ATME COLLEGE OF ENGINEERING

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DEPARTMENT OF ELECTRICAL & ELECTRONICS ENGINEERING

NOTES

COURSE TITLE: ELECTRICAL POWER GENERATION AND ECONOMICS

COURSE CODE: BEE405A

SEMESTER: IV

MODULE-4: GROUNDING

Prepared by

Department of EEE,
ATME College of Engineering

INSTITUTIONAL VISION AND MISSION

VISION:

- Development of academically excellent, culturally vibrant, socially responsible and globally competent human resources.

MISSION:

- To keep pace with advancements in knowledge and make the students competitive and capable at the global level.
- To create an environment for the students to acquire the right physical, intellectual, emotional and moral foundations and shine as torchbearers of tomorrow's society.
- To strive to attain ever-higher benchmarks of educational excellence.

Department Vision and Mission

Vision:

To create Electrical & Electronics Engineers who excel to be technically competent and fulfill the cultural and social aspirations of the society.

Mission:

- To provide knowledge to students that builds a strong foundation in the basic principles of electrical engineering, problem solving abilities, analytical skills, soft skills and communication skills for their overall development.
- To offer outcome based technical education.
- To encourage faculty in training & development and to offer consultancy through research & industry interaction.

Program Educational Objectives (PEOs)

PEO1: To produce competent and ethical Electrical and Electronics Engineers who will exhibit the necessary technical and managerial skills to perform their duties in society.

PEO2: To make Graduates continuously acquire and enhance their technical and socio-economic skills.

PEO3: To aspire Graduates on R&D activities leading to offering solutions and excel in various career paths.

PEO4: To produce quality engineers who have the capability to work in teams and contribute to real time projects.

Program Outcomes (POs)

Engineering Graduates will be able to:

PO1: Engineering Knowledge: Apply the knowledge of mathematics, science, engineering fundamentals and an engineering specialization to the solution of complex engineering problems.

PO2: Problem Analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO3: Design / Development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4: Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO5: Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO6: The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7: Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8: Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO9: Individual and team work: Function effectively as an individual and as a member or leader in diverse teams, and in multidisciplinary settings.

PO10: Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO11: Project management and finance: Demonstrate knowledge and understanding of the engineering management principles and apply these to one's own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO12: Life-long learning: Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

Program Specific Outcomes (PSOs)

The students will develop an ability to produce the following engineering traits:

PSO1: Apply the concepts of Electrical & Electronics Engineering to evaluate the performance of power systems and also to control industrial drives using power electronics

PSO2: Demonstrate the concepts of process control for Industrial Automation, design models for environmental and social concerns and also exhibit continuous self- learning

Module-4
Grounding Systems

Structure

4.0 Course Objective

- Classification of substation and explain the operation of different substation equipment.
- Explain the importance of grounding and different grounding methods used in practice.

4.1 Introduction

The purpose of grounding is to provide safe, reliable and cost efficient power distribution. (Note that the cost element includes damage to the equipment due to a fault or lightning strike.) These are the goals of grounding from a power distribution viewpoint where electrical noise interference is not a consideration. In the case of sensitive electronic systems, such as audio, video and computer systems it is also necessary that the grounding system provide a stable and low impedance connection to earth to control electromagnetic interference (EMI). The isolated star ground system as documented in this paper serves all of these purposes: safety, reliability, cost efficiency and control of electromagnetic interference.

In power system, grounding or earthing means connecting frame of electrical equipment (non-current carrying part) or some electrical part of the system (e.g. neutral point in a star-connected system, one conductor of the secondary of a transformer etc.) to earth i.e. soil. This connection to earth may be through a conductor or some other circuit element (e.g. a resistor, a circuit breaker etc.) depending upon the situation. Regardless of the method of connection to earth, grounding or earthing offers two principal advantages. First, it provides protection to the power system. For example, if the neutral point of a star-connected system is grounded through a circuit breaker and phase to earth fault occurs on any one line, a large fault current will flow through the circuit breaker. The circuit breaker will open to isolate the faulty line. This protects the power system from the harmful effects of the fault. Secondly, earthing of electrical equipment (e.g. domestic appliances, hand held tools, industrial motors etc.) ensures the safety of the persons handling the equipment. For example, if insulation fails, there will be a direct contact of the live conductor with the metallic part (i.e. frame) of the equipment. Any person in contact with the metallic part of this equipment will be subjected to a dangerous electrical shock which can be fatal. In this chapter, we shall discuss the importance of grounding or earthing in the line of power system with special emphasis on neutral grounding.

4.2 Neutral Grounding System

The process of connecting neutral point of 3-phase system to earth (i.e. soil) either directly or through some circuit element (e.g. resistance, reactance etc.) is called Neutral grounding.

Neutral grounding has been in practice in many systems all over the world, but there are some systems, which still operate with ungrounded neutrals. An ungrounded system is one in which there is no intentional connection between the system conductors and earth. When the neutral of the system is not grounded, it is possible for high voltages to appear from line to ground during normal switching of a circuit having a line to ground fault. These voltages may cause failure of insulation at other locations on the system and result to damage to equipment. A ground fault on one phase causes full line to line voltage to appear between ground and the two unfaulted phases. Line to ground fault on ungrounded neutral systems causes a small amount of ground fault current to flow which may not be enough to actuate protective relays.

Neutral grounding provides protection to personal and equipment. It is because during earth fault, the current path is completed through the earthed neutral and the protective devices (e.g. a fuse etc.) operate to isolate the faulty conductor from the rest of the system. This point is illustrated in Fig. 1

Fig. 1 shows a 3-phase, star-connected system with neutral earthed (i.e. neutral point is connected to soil). Suppose a single line to ground fault occurs in line Rat point F. This will cause the current to flow through ground path as shown in Fig. 26.10. Note that current flows from R-phase to earth, then to neutral point N and back to R-phase. Since the impedance of the current path is low, a large current flows through this path. This large current will blow the fuse in R-phase and isolate the faulty line R . This will protect the system from the harmful effects (e.g. damage to equipment, electric shock to personnel etc.) of the fault. One important feature of grounded neutral is that the potential difference between the live conductor and ground will not exceed the phase voltage of the system i.e. it will remain nearly constant.

Advantages:

The following are the advantages of neutral grounding:

1. Voltages of the healthy phases do not exceed line to ground voltages i.e. they remain nearly constant.

2. The high voltages due to arcing grounds are eliminated.

3. The protective relays can be used to provide protection against earth faults. In case earth fault occurs on any line, the protective relay will operate to isolate the faulty line.

4. The over voltages due to lightning are discharged to earth.

5. It provides greater safety to personnel and equipment.

6. It provides improved service reliability.

4. Operating and maintenance expenditures are reduced.

4.3 Resistance Grounding Systems:

Resistance Grounding Systems are used in industrial electrical power distribution facilities to limit phase-to-ground fault currents. The reasons for limiting the current by resistance grounding may be one or more of the following:

1. To reduce burning and melting effects in faulted electrical equipment, such as switchgear, transformers, cables, and rotating machines.

2. To reduce mechanical stresses in circuits and apparatus carrying fault currents.

3. To reduce electrical-shock hazards to personnel caused by stray ground fault currents in the ground return path.

4. To reduce the arc blast or flash hazard to personnel who may have accidentally caused or who happen to be in close proximity to the ground fault.

5. To reduce the momentary line-voltage dip occasioned by the occurrence and clearing of a ground fault.

6. To secure control of the transient over-voltages while at the same time avoiding the shutdown of a facility circuit on the occurrence of the first ground fault (high-resistance grounding).

Generally speaking, there are two types of resistors used to tie an electrical system‘s neutral to ground: low resistance and high resistance. Ground fault current flowing through either type of resistor when a single phase faults to ground will increase the phase-to-ground voltage of the remaining two phases. As a result, conductor insulation and surge arrestor ratings must be based on line-to-line voltage. This temporary increase in phase-to-ground voltage should also be considered when selecting two and three pole breakers installed on resistance grounded low voltage systems. Many 480/277V three-pole breakers.

For example, carry single-pole interrupting ratings that are based on 277V phase-to ground. Once the phase-to-ground voltage increases to 480V, the breaker‘s performance is not guaranteed. The increase in phase-to-ground voltage associated with ground fault currents also precludes the connection of line-to-neutral loads directly to the system. If line-to neutral loads (such as 277V lighting) are present, they must be served by a solidly grounded system. This can be achieved with an isolation transformer that has a three-phase delta primary and a three-phase, four-wire, wye secondary. Neither of these grounding systems (low or high resistance) reduce arc-flash hazards associated with phase-to-phase faults, but both systems significantly reduce or essentially eliminate the arc-flash hazards associated with phase-to-ground faults. Both types of grounding systems limit mechanical stresses and reduce thermal damage to electrical equipment, circuits, and apparatus carrying faulted current.

4.4 Ungrounded System:

Ungrounded systems operate without a grounded conductor. In other words, none of the circuit conductors of the electrical system are intentionally grounded to an earth ground such as a metal water pipe, building steel, etc. The same network of equipment grounding conductors is provided for ungrounded systems as for solidly grounded electrical systems. However, equipment grounding conductors (EGCs) are used only to locate phase-to-ground faults and sound some type of alarm.

Therefore, a single sustained line-to-ground fault does not result in an automatic trip of the over current protection device. This is a major benefit if electrical system continuity is required or if it would result in the shutdown of a continuous process. However, if an accidental ground fault occurs and is allowed to flow for a substantial time, over voltages can develop in the associated phase conductors. Such an overvoltage situation can lead to conductor insulation damage, and while a ground fault remains on one phase of an ungrounded system, personnel contacting one of the other phases and ground are subjected to 1.732 times the voltage they would experience on a solidly neutral grounded system.

In an ungrounded neutral system, the neutral is not connected to the ground i.e. the neutral is isolated from the ground. Therefore, this system is also called isolated neutral system or free neutral system. Fig. 2 shows ungrounded neutral system. The line conductors have capacitances between one another and to ground. The former are delta-connected while the latter are star-connected. The delta-connected capacitances have little effect on the grounding characteristics of the system (i.e. these capacitances do not effect the earth circuit) and, therefore, can be neglected.

4.5 Resonant grounding:

We have seen that capacitive currents are responsible for producing arcing grounds. These capacitive currents flow because capacitance exists between each line and earth. If inductance L of appropriate value is connected in parallel with the capacitance of the system, the fault current I_F flowing through L will be in phase opposition to the capacitive current I_C of the system. If L is so adjusted that $I_L = I_C$, then resultant current in the fault will be zero. This condition is known as resonant grounding.

When the value of L of arc suppression coil is such that the fault current I_F exactly balances the capacitive current I_C, it is called Resonant grounding.

Circuit Details: An arc suppression coil (also called Peterson coil) is an iron-cored coil connected between the neutral and earth as shown in Fig. 1(i). The reactor is provided with tap-pings to change the inductance of the coil. By adjusting the tappings on the coil, the coil can be tuned with the capacitance of the system i.e. resonant grounding can be achieved.

Operation:

Fig. 1(i) shows the 3-phase system employing Peterson coil grounding. Sup-pose line to ground fault occurs in the line B at point F. The fault current I_F and capacitive currents I_R and I_Y will flow as shown in Fig. 1(i). Note that I_F flows through the Peterson coil (or Arc suppression coil) to neutral and back through the fault. The total capacitive current I_C is the phasor sum of I_R and I_Y as shown in phasor diagram in Fig. 1(ii). The voltage of the faulty phase is applied across the arc suppression coil. Therefore, fault current I_F lags the faulty phase voltage by90°. The current I_F is in phase opposition to capacitive current I_C [See Fig. 1(ii)]. By adjusting the tappings on the Peterson coil, the resultant current in the fault can be reduced. If inductance of the coil is so adjusted that $I_L = I_C$ then resultant current in the fault will be zero

4.6 Solid grounding:

A solidly grounded system is one in which the neutral points have been intentionally connected to earth ground with a conductor having no intentional impedance, as shown in Figure 4. This partially reduces the problem of transient over voltages found on the ungrounded system, provided the ground fault current is in the range of 25 to 100% of the system three phase fault current. However, if the reactance of the generator or transformer is too great, the problem of transient over voltages will not be solved. While solidly grounded systems are an improvement over ungrounded systems, and speed up the location of faults, they lack the current limiting ability of resistance grounding and the extra protection this provides. Solidly grounded systems are usually limited to older low voltage applications at 600 volts or less.

When the neutral point of a 3-phase system (e.g. 3- phase generator, 3-phase transformer etc.) is directly connected to earth (i.e. soil) through a wire of negligible resistance and reactance, it is called Solid grounding or effective grounding. Fig. 2 shows the solid grounding of the neural point. Since the neutral point is directly connected to earth through a wire, the neutral point is held at earth potential under all conditions. Therefore, under fault conditions, the voltage of any conductor to earth will not exceed the normal phase voltage of the system.

4.6.1 Advantages:

The solid grounding of neutral point has the following advantages:
(i)The neutral is effectively held at earth potential.
(ii)When there is an earth fault on any phase of the system, the phase to earth voltage of the faulty phase becomes zero. However, the phase to earth voltages of the remaining two healthy phases remain at normal phase voltage because the potential of the neutral is fixed at earth potential. This permits to insulate the equipment for phase voltage. Therefore, there is a saving in the cost of equipment.

(iii)It becomes easier to protect the system from earth faults which frequently occur on the system. When there is an earth fault on any phase of the system, a large fault current flows between the fault point and the grounded neutral. This permits the easy operation of earth-fault relay.

4.6.2 Disadvantages:

The following are the disadvantages of solid grounding
(i)Since most of the faults on an overhead system are phase to earth faults, the system has to bear a large number of severe shocks. This causes the system to become unstable.
(ii)The solid grounding results in heavy earth fault currents. Since the fault has to be cleared by the circuit breakers, the heavy earth fault currents may cause the burning of circuit breaker contacts.
(iii)The increased earth fault current results in greater interference in the neighbouring communication lines.

4.6.3 Applications:

Solid grounding is usually employed where the circuit impedance is sufficiently high so as to keep the earth fault current within safe limits. This system of grounding is used for voltages upto 33 kV with total power capacity not exceeding 5000 kVA

4.7 Resistance grounding:

In order to limit the magnitude of earth fault current, it is a common practice to connect the neutral point of a 3-phase system to earth through a resistor. This is called resistance grounding. When the neutral point of a 3-phase system (e.g. 3-phase generator, 3-phase transformer etc.) is connected to earth (i.e. soil) through a resistor, it is called resistance grounding

Resistance grounding is by far the most effective and preferred method. It solves the problem of transient overvoltage, thereby reducing equipment damage. It accomplishes this by allowing the magnitude of the fault current to be predetermined by a simple ohms law calculation. Thus the fault current can be limited, in order to prevent equipment damage. In addition, limiting fault currents to predetermined maximum values permits the designer to selectively coordinate the operation of protective devices, which minimizes system disruption and allows for quick location of the fault. There are two broad categories of resistance grounding: low resistance and high resistance. In both types of grounding, the resistor is connected between the neutral of the transformer secondary and the earth ground.

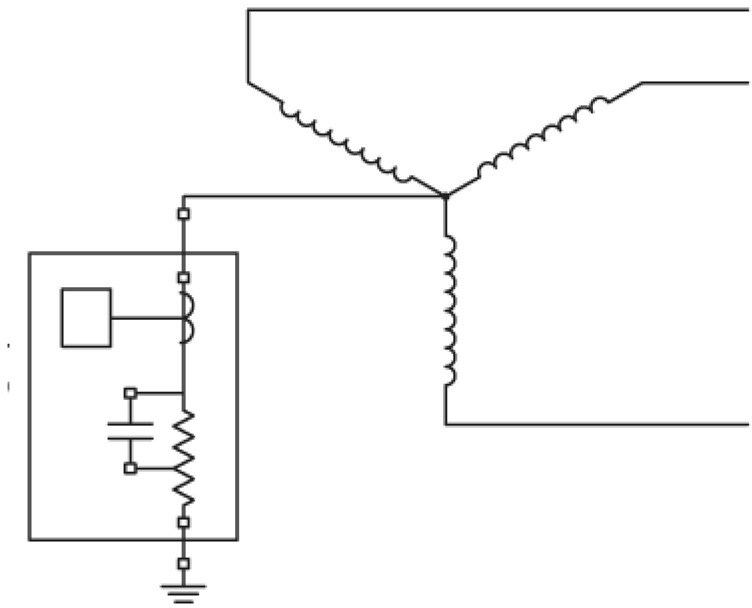

Fig.3: Resistance Grounding

Fig.3 shows the grounding of neutral point through a resistor R. The value of R should neither be very low nor very high. If the value of earthing resistance R is very low, the earth fault current will be large and the system becomes similar to the solid grounding system. On the other hand, if the earthing resistance R is very high, the system conditions become similar to ungrounded neutral system. The value of R is so chosen such that the earth fault current is limited to safe value but still sufficient to permit the operation of earth fault protection system. In practice, that value of R is selected that limits the earth fault current to 2 times the nor-mal full load current of the earthed generator or transformer

4.7.1 High Resistance grounding:

High Resistance Grounding (HRG) systems limit the fault current when one phase of the system shorts or arcs to ground, but at lower levels than low resistance systems. In the event that a ground fault condition exists, the HRG typically limits the current to 5-10A, though most resistor manufacturers label any resistor that limits the current to 25A or less as high resistance. HRG‘s are continuous current rated, so the description of a particular unit does not include a time rating. Unlike NGR‘s, ground fault current flowing through a HRG is usually not of significant magnitude to result in the operation of an over current device. Since the ground fault current is not interrupted, a ground fault detection system must be installed. These systems include a bypass contactor tapped across a portion of the resistor that pulses (periodically opens and closes). When the contactor is open, ground fault current flows through the entire resistor. When the contactor is closed a portion of the resistor is bypassed resulting in slightly lower resistance and slightly higher ground fault current. A hand held pulsing current detector can then be used to track the ground fault to its source.

4.7.2 Low Resistance Grounding:

Neutral Grounding Resistors (NGR‘s) limit the fault current when one phase of the system shorts or arcs to ground. In the event that a ground fault condition exists, the NGR typically limits the current to 200-400A, though most resistor manufacturers label any resistor that limits the current to 25A or greater as low resistance. A particular resistor may be specified as 2400V L-N, 400A, 10 seconds, meaning that the impedance of the resistor is such that 2400V applied across it will result in 400A of current through it, and that the unit can only carry this current for 10 seconds before overheating. As a rule of thumb, NGR‘s are designed with a continuous current rating equal to approximately 10% of its rated current. A unit that is rated 400A for 10 seconds may carry 40A (10% of 400A) continuously. In order to prevent the NGR from overheating, over current protective devices must be designed to trip before the resistor‘s damage curve is breached.

4.8 Earthing Transformer:

An earthing transformer is usually associated with three phase supply systems. Earthing of any electrical system at the source is considered by most countries to be the safer practice with regard to personnel and equipment safety.

On a three phase system, the neutral would be earthed either directly or through some limiting impedance / resistance. When the neutral point is not available or does not exist with a delta secondary winding of the transformer, a neutral point needs to be created. This is the purpose of the earthing transformer, which could consist of a zig- zag winding, or a two winding star delta transformer where the star winding of correct voltage supplies an accessible neutral point when connected to the supply system.

In areas where earth point is not available, a neutral point is created using an earthing transformer. Earthing transformer, having the zig-zag (interstar) winding is used to achieve the required zero phase impendence stage which provides the possibility of neutral earthing condition. In addition an auxiliary windings can also be provided to meet the requirement of an auxiliary power supply.

Earthing transformers are usually oil immersed and may be installed outdoor. As for connection, the earthing can be connected directly, through an arc-suppression reactor or through a neutral earthing reactor or resistor. In cases where a separate reactor is connected between the transformer neutral and earth, the reactor and the transformer can be incorporated into the same tank.

In this method of neutral earthing, the primary of a single-phase voltage transformer is connected between the neutral and the earth as shown in Fig. 4. A low resistor in series with a relay is connected across the secondary of the voltage transformer. The voltage transformer provides a high reactance in the neutral earthing circuit and operates virtually as an ungrounded neutral system. An earth fault on any phase produces a voltage across the relay. This causes the operation of the protective device.

Advantages:

The following are the advantages of voltage transformer earthing
(i)The transient over voltages on the system due to switching and arcing grounds are reduced. It
is because voltage transformer provides high reactance to the earth path.
(ii)This type of earthing has all the advantages of ungrounded neutral system.
(iii)Arcing grounds are eliminated.

Disadvantages:

The following are the disadvantages of voltage transformer earthing
(i)When earth fault occurs on any phase, the line voltage appears across line to earth capacitances. The system insulation will be overstressed.
(ii)The earthed neutral acts as a reflection point for the travelling waves through the machine winding. This may result in high voltage build up.

Applications:

The use of this system of neutral earthing is normally confined to generator equipments which are directly connected to step-up power transformers.

4.9 Neutral Grounding Transformer:

Neutral grounding has been in practice in many systems all over the world, but there are some systems, which still operate with ungrounded neutrals. An ungrounded system is one in which there is no intentional connection between the system conductors and earth. When the neutral of the system is not grounded, it is possible for high voltages to appear from line to ground during normal switching of a circuit having a line to ground fault. These voltages may cause failure of insulation at other locations on the system and result to damage to equipment. A ground fault on one phase causes full line to line voltage to appear between ground and the two unfaulted phases. Line to ground fault on ungrounded neutral systems causes a small amount of ground fault current to flow which may not be enough to actuate protective relays. The neutral of a system may be grounded through a resistance, reactance or directly. Generally, the neutrals of source transformers or generators with star connected windings are grounded. Grounding the neutral reduces the magnitude of transient voltages, improves protection against lightning, protection for line to ground fault becomes reliable, and improves reliability & safety. Also the potential of the neutral gets fixed, whereas in the ungrounded system, the neural remains floating. The value of the reactance used to ground the neutral is chosen to either neutralize the capacitive current or to limit the line to ground fault current to that of a three phase fault current.

4.10 Short circuit MVA calculation of a power system

The first step in analyzing a power system is to get the data for the power available at the site, the utility data. This data can be obtained from the power company. When calling the power company, explain the type of information you need and ask for the engineering department. It may be helpful to explain why you need the information. The power company will be able to supply this information for the point in the power system where their responsibility for the power system ends and the customer‘s responsibility starts. A common location for this point is the secondary of a pole or pad mounted transformer. If the customer is responsible for the transformer, the transition point would be the primary of the transformer. Sometimes a pole mounted disconnect will be the transition point. The power company will specify where in the system their responsibility ends.

The data needed is the line to line voltage (VLL), short-circuit MVA (SC MVA), and X/R. Obtaining the voltage is simple enough. SC MVA is the power available at a bolted three phase fault. Bolted means all three phases connected together with no added impedance. X/R is the ratio of reactance to resistance in the supply. SC MVA and X/R may need to be derived from other data.

Short-circuit current (ISC) is sometimes supplied by the power company rather than SC MVA. This current is the current in one phase of a three phase bolted fault. The SC MVA can be calculated from the short-circuit current using the following equation:

SC MVA = 1.732 I_{SC} V_{LL} , where I_{SC} is expressed in kA and V_{LL}- in kV

Power factor (PF) is sometimes specified instead of X/R. This must be the short circuit power factor. Power factor is defined as the cosine of the angle between voltage and current. X/R is the tangent of this same angle. X/R can be found from power factor by taking the tangent of the inverse cosine of the power factor.

$X/R = \tan(\cos^{-1} PF)$

4.11 Current-limiting reactors

Current-limiting reactors are series reactors intended to reduce the short circuit currents in the power system. The motive to reduce the short circuit currents in the is to use circuit breakers with lower short circuit current breaking capacity and consequently less expensive circuit breakers.

Sometimes other system components also need protection against too high short circuit currents, like for instance auto connected transformers that are not self-protecting due to their low impedance. Another application is limitation of the inrush current when starting large motors.

Current-limiting reactors are sometimes used to limit discharge currents of capacitor banks. In such cases, a bifilar wound resistance wire is induced and connected in parallel with the inductance.

4.12 Course Outcome

- Classify various substations and explain the importance of grounding.

4.13 Further Readings

- https://www.electrical4u.com/electrical-power-substation-engineering-and-layout/
- https://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&cad=rja&uact=8&ved=0ahUKEwiP0aW26bLUAhVHL8AKHWKfD7AQFggzMAI&url=http%3A%2F%2Fwww.springer.com%2Fcda%2Fcontent%2Fdocument%2Fcda_downloaddocument%2F9781461458296-c1.pdf%3FSGWID%3D0-0-45-1364123-p174673022&usg=AFQjCNHfXm4G9xRNNlTWdL1TlbDudtnyTA&sig2=Xz2jDQf7qYpC1Jw9SQvFUg