SKEE4683
POWER SYSTEM DESIGN AND OPERATION

OUTLINE

1. Introduction to Power Generation, Transmission and Distribution
2. Connection of Green-Energy Generation to Power Systems
3. Basic Transmission System Concepts
4. Mechanical Design of Overhead Lines and Distribution System
5. Secondary Distribution Systems Feeder Analysis

CHAPTER ONE

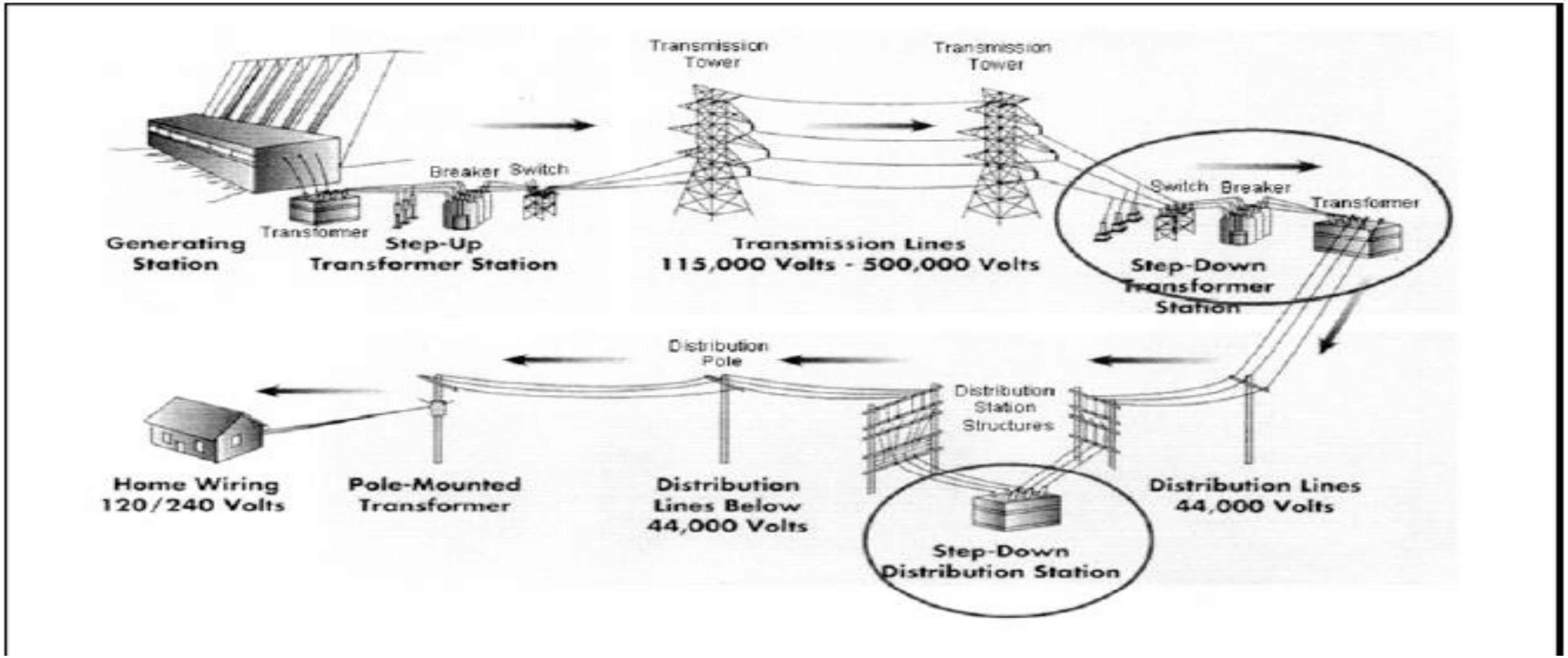
INTRODUCTION TO POWER GENERATION, TRANSMISSION AND DISTRIBUTION

Objective(s) of the Chapter:

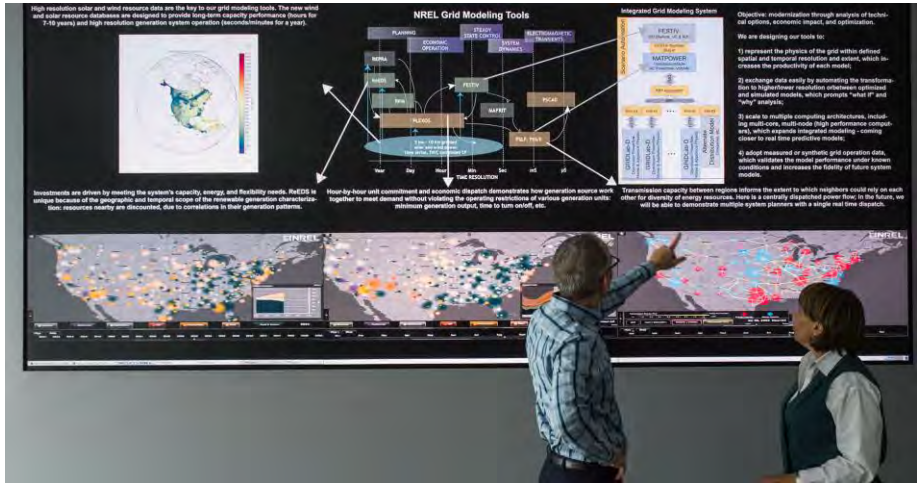
Students will be able to understand the concept of Power generation, transmission and distribution

Introduction to Power Generation, Transmission and Distribution

- The Figure below illustrates a typical sequence of electricity generation, transmission and distribution, from generation station to customers (consumer) unit.

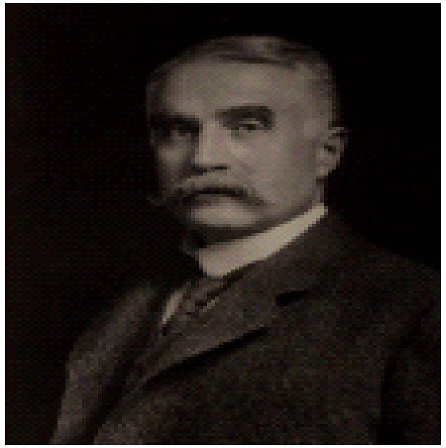


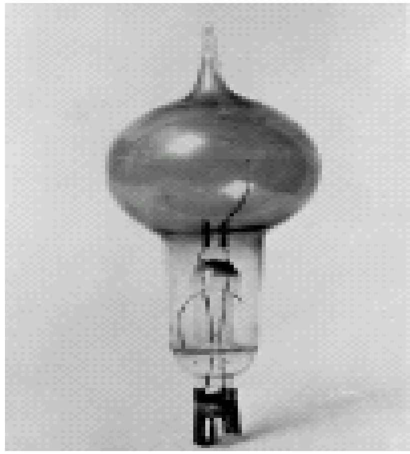
A power system is the infrastructure that enables the production of electrical energy and its transfer to the locations where it can be utilized

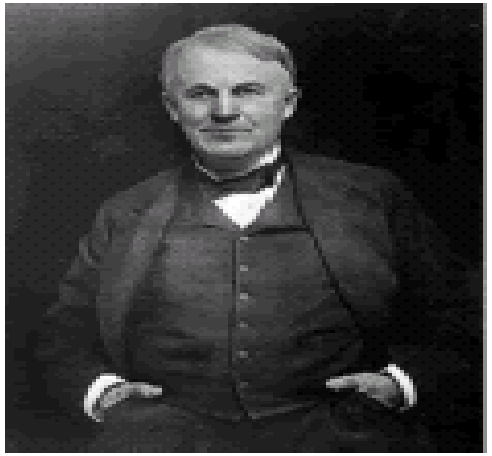


Origins & Early Developments

- Electricity was a revolutionary, new technology back in the late 1800s very much like the Internet is a new technology of modern times.
  - Charles Brush invented a dynamo and arc lamp lighting system for street lighting.
  - Thomas Alva Edison invented the incandescent light bulb for home lighting

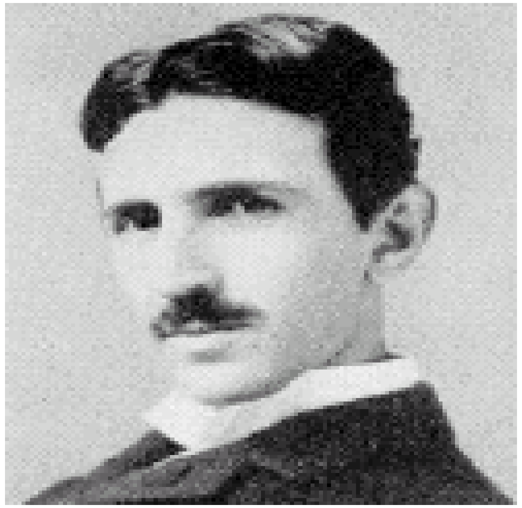


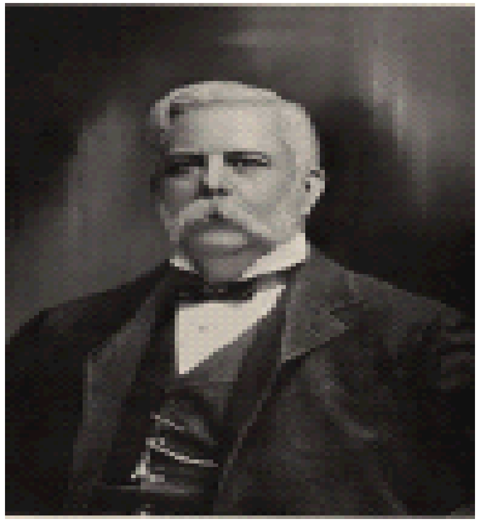




Origins & Early Developments

- During this same time period, another form of electricity - “alternating current (AC)” was being developed. The primary developers were Nikola Tesla, William Stanley, Jr., and George Westinghouse



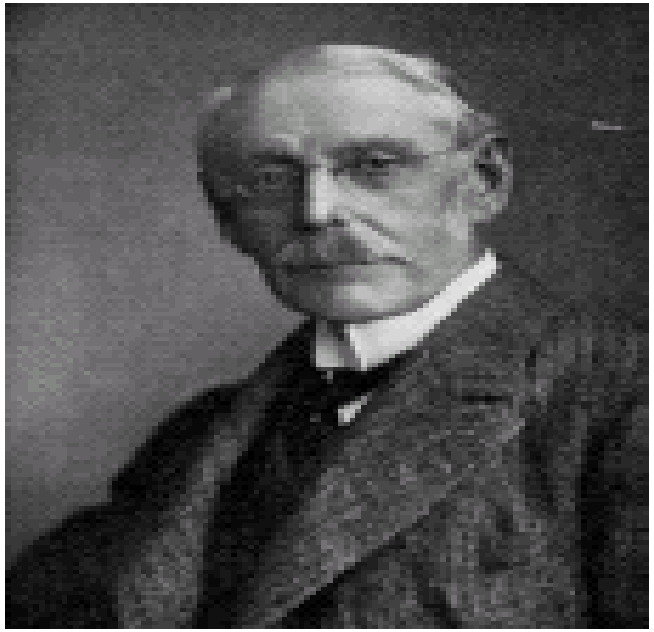


Origins & Early Developments

- In 1883, Stanley invented the first modern-day transformer used in AC electrical.
- Tesla invented the AC polyphase motor in 1885 and married it with the transformer.
- The first AC system, upon which today's is based, was built in 1891, to provide power from the Ames hydro-power station to the Gold King Mine near Telluride, CO.

Origins & Early Developments

- The next major development in the electric utility industry occurred in 1903 with the introduction of turbine generators. A turbine-generator set was revolutionary because it used a new technology known as a steam turbine as the generator's prime mover.



Main Components

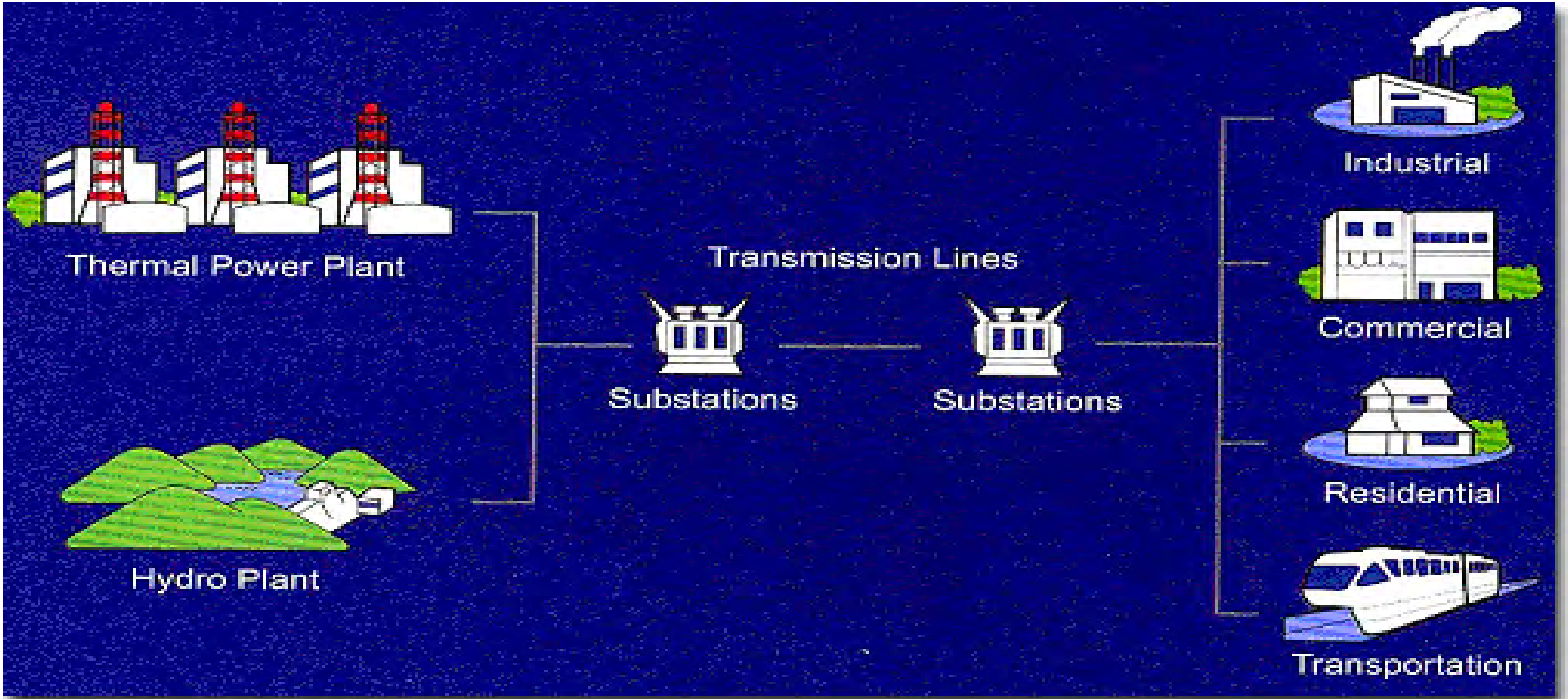
- Generation
  - Generation is the initial stage where some form of energy is converted into electricity.
- Transmission/Distribution
  - Once the electrical energy is generated it is transported and distributed to the various sources throughout the country.
- Consumption/Utilization/Load
  - Then electricity reaches the customer and is used.

Introduction

Power System

- Support Components
  - Measurement & Monitoring System
  - Protection System
- Main Components
  - Generation
  - Transmission
  - Distribution
  - Load

Supply of Electricity



Supply of Electricity

Malaysia RE Resources and Estimated Potential

TENAGA NASIONAL

Solar

Potential
- ~6,500 MW
- Yearly average irradiance 1,400 – 1,900 kWh/m^2

Status
- 148.40 MW (FiT) as of Jun 2014
- Building integrated & ground mounted (solar farm)

Biomass

Potential
- ~1,340 MW by 2030

Status
- 118.70MW (FiT) as of Jun 2014
- Biogen Project, palm oil waste (EFB), woodchips, paddy husks etc.

Biogas

Potential
- ~410 MW by 2028

Status
- 30.83 MW (FiT) as of Jun 2014
- Palm Oil Mill Effluent (POME), livestock, agro, industrial waste

Mini-Hydro

Potential
- ~490 MW by 2020

Status
- 122.35 MW (FiT) as of Jun 2014
- Run-of-river scheme with minimum impounding

Solid Waste

Potential
- ~360 MW by 2022
- ~21,000 tonnes of waste collected every day in M'sia

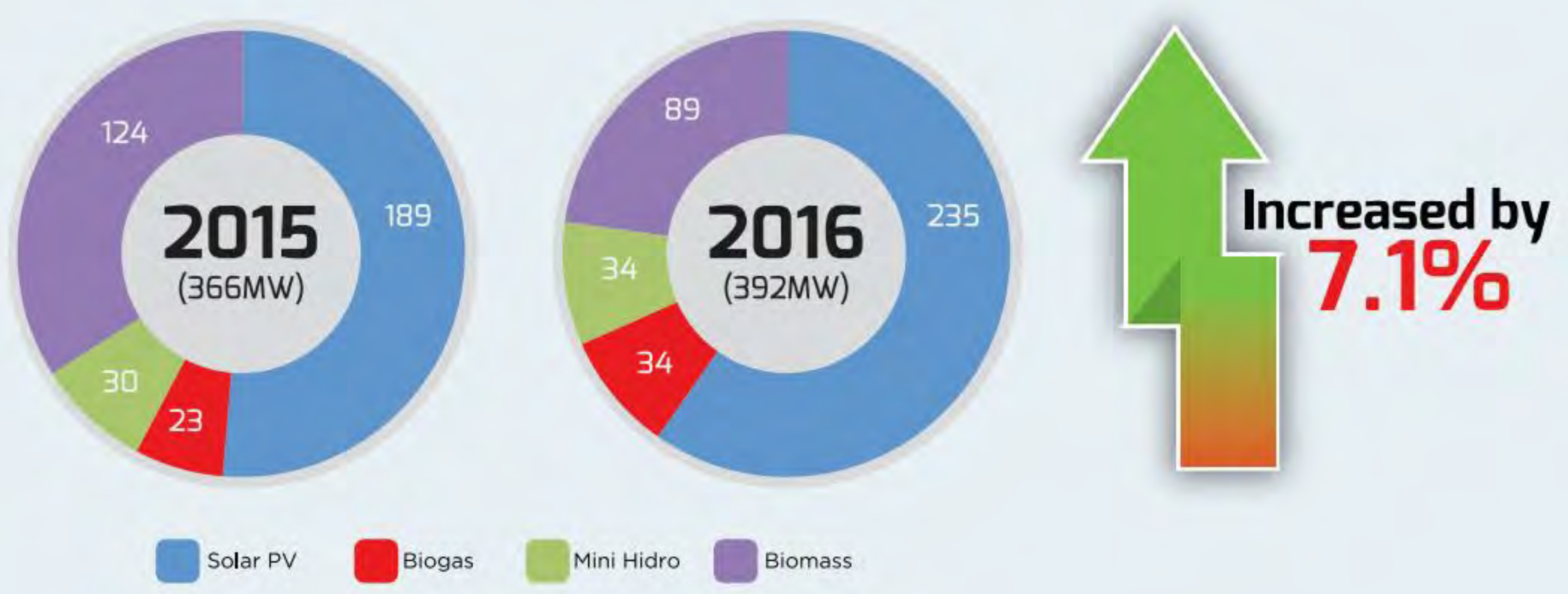
Status
- Total capacity (FiT) accounted in Biomass category

Others: Wind, geothermal, ocean-thermal, tidal wave etc.

Source: Ministry of Energy, Green Technology and Water, Energy Commission, (2010); SEDA website 2013

Supply of Electricity

Figure 12: RE capacity mix (MW) in Peninsular Malaysia (2015 vs 2016) y-o-y



Important terms and factors

NO.	ITEMS	DEFINITIONS
1.	**TOTAL CONNECTED LOAD (TCL)**	The sum of the continuous power ratings of all load-consuming apparatus connected to an electric power distribution system or any part thereof, i.e. the sum of all the individual loads.
2.	**COINCIDENT FACTOR (CF)**	• The ratio of coincident maximum demand of 2 or more loads to the sum of their non-coincident maximum demand for a given period (the reciprocal of diversity factor). • It is always less than or equal to 1.
3.	**MAXIMUM DEMAND (MD)**	The maximum load delivered to an electric system for a given period, i.e. the product of total connected load and coincident factor.

Important terms and factors

- (i) Connected load-The sum of continuous ratings of all the equipment connected to supply system

- (ii)Max. demand-The greatest demand of load on the power station during a given period. It helps in determining the installed capacity of the station

- (iii) Demand factor-The ratio of max. demand on the power station to its connected load. Its value usually <1 because max. demand is generally < the connected load. It helps in determining the capacity of plant equipment.

- (iv) Average load-The average of loads occurring on the ps in a given period
- i.e. daily average load = no. of units(kWh) generated in a day/ 24 hours

Important terms and factors

- (v) Load factor- the ratio of average load to the max. demand during a given period. Its value always < 1because average load is smaller than max. demand. Its help in determining the overall cost per unit generated. Higher the load factor lesser will be the cost per unit generated

- (vi) Diversity factor-the ratio of the sum of individual max. demands to the max. demand on ps. Its value always greater than 1. The greater the diversity factor, the lesser is the cost of generation power

(viii) Plant capacity factor- the ratio of actual energy produced to the maximum possible energy that could have been produced during a given period. It is an indication of the reserve capacity of the plant. A power station is so designed that it has some reserve capacity for meeting the increased load demand in future.

Therefore the installed capacity is always > the max. demand

Reserve capacity=plant capacity- max. demand or difference between load factor and plant capacity factor

Important terms and factors

- Multiple loads fed from distribution network experience diversity between times of their peak demand

  $\Rightarrow$ total demand fed < the sum of the individual loads
- important in estimating total maximum demand in a development.
- Depends on no. of customers of a group & different customer groups involved
- Always ≤ 1

Coincident Factor (CF)

$$\equiv \frac{\text{coincident MD of 2 (or more) loads}}{\sum \text{Non - coincident MD for given period}}$$

$$= \frac{1}{\text{Diversity Factor (DF)}}$$

Electrical Systems Demand

- Electricity energy cannot be stored.
- Generate electricity based on demand.
- Total power drawn by consumer fluctuates depends on the time of day and seasons.
- A number of generating units of different sizes are installed (efficiency of machine is max. at nearly 75% of its rated capacity)
- Demand Curve
  - Plot each demand of electricity by consumer daily/annually

Electrical Systems Demand

- The selection of the number and sizes of the units is decided from the annual load curve of the station
- The number and size of the units are selected in such a way that they correctly fit the station load curve(to operate at the point of max. efficiency).

Electrical Systems Demand

- Important points in the selection of units:

-the number and sizes of the units should be so selected that they approximately fit the annual load curve of the station

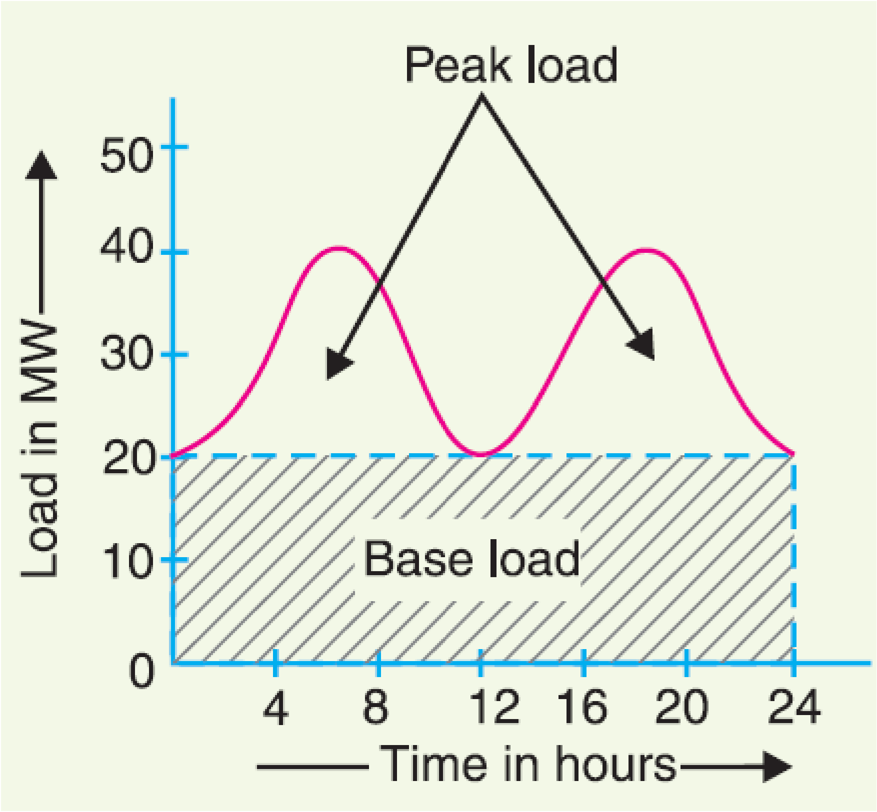
-the units should be preferably of different capacities to meet the load requirements. Although use of identical units (i.e. having same capacity) ensures saving in cost, they often do not meet the load requirement

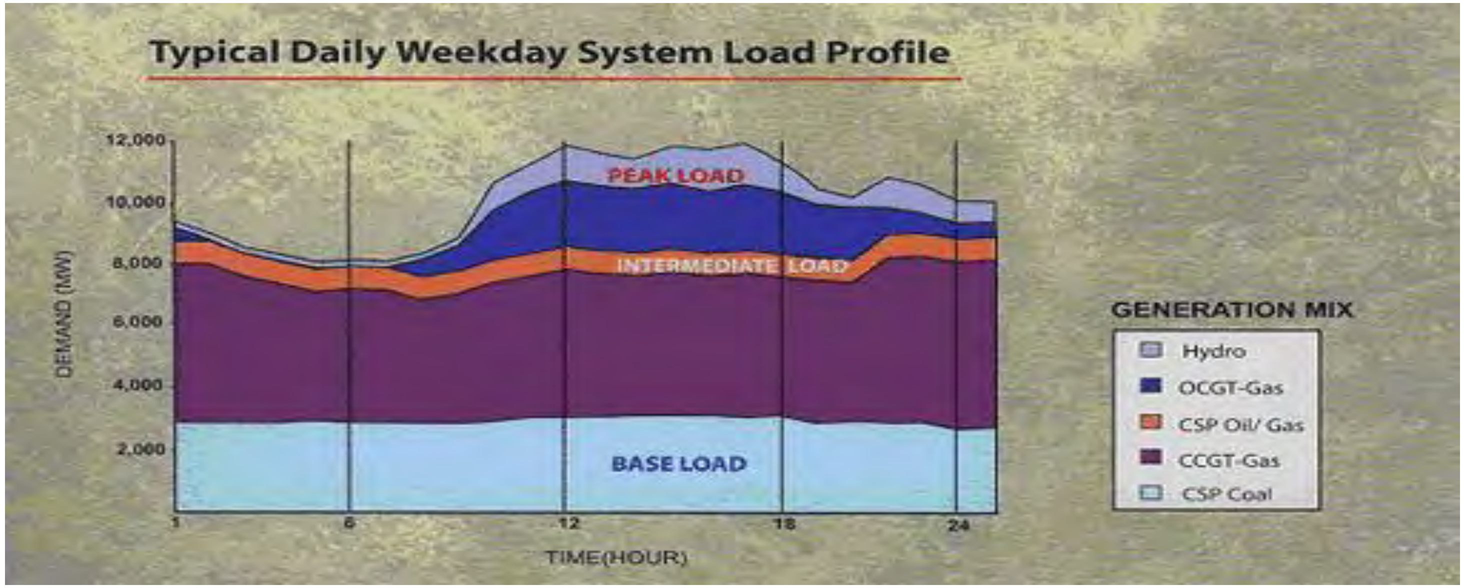
-the capacity of the plant should be made 15-20% > max demand to meet the future load

-there should be a spare generating units so that repairs of working units can be carried out

-the tendency to select a large number of unit of smaller capacity in order to fit the load curve very accurately should be avoided

Demand Curve





Load Duration Curve

- The changing load on the power station makes its load curve of variable nature
- The load on the power station can be considered in two parts:

(i) Base load: the unvarying load which occurs almost the whole day on the station

(ii) Peak load: the various peak demands of load over and above the base load of the station

Load Duration Curve

- To achieve overall economy, the best method to meet load is to interconnect two different power stations.
- The more efficient plant is used to supply the base load (base load power station)
- The less efficient plant is used to supply the peak loads (peak load power station)
- The selection of base/peak load stations depend upon the particular situation i.e. both hydro and steam power station can be used as base load as well as peak load

Load Duration Curve

- Advantages of interconnected system:

(i) Peak load of the station can be exchanged. If the load curve shows a peak demand > rated capacity then the excess load can be shared by other stations interconnected with it

(ii) Use of older plants to carry peak loads

(iii) Makes the operation of concerned station quite economical. Sharing of load is arranged in such a way that more efficient stations work continuously throughout the year at high load factor and less efficient plants work for peak load hours only

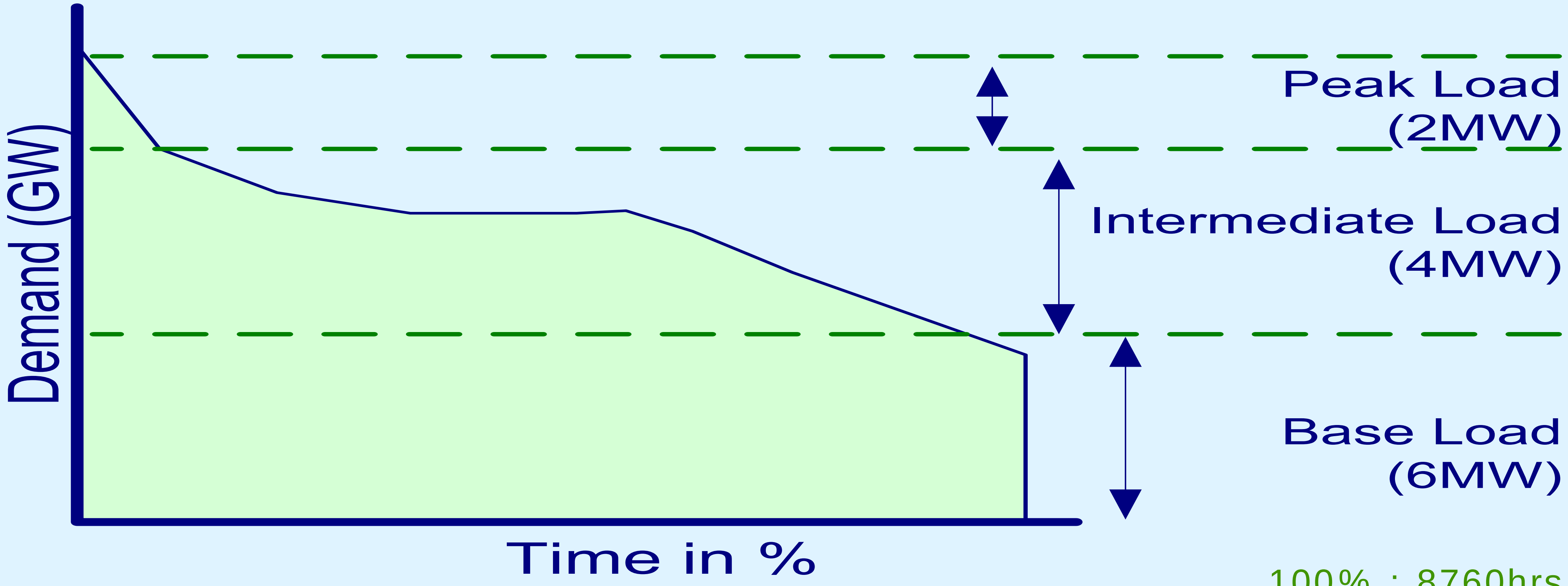
(iv) The diversity factor is improved, thereby increasing the effective capacity of the system

(v) The reserve capacity of the system is much reduced when several plants are connected in parallel. This increase the efficiency of the system

(iv) Increase reliability of supply

Load Duration Curve

- Plot the duration of each demand on annual based.

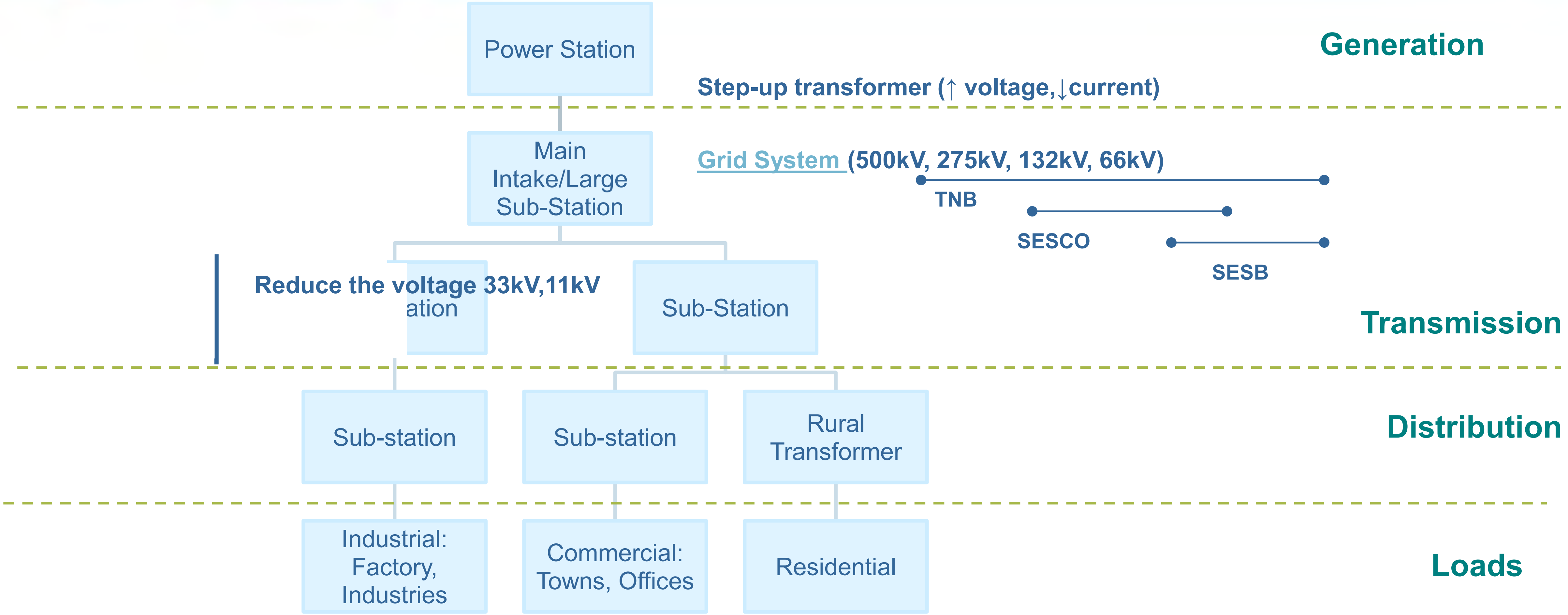


100% : 8760hrs

Load Duration Curve

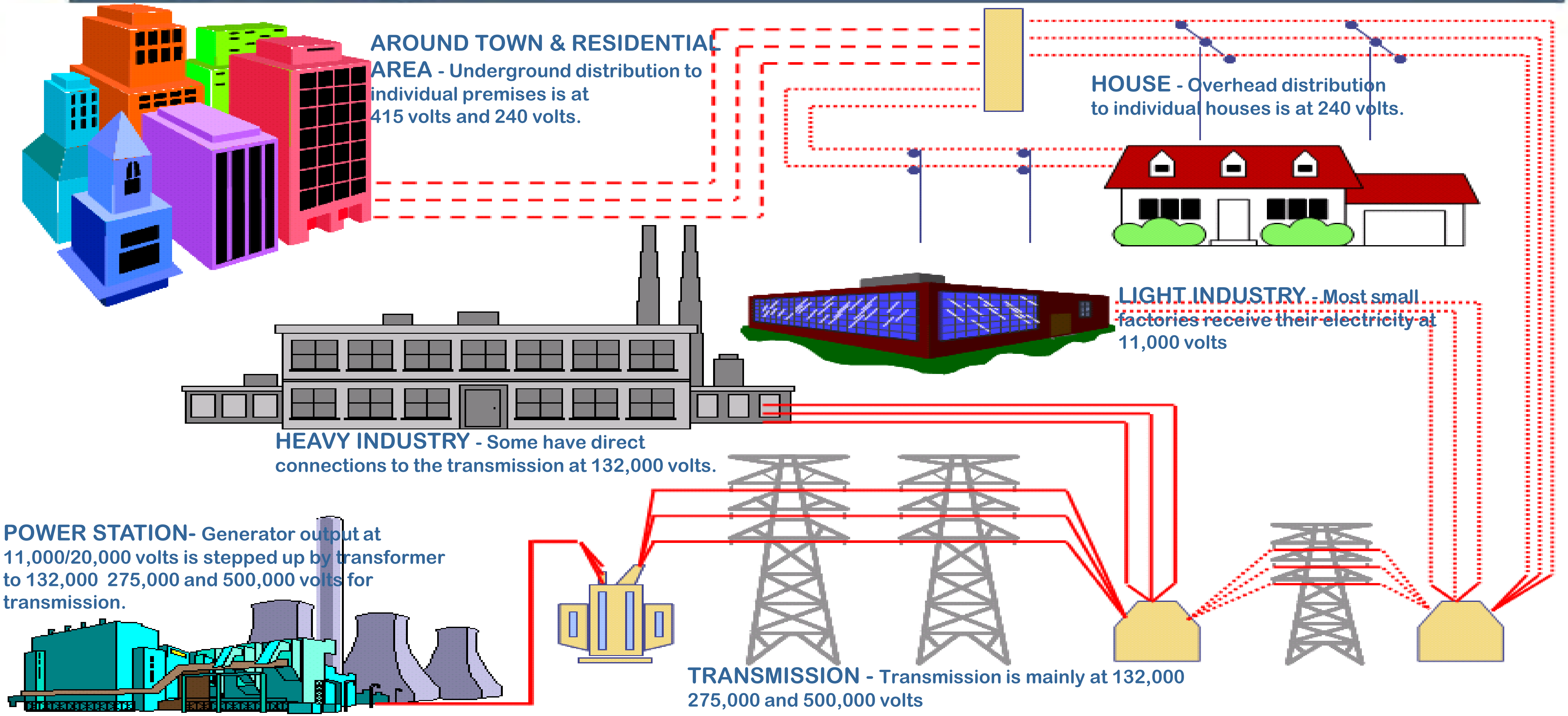
- Base-power stations
  - Deliver full power at all times
  - Nuclear, coal-fired stations
- Intermediate-power stations
  - Respond relatively quickly to changes in demand
  - Usually by adding/removing generating unit
  - Hydropower stations
- Peak-power stations
  - Deliver power for brief intervals during the day
  - Put into service very quickly
  - Equipped with prime movers that can be started up in a few minutes
  - Diesel, pumped-storage turbines, gas turbines etc.

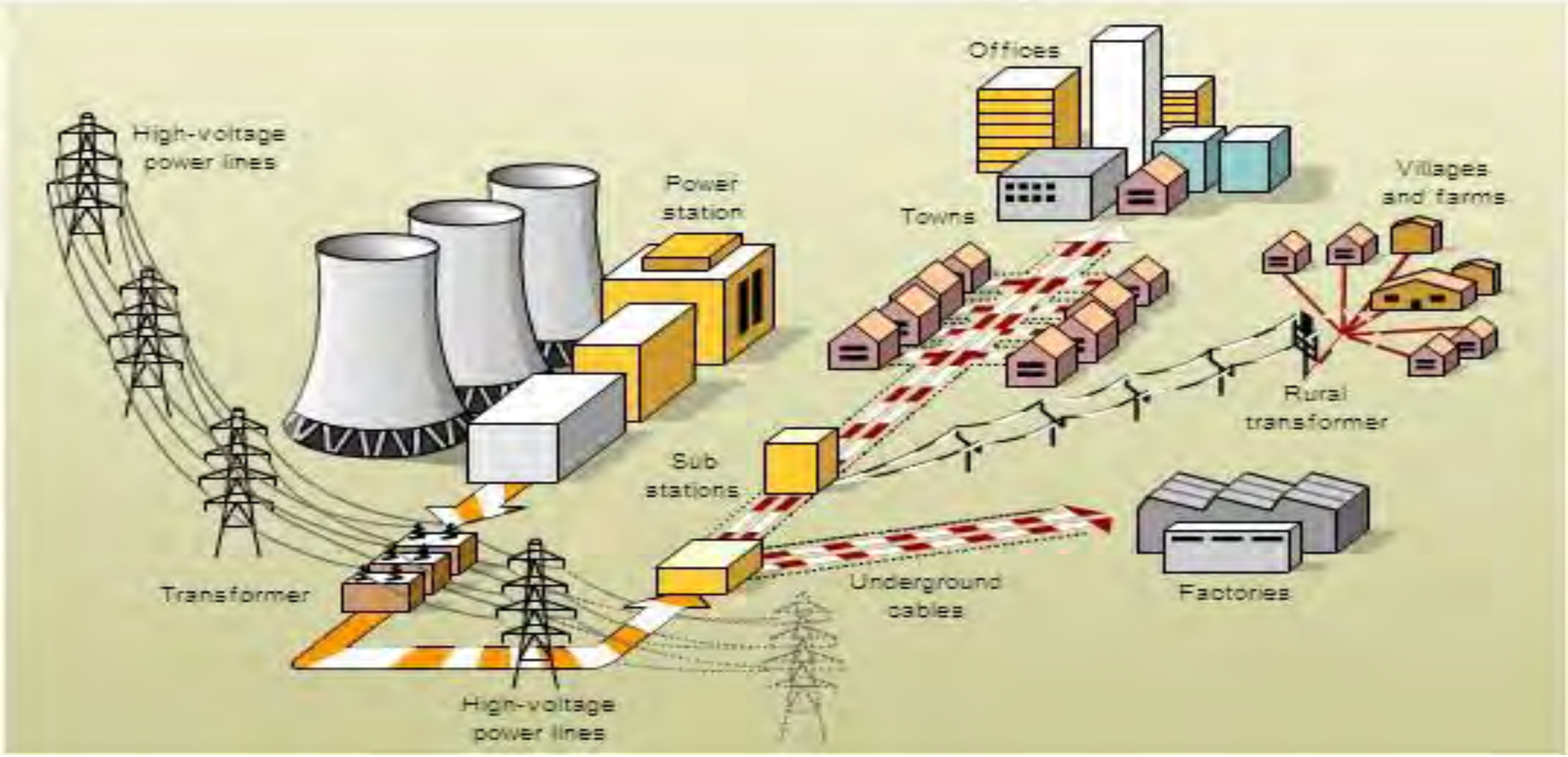
Power System Diagram

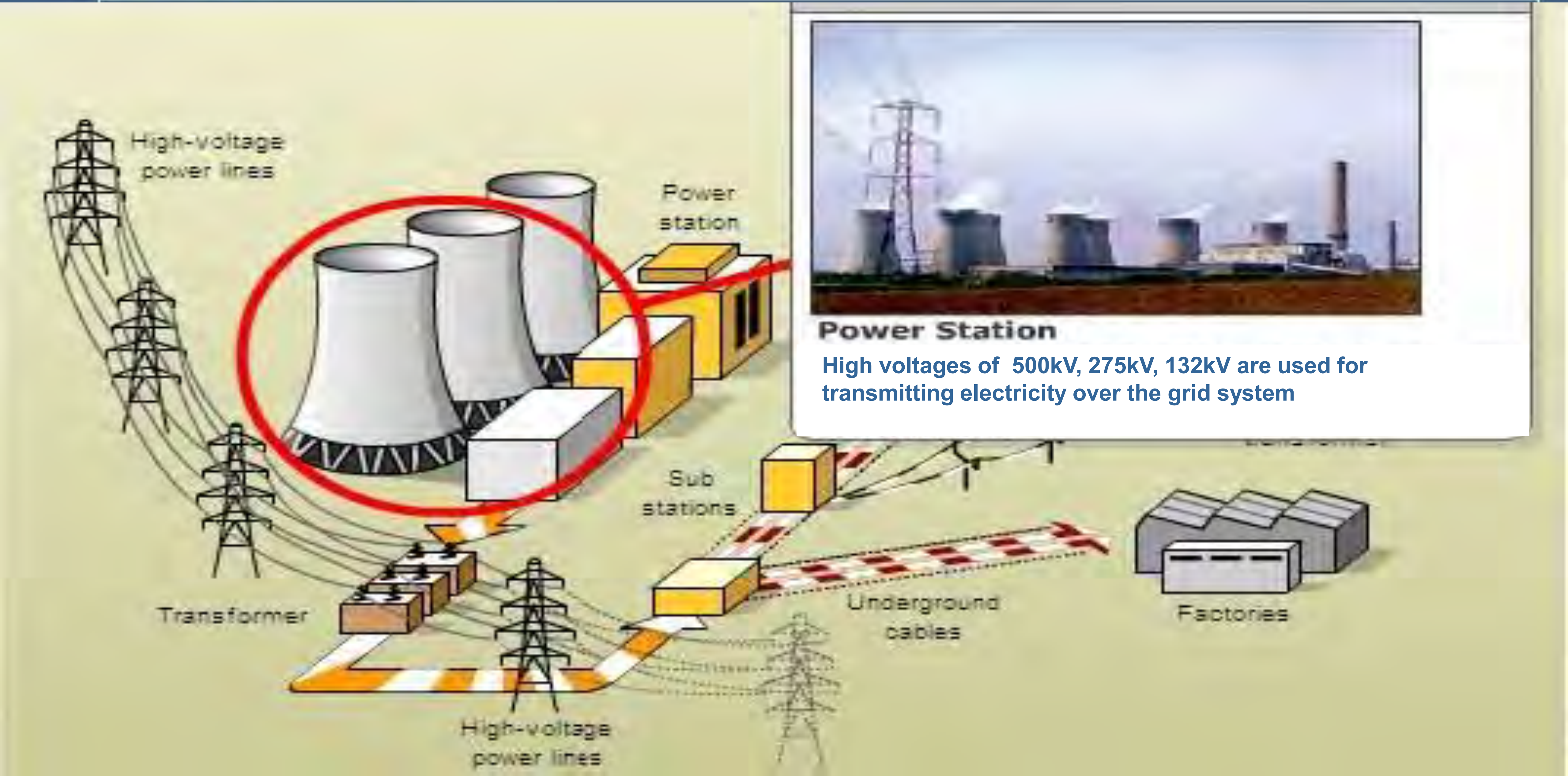


3 phase - 400 V, single phase - 230 V

Power System

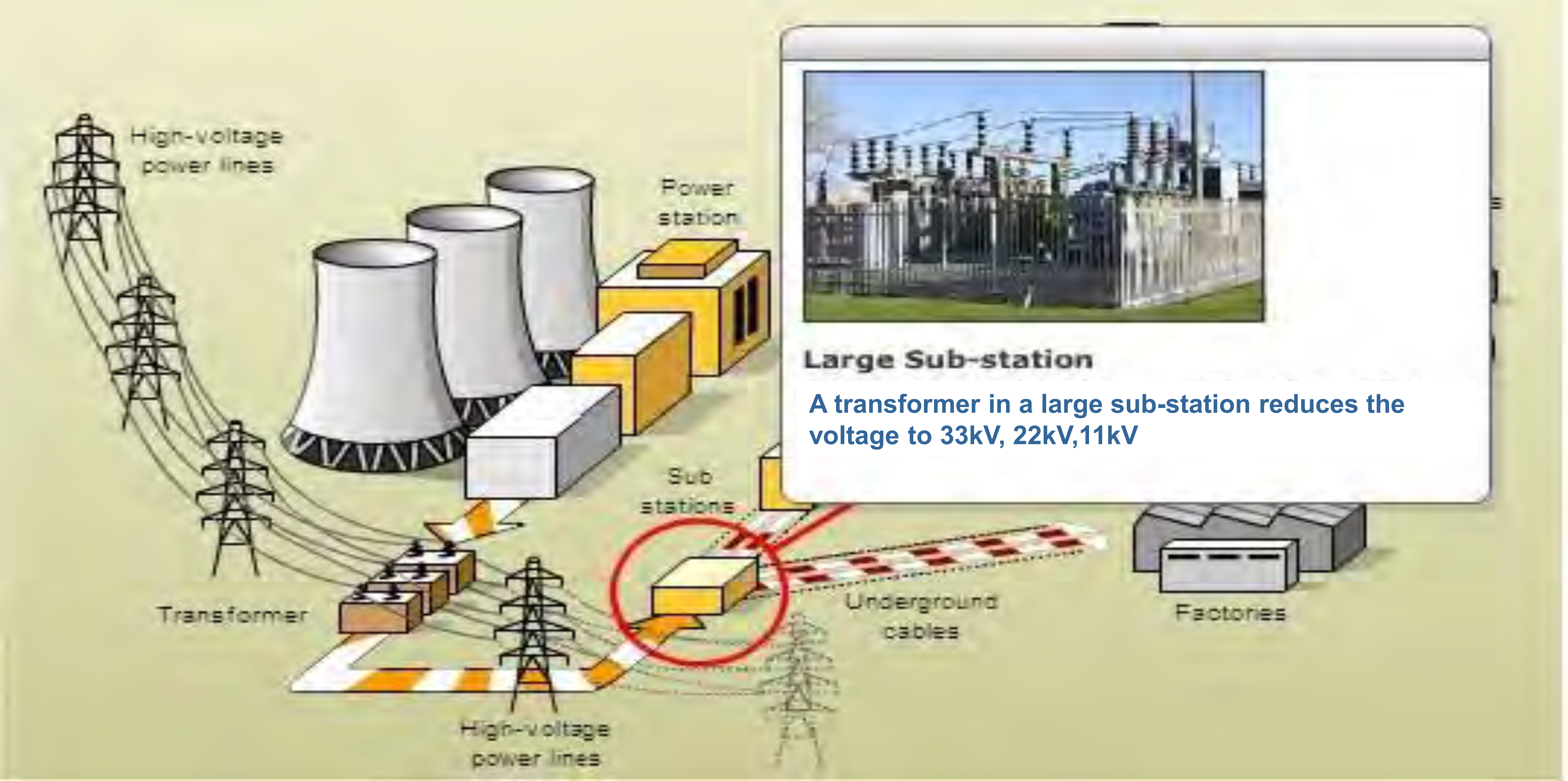



Offices
High-voltage
power lines
Power
station
Towns
Villages
and farms
Rural
transformer
Sub
stations
Transformer
Underground
cables
Factories
High-voltage
power lines



Power Station

High voltages of 500kV, 275kV, 132kV are used for transmitting electricity over the grid system

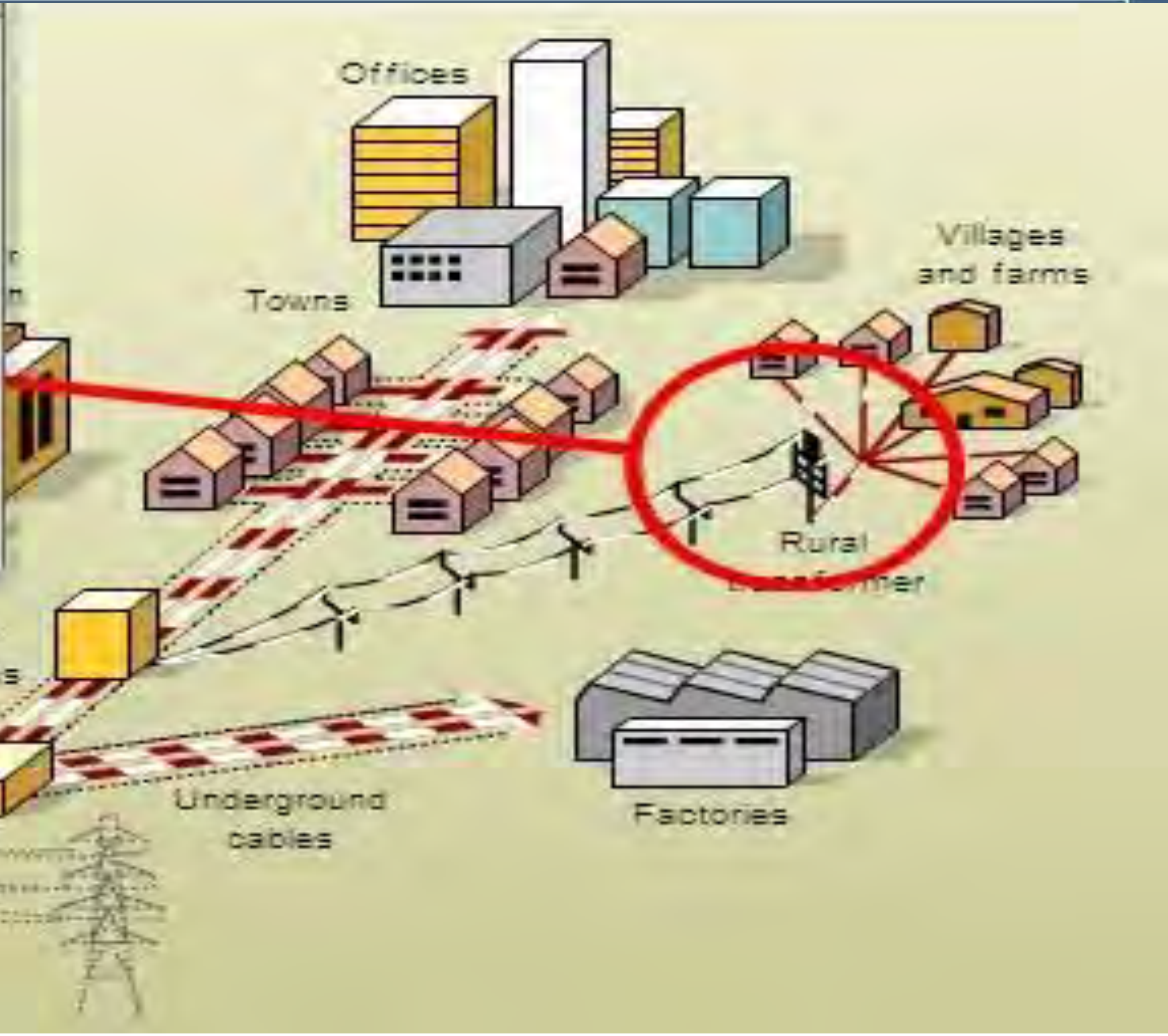


Large Sub-station

A transformer in a large sub-station reduces the voltage to 33kV, 22kV,11kV

Rural Transformer

Supplies to rural communities are often reduced from 11kV to domestic voltages (415/240V) by pole mounted transformers.



Generation

- At power generating station (generating voltage) → 11 – 20kV and frequency of 50 Hz
- Transform to higher voltage (transmission voltage) → 132kV, 275kV and 500kV
- Transform to lower voltage (distribution voltage) → 33kV or 11kV

Independent Power Producer (IPP)

Co-Generator

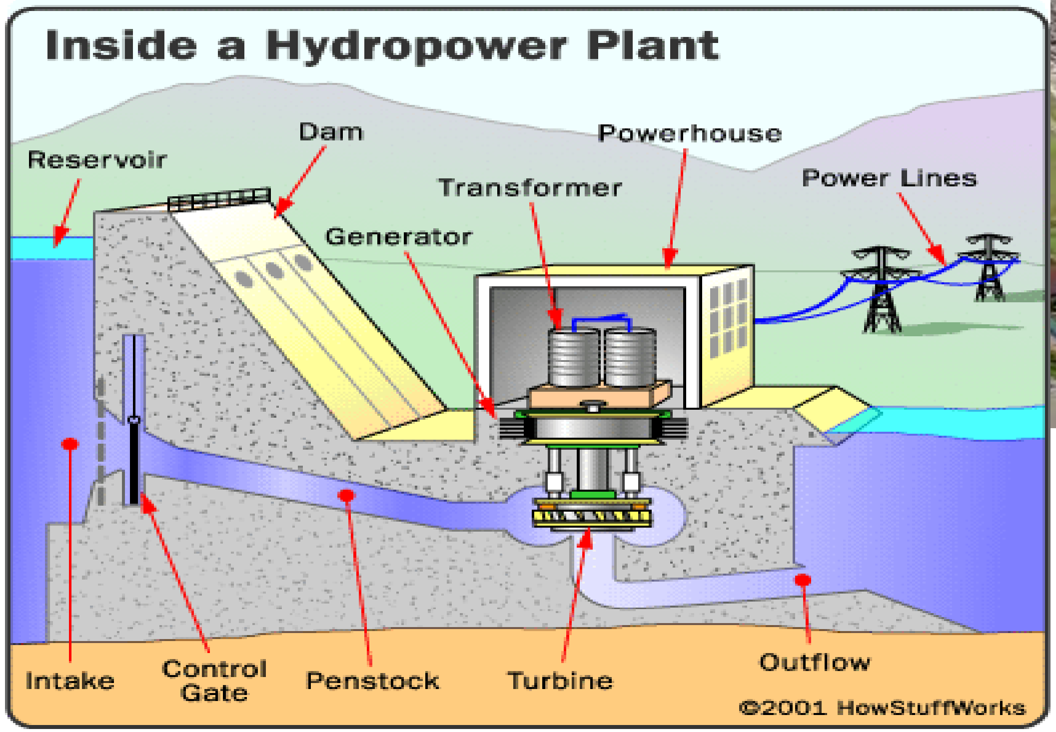
- Minor electricity supply
  - There are several small distributors buy electricity from the utilities or generate their own power, mostly by co-generation.
  - Then, distribute to customers within specific areas such as industrial complexes.

Co-Generator

- Example – Petronas
- Generate electricity – Co-generator
  - Distribute power within two Integrated Petrochemical Complexes (IPC)
  - Central Utilities Facilities (CUF)

TNB Power Stations

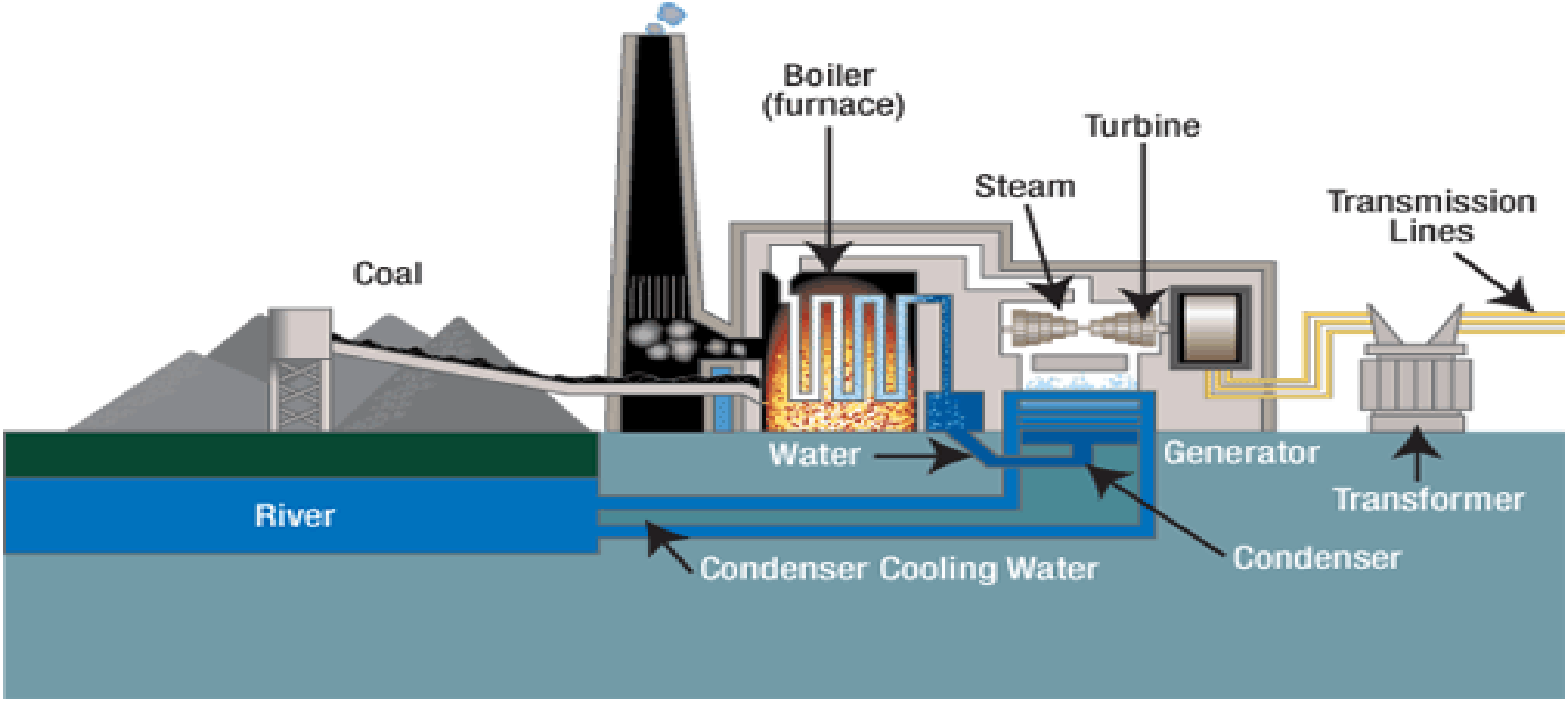
Hydroelectric Power Plant



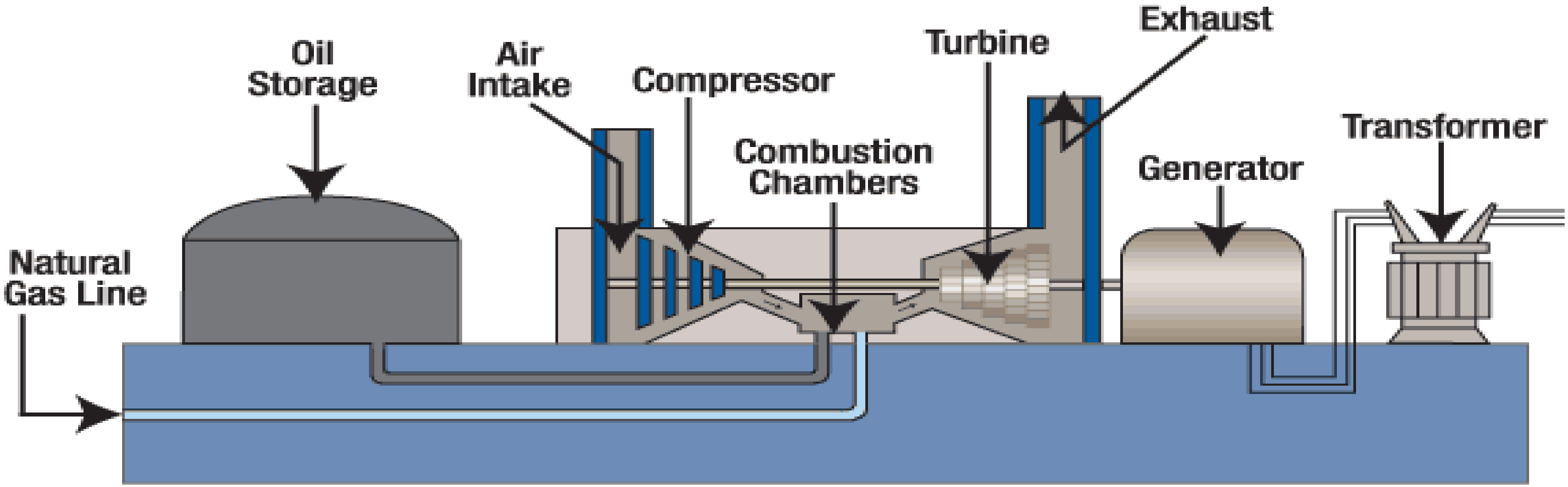
Sultan Mahmud Power Station, Kenyir

Bakun Dam:
Under construction

Coal-fired Power Plant



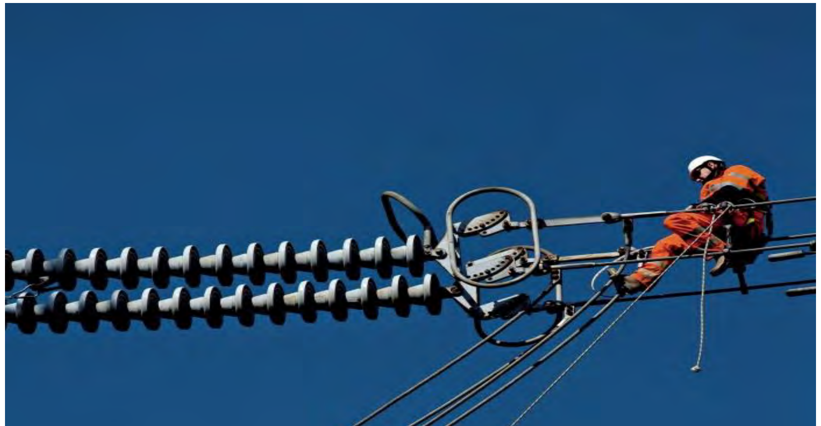
Combustion Turbine Power Plant



Transmission

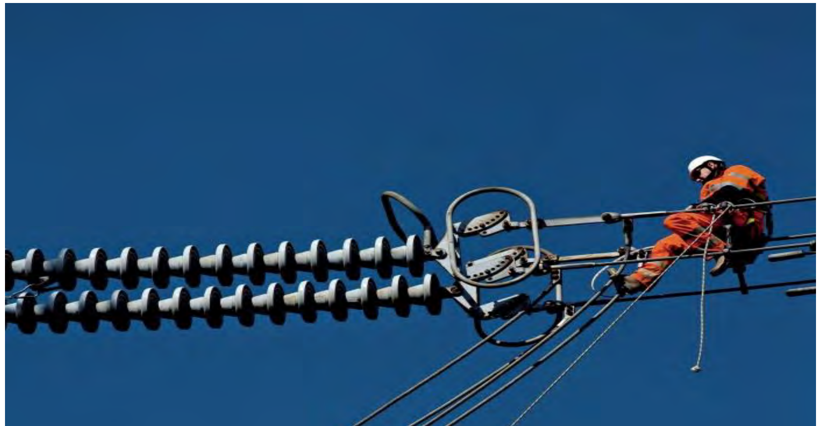
- To ensure the adequacy and reliability of supply that are fundamental needs of modern society.
- Provides the link between electricity suppliers (Utility Generators and IPPs) and electricity consumers.

- In order to study a power system, the physical system should be converted into a single line diagram.
- Every element should be presented by its electric model.
- An electric transmission line is modeled using series resistance, series inductance, shunt capacitance, and shunt conductance.
- Resistance, series inductance, shunt capacitance, and shunt conductance are called transmission line parameters.



System frequency

- Nominal system frequency: 50Hz
- Normal Condition: ±1% of nominal frequency
- Exceptional Circumstances: 47Hz - 52 Hz



Power system voltage levels

- The selection of an economical voltage level for the transmission line is based on the amount of power and the distance of transmission.

- The choice of voltage depends
  - I^2R losses,
  - Audible noise
  - Radio interference

- Standard voltage levels
  - Distribution: 6.3, 11, 13.8, 22, 33, 69 kV
  - Subtransmission: 69, 110, 132 kV
  - Transmission: 132, 220, 400 kV
  - EHV transmission: 500, 735, 765 kV
  - UHV (experimental): 1200, 1500 kV

Power system voltage levels

- Voltage variation in Normal Condition:
  - HV (500kV) : ±5% of nominal voltage
  - HV (275/132kV) : - 5%, +10% of nominal voltage
  - MV (6.6/11/22/33kV) : ±5% of nominal voltage
  - *LV (230V & 400V) : +10%, -6% of nominal voltage

- Voltage variation in Contingency Condition:
  - HV (500kV) : -10%, +5% of nominal voltage
  - HV (275/132kV) : ±10% of nominal voltage
  - MV : ±10% of nominal voltage
  - LV : ±10% of nominal voltage

Power system voltage levels

- Volt-drop should be limited ≤ 5% during planning stage – to optimize capital cost, PQ, distribution losses.
- Urban areas, LV cable ≤ 240m (to avoid LV joints which are weak points, volt-drop & losses).
- Operational Voltage:

	*LOW VOLTAGE		MEDIUM VOLTAGE
	1 ∅	3 ∅	
MAX LIMIT	253V (+10%)	440V (+10%)	11.55kV (+5%)
NOMINAL VOLTAGE	230V	400V	11.00kV
MIN LIMIT	216.2V (-6%)	376V (-6%)	10.45kV (-5%)

CAUSE:

- Impedance of cable/conductor
- $\%V_{d_{11kV}} < \%V_{d_{0.4kV}}$
- Voltage drop increases with:
  - ❑ Load supplied by lower voltage source
  - ❑ High load
  - ❑ Long conductor
  - ❑ Unbalance load
  - ❑ Small conductor size
  - ❑ Conductor type ($VD_{copper} < VD_{Al}$)

EFFECT:

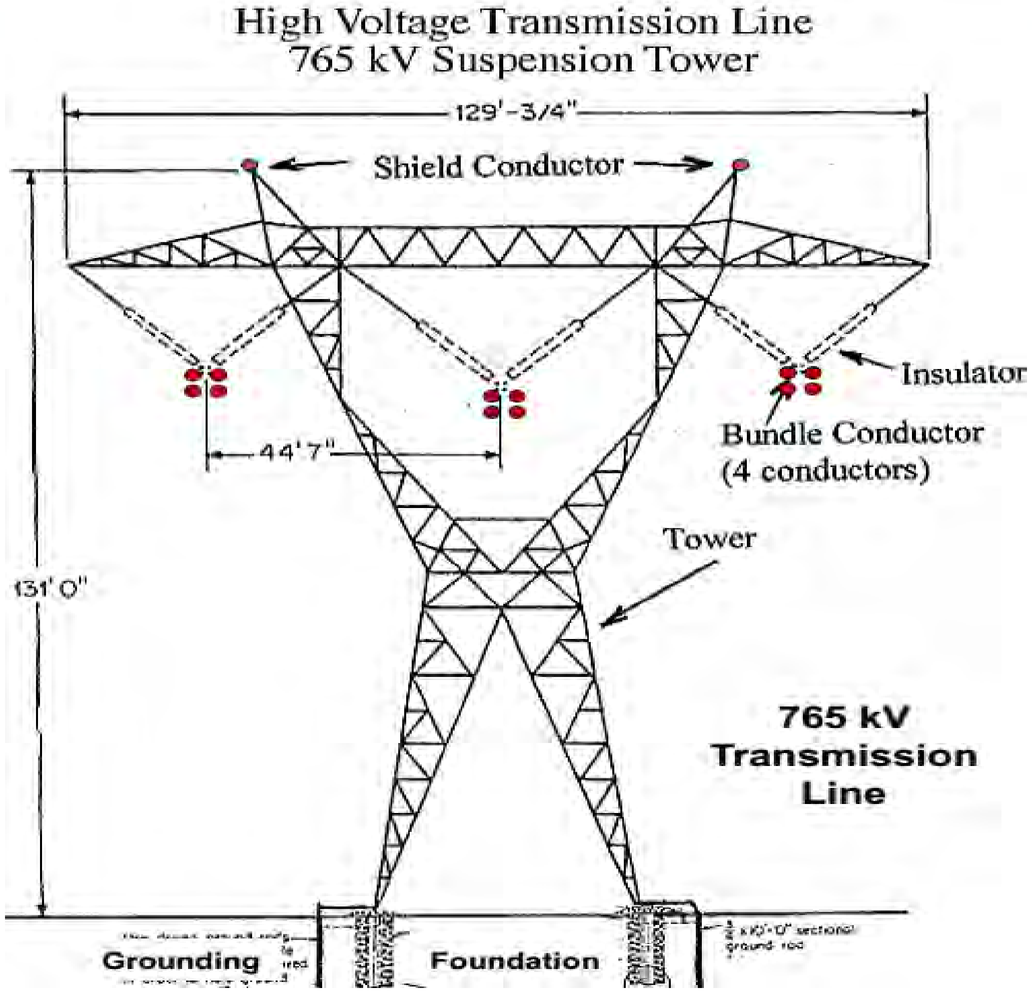
- Technical losses
- Economics

Power system voltage levels

OPTIONS OF MITIGATION	PLANNING	O&M
Load balancing (customer & feeder)		✓
↑ conductor size (to reduce % feeder loading)	✓	✓
Inject new feeder (LV system improvement only)	✓	✓
Inject new substation source	✓	
NOP relocation		✓
Ring with other sources		✓
↑ transformer tap		✓
Install LV capacitor bank		✓

Overhead Transmission Line Components

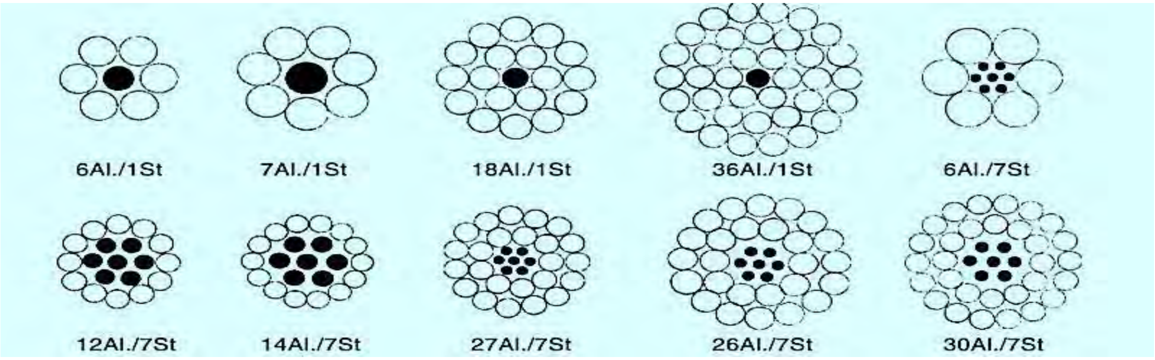
- Components consists of:
  - Conductors
  - Insulators
  - Support structures
  - Shield wires



Overhead Transmission Line Components

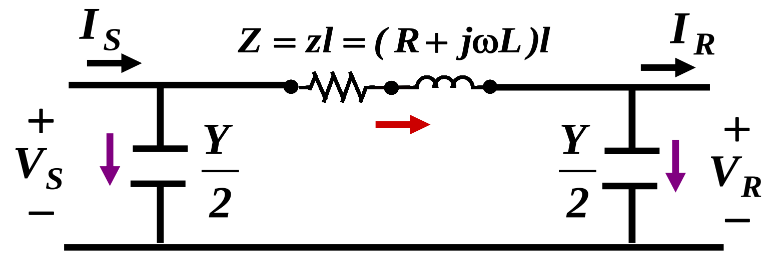
- **Conductors**
  - **AAC (all aluminium conductors)**
  - **AAAC (all aluminium aloy conductors)**
  - **ACSR (aluminium conductor, steel reinforced)**
  - **ACAR (aluminium conductor, alloy reinforced)**

Alternate layers of wire of a stranded conductor are spiraled in opposite directions to prevent unwinding and make the outer radius of one layer coincide with the inner radius of the next.



Parameters

- Resistance – Line losses
- Inductance and capacitance are due to the effects of magnetic and electric fields around the conductor.
- Inductance and capacitance gives rise to series-voltage drops along the line
- The shunt conductance accounts for leakage currents flowing across insulators and ionized pathways in the air.
- The leakage currents are negligible compared to the current flowing in the transmission lines and may be neglected.



Nominal pi-circuit

Transmission System

- Lines/transformers operating at voltages above 100 kV are usually called the transmission system.
- Consists of Transmission Line and Sub-stations
- Transmission network of 500kV, 275kV and 132kV known as National Grid.

Transmission Line Components

- Transmission Line
  - Overhead Lines
  - Cable
    - Underground Cables
    - Submarine Cables
- Sub-stations

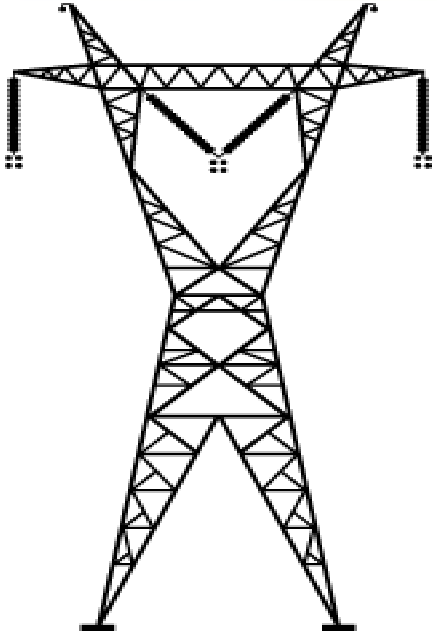
Transmission Parameters

OVERHEAD LINE		(17,258)
Length (circuit-km)	500kV	890
	275kV	6,199
	132kV	9,998
	66kV	171
CABLE		(723)
Length (circuit-km)	275kV	49
	132kV	674
	66kV	-
TRANSFORMERS		(69,381)
Transformation Capacity (MVA)	500kV	4,500
	275kV	26,213
	132kV	38,258
	66kV	410
SUBSTATIONS		(375)
Number of Substations (TNB)	500kV	4
	275kV	67
	132kV	299
	66kV	5

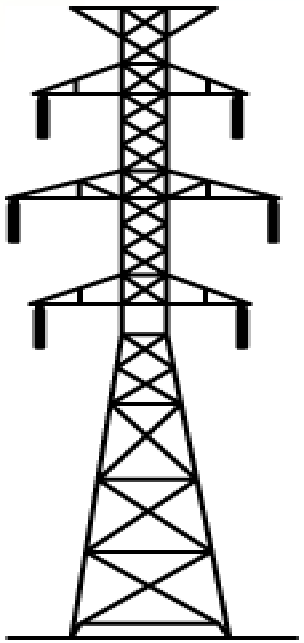
Transmission Line

- Components
  - Tower support structure
  - Cross-arms
  - Conductors
  - Insulators
  - Earth-wires

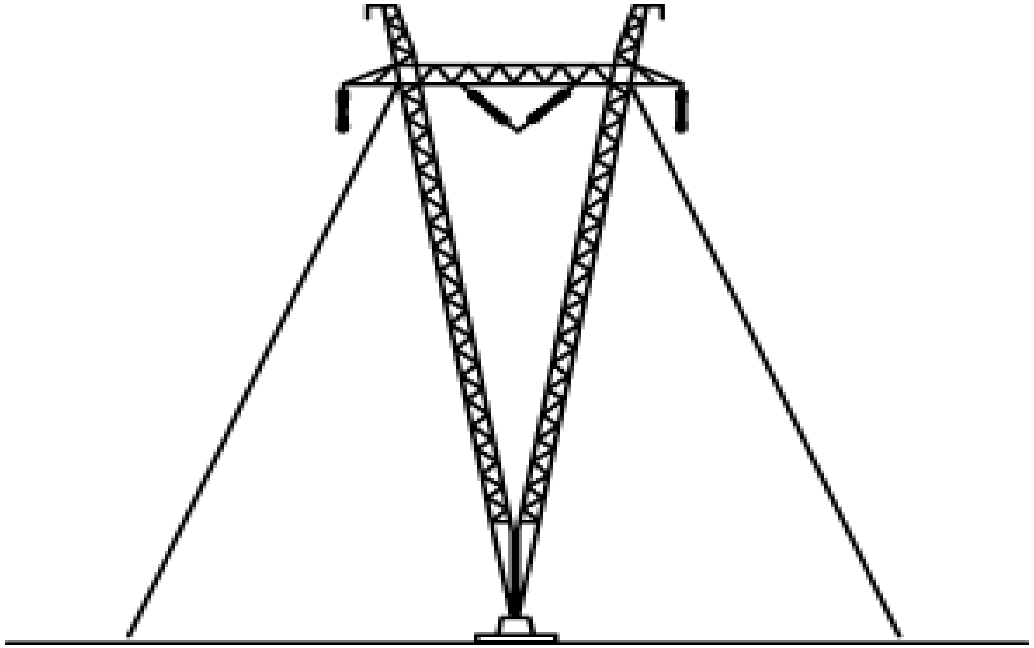
Transmission tower



Waist-Type Tower

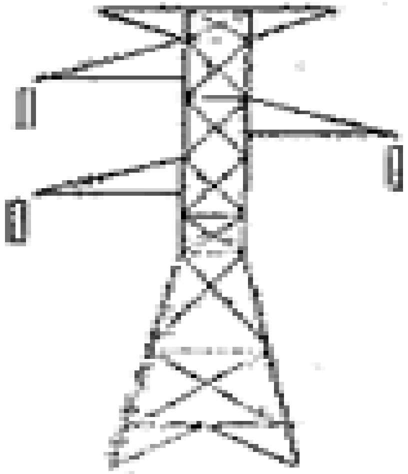


Double Circuit Tower

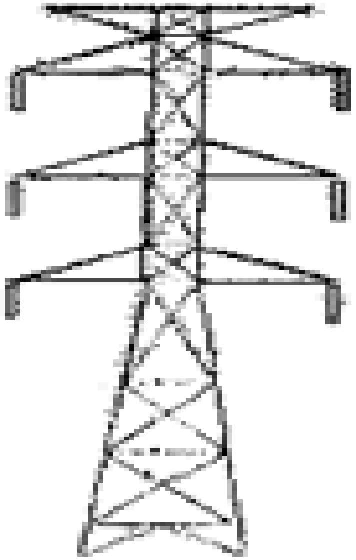


Guyed-V-Tower

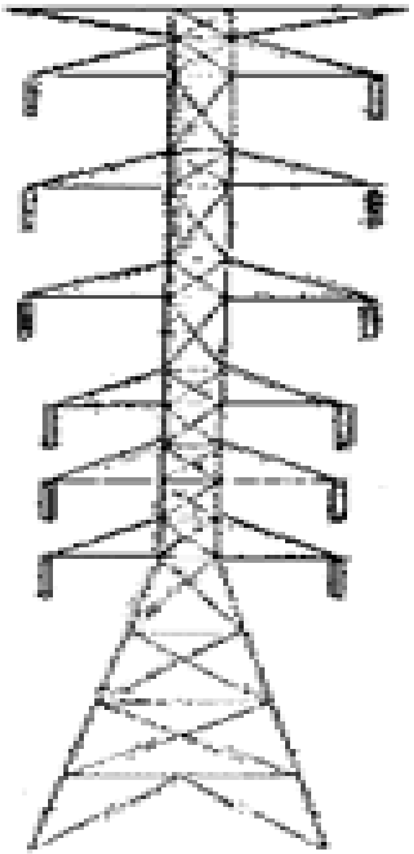
Transmission Tower



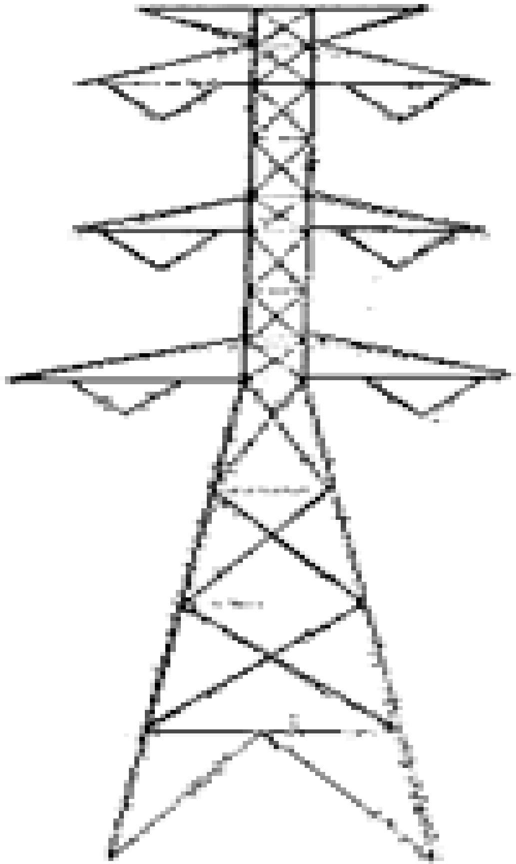
Single Circuit



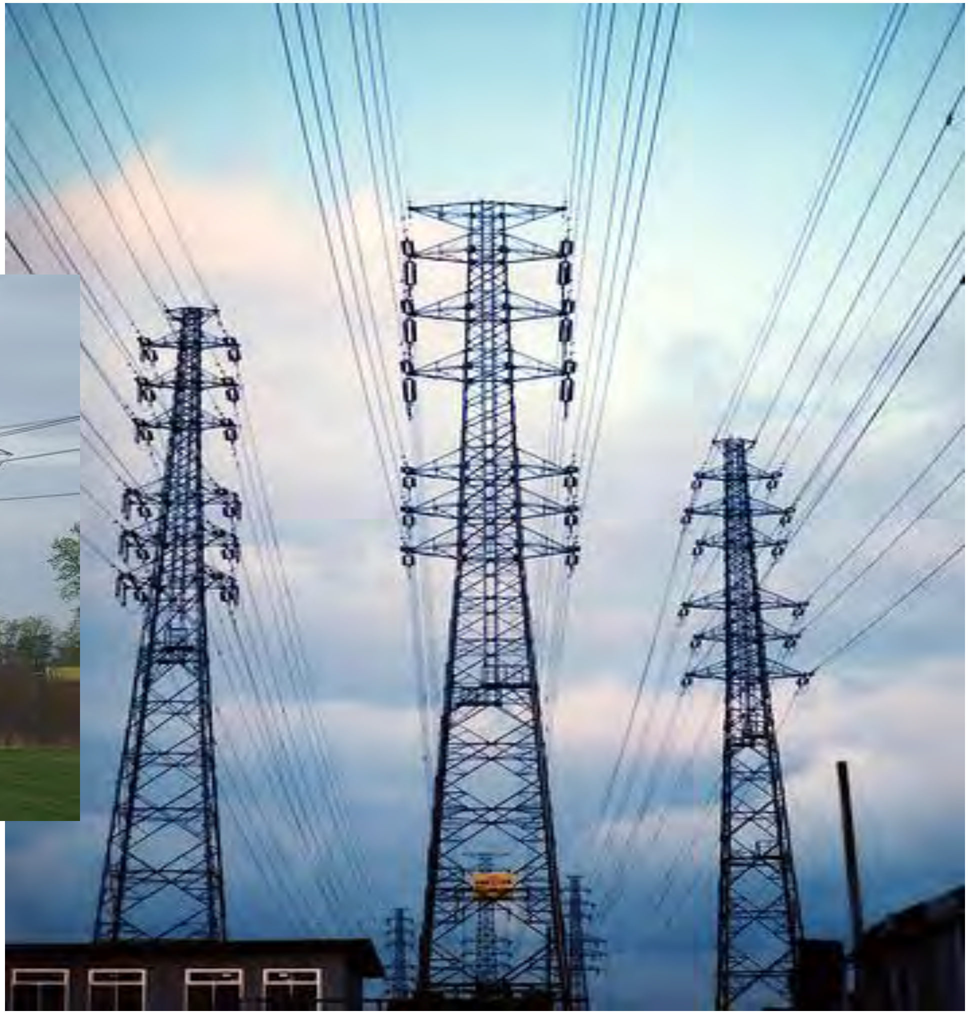
Double Circuit



Quadraple Circuit

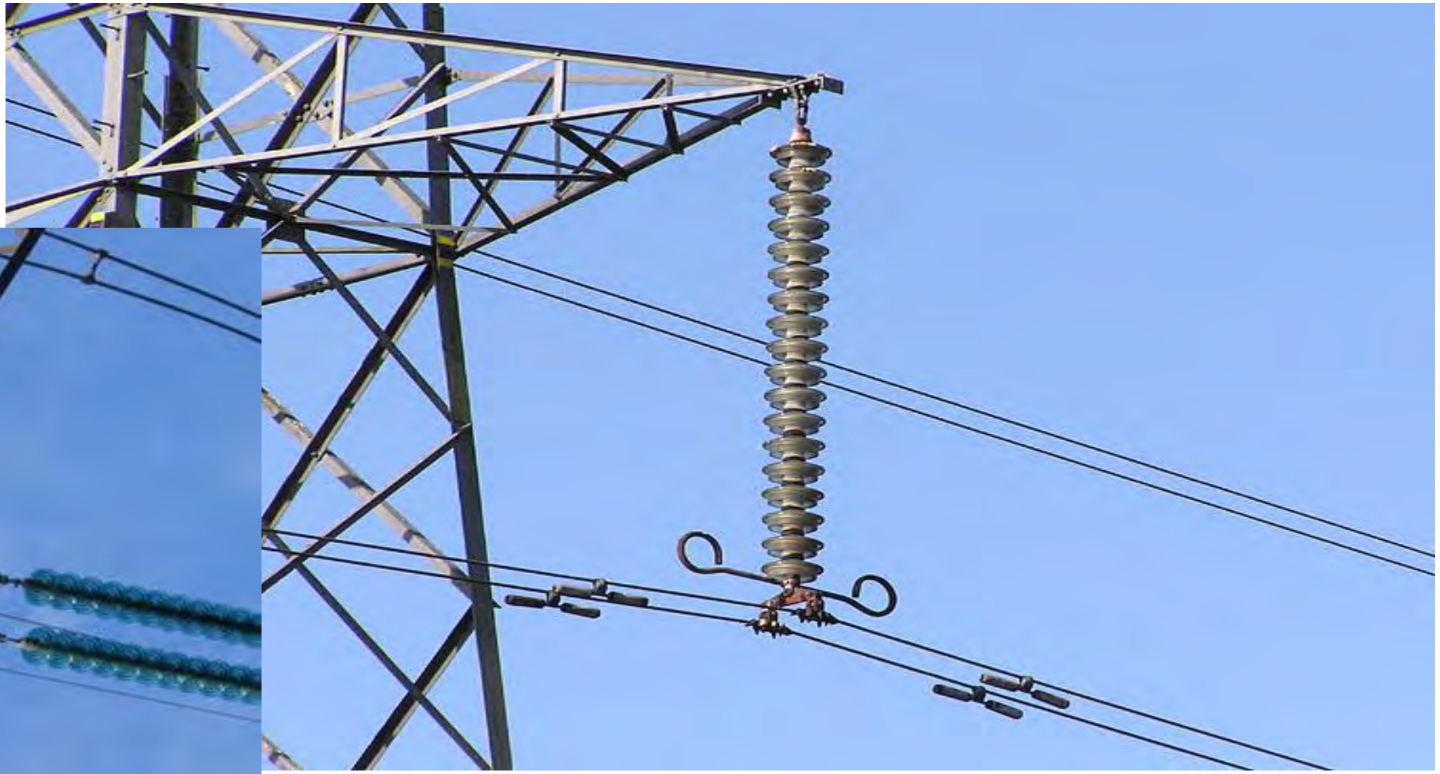


Double Circuit
500 kV



Overhead Line Conductors

Insulators

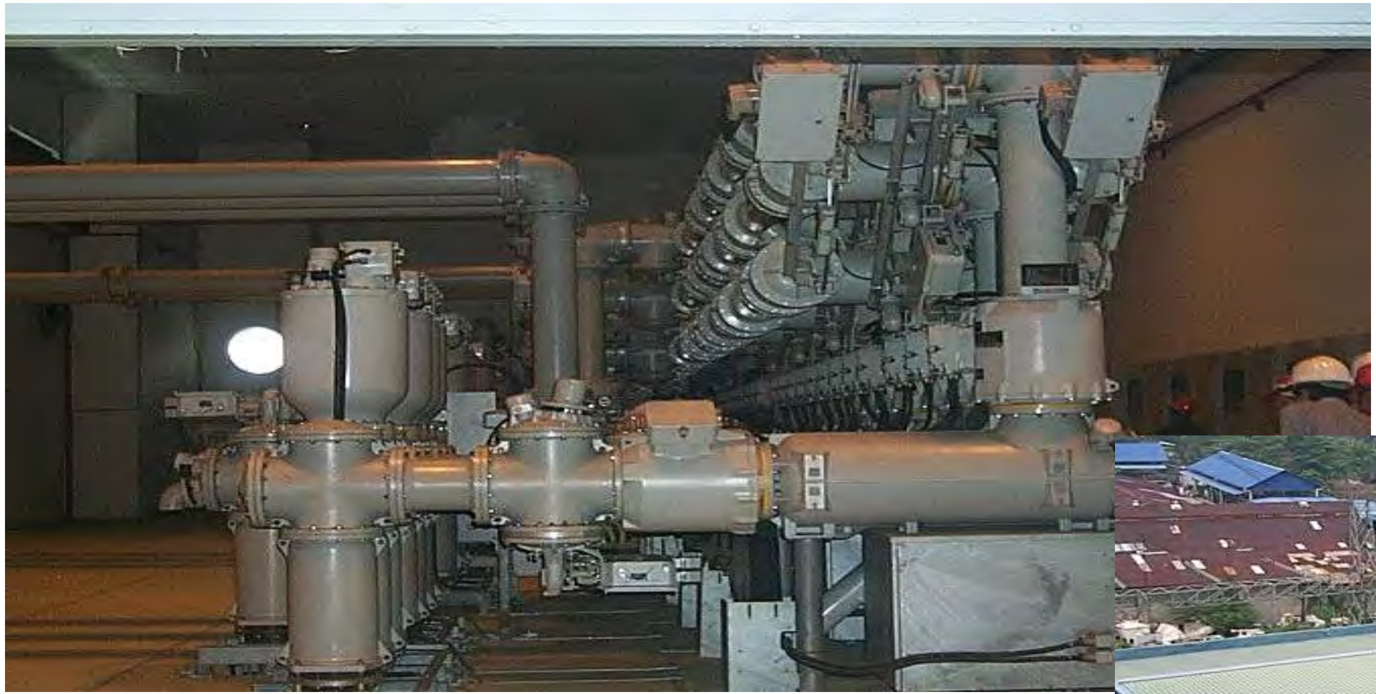


Sub-station

- Size of substation
  - Depends on transformer size
  - Typical sizes
    - 132kV; 2 x 30MVA, 3 x 45MVA, 2 x 90MVA
    - 275kV; 2 x 180MVA, 3 x 180MVA, 2 x 240MVA
- Types of Sub-station
  - Conventional outdoor
    - Require bigger space
  - GIS (gas insulated switchgear)
    - Less space
    - Outdoor or indoor

Outdoor Sub-station

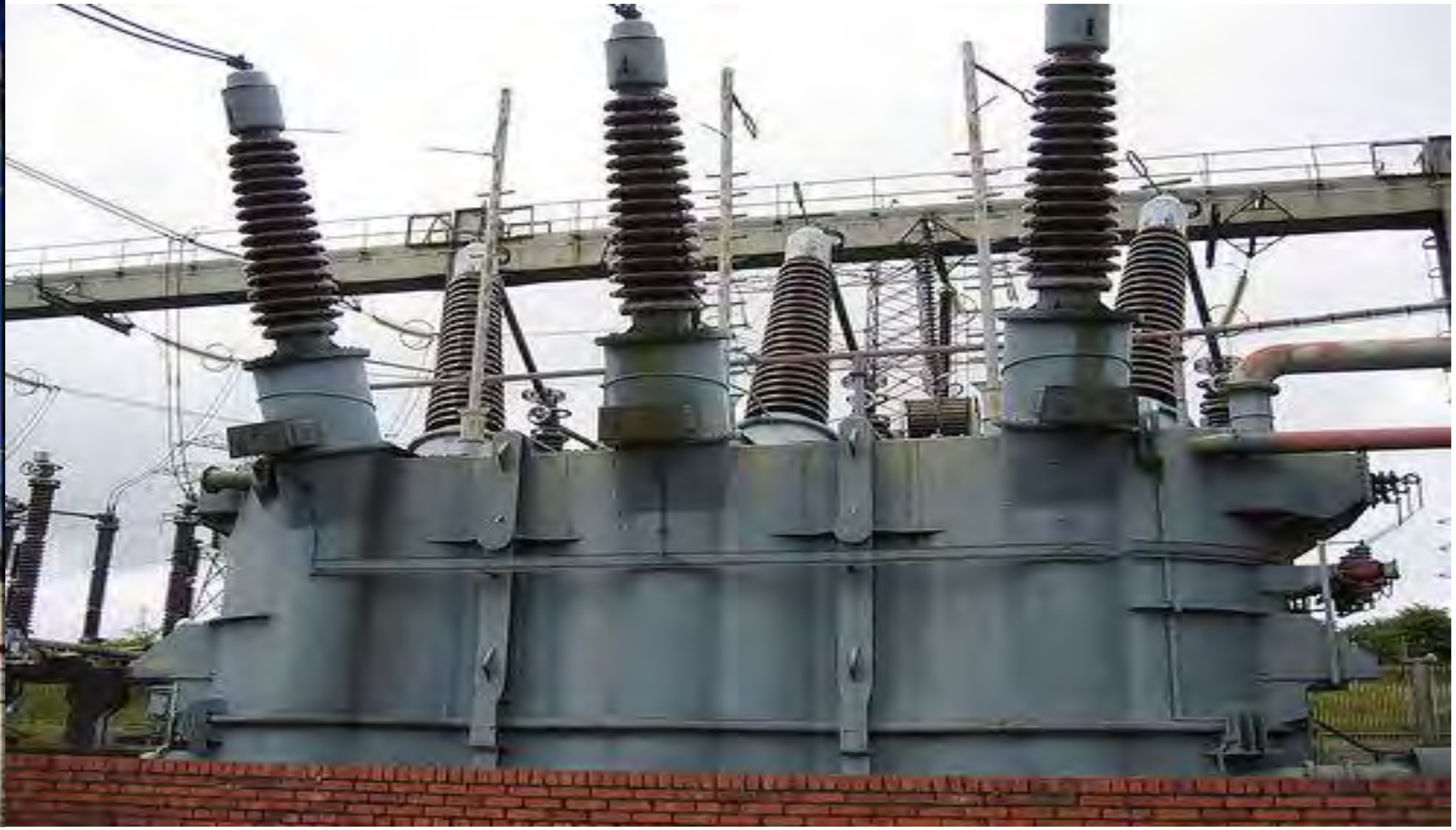
GIS



Sub-station Components

- Transformer
- Circuit Breaker / Switch Gear
- Isolator Switches
- Busbar
- Protection Relay & Control Equipment

Power Transformer



Transformer

No.	Type of Development	% Transformer Loading
1.	Residential	85%
2.	Commercial	60%
3.	Industrial	60%
4.	Mixed (Residential + Commercial / Industrial)	*Majority Residential: 85% Majority Commercial / Industrial: 60%
5.	Individual/Dedicated Commercial or Industrial	Based on customer’s load

Circuit Breaker

Spark gap. In event of a lightning strike on the line, the current can jump the gap between that ball and the protrusion on the tank, and make a path to earth. This prevents overloading the breaker.

Circuit Breaker

Distribution

- Lines/transformers operating at voltages below 100 kV are usually called the distribution system.
- Part of the electric utility system between the bulk power source and the customer service entrances (loads).
- 33kV, 22kV, 11kV, 6.6kV, 415V and 240V

Distribution Sub-station

- Distribution Intakes (33kV, 22kV)
- Distribution Substations (22kV, 11kV, 6.6kV)
  - Indoor substation
  - Outdoor substation
  - Pole mounted substation
  - Compact substation
  - Underground substation
- Transformer capacity
  - 100kVA, 300kVA, 500kVA, 750kVA and 1000kVA

Distribution Intake

Indoor Sub-station

Underground Sub-station

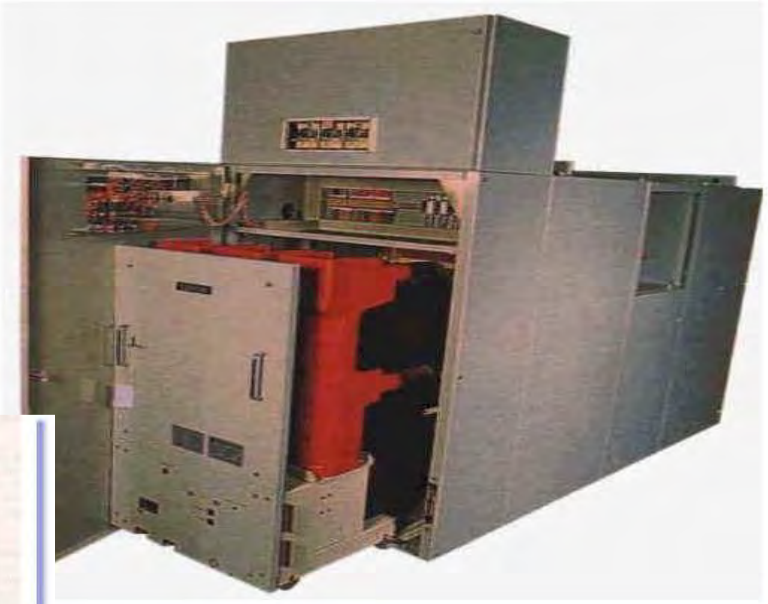
Compact Sub-station

Outdoor Sub-station

Pole-Mounted Sub-station

Distribution Transformer

Distribution Circuit Breaker



Load

- Types of Load:
  - Residential
  - Commercial
  - Industrial
  - Public Transportation
  - Public Lighting
  - etc.

Residential Load

- Consist of lighting, radio, TV, refrigerator, kitchen appliances, washing machine and etc.
- Usually, increases in the evening around 6 p.m. and return to a nominal value around 12 p.m.

Commercial Load

- Consists of lighting, air-condition and small appliances.
- Shops, business premises, schools, universities etc.
- The load is fairly constant from 9am until 9pm with the exception of any mid-day break.

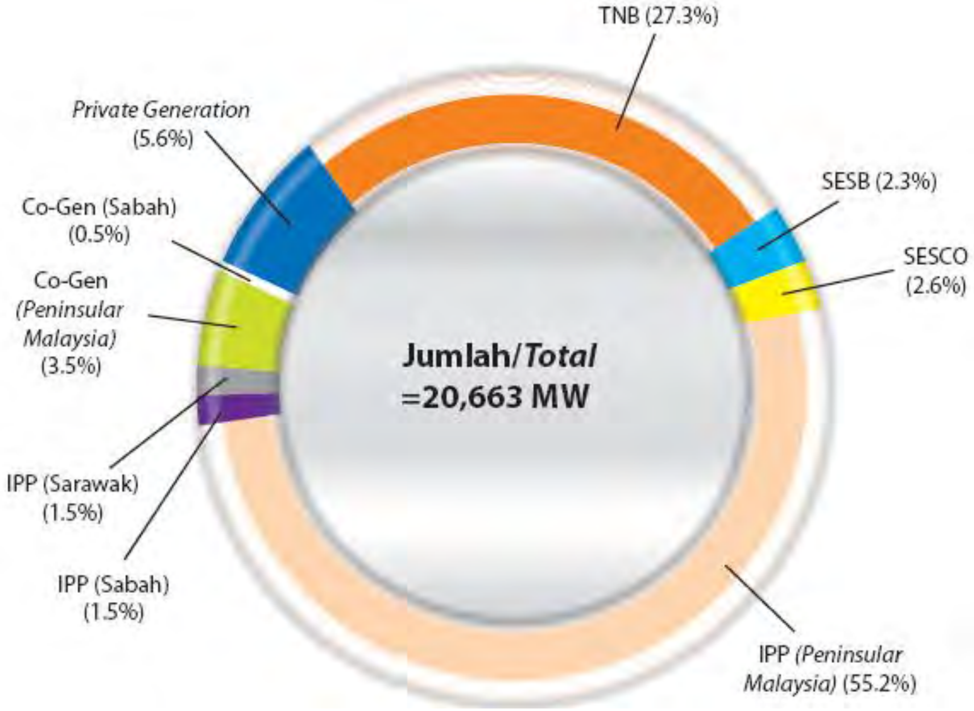
Industrial Load

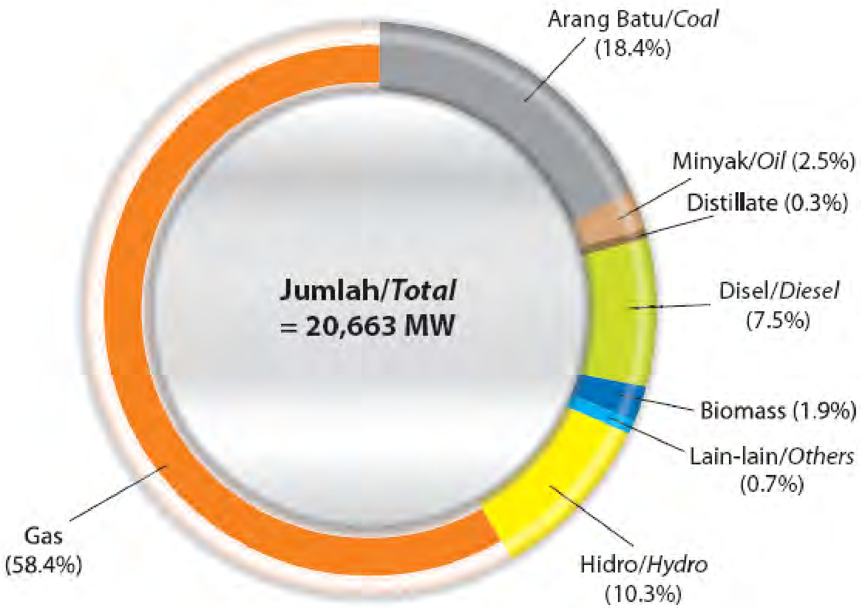
- Mainly consists of motor load, air conditioner, lighting, welding and furnaces etc. It can be divided into small, medium and large category. The nature of industrial load curve will depend on the number of shifts worked in the industry.

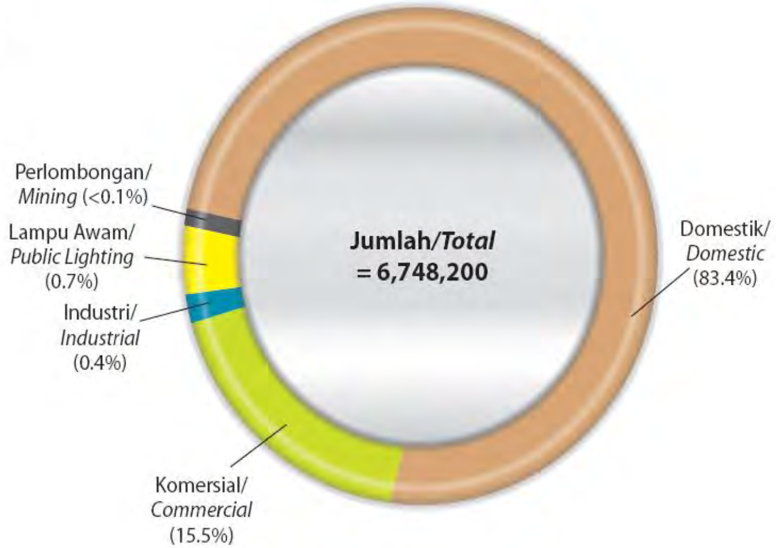
No.	Types Of Loads	Load Devices	Load Characteristics
1.	Lighting	Incandescent lamps	Operate at essentially power factor (p.f.).
		Fluorescent lamps and Neon lights	Operate at p.f. of 0.5 and need capacitors to improve load p.f..
		Mercury Vapour and Sodium Vapour, Metal Halide lights.	Operate at p.f. of 0.7 to 0.8 and need capacitors to improve load p.f..
2.	Electronic Gear	Radio, television, X-ray, ;laser equipment, computers, digital time pieces and timing devices, rectifiers, oscillators for high frequency current production.	Introduce harmonics to the system.
3.	Heating	Residential (small) cooking, water heaters, irons, toasters, clothes' dryers, house heaters	Essentially operate at unity p.f

No.	Types Of Loads	Load Devices	Load Characteristics
4.	Motor	Direct current shunt, series and compound type	Single phase fractional horse-power motors operate at p.f. of 0.5 to 0.7
		A/C single phase and three phase induction and synchronous type	Larger motors without suitable starters cause voltage flicker disturbance to other customers on the system Induction motors operate at p.f. of 0.5 to 0.95. At less than full load operation the p.f. may drop to 0.5-0.6
		Universal for both AC and DC operation	Synchronous motors can be used for p.f. correction for the installation

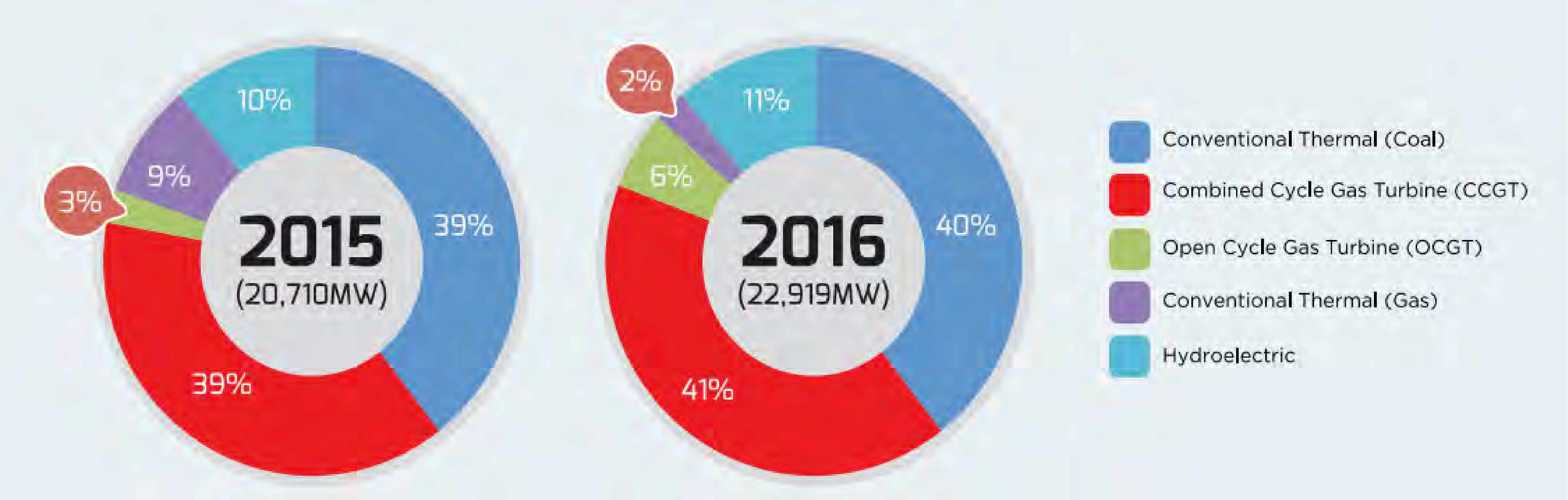
Generation capacity/Electricity Consumers







Generation capacity/Electricity Consumers




Perlis
Chuping
Kuah
PERLIS P/S
Alor Setar
Kota Setar
Gurun East
Sg Petani
Kedah
Pulau Pinang
George Town
Butterworth
GELUGOR
Kulim
Bukit Merah
PERGAU
BERSIA
TEMENGGOR
KENERING
SG PIAH LOWER
SG PIAH UPPER
CENDEROH
Kelantan
Kota Bahru
Tanah Merah
Kuala Terengganu
Kuala Berang
KENYIR
Gua Musang
Kuala Kangsar
Perak
Taiping
Kledang
Ipoh
Papan
Batu Gajah
SEGARI
Kampar
Ayer Tawar
Seri Iskandar
Lumut
JANAMANJUNG
JOR
WOH
Terengganu
PAKA
YTL
Teluk Kalong
Dungun
Kuala Lipis
Jerantut
Teluk Intan
Pahang
Kuantan
Mentakab
Bukit Berantung
Kuala Selangor
Kuala Kubu Baru
Kg. Awah
Bukit Tarik
Bentong
Temerloh
Selangor
Wilayah Persekutuan
KAPAR
CONNAUGHT BRIDGE
SERDANG
Muadzam Shah
Negeri Sembilan
GENTING SANYEN
Seremban
Kuala Pilah
PD POWER
TJPS
POWERTEK
Gemas
Segamat
Mersing
MELAKA
Melaka
Johor
Yong Peng (E)
Yong Peng (N)
Muar
Batu Pahat
Bkt Batu
Plentong
Pontian Kechil
Cahaya Baru
Permas Jaya
Johor Bahru
YTL Pasir Gudang
PASIR GUDANG
LEGEND
Hidro Power Station
Thermal Power Station
State Capital
Major Town
Major TNB Substation
Transmission Network
Existing
Under Construction
500 kV Overhead Line
275 kV Overhead Line

Advantages grid network

- Provide multiple paths between various generation sources and loads
- Provide for power transfers from one geographic area to another to achieve overall system operating economics
- Interconnect the bulk power facilities of individual power station/utilities so that they can better withstand major disturbances

Advantages

- Other advantages:
  - Stability
    - Load sharing
  - Continuity of service
    - Maintenance, breakdown
  - Economy
    - Cheap & efficient

Interconnection

National Load Dispatch Centre (NLDC)

- Objectives:
  - Grid system requires a grid controller/operator system.
  - In order to ensure the supply of energy is safe and reliable.

NLDC Function

- Maintains system stability
  - Frequency control
  - Voltage within limits
- Achieve minimum operating cost
  - Optimize transmission losses
  - Merit order generation
- maintain spinning reserve requirements
- co-ordinate generation and transmission maintenance outages
- Restoration of supply after system fault

In designing Power generation station, the following two important aspects must be considered

- Selection and placing of power generating equipment should be such that a maximum of return will result from a minimum expenditure over the working life of the plant
- The operation of the plant should be such that a cheap, reliable and continuous service is provided

- Power generation is the conversion of other available forms of energy to electrical energy.

- Power generating stations are mostly located in remote areas.

- Type of generating station depends on the energy conversion, e.g. hydro, nuclear, gas, coal, wind, solar stations etc.

The generation voltage varies depending on the size and capacity of the generating station.

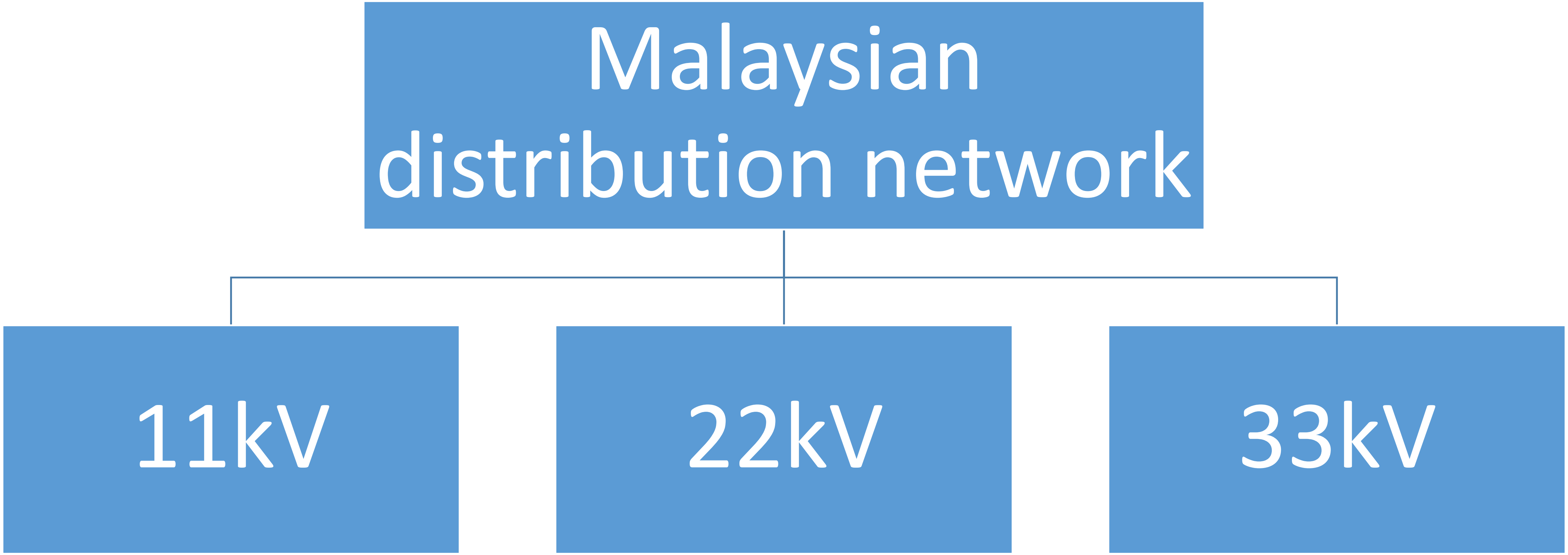
Common generation voltages are 11kV, 16kV, 22kV, 33kV and so on.

The generated voltage is then step-up using step-up transformers to transmission voltage levels.

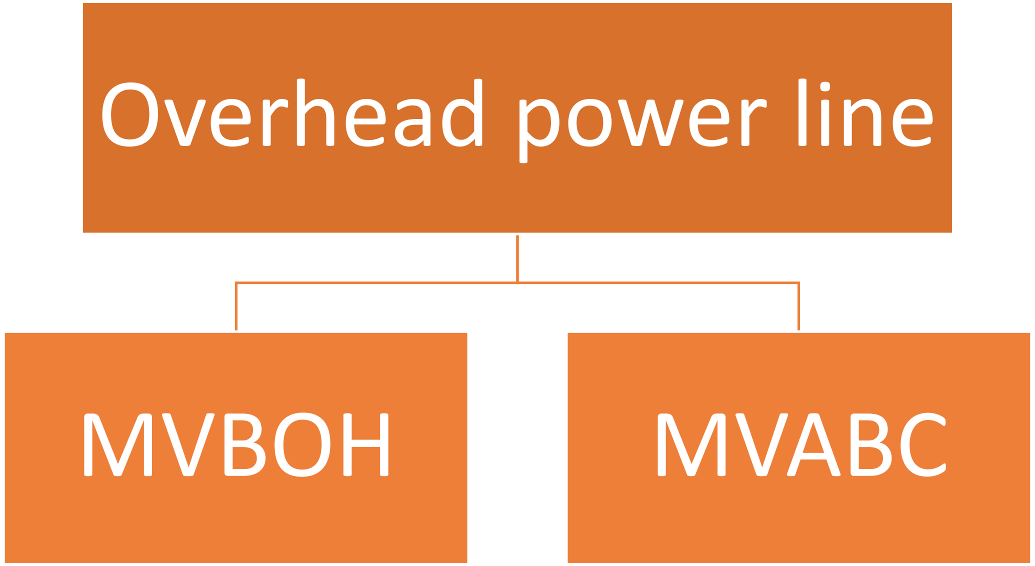
Transmission is the conveying of electricity in bulk from the point of generation to the point of distribution, usually over a long distance using mostly overhead power lines.

A typical overhead line consists of conductors, insulators, support structure and surge arrestors.

In Malaysia, the power distribution network operates at three voltage levels; via overhead power lines or underground cable lines



The overhead power line is further classified in two types



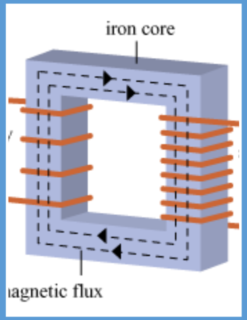
An overhead line conductor material has the following important properties

- high tensile strength, so that the spans between two towers or poles can be as long as possible and the sag as small as possible, thus reducing the number and height of towers and the number of insulators.
- low resistivity to reduce the power loss and voltage drop.
- invariably stranded to make them more flexible during

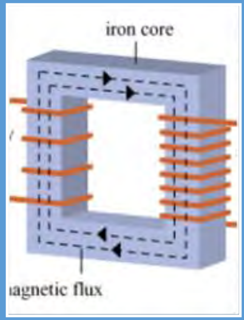
  construction and while in service.

Depending on the country, Transmission is implemented using high voltage levels such as 600kV, 450kV, 250kV,132kV, 66kV and so on. This to reduces losses and cost of transmission installations.

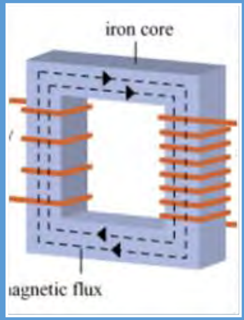
Transformer is one of the main equipment in TNB.



Transformer is classified in to two



power transformer (7.5 MVA and above)



distribution transformer. (1000 kVA and below)

- Transformer is one of the main equipment in distribution system which can be categorized into power transformer and distribution transformer.
- Power transformer (7.5 MVA and above) is mainly used in main intake substation and main distribution substation.
- Distribution transformer (1000 kVA and below) is usually utilized in electrical substation.

30 MVA, 132/11 kV power transformer in intake substation

45 MVA, 132/33 kV power transformer in intake substation

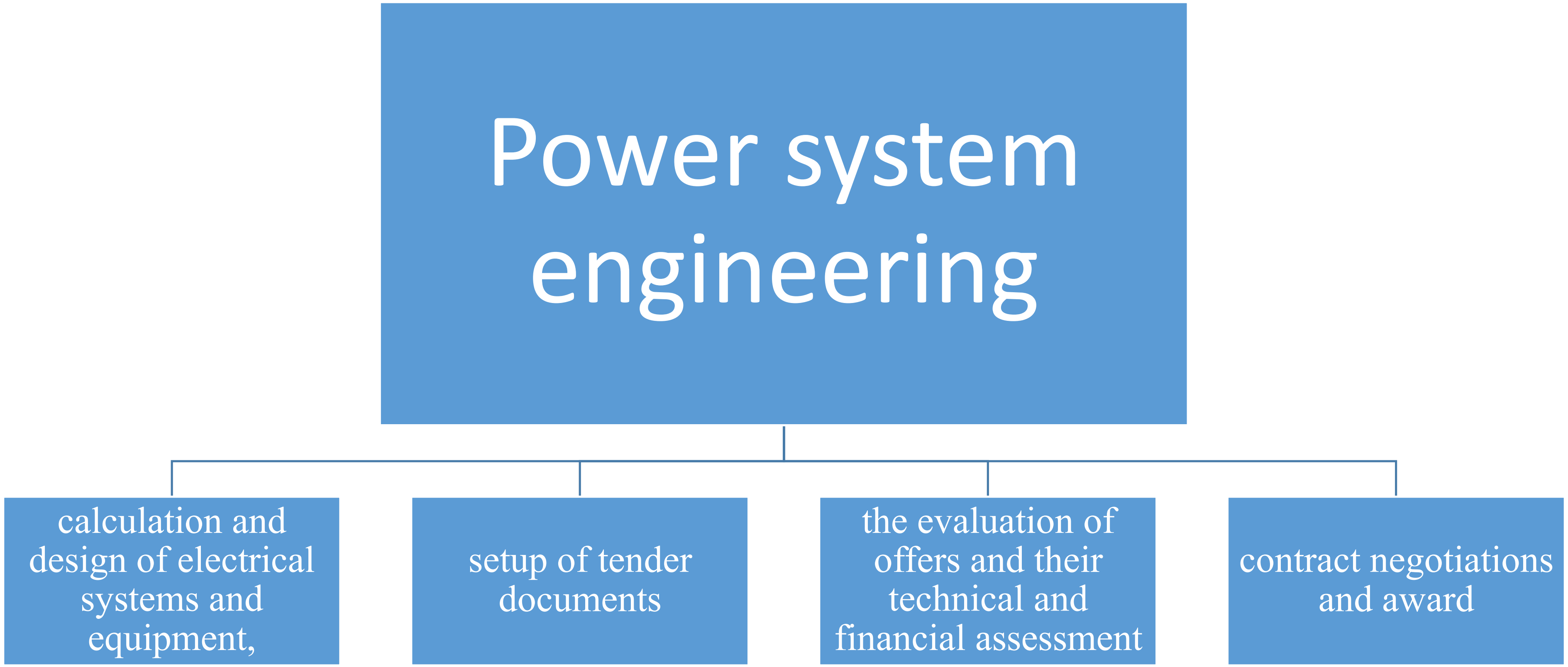
30 MVA, 33/11 kV power transformer in distribution substation

300 kVA, 11/ 0.433 kV distribution transformer in electrical substation

Distribution is the sharing of electricity to individual consumers for industrial, commercial or residential usage. It is mostly done in lower voltage suitable for the equipment of the consumers

The common used distribution voltages as 11kV, 3.3kV, 1.1kV, 0.415kV, 0.220kV, 0.110kV and so on. The practice of the above mentioned is known as power system engineering .

Power system engineering is the central area of activity for system planning, project engineering, operation and rehabilitation of network for electrical power supply



Power system engineering is an indispensable and integral part of the engineering activities for

- feasibility studies;
- planning and operating studies;
- project engineering;
- the development and rehabilitation of existing facilities
- the design of network protection concepts
- clearing up of disturbance

The supply of electricity as for other sources of energy at competitive unit price, in sufficient quantity and quality, and with safe and reliable supply through reliable equipment, system structures and devices is of crucial importance for the economic development of industries, regions and countries.

The planning of supply systems must take into account different boundary conditions, which are based on regional and structural consideration that in many cases have a considerable impact on the technical design.

Given that, in comparison with all other industries, the degree of capital investment in **electric utilities** takes the top position, not only from the monetary point of view but also in terms of **long term return of assets**, it become clear that each investment decision requires particularly careful **planning** and **investigation**, to which **power system engineering** and **planning** contribute substantially.

The **reliability of the supply** is determined not only by the quality of the **equipment** but also by **careful planning** and **detailed knowledge** of **power system**, together with a consistent use of relevant standards and norms as well as internal regulations.

Furthermore, the mode of **system operation** must conform to the conditions specified by **standards**, including the **planning process**, **manufacturing of equipment** and **commissioning**.

Just as faults in equipment cannot be totally excluded because of technical or human failure, likewise the equipment and installations cannot be designed to withstand any kind of fault, accordingly, the effects of faults must be limited.

Thus, violation of or damage to other equipment must be prevented in order to ensure undisturbed **system operation** and reliable and safe supply to the **consumers**.

Legal, Political and Social Restrictions

P.S are operated with certain restrictions imposed by legal requirements, technical standards, political issues, financial constraints and social, political and environment parameters which have a strong influence on the system structure, the design and the rating of equipment and thus on the cost of investment and cost of energy, without any compromise in terms of security, reliability and economy.

Some general areas pertaining to regulations, guidelines and laws for electrical p.s. are simply stated below, without any elaboration at this stage.

- Concession delivery regulations
- Market guidelines for domestic electricity supply
- Electrical power industry laws
- Energy taxation
- Laws supporting or promoting green-energy
- Environmental aspects
- Safety and security aspects
- Right of way for OHL and cable routing

Such regulations, laws and guidelines will have an impact on **planning**, **construction** and **operation** of **P.S**, likewise on the reliability of the power supply, the cost structure of equipment, the cost of electrical energy and finally on the attractiveness of the economic situation within the particular country.

- Generating plants will be operated in merit order, that is, the generator with lowest production cost will be operated in preference to operating generation with the highest efficiency.
- Criteria of profitability must be re-evaluated in the light of laws supporting green-energy
- Reduced revenues from energy sales will lead to a decrease in the investments, personnel and maintenance costs, with consequences of reduced availability and reliability

- Increasing the proportion of green-energy generation plants that have low availability leads to an increase in the running reserve of conventional power stations, with consequences of reduced efficiency of these plants and thus higher costs
- Reduction of investment for the construction of newer power stations leads to a decrease in reserve capabilities and thus to a decrease in the reliability of the power supply
- Expenditures for coordination during normal operation and during emergency conditions are increased with rising numbers of market participants, with the consequence of an increased risk of failures
- Power systems of today are planned for the generation of electrical energy in central locations by large power stations with transmission systems to the load centers.

A change of the **production structure**, for example, by increase of **green-energy production plants** and development of small **co-generation plants**, mainly installed in distributions, requires high additional investment for the extension of the **P.S**, resulting in rises in energy prices as well as reduced usage of existing plants.

The **power system** structure up to now has been determined by connections of the load centers with the locations of power stations, which were selected on the basis of the availability of primary energy, the presence of cooling water or hydrological conditions.

The construction of offshore wind energy parks requires substantial investment in new transmission lines to transmit the generated energy to the load centers.

- Increase of green-energy production plants, in particular photovoltaic, wind energy and fuel-cells, reduces the quality of the power supply due to the increased requirement for power electronics
- The long periods for planning and investment on power stations and high voltage transmission systems do not allow for fast and radical changes.

Decisions on a different development, i.e. away from nuclear power generation towards green-energy production, are to a certain extent irreversible if these decisions are not based on technical and economic background and detailed knowledge but are predominantly politically and ideologically motivated

Needs for power system planning

P.S planning must take due consideration of the restrictions and must develop concepts and structures which are technically and economically sound.

This includes the planning and project engineering of generation systems, transmission and distribution networks, and optimization of systems structures and equipment, in order to enable flexible and economic operation in the long as well as the short term.

P.S planning also has to react to changes in the technical, economic and political restrictions.

Key activities are the planning and construction of power stations, the associated planning of transmission and distribution systems, consideration of long-term supply contracts for primary energy and cost analysis.

The systematic planning of p.s. is an indispensable part of p.s engineering, but it must not be limited to the planning of individual system components or determination of the major parameters of equipment, which can result in suboptimal solutions.

P.S engineering must incorporate familiar aspects regarding technical and economic possibility, but also those that are sometimes difficult to quantify, such as the following:

- load forecast for the p.s under consideration for a period of several years
- energy forecast in the long term
- standardization, availability, exchangeability and compatibility of equipment
- standardized rated parameters of equipment
- restrictions on system operation
- feasibility with regard to technical, financial and time aspects
- political acceptance
- ecological and environmental compatibility

P.S engineering and p.s planning require a systematic approach, which has to take into account the financial and time restrictions of the investigations as well as to cope with all the technical and economic aspects for the analysis of complex problem definitions.

Planning of p.s. and project engineering of installations are initiated by:

- demand from customers for supply of higher load, or connection of new production plants in industry
- demand for higher s/c power to cover requirements of power quality at the connection point
- construction of large buildings, such as shopping centers, office buildings or department stores
- planning of industrial areas or extension of production process in industry with requirement of additional power
- planning of new residential area
- general increase in electricity demand

P.S planning is based on a reliable load forecast which takes into account the developments in the p.s.

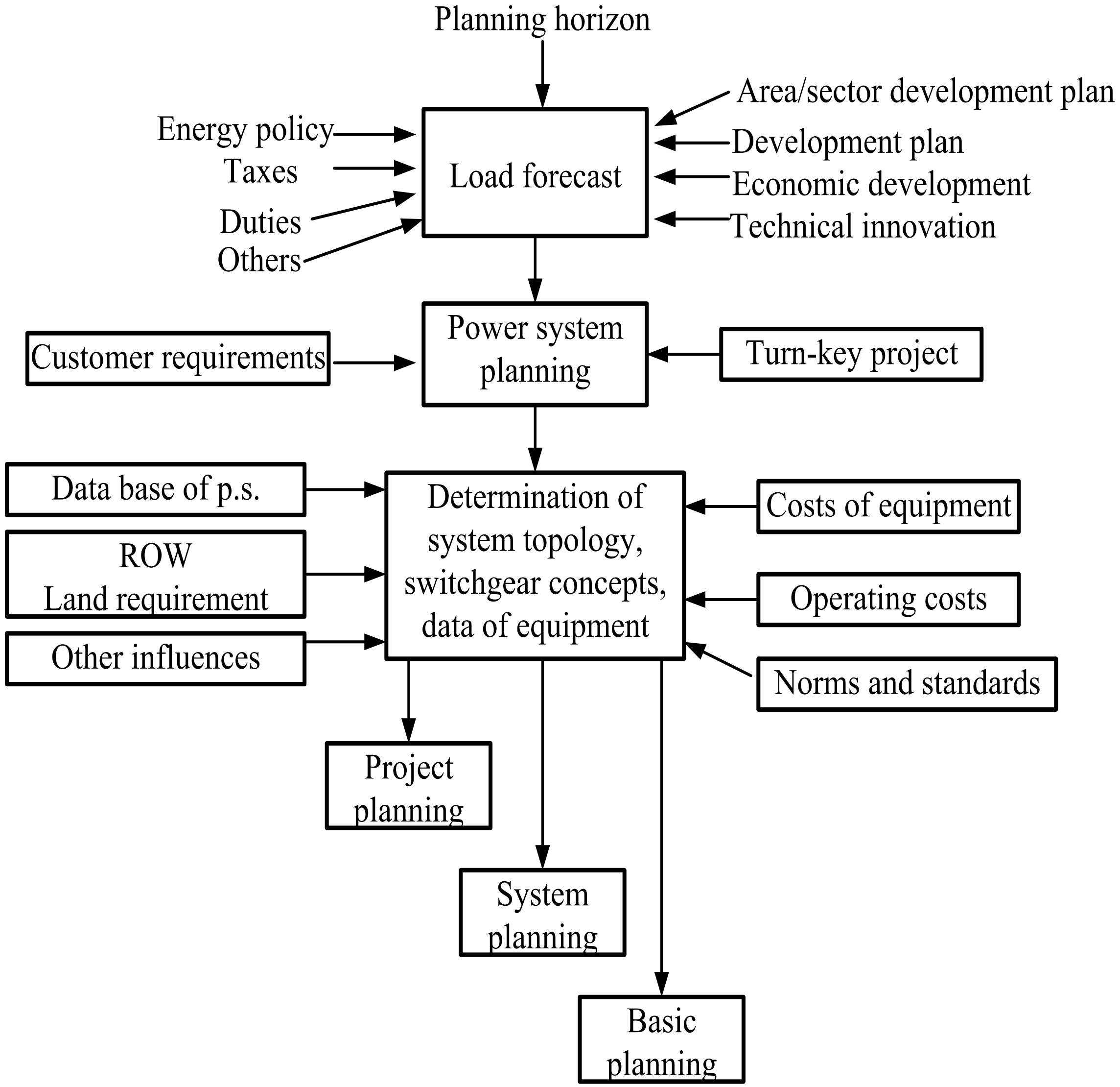
The load increase of households, commercial and industrial customers is affected by the overall economic development of the country, by classification by land development plans, by fiscal incentives and taxes and by political measures.

Needs for p.s planning also arises as a result of changed technical boundary conditions, such as the replacement of old installations and equipment, introduction of new standards and regulations, construction of new power stations and fundamental changes in the scenario of energy production.

The objective of p.s planning is the determination and justification of system topologies, schemes for substations and main parameters of equipment considering the criteria of economy, security and reliability.

Further aspects must be defined apart from the load forecast:

- The information database of the existing p.s with respect to geographical, topological and electrical parameters.
- Information about right-of-ways, right of possession and space requirements for substations and line routes
- Information about investment and operational costs of installations
- Information about the costs of losses
- knowledge of norms, standards and regulations



Basic, Development and Project Planning

Load forecast, power system planning and project engineering are assigned to special time intervals, defining partially the tasks to be carried out. Generally three steps of planning are to be considered- basic planning, development planning and project planning.

Basic Planning

For all voltage levels the fundamental system concepts are defined: standardization of equipment, neutral earthing concept, nominal voltages and basic of power system operation.

The planning horizon is up to 10 years in LV systems and can exceed 20 years in HV transmission system.

System Development Planning

Detailed planning of the system topology is carried out based on the load forecast. Alternative concepts are analyzed technically by LF calculations, SC analysis and stability computations. Cost estimates are also carried out.

Disturbance and operational statistics are evaluated and locations for installations are determined. The main parameters of equipment, such as CSA of overhead lines and cables, SC impedance of TX are defined.

The planning horizon is approximately five years in a LV system and up to 10 years for a HV transmission system.

Project Planning

The projects defined in the system development planning stage are implemented. Typical tasks of the project engineering are the connection types of new customers, connection of new substations to the power system, restructuring measures, evaluation of information on system loading, preparation of tender documents and evaluation of offers, supervising construction contracts, cost calculation and cost control.

Project planning covers a time range of one year in the LV system and up to four years in the HV system.

Instruments for power system planning

The use of computer programs as well as the extent and details of the investigations are oriented at the desired and/or required aim of the planning process.

The fundamental investigations that must be accomplished by p.s planning are explained below.

The load flow analysis is a fundamental task for planning and operation of p.s. It serves primarily

- to determine the loading and the utilization of the equipment.
- to calculate the active and reactive power flow in the branches of the p.s.
- to determine the voltage profile and to calculate the p.s losses.

Single or multiple outages of equipment can be simulated in the context of the investigations for different preloading conditions.

The required setting range of the transformer tap-changer and the reactive power supply by generators or compensation devices are determined.

S/c current calculations are carried out for selected system configurations, defined by load flow analysis.

For special applications, such as protection coordination, s/c current calculation should consider the preloading conditions as well.

Symmetrical and unsymmetrical faults are simulated and the results are taken as a basis for the assessment of the s/c strength.

Calculations of s/c current for faults between two systems are sometimes necessary to clarify system disturbances.

Faults between two systems may occur in cases of multiple-circuit towers in overhead-line systems.

The results obtained by calculation programs are as exact as the main parameters of the equipment.

If those data are not available, the parameters must be determined by calculation.

In the case of overhead lines and cables, the reactances, resistances and capacitances in the positive-sequence and zero-sequence component are calculated from the geometrical arrangement of the conductors and from the cable construction.

Subsequent calculation may determine the permissible thermal loading, the surge impedance, natural power and, in case of overhead lines, additionally the electric field strength at the conductor as well as the electric and magnetic field strengths in the surrounding of the line for certain applications.

The permissible thermal loading of equipment under steady-state conditions and under emergency conditions is based on ambient conditions, i.e. ambient temperature, thermal resistance of soil, wind velocity, sun exposure and so on.

The calculation of the maximum permissible loading plays a larger role with cables than with overhead lines because of the poorer heat dissipation and the lower thermal overload capability.

The investigation of the static and in particular transient stability is a typical task when planning and analyzing HV transmission systems.

Stability analysis is also important for the connection of industrial plants with their own generation to the public supply system. Stability analysis has to be carried out for the determination of frequency and voltage dependent load shedding schemes. The stability of a p.s. depends on the number and type of power stations, the type and rating of generators, their control and excitation schemes, devices for reactive power control, and the system load as well as on the voltage level and the complexity of the p.s. An imbalance between produced power and the system load results in a change of frequency and voltage.

In transient processes, i.e. s/c with subsequent disconnection of equipment, voltage and frequency fluctuations might result in cascading disconnections of equipment and subsequent collapse of the power supply.

In industrial p.s and auxiliary supply systems of power stations, both of which are characterized by a high portion of motor load, the motors must start again after s/c or change over with no voltage conditions.

Suitable measures, such as increase of the s/c power and time dependent control of the motor starts, are likewise tasks that are carried out by stability analyses. The insulation of equipment must withstand the foreseeable normal voltage stress. It is generally economically not justifiable and in detail not possible to design the insulation of equipment against every voltage stress.

Equipment and its over-voltage protection must be designed and selected with regard to the insulation and sensitivity level, considering all voltage stresses that may occur in the p.s. The main field of calculation of over-voltages and insulation coordination is for switchgears, as most of the equipment has non-self restoring insulation.

Equipment in p.s is loaded, apart from currents and voltages at power frequency, also by those with higher frequencies emitted by equipment with power electronics in common with the industrial load, in the transmission system by FACTS and by generation units in photovoltaic and wind energy plants.

Higher frequencies in current cause additional losses in transformers and capacitors and can lead to mal-operation of any equipment.

Due to the increasing electronic load and application of power electronics in generation plants, the emission of harmonics and interharmonics is increasing.

Using frequency dependent system parameters, the statistical distribution of the higher frequency currents and the voltage spectrum can be calculated as well as some characteristics values, such as total harmonic distortion, harmonic content and so on.

Equipment installations, communication circuits, and pipelines are affected by asymmetrical s/c in HV equipment due to the capacitive, inductive and conductive couplings existing between the equipment.

Thus, inadmissible HV can be induced and coupled into pipelines.

In p.s. with resonance earthing, **unsymmetry** in voltage can occur due to parallel line routing with HV transmission lines. The specific material properties and the geometric outline of the equipment must be known for the analysis of these interference problems.

Electromagnetic fields in the vicinity of overhead lines and installations must be calculated and compared with normative specified precaution limit values, to assess probable interference of humans and animals exposed to the electric and magnetic fields.

Earthing of neutrals is a central topic when planning power systems since the insulation coordination, the design of the protection schemes and other partial aspects, such as prospective current through earth, touch and step voltages, depend on the type of neutral earthing.

In addition to the technical investigations, questions of economy, loss evaluation and system optimization are of importance in the context of p.s planning. The extension of distribution systems, in particular in urban supply areas, requires a large number of investigations to cover all possible alternatives regarding technical and cost related criteria.

The analysis of all alternative concepts for distribution systems cannot normally be carried out without using suitable programs with search and optimization strategies.

Optimization strategies in HV transmission system are normally not applicable because of restrictions, since rights of way for overhead lines and cables as well as locations of substations cannot be freely chosen.

The conceptual design of network protection schemes determines the secure and reliable supply of the consumers with electricity.

Network protection schemes must recognize incorrect and inadmissible operating conditions clearly and separate the faulty equipment rapidly, safely and selectively from the p.s.

An expansion of the fault onto other equipment and system operation has to be avoided.

Besides the fundamental design of protection systems, the parameters of voltage and current transformers and transducers must be defined and the settings of the protective devices must be determined.

The analysis of the protection concept represents a substantial task for the analysis of disturbances.

Power system load

The forecasting of power system load is an essential task and forms the basis for planning of p.s. The estimation of the load demand must be as exact as possible.

P.S are to be planned in such a away that changing load developments can be accommodated by the extension of the system.

If the three stages of the planning process are correlated with the required details and the necessary accuracy of the load forecast, it is clear that planning procedures are becoming more detailed within the short time range and less detailed within the long time range.

Accordingly, different methods of load forecast have to be applied, depending on the planning horizon and thus on the voltage level and /or task of planning.

From a number of different load forecasting procedures, five methods are stated below.

- Load forecast with load increase factor
- Load forecast based on economic characteristic data
- Load forecast with estimated values
- Load forecast based on specific load values and extend of electrification
- Load forecast with standardized load curves

Planning principles

The aim of planning electrical power systems is to fully serve the interests of the consumers to be supplied with electricity.

The active and reactive power of the supply area to be expected in the long range planning period are taken as basic parameters.

In order to determine the configuration of p.s. in terms of technical, operational, economic, legal and ecological criteria, planning principles have to be defined and used.

High priority is to be given to the supply of consumers with a defined need for supply reliability, which can be accomplished if sufficient data are available on system disturbances or by means of quantitative and if necessary additional qualitative criteria.

The reliability of the electrical power supply system is influenced by:

The fundamental structure of the p.s. topology

- The consumer is supplied only via one line forming a radial supply system.

The operational mode of the p.s.

- The desired reliability of supply can be guaranteed only if power system is operated under the conditions for which it was planned.

The selection of equipment

- Qualified and detailed specification and tendering of any equipment, consistent use of international norms for testing and standardization of equipment guarantee high quality installations at favorable costs on an economic basis

Earthing of neutral point

- A single phase fault with earth connection (ground fault) in a system with resonance earthing does not lead to a disconnection of the equipment, whereas a single phase earth fault in a system with low impedance neutral grounding (s/c) leads to a disconnection of the faulted equipment and in some cases to interruption of supply.

Regular maintenance

- Regular and preventive maintenance according to specified criteria is important to preserve the availability of equipment.

Qualification of employees

- Apart from good engineering qualifications, continuing operational training of personnel obviously leads to an increase of employees competence and through this to an increase of supply reliability

Uniformity of planning, design and operation

- Operational experience must be included in the planning of p.s. and in the specification of the equipment

Safety standards for operation

- The low safety factor for human failure can be improved by automation and implementation of safety standards, thus improving the supply reliability

In each case a compromise between supply reliability, the design of the system and any equipment and the operational requirements must be agreed, and of course the interests of consumers are to be considered.

Prior to the definition of planning principles, agreement must be obtained concerning acceptable frequency of outages, their duration up to the reestablishment of the supply and the amount of energy not supplied and/or the loss of power due to outages.

Outages include both planned outages due to maintenance and unplanned outages due to system faults.

Unscheduled outages result from the following:

- The equipment itself, the cause here being the reduction of insulation strength, leading to s/c and flash over
- Malfunctioning of control, monitoring and protection equipment, which can cause switch-off of breakers

- External influences, such as lightning strokes or earthquakes, which lead to the loss of equipment and installations
- Human influences, such as crash accidents involving installations or cable damage followed by disconnection of the overhead line or the cable.

Even with careful design and selection of equipment, loading and overloading sequences in normal operation cycles, detailed monitoring of the system operation and preventive maintenance have to be considered.

The frequency and duration of outages can hardly be predicted and can only be estimated on the basis of evaluation and assessment of disturbance statistics.

The duration of outages up to the reestablishment of the supply can be estimated as a maximum value and is determined by the following:

P.S configuration and planning criteria

- If the p.s. is planned in such a away that the outage of one item of equipment or power system element does not lead to overloading of the remaining equipment, safe power supply is secured in case of failure of any piece of equipment, independently of the repair and reconnect duration.

Design of monitoring, protection and switching equipment

- If switchgear in a p.s can only be operated manually and locally, then the duration of the supply interruption is longer and thus the energy not supplied is larger than if the switched are operated automatically or from a central load dispatch center

Availability of spare parts

- A sufficient number of spare parts reduces the duration of supply interruption and the amount of energy not supplied, as the repair can be carried out much more quickly.

Availability of personnel

- The causes of failures and faults in the power system have to be analyzed and assessed carefully prior to any too hasty reestablishment of the supply after outages, in order to avoid further failures due to maloperation and erroneous switching

Availability of personnel

- The timely availability of skilled and qualified personnel in sufficient number reduces the repair time significantly

Availability of technical reserves

- A sufficient and suitable reserve is needed to cover the outage of any equipment. This need to imply the availability of equipment of identical designed to the faulty equipment; i.e. after the outage of a HV/MV transformer the supply can be ensured temporarily by a mobile emergency power generator

Basics of planning

1. P.S for electrical power supply must be planned and operated considering the loading of the equipment in such a way as to achieve the following:

- A reasonable and /or suitable relation between the maximal thermal stress and the actual load in the final stage of system voltage and/or until restructuring measures become effective and
- No inadmissible thermal loadings (load current) arise, except those which are permitted under certain operating and ambient site conditions

Thermal loading of equipment beyond the permissible values can lead to a reduction of the insulation strength in case of non-self-healing insulating media(oil-impregnated paper, XLPE, PVC, etc) with consequent reduction of the life time, an increase in frequency of insulation faults and thus an increase of the failure rate of the equipment.

The mechanical strength and the elasticity of overhead line conductors, bars and other metallic connections can be reduced if the temperature exceeds the permissible temperature for a certain duration. This may result it irreversible deformations, which can lead, for instance in overhead lines, to a reduction of the insulation clearances between conductor and earth and consequently to an increase of the flash over frequency and to an increased failure rate of the equipment.

Mechanical damage is also possible.

The thermally permissible load of equipment depends on:

- material properties
- ambient temperature
- other site conditions. i.e. wind and sun exposure
- number of load cycles
- preloading conditions of the equipment in case of variable load
- duration of the additional load arising after the preloading conditions
- past total actual time under operation

The permissible loads are to be taken from standards or manufacturers’ data or can be determined with suitable computer programs.

2. P.S. must be planned and operated with regard to s.c currents in such a way that

- The thermal strength of equipment and installations is always higher than the prospective thermal effects of the s/c currents.
- The electromagnetic effects of s/c currents are lower than the associated mechanical strength of the equipment and installations.
- The s/c and fault currents through earth do not cause any impermissible step or touch voltages or impermissible voltages at earthing electrodes.

The conditions mentioned must be fulfilled for symmetrical and unsymmetrical s/c.

S/C currents as well as their thermal and electromechanical effects and the thermal and electromechanical strength of equipment and installations must be determined in accordance with international standards, most suitably using computer programs.

The voltage at earthing resistances or reactances and step and touch voltages are to be determined on the basis of unsymmetrical s/c currents with earth connection.

For pipelines and other metallic circuits running in parallel, induced voltages need to be calculated.

3. P.S must be planned and operated with regard to the generation, transmission and distribution of electrical power and energy in such a way that;

- Sufficient generation capacity is available to supply the expected (forecast) load as well as the p.s. losses and to cover the internal consumption under normal operating conditions and in case of outages of power stations and any other equipment in the p.s.
- Transmission and distribution systems have sufficient capacity to supply the p.s load under normal operating conditions and under defined outage conditions

4. P.S must be planned and operated with regard to the system voltage in such a way that:

- A suitable and internationally standardized voltage level is selected for transmission and distribution systems.
- The voltage is within a suitable bandwidth as defined by international standards or by planning criteria under normal operation and under outage conditions.
- The pf of the system is on the lagging side and the generators can run in the over-excited mode.

IEC 60038 stipulates standardized voltages and the permissible voltage bandwidth or voltage range is also defined for some voltage levels.

In the extra HV range only the highest voltage for equipment is defined, see Table 3.1-3.4.

The permissible voltage band must be defined in the planning criteria in cooperation with other supply companies.

5. P.S must be planned and operated with regard to frequency control and transient behavior in such a way that:

. The frequency in the steady state condition remains within a permissible and agreed range for the entire p.s.

. Deviations from the nominal frequency (50Hz or 60Hz) are to be compensated within a fixed time period.

. No inadmissible frequency fluctuations shall be initiated due to disconnections of loads or due to s/c in the p.s. (Load-shedding by frequency relays is seen only as the last measure to secure the stability of the p.s)

.The frequency range shall remain within the limits defined for the operation of synchronous and asynchronous machines.

A stable frequency under steady-state conditions represents an essential condition for the regulation of the exchange of electricity between different supply partners.

The conditions for the analysis of transient stability, such as load conditions to be considered, time delay of the protection, automatic reclosing sequences, type of faults and s/c in the p.s. and so on, must be defined in planning criteria.

Table 3.1 Nominal system voltages according to IEC 60038 for LV three-phase and single-phase AC systems.

Nominal voltage		Voltage bandwidth	Remarks (Table I of IEC 60038)
Three-phase systems (V)	Single-phase systems (V)		
230/400	120/240	$\Delta U_{max} < \pm 10\% \times U_n$	277/480 V
277/480 400/690 1000		Normal operating conditions	Not to be used together with 400/690 V

Table 3.2 Nominal system voltages according to IEC 60038 for MV systems, AC voltage, $1\,kV < U_n \leq 35\,kV$.

Highest voltage for equipment, U_m (kV)	Nominal voltage, U_n (kV)		Tolerance ΔU	Remarks (Table III of IEC 60038) reference U_m
3.6	3.3	3	$\Delta U_{max} < \pm 10\% \times U_n$	Not for public supply systems
7.2	6.6	6	Normal operating conditions	Not for public supply systems
12	11	10		–
17.5		15		Not recommended for new installations
24	22	20		–
36	33	–		–
40.5	–	35		–

Table 3.3 Nominal system voltages according to IEC 60038 for HVAC-systems, 35 kV < $U_n \leq$ 230 kV.

Highest voltage for equipment, U_m (kV)	Nominal voltage, U_n (kV)		Remarks (Table IV of IEC 60038)	Remarks U_m
52	45		Not recommended for new installations	123 and 145 kV not to be used both in one country. 245 kV not to be used in one country, if 300 or 363 kV are present (Table 3.4)
72.5	66	69	–	
123	110	115	–	
145	132	138	–	
170	150		Not recommended for new installations	
245	220	230	–	

Table 3.4 Highest voltages for equipment according to IEC 60038 for EHVAC-systems, U_m > 245 kV.

Highest voltage for equipment, U_m (kV)	Remarks (Table V of IEC 60038)	Remarks U_m
300	Not recommended for new installations	245, 300 and 363 kV or 363 and 420 kV or 420 and 525 kV not be used together in one geographical area (see also Table 3.3)
363	Not recommended for new installations	
420	–	
525	Instead of 525 kV, 550 kV are to be used also	
765	Values between 765 kV and 800 kV to be used	
1200	–	

6. P.S must be planned and operated with regard to flexibility and economy in such a way that;

- The type and topology of the system allow supply to some extent even for load developments different from the forecast
- The system losses are minimal under normal operating conditions
- Different schedules of operation of power stations are possible
- The generation of energy is possible in economic priority sequence (merit order), and ecological and environmental conditions are taken into account.
- A suitable and favorable relation between design and rating of equipment and the actual load, in particular their thermal permissible loading, is achieved in the final system development stage
- Standardization of the equipment is possible, without impairment of operational flexibility

Planning Criteria

❑Voltage band according to IEC 60038

Planning criteria are understood to be objectively verifiable conditions, parameters and data, which are fixed in a quantitative way for planning and operation of equipment and the p.s defined in standards or other agreed documents.

The nominal voltage and the acceptable voltage range cannot be specified arbitrarily, since this is fixed for some voltage levels in IEC 60038. For LV systems the data of Table 3.1 are to be applied. P.S having nominal voltage above 1kV and below 35kV are termed MV systems. The specified voltages according to Table 3.2 are to be assured. It has to be considered that the highest voltage for equipment U_m does not correspond in some cases with the indicated voltage tolerance ΔU related to the nominal voltage, i.e. for the nominal voltage $U_n = 3.3$ kV the highest voltage for equipment $U_m = 3.6$ kV is lower than

the upper tolerance value of the voltage (1.1 x 3.3 kV = 3.63 kV)

Therefore, the upper tolerance of the voltage is to be taken as always smaller than or equal to the highest voltage for equipment.

- P.S. with voltages above 35 kV up to 230 kV are termed HV systems.
- IEC 60038, Table IV, specifies only the highest voltage for equipment, but no voltage tolerance.
- The respective data are given in Table 3.3.

P.S having voltages above 245 kV are termed extra HV systems.

IEC 60038 specifies only the highest voltage for equipment as outlined in Table 3.4.

No voltage tolerance and no nominal voltage are defined; nevertheless, the term nominal voltage is also used in loosely in this voltage range.

Thus one calls a p.s having U_m= 420 kV (highest voltage for equipment) a 400 kV system (sometimes also 380V system) with nominal voltage U_n= 400 kV.

The conditions indicated in Tables 3.1-3.4 define the minimal requirements.

Stronger conditions can be defined and may be needed especially for high and extra HV systems, for which no voltage tolerances are defined.

In addition, voltage tolerances should also be specified for operation after loss of equipment or under emergency conditions.

Voltage criteria

Criteria for voltage tolerance are to be defined for p.s under normal operating conditions and under single outage conditions, in some cases also for multiple outages, as outlined below.

LV Systems

If one uses the values in LV systems according to Table 3.1 at the point of connection of the customer to the utility, then the voltage drop in the customer's installation remains unconsidered; connected LV consumers are supplied with a system voltage below the permissible limit.

Similar considerations apply to voltage increase, which occurs mainly while connecting local generation in LV systems, such as photovoltaic generation.

Therefore the following criteria are recommended:

In LV systems the voltage is to be held in a tolerance of -5% and +10% in relation to the nominal system voltage during normal operation at the point of common coupling.

In case of single outage in the LV systems, the voltage at the PCC is to be kept within a tolerance of -8% and +10% in relation to the nominal system voltage.

If necessary, corrective measures are to be considered, such as changeover to another supply point in the LV system or in the medium voltage systems, by adjusting the tap-changer of the MV/LV transformer or by shifting the section point in the ring main feeders.

In LV systems without redundant supply, for instance in a radial power system, a longer outage time up to the repair has to be accepted.

Medium voltage systems

In the MV system with $U_n < 35kV$ similar criteria as for LV can be applied. The voltage is regulated by the automatic tap changer of the feeding transformer.

Note that in the MV system increase of voltage may have effects on the LV systems as well and also have to be considered. The following criteria are recommended:

(i) In MV systems the voltage is to be kept within a tolerance of $\pm$ 5% in relation to the nominal system voltage during normal operation.

(ii) With single outage in the MV system without supply interruptions, the voltage is to be held within a tolerance of $\pm$ 10% in relation to the nominal system voltage. After carrying out corrective measures such as switch-on of a reserve transformer or operating the tap changer of the feeding transformer, the voltage should remain in a tolerance of $\pm$ 8% in relation to the nominal system voltage.

Medium voltage systems (cont………………)

(iii) In MV system without redundant supply for example, in radial system a longer outage time up to the repair must be accepted. After restoring the supply without replacement or repair of the failed equipment, the voltage is to be held within a tolerance of ± 10% in relation to the nominal system voltage.

High and Extra high voltage system

High and extra HV systems with $U_n > 110$ kV are usually planned and operated as meshed p.s.

IEC 60038 does not define criteria for the voltage tolerance; the tolerance can be freely specified.

The voltage is regulated by the automatic tap-changer of the feeding transformers or by any other measures influencing the voltage, such as generator voltage control, reactive power compensation equipment and so on.

Voltage drops and voltage increase are to be compensated and controlled.

As the nominal system voltage is not defined for extra HV systems a value of 0.9 Um (90%of the highest voltage for equipment) is to be taken as nominal voltage.

The following criteria are recommended :

(i) In HV systems the voltage is to be held in a tolerance band of ± 5% in relation to the nominal system voltage during normal operation.

(ii) With single outage in the HV system and without switching or corrective measures, the voltage is to be kept within a tolerance of ± 10% in relation to the nominal system voltage. After execution of corrective measures, e.g. by operating the tap changer of feeding transformers or changing the generation schedule of power stations, the voltage is to be kept within a tolerance of ± 8% in relation to the nominal system voltage.

If the high and/or extra HV systems is planned in such a way that several independent outages do not lead to supply interruption, then graded criteria for single and multiple outages can be defined.

-With single outage the voltage is to be held within a tolerance of $\pm 8\%$ in relation to the nominal voltage. After execution of corrective measures, for instance by operating the tap changer of feeding transformers or changing the generation schedule of power stations, a tolerance of $\pm 6\%$ in relation to the nominal system voltage is to be maintained.

-If multiple outages that is, two independent outages are permitted as a planning principle a voltage tolerance of $\pm 10\%$ in relation to the nominal system voltage is allowed in case of multiple outage. After execution of corrective measures, e.g. by operating the tap changer of feeding transformers or changing the generation schedule of power stations, the voltage is to be held within a tolerance of $\pm 8\%$ in relation to the normal system voltage.

Loading Criteria

Criteria for the permissible loading of equipment in p.s under normal operating conditions and/or with single outage or multiple outages can be specified.

- the loading of any equipment may not exceed the values as defined in standards, norms and regulations, data sheets of manufactures or by means of computer programs during normal operating conditions
- in case of outage of any equipment, the loading of the remaining ones (still in operation in the p.s) may not exceed the values defined for a given period as specified in standards, norms and regulation, data sheets of manufacturers or determined by means of computer calculations.
- For the determination of load criteria such as duration and height of the load, preloading conditions and so on, application oriented standards are specified, which are to be used in planning and operation.

Stability criteria

P.S have to be operated in a stable manner in the event of transient disturbances without subsequent faults.

Such faults may include load shedding by frequency relays, switch off of generators, isolating of subsystems and so on.

The p.s frequency has to fulfill tolerance criteria.

Oscillations of power in case of defined scenarios most not be allowed to lead to loss of stability:

- three phase faults or single phase faults on any equipment with subsequent switch-off (fault clearing) of the faulted equipment within a specified time determined by the operating time of the protection.
- three phase faults on any overhead line with subsequent successful fault clearing by auto reclosing with a specified time sequence.

- three phase faults on any overhead-line with subsequent unsuccessful fault clearing by auto-reclosing with a specified time sequence.
- single phase faults on any overhead-line with subsequent successful fault clearing by three-phase or single-phase auto-reclosing with a specified time sequence.
- three phase faults on any overhead-line with subsequent unsuccessful three-phase or single-phase fault clearing by auto-reclosing with a specified time sequence.
- loss of load in the system, for instance, by switch-off of a HV-transformer or any other fault.
- loss of generation in the system, e.g. by switch-off of a power station or any generator.

To ensure normal frequency control in the p.s, sufficient generation reserve under primary control (primary reserve) must be available and activated in timely fashion.

The amount of primary reserve depends on the typical power station schedule.

Topology of power systems

P.S are constructed and operated as radial systems, ring-main systems, meshed systems

Additional criteria for distinction can be defined, such as the number and kind of feeders from supplying system level, the number and arrangement of lines and the reserve capability of the system to cover loss of load.

The three system topologies are constructed and operated at all voltage levels.

In the context of the sections below, the following definitions are used:

Feeder- outgoing connection of any overhead line or cable from a MV or LV substation

Grid station-switchyard including bus-bars, transformers and outgoing feeders to the EHV level

Substation- switchyard including bus-bars, transformers and outgoing feeders to the HV level

Station- switchyard including bus-bars, transformers and outgoing feeders to the MV level

Primary-switchyard including bus-bars, transformers and outgoing feeders to the LV level

Line-any overhead line or cable of any voltage level

Radial systems

The simplest system configuration, the radial system, can be found particularly at the LV and MV levels.

The individual feeders or lines, connected to the primary station, connects the primaries by radial feeders as represented in Fig. 5.2a.

Branching of the lines is possible and in fact usual (Fig 5.2b).

This network configuration is suitable for areas with low load density and is also used for the connection of bulk loads.

In this case the system is called a connection system.

The advantages of the simple topology and low capital investment cost have to be compared with the disadvantage that, in case of failure of lines, the load of the faulted lines cannot be supplied.

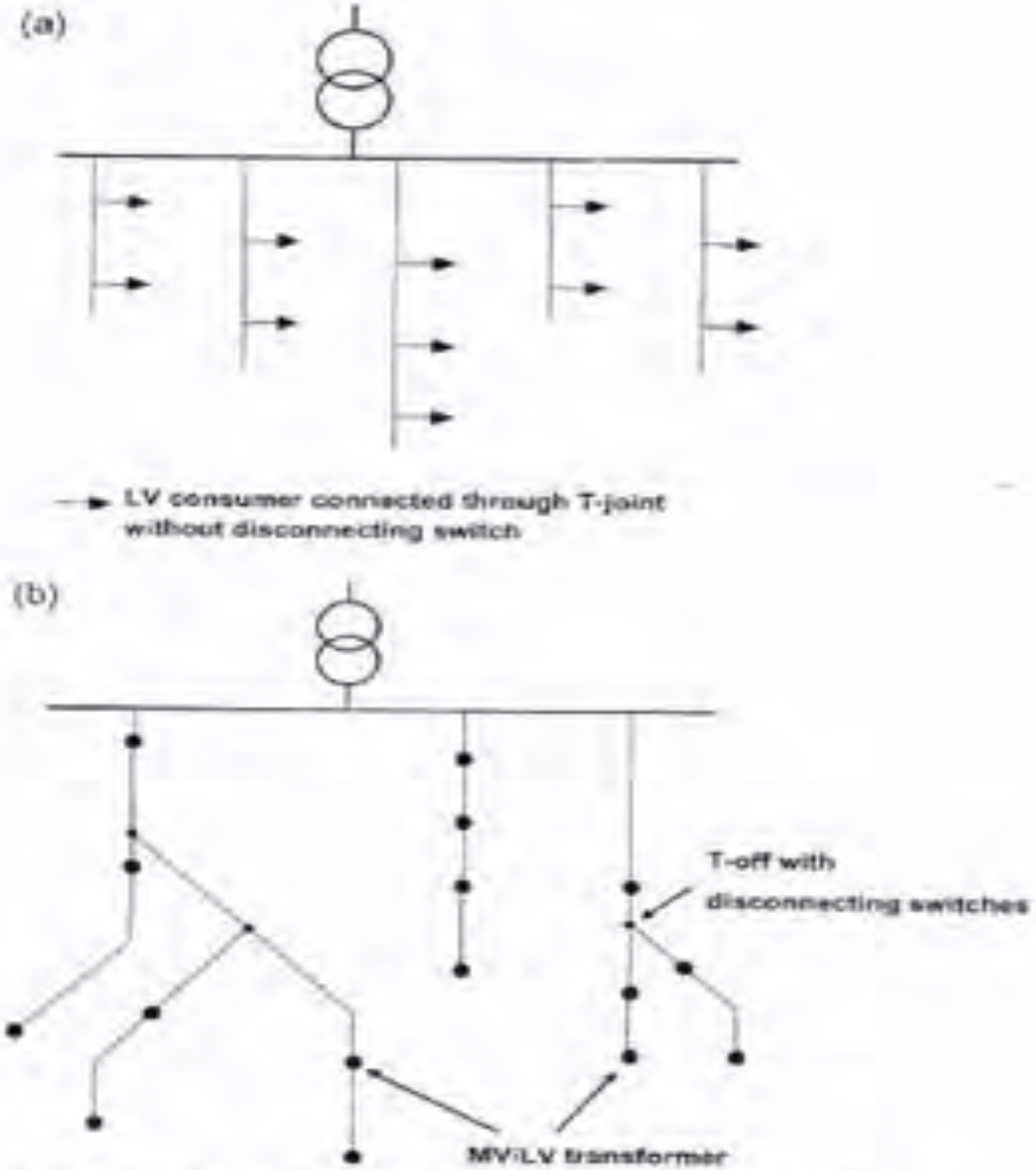


Figure 5.2 Topology of radial power systems. (a) Simple structure radial network (LV system); (b) radial network with branch lines (MV system).

The branch-off points in the LV system are sometimes implemented in the form of branch-off joints or T-connections without switching capability.

Radial systems in the MV level are usually built only in areas with low load density.

The branch-off points can then be implemented both with and without disconnecting switches or load-break switches.

The possibility of switch-off for each line exists in the feeding station or primary in the form of disconnecting switches, rarely as circuit-breakers.

If only disconnecting switches are installed, the switch on the secondary side of the feeding transformer has to be implemented as circuit-breaker.

The loading of the lines can be selected such that the thermally permissible load at the sending end of the lines amounts to 100%.

The system is characterized by:

- clear and simple structure
- low planning expenditure
- simple operation under normal operating conditions
- loading of lines during normal operation up to 100%
- no reserve for loss of lines
- low investment cost
- maintenance cost rather small
- system losses comparatively high, losses cannot be minimized
- Voltage profile not very good, distinct voltage drop between the feeding and the receiving end of the lines

- flexibility for changed load conditions is comparatively small
- reserve for losses of the feeding MV transformer usually missing
- protection usually only with overcurrent relays at the feeder, MV systems, sometimes also with circuit breakers, in LV systems with fuses.
- Typically application in MV systems up to 60 kV with small load densities up to approximately 1 MW km^{-2}, typically in LV systems.

The reliability and/or the reserve capability of radial systems can only be improved in principle if another concept is used; the pure radial system is converted into a ring-main system or even a meshed system.

Ring-Main systems

Ring main systems are common in the MV range

A large variety of ring-main systems are in operation with respect to permissible loading of the lines, reserve capability against outages, different arrangement of the feeding station and supply reliability.

Ring-Main systems- Simple topology

The simplest kind of ring-main system is obtained by connecting the line ends back to the feeding station as outlined in Fig 5.3

Usually ring-main systems are operated with open disconnection points at defined locations on each line, which provides for simple operation including a switchable reserve capability, depending on the loading of the lines.

The loading of the lines must be selected in such a way that in case of failure of a line the total load of this line concerned can be supplied after closing the load-switch at the open disconnection point.

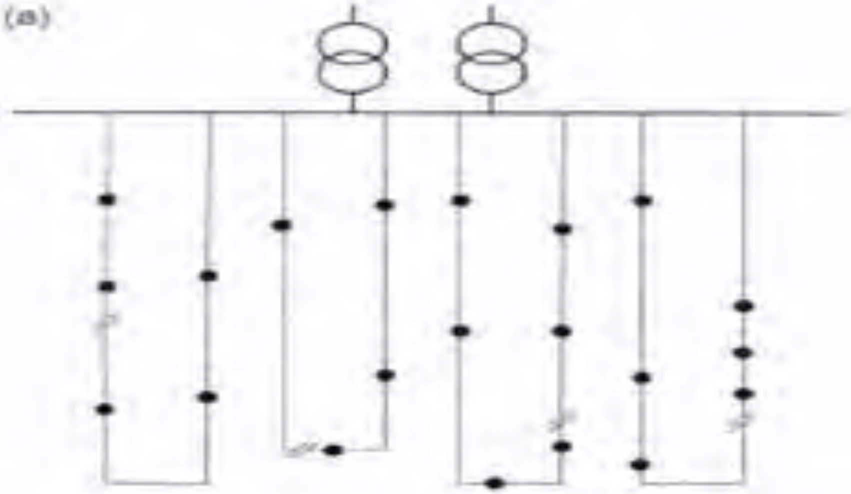
This means that the loading of each feeder must be maintained at 50% of the thermally permissible loading as an average for normal operating conditions.

Each feeder offers reserve in case of faults of the respective feeder itself.

The system is characterized by:

- Clear and simple structure
- moderate planning expenditure
- Simple operation (similar to radial system) under normal operating conditions
- loading of lines during normal operation 50% of the permissible loading, higher loading possible depending on load duration

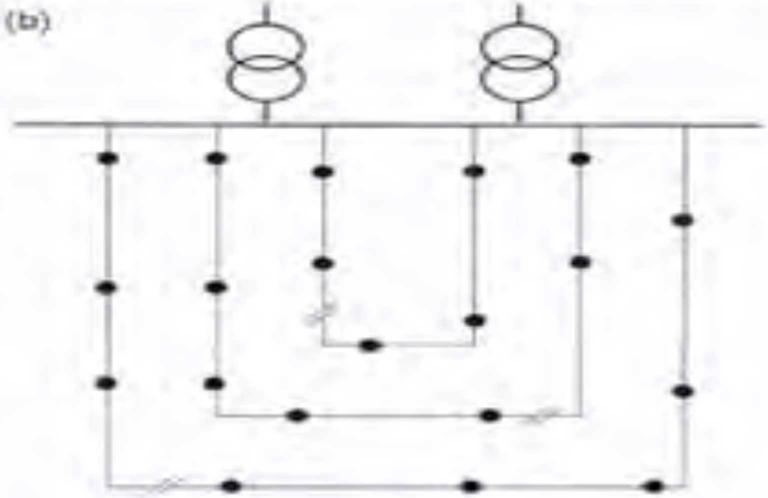
(a)



// Disconnection point (n.o.)

• MV/LV transformer connected through fuse or disconnecting switch

(b)



// Disconnection point (n.o.)

• MV/LV transformer connected through fuse or disconnecting switch

Figure 5.3 Ring-main system simple topology.
(a) Arrangement with limited reserve in feeding station;
(b) arrangement with reserve to cover outages in the feeding station.

- reserve for outage of each line section given by the line itself
- investment cost not very high, reduction possible, if circuit breakers are omitted; in this case one circuit breaker has to be installed on the secondary side of the feeding transformer.
- maintenance cost rather low
- system losses can be minimized by changing the location of the open disconnection point
- voltage profile can be optimized, differences between feeding and receiving end of the lines depend on the location of the open disconnection point
- flexibility to respond to changing load conditions
- reserve for outage of feeding transformer or bus section
- standardization of cross-sections of the lines is given
- feeder protection can be realized with overcurrent protection
- application in MV systems up to 35 kV, in case of high load density, in principle also in LV systems

Special-spare cable system

Is widely known, though the system can be realized with cables or overhead lines.

This system is found in urban areas of densely populated areas in Asia but also as overhead line systems in North and South America.

In European countries this system configuration is rather uncommon. The system can be described as a combination of ring main system and radial system.

The load is supplied through radial lines, called tap lines, connected to main lines having larger cross section.

Connection is realized by means of T-connectors in overhead line systems and special T-joints in cable system.

A spare cable(special cable system), with the same cross-section as the main cable is connected to the other end of the tap lines by T-connecters or T-joints.

The special-spare cable does not supply load under normal operating conditions but is kept energized.

Reserve for outages by the special-spare cable is only given for outages of the tap lines and only to a minor extent for outage of a main line. Generally one can assume the loading of the tap lines as up to 100% of the thermal permissible loading.

The system is characterized by:

-Simple and clear structure

-Moderate planning expenditure

-Easy operation under normal operating conditions

-Voltage profile only moderate, partially large differences between feeding and receiving end of the tap lines

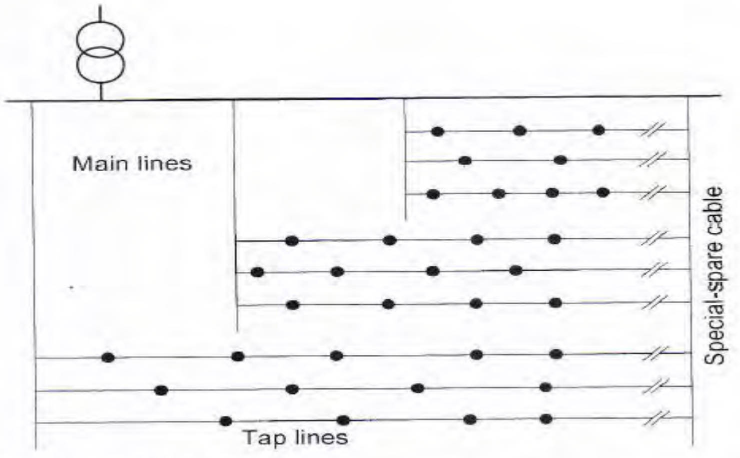
-Flexibility for changed load conditions is small

-Reserve for losses of the feeding MV transformer usually available

-Standardization of cross sections of line possible

-Protection usually only with overcurrent protection for the main lines

-advisable application in MV systems up to 35 kV with small load densities however, the system is widely used in urban p.s.



// Disconnection point (n.o.)

• MV/LV transformer connected through fuse or disconnecting switch

Figure 5.11 Special-spare cable system.

Double-T connection

The double-T connection concept in MV systems is found especially in centers of large cities with high load density.

The primaries, feeding the LV systems, are connected to two independent lines which are connected to different substations.

High reliability is achieved by this scheme compared with the ring main systems(with remote station and with reserved lines).

The system can cover any outage of a MV line. A line fault leads to the outage of the complete feeder. If the primaries are connected to the line by three load switches, the outage of one line results only in the outage of a section of the line.

The system can be operated either in open circuit mode or fed from both primaries, in this case it is more a meshed system than a ring main system.

The system is characterized by:

-Simple and clear system structure

-Moderate planning expenditure

Simple operation for normal operating and emergency conditions

-Loading of line under normal operating conditions up to 60% of thermal permissible loading

-Reserve for outage of MV line

-Investment cost moderate

-Maintenance cost comparatively low

-System losses can be minimized by suitable selection of open disconnection point

-Voltage profile flat

-Flexibility to respond to change in load conditions

-Reserve for loss of substation available

-Standardization of cross sections of all lines

-Protection of circuits with overcurrent relays

-Application in MV systems with cables up to 35 kV with medium to high load densities in urban areas

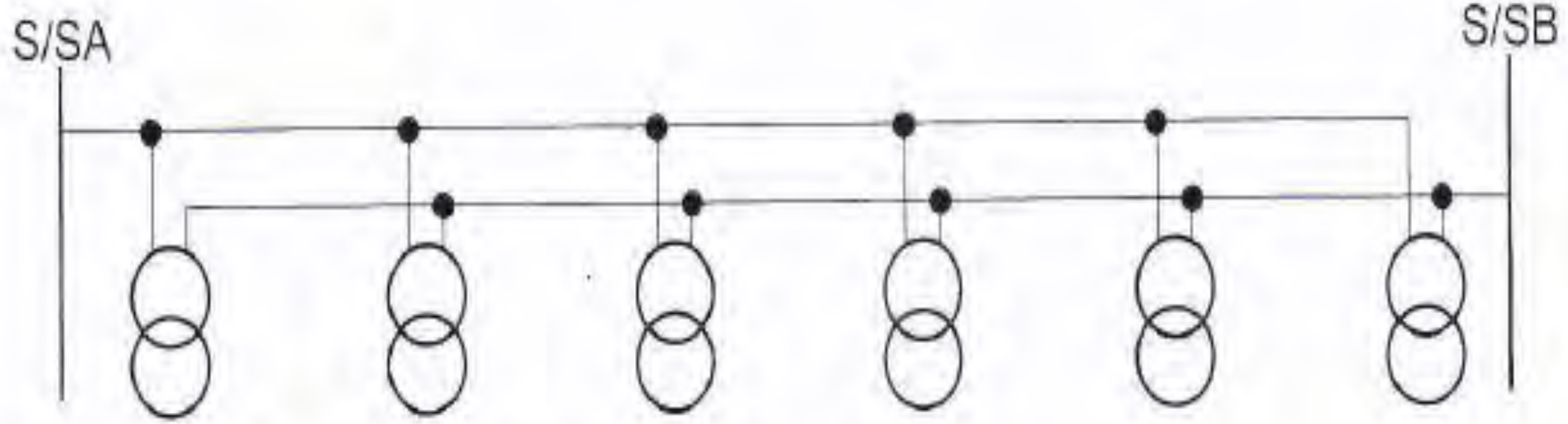


Figure 5.12 System with double-T connection.

Mesh systems at HV and MV levels

HV transmission systems

Meshed systems used for the medium and HV level are planned and operated in such a way that outage of any equipment, such as overhead lines, cables, transformers, compensation or bus-bar sections, will not cause a loss of supply to any load.

Increase of loading of the remaining equipment is obvious and can be accepted for a specified period up to the emergency rating of the equipment.

The voltage profile in the system will worsen during the outage.

The system is characterized by:

- complicated system structure
- high expenditure for system planning

- operation for normal operating conditions normally with all breakers closed
- loading of lines under normal operating conditions according to the planning criteria
- reserve for outages according to planning criteria
- high investment cost
- high cost of maintenance
- system losses minimal, in some cases the system topology needs to be changed
- Voltage profile for normal operating and for outage conditions according to planning criteria
- high flexibility for changed load conditions
- no interruption of supply according to planning criteria
- protection with distance protection relays or with differential protection
- applicable for HV and EHV systems for high load density

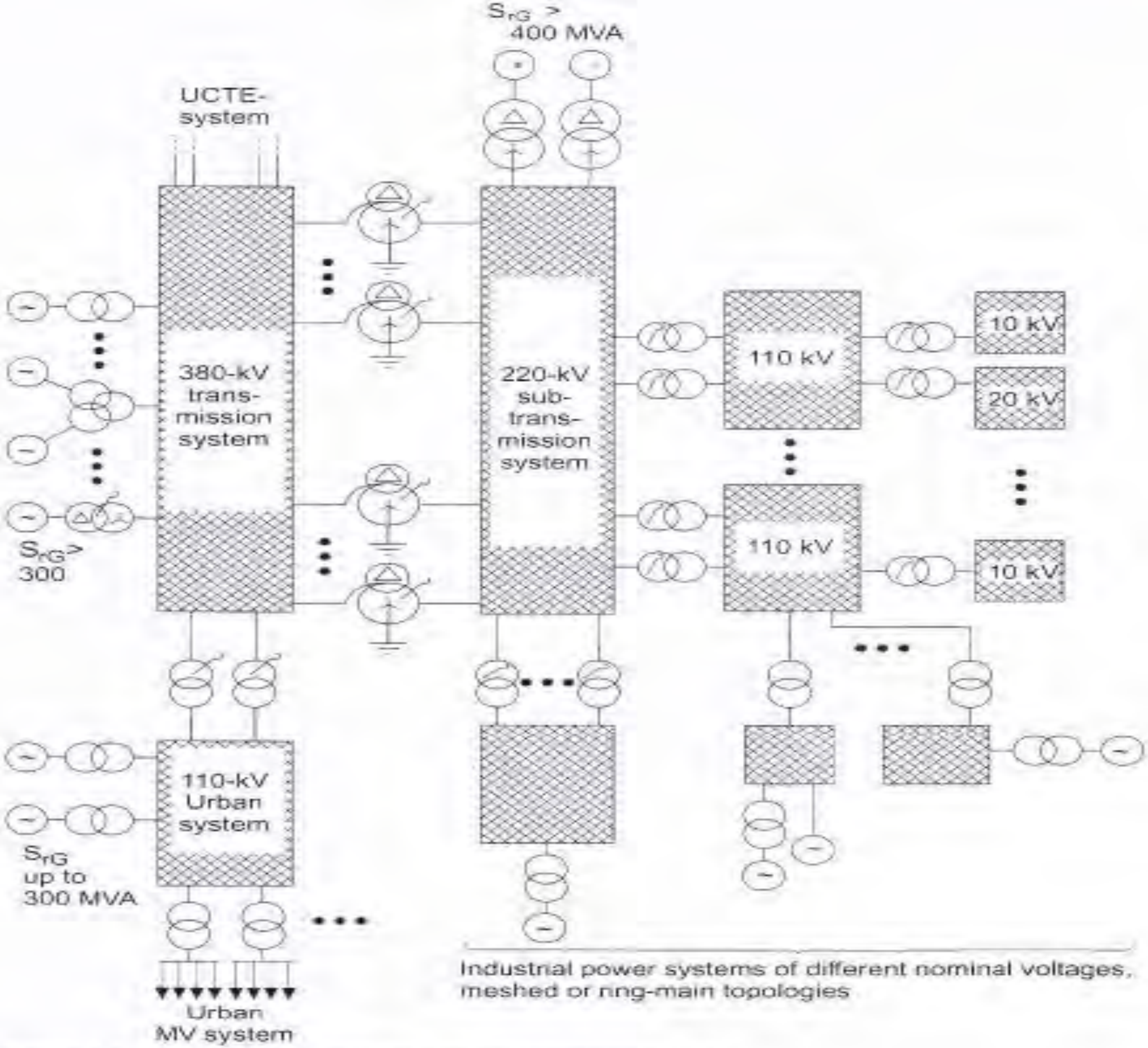
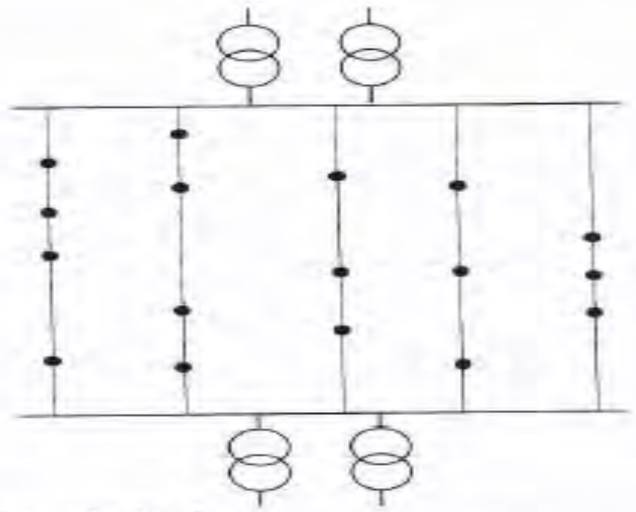


Figure 5.13 Diagram of a high-voltage transmission system with different voltage levels.

Meshed MV Systems

A typical meshed structure for MV systems is the ring main systems with all switches in closed position. Ring main systems can also be operated as meshed systems if the protection is designed accordingly i.e. ring main systems with feeding remote station.

All breakers and load-switches are closed, the loading of the lines depends on the load, the line impedance, and the r.m.s value and the phase angle of the voltages in the feeding substations.



// Disconnection point (n.o.)

• MV/LV transformer connected through fuse or disconnecting switch

Figure 5.14 Meshed MV system based on a ring-main structure.

The system is characterized by:

-Clear and simple structure

-Moderate to high planning expenditure

-Simple operation under normal operating conditions

-Loading of lines under normal operating conditions up to 70%

-Reserve for outages of more than one line

-Investment cost within the high range, especially if CB are installed

-Maintenance costs high

-System losses minimal

-Voltage profile in the system optimal, small differences between feeding station and remote station

- High flexibility for changed load conditions

-Reserve for outage of the feeding MV transformer and station available

-Standardization of cross sections of all lines

-Feeder protection usually with distance or differential protection relays

-Application in MV systems up to 35 kV also in case of high load density, for the supply of important consumers and in industrial power systems.

Meshed systems at the LV level

This systems are still found in older installations and in industrial power supply. The reliability is very high and multiple outage of equipment is covered with this scheme.

The voltage profile is flat and the system losses are minimal.

Depending on the connection of the feeding primaries, three different types of systems can be distinguished:

-supply station-by-station

-single-line supply

-multiple-line supply

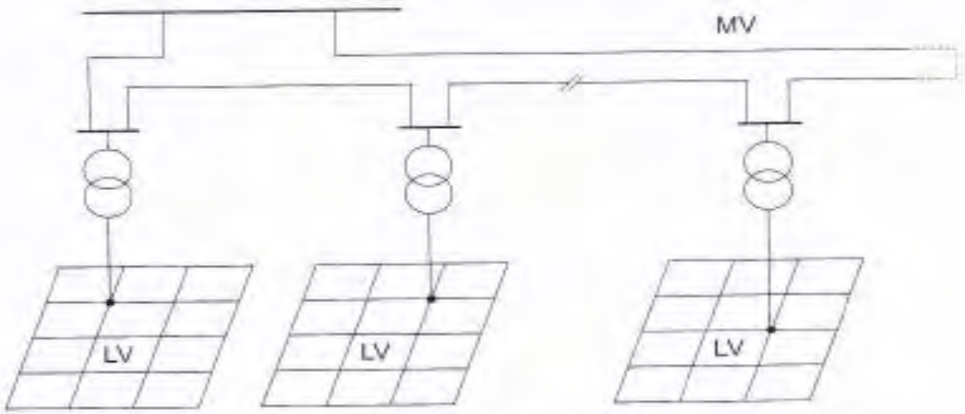


Figure 5.15 Structure of a meshed LV system supplied station-by-station.

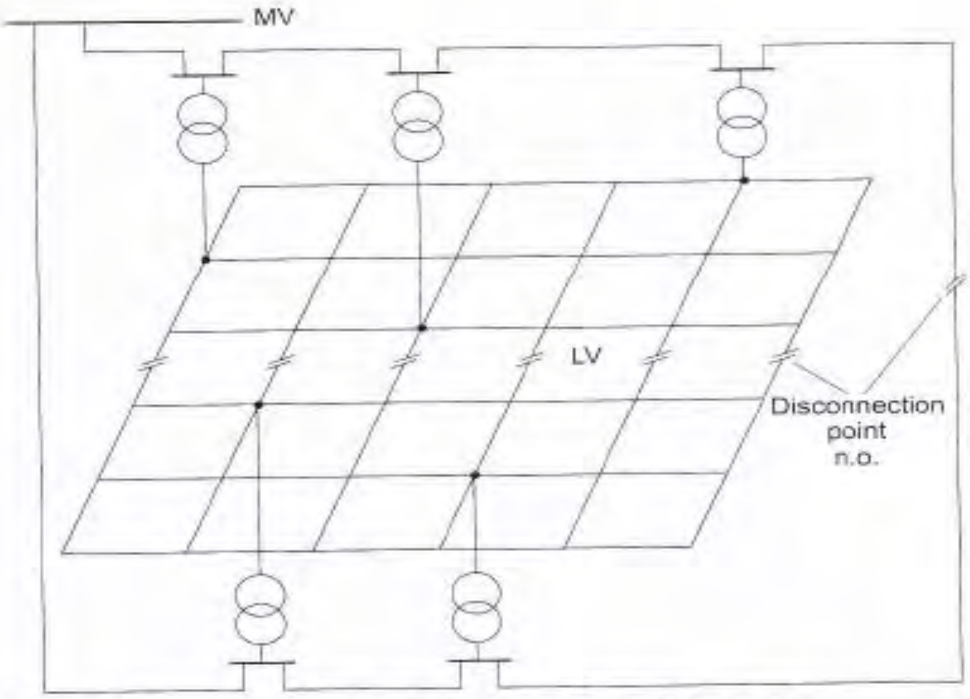


Figure 5.16 Structure of a meshed LV system with single-line supply.

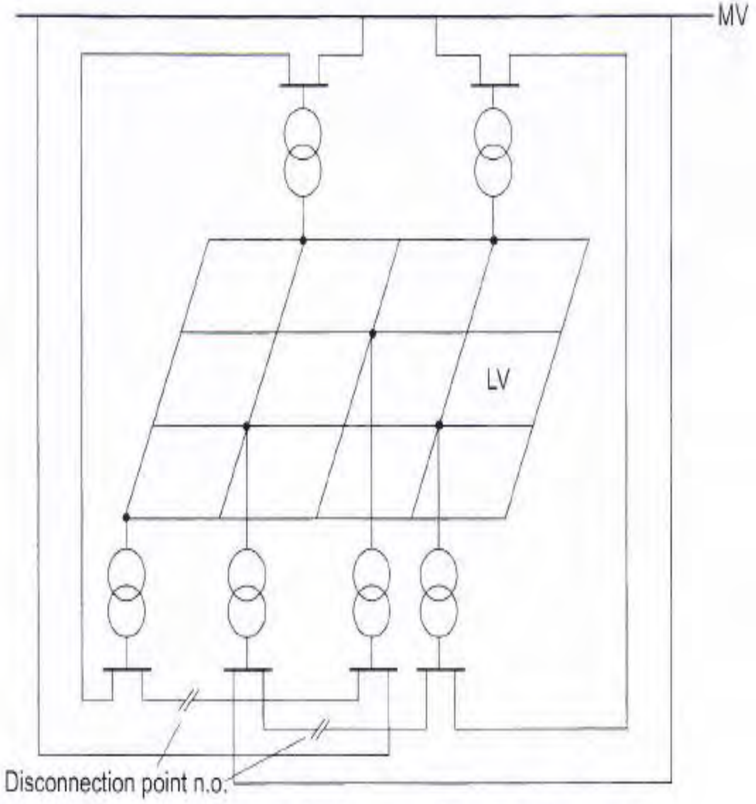


Figure 5.17 Structure of a meshed LV system with multiple-line supply.

Special operating considerations

Power system planning take into account operational constraints and a long-term view of load development by selecting a suitable voltage level. A general change of the system topology and of planning and operating criteria is introduced gradually into the system over a long period of time to allow for restructuring of existing systems.

Different voltages level e.g. medium and low voltage system should be planned and operated in such a way that a suitable structure is maintained on both levels, for instance if a medium voltage system is operated as a meshed system, the low voltage system can be operated as meshed or radial system.

The loading of equipment for normal and emergency conditions as well as the losses and the voltage profile for normal operating and for emergency conditions must be determined by load flow calculations.

Arrangement in Gridstations and substations

Busbar arrangements-General

The arrangement and connection of incoming and outgoing feeders in grid stations and substations and the number of bus-bars have an important influence on the supply reliability of the p.s.

Grid stations and substation and the topology of the p.s. must be designed in a similar way and must therefore be included in the context of planning as a single task.

Single busbar without separation

The simplest arrangement of a substation is presented in Fig 6.1a.

The outgoing feeders are connected to a single bus-bar and a single transformer is installed.

Independently of the number of feeders supplied according to the topology of the system, no supply reserve exists for the outage of the transformer or of the bus-bar.

The transformer can therefore be loaded up to 100% of its permissible (rated) load.

This arrangement is found in MV and LV systems but also in 110/10 kV systems, where a three winding transformer can be installed to feed two MV systems (see Fig 6.1c).

The arrangement with two transformers, as in Fig 6.1b, offers a supply reserve for the outage of one transformer if both transformers are loaded under normal operating conditions only to the extent that each one can take over the total load of the substation in case of outage of the other transformer, which is usually not substantially more than 50% of the rated load.

If circuit-breakers are installed in the outgoing feeders, s/c of the lines affect only the consumers attached to the faulted line, since the network protection disconnects the faulted line selectively.

If load break switches are installed in the outgoing feeders then one CB is needed either on the MV or on the LV side of the transformer.

In case of s/c on any feeder, the total load is switched off and supplied again only after isolation of the faulted line by the associated load-break switch.

This arrangement is characterized by the following features:

- supply reserve in the case of bus-bar faults not provided by the substation itself
- supply reserve against transformer outage only given with second transformer

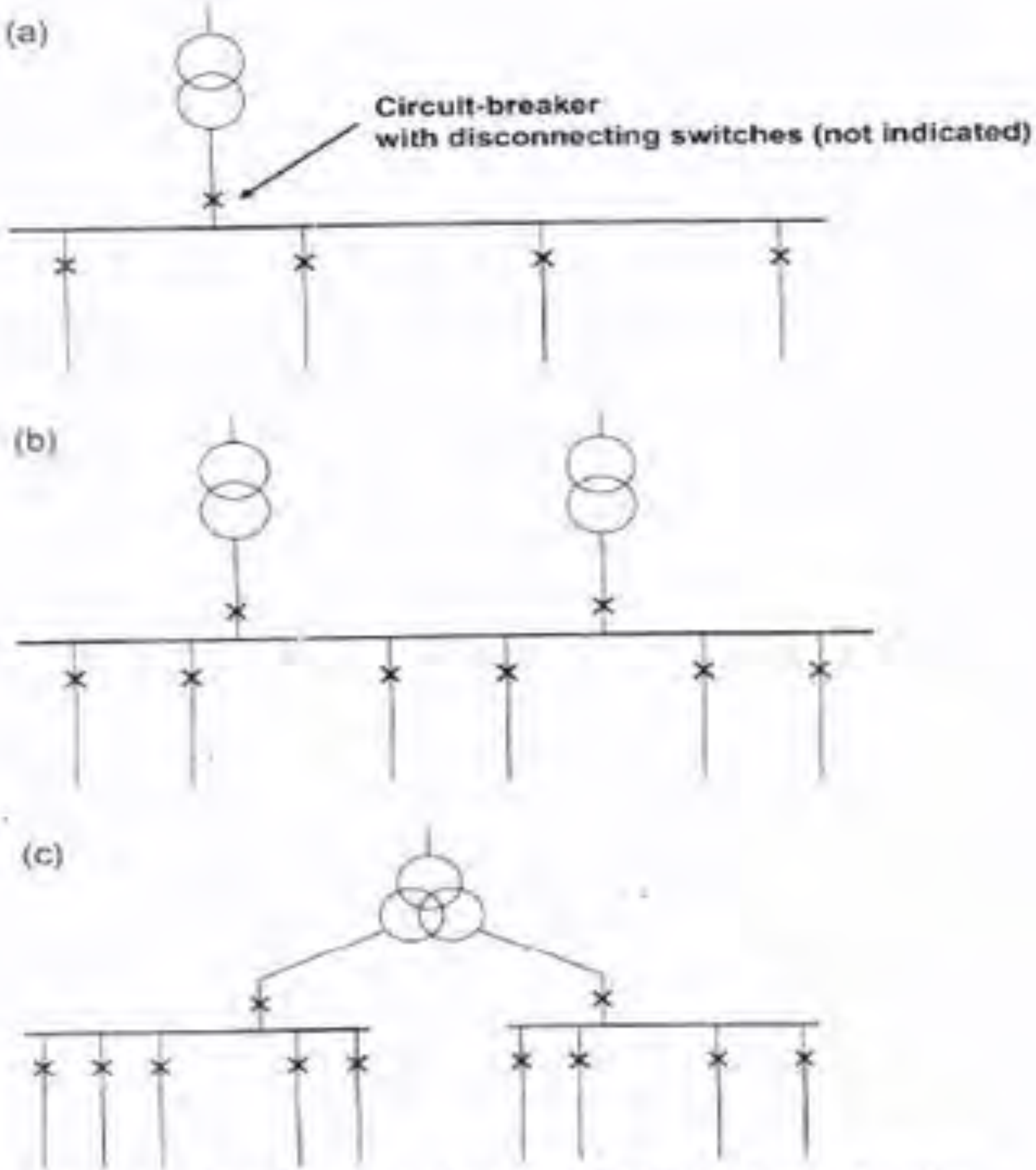


Figure 6.1 Substation single busbar on load-side. (a) Supply by one transformer; (b) supply by two transformers; (c) block arrangement to supply two MV systems.

- de-energizing the bus-bar requires interruption of supply
- installed usually only in areas with small load density in the LV and MV voltage range
- flexibility for operation is comparatively low
- feeder arrangement in radial systems possible without CB
- supply of ring main systems advisable only if a remote station is available

Single busbar with sectionalizer

The disadvantages described above can be avoided by arrangement of a bus-bar with sectionalizer.

In the first case the sectionalizing function is realized by a load-break switch, in the second case by a CB. It is generally not meaningful to construct substations having two transformers with single bus-bar without sectionalizer.

In principle with use of two transformers further arrangements of the substation are possible.

The block arrangement outlined in Fig 6.1c with sectionalizer or coupling is one of these possibilities.

Different arrangements with single bus-bar and more than one transformer are outlined in Fig 6.2

The arrangement is characterized by the following features:

- supply reserve in the case of bus-bar faults available for 50% of the load in the case of two bus-bar sections (66% in case of three bus-bar sections)
- supply reserve in the case of transformer outages available, depending on the loading transformers.

- deenergizing of a bus-bar section requires supply interruption for 50% or 33% of the load, depending on the number of bus-bar sections
- installed usually only in areas with medium load density in LV and MV systems
- used as an intermediate installation if three transformers are to be installed finally.
- flexibility in operation in the medium range
- arrangement of feeders in radial systems possible without CBs
- supply of ring main systems with remote station enables higher loading of the transformers.

Substation H-arrangement

Substations with single bus-bar, longitudinal bus coupler and two transformers are also installed in the 110 kV systems in urban areas.

The 110 kV cables are looped in and out to the substation as outlined in Fig.6.3.

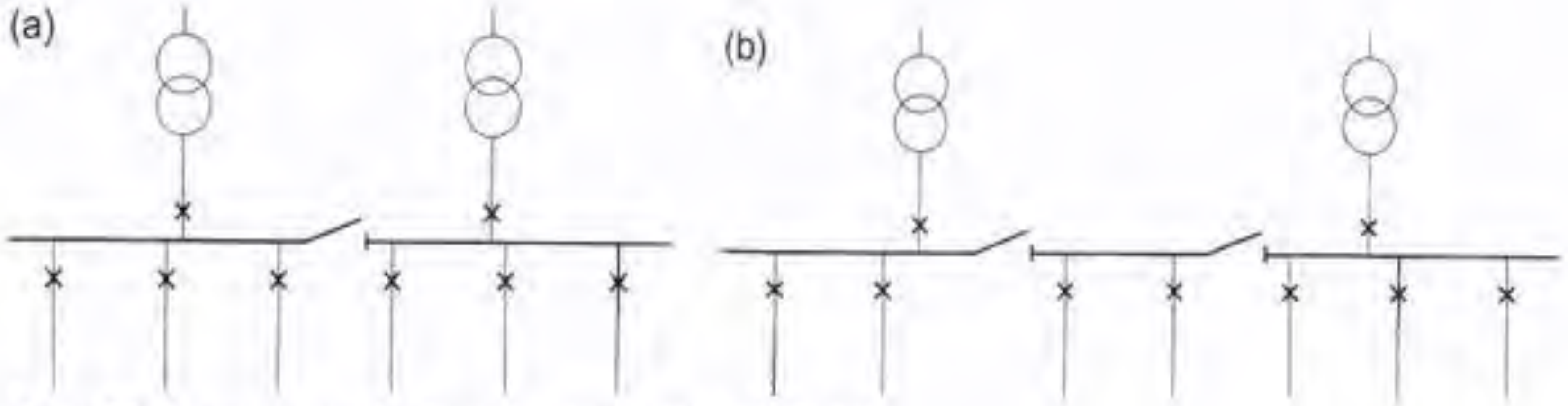


Figure 6.2 Arrangement of substations with single busbar and several transformers on the load-side. (a) Two transformers, two busbar sections; (b) two transformers, three busbar sections.

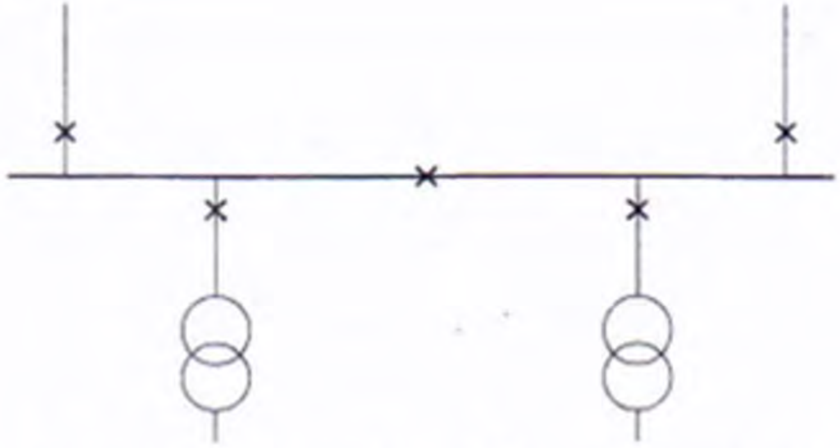


Figure 6.3 Arrangement of a substation in H-arrangement (fully equipped with circuit-breakers) on the feeding side.

If the parameters of the line protection are set in such a way that the longitudinal bus coupler is opened in case of s/c on the lines, CBs in the outgoing feeders can be avoided and only load break switches are needed.

A similar arrangement is applied for the transformer CBs, where in case of faults the feeding line is then possibly switched off also.

A substation arrangement without any CBs is called load disconnecting substations, but this requires two load-break switches in the bus-bar in order to be able to de-energize each section of the bus-bar.

The characteristic features of the arrangement are:

- supply reserve in the case of bus-bar faults available for 50% of the load, depending on the arrangement of the lower voltage side also for 100% of the load.
- in the case of bus-bar faults, no energy supply through the connected cables or overhead lines.

- supply reserve in the case of outage of transformer faults available
- de-energizing of a bus-bar section possible without supply interruption with an appropriate arrangement on the lower voltage side.
- used in areas with medium load density, sometimes also with high load density in urban systems
- limited flexibility in operation
- reduced investment cost for 110 kV also possible

Double busbar arrangement

Switchgear with double bus-bar is a typical arrangement for grid-stations in MV, HV and EHV systems.

All incoming and outgoing lines and transformers are connected with CB and disconnecting switches to the bus-bars, as outlined in Fig. 6.4

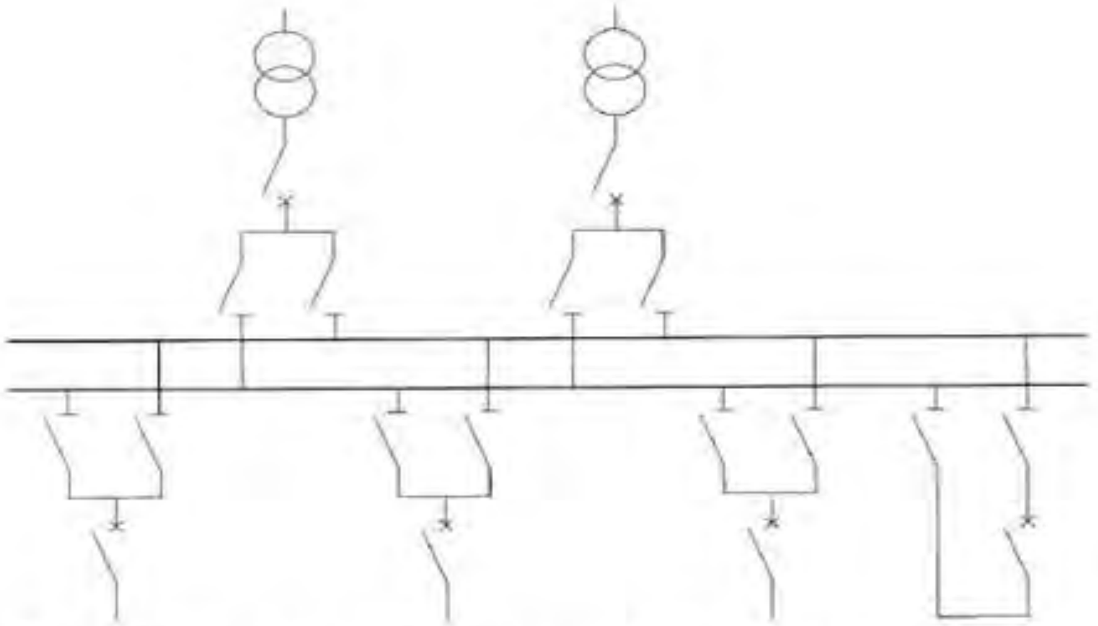


Figure 6.4 Switchgear arrangement in a HV gridstation with double busbar.

A bus coupler, consisting of CB and disconnecting switches, is necessary to separate the two bus-bars in case of bus-bar faults.

The arrangement offers a high degree of supply reliability and operational flexibility, since each outgoing line and transformer can be switched without supply interruption from one bus-bar to the other if the bus-bars are operated in coupled mode.

For separate operation of the bus-bars, separated network groups can be operated.

Typical characteristics of the arrangement with double bus-bar are:

- supply reserve in the case of bus-bar faults available for the entire load
- supply reserve for outage of transformers available, depending on the loading of the transformers
- de-energizing of a bus-bar section possible without supply interruption
- used even in urban areas with very high load density
- used in HV and EHV transmission systems
- used in important substations in MV systems
- used for supply of industrial systems
- very high operation flexibility

Arrangement in switchyards

Switchyards need to be designed with respect to the foreseeable voltage stress, switching and breaking capability, s/c withstand capability, loading under normal and emergency conditions taking account of the requirements of load dispatch management, operational security and supply reliability.

A switchyard consists of:

- electrotechnical equipment such as switchgear, current and voltage transformers, surge arresters, insulation joints, and armatures
- mechanical structural parts such as conductors, bars and pipes for bus-bars and gantries, partly seen as electrotechnical equipment as well

- secondary devices such as measuring and protection transformers and transducers, protective relays, coupling for remote control, batteries and so on
- civil engineering structures such as buildings, foundations, fire-extinguishing equipment and fences

The document of switchyards becomes extensive when account is taken of the multiplicity of items of equipment, their interdependency and their importance.

Knowledge of the appropriate standardized symbols according to the different parts of IEC 60617 (DIN 40101) is therefore necessary.

Breaker and switches

The different types of breakers and switches to be used in switchgears are described in different parts of IEC 60947 and IEC 60890 (VDE 0660) for LV installations as well as in EN 50052 and EN 50064 (VDE 0670) for HV installations.

- CB have a switching capability for switching on and off any kind of current up to the rated current, that is, load current and s/c currents.
- CB installed in overhead systems should have the capability of operating sequences for successful and unsuccessful autoreclosing.
- Load-break switches are capable of switching load currents under normal operating conditions, but have no capability for switching s/c currents.

- disconnecting switches can be operated only under no load conditions. Currents of bus-bars without load and no-load currents of transformers with low rating can be switched on and off as well. Interlocking with the CB is necessary.
- Earthing switches are used for earthing of equipment.

  The combination of earthing switch with disconnecting switch is common.
- Fuses are installed in LV and MV systems only. They interrupt currents of any kind by the melting of a specially designed conductor and must thereafter be replaced. Combination of fuses with disconnecting switches can be found especially in LV systems

CB are named according to the method of arc quenching they use. VCB are nowadays installed in MV systems, in the HV and EHV range outdoor CB are operated with compressed air or sulfur hexafluoride (SF_6). CB in gas insulated switchgear (SF_6 – isolated) are of the SF_6 –type.

Incoming and outgoing feeders

Incoming and outgoing feeders in switchgear are equipped with CB and disconnection and earthing switches.

Current and voltage transformers for the connection of protection and measurement devices are usually installed at each feeder in HV switchyards.

The CT is placed at the bus-bar side of the voltage transformer in order to detect s/c of the voltage transformer by the protection device.

Installations without voltage transformers in each feeder are also found: in this case the voltage transformer is placed at the bus-bar.

In addition, the feeders are equipped with surge arresters and coupling devices for frequency carrier signals depending on the requirements of the switchgear.

A typical arrangement of the individual devices of feeder arrangement in a HV switchyard is outlined in Fig. 6.5.

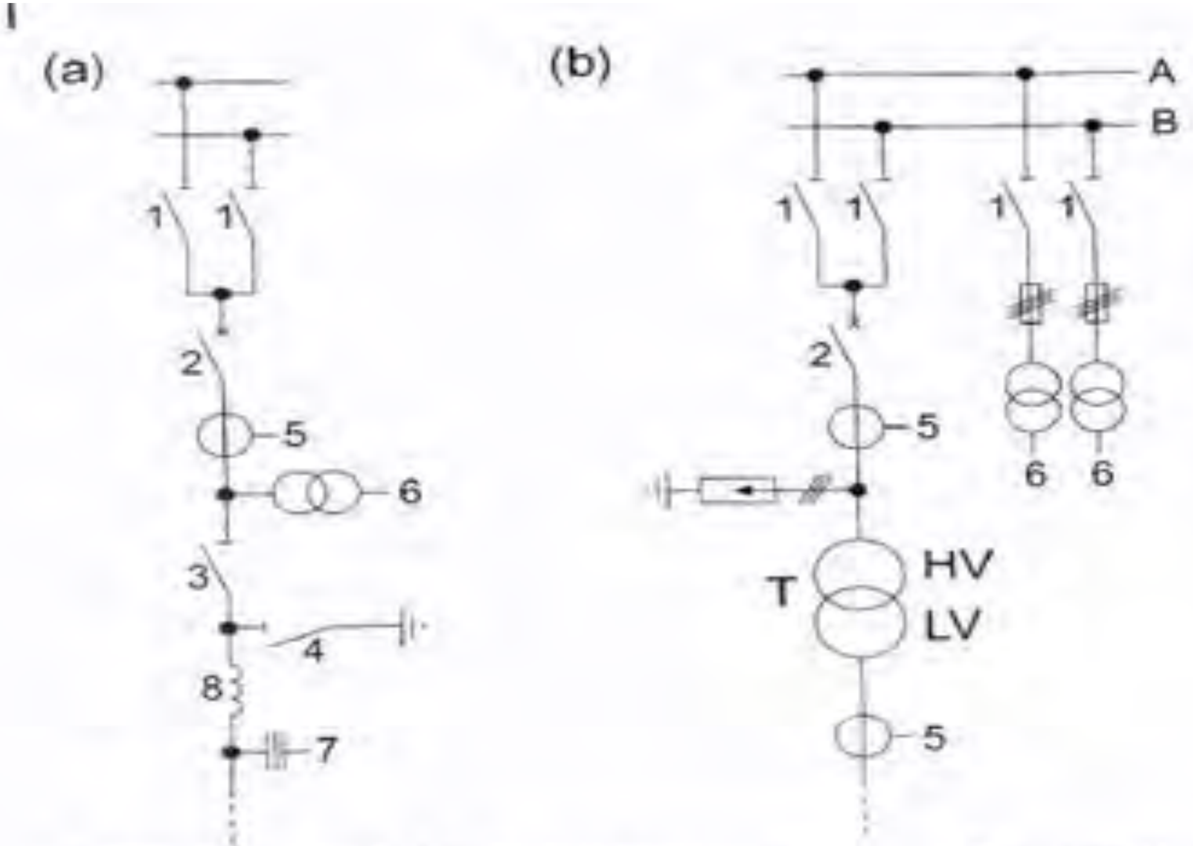


Figure 6.5 Typical feeder arrangement in a HV switchyard [12]. (a) Overhead line feeder with double busbar; (b) transformer feeder with double busbar. **1**, Busbar disconnecting switch; **2**, circuit-breaker; **3**, feeder disconnecting switch; **4**, earthing switch; **5**, current transformer; **6**, voltage transformer; **7**, capacitive voltage transformer with coupling for frequency carrier signal; **8**, blocking reactor against frequency carrier signals.

Transformers-General

The design and rating of transformers for utilization in power stations and industrial systems as well as in transmission and distribution systems are subject to the particular conditions of the respective application.

The main data, besides the construction type, are the rated apparent power, the rated voltages of the windings, the impedance voltage and the no load and s/c losses.

The rated apparent power can in principle be determined individually for each specific installation, but it should be noted that, with respect to reserve capability of spare transformers and replacement and maintenance requirements, the number of different types and ratings should be limited.

For transformers to be installed in medium and LV systems, standardized values of apparent power, impedance voltage and losses should preferably be used.

Transformers used within a HV range in general are designed individually according to owner’s specification.

Transformers are usually provided with additional tap windings, to be switched on and off by tap-changers to control the voltage drop within a small range defined by the additional voltage of the tap winding. LV transformers are constructed with tap-windings,

but these can be operated only under no-load and no-voltage condition.

The weight and dimensions of power transformers are determining factor concerning transport and maneuverability, that is, the load carrying capacity of bridges, road and railway constructions, the minimum clearance profile in tunnels, under bridges and at road embankments

Transformers Loading

No.	Type of Development	% Transformer Loading
1.	Residential	85%
2.	Commercial	60%
3.	Industrial	60%
4.	Mixed (Residential + Commercial / Industrial)	*Majority Residential: 85% Majority Commercial / Industrial: 60%
5.	Individual/Dedicated Commercial or Industrial	Based on customer's load

*Note:

Majority ⇒ if more than 50% residential load, choose 85% Tx loading; otherwise, choose 60%

Transformer Impedance Voltage

- Transformer impedance voltage, % Z, is usually listed on the transformer nameplate and expressed as a percentage (%).

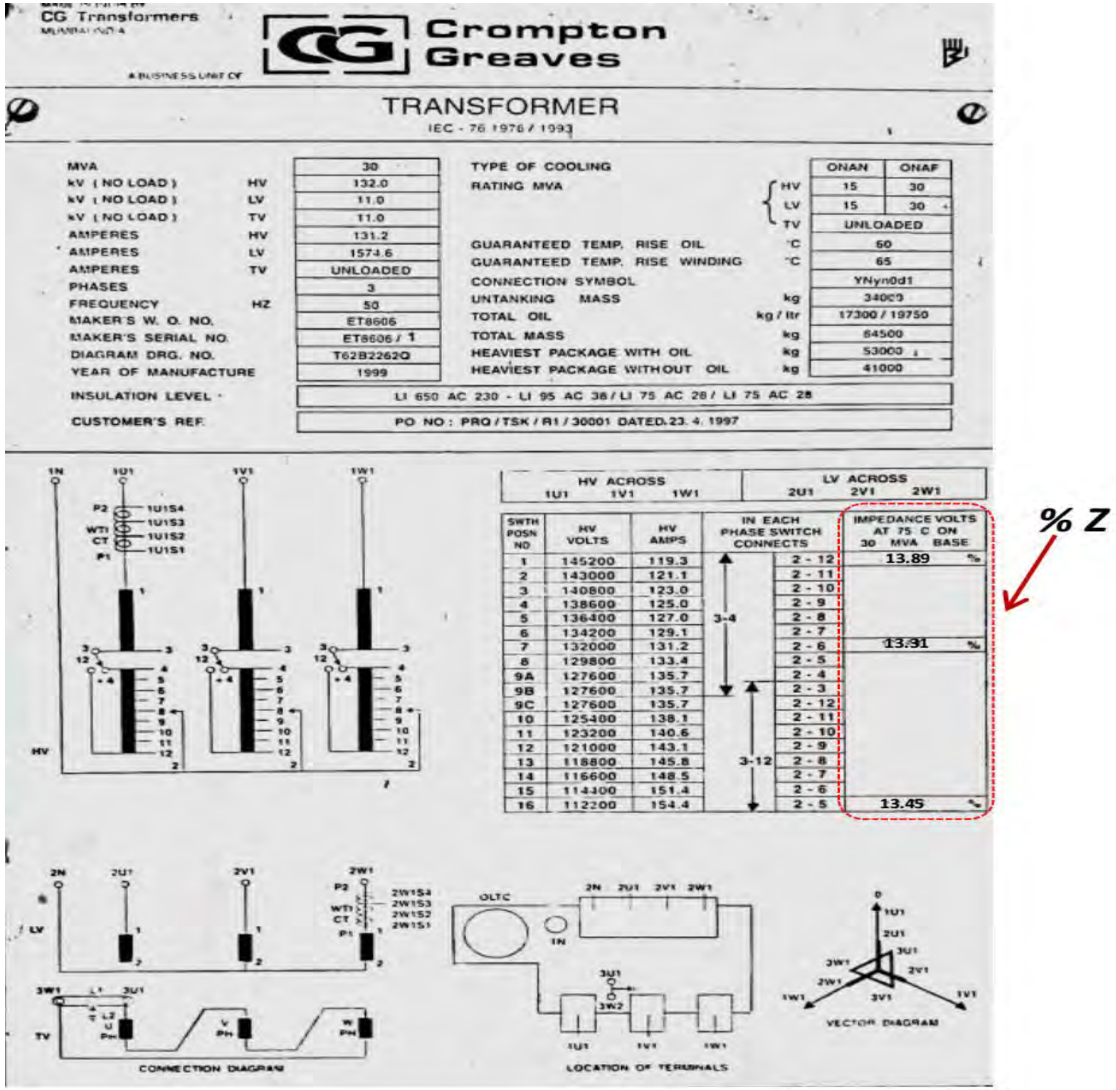
- The transformer impedance voltage value is expressed as a percentage of the rated voltage.

- It is an important parameter as it is used for fault level calculation.

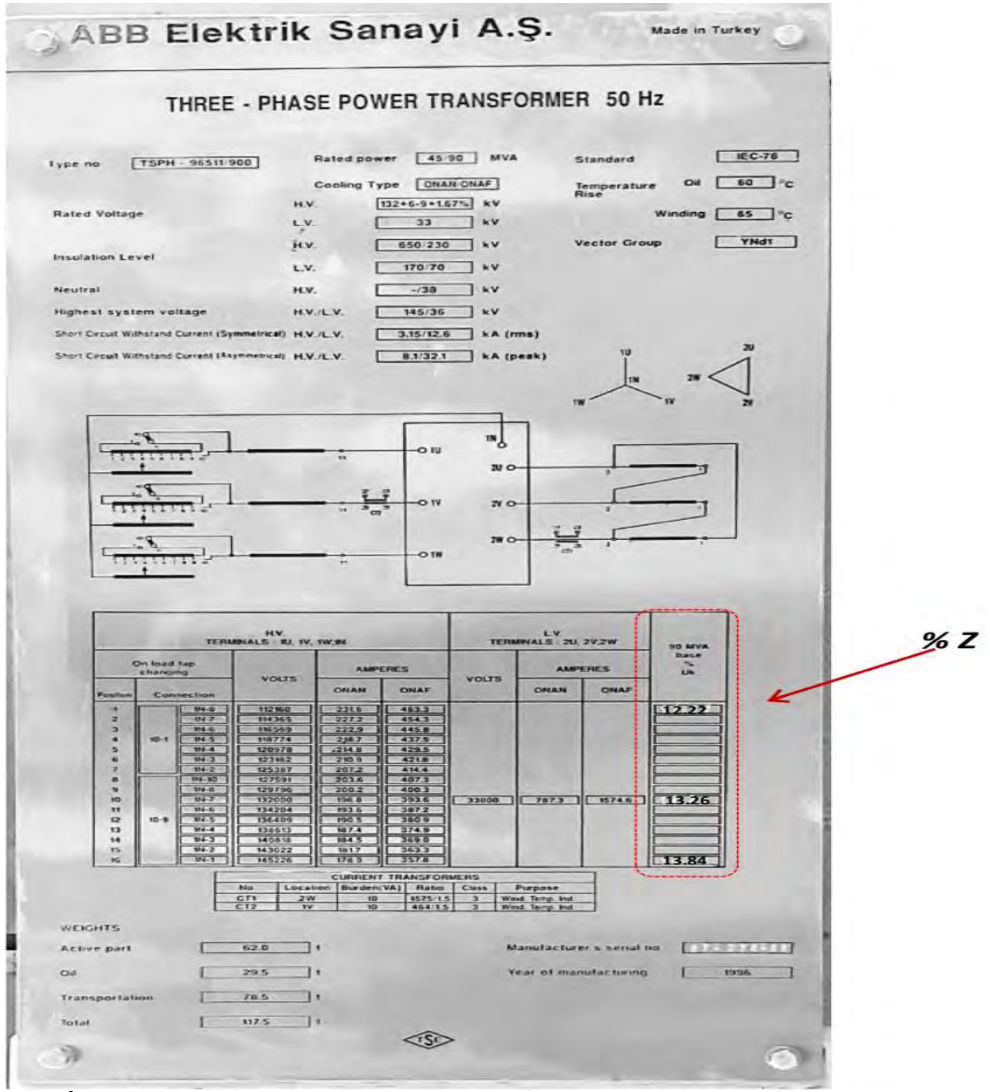
- The transformer impedance voltage is measured by short circuiting the secondary winding of the transformer and the voltage at the primary side is increased until rated current flow at the secondary.

- %Z signifies the percentage of the nominal voltage in the primary side that is required to circulate the rated current in the secondary side.

Transformer Impedance Voltage



132/11 kV transformer nameplate



132/33 kV transformer nameplate

Transformer Impedance Voltage

Typical transformer impedance voltage

Transformer Type	Impedance voltage
Potential Transformer (PT) (100 VA – 500 VA)	1 %
Small Distribution Transformer (≤ 1 MVA)	4.75%
Large Distribution Transformer (2 MVA – 5 MVA)	5 - 6 %
Small Power Transformer (7.5 MVA)	6 - 7 %
Medium Power Transformer (12.5 MVA– 15 MVA)	7 - 9 %
Large Power Transformer (>15 MVA– 30 MVA) at PPU	9 -11 %
Very Large Power Transformer (≥ 30 MVA) at PMU	11– 15 %

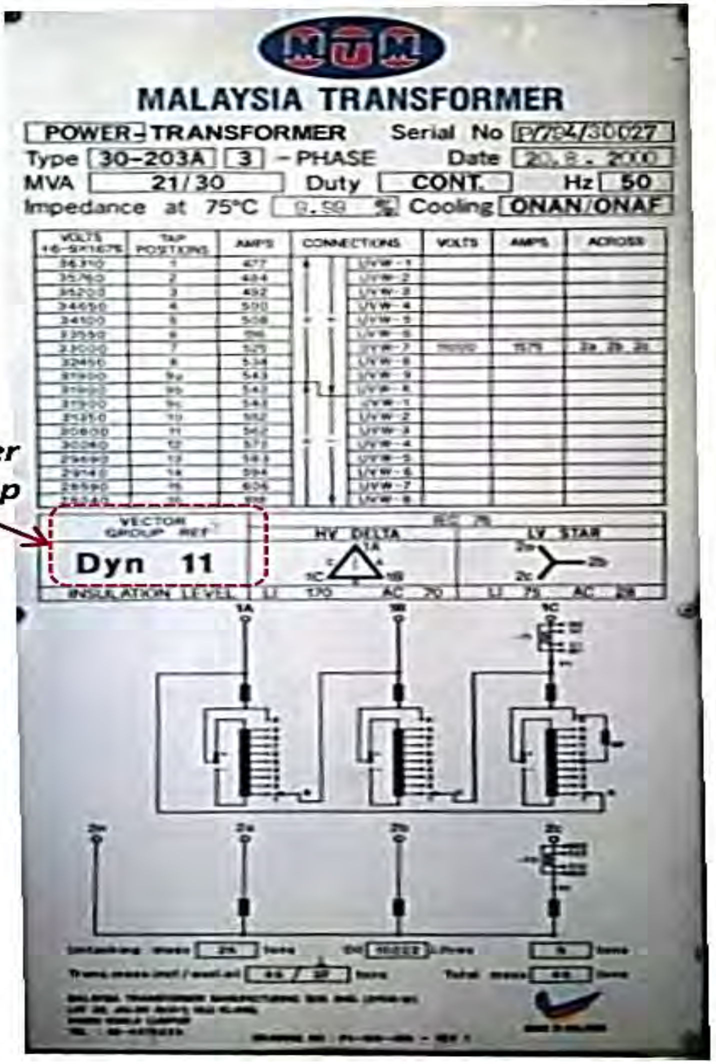
Transformer Windings Connection Symbol

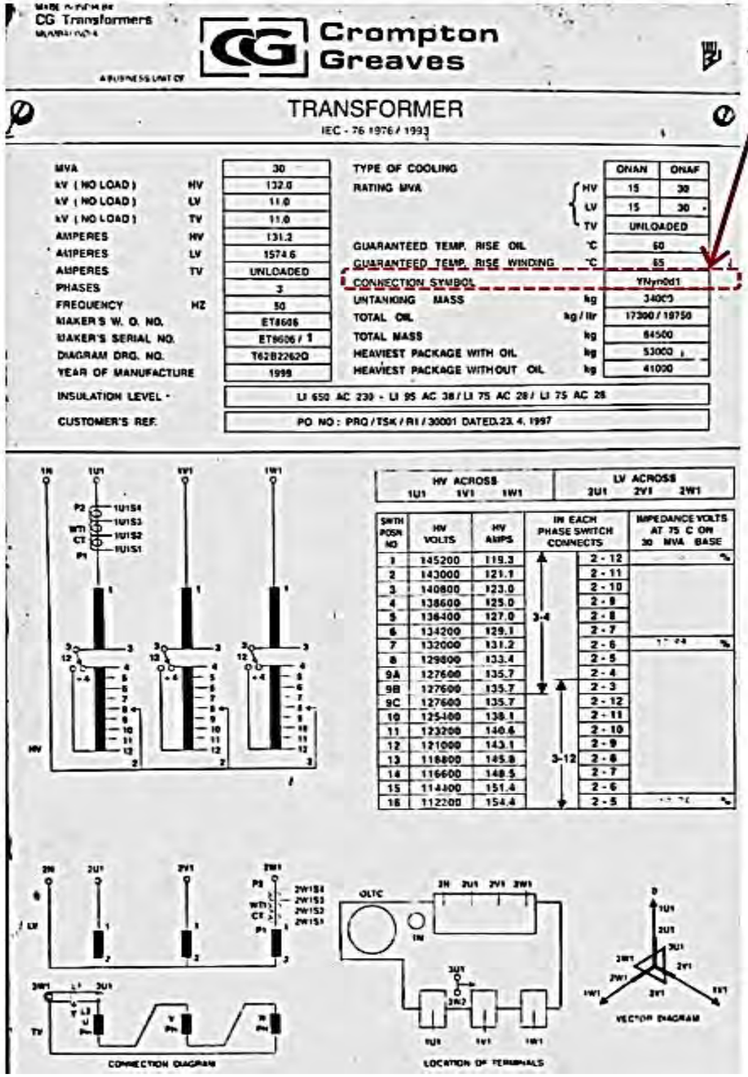
- Transformer windings connection symbol or loosely known as transformer vector group provides information on the connection of the three phase windings and phase displacement.

Transformer Vector Group

Configuration	(I)	(III)	(VI)
Delta	D	d	d
Wye	Y	y	y
Zigzag	Z	z	z

Transformer vector group





Transformer vector group

Alphanumeric	Description
(I)	Transformer configuration at the high voltage winding.
(II)	Indication if the neutral point of the wye connected high voltage winding is brought out.
(III)	Transformer configuration at the lower voltage winding with respect to **(I)**.
(IV)	Indication if the neutral point of the wye connected lower voltage winding is brought out.
(V)	Phase displacement between the high voltage winding and lower voltage winding.
(VI)	Transformer configuration at the tertiary winding.
(VII)	Phase displacement between the high voltage winding and tertiary winding.

Samples of transformer name plate showing the transformer vector group

Cables system-general

Cables are used for the transmission and distribution of electrical energy in public and industrial p.s.

The permissible loading of the cables is determined by different parameters such as environmental conditions, type of laying(in ground or in air), cable design and type of insulation, operating conditions and so on.

Conductors are made of aluminum or copper.

The insulation is of various materials: PVC (polyvinyl chloride) and PE (polyethylene) are used as standard used in LV and MV cables; oil insulation and gas pressure cables can still be found in HV systems, whereas XLPE (cross linked polyethylene) insulated cables are today standard in p.s with nominal voltages of 110 kV and above.

Mass-impregnated paper-insulated cables are still in use in the MV range, but are found only on older cable routed; this type will no longer be installed.

Cable abbreviation codes are used that indicate the material of the cable from the inner layer to outer layers.

Copper conductors, mass-impregnated paper insulated cables, and internal protection shields are not specially indicated.

In addition to the coding of the inner construction, the number of conductors, the cross-section and the shape of the conduct as well as the nominal voltage is indicated.

Special coding is defined in the specific cable standards.

Abbreviation codes for impregnated paper-insulated cables and cables with PVC or XLPE insulation are listed in Tables 8.1 and 8.2.

Conductor shape and type are identified as

RE -solid round conductor

RM –stranded round conductor

SE-solid sector-shape conductor

SM-stranded sector-shape conductor

RF-flexible stranded round conductor

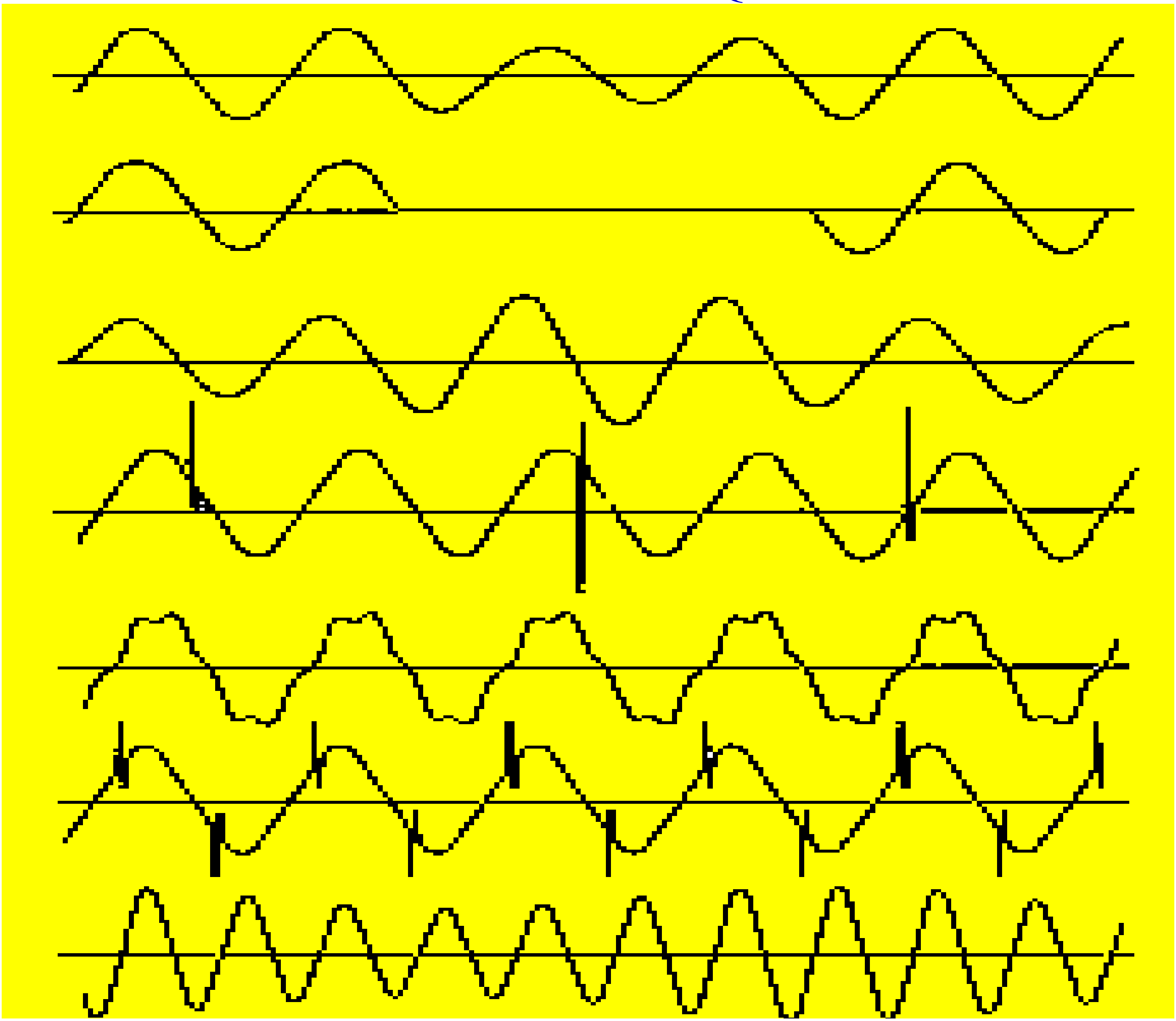
Table 8.1 Alphanumeric abbreviations for cables with impregnated paper insulation.

Abbreviation	Meaning
A	Aluminum conductor
H	Screening for "Hochstadter" cable
E	Individual wires wrapped with metal screen and corrosion protection
K	Lead alloy screen
KL	Pressed or smooth extruded aluminum jacket
KLD	Pressed or smooth extruded aluminum jacket, extension elements
u	Nonmagnetic
D	Pressure bandage
E	Protective covering with embedded layer of elastic bands or foils
D	Nonmagnetic pressure bandage
v	Twisted conductors
F	Armoring of galvanized steel strips with retaining metallic spiral of metal strip
Gl	Nonmagnetic gliding wires
u	Nontwisted conductors
St	Steel tube
B	Armoring of galvanized steel strips
F	Armoring of galvanized flat steel wires
FO	Armoring of galvanized flat steel wires, open
R	Armoring of galvanized round steel wires
RO	Armoring of galvanized round steel wires, open
Gb	Retaining spiral of galvanized steel strip (anti-twist tape)
A	Protective cover of fibers
AA	Double protective cover of fibers or glass-fiber tapes
Y	Outer PVC-sheath
2Y	Outer sheath of thermoplastic material (PE)
YV	Reinforced PVC sheath

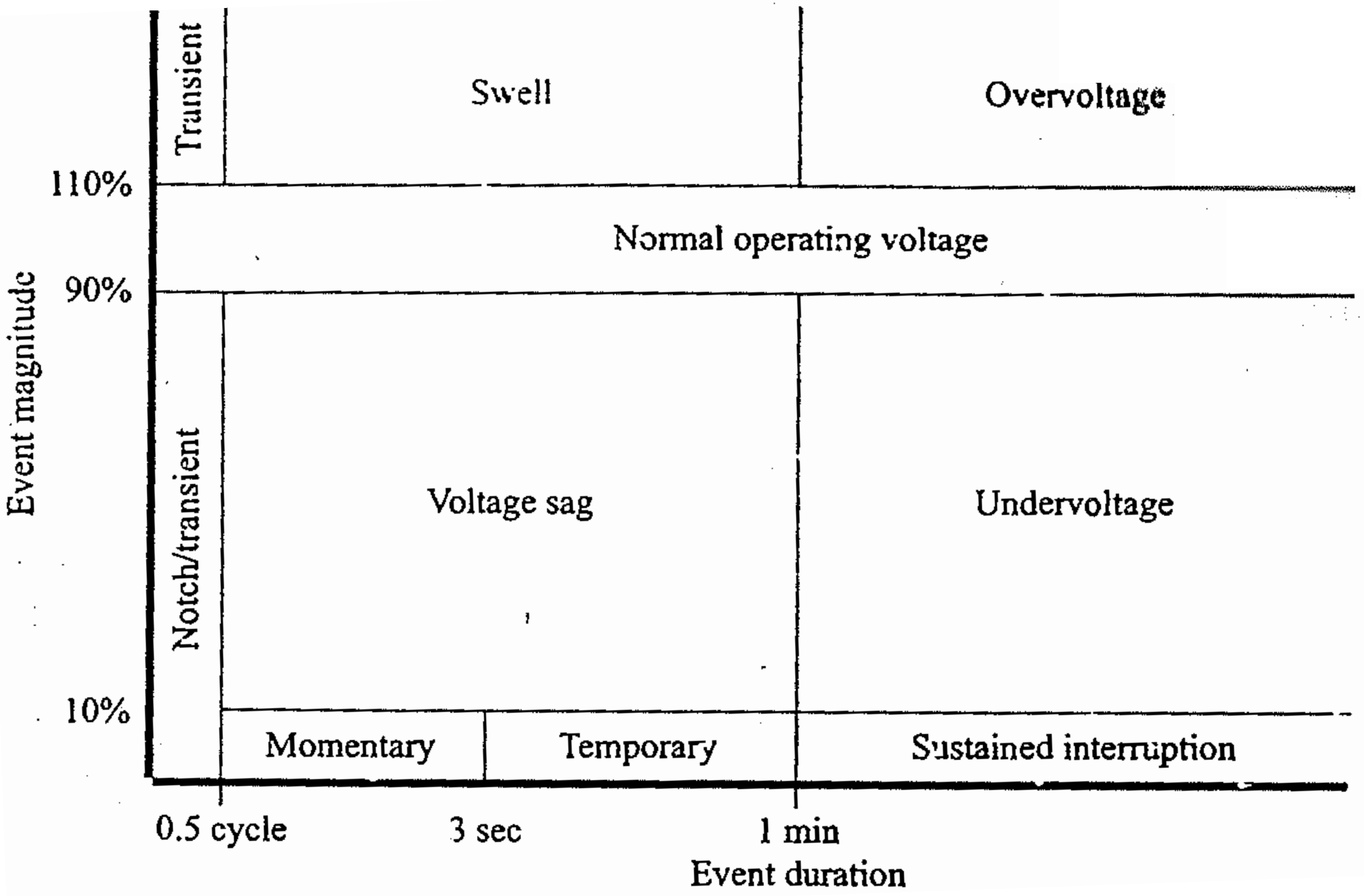
Table 8.2 Alphanumeric abbreviations for cables with plastic insulation (PVC, PE, XLPE).

Abbreviation	Meaning
A	Aluminum conductor
I	House wiring cables
Y	PVC thermoplastic insulation
2Y	PE thermoplastic insulation
2X	Polymerized (cross-linked) PE insulation (XLPE)
H	Conductive, electric field limiting layer, covering conductor and insulation
HX	Insulation of interlaced halogen-free polymer mixture
C	Concentric conductive layer of copper
CW	Concentric corrugated conductive layer of copper
CE	Concentric conductive layer of copper, applied to each core of multiple-core cables
S	Copper screen or screen
SE	Conductive electric field limiting layer, covering conductor, insulation, and copper screen, applied to each core of multiple-core cables
K	Metal screen of lead alloy
F	Metal jacket screen of galvanized flat steel wires
R	Armoring of galvanized round steel wires
Gb	Retaining spiral of galvanized steel strip (anti-twist tape)
HX	Coating of cross-linked halogen-free polymer mixture
Y	Protective cover between screen or concentric layer and armoring made of PVC
Y	PVC outer covering
2Y	Outer covering of thermoplastic material (PE)
FE	Flame resistance of insulation, flash point to be specified

TYPES OF POWER QUALITY DISTURBANCES



DEFINITION OF IEEE 1159 - 1995



CAUSES, EFFECTS & MITIGATION OF PQ EVENTS

EVENTS	CAUSES	EFFECTS	MITIGATION
Sags & Swells	Electromagnetic disturbance (by components failure – fault clearing, utility power system, trees, animals, lightning, 3rd party digging)	Equipment trip / process interrupted	System improvement (utility), power conditioner (customer), improvement of equipment immunity (manufacturer)
Harmonics	Electronic gear (3Ø rectifier, power regulator, customer's capacitive component), welders, arc furnaces, fluorescent ballasts, pc	CB tripping, unexplained fuse operation, capacitor failure, electronic equipment malfunction, flicking lights & telephone interference	Harmonic filter (shunt passive/active filter), ensure minimum harmonic emission on network design stage

CAUSES, EFFECTS & MITIGATION OF PQ EVENTS

EVENTS	CAUSES	EFFECTS	MITIGATION
Flickers	Mainly by intermittent heavy load starting or pulsating loads, huge arcing generated by furnaces in steel mill (cause health problem such as epilepsy), electronic gears, motors	Equipment trip / process interrupted	Review starting arrangements or system capacity & configuration, flicker compensator
Voltage Fluctuation	Generation voltage, load end, long line-length $\Rightarrow$ $\uparrow$capacitance	Ferranti effect, voltage violation, customer equipment affected	Cap bank, cable sizing, transformer tap, booster
Frequency Deviations	Generation Vs load	Generation $\approx$ Load (freq unstable)	Maintain healthy spinning margin
Transients (Bare O/h only)	Animals, lightning, vegetation	Intermitent outage & auto-recloser operation	Rentice maintenance

POWER QUALITY REQUIREMENT

Type Of Disturbance	Indices	Acceptable permissible values at point of common coupling (PCC)	Reference Document
Voltage Step Change	ΔV %	1% - Frequent starting/switching and/or disconnection of load.	UK's Engineering Recommendation P28
		3 % - Infrequent single starting/ switching or disconnection of Load – once in two hours or more hours.	
		6 % - Starting/switching once or twice a year.	
Voltage Fluctuation and Flicker	Absolute Short Term Flicker Severity (P_{st})	1.0 (at 132kV and below)	UK's Engineering Recommendation P28
		0.8 (Above 132kV)	
	Absolute Long Term Flicker Severity (P_{lt})	0.8 (at 132kV and below)	
		0.6 (Above 132kV)	
Harmonic Distortion[2]	Total Harmonic Distortion Voltage (THDV) %	5 % at $\leq$ 400 Volt	Engineering Recommendation ER G5/4
		4 % at 11kV to 22kV	
		3% at 33kV	
		3% at 132kV	
Voltage Unbalance	Negative Phase Sequence Voltage %	2% for 1 minute	UK's Engineering Recommendation P29