Power System Protection and Switchgear
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Lecture - 01
Fundamentals of Protective Relaying - 1

So, good afternoon to all, and today, I am just starting the lecture on Power System Protection and Switchgear. So, we know that this subject, the name of this subject is Power System Protection and Switchgear. So, this covers two-part, one is the protection part and the other is the switchgear part. So, if we consider protective devices such as fuse, miniature circuit breaker that is MCB, relay; so all these devices come under the protection part, and the main function of all these devices that is to sense the fault.

If I consider the on the other hand, switchgear, then circuit breakers that is act as a, that comes under the switchgear part. Of course, the other devices such as current transformers and potential transformers, they also fall in this category. So the main function of switchgear that is to isolate the faulty section from the whole power system network without affecting the healthy section.

So, let us start with some few fundamentals. We know that in power system, faults are inevitable. So, they are bound to occur. So, usually, the faults are classified by two ways, one is known as Symmetrical fault and the other is known as the Asymmetrical faults.

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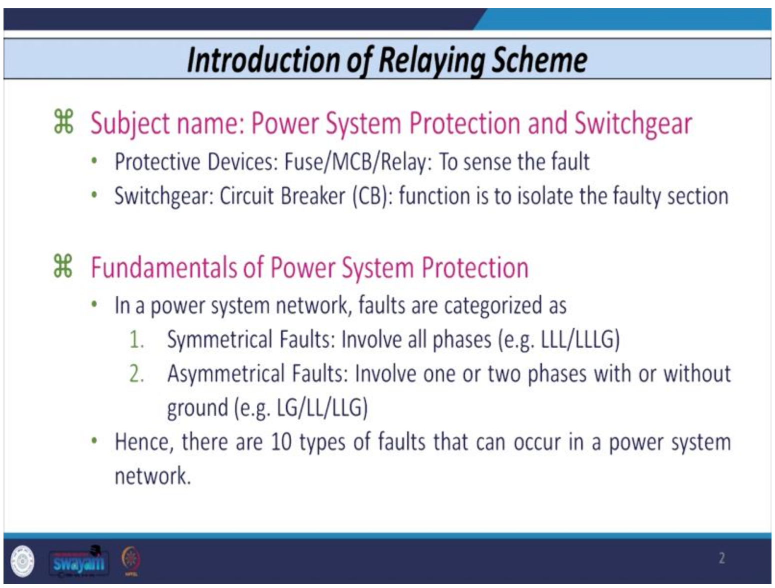

So, if we consider symmetrical faults, then these faults involve all the three phases. So, example is triple line fault or triple line to ground fault, whereas, in case of asymmetrical faults, they involve either one phase or two phases with or without ground. So, the examples are line to ground fault, double line fault, and double line to ground faults, these are the examples of asymmetrical faults.

So hence, there are total, there are 10 types of fault that can occur in a power system network. So, if we consider the symmetrical faults, then symmetrical faults usually occur by wrong operation or wrong, I should say, wrong coordination between circuit breakers and the earthing switch.

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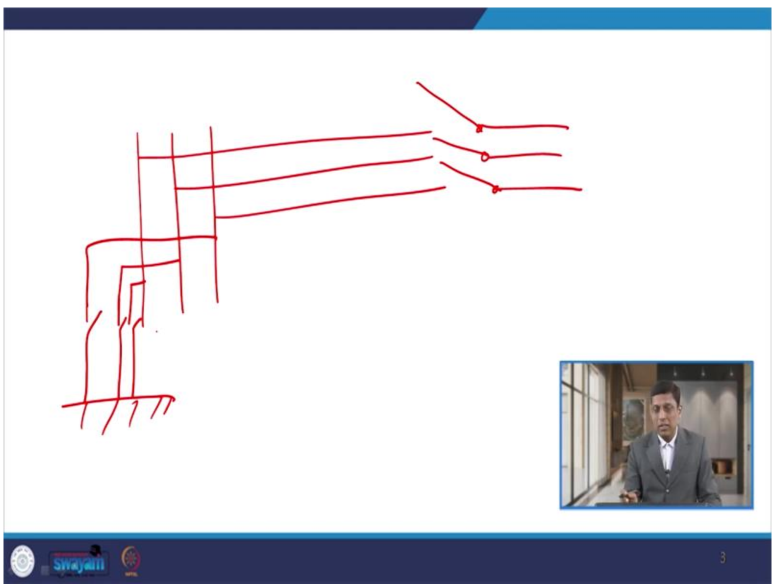

So, for example, if I consider the, suppose let us consider a simple transmission line connecting the three bus and if I consider that the circuit breaker is located at this sending end, and at this bus, bus side, we have earthing switch which is also kept, usually earthing switch is connected like this. So, whenever we energize the transmission line by closing the circuit breaker, at that time the earthing switch should be kept off. If by, by mistake, if earthing switch is kept on and if we energize the transmission line by closing these circuit breakers or all the three poles of the circuit breaker, then there are fair chances of the triple line fault.

Now, the next is, let us say, asymmetrical fault. So, asymmetrical faults, if we consider the first type of asymmetrical fault that is line to ground fault.

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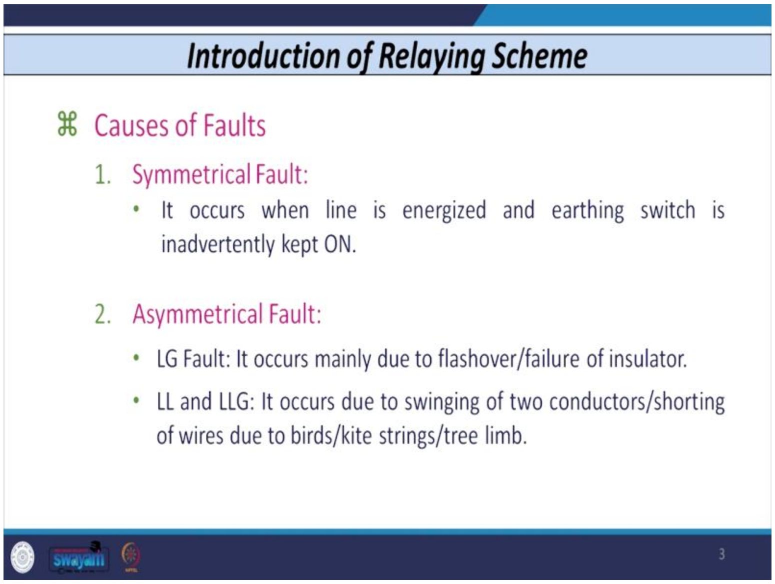

So, line to ground fault usually occurs due to flashover of insulator or sometimes the failure of the insulator.

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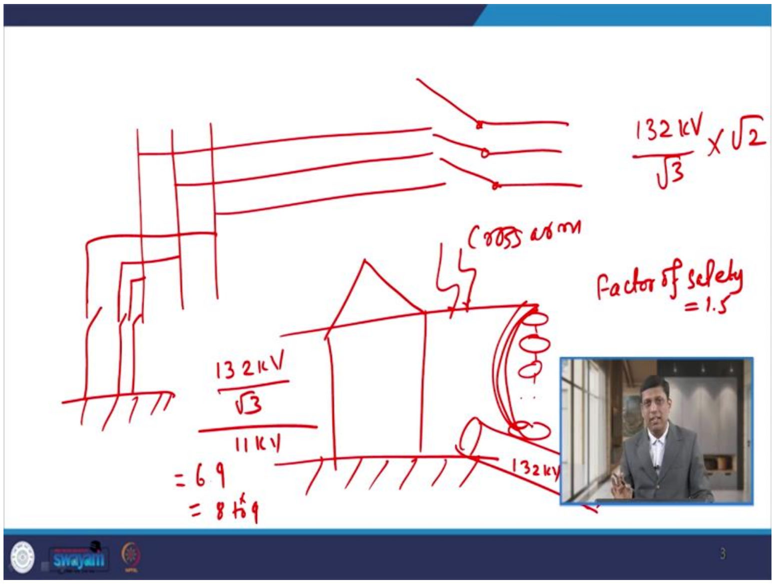

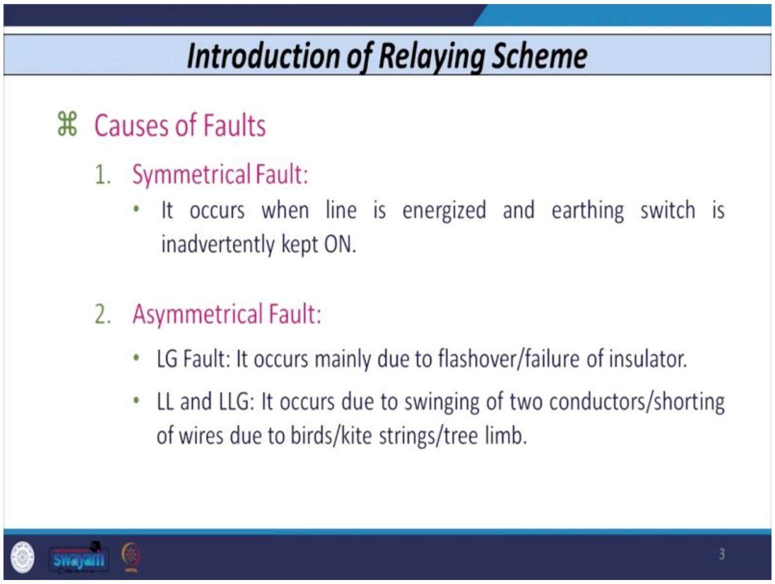

So, to understand this let us consider, simple if I consider a tower, transmission tower, and on transmission tower let us consider this is a cross arm and on this tower, we have a different suspension insulator on this side. So, suppose if I consider that and below this suspension insulator, there will be a conductor. So, if I consider that let us say the line voltage is 132 kV. So, this line voltage across this number of string of insulators that is connected to cross arm and cross arm is finally connected to the earth. So, the total voltage that will be 132 kV divided by root 3 and whole divided by the number of rating of each insulator disc. So if, normally the suspension type of insulator rating is usually 11 kV. So, if I divided by this whole, then this comes out to be roughly around 6.9.

So, that means, the total number of disk required, if I consider with some factor of safety, let us say, the factor of safety is, let us say, 1.5 or 2, then this multiplying this factor of safety with 6.9 that comes out to be the, if I integer it, then that comes out to be roughly around 8 to 9. So, that means, for 132 kV line, total 8 or 9 suspension insulators are required.

Now, whenever there is a lightning surge occurs, then lightning surge may occurs maybe on this cross arm or maybe if switching surge is there then that, because of that, the voltage increases. If voltage across this string of insulators exceeds the value which is withstand by this string, this string can withstand the voltage that is 132 kV divided by root 3 into root 2. That is the peak value. So, if voltage across the string exceeds this value, then there is, there are fair chances of flashover of insulators like this. So, whenever there is a flashover of insulator, your conductor which is at 132 kV, that is directly connected to ground and that creates or simulates the single line to ground faults. So, this is how the line to ground fault occurs on the overhead conductor.

The other two types of fault that is line to line fault and double line to ground faults. These two faults occur due to switching of two conductors that means whenever the two conductors swing because and particularly during monsoon season, the dielectric strength reduces. So, there are fair chances of flashover or power arc between the two conductors. Sometimes, because of shorting of wires also these two types of fault occur and this can be because of the birds or kite strings or if any tree limb falls and touches two conductors, then also such type of faults occur.

Now, let us see, what are the consequences of this fault? So, whatever may be the type of fault whether symmetrical fault or asymmetrical fault, these faults are going to create major damage for the equipment. The first damage that is known as thermal damage.

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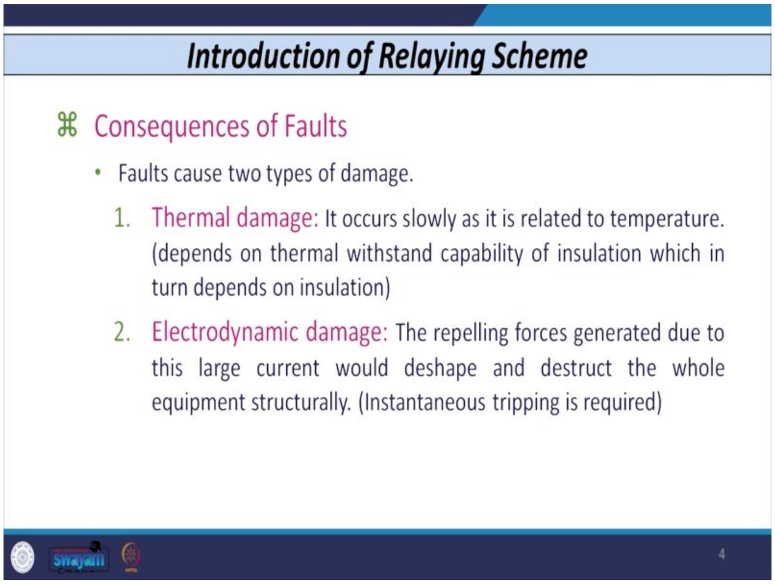

So this, the name itself suggests thermal damage, so it is related to the temperature. So, thermal damage occurs very slowly and because it is related to thermal or heating effect. So, usually it depends on withstand capability of the equipment which in turn depends on the insulation. So, whenever we know that whenever we design any conductor or any winding of the equipment, whatever, depending upon the type of insulation we use starting from class S to class H, each type of insulation is capable to withstand certain level of temperature. So, whenever that, whenever the current exceeds the full load current or rated value, the temperature goes on increasing and whenever it exceeds the temperature withstand by that particular insulation, then such type of thermal damage may occur.

The second type of damage that occur that is known as electrodynamic type of damage. So, in this case, the magnitude of current is very high roughly 10 times or 15 times or 20 times the full load current or rated current. So in this case, the repelling forces generated are such that they are going to de-shape and sometimes disrupt the whole equipment structurally. So, your equipment is going to damage structure-wise. So, in this case as the magnitude of current is very high 10 times or 20 times, so, instantaneous tripping is required. Whereas, in earlier case of damage that is thermal damage, instantaneous tripping is not required because immediately there is no harm as far as insulation is concerned.

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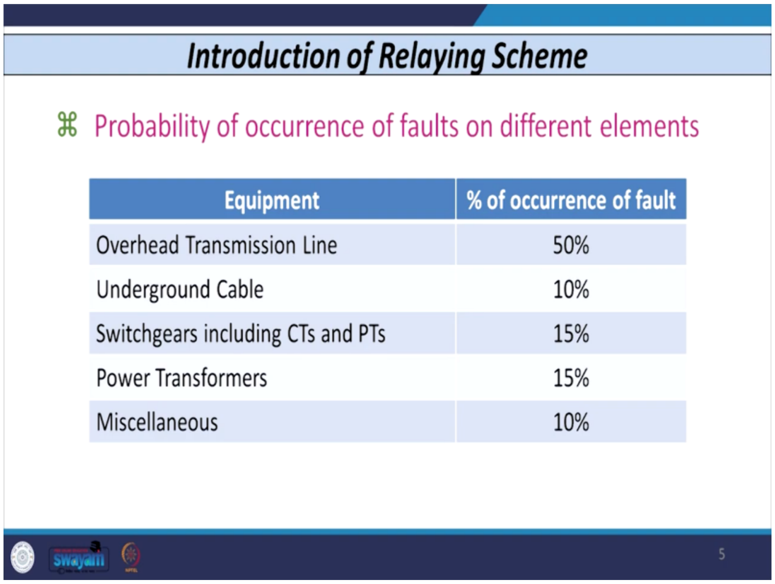

So, if I consider a rough overview of what is the probability of occurrence of faults on different elements on the power system network, then on overhead transmission line or conductors, the percentage of occurrence of faults are 50 percent as it is on overhead. So, weather condition and other conditions also affect and there are fair chances of fault on these overhead conductors. Conversely, on the other hand, the underground cables, as they are laid below the ground, so the chances of weather conditions are less affected. So, there are, 10 percent are the only chances of occurrence of fault on underground cables.

If we consider the switchgear including CTs and PTs, then there are 10 to 15 percent of chances of occurrence of fault. If we consider power transformers then 15 to 20 percent are the chances of occurrence of faults on power transformers. And these are the main reason why whenever any fault or abnormality occurs in the power system network, then the major type of faults usually they occur either on overhead conductor or on the power transformers. The miscellaneous percentage are 10 percent which includes the faults in some control circuit or some other auxiliary circuits and so on.

Also, if I consider the overview of let us say, what is the probability of occurrence of faults on overhead lines, then depending upon the type of fault, percentage of occurrence of fault also changes.

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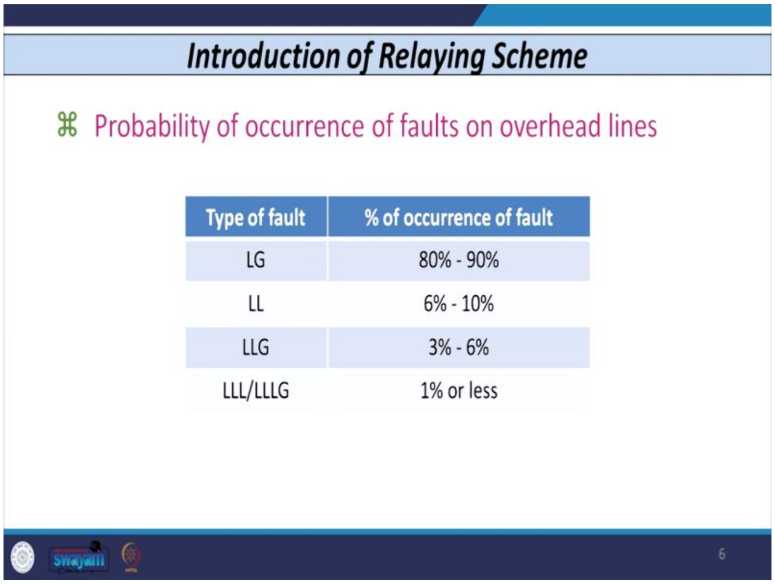

So, if I consider single line to ground fault, then the 80 to 90 percent are the chances for occurrence of this type of fault on overhead conductors. If I consider line to line fault, then 6 to 10 percent of the chances and for double line to ground fault, 3 to 6 percent and for triple line or triple line to ground fault, which is asymmetrical fault, the chances are very rare, so 1 percent or even lower than that. So, out of this we can conclude that from this table, that the single line to ground fault is the most common type of fault that occurs on overhead conductors.

So, one more thing in addition to all above-mentioned points, that faults that can be also categorized or classified as transient faults and permanent faults.

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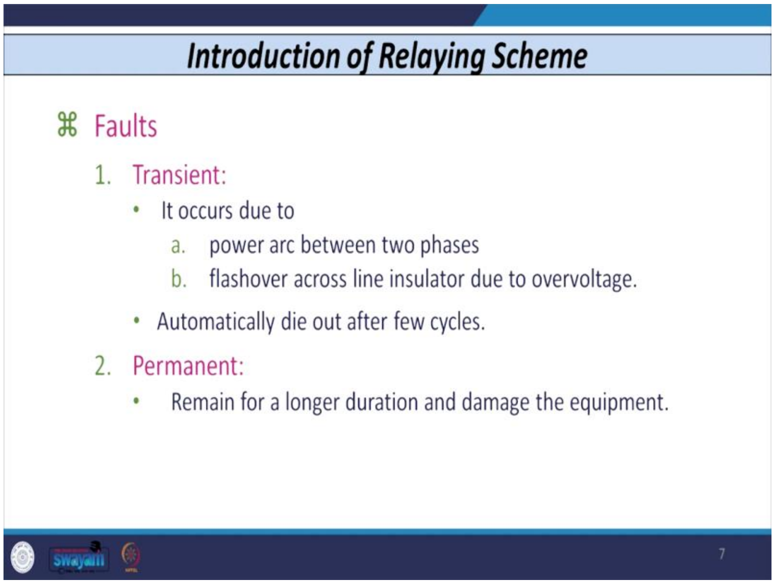

So usually, transient faults occur due to power arc between two phases and sometimes it also occurs because of flashover across the line insulator due to over voltages. So, suppose lightning surge occurs and because of that the voltage across the string of insulator increases or maybe if switching surges occurs because of operation of de-energization of line or energization of some other equipment then also there are fair chances of increase in voltages and so, that means if voltage exceeds beyond nominal value of the voltage, then also the transient faults occurs.

The transient faults, these faults are die out after a few cycles. So, sometimes we do not, there is no need to isolate the section because this faults are going to die out after some time and system that can be easily restored. On the other hand, permanent type of fault, this remain for a longer period of time and duration. So, in this case, it is definitely going to damage the equipment and hence, and at the same time, as it remains for longer duration, so stability of the power system, that is also affected.

So, for permanent fault, we need some protective device which is capable to sense the fault as well as we need also, some other devices which are capable to isolate the faulty section from the whole power system network. So, with this background, we can say that the occurrence of a fault that can cause many, many problems.

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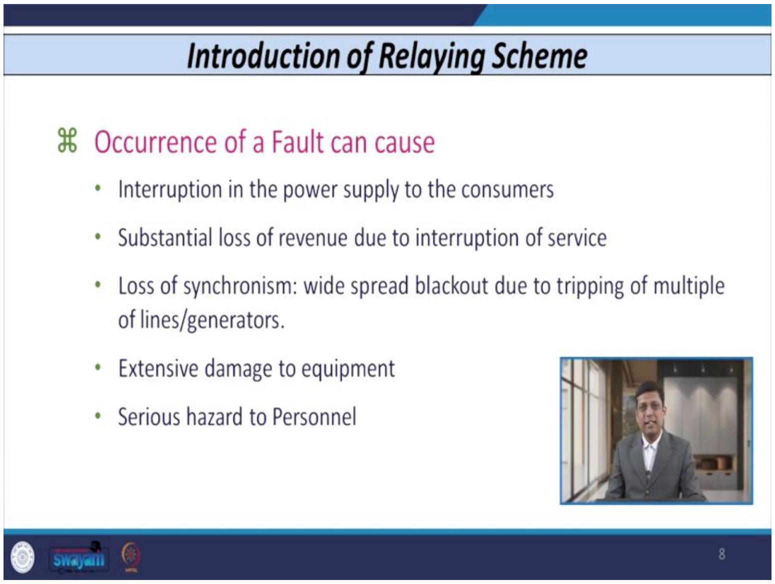

If I list, the first is the interruption of power, of the power supply to the consumer. So, consumers are not able to get the power supply. The second is the substantial loss of revenue due to interruption of services. So, that means, when there is an interruption of power, so that power is not utilized. So, obviously, whatever state electricity board or company is there, they will lose the revenue. The third point that is known as loss of synchronism.

So, we know that in our power system networks, many big transmission lines are connected with the power station. So, whenever there is a tripping of any big line, obviously, whatever load that is or power is transferred by that line that has to be shared by some other lines and if other lines are not capable to share that load, if they are overloaded, then there are fair chances of tripping of that lines also which further, which further create that tripping of the several power stations. So, because of multiple tripping of lines and generators, there are fair chances of blackout, maybe partial blackout or full blackout of the network which is known as loss of synchronism or cascading outages.

The next one is the extensive damage to the equipment. As we have already discussed that the magnitude of fault current is very high, if fault is solid type of fault which does not involve any fault impedance, high magnitude of fault current flows through, through the equipment, may be the any apparatus like transformer, induction motor, generator or maybe transmission line, then they are going to damage the equipment and hence, we need to protect the equipment from such type of damages. And last but not the least that is a serious hazard to the personnel. So, sometimes the high magnitude of fault current also affects or creates the problem to the personnel working in the substation.

So, to avoid all this problems, we need to design a certain type of system, which we call it as a protective system.

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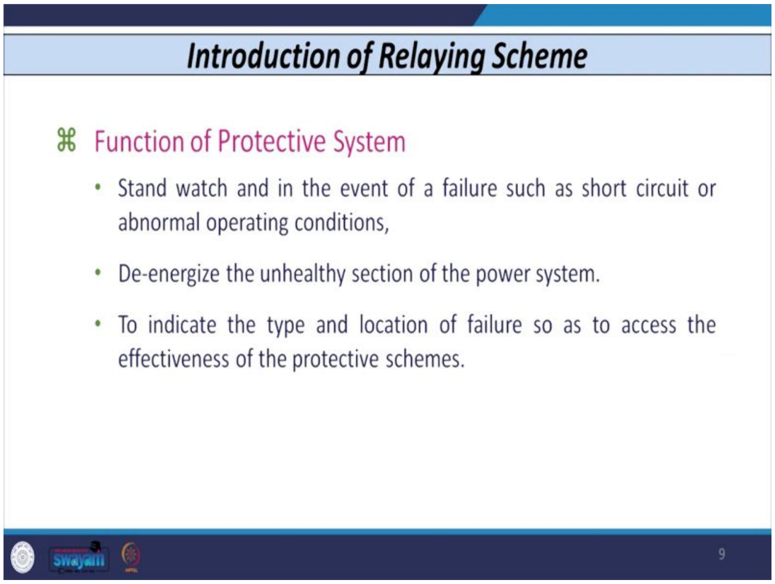

So protective system stand watch and senses the fault whenever any short circuit or any abnormal operating condition occurs in the power system network, maybe in the equipment or apparatus or in the transmission line, then that device, protective device is capable to sense the fault, and not only that, it gives signal further to the other devices like circuit breakers and circuit breakers are also capable to isolate the faulty section without affecting the healthy, healthy section of the whole power system network so that the interruption of power should be minimum and duration of interruption of supply, that is also minimum. So, with this background, let us consider, what are the major components of power system network.

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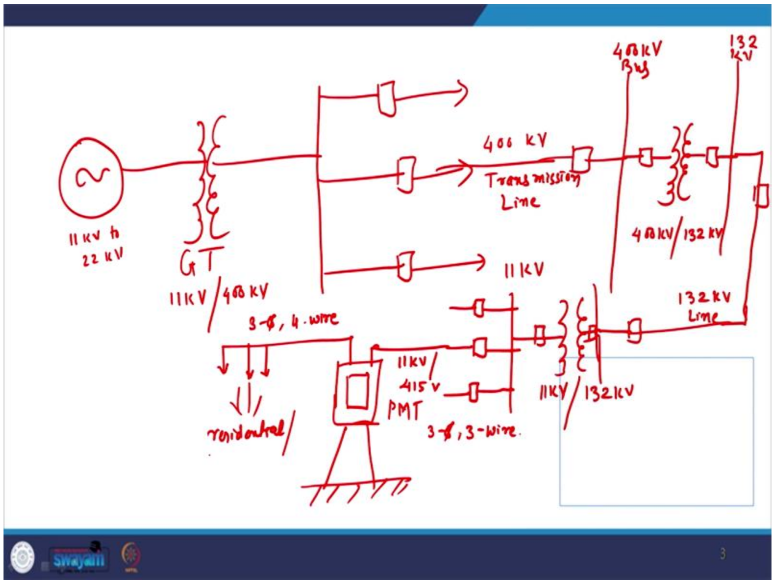

If we consider the major components of power system network, then we know that normally, the power is generated in the power station. The power is generated in the power station at the voltage between 11 kV to 22 kV. So, usually in our country, the power is generated at 11 kV or at the most 13.2 kV, whereas in some other developed countries, the power is generated at voltage 22 kV.

The reason for generating power in power station at voltages between 11 kV to 22 kV that is because at this voltage only the most effective economics is achieved as far as cost of copper is concerned, cost of insulation is concerned and cost of mechanical strength against the vibration and the other repelling forces is concerned. So, we will have most effective cost if we generate the power in power station between 11 kV to 22 kV.

After this, the next device comes that is known as the generating transformer. So, generating transformer is nothing but the transformer which steps up the voltage from say, let us say, 11 kV to at the most, let us say it is 400 kV. So, the voltage is stepped up at from 11 kV to 400 kV, and then further, from the switchyard of the power station, this 400 kV high voltages are transferred. So, power is transferred at high voltages because we know that as the value of voltage increases, the magnitude of current reduces, so the economy as far as the cross-sectional area of conductor is concerned that we can achieve.

Moreover, one more thing is that there is also a, means some of these students they may believe that the power is always transmitted in the multiple of 11, say 11 kV, 22 kV, 33 kV, 66 kV, 132 kV, this is okay, fine. But if we go beyond say, 220 kV, like say, 400 kV, 765 kV, then this, this voltages are not in the multiple of 11 kV. So, the transmission of power at the multiple of voltages of 11 that is not correct, it is not always true.

Some of the students, they also believe that we transmit the voltage, we transmit the power at higher voltages or in the multiple of 11 because of the form factor that is 1.1. So, if we multiply 10 kV with 1.1 then it would not come out to be 11 kV, it comes out to be 11.1 kV and so on. So, if you go up on multiplying with the other voltages, then it would not comes out to be the exactly multiple of 11.

So, from the other side of this generating transformer which is at 400 kV, the power that has to be transmitted by multiple of lines, so many transmission lines are emanating from this. So, if I consider that say, the power is transmitted at 400 kV, so this is your 400 kV transmission line. So, power is transmitted by this 400 kV transmission line, when it receives at the other remote bus, so we do have, at here we have 400 kV bus, then we have a transformer which further step down the voltage level. So, let us say this transformer is 400 kV by say, 132 kV. So, here this bus is 132 kV bus.

So then, further from this again, the further transmission is carried out and then we have a 132 kV bus, here also this is your 132 kV line and then after this, whenever it receives the power at other remote end of 132 kV bus, we have the transformer again with two breakers on each side and then, so, let us say this transformer is 132 kV by either 66 kV or 11 kV.

So from this 11 kV the distribution of power that starts. So, from 11 kV, we have the multiple of 11 kV consumers are there, so these consumers are called HT consumers and from this, the power that is received to the another transformer that is known as the pole-mounted transformers. So, this is nothing but your pole-mounted transformers where the power is available.

So, pole-mounted transformer, you have 11 kV that is on one side, and on the other side, you have 415 volt. So, from 415 volt, you have the number of distributors, 415 volt. So, on 11 kV side, we have three-phase, three wire system, because we have only three phases R, Y and B. And on 415 volt side, we have three-phase, four-wire system as we are also going to use the neutral along with three conductors that is R, Y, B. And then further, this, this power that is delivered to the either for residential loads or maybe for the agriculture loads or maybe for the some other customers.

So, with this background, now we can say that, we know that we started with the power generated in power station, then the step-up of the voltage from by transformer, then we have transmitted the power, then we have also distributed the power and then we connect the load at the tail end. So, with this background, now we can say that whenever the power is transmitted, maybe from power station to the last consumers, then we have to consider that this involves different equipment, starting from let us say, generator, transformer, bus bar, transmission line, distribution line, loads.

So obviously, faults are going to occur in any of this equipment. So, to avoid or to protect the equipment against such any type of or all types of fault, we need a particular protective device and in the market, not a single device is available which can take care of the fault on all this equipment simultaneously. So, we have to give or we have to provide or we have to assign or install a particular protective device for each and every equipment and we have to design a specific zone. So that means, we know that, what do you mean by zone?

So, zone means nothing but a particular area or region in which if any fault occurs, then that protective device is capable to take care of that zones. So zone usually protected by relays, circuit breakers, and other associated equipments like current transformers, potential transformers, and so on.

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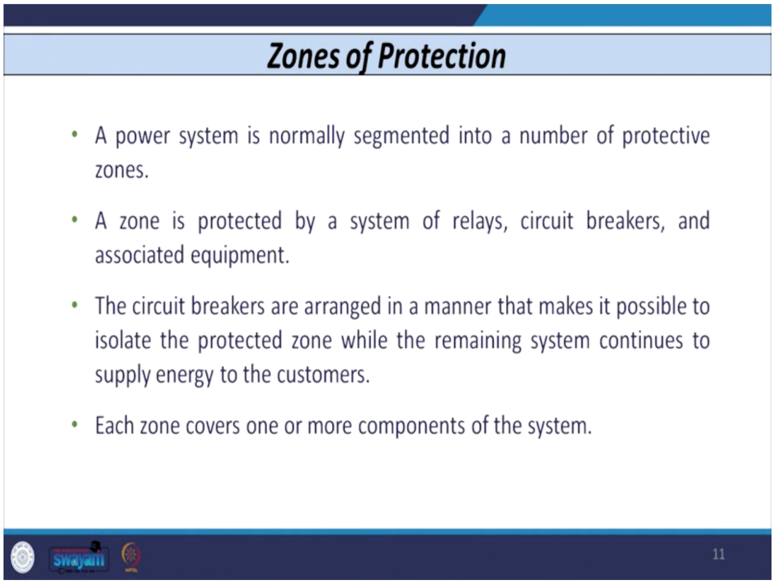

So, these circuit breakers are arranged in number of different manners so that we have the, all the devices which we have discussed in earlier slide, all are protected against all types of fault.

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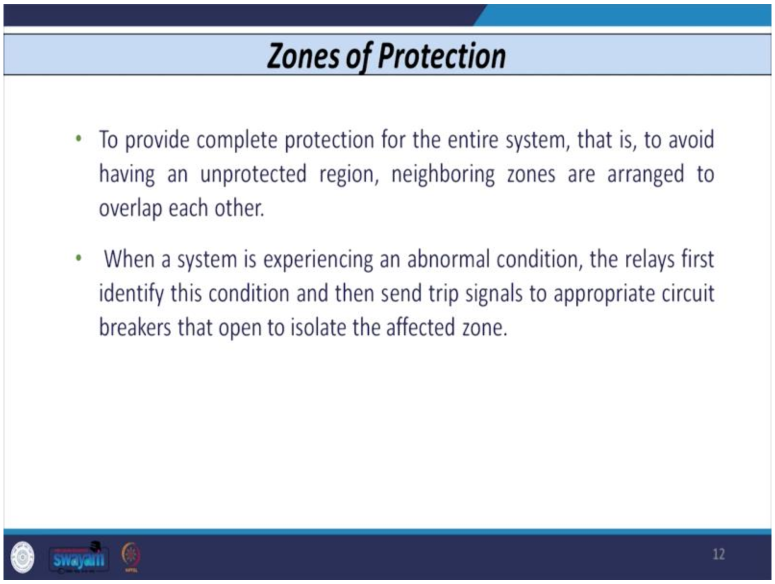

Now if we consider, one more thing that is very important that is whenever we provide or whenever we assign a particular protection zone to a particular device or equipment, we need to keep in mind that not a single point should remain unprotected. So, that means, if any, unprotected means any, any region or any particular distance or location at which fault occurs, then not a single device is capable to sense the fault and isolate that fault from the system otherwise there will be a blind spot. So to understand this, so that means we have to overlap the zones of different equipment with other associated equipment. So, for that let us consider the simple example.

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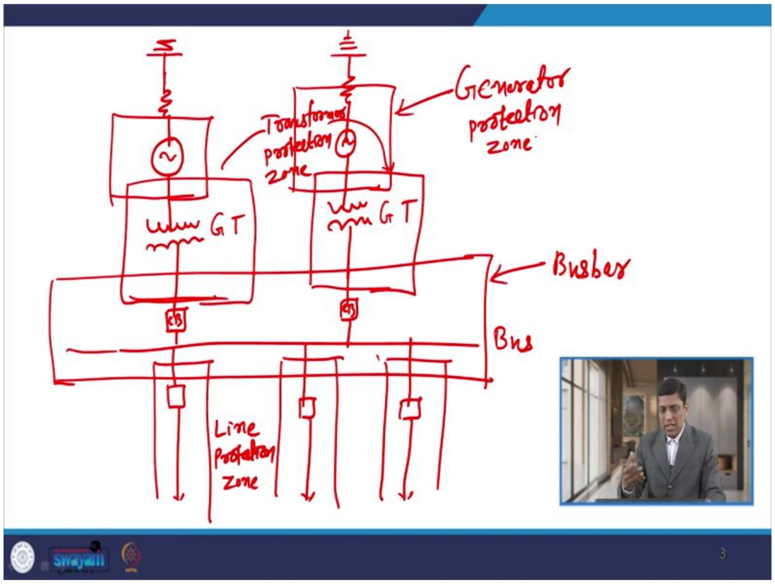

Say, if I have, suppose the generators, let us say, the generator is connected here and then that is followed by the, let us say, the transformer and then that transformer is connected through circuit breaker to a bus. Say let us have, we have another generator that is associated with the generating transformer and which is connected to the bus through a circuit breaker. So, that means whenever I want to design a zone for particular device, then this generator or this transformer has its own protection zone.

So if I define, let us say, the protection zone of the transformer; let us say, this is your generator, transformer on both the side and then further from this bus we have the different lines that is emanating from this bus, let us say, the three lines are emanating from this bus. So if this is, this three transmission lines are emanating from the bus, then this lines have its own particular zone. So, each line has a particular zone. So any fault occurs on this zone within this region then, that protective device senses that fault and it gives signal to the breaker and further breaker isolate the faulty section.

Now, if I consider this bus, this is bus, so this bus has also its own zone and as I told you the zones, all the protective zones are overlap. So, if I define the protective zones for the bus, let us say, let us mark the region or zone for bus bar or this bus, then this has to be overlapped like this. So, whenever I say this is the zone for bus bar protection, then you know that bus bar zone and this is the line protection zone, both are overlapped. So that means, if any fault occurs in particular section, then that section device has to operate and if that device fails, then other, other zone, other device that is capable to provide sufficient backup.

Similarly, if I consider the zone for transformer, then transformer zone should be overlapped with bus bar zone. So, if I consider the transformer zone, then transformer zone that is like this, this is our transformer zone. So, this is the transformer protection zone. Same way, we have the another transformer protection zone on this side. So, this is also the transformer protection zone. Same way, if I define the protection zone for the generator, then generator protection zone that should be overlapped with the generator transformer protection zone.

So, if I consider the generator zone, then generator zone should be like this. So, both are overlap. Similarly, here also we have the generator protection zone that has to be overlap. So, this is generator protection zone. So, all, all the protection zones should be overlapped. Now, the question comes how we overlap this each and every protection zone?

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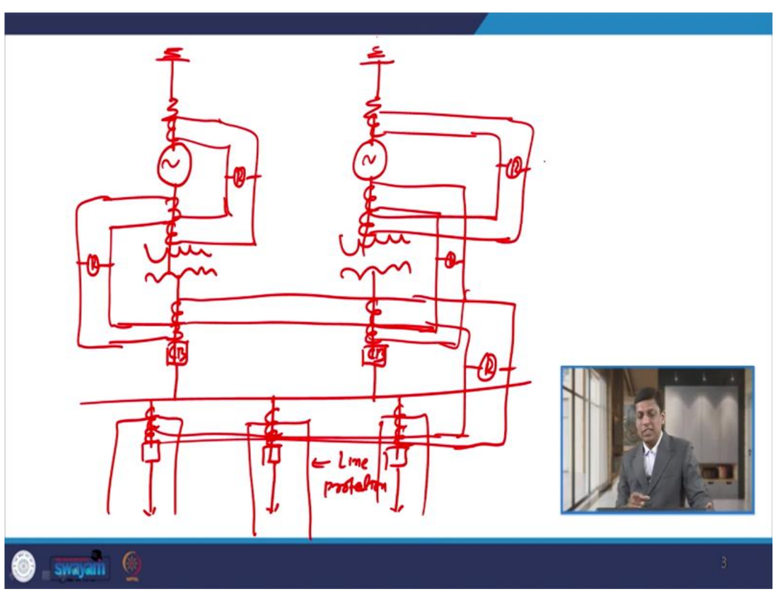

So, for that, if I consider the same diagram, let us say, we have the generator right here, then we have the generating transformer and then we have the breaker along with which is connected to the bus. Same way, let us consider the same on this side also we have the generator, we have the generating transformer and then it is connected to the bus through the circuit breaker. So, these two are the circuit breakers.

Same way, here also we have the circuit breakers and that is for the transmission line. So now, the question is how to give or overlap the protection zone. So the location at which we placed the CT, current transformer, that is going to decide the zone of the, or overlapping zone of the different devices. For example, if I consider the line protection zone, then I connect the CT somewhere here. So, this zone is meant for the line. So, this is our line protection zone. Similarly, you can put CT here and this is the line protection zone, you can put CT here this is the line protection zone.

Now, if I consider the another device let us say, bus bar, then we have to overlap the bus bar protection zone. So we can put the CT somewhere here. Let us say, I put the CT for bus bar here and I connect these two on this side. Now, on the line side, where I have to put the CT? Either on upper side or lower side of this line CT. So, if I put upper side of line CT, then line and bus bar zone both are not overlapped. So, I put this bus bar CT somewhere here on this side below the line CT and I connect it like this. So, then the bus bar zone and the bus bar relay that is connected here. So, bus bar protection zone and line protection zone both are overlapped.

Similarly, if I do for the transformer protection zone, then transformer protection zone, it has to be overlapped with bus bar protection zone. So, I have to put the CT on bottom side of the bus bar protection zone CT. So, I put it here and then I connected the transformer relay somewhere here. So, this is nothing but the, my transformer protection zone which is overlapped with the, my bus bar protection zone. Same way we can do on this side also, we have to overlap these two zones on this side and we put the relay here.

Similarly, we have to overlap the generator protection zone with the transformer. So, I put the CT on below, bottom side of the generator protective zone CT and somewhere here. So I have to connect the relay, generator relay somewhere here, and same way on this side also, I have to connect the generator protection relay on this side also. So here, I have to connect the generator relay on this side. So, in this way all the overlapping, all the zones are overlapped.

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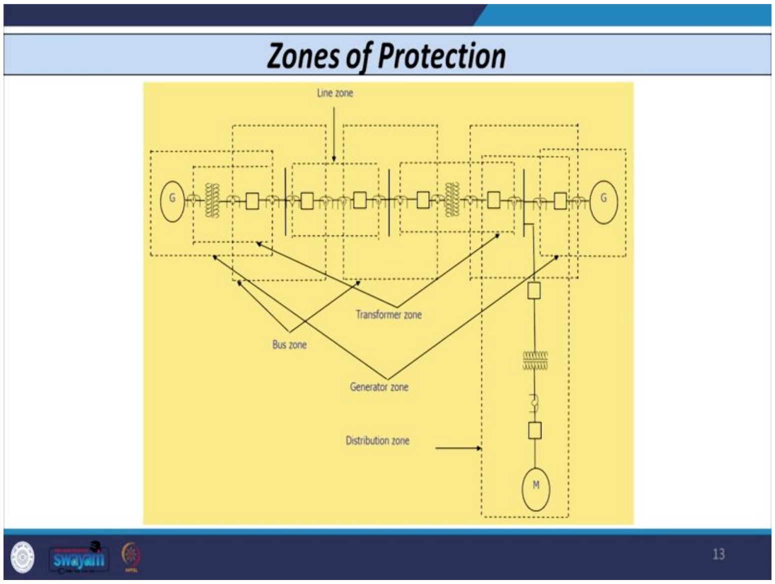

So, with this background, now, we can consider that the, I have shown here the overlapping zones of all the protection zones starting from the generator. So, you can see here that we have the generating protection zone here and then we have the bus zones, transformer zone, generator zone, distribution zone, all are overlapped.

So with this, all the background of zones of protection and the, what are the causes and consequences of fault and importance of protective system and circuit breakers, we will, we have already discussed all these points and in the next part, we will discuss further, the requirements of different protective devices. Thank you.