STRUCTURE OF ELECTRICAL NETWORKS AND SUBSTATION ARCHITECTURES

1. Introduction

Generation, transmission and distribution systems are the main components of an electric power system. Generating stations and distribution systems are connected through transmission lines. Normally, transmission lines imply the bulk transfer of power by high-voltage links between main load centres. On the other hand, distribution system is mainly responsible for the conveyance of this power to the consumers by means of lower voltage networks. Electric power is generated in the range of 11 kV to 25 kV, which is increased by stepped up transformers to the main transmission voltage. At sub-stations, the connection between various components are made, for example, lines and transformers and switching of these components is carried out. Transmission level voltages are in the range of 66 kV to 400 kV (or higher). Large amounts of power are transmitted from the generating stations to the load centres at 220 kV or higher. The network formed by these very high voltage lines is sometimes called as the super-grid. This grid, in turn, feeds a sub-transmission network operating at 132 kV or less.

These electricity supply systems are invariably three-phase. The design of transmission and distribution networks is such that normal operation is reasonably close to balanced three-phase working, and often a study of the electrical conditions in one phase is sufficient to give a complete analysis. Equal loading on all three phases of a network is ensured by allotting, as far as possible, equal domestic loads to each phase of the low-voltage distribution feeders; industrial loads usually take three phase supplies.

2. Overall architecture of the electrical network

An electric power system is a complex interconnected network which can be subdivided into three major parts: Generation, Transmission and Distribution. The transmission system may be divided into primary and secondary (sub-transmission) transmission system. Distribution system can be divided into primary and secondary distribution system. Most of the distribution networks operate radially for less short circuit current and better protective.
Fig. 2.1 shows the schematic diagram of structure of a power supply network.

2.1. Generation

Generation is used to produce electrical energy using turbo-alternators that transform the mechanical energy of the turbines into electrical energy from a primary source (gas, oil, hydraulics, etc.). Generators usually produce voltages in the range 11–25 kV, which is increased by transformers to the main transmission voltage. Primary sources vary from one country to another, for example in Algeria natural gas covers more than 70% of production, in France, 75% of electricity is of nuclear origin. In general, each source of production (power plant) groups together several turbo-alternator groups to ensure availability during maintenance periods. In addition, in industrialized countries, we find increasingly high installed powers to meet the growing demand for electrical energy, for example the

Three Gorges hydroelectric power plant in China 34x700 MW (which became the largest power plant in the world in 2014).

With today's emphasis on environmental consideration and conservation of fossil fuels, many alternate sources are considered for employing the untapped energy sources of the sun and the earth for generation of power (renewable energies). Some of these alternate sources which are being used to some extent are solar power, geothermal power, wind power, tidal power, and biomass. The aspiration for bulk generation of power in the future is the nuclear fusion. If nuclear fusion is harnessed economically, it would provide clean energy from an abundant source of fuel, namely water.

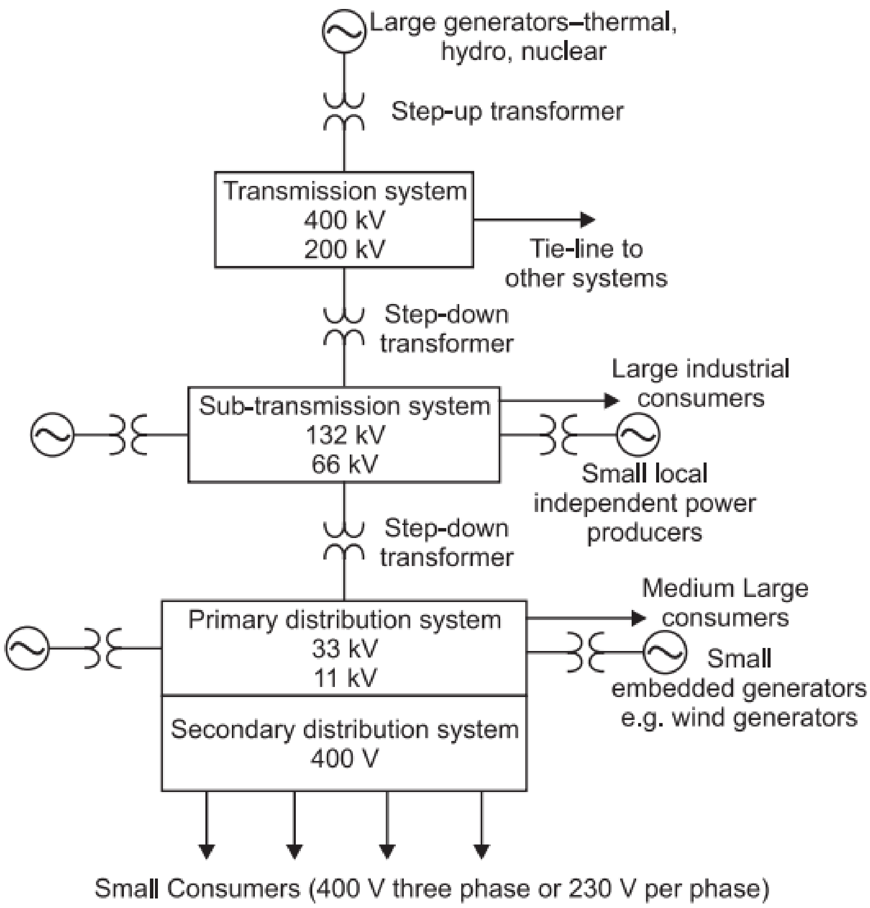


Fig. 2.1: Structure of a power supply system

2.2. Transmission and sub-transmission

The purpose of an overhead transmission network is to transfer electric energy from generating units at various locations to the distribution system which ultimately supplies the load. Transmission lines also interconnect neighboring utilities which permits not only economic dispatch of power within regions during normal conditions, but also the transfer of power between regions during emergencies. Transmission voltage lines operating at more than 60 kV are standardized at 69 kV, 115kV, 138 kV, 161 kV, 230 kV, 345 kV, 500 kV, and 765 kV line-to-line. Transmission voltages above 230 kV are usually referred to as extra-high voltage (EHV).

High voltage transmission lines are terminated in substations, which are called high-voltage substations, receiving substations, or primary substations. The function of some substations is switching circuits in and out of service; they are referred to as switching stations. At the primary substations, the voltage is stepped down to a value more suitable for the next part of the journey toward the load. Very large industrial customers may be served from the transmission system.

The portion of the transmission system that connects the high-voltage substations through step-down transformers to the distribution substations are called the sub-transmission network. There is no clear delineation between transmission and sub-transmission voltage levels. Typically, the sub-transmission voltage level ranges from 69 to 138 kV. Some large industrial customers may be served from the sub-transmission system. Capacitor banks and reactor banks are usually installed in the substations for maintaining the transmission line voltage.

Fig. 2.2 shows an elementary diagram of a transmission and distribution system.

2.3. Reasons of interconnection

The transmission system of a particular area is known as a grid. Different grids are interconnected through tie-lines to form a regional grid (also called power pools). Different regional grids are further connected to form a national grid. Cooperative assistance is one of the planned benefits of interconnected operation. Interconnected operation is always economical and reliable. Generating stations having large MW capacity are available to provide base or intermediate load. These generating stations must be interconnected so that they feed into the general system but not into a particular load. Economic advantage of interconnection is to reduce the reserve generation capacity in each area. If there is sudden increase of load or loss of generation in one area, it is possible to borrow power from adjoining interconnected areas. To meet sudden increase in load, a certain amount of generating capacity (in each area) known as the ‘’spinning reserve’’ is required. This consists of generators running at normal speed and ready to supply power instantaneously.

Interconnection also allows for alternative paths to exist between generators and bulk supply points supplying the distribution systems. This provides security of supply should any one path fail.

This configuration can be illustrated by the diagram of Fig. 2.3.

2.4. Distribution

Distribution networks differ from transmission networks in many ways, quite apart from their voltage levels. The number of branches and sources is much higher in distribution networks and the general structure or topology is different. A typical distribution system consists of a step-down transformer (e.g. 132/11 kV or 66/11 kV or 33/11 kV) at a bulk supply point feeding a number of lines with varying length from a few hundred metres to several kilometres. Several step-down three-phase transformers, e.g., 11 kV/400 V are spaced along the feeders and from these, three-phase four-wire networks of consumers are supplied which give 230 V single-phase supplies to houses and similar loads. Distribution systems are both overhead and underground. The growth of underground distribution has been extremely rapid.

Fig. 2.4 shows a typical distribution system.

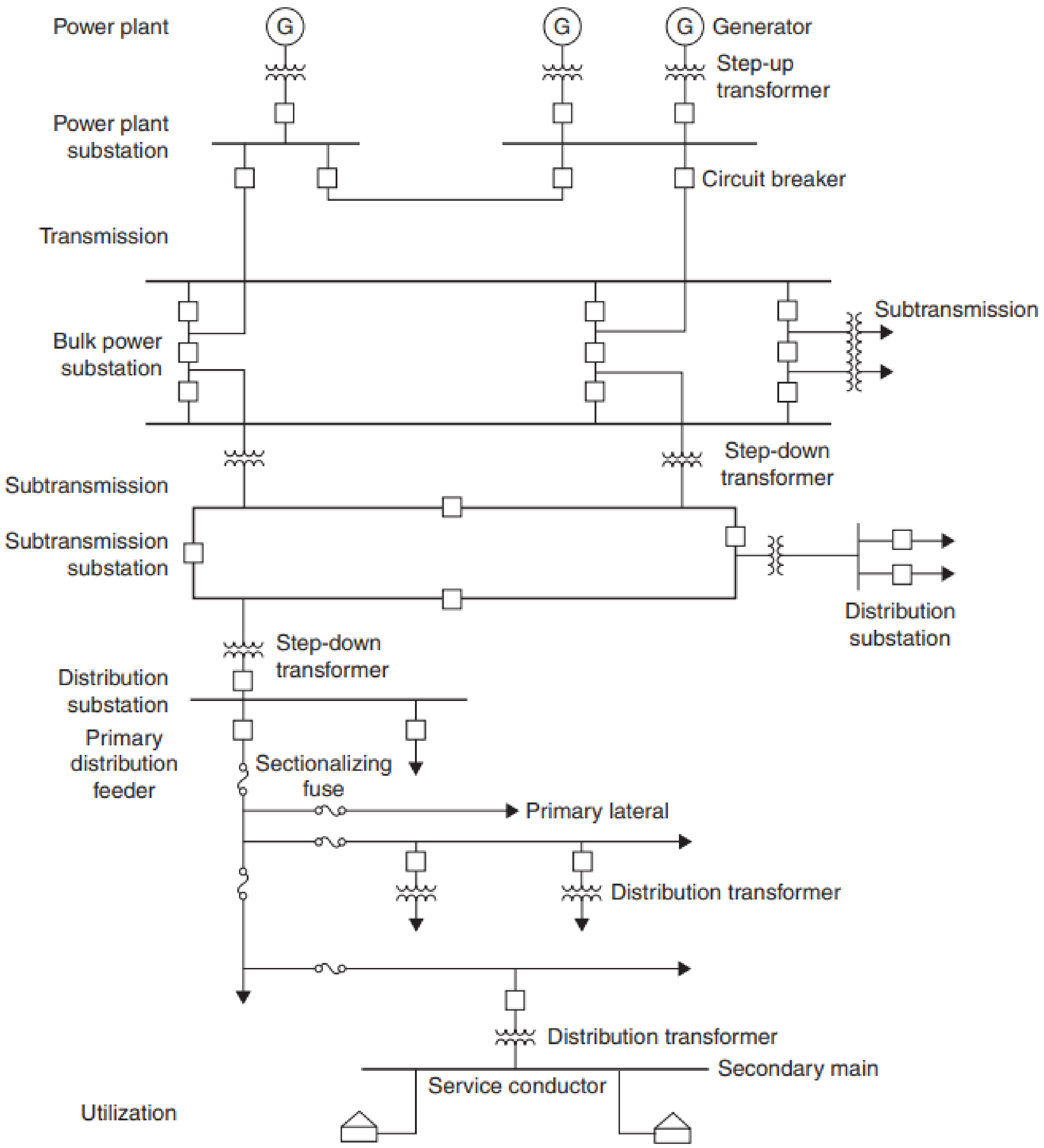


Fig. 2.2: Schematic diagram of transmission and distribution

2.5. Loads

Loads of power systems are divided into industrial, commercial, and residential. Very large industrial loads may be served from the transmission system. Large industrial loads are served from the sub-transmission network, and small industrial loads are served from the primary distribution network. The industrial loads are composite loads, and induction motors form a high proportion of these load. These composite loads are functions of voltage and frequency and form a major part of the system load. Commercial and residential loads consist largely of lighting, heating, and cooling. These loads are independent of frequency and consume negligibly small reactive power.

The real power of loads is expressed in terms of kilowatts. The magnitude of load varies throughout the day, and power must be available to consumers on demand.

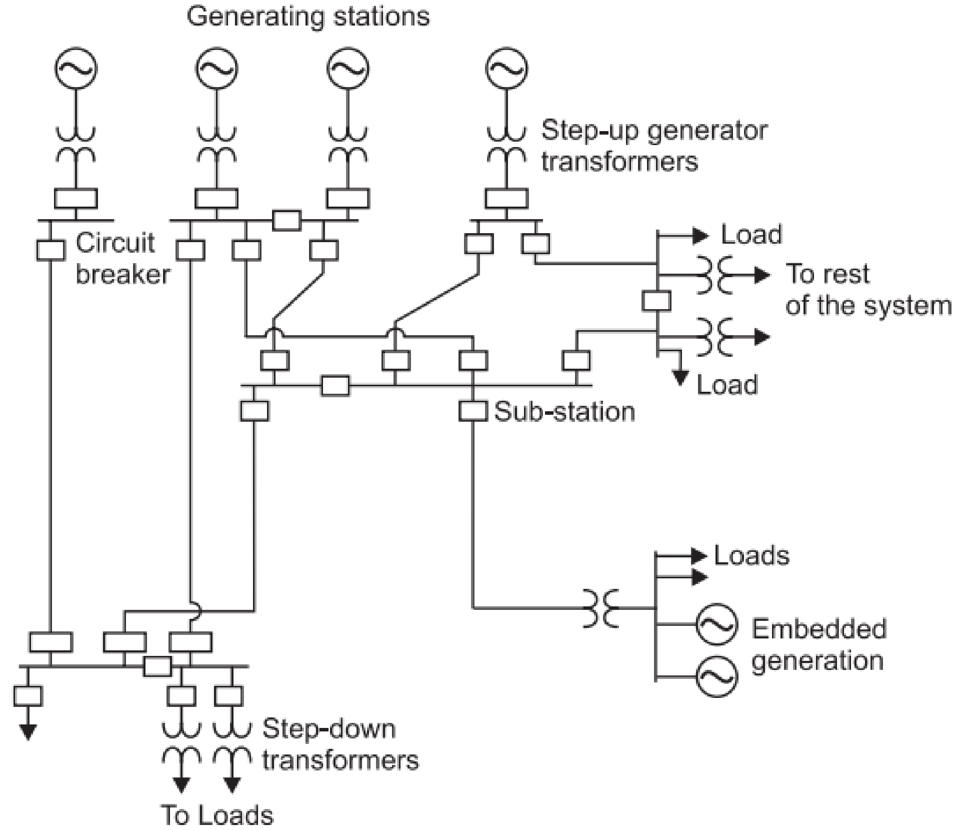


Fig. 2.3: Interconnections in a power system

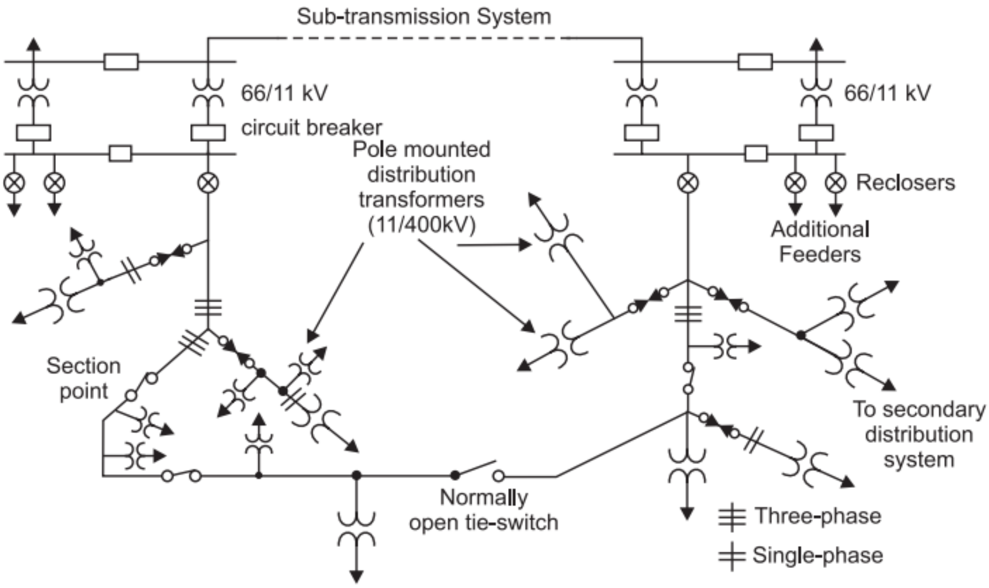


Fig. 2.4: Typical distribution system

3. Equipment and architecture of substations

3.1. Substations

A substation is a station in the power transmission system at which electric power is transformed to a conveniently used form. The station may consist of transformers, switches, circuit breakers and other auxiliary equipment. Its main function is to receive energy transmitted at high voltage from the generating station, by either step-up or step-down the voltage to a value appropriate for local use and provide facilities for switching. Substations serve as sources of energy supply for the local areas of distribution in which these are located. Substations have some additional functions. Its provide points where safety devices may be installed to disconnect circuits or equipment in the event of trouble.
Some substations, such as power plant switchyard are simply switching stations where different connections can be made between various transmission lines.
There are many classifications of substations.

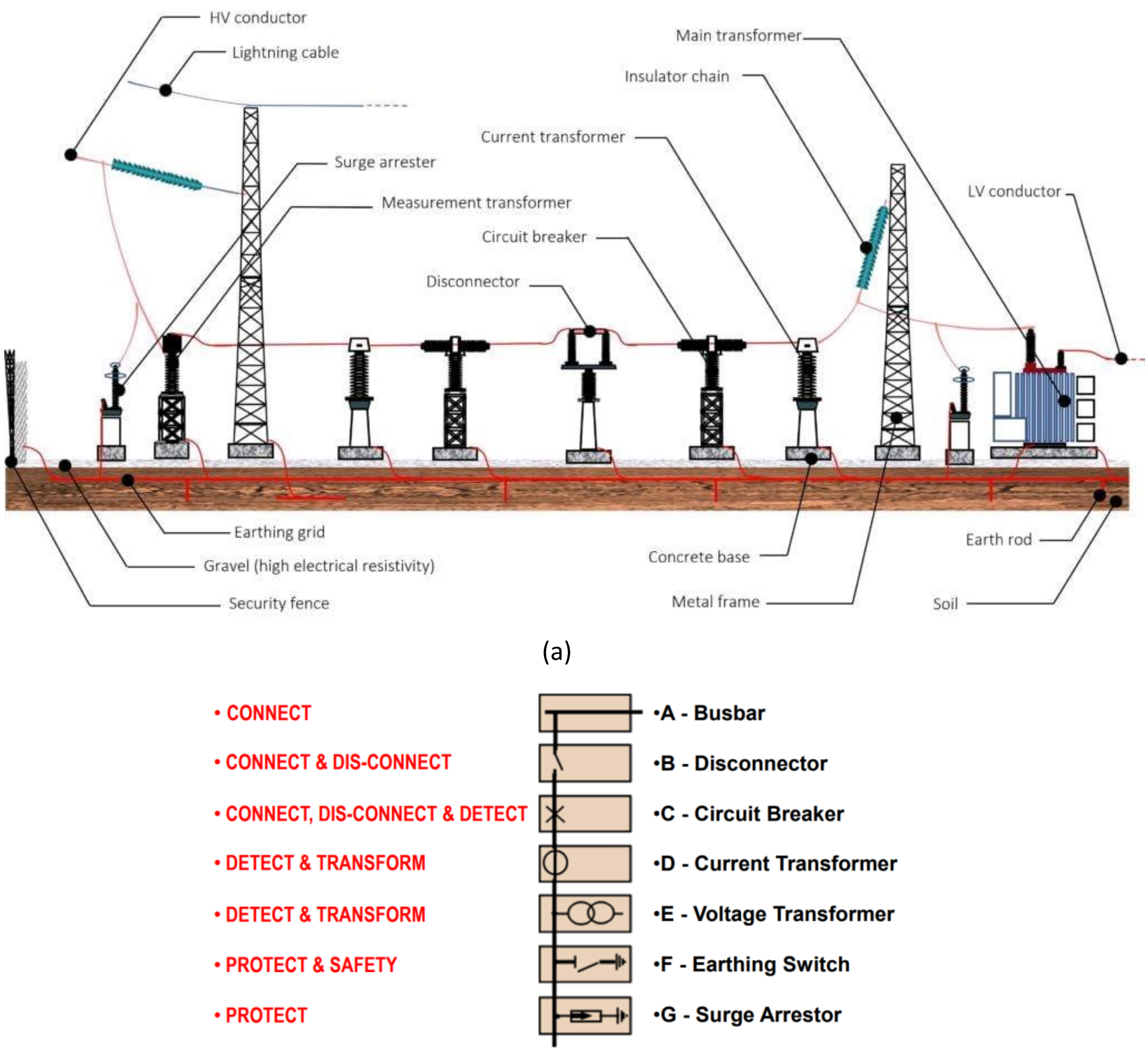
Table 2.1: classifications of substations

based on nature of duties	based on service rendered	based on the basis of design
- Step-up or primary substations - Primary grid substations - Step down or distribution substations	- Transformer substations - Switching substations - Converting substations	- Indoor type substations - Outdoor substations

Fig.2.5: high voltage substation

3.2. High Voltage Substation Components

Typical components of a high voltage substation are given by Fig. 2.6.



(b)

Fig. 2.6: Components of a high voltage substation
a. main components b. functions

Busbar (or **bus**, for short)**:**

It is a term we use for a main bar or conductor carrying an electric current to which many connections may be made. Buses are merely convenient means of connecting switches and other equipment into various arrangements. The usual arrangement of connections in most substations permit working on almost any piece of equipment without interruption to incoming or outgoing feeders. In the switchyard or substation, buses are open to the air. Aluminium or copper conductors supported on porcelain insulators, carry the electric energy from point to point.

Fig. 2.7: Busbars

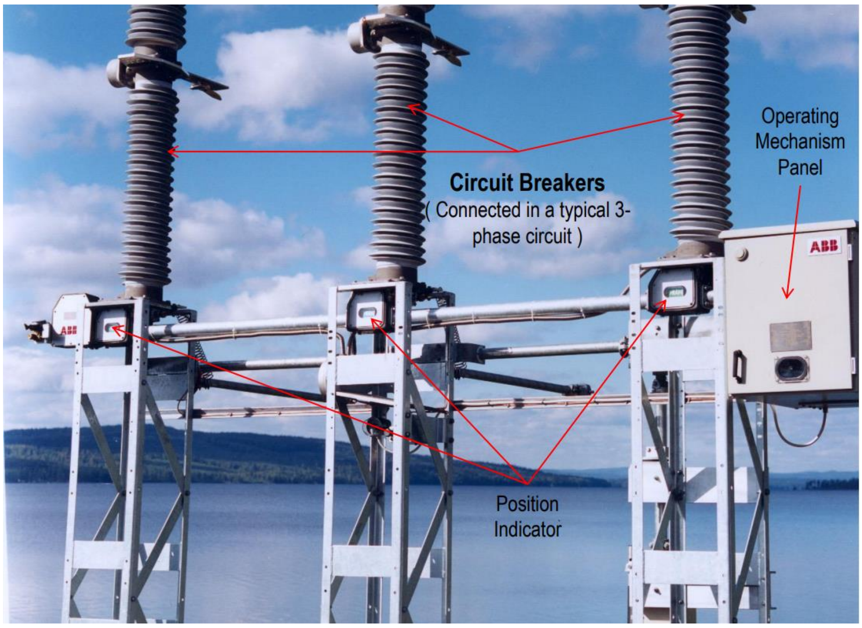
Disconnector:

It is an easily removed piece of the actual conductor of a circuit. The purpose of disconnects is to isolate equipment. Disconnects are not used to interrupt circuits; they are no-load devices. A typical use of disconnects is to isolate a circuit breaker by installing one disconnect on either side of the circuit breaker (in series with the breaker). Operation of disconnects is one of the most important and responsible jobs of a power plant operator. One error in isolation of equipment, or the accidental grounding of line equipment, can be a fatal mistake.

Fig. 2.8: Disconnector

Circuit Breaker:

is used to interrupt circuits while current is flowing through them. The making and breaking of contacts in an oil type circuit breaker are done under oil, this oil serves to quench the arc when the circuit is opened. The operation of the breaker is very rapid when opening. As with the transformer, the high voltage connections are made through bushings. Circuit breakers of this type are usually arranged for remote electrical control from a suitably located switchboard. Some recently developed circuit breakers have no oil, but put out the arc by a blast of compressed air; these are called air circuit breakers. Another type encloses the contacts in a vacuum or a gas (sulfur hexafluoride, SF_6) which tends to self-maintain the arc.



Oil circuit breaker

SF_6 circuit breaker

Fig. 2.9: Circuit breaker

Current Transformer:

Current transformer is used with ammeters, watt meters, power-factor meters, watt-hour meters, compensators, protective and regulating relays and the trip coil of circuit breakers. One current transformer can be used to operate several instruments, provided that the combined burden does not exceed that for which the transformer is designed and compensated. The current transformer is connected directly in series with the line.

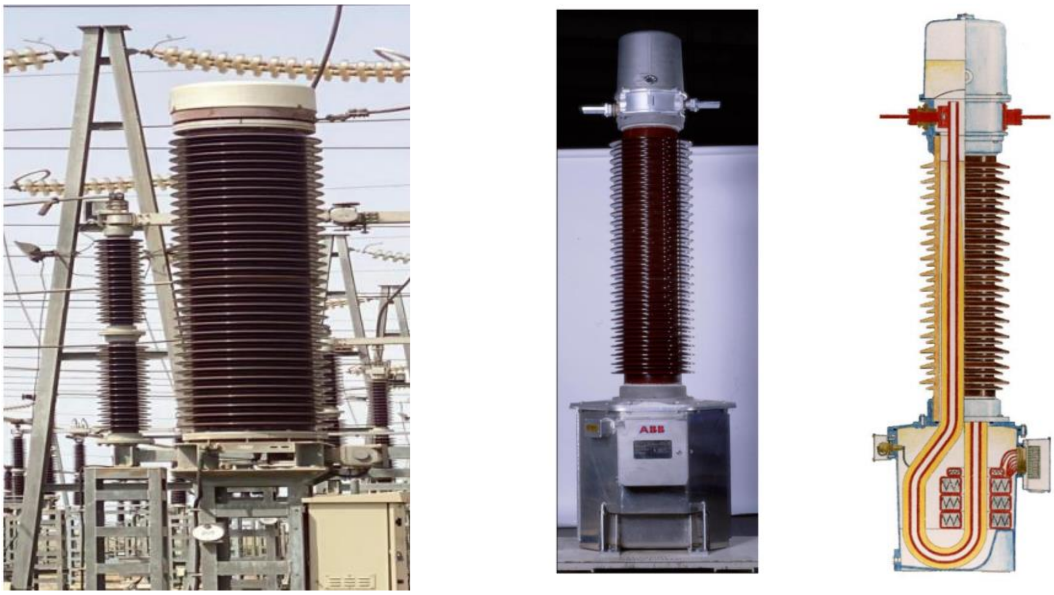


Fig. 2.10: Current transformer

Voltage Transformer :

also known as potential transformer, are used with volt-meters, watt-meters, watthour meters, power-factor meters, frequency meters, synchroscopes and synchronizing apparatus, protective and regulating relays and the no-voltage and over-voltage trip coils of automatic circuit breakers. One transformer can be used for a number of instruments at the same time if the total current taken by the instrument does not exceed that for which the transformer is designed and compensated. The ordinary voltage transformer is connected across the line, and the magnetic flux in the core depends upon the primary voltage.

Fig. 2.11: Voltage transformer

Earthing Switch:

also known as ground disconnect, which used to connect the equipment to a grid of electrical conductors buried in the earth on the station property. It is intended to protect people working on the grounded equipment. It does this by completing a circuit path, thereby reducing the voltage difference between the equipment and its surroundings. For safety reasons, it is important that ground disconnects and all associated connections have good contact and low resistance. It is also important that the protective ground not be accidentally remove, that is why all the earthing switches, disconnect switches and circuit breakers are all interlocked to each other and proper/correct sequencing must be followed.

Surge Arrestor:

are devices used to provide the necessary path to ground for such surges, yet prevent any power current from following the surge. An ideal arrester must therefore have the following properties:

1. Ability to remove the surge energy from the line in a min. time.
2. High resistive to flow of power current.
3. A valve action automatically allowing surge to pass and then closing up so as not to permit power current to flow to ground.
4. Always ready to perform.
5. Performance such that no system disturbances are introduced by its operation.
6. Economically feasible

Fig. 2.12: surge arrestor

Overhead Ground Wire:

by a ground wire is meant a wire, generally of steel, supported from the top of transmission-line towers and solidly grounded at each tower. It is considered a preventive device, but it does not entirely prevent the formation of travelling waves on a line. Furthermore, those lines which are not equipped with ground wires will be subjected to disturbances which produce surges that must be allowed to escaped to ground, or the apparatus connected to the line must be strong enough to reflect or absorb these surges until they are entirely damped out.

3.3. Types of Bus Bar Scheme in substation

The switching equipment in substations can be connected in a variety of ways. The selection of a particular scheme depends upon the system voltage, position of substation in electrical power system, simplicity, initial cost of equipment, flexibility of operation, possibility of system expansion and ease of maintenance.

Some very commonly used bus-bar arrangement are below:

- Single bus system
- Single bus system with bus sectionlizer
- Double bus system
- One & half breaker bus system

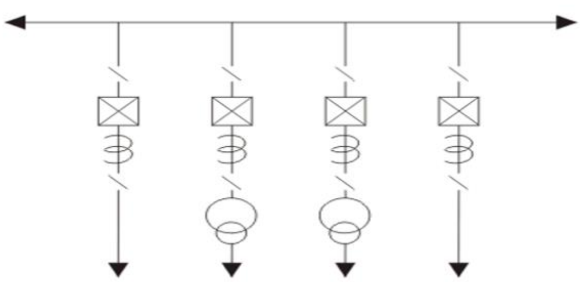


Fig. 2.13: Single bus system

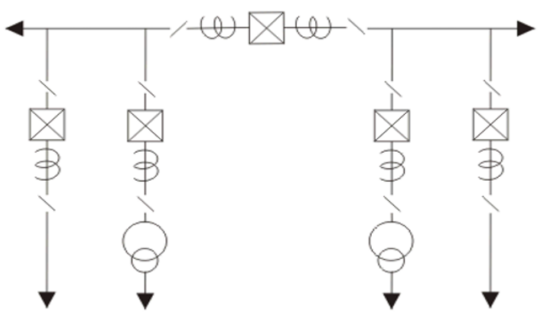


Fig. 2.14: Single section bus system

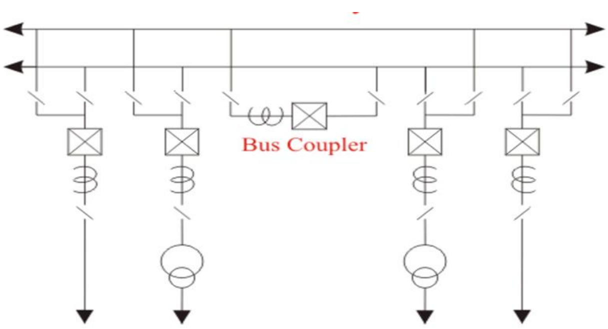


Fig. 2.15: Double bus system

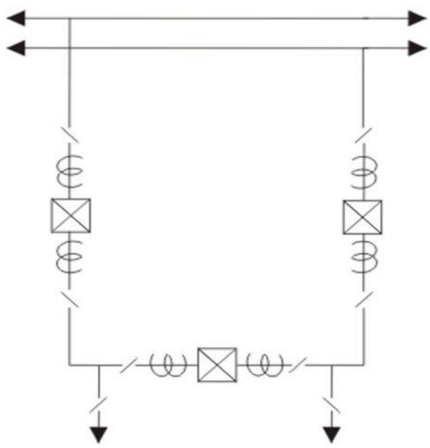


Fig. 2.16: One and Half Breaker Bus System