UNIT – 4

System Protection

Unit-04 /Lecture-01

INTRODUCTION ABOUT GENERATOR PROTECTION

GENERATOR PROTECTION

Introduction

Generator protection and control are interdependent problems. A generator has to be protected not only from electrical faults (stator and rotor faults) and mechanical problems (e.g. Related to turbine, boilers etc), but it also has to be protected from adverse system interaction arising if generator going of out of step with the rest of system, loss of field winding etc. Under certain situations like internal faults, the generator has to be quickly isolated (shut down), while problems like loss of field problem requires an 'alarm' to alert the operator. Following is a descriptive list of internal faults and abnormal operating conditions.

1. Internal Faults

a. Phase and /or ground faults in the stator and associated protection zone

b. Ground faults in the rotor (field winding)

2. Abnormal Operating Conditions.

a. Loss of field.

b. Overload.

c. Overvoltage.

d. Under and over frequency

e. Unbalanced Operation e.g. single phasing.

f. Loss motoring i.e. loss of prime mover.

g. Loss of synchronization (out of step).

h. Sub synchronous oscillation.

RGPV/ June 2011

INTRODUCTION OF THE STATOR WINDINGS FAULTS:

Stator winding faults:

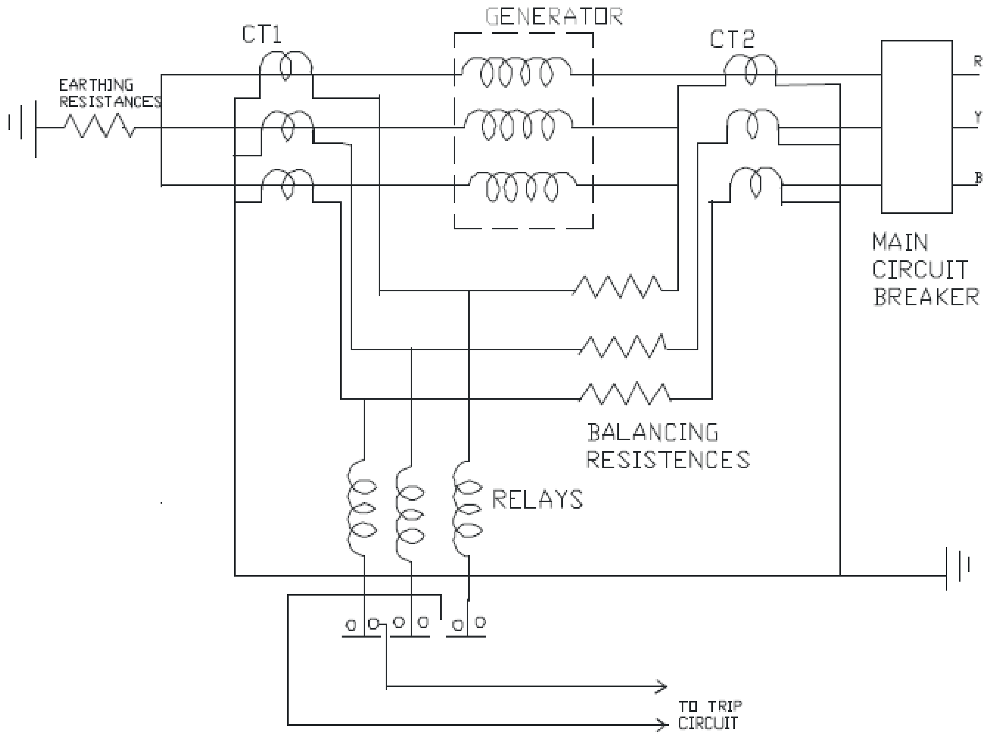
These types of faults occur due to the insulation breakdown of the stator coils. **Different types of stator windings faults are:**

a) phase to earth fault

b) phase to phase fault

c) inter turn fault

Phase to earth fault are limited by resistance of the neutral grounding resistor. There are fewer chances for the occurrence of the phase to phase and interturn faults. The insulation between the two phases is at least twice as thick as the insulation between one coil and the iron core, so phase to phase fault is less likely to occur. Inter turn fault occurs due the incoming current surges with steep wave front.



In this type of protection scheme currents at two ends of the protection system are compared. Under normal conditions, currents at two ends will be same. But when the fault occurs, current at one end will be different from the current at the end and this difference of current is made to flow through relay operating coils. The relays then closes its contacts and makes the circuit breaker to trip, thus isolate the faulty section. This type of protection is called the *merz price circulating current* system.

Limitations of this method: The earth fault is limited by the resistance of the neural earthing. When the fault occurs near the neutral point, this causes a small current to flow through the operating coil and it is further reduced by the neutral resistance. Thus this current is not sufficient to trip the circuit breaker. By this protection scheme , one can protect only 80 to 85 percent of the stator winding. If the relays with low settings are used the it will not provide desire stability. This difficulty is overcome by using the *modified differential protection.*

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	List various kinds of faults that may occur in an alternator.	**RGPV/ June 2013,2012,2011**	7
Q.2	List various kind of stator winding fault	**RGPV/ June** 20 **2011**	7

Unit-04 /Lecture-02

2.2 Modified differential protection: In modified differential protection setting of the earth faults can be reduced without any effect on the stability.

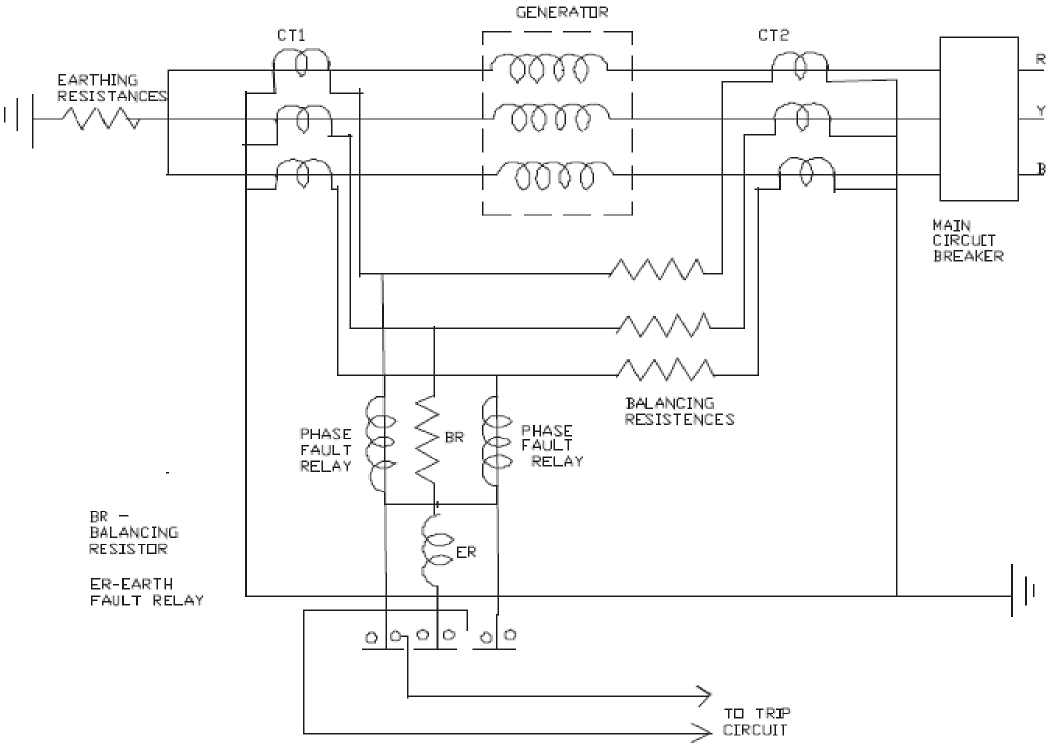


Fig 2: modified differential protection for the generators

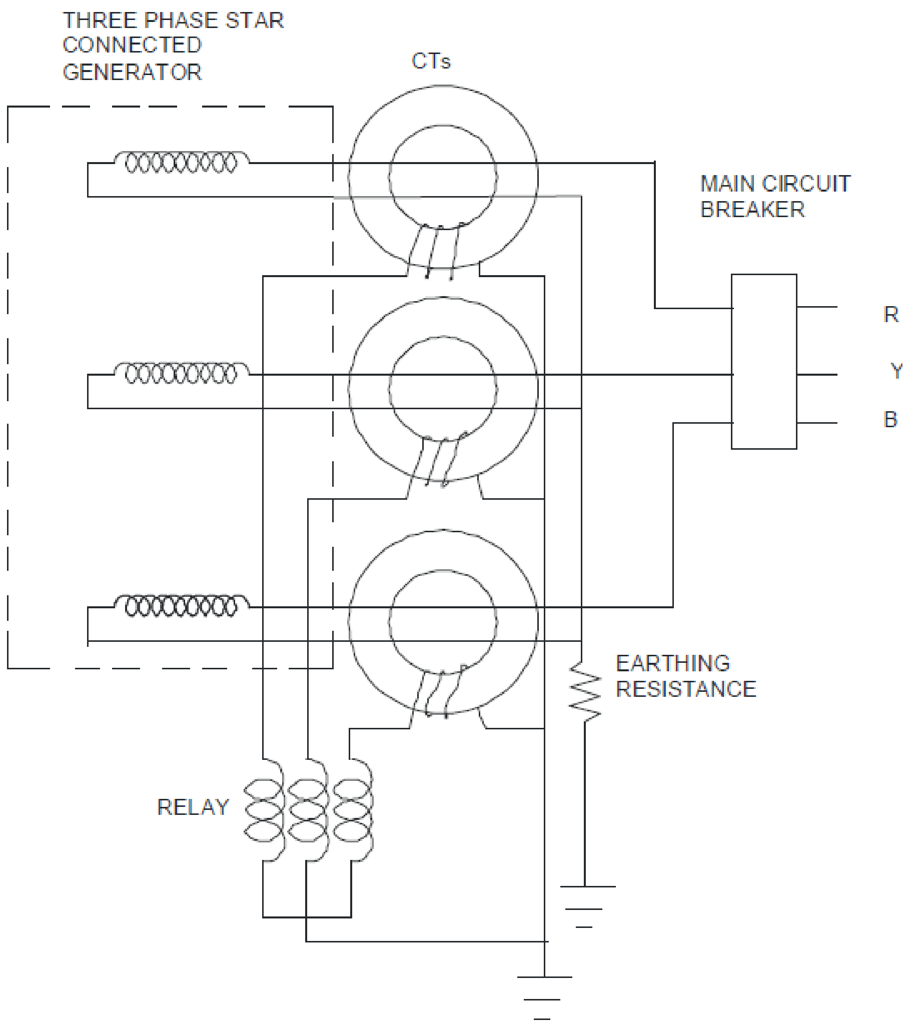
In this method two relays are used for the phase to phase fault and one relay is used for the protection of earth fault. In this method the two relays and the balancing resistance are connected in star and the phase fault relay is connected between the star point and the neutral pilot wire. The star connected circuit is symmetrical in terms of impedance. So when the fault current occurs due to the phase to phase fault, it cancels at the star point due to the equal impedance. Thus it is possible with this scheme to operate with the sensitive earth fault relays. Thus this scheme provides protection to the greater percentage of the stator winding.

2.3 Biased circulating current protection (percentage differential relay protection): With the differential protection relaying, the CTs at both end of the stator windings must be same. If there is any difference in the accuracy of the CTs the mal-operation of the relay will occurs. To overcome this difficulty, biased circulating current protection is used. In this protection system we can automatically increase the relay setting in proportion to the fault current. By suitable proportioning of the ratio of the relay restraining coil to the relay operating coil any biased can be achieved.

Under normal operating condition current in secondary of the line CTs will be same as the current in the secondary of the CTs at the neutral end. Hence there are balanced current flows in the restraining coils and no current flows in the operating coil. If there is any phase to phase or phase to earth fault occurs then it causes the differences in the secondary current of the two CTs. Thus the current flows through the operating coil and make the circuit breaker to trip.

Advantages of this method: a) It does not require the CTs with balancing features.
b) It also permit the low fault setting of the relay, thus protects the greater percentage of the stator winding.

2.4 Self balance protection system: This type of protection is employed for *earth fault* and also for the *phase to phase fault*.



In this type of protection two cables are required which is connected to the two ends of the each phase. These two cables are passed through the circular aperature of the ring type CTs. Under normal conditions the current flowing in the two leads of the cable will be in the same direction and no magnetisation occurs in the ring type CTs. When the earth fault occurs in any phase the fault current occurs only once through the CTs and thus magnetic flux induced, this induces the emf in the relay circuit causes the circuit breaker to trip.

This is very sensitive type earth fault protection but it also have some limitations:
a) a different design of the cable lead is required in this scheme.
b) large electromagnetic forces are develop in the CT ring under the condition of heavy short circuit.

2.5 <u>Stator ground fault protection</u>: The method of grounding effect the degree of protection which is employed by the differential protection. High impedance reduces the fault current and thus it is very difficult to detect the high impedance faults. So the differential protection does not work for the high impedance grounding. The separate relay to the ground neutral provides the sensitive protection. But ground relay can also detect the fault beyond the generator, it the time co-ordination is necessary to over come this difficulty.

If we use the star- delta transformer bank, then it will block the flow of ground currents, thus preventing the occurrence of the fault on other side of the bank from operating ground relays. In unit protection scheme the transformer bank limits the operation of the fault relay to the generator.

Unit connected schemes: In this scheme high resistance grounding is used and system is grounded through the transformer bank and through the resistors.

95% scheme: Relay which uses in the unit connected schemes must be insensitive to the normal third harmonics voltage that may be present between the neutral and the ground, and it must be sensitive to the fundamental harmonics voltage that is the cause of the fault. The magnitude of the neutral shift depends upon its location in the winding of the ground fault. And the general choice of the relay sensitive and distribution transformer voltage provide 95% protection of the winding so this scheme is called 95% scheme.

Neutral third harmonic under voltage: There is the third harmonic present between the neutral and the ground , and other schemes takes advantages of this and respond to the under voltage between the neutral and the ground.

100% scheme: This scheme provides complete protection of the stator winding by injecting the signal between the stator winding and monitors it for change. 95% scheme and third harmonics protection scheme provide protection only at rated speed and rated voltage but it 100% scheme also provide protection at standstill.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain Merz price differential protection	**RGPV/ June 2013**	7
Q.2	List various kind of stator winding fault	**RGPV/ June** 20 **2011**	7

Unit-04 /Lecture-03

2.7 Stator over heating protection: Stator over heating is caused due to the overloads and failure in cooling system. It is very difficult to detect the over heating due to the short circuiting of the lamination before any serious damage is caused. Temperature rise depend upon I^2Rt and also on the cooling. Over current relays can not detect the winding temperature because electrical protection can not detect the failure of the cooling system.

So to protect the stator against over heating, embed resistance temperature detector or thermocouples are used in the slots below the stator coils. These detectors are located on the different places in the windings so that to detect the temperature throughout the stator. Detectors which provide the indication of temperature change are arranged to operate the temperature relay to sound an alarm.

3. UNDER/OVER FREQUENCY PROTECTION:

3.1 Over frequency operation: Over frequency results from the excess generation and it can easily be corrected by reduction in the power outputs with the help of the governor or manual control.

3.2 Under frequency operation: Under frequency occurs due to the excess. During an overload, generation capability of the generator increases and reduction in frequency occurs. The power system survives only if we drop the load so that the generator output becomes equal or greater than the connected load. If the load increases the generation, then frequency will drop and load need to shed down to create the balance between the generator and the connected load. The rate at which frequency drops depend on the time, amount of overload and also on the load and generator variations as the frequency changes. Frequency decay occurs within the seconds so we can not correct it manually. Therefore automatic load shedding facility needs to be applied.

These schemes drops load in steps as the frequency decays. Generally load shedding drops 20 to 50% of load in four to six frequency steps. Load shedding scheme works by tripping the substation feeders to decrease the system load. Generally automatic load shedding schemes are designed to maintain the balance between the load connected and the generator.

The present practice is to use the under frequency relays at various load points so as to drop the load in steps until the declined frequency return to normal. Non essential load is removed first when decline in frequency occurs. The setting of the under frequency relays based on the most probable condition occurs and also depend upon the worst case possibilities.

During the overload conditions, load shedding must occur before the operation of the under frequency relays. In other words load must be shed before the generators are tripped.

4. UNDER/OVER VOLTAGE PROTECTION:

4.1 Over voltage protection: Over voltage occurs because of the increase in the speed of the prime mover due to sudden loss in the load on the generator. Generator over voltage does not occur in the turbo generator because the control governors of the turbo generators are very sensitive to the speed variation. But the over voltage protection is required for the hydro generator or gas turbine generators. The over voltage protection is provided by two over voltage relays have two units – one is the instantaneous relays which is set to pick up at 130 to 150% of the rated voltage and another unit is IDMT which is set to pick up at 110% of rated voltage. Over voltage may occur due to the defective voltage regulator and also due to manual control errors.

4.2 Under voltage protection: If more than one generators supply the load and due to some reason one generator is suddenly trip , then another generators try to supply the load. Each of these generators will experience a sudden increase in current and thus decreases the terminal voltage. Automatic voltage regulator connected to the system try to restore the voltage. And under voltage relay type-27 is also used for the under voltage protection.

5. PROTECTION OF THE GENERATOR DUE TO UNBALANCE LOADING:

Due to fault there is an imbalance in the three phase stator currents and due to these imbalance currents, double frequency currents are induced in the rotor core. This causes the over heating of the rotor and thus the rotor damage. Unbalanced stator currents also damage the stator.

Negative sequence filter provided with the over current relay is used for the protection against unbalance loading. From the theory of the symmetrical components, we know that an unbalanced three phase currents contain the negative sequence component. This negative phase sequence current causes heating of the stator. The negative heating follows the resistance law so it is proportional to the square of the current. The heating time constant usually depend upon the cooling system used and is equal to $I^2t=k$ where I is the negative sequence current and t is the current duration in seconds and k is the constant usually lies between 3 and 20.

Its general practice to use negative current relays which matches with the above heating characteristics of the generator. In this type of protection three CTs are connected to three phases and the output from the secondaries of the CTs is fed to the coil of over current relay through negative sequence filter. Negative sequence circuit consists of the resistors and capacitors and these are connected in such way that negative sequence currents flows through the relay coil. The relay can be set to operate at any particular value of the unbalance currents or the negative sequence component current.

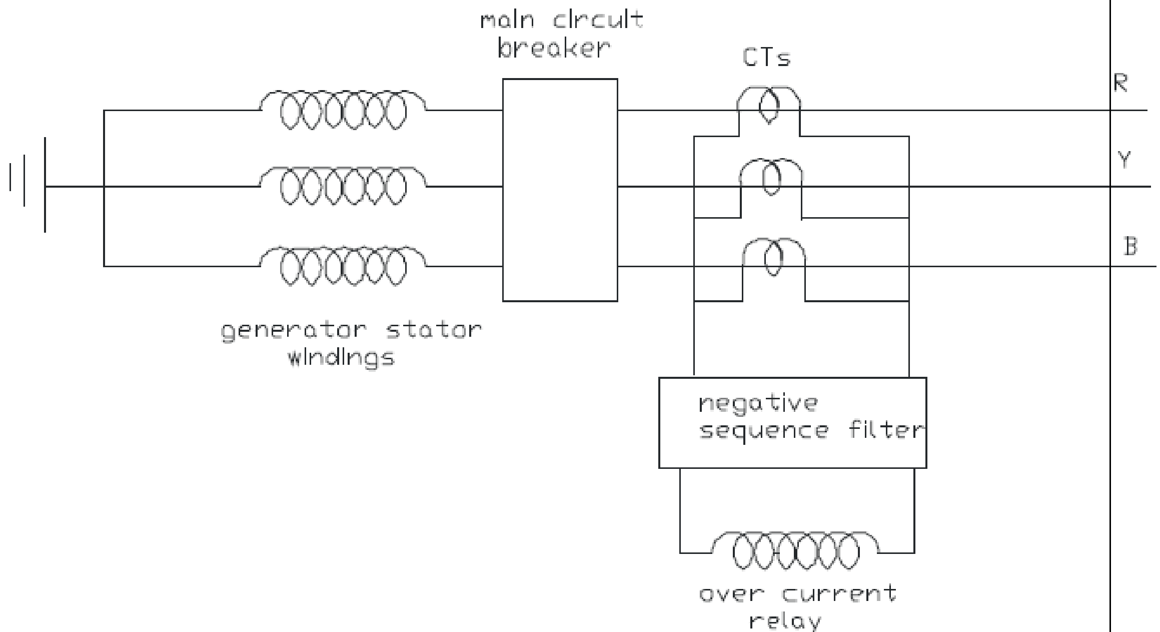


fig 6: protection against unbalance loading

Loss of Excitation Protection

When there is a reduced or lost of excitation of the synchronous generator, conceptionaly it will start functioning like an induction generator. Otherwise, if the system cannot provide adequate reactive power support for induction generator mode of operation, then synchronism is lost. The change is a gradual one and if the field is tripped by accident, an alarm can be used to alert the operator. However, if the field is not quickly restored, then the unit should be shut down.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	List various kinds of faults type of over voltage / under voltage, over frequency / under frequency fault that may occur in an alternator.	**RGPV/ June 2013,2011**	7
Q.2	Explain loss of excitation	**RGPV/ June** 20 **2011**	7

Unit-04 /Lecture-04

RGPV/ Dec 2013,2011

TRANSFORMER PROTECTION

There are different kinds of transformers such as two winding or three winding electrical power transformers, auto transformer, regulating transformers, transformers, rectifier transformers etc. Different transformers demand different schemes of transformer **protection** depending upon their importance, winding connections, earthing methods and mode of operation etc.

It is common practice to provide **Buchholz relay protection to all 0.5 MVA** and above transformers. While for all small size distribution transformers, only high voltage fuses are used as main protective device. For all larger rated and important distribution transformers, over current protection along with restricted earth fault protection is applied. Differential protection should be provided in the transformers rated above 5 MVA.

Depending upon the normal service condition, nature of transformer faults, degree of sustained over load, scheme of tap changing, and many other factors, the suitable **transformer protection** schemes are chosen.

Nature of Transformer Faults

Although an electrical power transformer is a static device, but internal stresses arising from abnormal system conditions, must be taken into consideration.

A transformer generally suffers from following types of transformer fault-

- Over current due to overloads and external short circuits,
  Terminal faults,
  Winding faults,
  Incipient faults.

All the above mentioned transformer faults cause mechanical and thermal stresses inside the transformer winding and its connecting terminals. Thermal stresses lead to overheating which ultimately affect the insulation system of transformer. Deterioration of insulation leads to winding faults. Some time failure of transformer cooling system, leads to overheating of transformer. So the transformer protection schemes are very much required.

The **general winding faults** in transformer are either earth faults or inter-turns faults.Phase to phase winding faults in a transformer is rare. The phase faults in an electrical transformer may be occurred due to bushing flash over and faults in tap changer equipment. Whatever may be the faults, the transformer must be isolated instantly during fault otherwise major breakdown may occur in the electrical power system.

Incipient faults are internal faults which constitute no immediate hazard. But it these faults are over looked and not taken care of, these may lead to major faults. The faults in this group are mainly inter-lamination short circuit due to insulation failure between core lamination, lowering the oil level due to oil leakage, blockage of oil flow paths. All these faults lead to overheating. So transformer protection scheme is required for incipient transformer faults also. The earth fault, very nearer to neutral point of transformer star winding may also be considered as an incipient fault.Influence of winding connections and earthing on **earth fault** current magnitude.There are mainly two conditions for earth fault current to flow during winding to earth faults,

A current exists for the current to flow into and out of the winding.Ampere-turns balance is maintained between the windings.

The value of winding earth fault current depends upon position of the fault on the winding, method of winding connection and method of earthing. The star point of the windings may be earthed either solidly or via a resistor. On delta side of the transformer the system is earthed through an earthing transformer. Grounding or earthing transformerprovides low impedance path to the zero sequence current and high impedance to the positive and negative sequence currents.

Buchholz relay

Two ball-shaped floats and two glass-enclosed reed switches are visible inside this cutaway view of a Buchholz relay In the field of electric power distribution and transmission, a **Buchholz relay** is a safety device mounted on some oil-filled power transformers and reactors, equipped with an external overhead oil reservoir called a *conservator*. The Buchholz Relay is used as a protective device sensitive to the effects of dielectric failure inside the equipment.

Depending on the model, the relay has multiple methods to detect a failing transformer. On a slow accumulation of gas, due perhaps to slight overload, gas produced by decomposition of insulating oil accumulates in the top of the relay and forces the oil level down. A float switch in the relay is used to initiate an alarm signal. Depending on design, a second float may also serve to detect slow oil leaks.

If an arc forms, gas accumulation is rapid, and oil flows rapidly into the conservator. This flow of oil operates a switch attached to a vane located in the path of the moving oil. This switch normally will operate a circuit breaker to isolate the apparatus before the fault causes additional damage. Buchholz relays have a test port to allow the accumulated gas to be withdrawn for testing. Flammable gas found in the relay indicates some internal fault such as overheating or arcing, whereas air found in the relay may only indicate low oil level or a leak.

Buchholz relays have been applied to large power transformers

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Various type of faults in transformer	**RGPV/ Dec 2013,2011**	7
Q.2	Write short note on Buchholz relay	**RGPV/ June** 20 **14**	7

Unit-04 /Lecture-05

Star Winding with Neutral Resistance Earthed

In this case the neutral point of the transformer is earthed via a resistor and the value of impedance of it, is much higher than that of winding impedance of the transformer. That means the value of transformer winding impedance is negligible compared to impedance of earthing resistor. The value of earth current is, therefore, proportional to the position of the fault in the winding. As the fault current in the primary winding of the transformer is proportional to the ratio of the short circuited secondary turns to the total turns on the primary winding, the primary fault current will be proportional to the square of the percentage of winding short circuited. The variation of fault current both in the primary and secondary winding is shown below.

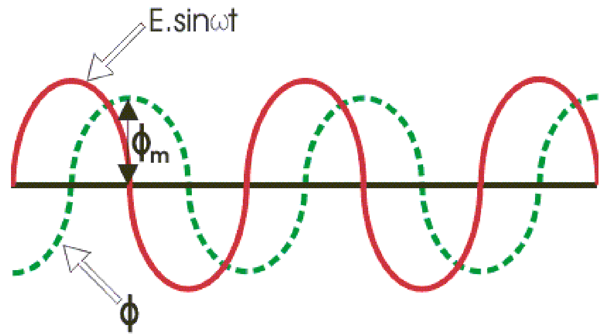
Star Winding with Neutral Solidly Earthed

In this case the earth fault current magnitude is limited solely by the winding impedance and the fault is no longer proportional to the position of the fault. The reason for this non linearity is unbalanced flux linkage.

Magnetizing Inrush Current in Power Transformer

When an electrical power transformer is switch on from primary side, with keeping its secondary circuit open, it acts as a simple inductance. When electrical power transformer runs normally, the flux produced in the core is in quadrature with applied voltage as shown in the figure below. That means, flux wave will reach its maximum value, 1/4 cycle or $\pi/2$ angle after, reaching maximum value of voltage wave. Hence as per the waves shown in the figure, at the instant when, the voltage is zero, the corresponding steady state value of flux should be negative maximum. But practically it is not possible to have flux at the instant of switching on the supply of transformer. This is because, there will be no flux linked to the core prior to switch on the supply. The steady state value of flux will only reach after a finite time, depending upon how fast the circuit can take energy. This is because the rate of energy transfer to a circuit cannot be infinity. So the flux in the core also will start from its zero value at the time of switching on the transformer.

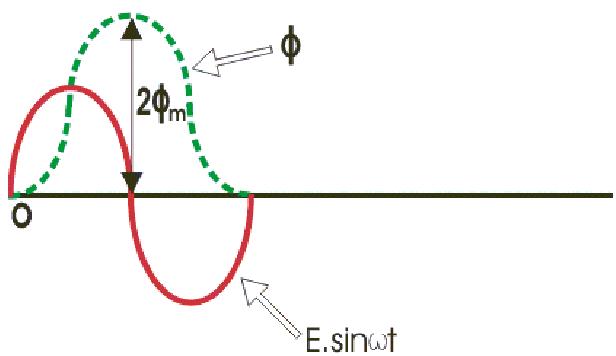
According to Faraday's law of electromagnetic induction the voltage induced across the winding is is given as $e = d\phi/dt$. Where ϕ is the flux in the core. Hence the flux will be integral of the voltage wave.

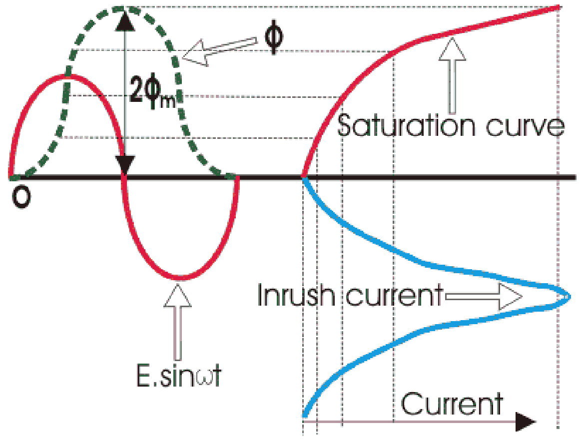


If the transformer is switched on at the instant of voltage zero, the flux wave is initiated from the same origin as voltage waveform, the value of flux at the end of first half cycle of the voltage waveform will be,

$$\boxed{\varphi_m' = (E/\omega)\int_0^{\pi} \omega.\sin\omega t.dt = \varphi_m \int_0^{\pi} \sin\omega t.d(\omega t) = 2\varphi_m}$$

Where ϕ_m is the maximum value of steady state flux. The transformer core are generally saturated just above the maximum steady state value of flux. But in our example, during switching on the transformer the maximum value of flux will jump to double of its steady state maximum value. As, after steady state maximum value of flux, the core becomes saturated, the current required to produced rest of flux will be very high. So transformer primary will draw a very high peaky current from the source which is called **magnetizing inrush current in transformer** or simply **inrush current in transformer**.





Magnetizing inrush current in transformer is the current which is drown by a transformer at the time of energizing the transformer. This current is transient in nature and exists for few milliseconds. The inrush current may be up to 10 times higher than normal rated current of transformer. Although the magnitude of inrush current is so high but it generally does not create any permanent fault in transformer as it exists for very small time. But still **inrush current in power transformer** is a problem, because it interferes with the operation of circuits as they have been designed to function. Some effects of high inrush include nuisance fuse or breaker interruptions, as well as arcing and failure of primary circuit components, such as switches. High magnetizing inrush current in transformer also necessitate over-sizing of fuses or breakers. Another side effect of high inrush is the injection of noise and distortion back into the mains.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain magnetic inrush of current	**RGPV/ Dec 2013,2011**	7
Q.2	Write short note on Buchholz relay	**RGPV/ June** 20 **14**	7
Q.3	Discuss the different kind of transformer faults and various protection scheme used for transformer	**RGPV/ Dec 2013, 2012**	7

	protection		

Unit-04 /Lecture-06

Small and Large Motor Protection Scheme

The electric motor is most essential drive in modern era of industrialization. From fractional hp AC motor used for different home appliances to giant synchronous motor and induction motor of up to 10,000 hp used for different industrial applications, should be protected against different electrical and mechanical faults for serving their purposes smoothly. The motor characteristics must be very carefully considered in selecting the right **motor protection** scheme.

The abnormalities in motor or motor faults may appear due to mainly two reasons –

1. Conditions imposed by the external power supply network,
2. Internal faults, either in the motor or in the driven plant.

Unbalanced supply voltages, under-voltage, reversed phase sequence and loss of synchronism (in the case of synchronous motor) come under former category. The later category includes bearing failures, stator winding faults, motor earth faults and overload etc.

The degree of **motor protection system** depends on the costs and applications of the electrical motor.

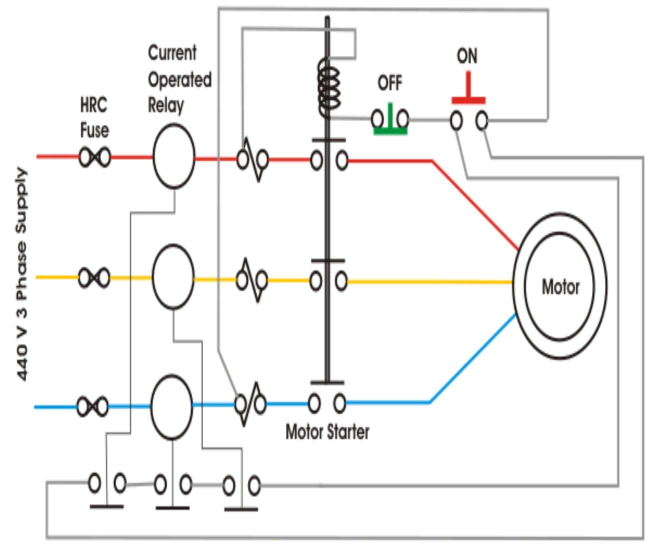
Small Motor Protection Scheme

Generally motors up to 30 hp are considered in small category. The **small motor protection** in this case is arranged by HRC fuse, bimetallic relay and under voltage relay – all assembled into the motor contractor – starter itself.

Most common cause of motor burn outs on LV fuse protected system is due to single phasing. This single phasing may remain undetected even if the motors are protected by conventional bimetallic relay. It can not be detected by a set of voltage relays connected across the lines. Since, even when one phase is dead, the motor maintains substantial back emf on its faulty phase terminal and hence voltage across the voltage relay is prevented from dropping – off.

The difficulties of detecting single phasing can be overcome by employing a set of three current operated relays as shown in the **small motor protection** circuit given below.

The current operated relays are very simple instantaneous relays. There are mainly two parts in this relay one is a current coil and other is one or more normally open contacts (NO Contacts). The NO contacts are operated by the mmf of the current coil. This relay is connected in series with each phase of the supply and backup by HRC fuse. When the electrical motor starts and runs the supply current passes through the current coil of the protective relay. The mmf of the current coil makes the NO contacts closed. If suddenly a single phasing occurs the corresponding current through the current coil will falls and the contacts of the corresponding relay will become to its normal open position. The NO contacts of the all three relays are connected in series to hold – in the motor contractor. So if any one relay contact opens, results to release of motor contractor and hence motor will stop running.



Large Motor Protection

Large motor specially induction motors require protection against-

1. **Motor bearing failure,**
2. **Motor over heating,**
3. **Motor winding failure,**
4. **Reverse motor rotation.**

Motor Bearing Failure

Ball and roller bearings are used for the motor up to 500 hp and beyond this size sleeve bearings are used. failure of ball or roller bearing usually causes the motor to a standstill very quickly. Due to sudden mechanical jamming in motor bearing, the input current of the motor becomes very high. Current operated protection, attached to the input of the motor can not serve satisfactorily. Since this motor protection system has to be set to override the high motor starting current. The difficulty can be over come by providing thermal over load relay. As the starting current of the motor is high but exists only during starting so for that current the there will be no over heating effect. But over current due mechanical jamming exists for longer time hence there will be a over heating effect. So stalling motor protection can be offered by the thermal overload relay. Stalling protection can also be provided by separate definite time over current relay which is operated only after a certain predefined time if over current persists beyond that period. In the case of sleeve bearing, a temperature sensing device embedded in the bearing itself. This scheme of motor protection is more reliable and sensitive to **motor bearing failure** since the thermal withstand limit of the motor is quite higher than that of bearing. If we allow the bearing over heating and wait for motor thermal relay to trip, the bearing may be permanently damaged. The temperature sensing device embedded in the bearing stops the motor if the bearing temperature rises beyond its predefined limit.

Motor Over Heating

The main reason of **motor over heating** that means over heating of motor winding is due to either of mechanical over loading, reduced supply voltage, unbalanced supply voltage and single phasing. The over heating may cause deterioration of insulation life of motor hence it must be avoided by providing proper motor protection scheme. To avoid over heating, the motor should be isolated in 40 to 50 minutes even in the event of small overloads of the order of 10 %. The protective relay should take into account the detrimental heating effects on the motor rotor due to negative sequence currents in the stator arising out of unbalance in supply voltage. The motor should also be protected by instantaneous **motor protection relay** against single phasing such as a stall on loss of one phase when running at full load or attempting to start with only two of three phases alive.

Motor Winding Failure

The **motor protection relay** should should have instantaneous trip elements to detect **motor winding failure** such as phase to phase and phase to earth faults. Preferably phase to phase fault unit should be energized from positive phase sequence component of the motor current and another instantaneous unit connected in the residual circuit of the current transformers be used for earth faults protection.

Reverse Motor Rotation

Specially in the case of conveyor belt, the **reverse motor rotation** must be avoided. The reverse rotation during starting can be caused due to inadvertent reversing of supply phases. A comprehensive motor protection relay with an instantaneous negative sequence unit will satisfy this requirement. If such relay has not been provided, a watt-meter type relay can be employed.

NB: However, we have to provide some additional motor protection system for synchronous motor which is discussed in details in synchronous motor protection topic.

S.NO	RGPV QUESTIONS	Year	Marks

Q.1	Explain various type of fault in motor and protection scheme used.	**RGPV/ Dec 2013,2011**	7

Unit-04 /Lecture-07

Motor Thermal Overload Protection

For understanding **motor thermal overload protection** in induction motor we can discuss the operating principle of three phase induction motor. There is one cylindrical stator and a three phase winding is symmetrically distributed in the inner periphery of the stator. Due to such symmetrical distribution, when three phase power supply is applied to the stator winding, a rotating magnetic field is produced. This field rotates at synchronous speed. The rotor is created in induction motor mainly by numbers solid copper bars which are shorted at both ends in such a manner that they form a cylinder cage like structure. This is why this motor is also referred as squirrel cage induction motor. Anyway let's come to the basic point of three phase induction motor – which will help us to understand clearly about **motor thermal overload protection**.

As the rotating magnetic flux cuts each of the bar conductor of rotor, there will be an induced circulating current flowing through the bar conductors. At starting the rotor is stand still and stator field is rotating at synchronous speed, the relative motion between rotating field and rotor is maximum. Hence the rate of cuts of flux with rotor bars is maximum, the induced current is maximum at this condition. But as the cause of induced current is, this relative speed, the rotor will try to reduce this relative speed and hence it will start rotating in the direction of rotating magnetic field to catch the synchronous speed. As soon as the rotor will come to the synchronous speed this relative speed between rotor and rotating magnetic field becomes zero, hence there will not be any further flux cutting and consequently there will not be any induced current in the rotor bars. As the induced current becomes zero, there will not be any further need of maintaining zero relative speed between rotor and rotating magnetic field hence rotor speed falls. As soon as the rotor speed falls the relative speed between rotor and rotating magnetic field again acquires a non zero value which again causes induced current in the rotor bars then rotor will again try to achieve the synchronous speed and this will continue till the motor is switch on. Due to this phenomenon the rotor will never achieve the synchronous speed as well as it will never stop running during normal operation. The difference between the synchronous speed with rotor speed in respect of synchronous speed, is termed as slip of induction motor.

The slip in a normally running induction motor typically varies from 1% to 3 % depending upon the loading condition of the motor. Now we will try to draw speed current characteristics of induction motor – let's have an example of large boiler fan.

Motor Starting Current

In the characteristic Y axis is taken as time in second, X axis is taken as % of stator current. When rotor is stand still that is at starting condition, the slip is maximum hence the induced current in the rotor is maximum and due to transformation action, stator will also draw a heavy current from the supply and it would be around 600% of the rated full load stator current. As the rotor is being accelerated the slip is reduced, consequently the rotor current hence stator current falls to around 500% of the full load rated current within 12 seconds when the rotor speed attains 80% of synchronous speed. After that the stator current falls rapidly to the rated value as the rotor reaches its normal speed.

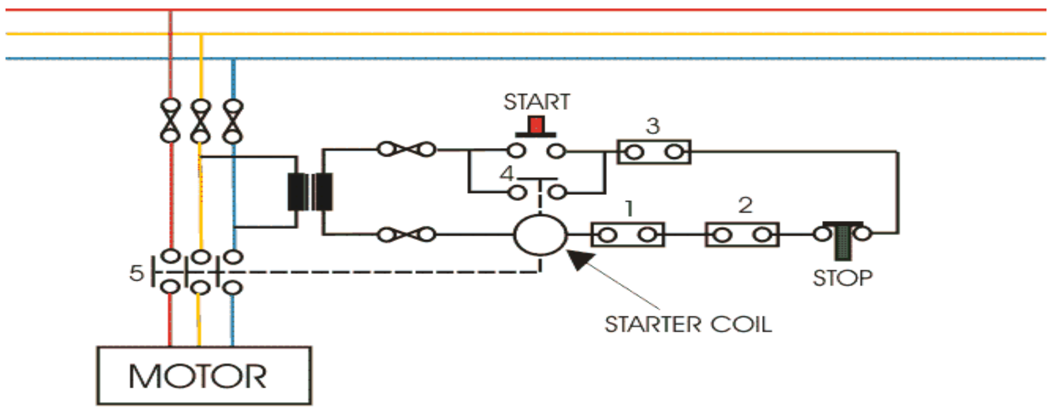
Now we will discuss about **thermal over loading of electrical motor** or over heating problem of electric motor and the necessity of **motor thermal overload protection**.

Whenever we think about the overheating of a motor, the first thing strikes in our mind is over loading. Due to mechanical over loading of the motor draws higher current from the supply which leads to excessive over heating of the motor. The motor can also be excessively over heated if the rotor is mechanically locked i.e. becomes stationary by any external mechanical force. In this situation the motor will draw excessively high current from the supply which also leads to thermal over loading of electrical motor or excessive over heating problem. Another cause of overheating is low supply voltage. As the power id drawn by the motor from the supply depends upon the loading condition of the motor, for lower supply voltage, motor will draw higher current from mains to maintain required torque. Single phasing also causes **thermal over loading of motor**. When one phase of the supply is out of service, the remaining two phases draw higher current to maintain required load torque and this leads to overheating of the motor. Unbalance condition between three phases of supply also causes over heating of the motor winding, as because unbalance system results to negative sequence current in the stator winding. Again, due to sudden loss and re-establish of supply voltage may cause excessive heating of the motor. Since due to sudden loss of supply voltage, the motor is de-accelerated and due to sudden reestablishment of voltage the motor is accelerated to achieve its rated speed and hence for that motor draws higher current form the supply.

As the thermal over loading or over heating of the motor may lead to insulation failure and damage of winding, hence for proper **motor thermal overload protection**, the motor should be protected against the following conditions

1. Mechanical over loading,
2. Stalling of motor shaft,
3. Low supply voltage,
4. Single phasing of supply mains,
5. Unbalancing of supply mains,
6. Sudden Loss and rebuilding of supply voltage.

The most basic protection scheme of the motor is thermal over load protection which primarily covers the protection of all the above mentioned condition. To understand the basic principle of thermal over load protection.

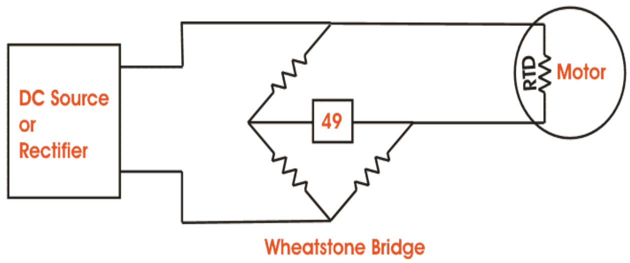


In the figure above, when START push is closed, the starter coil is energized through the transformer. As the starter coil is energized, normally open (NO) contacts 5 are closed hence motor gets supply voltage at its terminal and it starts rotating. This start coil also closes contact 4 which makes the starter coil energized even the START push button contact is released from its close position. To stop the motor there are several normally closed (NC) contacts in series with the starter coil as shown in the figure. One of them is STOP push button contact. If the STOP push button is pressed, this button contact opens and breaks the continuity of the starter coil circuit consequently makes the starter coil de-energized. Hence the contact 5 and 4 come back to their normally open position. Then, in absence of voltage at motor terminals it will ultimately stop running. Similarly any of the other NC contacts (1, 2 & 3) connected in series with starter coil if open; it will also stop the motor. These NC contacts are electrically coupled with various protection relays to stop operation of the motor in different abnormal conditions.

Let's look at the thermal over load relay and its function in motor thermal overload protection. The secondary of the CTs in series with motor supply circuit, are connected with a bimetallic strip of the thermal over load relay (49). As shown in the figure below, when current through the secondary of any of the CTs, crosses it's predetermined values for a predetermined time, the bi-metallic strip is over heated and it deforms which ultimately causes to operate the relay 49. As soon as the relay 49 is operated, the NC contacts 1 and 2 are opened which de-energizes the starter coil and hence stop the motor.

Thermal Overload Protection of Motor

This motor thermal overload protection scheme is very simple. RTD of stator is used as one arm of balanced Wheatstone bridge. The amount of current through the relay 49 depends upon the degree of unbalancing of the bridge. As the temperature of the stator winding is increased, the electrical resistance of the detector increases which disturbs the balanced condition of the bridge. As a result current start flowing through the relay 49 and the relay will be actuated after a predetermined value of this unbalanced current and ultimately starter contact will open to stop the supply to the motor.



RTD Protection of Motor

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	What are various type of thermal overloading protection scheme in large size motor.	**RGPV/ Dec 2013,2011**	7
Q.2	Thermal Overload Protection of Motor	**RGPV/ June** 20 **14**	7

Busbar Differential Protection Scheme

In early days only conventional over current relays were used for **busbar protection**. But it is desired that fault in any feeder or transformer connected to the busbar should not disturb busbar system. In viewing of this time setting of busbar protection relays are made lengthy. So when faults occurs on busbar itself, it takes much time to isolate the bus from source which may came much damage in the bus system.

In recent days, the second zone distance protection relays on incoming feeder, with operating time of 0.3 to 0.5 seconds have been applied for **busbar protection**.

But this scheme has also a main disadvantage. This scheme of protection can not discriminate the faulty section of the busbar.

Now days, electrical power system deals with huge amount of power. Hence any interruption in total bus system causes big loss to the company. So it becomes essential to isolate only faulty section of busbar during bus fault.

Another drawback of second zone distance protection scheme is that, sometime the clearing time is not short enough to ensure the system stability.

To overcome the above mentioned difficulties, differential busbar protection scheme with an operating time less than 0.1 sec., is commonly applied to many SHT bus systems.

Differential Busbar Protection

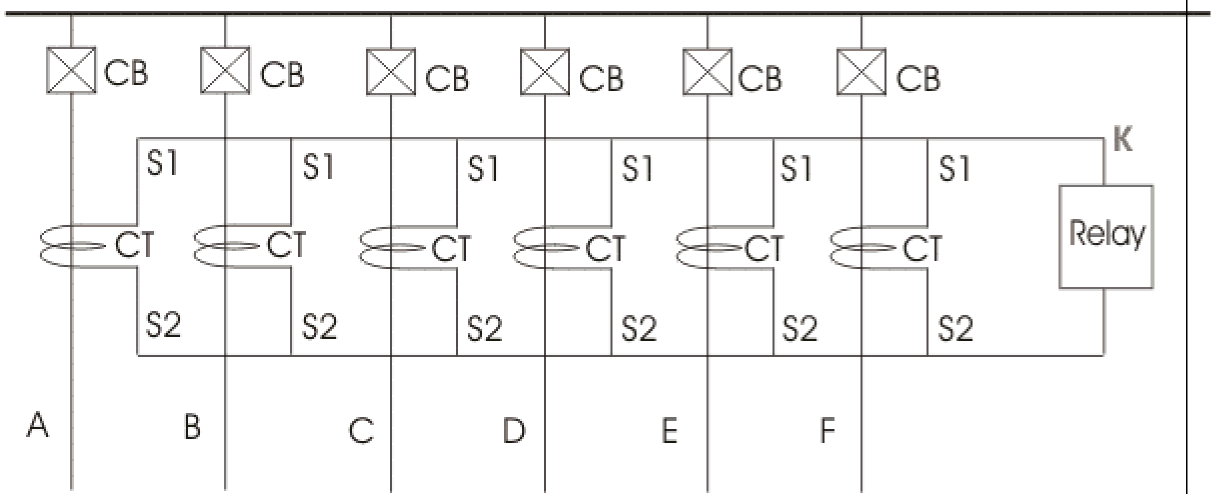
Current Differential Protection

The scheme of **busbar protection**, involves, Kirchoff's current law, which states that, total current entering an electrical node is exactly equal to total current leaving the node.

Hence, total current entering into a bus section is equal to total current leaving the bus section.

The principle of differential busbar protection is very simple. Here, secondaries of CTs are connected parallel. That means, S_1 terminals of all CTs connected together and forms a bus wire. Similarly S_2 terminals of all CTs connected together to form another bus wire.

A tripping relay is connected across these two bus wires.



Here, in the figure above we assume that at normal condition feed, A, B, C, D, E & F carries current I_A, I_B, I_C, I_D, I_E and I_F.

Now, according to Kirchoff's current law,

Essentially all the CTs used for differential busbar protection are of same current ratio. Hence, the summation of all secondary currents must also be equal to zero.

Now, say current through the relay connected in parallel with all CT secondaries, is i_R, and i_A, i_B, i_C, i_D, i_E and i_F are secondary currents.

Now, let us apply KCL at node X. As per KCL at node X,

$$I_A + I_B + I_C + I_D + I_E + I_F = 0$$

So, it is clear that under normal condition there is no current flows through the **busbar protection** tripping relay. This relay is generally referred as Relay 87. Now, say fault is occurred at any of the feeders, outside the protected zone. In that case, the faulty current will pass through primary of the CT of that feeder. This fault current is contributed by all other feeders connected to the bus. So, contributed part of fault current flows through the corresponding CT of respective feeder. Hence at that faulty condition, if we apply KCL at node K, we will still get, $i_R = 0$.

$$i_R + i_A + i_B + i_C + i_D + i_E + i_F = 0$$

$$\Rightarrow i_R + (i_A + i_B + i_C + i_D + i_E + i_F) = 0$$

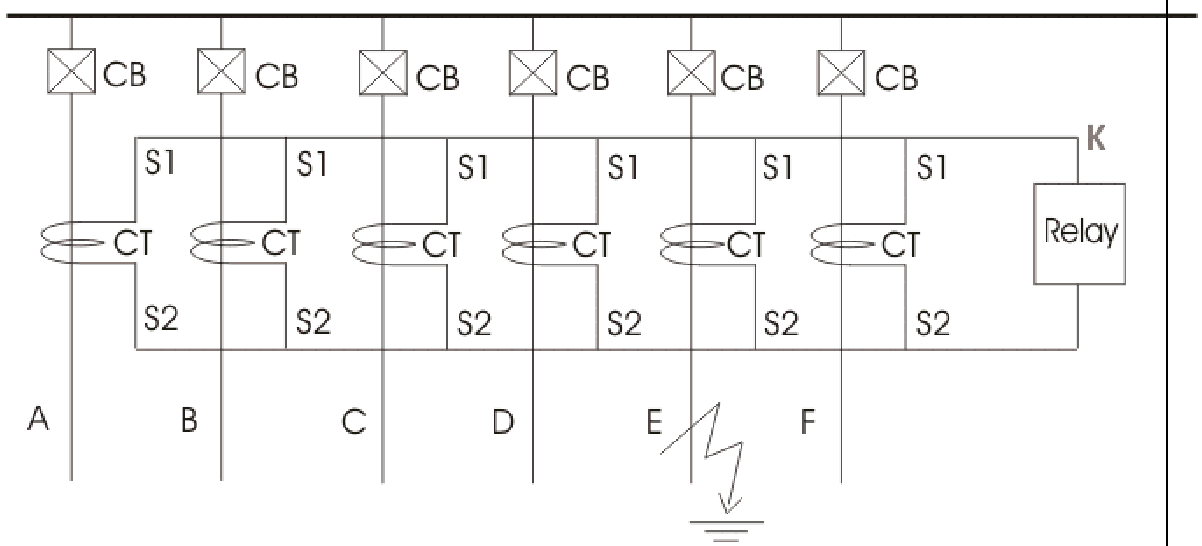
$$\Rightarrow i_R + (Sum\ of\ all\ secondary\ currents) = 0$$

$$\Rightarrow i_R + 0 = 0\ [As\ sum\ of\ all\ secondary\ currents\ is\ zero]$$

That means, at external faulty condition, there is no current flows through relay 87. Now consider a situation when fault is occurred on the bus itself.

At this condition, also the faulty current is contributed by all feeders connected to the bus. Hence, at this condition, sum of all contributed fault current is equal to total faulty current.

Now, at faulty path there is no CT. (in external fault, both fault current and contributed current to the fault by different feeder get CT in their path of flowing).

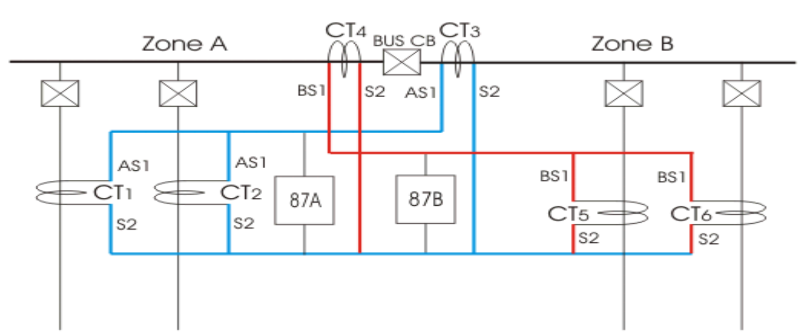


The sum of all secondary currents is no longer zero. It is equal to secondary equivalent of faulty current.

Now, if we apply KCL at the nodes, we will get a non zero value of i_R.

So at this condition current starts flowing through 87 relay and it makes trip the circuit breaker corresponding to all the feeders connected to this section of the busbar. As all the incoming and outgoing feeders, connected to this section of bus are tripped, the bus becomes dead.

This differential busbar protection scheme is also referred as current differential protection of busbar.



Here, CSSA and CSSB are two selector switch which are used to put into service, the **busbar protection** system for zone A and zone B respectively.

If CSSA is in “IN” position, protection scheme for zone A is in service.

If CSSB is in “IN” position, protection for zone B is in service.

Generally both of the switches are in “IN’ position in normal operating condition. Here, relay coil of 96A and 96B are in series with differential busbar protection relay contact 87A-1 and 87B-1 respectively.96A relay is multi contacts relay. Each circuit breaker in zone A is connected with individual contact of 96A.Similarly, 96B is multi contacts relay and each circuit breaker in zone-B is connected with individual contacts of 96B.Although here we use only one tripping relay per protected zone, but this is better to use one individual tripping relay per feeder. In this scheme one protective relay is provided per feeder circuit breaker, whereas two tripping relays one for zone A and other for zone B are provided to bus section or bus coupler circuit breaker.

On an interval fault in zone A or bus section A, the respective bus protection relay 87A, be energized whereas during internal fault in zone B, the respective relay 87B will be energized.

As soon as relay coil of 87A or 87B is energized respective no. contact 87A-1 or 87B-1 is closed.Hence, the tripping relay 96 will trip the breakers connected to the faulty zone. To indicate whether zone A or B busbar protection operated, relay 30 is used.

For example, if relay 87A is operated, corresponding “No” contact 87A-2 is closed which energized relay 30A. Then the No contact 30A-1 of relay 30A is closed to energized alarm relay 74. Supervision relay 95 of respective zone is also energized during internal fault, but it has a time delay of 3 second. So, it reset as soon as the fault is cleared and therefore does not pick up zone bus wire shorting relay 95x which in turn shorts out the bus wires. An alarm contact is also given to this auxiliary 95x relay to indicate which CT is open circuited. No volt relay 80 is provided in both trip and non-trip section of the D. C. circuit of differential busbar protection system to indicate any discontinuity of D. C. supply.

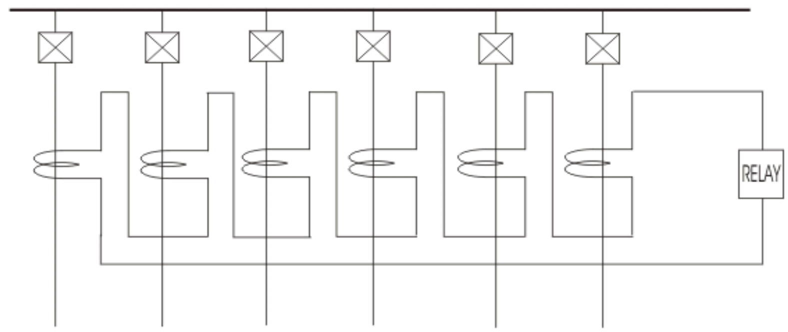
Voltage Differential Protection of Busbar

The current differential scheme is sensitive only when the CTs do not get saturated and maintain same current ratio, phase angle error under maximum faulty condition. This is usually not 80, particularly, in the case of an external fault on one of the feeders. The CT on the faulty feeder may be saturated by total current and consequently it will have very large errors. Due to this large error, the summation of secondary current of all CTs in a particular zone may not be zero. So there may be a high chance of tripping of all circuit breakers associated with this protection zone even in the case of an external large fault. To prevent this maloperation of current differential busbar protection, the 87 relays are provided with high pick up current and enough time delay.

The greatest troublesome cause of current transformer saturation is the transient dc component of the short circuit current.

This difficulties can be overcome by using air core CTs. This current transformer is also called linear coupler. As the core of the CT does not use iron the secondary characteristic of these CTs, is straight line.

In <u>voltage</u> differential busbar protection the CTs of all incoming and outgoing feeders are connected in series instead of connecting them in parallel.



The secondaries of all CTs and differential relay form a closed loop. If polarity of all CTs are properly matched, the sum of voltage across all CT secondaries is zero. Hence there would be no resultant voltage appears across the differential relay. When a buss fault occurs, sum of the all CT secondary voltage is no longer zero. Hence, there would be current circulate in the loop due to the resultant voltage. As this loop current also flows through the differential relay, the relay is operated to trip all the circuit beaker associated with protected bus zone. Except when ground fault current is severally limited by neutral impedance there is usually no selectivity problem When such a problem exists, it is solved by use of an additional more sensitive relaying equipment including a supervising protective relay.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain differential current and voltage differential scheme of bus bar protection.	**RGPV/ Dec 2013,2011**	7

Unit-04 /Lecture-09

Protection of Lines or Feeder

As the length of electrical power transmission line is generally long enough and it runs through open atmosphere, the probability of occurring fault in electrical power transmission line is much higher than that of electrical power transformers and alternators. That is why a transmission line requires much more protective schemes than a transformer and an alternator.

Protection of line should have some special features, such as-

1. During fault, the only circuit breaker closest to the fault point should be tripped.
2. If the circuit breaker closest the faulty point, fails to trip the circuit breaker just next to this breaker will trip as back up.
3. The operating time of relay associated with protection of line should be as minimum as possible in order to prevent unnecessary tripping of circuit breakers associated with other healthy parts of power system.

These above mentioned requirements cause **protection of transmission line** much different from protection of transformer and other equipment of power systems. The main three methods of **transmission line protection** are –

1. Time graded over current protection.
2. Differential protection.
3. Distance protection.

Time Graded Over Current Protection

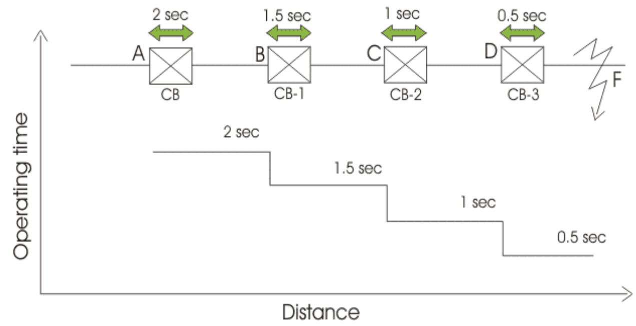
This may also be referred simply as over-current protection of electrical power transmission line. Let' discuss different schemes of time graded over current protection.

Protection of Radial Feeder

In radial feeder, the power flows in one direction only, that is from source to load. This type of feeders can easily protected by using either definite time relays or inverse time relays.

Line Protection by Definite Time Relay

This protection scheme is very simple. Here total line is divided into different sections and each section is provided with definite time relay. The relay nearest to the end of the line has minimum time setting. while time setting of other relays successively increased, towards the source.



For example, suppose there is a source at point A, in the figure below At point D the circuit breaker CB-3 is installed with definite time of relay operation 0.5 sec. Successively, at point C an other circuit breaker CB-2 is installed with definite time of relay operation 1 sec. The next circuit breaker CB-1 is installed at point B which is nearest of the point A. At point B, the relay is set at time of operation 1.5 sec.

Now, assume a fault occurs at point F. Due to this fault, the faulty current flow through all the current transformers or CTs connected in the line. But as the time of operation of relay at point D is minimum the CB-3, associated with this relay will trip first to isolate the faulty zone from rest part of the line. In case due to any reason, CB-3 fails to trip, then next higher timed relay will operate the associated CB to trip. In this case, CB-2 will trip. If CB-2 also fails to trip, then next circuit breaker i.e. CB-1 will trip to isolate major portion of the line.

Advantages of Definite Time Line Protection

The main advantage of this scheme is simplicity. The second major advantage is, during fault, only nearest CB towards the source from fault point will operate to isolate the specific position of the line.

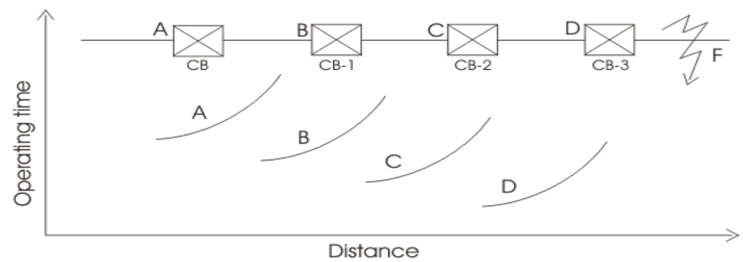
Disadvantage of Definite Time Line Protection

If the number of sections in the line is quite large, the time setting of relay nearest to the source, would be very long. So during any fault nearer to the source will take much time to be isolated. This may cause severe destructive effect on the system.

Unit-04 /Lecture-10

Over Current Line Protection by Inverse Relay

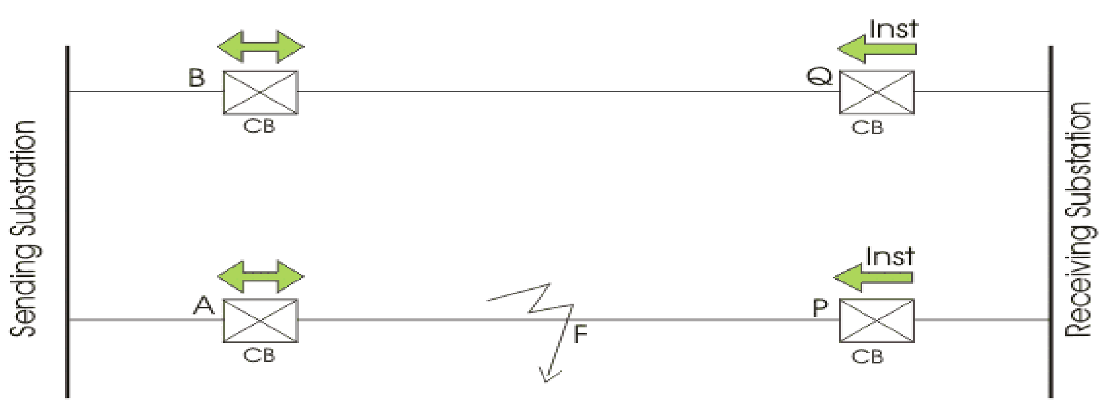
The drawback as we discussed just in definite time over current protection of transmission line, can easily be overcome by using inverse time relays. In inverse relay the time of operation is inversely proportional to fault current.



In the above figure, overall time setting of relay at point D is minimum and successively this time setting is increased for the relays associated with the points towards the point A.
In case of any fault at point F will obviously trip CB-3 at point D. In failure of opening CB-3, CB-2 will be operated as overall time setting is higher in relay at point C.
Although, the time setting of relay nearest to the source is maximum but still it will trip in shorter period, if major fault occurs near the source, as the time of operation of relay is inversely proportional to faulty current.

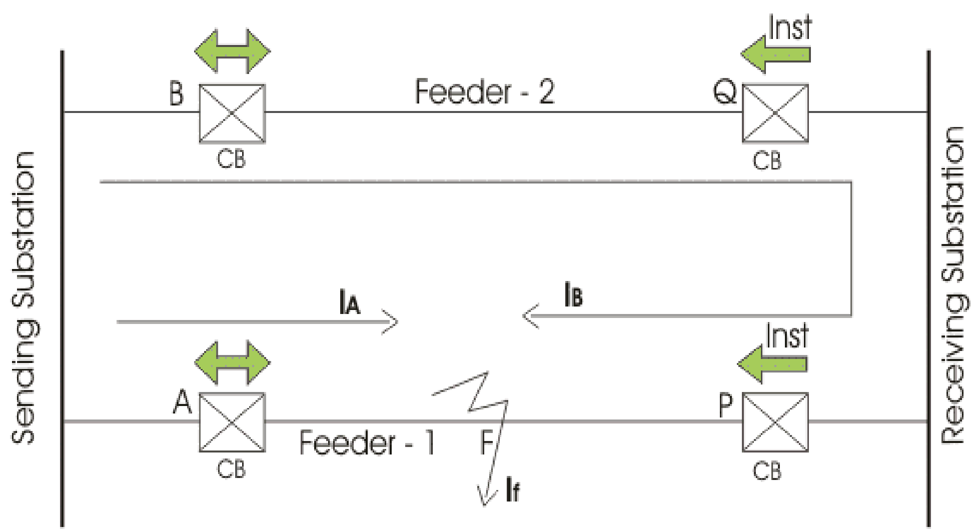
Over Current Protection of Parallel Feeders

For maintaining stability of the system it is required to feed a load from source by two or more than two feeders in parallel. If fault occurs in any of the feeders, only that faulty feeder should be isolated from the system in order to maintain continuity of supply from source to load. This requirement makes the protection of parallel feeders little bit more complex than simple non direction over current protection of line as in the case of radial feeders. The protection of parallel feeder requires to use directional relays and to grade the time setting of relay for selective tripping.



There are two feeders connected in parallel from source to load. Both of the feeders have non-directional over current relay at source end. These relays should be inverse time relay. Also both of the feeders have directional relay or reverse power relay at their load end. The reverse power relays used here should be instantaneous type. That means these relays should be operated as soon as flow of power in the feeder is reversed. The normal direction of power from source to load.

Now, suppose a fault occurs at point F, say the fault current is I_f. This fault will get two parallel paths from source, one through circuit breaker A only and other via CB-B, feeder-2, CB-Q, load bus and CB-P. This is clearly shown in figure below, where I_A and I_B are current of fault shared by feeder-1 and feeder-2 respectively.



As per Kirchoff's current law, $I_A + I_B = I_f$.

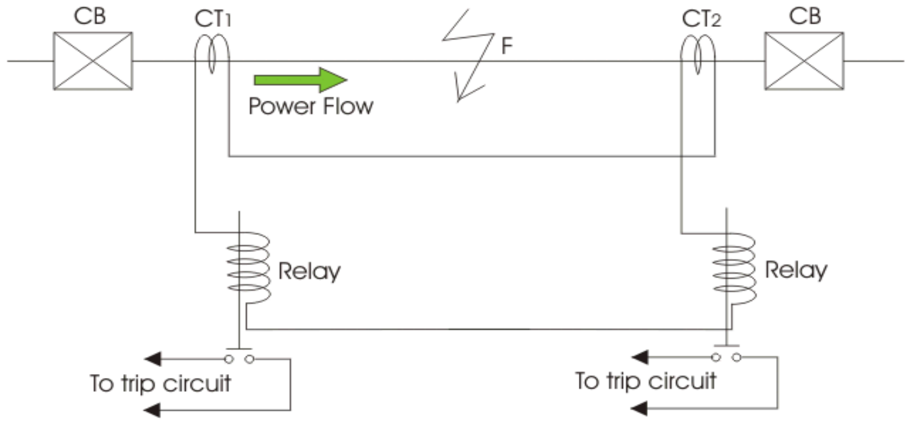
Now, I_A is flowing through CB-A, I_B is flowing through CB-P. As the direction of flow of CB-P is reversed it will trip instantly. But CB-Q will not trip as flow of current (power) in this circuit breaker is not reversed. As soon as CB-P is tripped, the fault current I_B stops flowing through feeder and hence there is no question of further operating of inverse time over current relay. I_A still continues to flow even CB-P is tripped. Then because of over current I_A, CB-A will trip. In this way the faulty feeder is isolated from system.

Differential Pilot Wire Protection

This is simply a differential protection scheme applied to feeders. Several differential schemes are applied for protection of line but Mess Price Voltage balance system and Translay Scheme are most popularly used.

Merz Price Balance System

The working principle of Merz Price Balance system is quite simple. In this scheme of line protection, identical CT is connected to each of the both ends of the line. The polarity of the CTs are same. The secondary of these current transformer and operating coil of two instantaneous relays are formed a closed loop as shown in the figure below. In the loop pilot wire is used to connect both CT secondary and both relay coil as shown.



Now, from the figure it is quite clear that when the system is under normal condition, there would not be any current flowing through the loop. As the secondary current of one CT will cancel out secondary current of other CT.

Now, if any fault occurs in the portion of the line between these two CTs, the secondary current of one CT will no longer equal and opposite of secondary current of other CT. Hence there would be a resultant circulating current in the loop.

Due this circulating current, the coil of both relays will close the trip circuit of associate circuit breaker. Hence, the faulty line will be isolated from both ends.

S.NO	RGPV QUESTIONS	Year	Marks
Q.1	Explain differential current and voltage differential scheme of bus bar protection.	**RGPV/ Dec 2013,2011**	7
Q.2	Explain time graded and current graded protection scheme of bus bar.	**RGPV/ June 2012**	7

Switchgear and protection (EX-603)

(Strictly Based on RGPV EXAMINATION)

Unit-4

1. Numerical on protection of alternator. **RGPV/ June 2014**
2. How would you protect a transformer from internal faults? **RGPV/ June 2014**
3. Write short notes on time graded over current protection of feeder.

   RGPV/ June 2014
4. Describe the schematic diagram of impedance relay. **RGPV/ June 2014**
5. Write short notes on Buchholz relay. **RGPV/ June 2014**
6. Why biased differential relay is preferred over a simple differential relay. Explain the principle of operation of biased differential relay with neat schematic diagram. Write applications. **RGPV/ June 2013**
7. List various kinds of faults that may occur in an alternator.

   RGPV/ June 2013,dec 2013, 2012
8. Explain with neat sketch different protection scheme for each type of fault of alternator. **RGPV/ June 2013**
9. Discuss the different kind of transformer faults and various protection scheme used for transformer protection. **RGPV/ Dec 2013, 2012**
10. Explain with neat sketch Merz price protection scheme of an alternator.

    RGPV/ Dec 2013
11. Distance protection scheme of Transmission line. Distance protection scheme of Transmission line. **RGPV/ Dec 2011**
12. Discuss the protection of three phase alternator for 9i) Loss of Prime mover (ii) loss of excitation. **RGPV/ Dec 2011**