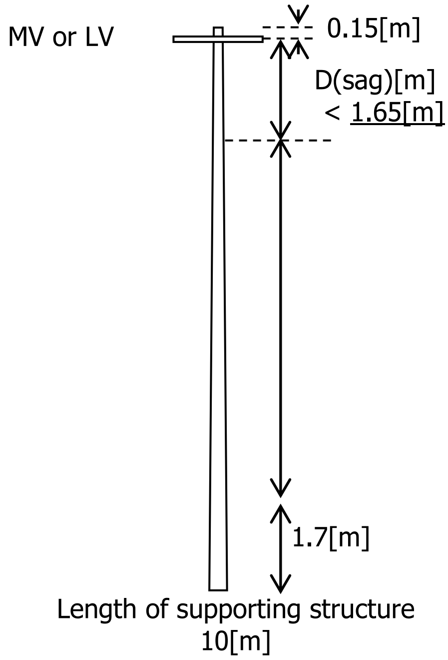
Length of supporting structure
5[m]

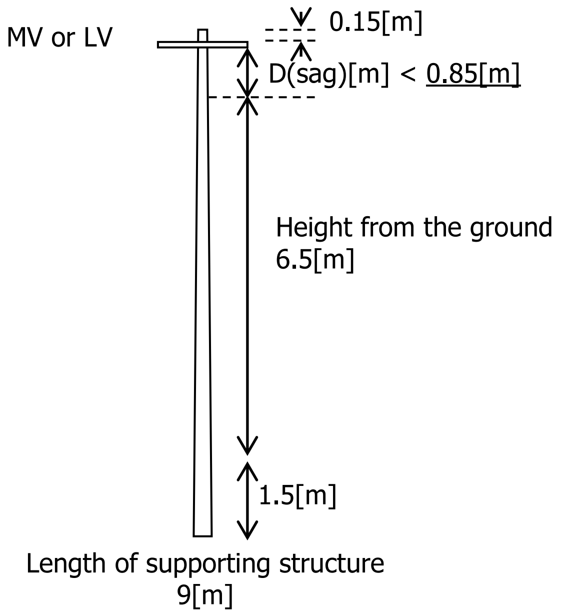


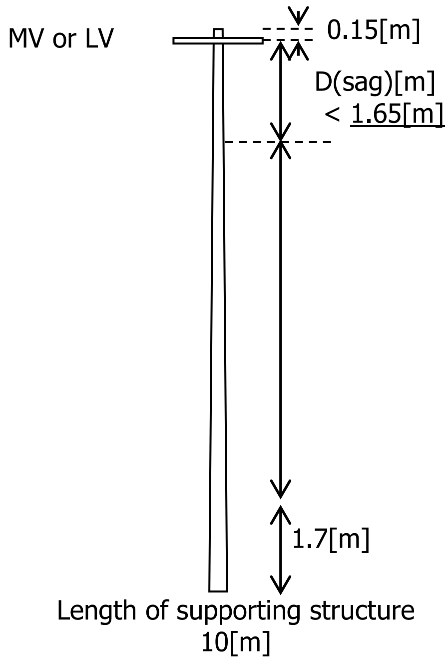
Length of supporting structure
6[m]

<Usual Case>

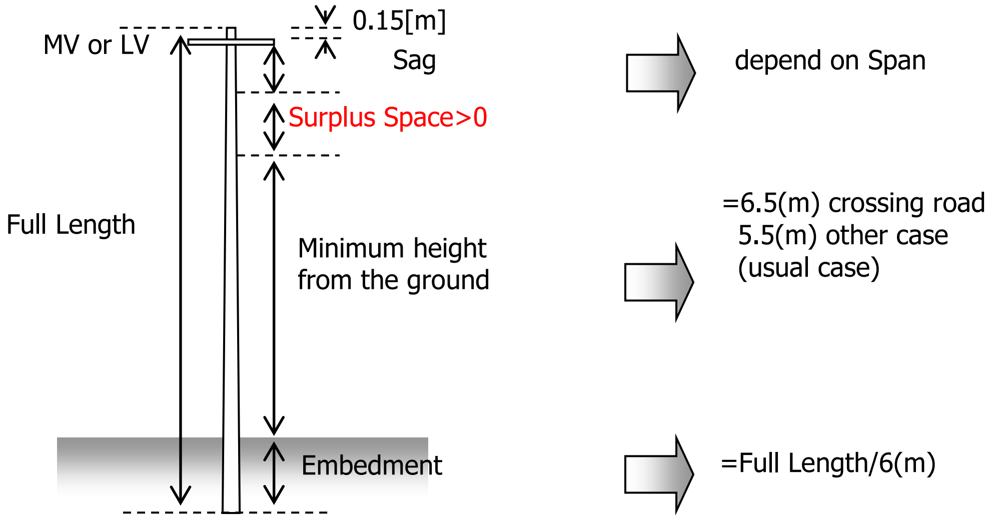






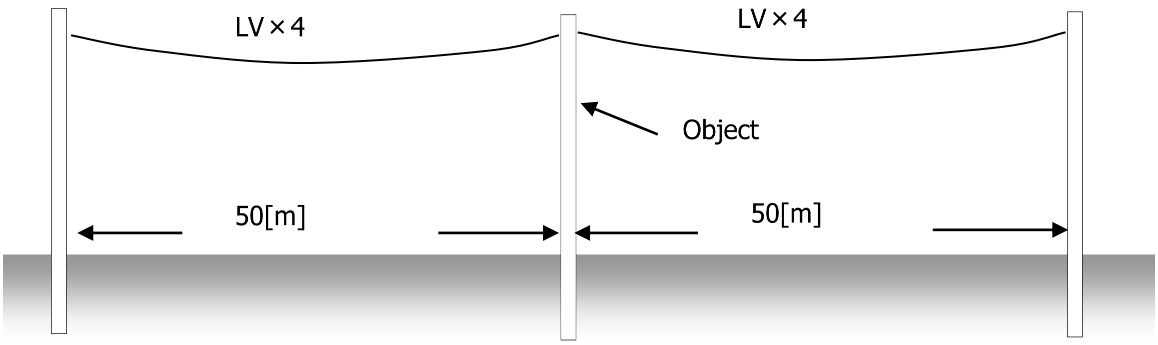


How many meters should we use the pole?



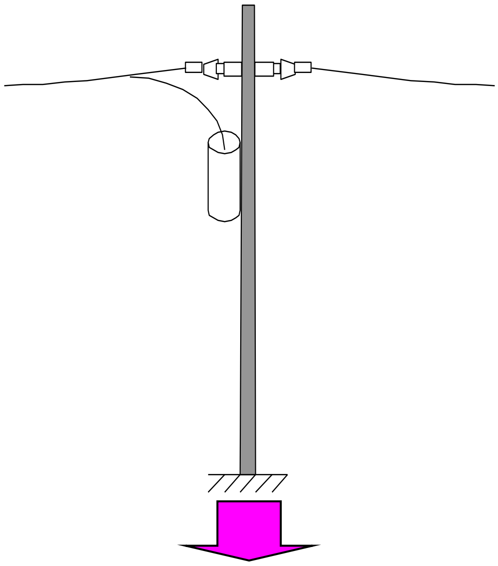
Example

1. Determine the sag using sag table (depend on the span) → 0.9m, because the span is 50m
2. The wire is crossing the road or not → 5.5m, because the wire is not crossing the road
3. 0.9+5.5+0.15+Full Length(m)/6＜Full Length(m) , so Full Length is 8m or over.



[Vertical Loads]

①Weight of Supporting Structure
②Weight of Conductors, Accessories such as Tr
③Weight of Insulating Devices



[Horizontal transverse Loads]
①Wind Load of Supporting Structure
②Wind Load of Conductors, GW
③Wind Load of Insulators, Fittings
④Horizontal Transverse Component of
the maximum tension of Conductors
[Horizontal longitudinal Loads]
①Wind Load of Supporting Structure
②, ②' Horizontal Transverse Component of
the maximum tension of Conductors

6.3Calculation of the Strength of Supporting Structure
Calculation of Strength of Wooden Poles
Bending moment due to Wind Load of Supporting Structures

$$Mp = \int_0^H \frac{x \cdot dW_L}{100} = \frac{K_1}{100} \int_0^H (D_0 - kx)x \cdot dx$$

$$\boxed{Mp = \frac{K_1}{100}\left(\frac{D_0 H^2}{2} - \frac{kH^3}{3}\right)}$$

K1 : Wind load per 1m2 of wooden pole (N/m2)
D0 : The diameter of the pole at the surface of the ground (=D+kH) (cm)
H : The height of the pole above the ground (m)
k : The increase rate of the diameter of the wooden pole (cm/m) (=0.9)
D : The diameter of the top of the pole (cm)
Bending moment due to wind Load of Conductors

$$\boxed{Mw = \sum\left\{K_2\left(\frac{d}{1000} \times S\right) \times h\right\} = K_2 \cdot \frac{S\left(\sum dh\right)}{1000}}$$

K2:Wind load per 1m2 vertically projected area of the distribution conductors (N/m2)
d : diameter of the conductor (mm)
S : A half of the spans on the both sides (m)
h : Height of the supported position of the conductor (m)

The allowable stress of wooden poles

$$f = \frac{P(1000)^2}{F} \quad (N/m^2)$$

P : Breaking strength
(N/mm2)

The modulus of the cross section

$$\mathbf{Z} = \frac{\pi}{32}\left(\frac{D_0}{100}\right)^3 \quad (m^3)$$

The resistant moment of the wooden pole

a. Single pole without guy

$$Mr \geq K(Mp + Mw)$$

$$\frac{\pi}{32} \cdot \frac{P(D_0)^3}{F} \geq K\left\{\frac{K_1}{100}\left(\frac{D_0H^2}{2} - \frac{kH^3}{3}\right) + K_2\frac{S\left(\sum dh\right)}{1000}\right\}$$

$$\frac{P}{F} \geq K\frac{32}{\pi}\left\{\frac{K_1}{100}\left(\frac{D_0H^2}{2} - \frac{kH^3}{3}\right) + K_2\frac{S\left(\sum dh\right)}{1000}\right\} \Big/ (D_0)^3$$

K1=520(N/m2), K2=680(N/m2), k=0.9(cm/m) are substituted

=> $$\boxed{\frac{P}{F} \geq K\frac{265D_0H^2 - 158H^3 + S\left(69\sum dh\right)}{10(D_0)^3}}$$

- **Calculation of Strength of Reinforced Concrete Pole and Iron Pole**

$$k = \frac{D_0 - D_1}{H}, \qquad therefore,$$

$$Mp = K_1\left(\frac{D_0H^2}{2} - \frac{D_0 - D_1}{H} \cdot \frac{H^3}{3}\right) = \frac{K_1(2D_1 + D_0)H^2}{6}$$

Pole shall have enough strength to withstand the total bending moment by safety factor

$$(H - dm)P \geq f(Mp + Mw)$$

- **Calculation of Strength of Reinforced Concrete Pole**

$$\boxed{\frac{(H - dm)P}{f} \geq K_1\frac{(2D_1 + D_0)H^2}{6} + K_2S\left(\sum dh\right)}$$

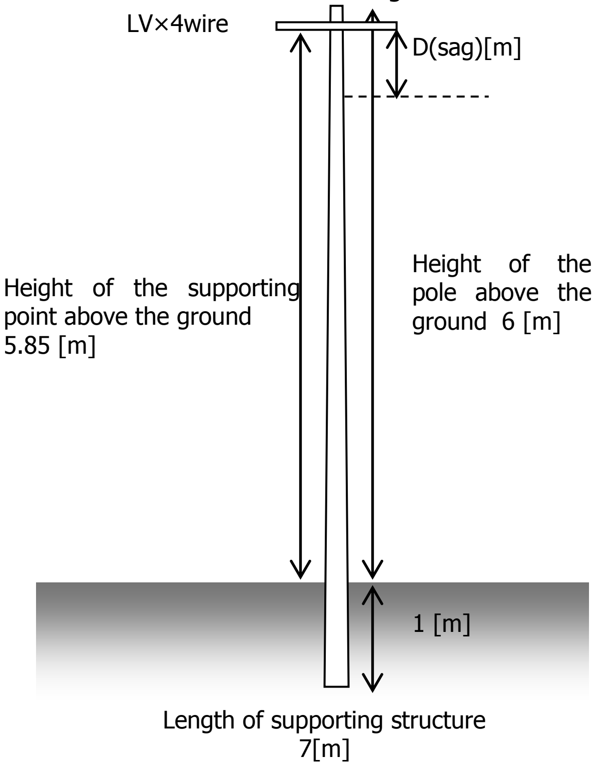
P : Breaking strength of the supporting structure (N)
dm : Length from the top of the structure to the design top load (m) (=0.15)
f : Safety factor (=1, in the case of concrete pole)
K1 : Wind load to 1m2 of the concrete pole (N/m2) (=1,290)
D1 : Top end breadth of the concrete pole (m)
D0 : Ground-level breadth of the concrete pole (m)
H : Height of the concrete pole above the ground (m)
K2 : Wind load to 1m2 of distribution conductor (N/m2) (=680)
S : A half of the sum of the spans on the both sides (m)
d : Diameter of the distribution conductor (m)
h : Height of the supported position of a conductor (m)

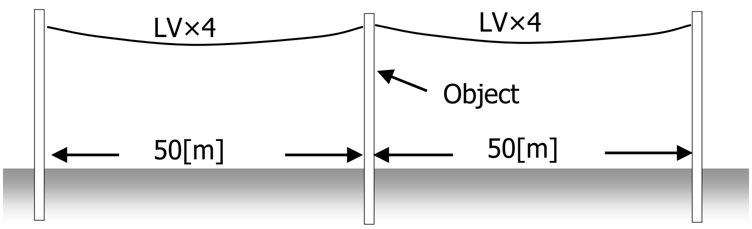
<u>Question 1</u>

Calculate the safety factor of wooden pole

P = 11 [N/mm2] : The breaking strength to the bend of
the pole (using Phchok)

K = 1 : constant
D0 = 12 [cm] : The diameter of the pole at the surface of the ground
H = 6 [m] : The height of the pole above the ground (the length of pole = 7 [m])
S = 50 [m] : span
d = 0.0074 [m] : The outer diameter of each wire
h = 5.85 [m] : The height of the supporting point of each wire above the ground





Answer 1

$$\frac{P}{F} \geq K \frac{265 D_0 H^2 - 158 H^3 + S\left(\sum 69 dh\right)}{10\left(D_0\right)^3}$$

$$\frac{P}{F} = \frac{11}{F}$$

$$K\frac{265D_0H^2-158H^3+S\left(\sum 69dh\right)}{10\left(D_0\right)^3}$$

$$=\frac{265\times12\times6^2-158\times6^3+50\times69\times0.0074\times5.85\times4}{10\times12^3}$$

$$=\frac{114480-34128+597}{17280}=4.68$$

$$F=\frac{11}{4.68}=2.35$$

<u>The safety factor is 1.2 or more</u>

<u>Question 2</u>

Calculate the safety factor of wooden pole

P = 17 [N/mm2] : The breaking strength to the bend of the pole (using Koki Khsach)

K = 1 : constant

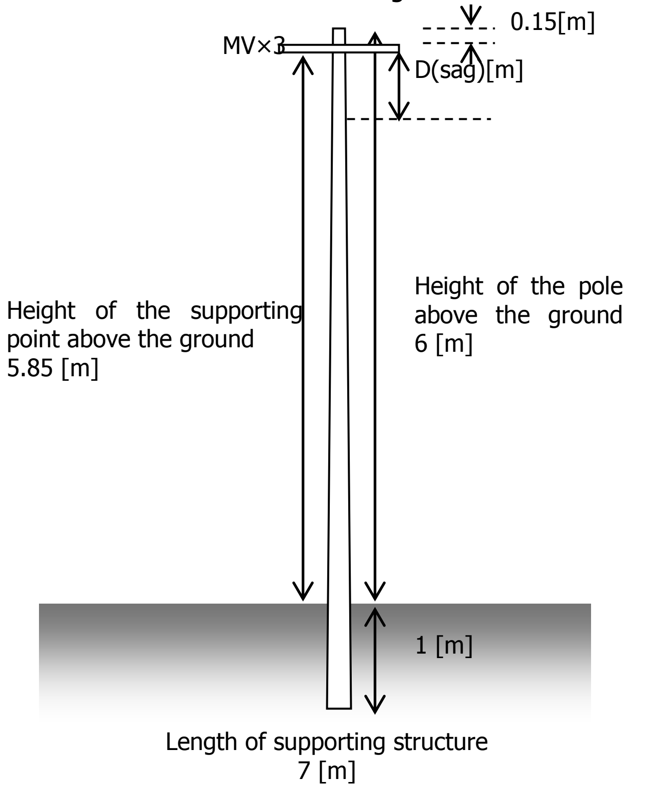
D0 = 12 [cm] : The diameter of the pole at the surface of the ground

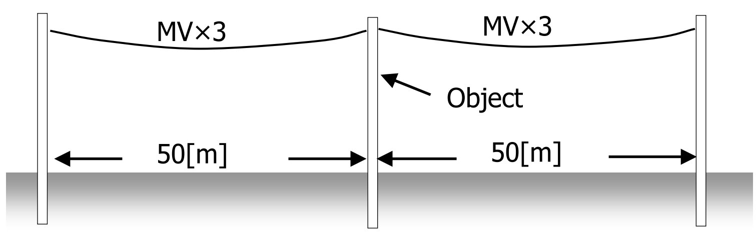
H = 6 [m] : The height of the pole above the ground (the length of pole = 7 [m])

S = 50 [m] : span

d = 0.0158 [m] : The outer diameter of each wire

h = 5.85 [m] : The height of the supporting point of each wire above the ground





Answer 2

$$\frac{P}{F} \geq K\,\frac{265D_0H^2 - 158H^3 + S\left(\sum 69dh\right)}{10\left(D_0\right)^3}$$

$$\frac{P}{F} = \frac{17}{F}$$

$$K\,\frac{265D_0H^2 - 158H^3 + S\left(\sum 69dh\right)}{10\left(D_0\right)^3}$$

$$= \frac{265 \times 12 \times 6^2 - 158 \times 6^3 + 50 \times 69 \times 0.0158 \times 5.85 \times 3}{10 \times 12^3}$$

$$= \frac{114480 - 34128 + 957}{17280} = 4.71$$

$$F = \frac{17}{4.71} = 3.61$$

The safety factor is 1.5 or more

Question 3

Calculate the breaking strength of wooden pole

f = 1.5 : safety factor

K = 1 : constant

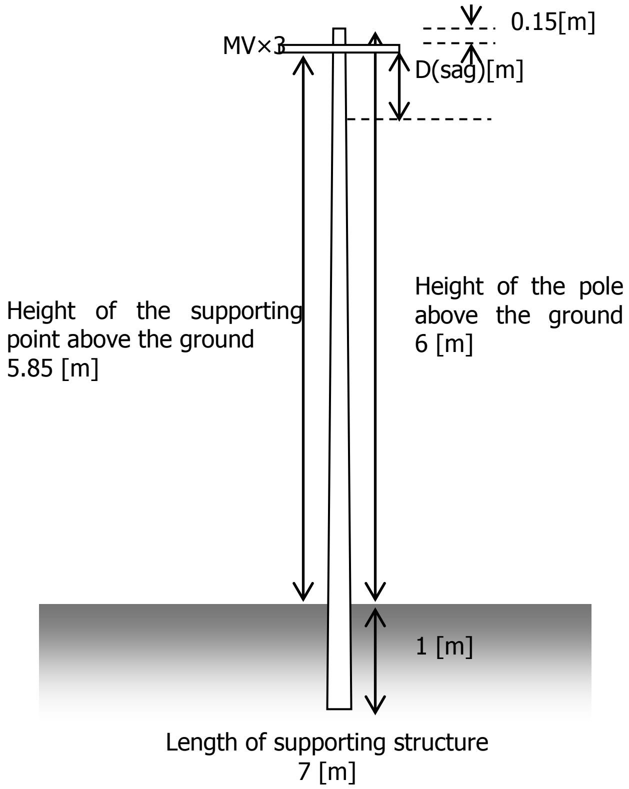
D0 = 12 [cm] : The diameter of the pole at the surface of the ground

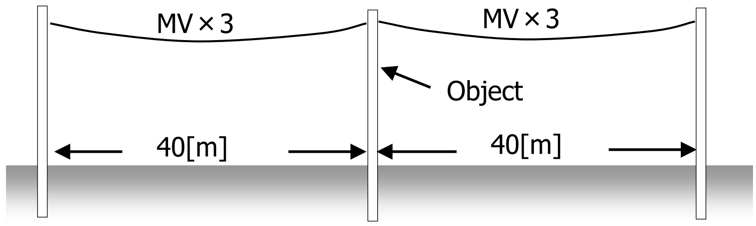
H = 6 [m] : The height of the pole above the ground (the length of pole = 7 [m])

S = 40 [m] : span

d = 0.0085 [m] : The outer diameter of each wire

h = 5.85 [m] : The height of the supporting point of each wire above the ground





<u>Answer 3</u>

$$\frac{P}{F} \geq K\frac{265D_0H^2 - 158H^3 + S\left(\sum 69dh\right)}{10\left(D_0\right)^3}$$

$$\therefore P \geq FK\frac{265D_0H^2 - 158H^3 + S\left(\sum 69dh\right)}{10\left(D_0\right)^3}$$

$$FK\frac{265D_0H^2 - 158H^3 + S\left(\sum 69dh\right)}{10\left(D_0\right)^3}$$

$$= 1.5 \times 1 \times \frac{265 \times 12 \times 6^2 - 158 \times 6^3 + 40 \times 69 \times 0.0085 \times 5.85 \times 3}{10 \times 12^3}$$

$$= 1.5 \times \frac{114480 - 34128 + 412}{17280}$$

$$= 7$$

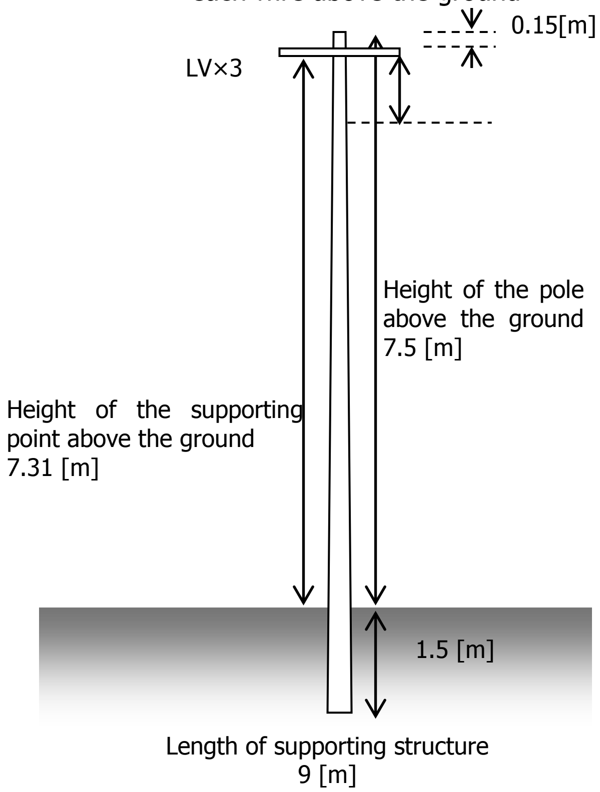
$$P \geq 7$$

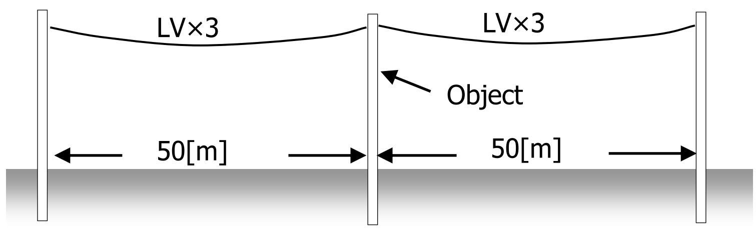
…so we can use Phchok, Koki Khsach, Thbaeng and Khlong.

<u>Question 4</u>

Calculate the safety factor of concrete pole
H = 7.5 [m] : The height of the pole above the ground

dm = 0.15 [m] : length from the top of the structure to the design top load
P = 4×103 [N] : breaking load of the supporting structure
K1 = 1290 [Pa] : wind pressure to 1m2 of the vertical projected area (square pole)
D1 = 0.13 [m] : top end breadth
D0 = 0.23 [m] : ground level breadth
K2 = 680 [Pa] : wind pressure to 1m2 of the vertical projected area (conductor)
S = 50 [m] : span
d = 0.0078 [m] : outer diameter of each wire
h = 7.31 [m] : height of the supporting point of each wire above the ground





Answer 4

$$\frac{(H-d_m)P}{f} \geq K_1\frac{(2D_1+D_0)H^2}{6}+K_2S\left(\sum dh\right)$$

$$\frac{(H-d_m)P}{f}=\frac{(7.5-0.15)\times 4\times 10^3}{f}=\frac{29400}{f}$$

$$K_1\frac{(2D_1+D_0)H^2}{6}=1290\times\frac{(2\times 0.13+0.23)\times 7.5^2}{6}=5926$$

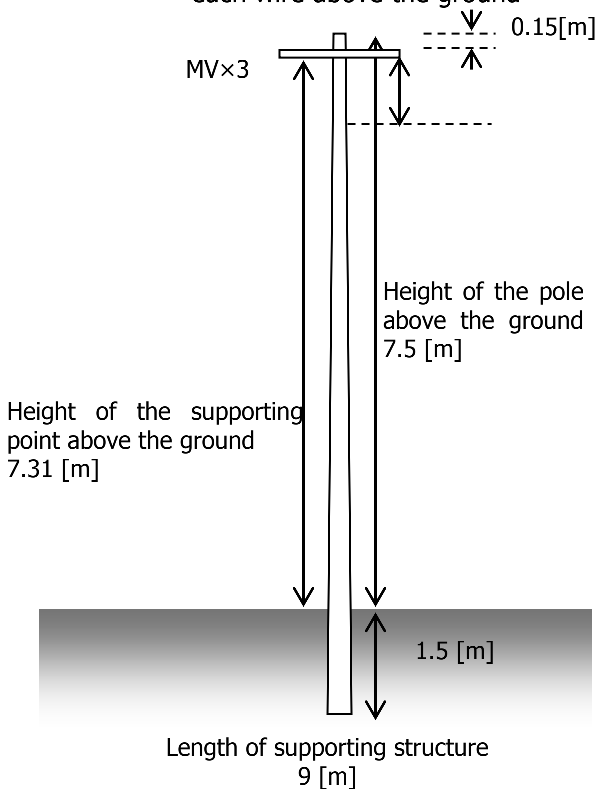
$$K_2 S\left(\sum dh\right) = 680 \times 50 \times (0.0078 \times 7.31 \times 3) = 5816$$

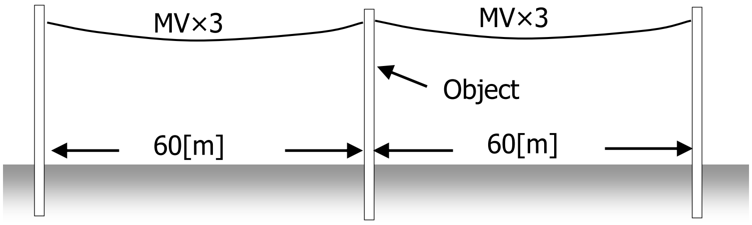
$$f = \frac{29400}{5926 + 5816} = 2.50$$

The safety factor is 1 or more

Question 5

Calculate the breaking strength of concrete pole
H = 7.5 [m] : The height of the pole above the ground
dm = 0.15 [m] : length from the top of the structure to the design top load
f = 1 : safety factor
K1 = 1290 [Pa] : wind pressure to 1m2 of the vertical projected area (square pole)
D1 = 0.20 [m] : top end breadth
D0 = 0.28 [m] : ground level breadth
K2 = 680 [Pa] : wind pressure to 1m2 of the vertical projected area (conductor)
S = 60 [m] : span
d = 0.0128 [m] : outer diameter of each wire
h = 7.35 [m] : height of the supporting point of each wire above the ground





Answer 5

$$\frac{(H-d_m)P}{f} \geq K_1\frac{(2D_1+D_0)H^2}{6} + K_2S\left(\sum dh\right)$$

$$\therefore P \geq \left(\frac{f}{H-d_m}\right)\cdot\left\{K_1\frac{(2D_1+D_0)H^2}{6} + K_2S\left(\sum dh\right)\right\}$$

$$\frac{f}{H-d_m} = \frac{1}{7.5-0.15} = 0.136$$

$$K_1\frac{(2D_1+D_0)H^2}{6} = 1290\times\frac{(2\times0.20+0.28)\times7.5^2}{6} = 8224$$

$$K_2S\left(\sum dh\right) = 680\times60\times0.0128\times7.35\times3 = 11515$$

$$P \geq 0.136\times(8224+11515) = 2685[N]$$

$$P \geq 2.7[kN]$$

…so we can use the concrete pole that has 2.7kN or more strength.

- **Calculation of the Strength of Foundation of Supporting Structure**

If the soil isn't soft and the supporting structure is set under the below conditions, you don't have to calculate the strength of foundations of supporting structure.

	Design Load of Supporting Structure	The Total Length of Supporting Structure	Embedment
Wooden Pole	**-**	**15m or less**	**1/6 or more of total**
		15m - 16m	**2.5m or more**
Iron Pole	**-**	**15m or less**	**1/6 or more of total**
		15m - 16m	**2.5m or more**
Iron-reinforced Concrete Pole	**6.5kN or less**	**15m or less**	**1/6 or more of total**
		15m - 16m	**2.5m or more**
		16m - 20m	**2.8m or more**

Chapter 12: Earthing and Safety

12 Earthing and safety

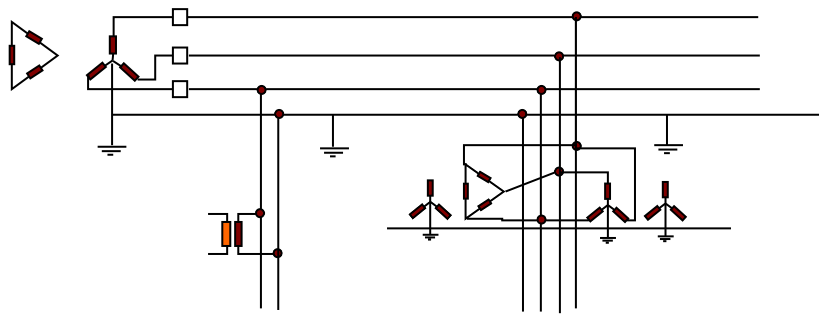
Grounding is a mean to defense against hazardous electric shocks and hazardous overvoltage. There are equipment grounding and system grounding. Equipment grounding helps reduce the chances that people get shocks from internal failures of the equipment. System grounding determines how loads are connected and how line-to-ground faults are clears.

12.1 System Grounding Configuration

12.1.1 Four wire multi-grounded systems

Advantages: Low cost serving single-phase loads because:

- single cable for underground single-phase load
- Single-phase overhead lines are less expensive
- single-bushing transformers
- One arrester and one fuse for a single-phase transformer.
- the neutral can be located lower on the pole
- Lower rated arresters
- lower insulation required



Use of single-phase lines provides cost savings. The primary neutral may be shared with the secondary neutral for further cost savings. Flexibility in upgrading a single-phase line to two- or three phase service on overhead lines following load growth should be done.

Safety is good. If a transformer pole-ground down lead gets broken, little safety margin is lost. A low-impedance path to earth protect against internal faults in the transformer.

A grounding transformer must not be disconnected during operation of the distribution line, because a single-line-to-ground fault causes high overvoltages on the unfaulted phases and load unbalances may create overvoltage.

12.1.2 Three wire system, either grounded or ungrounded

An ungrounded is grounded at one place, normally the substation.

Three wire systems have following advantages:

- lower cost for three-phase loads
- lower stray voltage
- easier detection of high-impedance faults
- lower magnetic fields

12.2 Single-wire earth return

The earth carries all of the return current. On earth-return systems, the resistance of ground electrodes is critical. Poor ground connections can cause low end-use voltage and can create dangerous step-and-touch potentials to the transformer tank.

12.2.1 High resistance grounding and high reactance grounding

This grounding is rarely used in distribution system. The main advantage is that it can operate with one phase fault.

12.3 Neutral shift during ground fault

The system grounding determines the overvoltages that can arise during a line-to-ground fault. A single line-to-ground fault shifts the ground potential at the fault location. If system is grounded solidly with a good return path to the grounding source, a little reference shift occurs. For the wye configuration, the fault shift ground potential to phase voltage. The line-to-ground voltage on the unfaulted phases rises to the line-to-line voltage, 1.73 per unit. For multigrounded system with a solidly grounded station transformer, overvoltage above 1.3 per unit is rare.

12.3.1 Neutral shift on multigrounded systems

- Overvoltage is highest for faults near the substation.
- Overvoltage is higher on shorter feeders
- A large neutral provides a better return path.
- More ground rods and lower rod resistance reduce overvoltage
- A neutral reactor on the substation transformer causes a higher overvoltage mainly for faults near the station.

12.3.2 Overvoltage on Ungrounded systems

Ungrounded systems may have extra-high overvoltages under certain conditions:

- Resonance- the line-to-ground capacitance can resonate with the system reactance.
- Arcing ground faults-a restriking ground fault can create significant line-to-ground voltage.

This overvoltage affects the insulation and arresters (so higher arresters are necessary). A bolted line-to-ground fault on one phase draws very little current on ungrounded system, so the system can continue to operate.

12.4 Equipment grounding

Effective grounds are required for:

- surge arresters
- primary, secondary, and common neutrals
- unguarded metal or metal-reinforced supporting structures
- other intentionally ground wires
- instrument transformers
- cable cocentric neutrals

- most equipment including transformers, capacitors, regulators, reclosers, and sectionalizers.
- uninsulated guy
- customer meters.

12.4.1 Ungrounded system of customer

If the transformer fails from the primary to secondary or high-to-low fault, the secondary grounding system must be effective enough to prevent unsafe voltage on customer wiring. The distribution transformer, customer meter are grounded as well as possible.

The primary surge arrester shall be separated from the secondary ground through a spark gap, which breaks down at least twice the primary circuit voltage but <= 10 kV.

12.4.2 Secondary grounding problem

If the neutral is open (has poor connection), the unbalanced current must return through the grounding electrodes (may have high impedance). It may happen light flicker, and high voltage on the less loaded of the secondary legs.

If the load is connected to equipment grounded and not to neutral, or ground wire is connected wrongly to neutral anywhere in customer facility, current flowing in the grounding conductor wire increases shock hazards.
Other problems are isolated grounding, ground loop and missing safety grounds.

12.5 Grounding electrodes

Ground rod is the most common grounding electrodes. The length of the rod is 1.5m. If a driven rod hits a rock bottom, the rod should be to drive at an angle or to use another type of ground.
The resistance of a ground rod is:

R = (rho/2 pi Ll)(ln(4L/a -1)

Where

rho = soil resistivity ohm/m
L = length of the ground rod, m
a = radius of the ground rod, m

Rod diameter is needed for mechanical strength and to survive corrosion.
The rod is better driven deeper is the soil has low resistivity at lower levels.
Multiple ground rods in parallel reduce resistance, but they must be not to close to each other.

Resistance of multiple rods

Number of rods	Multiplying factor	Total resistance % of one rod
2	1.16	58%
3	1.29	43%
4	1.36	34%
8	1.68	21%
12	1.80	15%
16	1.92	12%
20	2.00	10%
24	2.16	9%

Water piping is allowed to be used as ground, but gas piping is not allowed.

Other type of ground may be buried wires, strips, and plates.

- Buried wires must have at least 4mm diameter, at least 3m long and 0.45m deep.
- Strips must have at least 3m long, buried at least 0.45m deep, and have total surface area on both sides of 0.47m2.
- Plates must be buried at least 1.5m deep and have a total surface area of at least 0.185m2.
- Both plates and strips must have a thickness of at least 1.5mm wde for nonferrous metals and at least 6mm wide for ferrous metals.

12.5.1 Soil characteristics

Soil resistivity varies widely.

Soil	Average resistivity	resistance of 16mm diameter
	ohm-m	and 3m length rod
well graded gravel, gravel-sand mix	600-1000	180-300
poorly graded gravel	1000-2500	300-750
clayey gravel, sand-clay mixture	200-400	60-120
Silty, sands, poorly graded		
sand-silts mixtures	100-500	30-350
Clayey sands, poorly graded		
sand-clay mixture	50-200	15-60
Silty and clayey fine sands	30-80	9-24
Fine sandy or silty soil, elastic silt	80-300	24-90
Gravelly clays, sandy clays, silty clays	25-60	17-18
Inorganic clays or high plasticity	10-55	3-16

Source IEEE Std. 142-1991

Soil resistivity often varies with depth because in most case as moisture increases with depth. In this case resistivity decreases significantly with depth. Underlying bedrock significantly increases resistivity at lower levels. Several different layers of soil with different resistivities may be present.

Soil resistivity is affected by moisture (dryer the soil, higher the resistivity), temperature and salts.

We can use chemical treatments or backfills to reduce the soil resistivity near the electrode. Be careful with the chemical treatments, because this increase rod corrosion.

The ground current will dry the soil and degrade ground resistance. High voltage stress and high current from lightning or fault degrade ground resistance by breakdown the soil.

12.5.2 Corrosion

Ground electrodes may be copper-clad steel or galvanized steel. Steel and aluminium corrode quickly for grounding use. Copper may be stolen.

Mixing metals increases corrosion (galvanic corrosion). Different metals create an elctrochemical battery in the soil. Galvanic corrosion between dissimilar metals can eat up grounding electrodes.
Copper has good properties that limit corrosion, because the copper oxyde layer greatly reduces the corrosion rate.

Zinc coating on a steel ground rod provides corrosion protection for the rod. It protect steel core and exposed area.

With lower soil resistivity, electrodes corrode faster because of high ground current.

To avoid excessive corrosion, use only galvanized steel or copper-clad steel for electrodes and other metallic structure to buried in ground.

12.6 Shock and Stray Voltage

Electricity is dangerous. A small amount of current through a person's body can kill. Direct and indirect contact to utility circuits may occur in different ways. The current flowing into the ground can pose step and touch potential hazards to the people. Electric dangers are almost invisible.

Multigrounded system may be imperfect and may have voltage over the true ground. This voltage under certain conditions may shock people.

12.6.1 Biological models

The body resistance is important component in electrical circuit in shocking situations.

Human resistance values for several contact conditions (unit: Ohm)

Finger touch	400,000-1,000,000	4,000-15,000
Hand holding wire	15,000-50,000	3,000-6,000
Finger-thumb grasp	10,000-30,000	2,000-5,000
Hand holding pliers	5,000-10,000	1,000-3,000
Palm touch	3000-8,000	1,000-2,000
Hand around 3.8cm pipe	1,000-3,000	500-1,500
Two hands around 3.8 cm pipe.	500-1,500	250-750
Hand immersed in water		200-500
Foot immersed in water		100-300
Human body, internal, excluding skin	200-1000	

Electric current does damage.
Threshold Levels

rms current mA	Threshold reaction/sensation
Perception	
0.09	Touch perception for 1% of women
0.13	Touch perception for 1% of men
0.24	Touch perception for 50% of women
0.33	Grip perception for 1% of women
0.36	Touch perception for 50% of men
0.49	Grip perception for 1% of men
0.73	Grip perception for 50% of women
1.19	Grip perception for 50% of men

Startle

2.2	Estimated borderline hazardous reaction, 50% probably for women (arm contact)
3.2	Estimated borderline hazardous reaction, 50% probably for women (pinch contact)

Let-Go

4.5	Estimated let-go for 0.5% of children
6.0	Let-go for 0.5% of women
9.0	Let-go for 0.5% of men
10.5	Let-go for 50% of women
16.0	Let-go for 50% of men
Respiratory Tetanus	
15	Breathing difficulty for 50% of women
23	Breathing difficulty for 50% of men
Fibrillation	
35	Estimated 3s fibrillation current for children
100	Estimated 3s fibrillation current for adults

12.6.2 Step and touch potentials

During ground faults, all the ground current returns to the substation's transformer. This current creates a significant voltage gradient along the ground and at between the ground and conducting objects.

A touch potential is considered a hand-to-foot or hand-to-hand contact.
A step potential creates a path through the legs from one foot to another.

For a step potential, the body current is Ibody = V step / (R body + 6 rho)
Where rho = soil resistivity (ohm-m), 6 rho = approximated twice earth-foot resistance
For a touch potential, the body current I body = V touch / (R body + 1.5 rho)

12.6.3 Stray voltage

Stray voltage is a touch voltage that end-users experience. Many of stray voltage problems are due to improper facility grounding and bonding. Many stray voltage problems originate on the secondary system. Regardless of the origin of the stray voltage, localized bonding can eliminate touch potentials.

Utility side solution to stray voltage includes:

- Balancing load among the phases (This can reduce he earth-return current)
- Single-phase lines should be converted to two or three phase. This helps reduce the neutral-to-earth current.
- Upgrading neutral size provides a lower-impedance path for earth-return current.
- Check capacitor banks for blown fuses because of the blown fuse the unbalance can create excessive neutral current.

12.6.4Tree contacts

Trees cause possibly dangerous shocking hazard. A tree in contact with an energized phase conductor may create touch potential hazard near the ground.

The body current for a touch potential to a tree involves resistance of tree, the tree's resistance to ground in the earth, the conductor voltage, person's hand and foot contact resistance. To reduce possible tree-related shock should be reduced by:

- Educating the public on the dangers of cutting trees in the vicinity of power lines.
- trimming trees away from power lines
- training tree-trimming crews
- Using covered wire instead of bare wire.