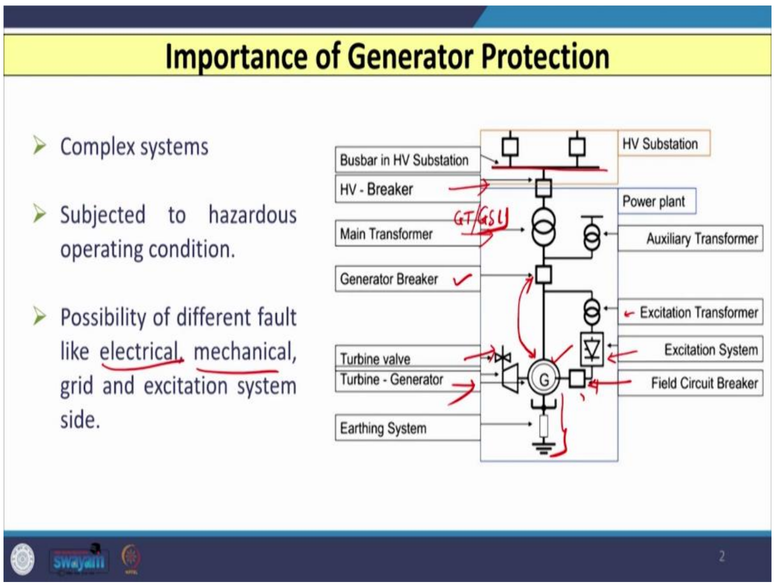
Digital Protection of Power System
Professor Bhaveshkumar Bhalja
Department of Electrical Engineering
Indian Institute of Technology Roorkee
Lecture 19
Digital Protection of Generators -1

Hello friends. So, in this lecture, we will discuss about the digital protection of generator. When we talk about the generator we are dealing with the large generator having its capacity in terms of megawatt, large generator is a very complex device.

(Refer Slide Time: 0:41)



If we talk about the generator, then along with this generator, you have some earthing systems associated with these generators. You also have the breaker associated with these generators and this breaker is known as generator breaker. So, with this generator, you have the generator breaker also along with this generator, you have the excitation system. So, excitation system is also available for the generator.

And with this excitation system, the excitation breaker which is known as filled circuit breaker that is also there. And along with the excitation system you have excitation transformer is also connected generator is a very complex system because it contains the device of stator and rotor also along with that excitation systems are also there in the generator.

So, if any fault occurs in the excitation system or in the stator or in the rotor then relays has to operate instantaneously, so that whatever damage is there that can be avoided. Now, in this diagram (as shown in above slide) if you look along with this the excitation system the generator also has the turbine generator mechanism. So, prime mover or turbine will also be there and the turbine wall is also there using which we can change the mechanical input given to the turbine.

And accordingly steam that can be there and so, that the power generated by the alternator that can be changed. And all the systems are you can see (as shown in above slide) that is connected with the main transformer which is known as the generator transformer or sometimes GSU utility generator transformer that is also there with auxiliary transformer is also there. So, if main transformer fails then auxiliary transformer that can be used.

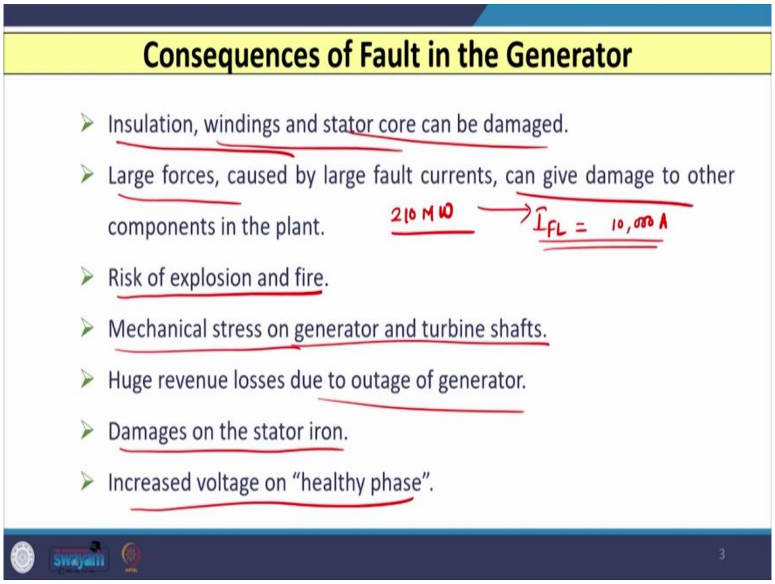
And then you have the high voltage breaker and then Busbar systems are also there. Now, when we consider this generator, which contains stator rotor, then excitation system and the turbine or prime mover system, then all these mechanisms or component are subjected to the various conditions abnormal conditions faults. So, there are fair chances or possibility of the internal faults inside the winding or core of the generator.

Let us say there is a possibility of fault inside the stator. There is a possibility of the turn to turn faults there is a possibility of faults inside the rotor. So, that is why electrical faults are very common in the generator, we do have the mechanical faults those are also possible we do have the faults possible in the excitation system itself. So, we need to detect the fault if it is there in the excitation system.

And we have to trip the field circuit breaker if required. Along with that we do have a reverse power let us say initially generator is delivering the power to the system. But we know that sometimes let us say the some situation arises in which now your generator that is the synchronous generator that becomes synchronous motor. So, instead of delivering power to the system, it takes power from the system.

So, it will act as a motor and whatever the turbine or prime mover that will act as the load. So, in this case also we need to detect the reverse power flow if it is not detected then that can be damaged to the turbine, maybe if you have steam turbine or maybe you have hydro turbine or maybe you have diesel or gas turbine and those can be damaged.

(Refer Slide Time: 4:33)



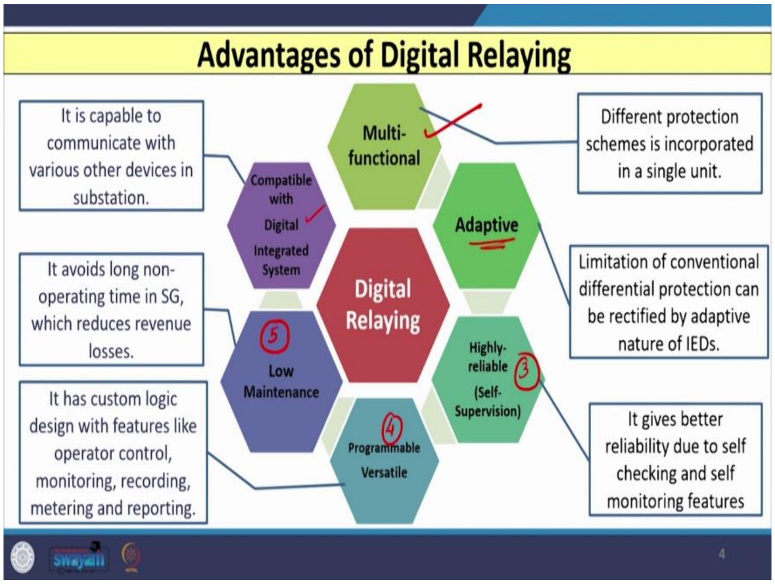
The point is if any fault occurs in the synchronous generator, then the consequences of this faults are the damage of the insulation or deterioration of the insulation windings can be damaged or core of the stator that can be damaged. So, this is one of the consequences of the occurrence of fault inside the generator if it is not cleared, sometimes large forces maybe because of the large magnitude of fault current that can also be there, which can damage the other components of the plant.

Because we know that if I consider 210 MW generator, then for this generator, the full load current or the normal current which the winding of the generator can easily carry is very close to the 10,000 ampere. So, this is the normal or full load current, if fault occurs 6 or 10 times this current that will flow through the winding. So, because of these large forces can be produced which may damage the several other components associated or connected with the generator.

There is a chance of explosion and fire because of the large magnitude of current in case of fault. Mechanical stress on the generator and turbine shafts is also possible. Huge revenue losses are there due to outage of the generator. So, in any case outage or damage to the generator that is not advisable because if generator trips which is generating 210 megawatt or 200 or 300 megawatt of power then that revenue loss always there.

Sometimes damages on the stator iron that is also there. And the other thing which is observed is a fault is there in one of the phases or one of the windings, then the other two winding voltage that can be increased. So, earlier for the protection of this large generator, electromechanical and static relays were widely used. However, because of the next generation by generation progress nowadays most of the power station utility they use the digital or numerical relays or nowadays, intelligent electronic devices that can be also used.

(Refer Slide Time: 7:04)



The reason for that is this digital or numerical or IED that is multifunctional in nature, so all types of functions or abnormalities that can be possible in a generator that is covered in a single unit. That is why digital or numerical relays are used. This numerical relays or digital relays are adaptive in nature.

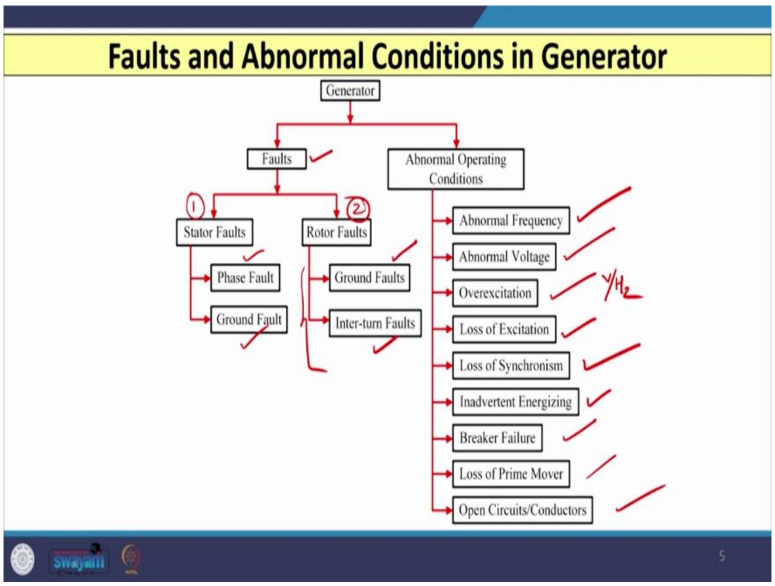
So, if any changes are there in the external system, maybe let us say there is a change in transformer or maybe addition of transformer of anything is there, then those changes can be detected automatically by this IEDs and accordingly, settings can be changed automatically. So, that is why this type of digital or numerical relays are adaptive in nature and it can also helpful compared to the conventional relays in which this type of features were not available.

The third point is that it is highly reliable because it has a self checking feature. So, it gives a better reliability, because of this self-checking and self-monitoring features. Then the programming or custom logic design that is possible if you use digital relay for the protection of generator large generator and other features like operator control monitoring, recording, metering and reporting those are also available in the digital relay used for the protection of generator.

This has a low maintenance because of low moving parts are available there in this relays. So, it can also reduce is the revenue losses, because of the long non-operating time in the synchronous generator in the earlier relays compared to the digital relays. And this relays is compatible with the digital integrated system because it is capable to communicate with various other devices.

And hence, you have several other communication capabilities, it is also compatible with several other protocols also. So, that is why digital or numerical relays are widely used for the protection of large alternator or synchronous generator.

(Refer Slide Time: 9:20)



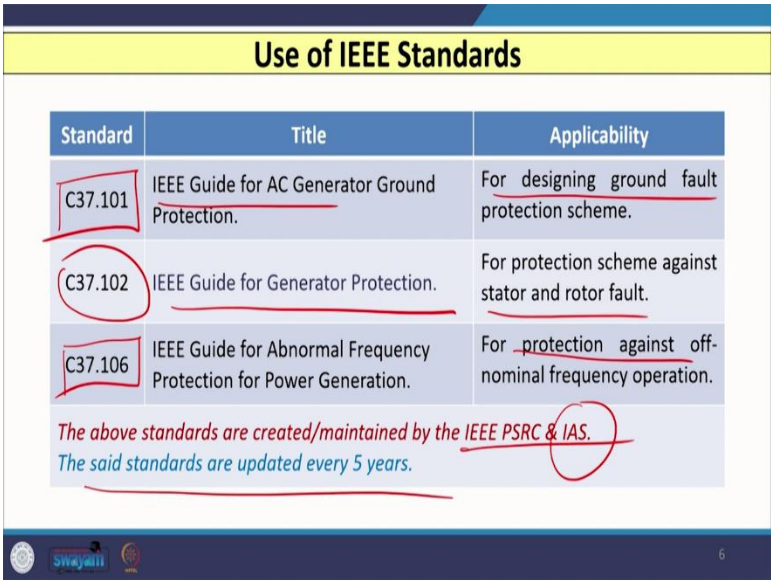
Now, with this let us see what are the faults or abnormal conditions possible in large synchronous generator or alternator. So, in any large generator, the faults and abnormal operating conditions are also there. So, if we categorize the faults, then these faults can be classified as the stator faults and the rotor faults even in stator faults also if we want to sub categorize then phase faults and ground faults are the two important faults which we need to detect and we have to isolate the generator breaker if required.

And in this case, instantaneous tripping is necessary, we do have rotor faults and if we sub categorize the rotor faults then we have ground faults and the inter-turn faults are there. First ground fault in rotor that is not that dangerous only alarm is required second ground fault of course that need to be detected and then appropriate action can be taken inter-turn faults or the fault in particular phase of winding where the few turns are shorted.

And because of that circulating current may increase and for that transfers differential protections is widely used by most of the utilities. However, in case of rotor faults, immediate action is not required. So, you can give some time delay and then operation that can be done. Now, if we consider on the other hand abnormal operating conditions, then this can be because of the abnormal frequency, so, under frequency or over frequency abnormal voltage, so under voltage over voltage over excitation condition is also there, which is known as the voltage by frequency v by hertz loss of excitation is also there. So, if there is a fault inside the excitation or if excitation is completely lost all if excitation is partially lost, then we need to detect it and we need if required, we need to also open the field breaker.

Loss of synchronism is also there this is known as pole sleeping protection. So, when group of generators are working, then the angle between the stator and rotor that need to be detected and for that this type of protection is required, in advertent energizing breaker failure loss of primer and open circuit oblique open conductors are the several other abnormal operating conditions which is going to occur in in a large generator and which need to be detected.

(Refer Slide Time: 12:00)

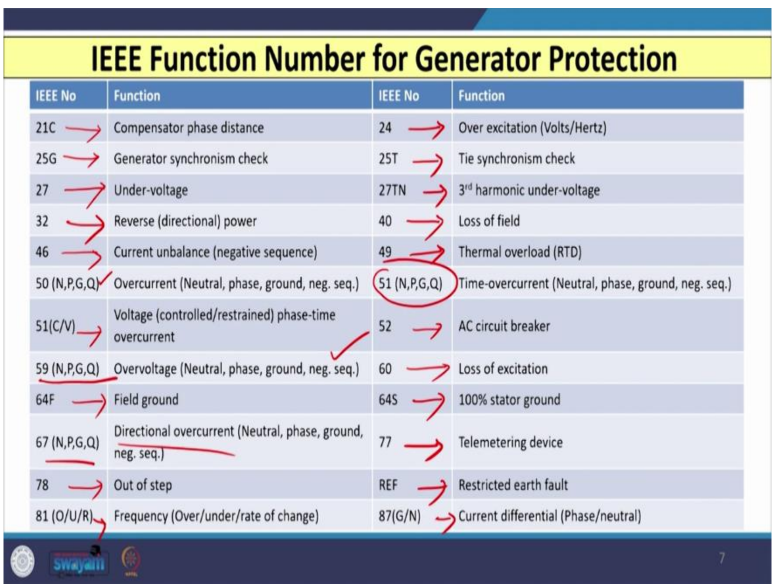


Now before we see the different conditions let us see what are the IEEE standards we can use for the digital or numerical release or for the IED which will be used for the Protection of large generator. So, the first standard we can use that is the C37.101. And this standard is the IEEE guide for AC generator ground fault protection. So, it is meant for ground fault protection of AC generator and it is used for designing ground fault protection scheme.

So, whenever we design any ground fault protection scheme, then we have to refer this standard. The other standard is the C37.102. And this is a complete guide for generator protection. And this we can use for the designing of the protection scheme against the faults that is going to occur in the stator as well as rotors circuit. Then we have C37.106 which is IEEE guide for abnormal frequency protection in power generation.

And this is used for protection against off nominal frequency operation. So, when we have under frequency or lower frequency we have to refer this IEEE standard and all three standards are again created and designed by IEEE power system relaying committee and IEEE IAS committee, that is industry application society committee. And the above standards are updated usually at every 5 years.

(Refer Slide Time: 13:43)



IEEE Function Number for Generator Protection

IEEE No	Function	IEEE No	Function
21C	Compensator phase distance	24	Over excitation (Volts/Hertz)
25G	Generator synchronism check	25T	Tie synchronism check
27	Under-voltage	27TN	3rd harmonic under-voltage
32	Reverse (directional) power	40	Loss of field
46	Current unbalance (negative sequence)	49	Thermal overload (RTD)
50 (N,P,G,Q)	Overcurrent (Neutral, phase, ground, neg. seq.)	51 (N,P,G,Q)	Time-overcurrent (Neutral, phase, ground, neg. seq.)
51(C/V)	Voltage (controlled/restrained) phase-time overcurrent	52	AC circuit breaker
59 (N,P,G,Q)	Overvoltage (Neutral, phase, ground, neg. seq.)	60	Loss of excitation
64F	Field ground	64S	100% stator ground
67 (N,P,G,Q)	Directional overcurrent (Neutral, phase, ground, neg. seq.)	77	Telemetering device
78	Out of step	REF	Restricted earth fault
81 (O/U/R)	Frequency (Over/under/rate of change)	87(G/N)	Current differential (Phase/neutral)

Now, apart from these three standards, we do have an IEEE standard which is used to give the particular function number in generator protection. So, for example, if I give the number 21C, then it is for the compensator phase distance function and which is normally used to achieve backup protection in large generator. You do have the 25G number which is meant for the synchronism check so synchro check relay is also there, and this type of function is also there. You do have 27 number for under voltage, 32 number for the reversal of power. So, reverse power protection which is directional in nature, 46 is for the negative sequence, 50 that is comes under the overcurrent and overcurrent can be in the neutral circuit, it can be in the face circuit, it can be in the ground circuit or it can be in the form of negative sequence.

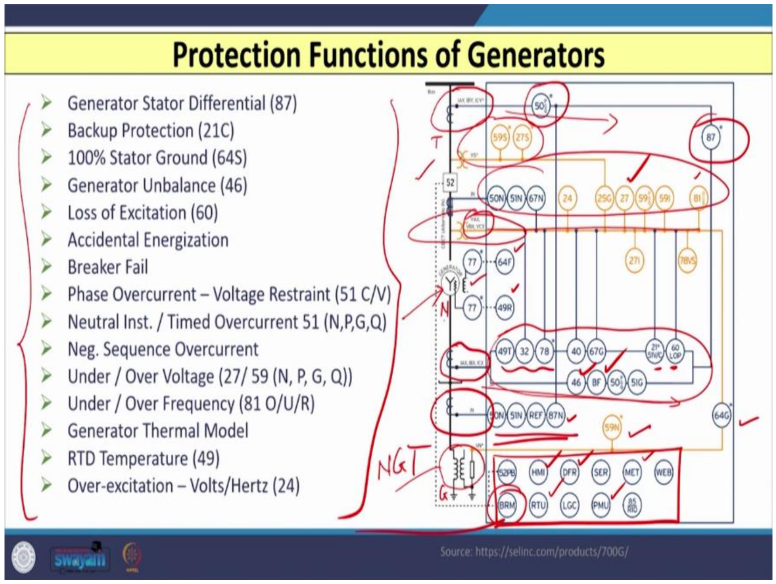
And then you have 51 that is voltage controlled over current or voltage restraint over current we do have the 59 which is meant for the over voltage function and over voltage that can be neutral circuit can be in phase or ground circuit or can be in the form of negative sequence. 64F is meant for field ground 67 is again for directional overcurrent and it can be in neutral phase ground or in the form of negative sequence.

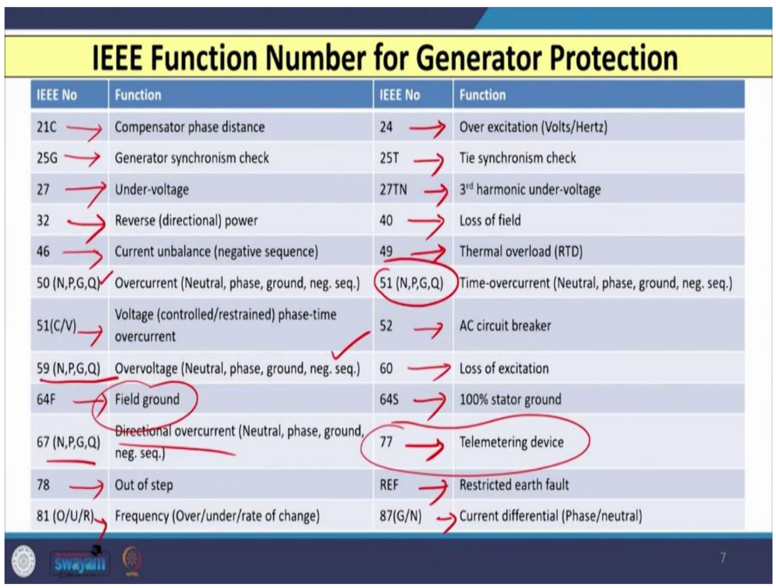
78 is meant for out of step condition. 81 is for frequency operation, maybe over frequency that is O, 81U is for under frequency and 81R that is for rate of change of frequency. 24 number is given to over excitation that is volts per hertz protection. 25T is for tie synchronism check, 27 TN that is third harmonic under voltage which is used to achieve 100 percent stator protection. 40 is meant for loss of field.

So, if excitation is lost then this number is very important, then the thermal modeling of the generator is carried out for protection against overload. So, 49 number is given, 51 is again the overcurrent but this is time over current compared to the 50 which is instantaneous operation whereas 51 is the delayed operation and it can be in neutral phase ground or in the form of negative sequence.

52 number is for AC circuit breaker. 60 is for loss of excitation. 64 is for 100 percent stator ground fault. And 77 is for telemetering devices. And REF is for restricted earth for protection. And 87 that is for the differential protection this can be in the ground or it can be in the neutral, so 87 that is meant for 87G and 87N both.

(Refer Slide Time: 16:48)





IEEE No	Function	IEEE No	Function
21C	Compensator phase distance	24	Over excitation (Volts/Hertz)
25G	Generator synchronism check	25T	Tie synchronism check
27	Under-voltage	27TN	3rd harmonic under-voltage
32	Reverse (directional) power	40	Loss of field
46	Current unbalance (negative sequence)	49	Thermal overload (RTD)
50 (N,P,G,Q)	Overcurrent (Neutral, phase, ground, neg. seq.)	51 (N,P,G,Q)	Time-overcurrent (Neutral, phase, ground, neg. seq.)
51(C/V)	Voltage (controlled/restrained) phase-time overcurrent	52	AC circuit breaker
59 (N,P,G,Q)	Overvoltage (Neutral, phase, ground, neg. seq.)	60	Loss of excitation
64F	Field ground	64S	100% stator ground
67 (N,P,G,Q)	Directional overcurrent (Neutral, phase, ground, neg. seq.)	77	Telemetering device
78	Out of step	REF	Restricted earth fault
81 (O/U/R)	Frequency (Over/under/rate of change)	87(G/N)	Current differential (Phase/neutral)

So, now, with this different device function number, if I look at the diagram of the generator (as shown in above slide), then you can see I have shown the diagram of the generator here. And you can see (as shown in above slide) that you have the generator available here and with this generator you have the generator field is also available here and this field you have the two important device that is 77 and 64F. So, you can see that here (as shown in above slide), you have the 77 number.

And you have the 64 F number which is field ground, if a field ground protection is required then you have to go for this and 77 is for telemetering devices. So, this is available here. Then you do have the 77 and 49 R is also there. So, if you wish to monitor winding temperature, then you can see that thermal modeling is possible. Now on this two sides of the generator, you can see the CT where I have mentioned the three currents IA IB IC in the form of x.

And here you have another CT where I here mentioned the three currents IA B IC in the form of y. So, these three currents on this side; because this is the neutral terminal, because neutral is connected here to ground and this is your terminal of the generator, so this is terminal side and the lower one is the neutral side. So, on terminal and neutral side three currents are available here and three currents are also taken here.

And that can be connected with the differential relay. Now, along with this to achieve the backup if differential fails, then you can see the 50 that is overcurrent relays also there. And here on the lower side where I have the neutral CTs where three currents I am taking in that you will find that several other relays are also connected like 60 LOP that is loss of phase, you do have the 51 that is the voltage controlled overcurrent relay or voltage restraint overcurrent relay (as shown in above slide).

You do have the breaker failure you do have the negative sequence 46 and so, on. So, all these are available here so as this is a neutral terminal. So, neutral CTs separately there where you have this four functions available starting from 50 and that is the overcurrent neutral 51 and that is time delayed overcurrent in neutral REF that is restricted earth for protection and that 87N that is the differential in neutral circuit. So, this is meant for that.

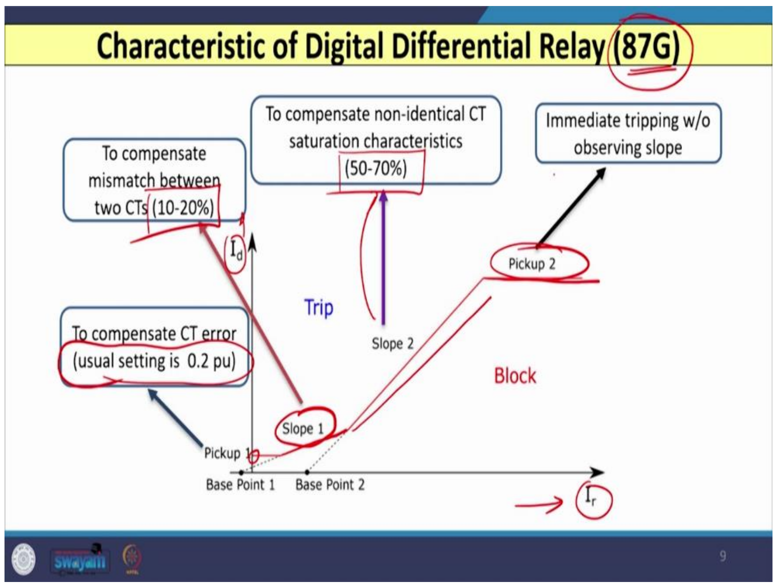
Now, on the lower side where neutral is connected to ground you have this that is the NGT neutral grounding transformer. And on the secondary side of this NGT several devices are connected you can see 59N 64G several devices are connected (as shown in above slide). So, you can see that the 59N is meant for overvoltage along with that, on the lower side you can see (as shown in above slide) it has been mentioned HMI, that is human machine interface DFR that is digital fault recorders.

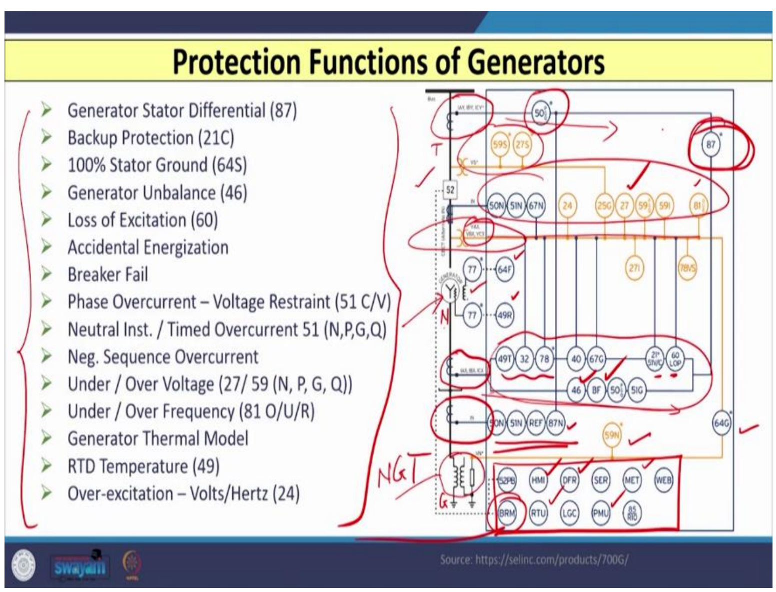
Then you have metering functions, it can also act as a PMU, remote terminal unit is also there. BRM that is breaker monitoring is also there. So, several other recording metering functions are also available in digital relay used for the protection of large generator. Along with that you can see the others voltage transformer are also there on the terminal side of the generator, which is nothing but the voltage transformer or the potential transformer or this see CVT.

So, here three voltages are taken and you can see (as shown in above slide) this are connected with several other devices. So, 27 is meant for under voltage and 81 that is meant for frequency, so 81 over frequency you under frequency and R that is rate of change of frequency and so on. And along with this some synchro check devices or elements are also connected. So, overall all these functions are available in a digital relay in a single unit.

So, compared to the previous electromechanical and the static relays, we have a single unit. Now, let us see what is the characteristic of digital differential relay?

(Refer Slide Time: 21:39)





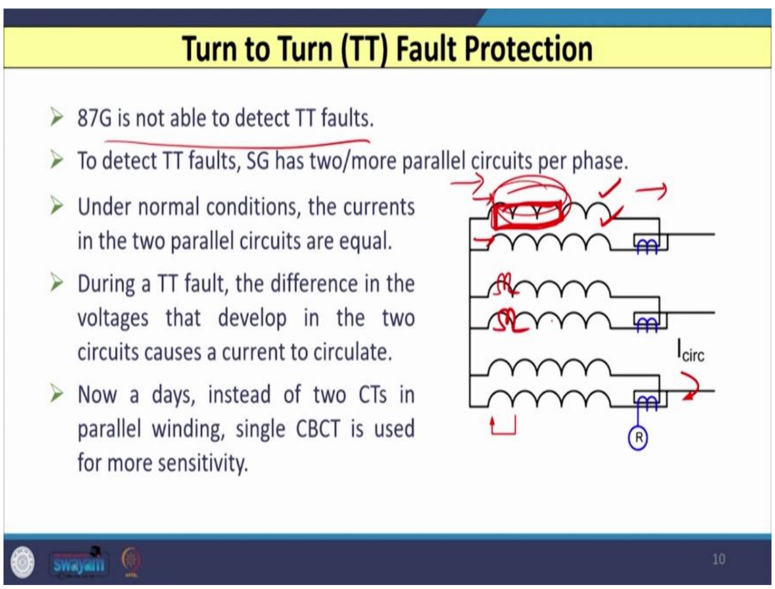
So, now we are talking about 87G function which is available here (as shown in above slide). So, when we talk about the characteristic of the differential relay, we know that it is always plotted considering on x axis the restraining current and on y axis the differential current or the operating current. So, we have these currents on x axis and this current on y axis. So, compared to the characteristic of bias differential relay, which you know very well, for electromechanical or static relay, this relay digital relay has slightly different differential characteristic.

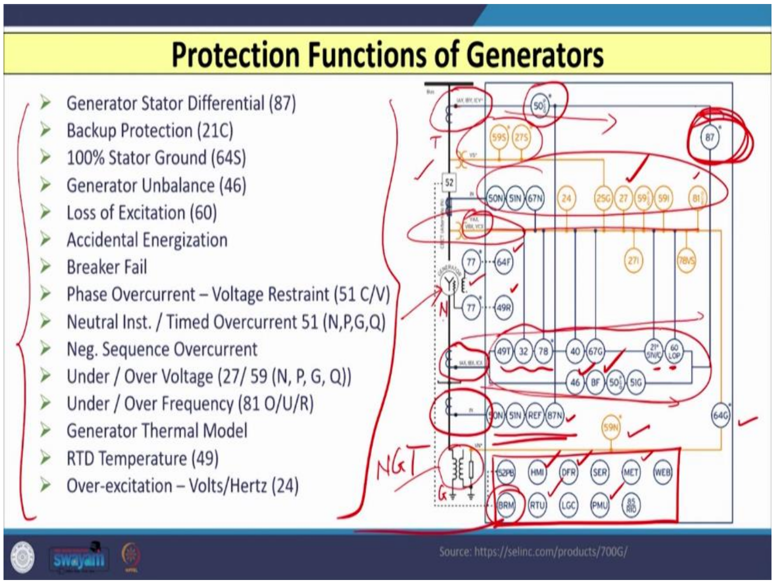
And you can see that I have shown here and the first point here you can see that is this point that is known as pickup one, so this pickup one which is on a y axis that is used to compensate the errors available in the CT. And its usual setting placed by the utility that is 0.2 per unit, then you have two slopes, because this is a dual slope differential characteristic.

So, you have slope one (as shown in above slide), and this slope one is meant to compensate mismatch between the two CTs. And its setting is usually in the range of 10 to 20 percent. And then you have the second slope here. And this slope is used to compensate the non-identical citizens duration characteristics and its setting is usually in the range of 50 percent to 70 percent.

And then you have the third that is pick up 2 is also there, which is meant for immediate tripping without observing any slope. Because if the value of current or magnitude of fault current is very large, let us say 10 15 20 times, then there is no waiting period immediate trip is given and that is done by this pick up 2 function.

(Refer Slide Time: 23:39)





So, normally whatever 87G unit we used, where you have the three CT currents from terminal side and where we have the three CT currents here from the neutral side and that is compared both magnitude and phase wise, but if I go for turn to turn fault, then our conventional differential relay 87G unit is not capable to detect this turn to turn faults. The reason is the S differential relay works on the principle of Kirchhoff's current loss.

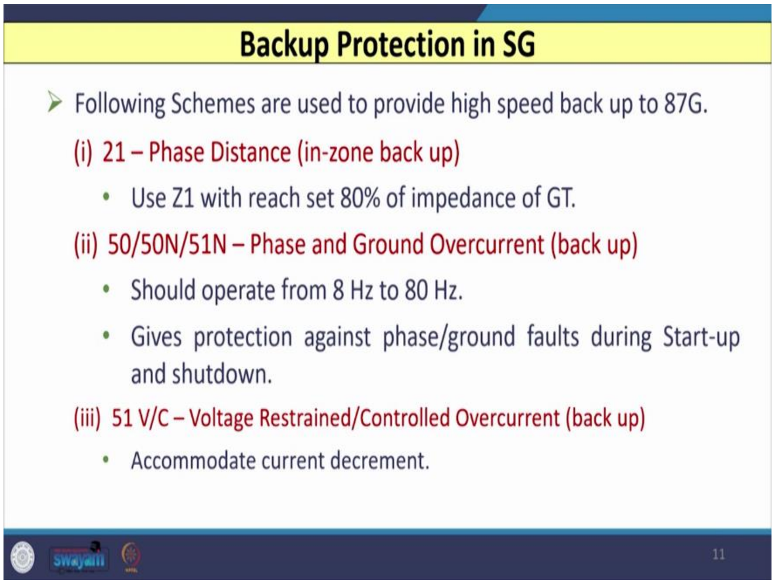
So, current entering and current leaving both are same where is in case of turn to turn faults, only few turns are shorted. So, circulating current is there, but the current entering and current leaving that remains same that is why this type of turn to turn faults are inter-turn faults in the winding that is not detected by conventional 87G unit. So, if we wish to detect this type of fault, then each and every synchronous generator must have the 2 parallel circuit in one phase of the winding.

So, two parallel circuits circuit 1 and circuit 2, two parallel windings are there and usually for large generators two parallel windings are very common. Because of the magnitude of normal current that flows through the winding. So, under normal conditions, the currents in the two parallel circuits are same.

However, whenever the turn to turn faults occur, when few turns are shorted together, there is a difference in the voltages that develops the two circuits so, that circulating current will flow in this shorter turns. So, to detect this nowadays two CTs a that is used or that is placed in parallel winding single core balance CTs that can be also used to increase the sensitivity.

However, but in conventional ways, if we wish to detect turn to turn fault, then we need parallel winding and we have to put the one CT on each parallel winding basically so, that we can detect this type of fault.

(Refer Slide Time: 25:51)



Till now, we started our discussion with the what are the features of the digital relays and we have seen that based on three standards, we can go and we can refer those standards and then we have discussed the important characteristic of 87G used for the protection of generator and then at last we have discussed with the turn to turn for protection and for that we need two parallel winding.

And again we have to put the CT and we have to go for transfers differential protection, the conventional 87G is not capable to detect this type of fault. So, I stop here and we will discuss more about the other features and functions used in the protection of large generator. Thank you.