Power System Protection

EE454

Lecture ppt. # 1

- **Note:**

  The materials in this presentation are only for the use of students enrolled in this course in the specific campus; these materials are for purposes associated with this course and may not be further disseminated or retained after expiry of the course.

Some of the Contents	
Lect. File 1 – **Chapter 1** of PS Relaying	
1	Basic concepts – Relaying – Philosophy of PSP – Major challenges – Disturbances in the system occur
2	Layers (Sub-systems) in the power system
3	Grounding of power system
4	Radial/Network system – Substation Bus configuration
5	Dependability – Zones - Primary and backup protection
6	Circuit Breakers


بسم الله الرحمن الرحيم

The CLOs and Books may have changed after 2020 - Please refer to course outline file provided to you.

CLOs	Description	PLOs	Domain	Domain Level
Measureable Student Learning Outcomes				
CLO1	Illustrate the basic working principles and requirements of different relaying schemes and relaying components.	PLO01	Cognitive	2. Understand
CLO2	Determine the impact of current and voltage transformers on the performance of protection system	PLO02	Cognitive	3. Apply
CLO3	Evaluate the relay settings for the coordination of overcurrent and distance relays in distribution and transmission lines respectively.	PLO03	Cognitive	5. Evaluate
CLO4	Design appropriate protection schemes for various components like transformers, rotating machinery, bus-bars, shunt and series compensating devices.	PLO04	Cognitive	6. Create

1. Power System Relaying by "Stanley H. Horowitz & Arun G. Phadke", John Wiley & Sons, 4th Edition, 2014.
2. Protective Relaying: Principles and Applications by "J. Lewis Blackburn & Thomas J. Domin", CRC Press, 4th Edition, 2014.
3. Fundamentals of Power System Protection by "Y.G. Paithankar & S.R. Bhide", PHI Learning, 2nd Edition, 2013.
4. Protective Relays Application Guide published by GEC ALSTHOM MEASURMENT LIMITED, 3rd Edition, 1990.

1

Introduction to protective relaying

Relaying is the branch of electric power engineering concerned with the principles of design and operation of equipment (called ‘relays’ or ‘protective relays’) that detects abnormal power system conditions, and initiates corrective action as quickly as possible in order to return the power system to its normal state.

Opinion

2019 – A Year Of Power System Collapses – Part II

By **Idowu Oyebanjo** - Dec 26, 2019

A power system collapse occurs when there are system disturbances and the grid is unable to withstand the stress. This can lead to blackouts or abnormally low voltage in the system.

In the case of Nigeria, such disturbances can be caused by a lack of investment in the dilapidated power network, obsolete substation equipment, overloading of certain transmission and distribution corridors, poor operations and maintenance of the grid, lack of power system protection and control, load rejection, sudden loss of generation, plant overloads, frequency fluctuations, generator pole–slipping and loss of synchronism, faults etc.

This gives you an idea of power system disturbances from a non-bookish source

https://newsghana.com.gh/2019-a-year-of-power-system-collapses-part-ii/
Accessed – 29 Sept. 2020

An example of a temporary fault

CAUSES FOR FAULTS

- ✓ Lightning
- ✓ Wind
- ✓ Ice and snow storms
- ✓ Flying Objects
- ✓ Contamination of insulators
- ✓ Physical contact by animals
- ✓ Human error
- ✓ Falling trees
- ✓ Insulation aging

1.2 Power system structural considerations

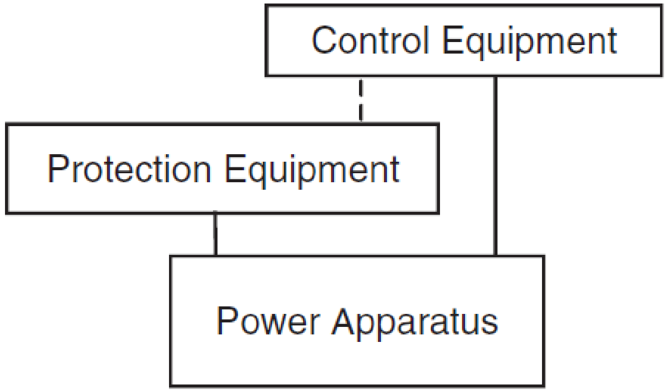
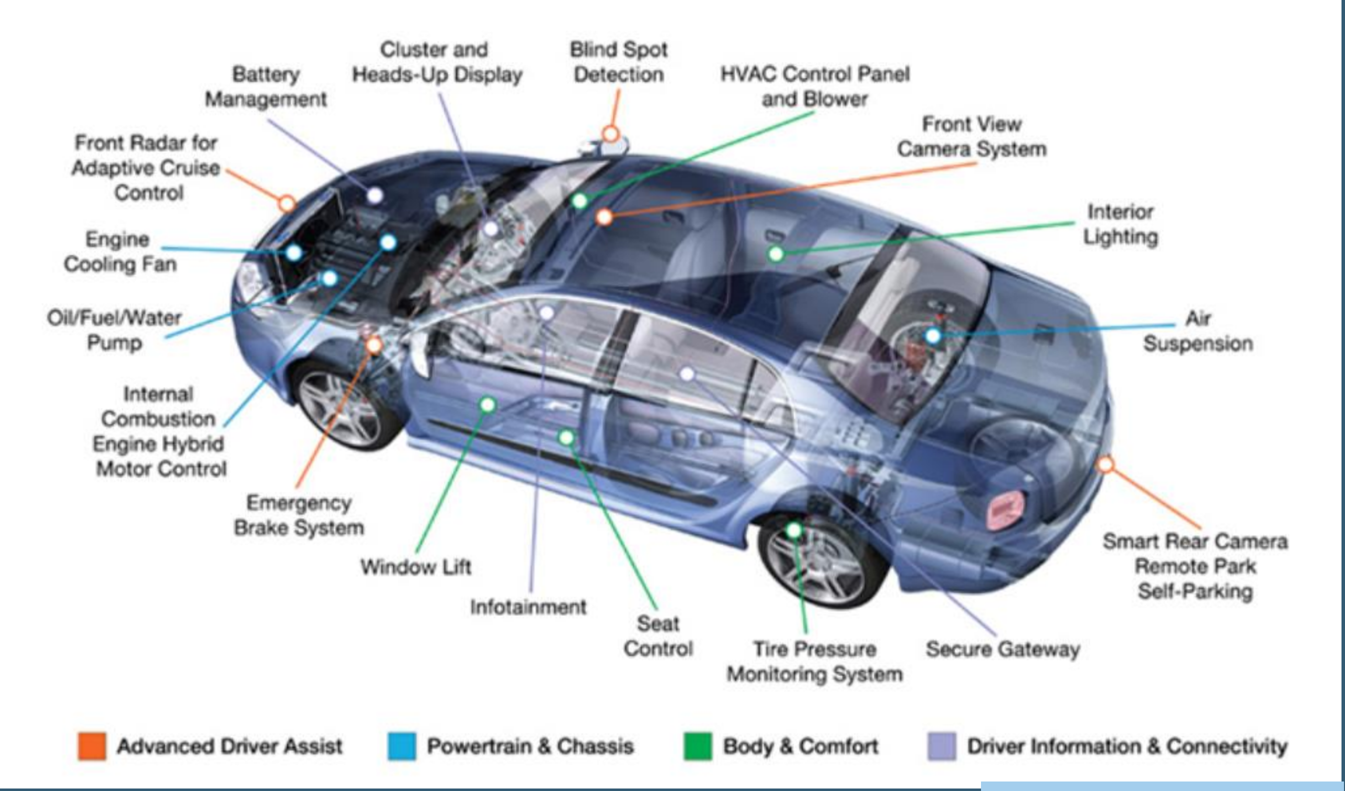


Figure 1.1 Three-layered structure of power systems

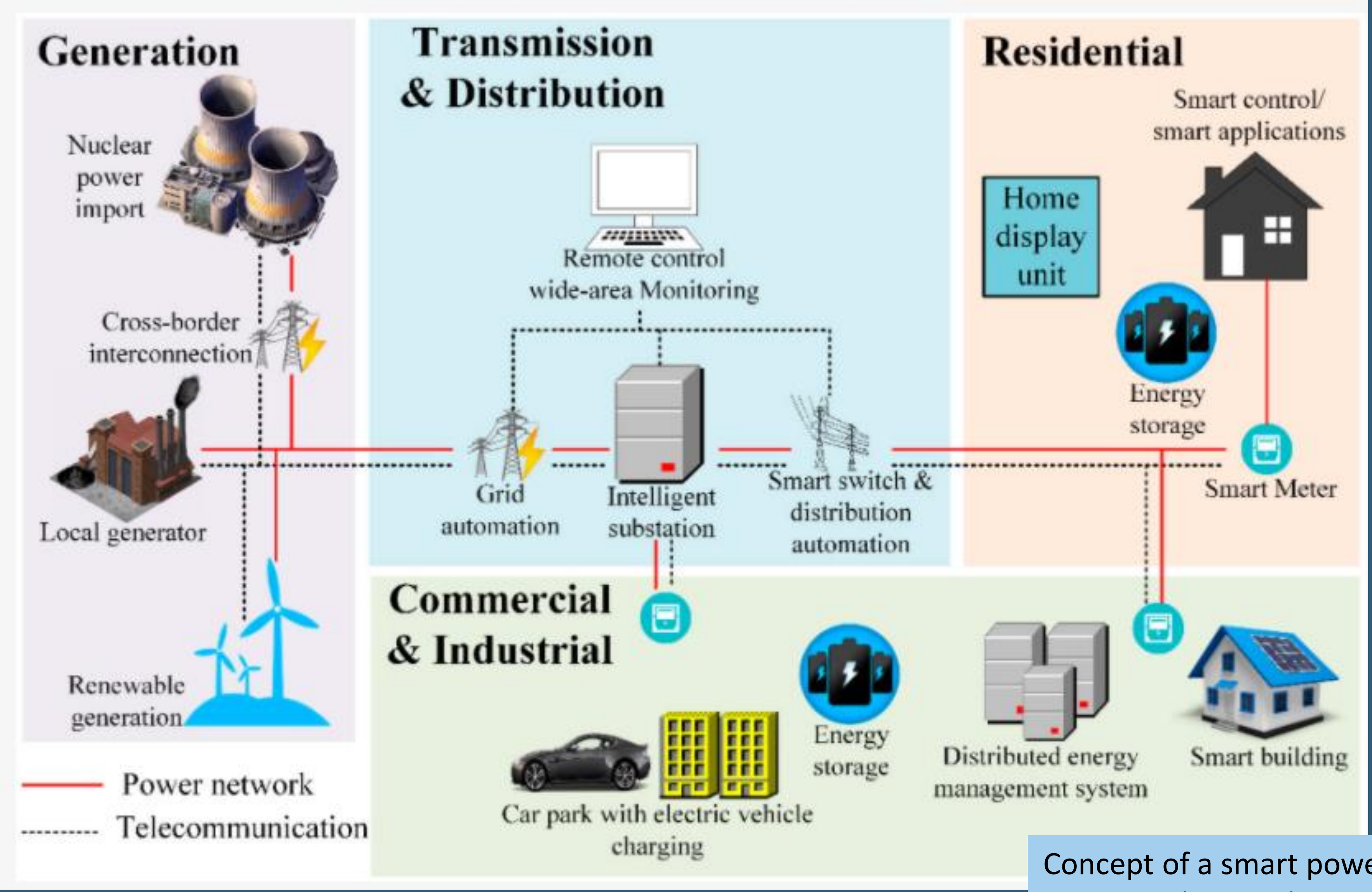


An example of a multi-layered system

control equipment. This equipment helps maintain the power system at its normal voltage and frequency, generates sufficient power to meet the load and maintains optimum economy and security in the interconnected network.

You may see these in your course of PSO&C – e.g. AVR

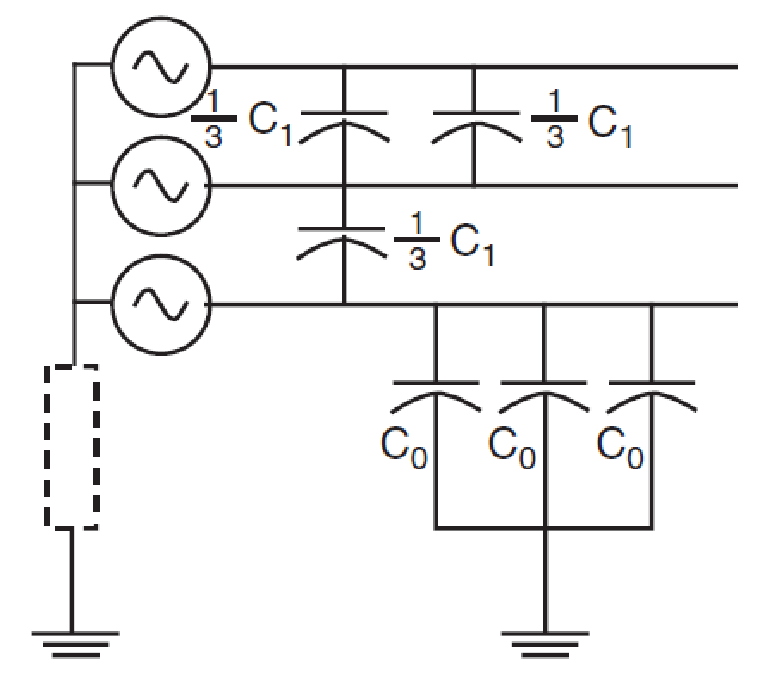
The response time of protection functions is generally faster than that of the control functions. Protection acts to open and close circuit breakers, thus changing the structure of the power system, whereas the control functions act continuously to adjust system variables, such as the voltages, currents and power flow on the network.

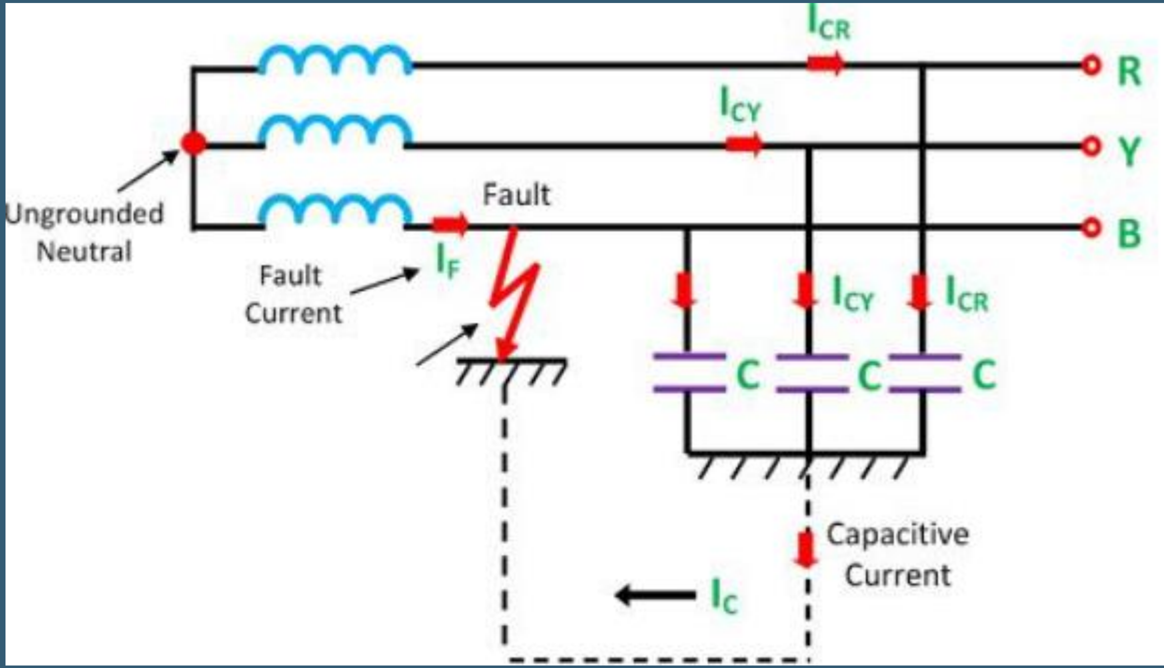


Concept of a smart power system – showing layer of communication (may be referred to as control)

Neutral grounding of power systems

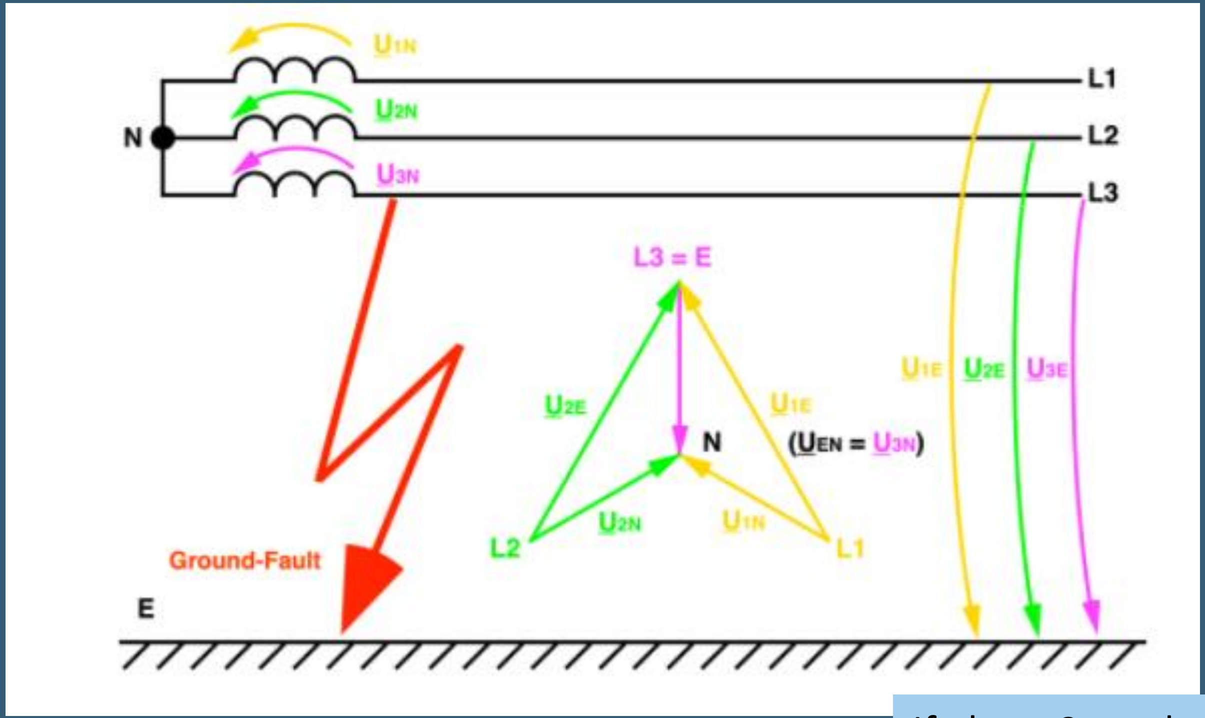
Problems with un-grounded system





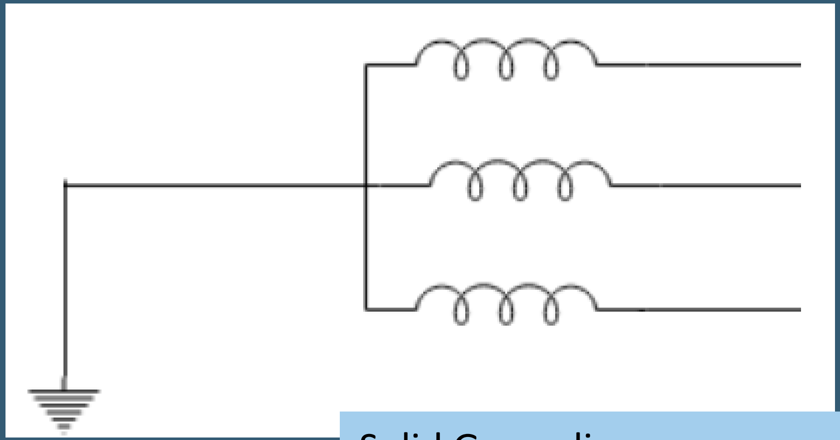
C_o provides path for flow of a ground fault current even if the system is ungrounded. Relaying problem becomes detection of such low magnitude of fault current.

Problems with un-grounded system

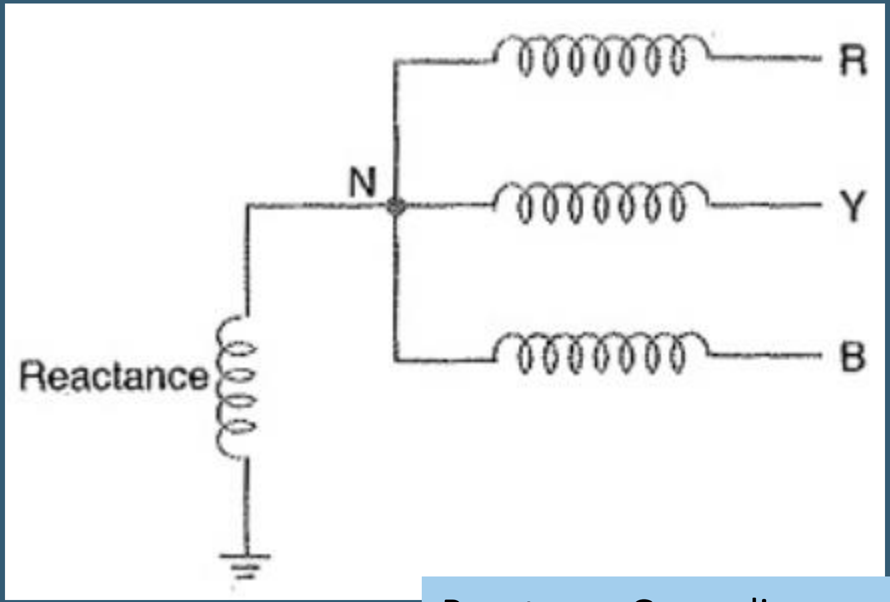


If phase 3 conductor touches ground (due to a fault), then ground is at phase 3 voltage – hence LG voltages of other phases have now become LL voltages.

Grounding

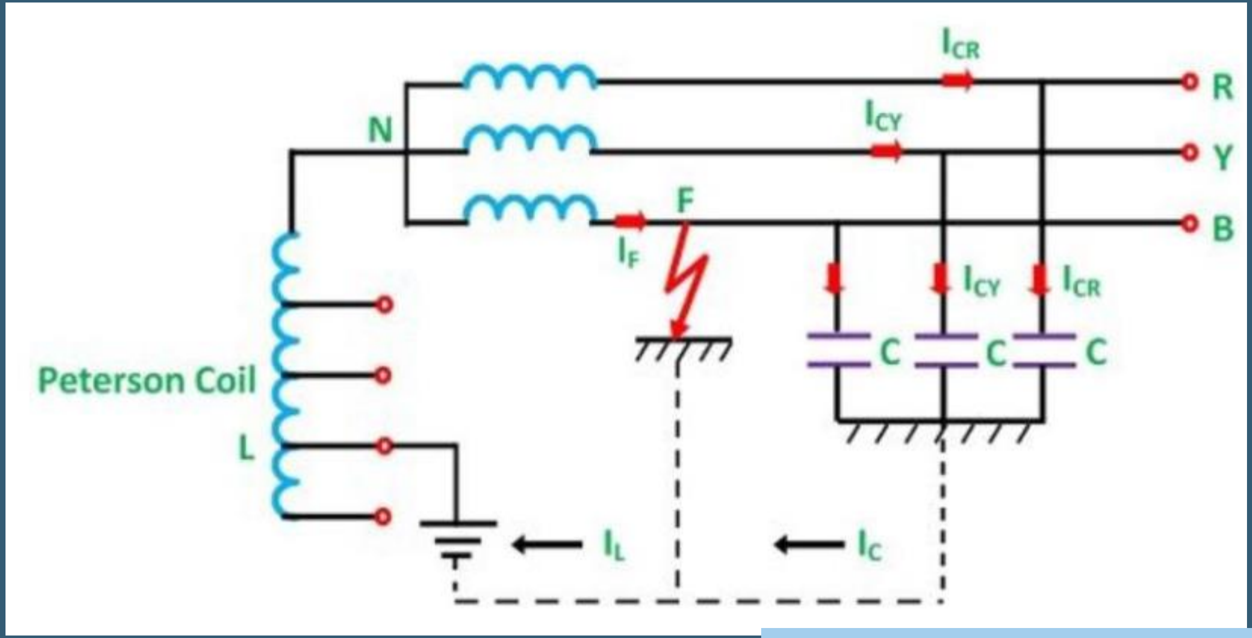


Solid Grounding –
Leads to high fault current

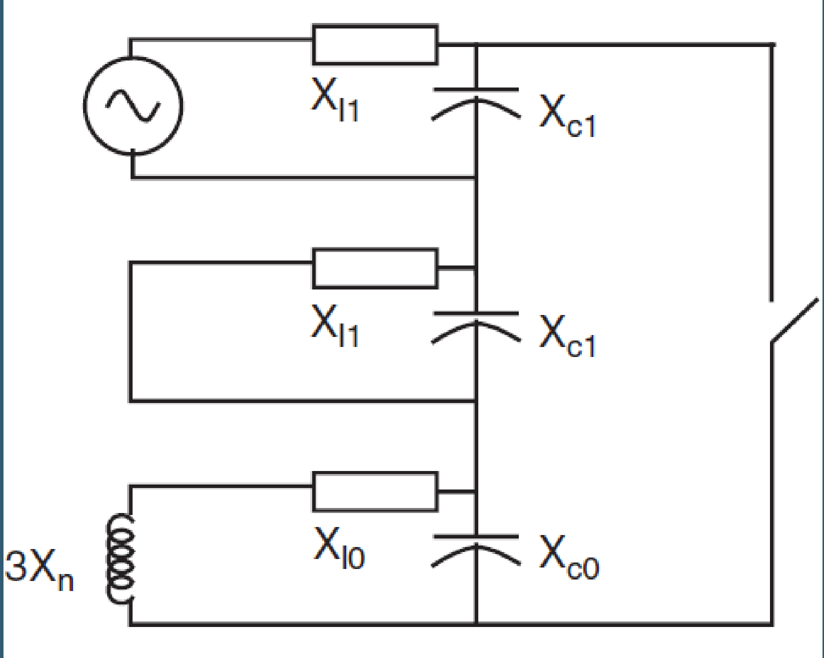


Reactance Grounding –
Reduces fault current level

Grounding



Peterson Coil (also known as Ground Fault Neutralizer GFN)



If 3Xn is made equal to Xco – the parallel combination becomes open circuit and no ground fault current flows.
GFN needs to be tuned to the system.

1.3 Power system bus configurations

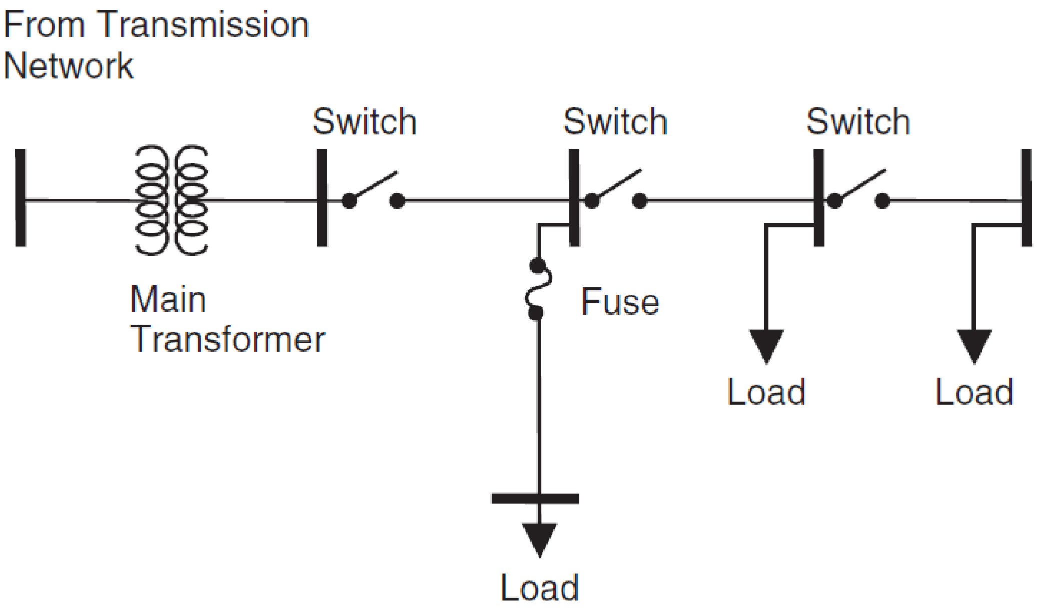


Figure 1.4 Radial power system

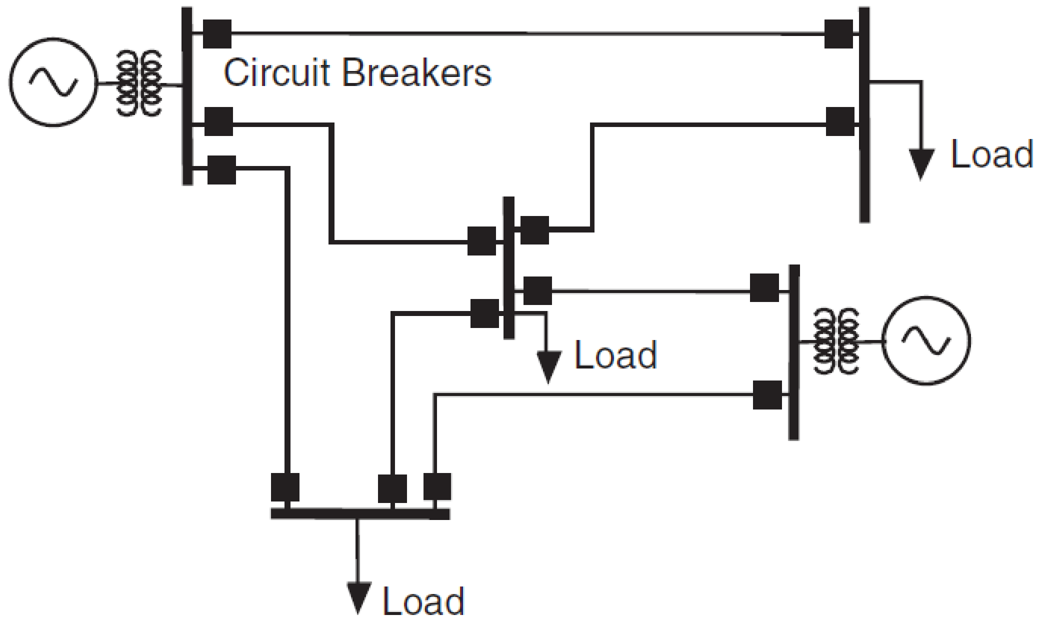


Figure 1.5 Network power system

Example 1.1

Consider the simple network shown in Figure 1.6. The load at bus 2 has secure service for the loss of a single power system element. Further, the fault current for a fault at bus 2 is –j20.0 pu when

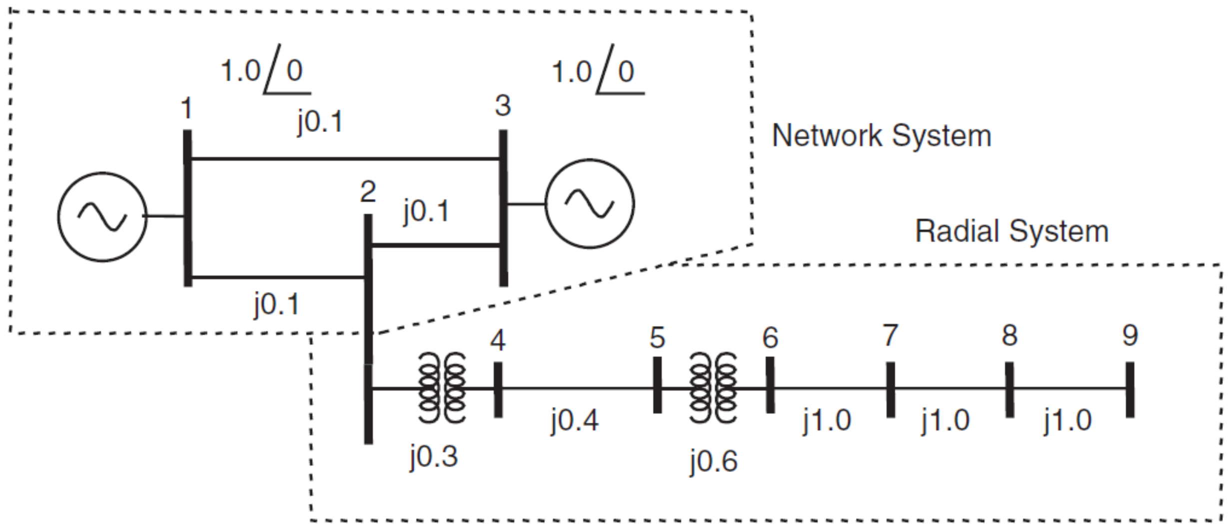


Figure 1.6 Power system for Example 1.1

all lines are in service. If line 2–3 goes out of service, the fault current changes to –j10.0 pu. This is a significant change.

Now consider the distribution feeder with two intervening transformers connected to bus 2. All the loads on the feeder will lose their source of power if transformer 2–4 is lost. The fault current at bus 9 on the distribution feeder with system normal is –j0.23 pu, whereas the same fault when one of the two generators on the transmission system is lost is –j0.229 pu. This is an insignificant change. The reason for this of course is that, with the impedances of the intervening transformers and transmission network, the distribution system sees the source as almost a constant impedance source, regardless of the changes taking place on the transmission network.

Electrical Substation Bus Schemes Explained

The **electrical substation** is a junction point where two or more **transmission lines** terminate. In actuality, most **EHV** and **HV substations** can be the point where *more than* half a dozen of lines terminate. In many large **transmission substations**, the total numbers of lines terminating *exceeds* one or two dozen.

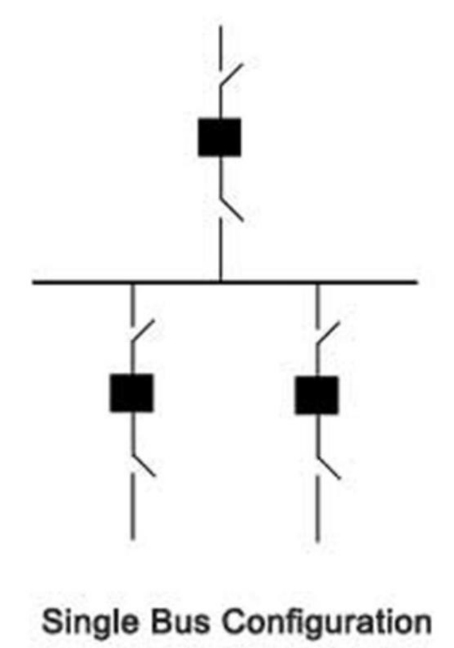
A substation bus scheme is the arrangement of overhead bus bar and associated switching equipment. Photo: ENMAS GB Power Systems

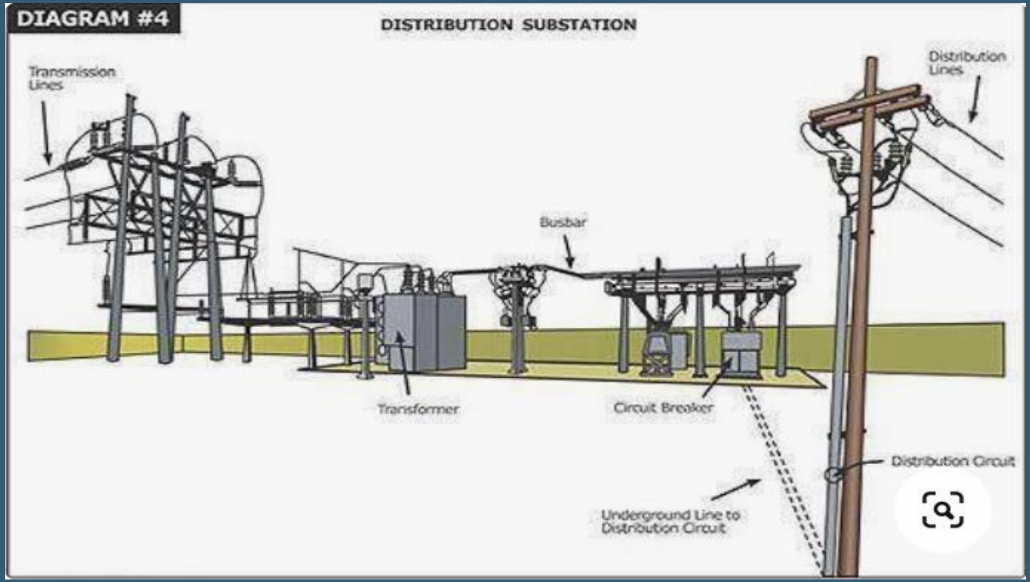
A **substation bus scheme** is the arrangement of overhead **bus bar** and associated **switching equipment** (circuit breakers and isolators) in a substation. The operational **flexibility** and **reliability** of the substation greatly depends upon the bus scheme.

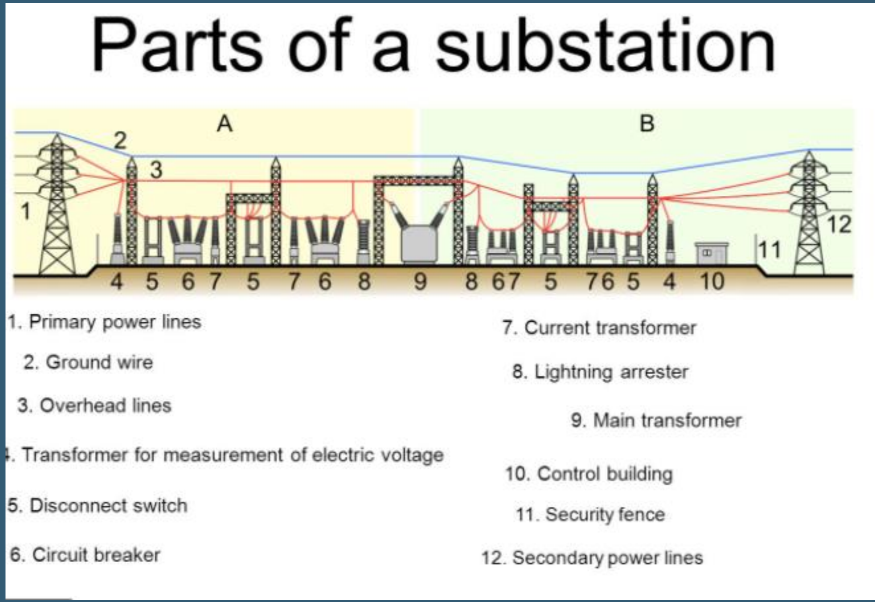
The first requirement of any **substation design** is to *avoid a total shutdown* of the substation for the purpose of maintenance, or due to fault somewhere out on the line. A **total shutdown** of the substation means complete shutdown of all the lines connected to the substation.

Clearly, a **EHV** or **UHV transmission substation** where a large number of critical lines terminate is extremely important, and the substation should be designed to **avoid total failure** and interruption of minimum numbers of circuits.

Substation Bus Schemes

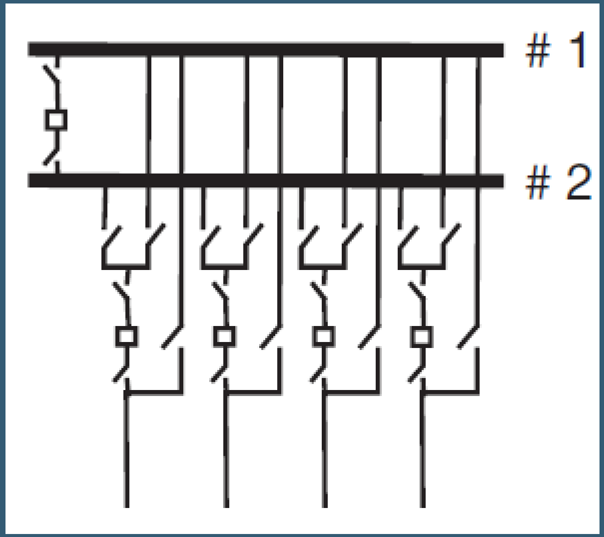




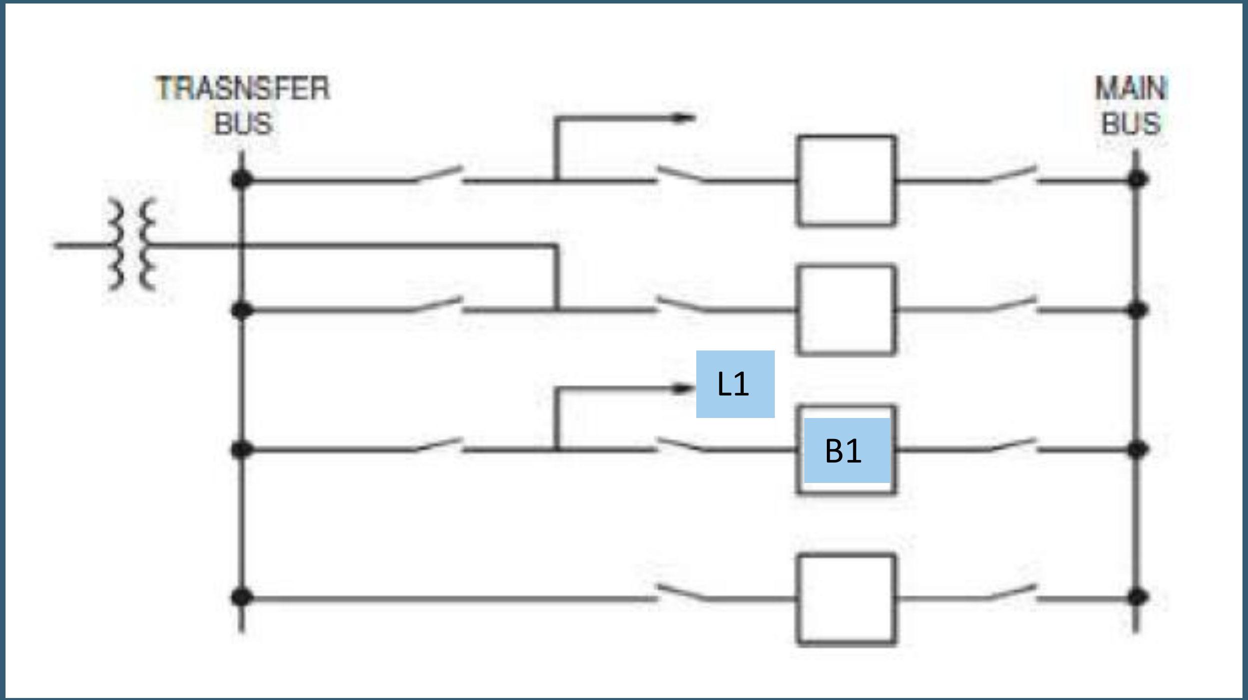


Very inflexible – Maintenance work of primary breaker will shutdown the substation

Substation Bus Schemes



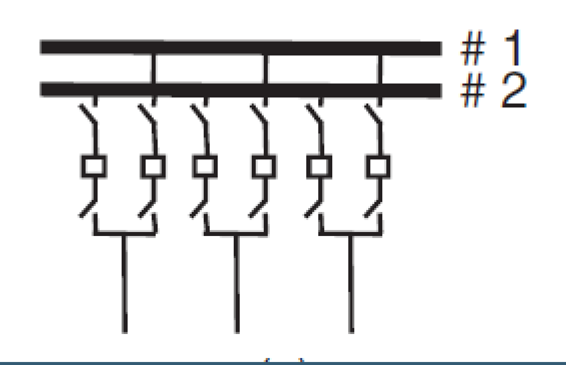
Two bus single breaker scheme.



For maintaining a breaker – e.g. B1
Close bus tie breaker
And supply power to L1 through transfer bus.
The bus tie breaker becomes main breaker for L1.

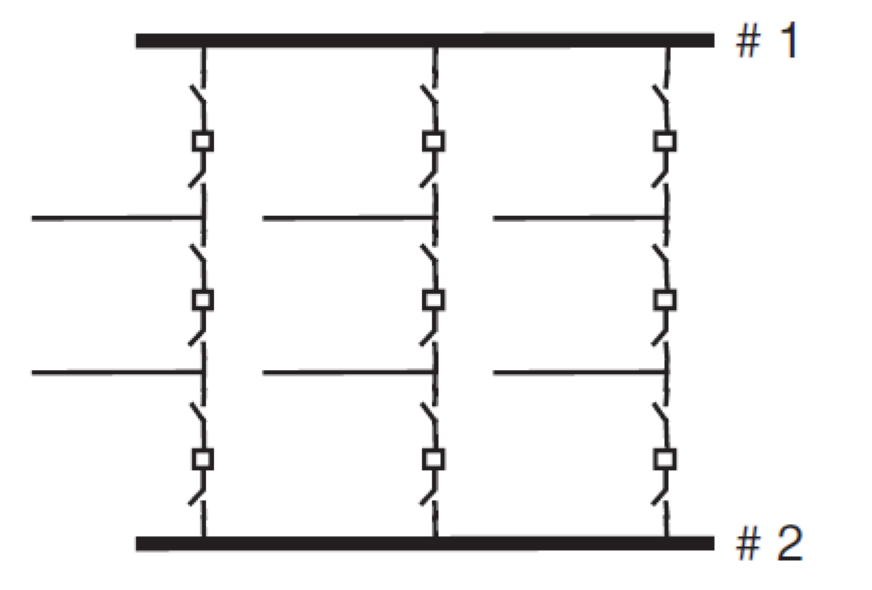
Only one breaker can be maintained at a time

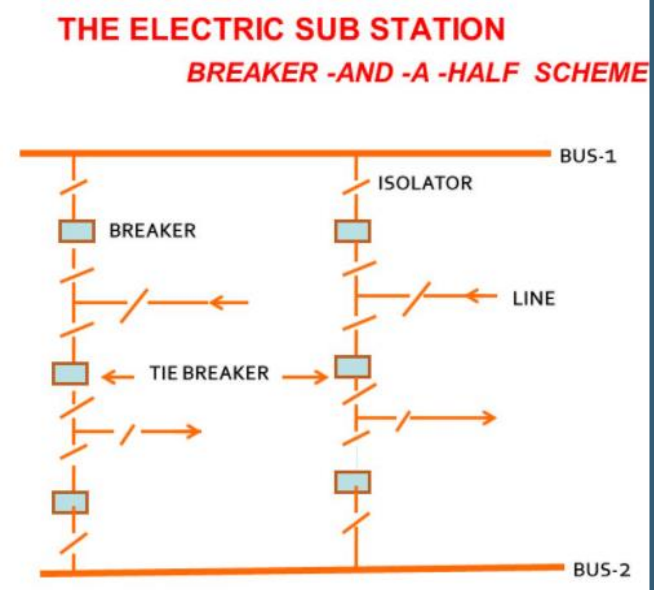
Substation Bus Schemes



Two-bus two-breaker scheme

Allows any bus or breaker to be maintained. Gives highest flexibility however cost is high too.





Breaker and a half scheme

Finally, the breaker-and-a-half scheme, shown in Figure 1.7(e), is most commonly used in most extra high voltage (EHV) transmission substations.

1.4 The nature of relaying

The basic philosophy of relaying/PSP is to disconnect the faulty/abnormal portion from the healthy portion. Thus

i. operation of the healthy part is maintained
ii. excessive damage in the faulty part is avoided

Major challenges of the protection engineer are:

i. Detection of fault
ii. Isolation of minimum system portion

1.4.1 Reliability, dependability and security

Dependability is defined as the measure of the certainty that the relays will operate correctly for all the faults for which they are designed to operate. Security is defined as the measure of the certainty that the relays will not operate incorrectly for any fault.

Most protection systems are designed for high dependability.

Example 1.2

Consider the fault F on the transmission line shown in Figure 1.8. In normal operation, this fault should be cleared by the two relays R_1 and R_2 through the circuit breakers B_1 and B_2. If R_2 does not operate for this fault, it has become unreliable through a loss of dependability. If relay R_5 operates through breaker B_5 for the same fault, and before breaker B_2 clears the fault, it has become unreliable through a loss of security.

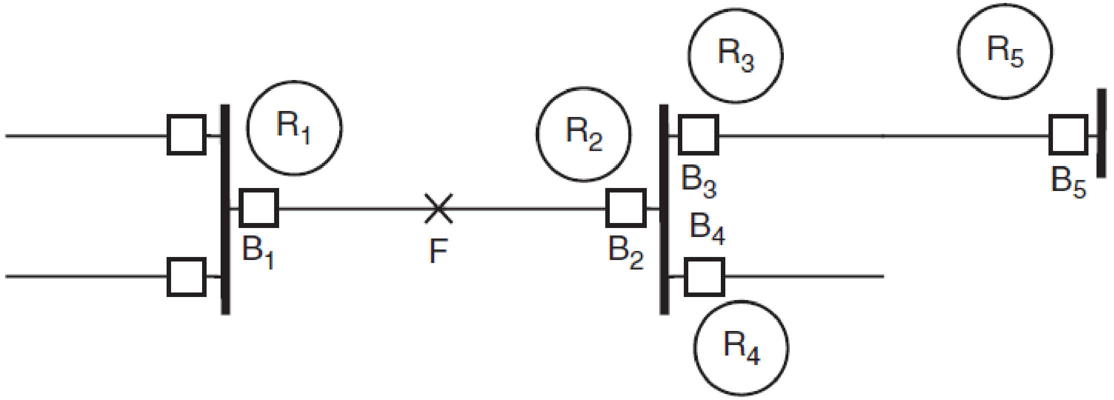


Figure 1.8 Reliability of protection system

1.4.2 Selectivity of relays and zones of protection

Zone of protection – Region where a relay should work; beyond this it should not work.

- All power system elements must be encompassed by at least one zone. Good relaying practice is to be sure that the more important elements are included in at least two zones.
- Zones of protection must overlap to prevent any system element from being unprotected. Without such an overlap, the boundary between two nonoverlapping zones may go unprotected. . . . .

Example 1.3

Consider the fault at F_1 in Figure 1.9. This fault lies in a closed zone, and will cause circuit breakers B_1 and B_2 to trip. The fault at F_2, being inside the overlap between the zones of protection of the transmission line and the bus, will cause circuit breakers B_1, B_2, B_3 and B_4 to trip, although opening B_3 and B_4 is unnecessary. Both of these zones of protection are closed zones.

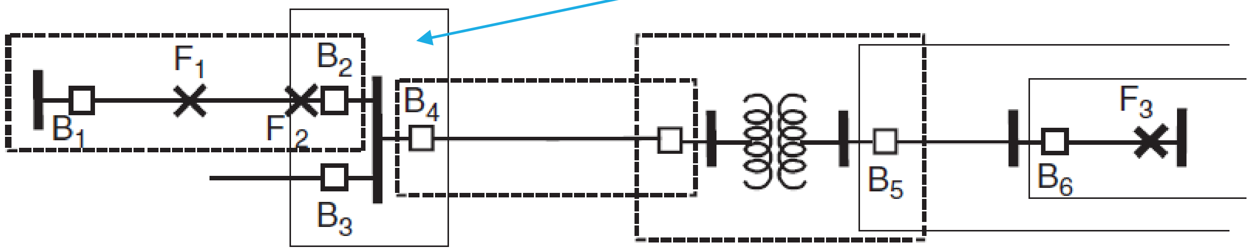


Figure 1.9 Closed and open zones of protection

Now consider the fault at F_3. This fault lies in two open zones. The fault should cause circuit breaker B_6 to trip. B_5 is the backup breaker for this fault, and will trip if for some reason B_6 fails to clear the fault.

Zone of bus protection – Overlaps line protection - Fault in overlapping region causes both protections (line and bus) to operate. Operation of bus protection (may be a differential relay) trips all Breakers associated with the bus.

1.4.3 *Relay speed*

1. **Instantaneous.** These relays operate as soon as a secure decision is made. No intentional time delay is introduced to slow down the relay response.†
2. **Time delay.** An intentional time delay is inserted between the relay decision time and the initiation of the trip action.‡

1.4.4 *Primary and backup protection*[4,5]

Example 1.4

Consider the fault at location F in Figure 1.10. It is inside the zone of protection of transmission line AB. Primary relays R_1 and R_5 will clear this fault by acting through breakers B_1 and B_5. At station B, a duplicate primary relay R_2 may be installed to trip the breaker B_1 to cover the possibility that the relay R_1 may fail to trip. R_2 will operate in the same time as R_1 and may use the same or different elements of the protection chain. For instance, on EHV lines it is usual to provide separate CTs, but use the same potential device with separate windings. The circuit breakers are not duplicated but the battery may be. On lower voltage circuits it is not uncommon to share all of the transducers and DC circuits. The local backup relay R_3 is designed to operate at a slower speed than R_1 and R_2; it is probably set to see more of the system. It will first attempt to trip breaker B_1 and then its breaker failure relay will trip breakers B_5, B_6, B_7 and B_8. This is local backup relaying, often known as breaker-failure protection, for circuit breaker B_1. Relays R_9, R_{10} and R_4 constitute the remote backup protection for the primary protection R_1. No elements of the protection system associated with R_1 are shared by these protection systems, and hence no common modes of failure between R_1 and R_4, R_9 and R_{10} are possible. These remote backup protections will be slower than R_1, R_2 or R_3; and also remove additional elements of the power system – namely lines BC, BD and BE – from service, which would also de-energize any loads connected to these lines.

A similar set of backup relays is used for the system behind station A.

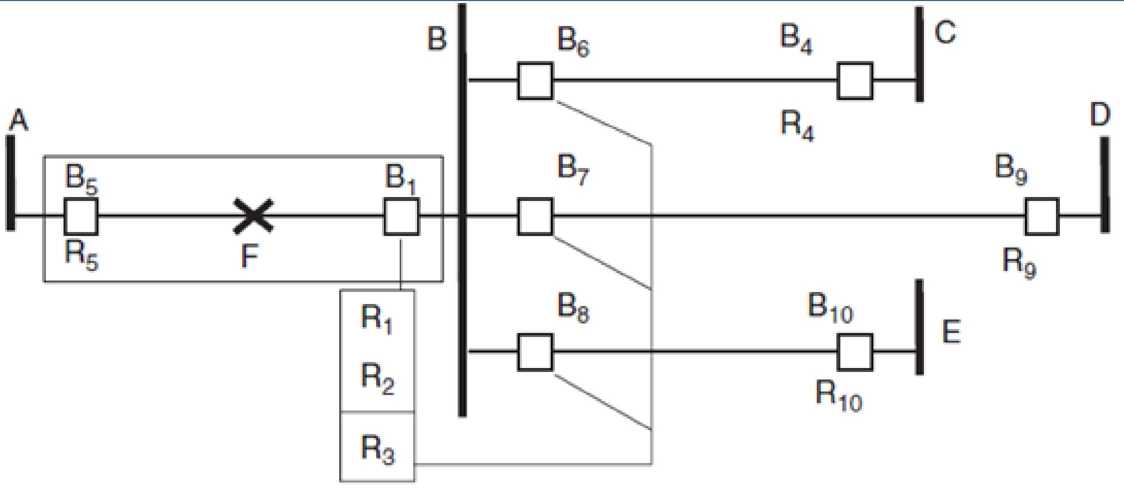


Figure 1.10 Duplicate primary, local backup and remote backup protection

1.5 Elements of a protection system

Three important elements are:
Relay – Brain of the protection system
CB - The switch that makes/breaks
CT,PT - The transducers through which relay sees

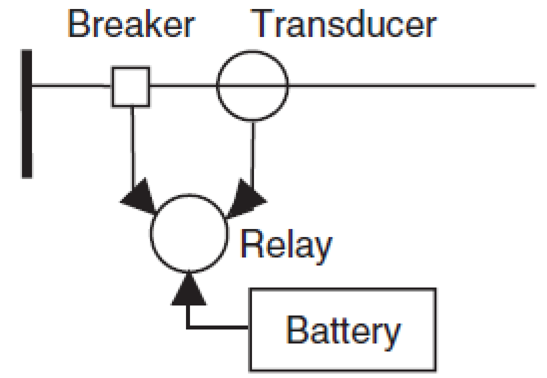
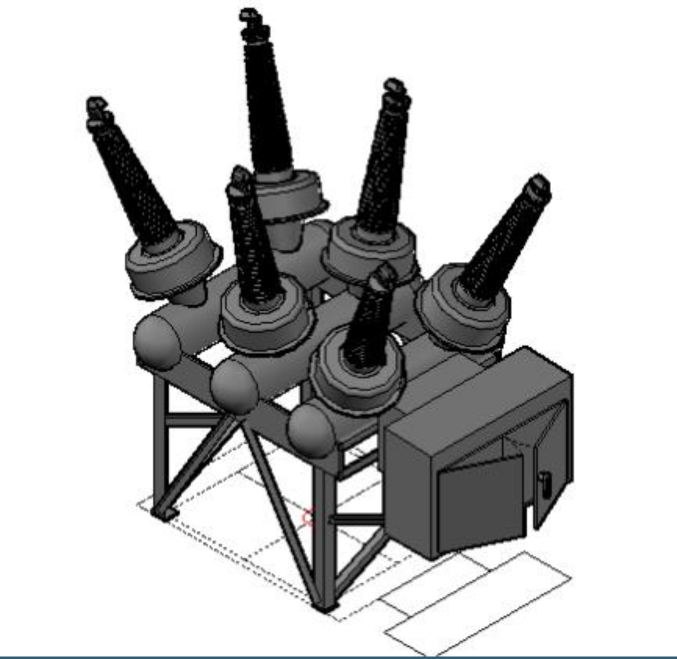


Figure 1.11 Elements of a protection system

1.5.1 Battery and DC supply

For example, a close-in three-phase fault can result in zero AC voltage at the substation AC outlets. Tripping power, as well as the power required by the relays, cannot therefore be obtained from the AC system, and is usually provided by the station battery.

1.5.2 Circuit breakers



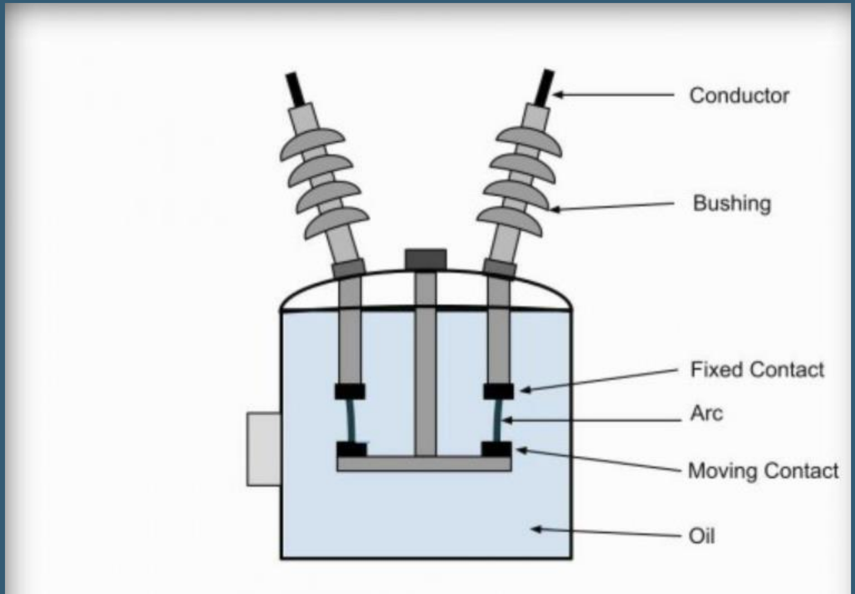
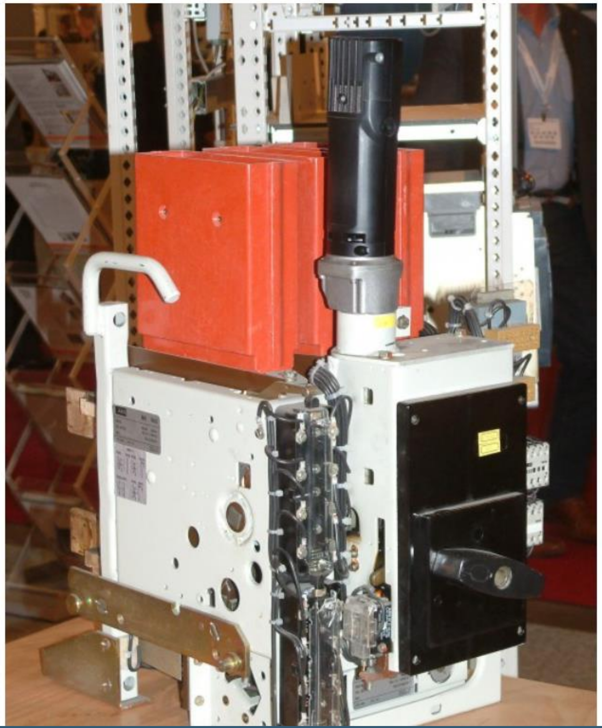


Fig-A: Bulk Oil Circuit Breaker (BOCB)

Vacuum circuit breaker (VCB)



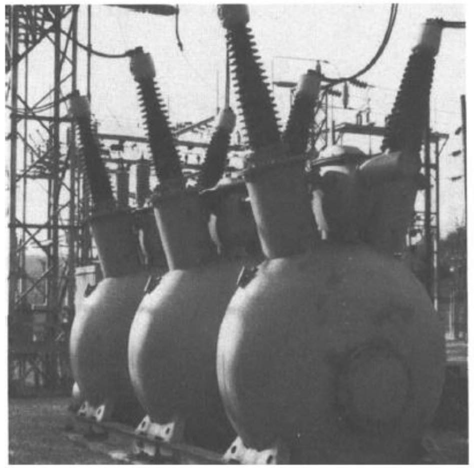
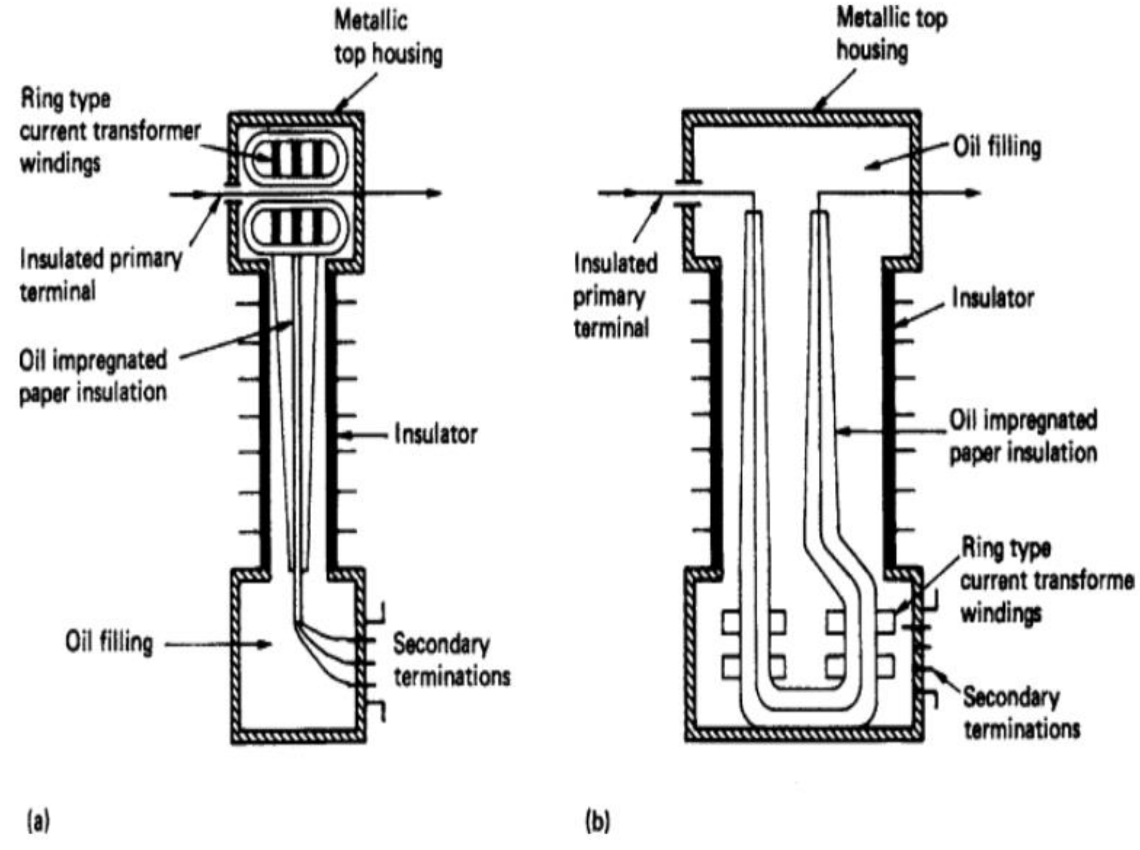


Figure 1.12 A 138 kV oil circuit breaker. (Courtesy of Appalachian Power Company)

earlier 'dead-tank' (Figure 1.12) designs incorporated CTs in the bushing pocket of the tank, thereby providing CTs on both sides of the contacts. This arrangement provided a very nice mechanism for providing overlapping zones of protection on the two sides of the circuit breakers.

Dead-Tank Circuit Breaker with Bushing-Type CTs

In the live-tank design, since the entire equipment is at line potential, it is not possible to incorporate CTs which have their secondary windings essentially at the ground potential. It then becomes necessary to design the CTs with their own insulating system, as separate free-standing devices, a design which is quite expensive. With free-standing CTs, it is no longer economical to provide CTs on both sides of a circuit breaker, and one must make do with only one CT on one side of the breaker. Of course, a free-standing CT has multiple secondaries, and protection zone overlap is achieved by using secondary windings on opposite sides of the zones of protection.



Cross-section of (a) live-tank and (b) dead-tank current transformers

Free standing CTs can further be live tank or dead tank – and they can have multiple secondaries

Example 1.5

Consider the dead-tank circuit breaker shown in Figure 1.14(b). The bushing CTs are on either side of the breaker and the secondaries are connected to the bus and line protection so that they overlap at the breaker. For a fault at F_1 both protective systems will operate. The bus differential relays will trip B_1 and all other breakers on the bus. This will clear the fault. The line protection will similarly trip breaker B_1; and the corresponding relays at the remote station will also trip their associated breakers. This is unnecessary, but unavoidable. If there are tapped loads on the line, they will be de-energized until the breakers reclose. For a fault at F_2, again both protective systems will operate. For this fault, tripping the other bus breakers is not necessary to clear the fault, but tripping the two ends of the line is necessary.

Now consider the live-tank design shown in Figure 1.14(c). For a fault at F_1, only the bus protection sees the fault and correctly trips B_1 and all the other bus breakers to clear the fault. For a fault at F_2, however, tripping the bus breakers does not clear the fault, since it is still energized from the remote end, and the line relays do not operate. This is a blind spot in this configuaration. Column protection will cover this area. For a fault at F_3 and F_4, the line relays will operate and the fault will be cleared from both ends. The fault at F_3 again results in unnecessary tripping of the bus breakers.

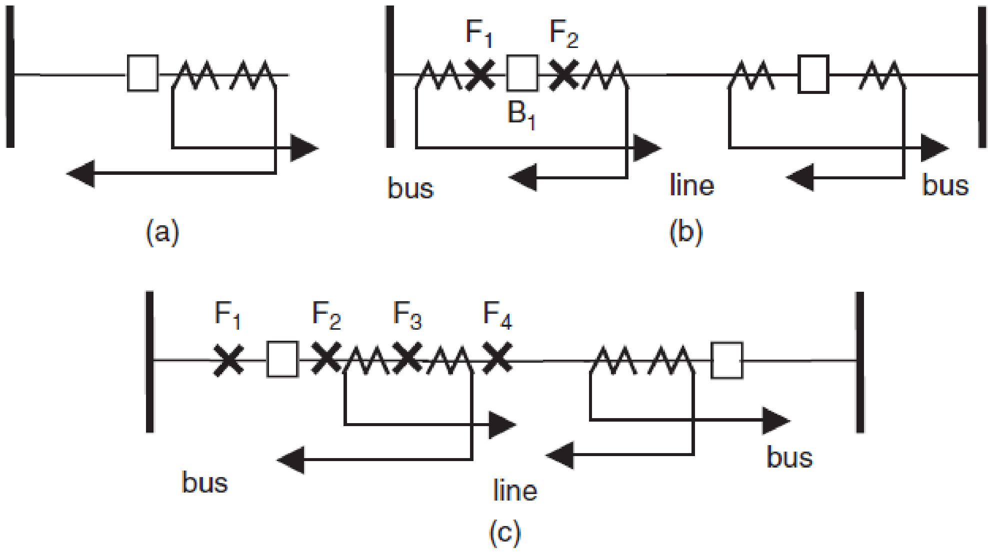


Figure 1.14 Zone overlap with different types of CTs and circuit breakers