Power System Protection and Switchgear
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Lecture - 02
Fundamentals of Protective Relaying - 2

So, in the last class, we have discussed regarding the, we started with the different types of faults, that is asymmetrical and symmetrical. Then we have finally discussed the zones of protection and we have also discussed how these zones are overlapped by proper location of CTs that is current transformer.

So now, let us discuss the, what are the different requirements of protective system or protective device. Now, this, there are total seven requirements of protecting system.

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Starting from selectivity, speed, sensitivity, discrimination, stability, reliability, and economics. So, all these seven requirements are applicable to any of the equipment for which we need protection or it is also equally applicable for the transmission line as well as underground cables. So, let us start with the first requirement of protective system that is, selectivity. So now, what is selectivity?

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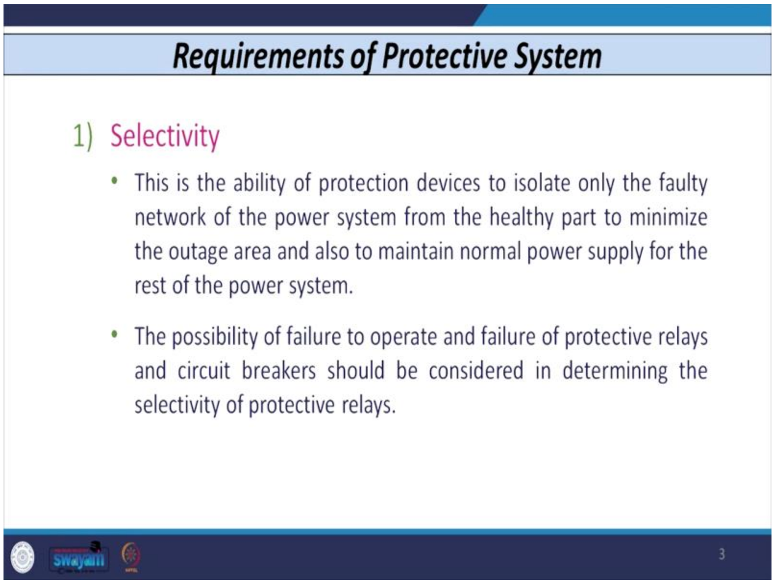

So, selectivity is nothing but the ability of protective device to isolate the faulty section from the power system network, considering that the healthy section should remain intact in the power system network. In this case, the main point, main objective is the outage area that should be minimum and at the same time, the interruption of power or duration of interruption of power that is also minimum. So, if we, there are two, basically there are two types of selectivity. So, if we just look at the selectivity part.

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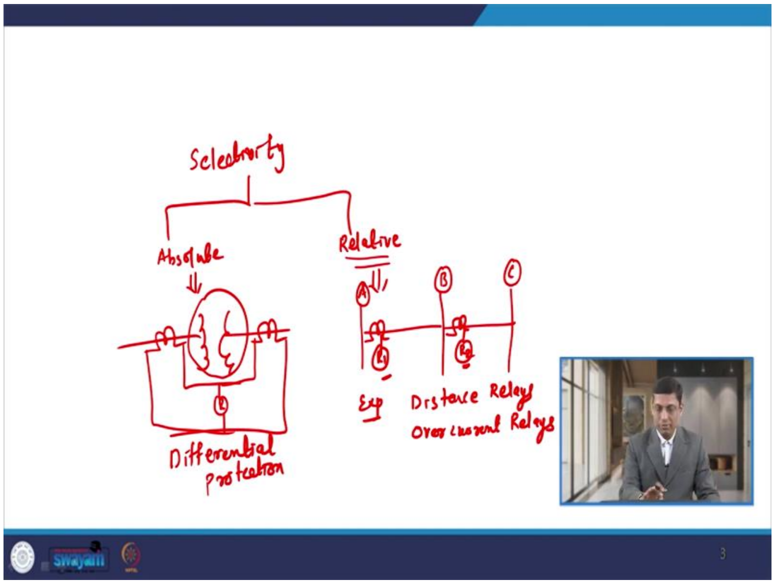

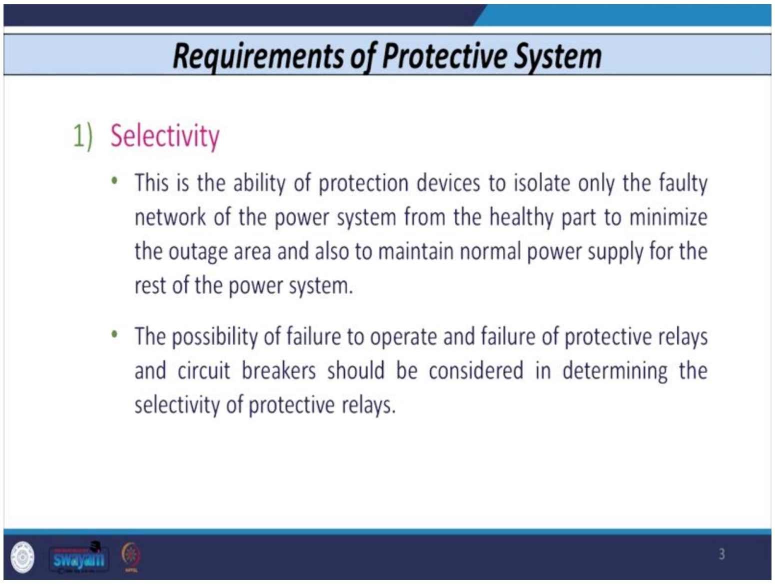

So, then selectivity that can be categorized or classified as, one is known as absolute selectivity and the other that is known as the relative selectivity. So, when we consider the absolute selectivity, then absolute selectivity, that is achieved when we want to protect a particular equipment or winding of the equipment at small distances, for example, if we have a winding of the transformer and if we want to protect this, then we put the CT on each side of the transformer winding and then we connect it and finally, we put the relay here. So, here thus, any fault occurs inside this equipment or winding of the transformer, then the relay should capable to operate. So, this type of selectivity that is known as absolute selectivity.

On the other hand, the relative selectivity, this is achieved when we want to obtain the selectivity by coordination of different protective device. So, for example, if I have the different bus, say, let us say, bus A, bus B, and bus C and between each bus, say, transmission line is connected and I want selectivity from one bus of one relay with other bus of other relay, then selectivity can be achieved by coordinating relay R1 and R2 using some standard procedures. So, this type of selectivity that is known as the relative selectivity.

The example of absolute selectivity that is known as, let us say differential protection that is the best example of the absolute selectivity. The example of relative selectivity, that is the distance relays and the overcurrent relays. So, these two are the example of relative selectivities.

So, in this case, in case of selectivity, the possibility to failure and failure of protective relays and circuit breaker that has to be considered in determining the selectivity of whole system or whole network.

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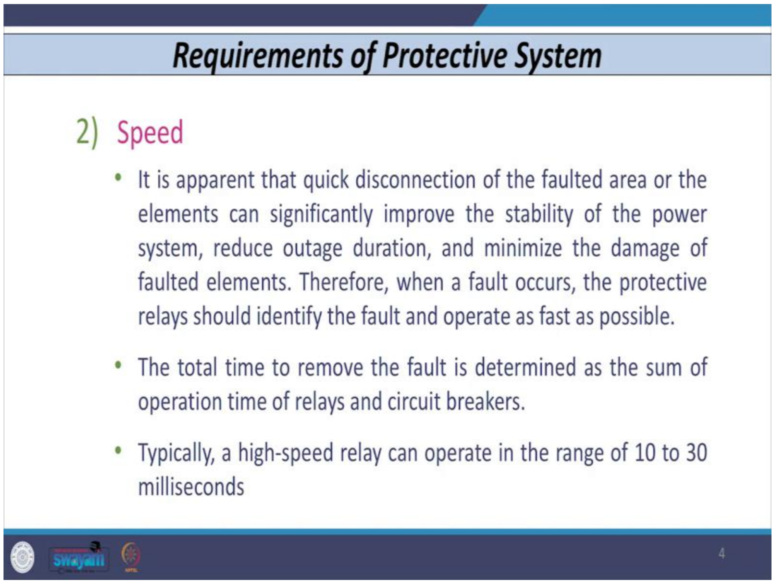

The next is known as speed. So, we know that the quick disconnection of faulted area or faulty section in which fault has already occurred, that gives different benefits. For example, if we remove the faulty element from the network quickly, then stability of the power system, that is improved, it is also going to reduce the outage duration and at the same time, it also minimize the damage to the equipment.

So, that means, if we remove, that means, if any fault occurs in the system and the less time the fault remains in the system, then obviously, the whatever damage to the equipment that is caused by that fault, because in that case magnitude of current is very high, so, damage to the equipment, that can be prevented. That is first benefit.

The second benefit is that the outage duration. If we quickly isolate the fault or faulty section from the network so that healthy section remain in the system, then the outage duration, that should be, that is reduced. So, obviously, we will have a better benefit for reduced outage duration. And the last that is, we can also improve the stability of power system because the chances of loss of synchronism that can be also reduced.

Now, in case of speed, that is one of the requirements of protective system, the total time to remove the fault that is normally defined or known as fault clearing time.

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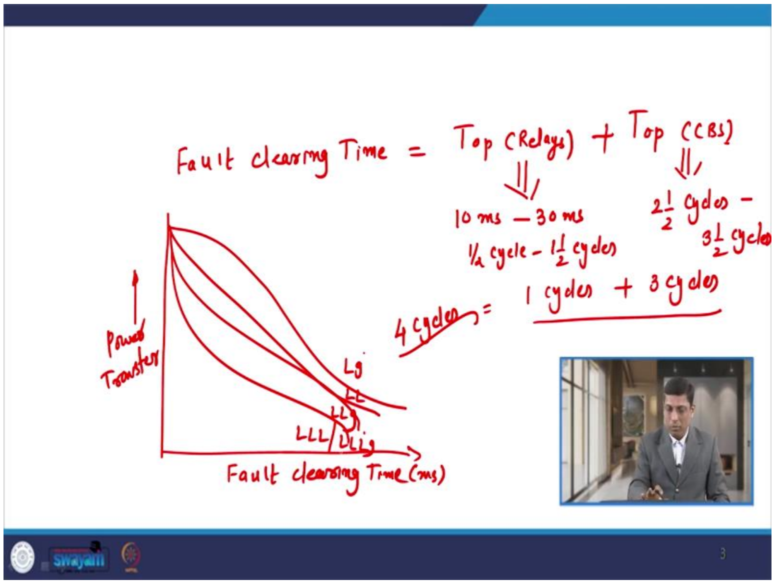

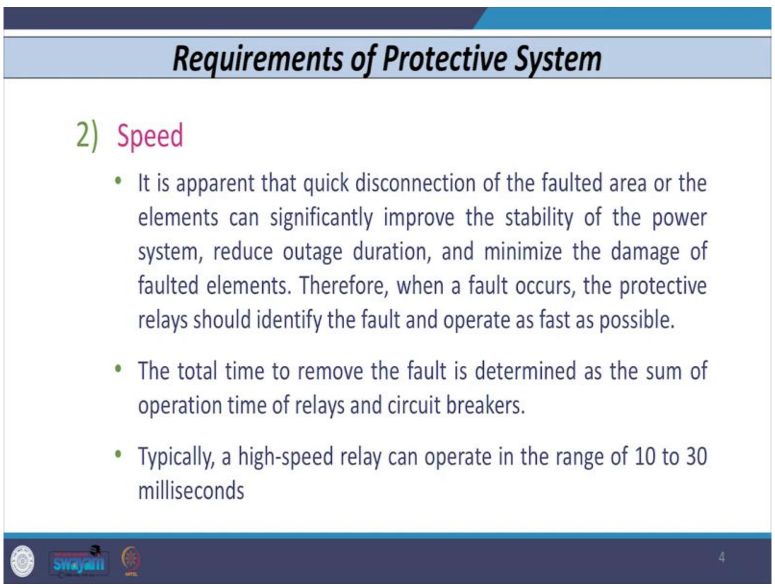

So, if I consider the fault clearing time, then fault clearing time, fault clearing time, that is nothing but the summation of time of operation of protective relays plus time of operation of circuit breakers. So, usually, if I consider the relays, then time of operation of protective relays varies from 10 millisecond to 30 millisecond. So if I consider 50-hertz system, then in that case, the time of operation of relays that varies from half-cycle to the one and half cycles.

On the other hand, if I consider the time of operation of circuit breakers, then time of operation of circuit breakers varies from two and half cycles to three and half cycles. It depends basically on what type of circuit breaker we are using. If we use, if we use or utilize the air circuit breaker or air-blast circuit breaker or oil circuit breaker, then the time of operation is very comparatively larger, maybe 3 and a half cycle or 4 cycles. And if we use SF6 or other vacuum type of circuit breaker, then the time of operation can be reduced.

So, if I add these two time, that is time of operation of relays and time of operation of circuit breakers, then the total time of operation, that is 1 cycles plus the 3 cycles. So, the total fault clearing time that should be almost 4 cycles. So, fault clearing time that should be 4 cycles and the objective of the protective or protection engineer is to reduce this total fault clearing time. Now why this is important?

So, if I consider say, fault clearing time on X-axis, fault clearing time here say, in millisecond and if I consider the power transfer and if I draw a curve for different types of fault, starting from say, line to ground fault, line to line and so this is for LG fault, this next one is for LL fault, the next one is for LLG fault and the lowest that is for symmetrical fault triple line or triple line to ground fault.

So, as we can see that the fault clearing time is lower, then we will have more time to transmit the power because we know that whenever fault occurs on a transmission line, which is transmitting a bulk of power, then those power has to be shared by some other lines. So, if we get more time to transfer the power of the, of the faulted line, then we have to reduce the fault clearing time in that case. So, speed of the, this criteria that is speed of the protective system that plays an important role. So typically, if we consider, then fault clearing time, that should be 4 cycles that we can achieve. The next requirement that is known as sensitivity. So, what is sensitivity?

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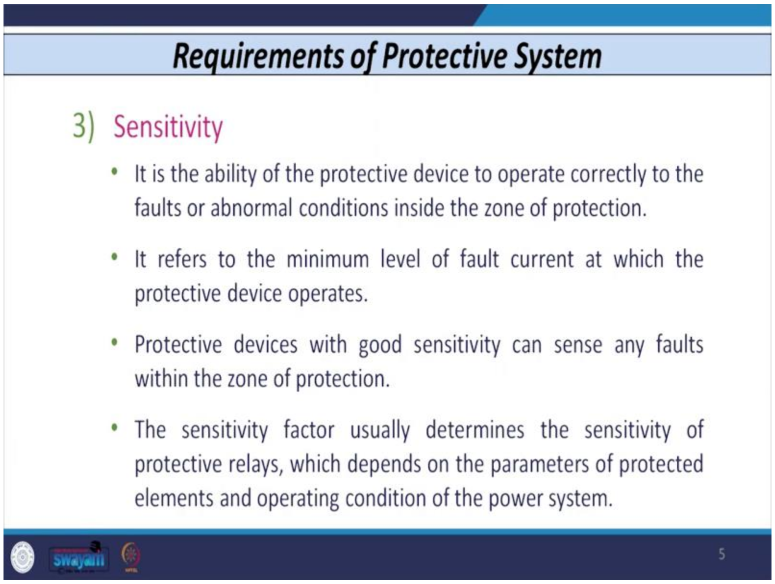

So, sensitivity is nothing but the ability of protective device to operate correctly for any fault or abnormal condition inside the zone of protection. So basically, it is related to the minimum level of fault current at which your protective device operates. So, protective device with good sensitivity can sense any faults within the zone of protection.

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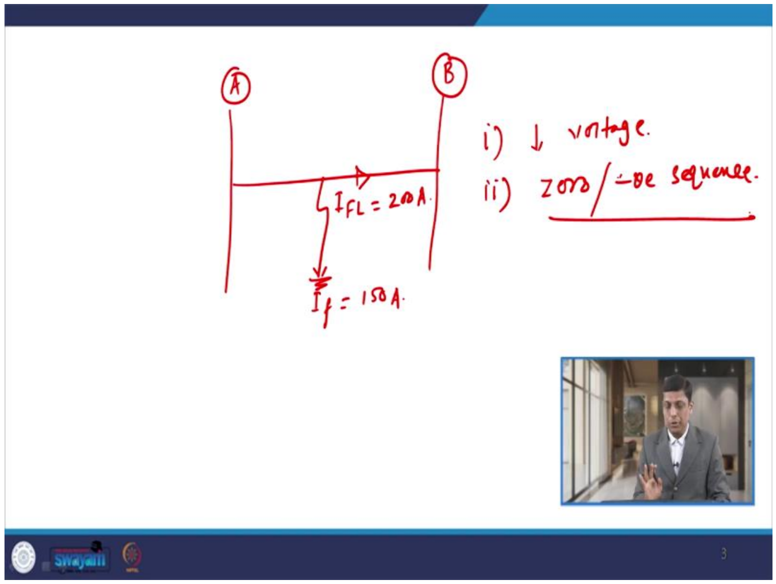

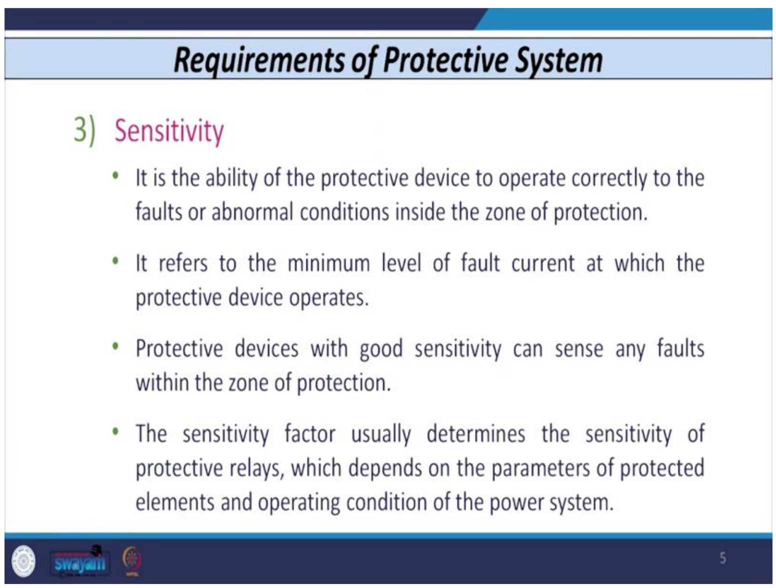

So, for example, if I consider, let us consider the one transmission line connected between bus A and bus B. Say, let us also assume that the full load current of this line that is, 200 ampere. That means this line can take 200 ampere continuously without any damage, without any temperature rise. Now, if fault occurs on this line and let us say, the magnitude of fault current that is, 150 ampere.

So, here the magnitude of fault current is lower than the full load current of the line that is 200 ampere. But in this case also your protective device or system should be capable to sense this fault which is low, whose magnitude is lower than the full load current of the feeder or the rated current of the equipment or any device like motor or transformer. Though the magnitude of fault current is lower than the full load current, it is harmful because it is going to generate the negative and zero sequence voltages and currents.

Two things happen whenever fault occurs, the first thing happens that is the reduction in voltage. So, if your equipment whatever you have installed, if those equipments are usually designed to run within specific voltage range, if voltage goes below, outside that range, then those equipments may damage and second thing that is the zero-sequence and negative sequence, negative sequence also generated. Now what is the, what is the harm of this zero-sequence and negative sequence currents and voltages?

So, whenever positive sequence voltages or currents are there and in case of zero and negative sequence voltages and current, the heat produce, that is almost 5 to 6 times the heat produced by positive sequence component. So, that is why in any case, even though the magnitude of fault current is lower than the full load current of the feeder or equipment, their device, protective device should be capable to sense or to detect that value.

So, that means the protective device with good sensitivity can sense any type of fault in the protective system. Now usually, sensitivity is usually given by the factor known as sensitivity factor. So, sensitivity factor depends on what type of sensitivity we want.

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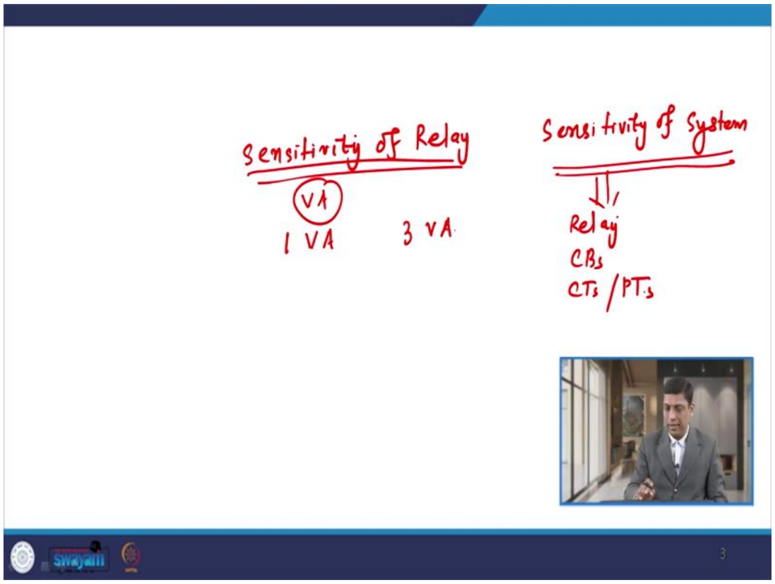

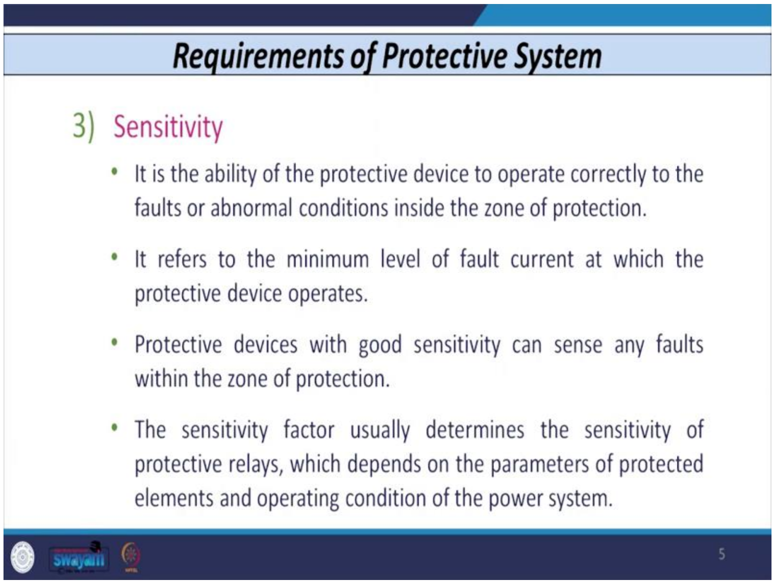

So, for example, if I consider the sensitivity of a protective device or of a relay, then sensitivity of relay that is different than sensitivity of whole system. So, when I say my, usually sensitivity of relay is defined as the apparent power required in VA to operate that protective device. So usually, this is defined in VA. So if I, whenever I say that one relay has 1 VA sensitivity and other relay has 3 VA sensitivity, then one, the relay which has 1 VA sensitivity that is better than the 3 VA relay.

Sensitivity of the system on the other hand, if I considered, then that, in that case, it also involves sensitivity of relay, it also involves sensitivity of circuit breakers, it also involves sensitivity of CTs, PTs, and some other equipment. So, both sensitivity of relay and sensitivity of system, both are different.

So, that means, whenever we defined the sensitivity of protective system, then we have to define the sensitivity factor and basically sensitivity factor is usually related with the full load current of the feeder or rated current of the any device or equipment. The next criteria that is, next requirement that is known as discrimination. Now, what is discrimination?

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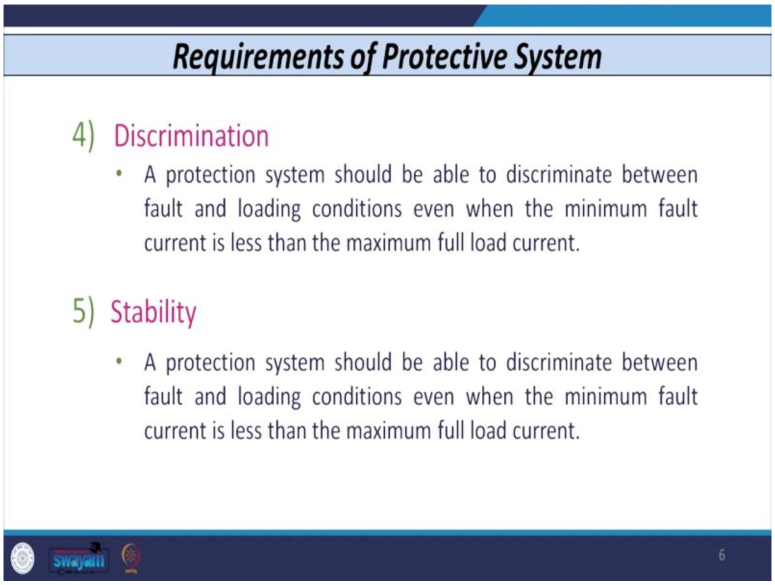

So, discrimination is defined as the capability or ability of the protective device to discriminate between fault and loading condition even when magnitude of fault current is lower than the maximum full load current. So, what do you mean by discrimination?

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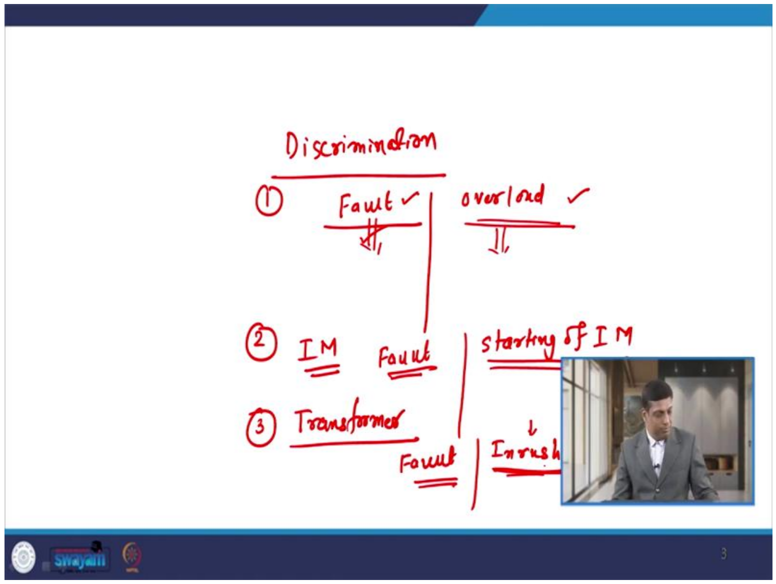

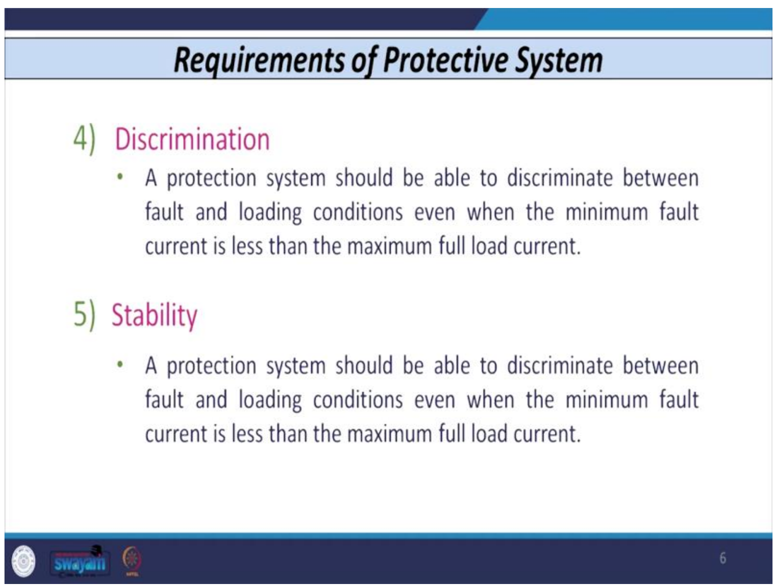

So, to understand this, let us consider, when I say discrimination, then in this case, discrimination can be between either fault and the other phenomena like overload. So, fault means, we know that fault is defined as, it is the abnormal stoppage of current or undesired flow of current that is known as fault. Whereas, in case of overload means gradual increase in load above the rated value. So, there is a fundamental difference between fault and overload.

In fault, there is an abrupt or rapid increase in current above the rated value, whereas here in overload, there is a gradual increase in current above the rated change. So, your protective device should be capable to distinguish or discriminate between fault and overload phenomena because both are different. In case of fault, the increase in current that is very high and rapidly, and in case of overload, the increase in current, above-rated current that is gradual. So, there is no immediate harm in case of overload whereas, in case of fault, there is an immediate harm that is one thing. So, this is all this is one point about the discrimination.

The second point is if I consider the induction motor, then your protective device should be able to distinguish between the fault that occurs in the winding of the induction motor and the other case, it is also capable to detect the starting phenomena of the induction motor. Because whenever you start the induction motor, it draws a very high current, 5 to 6 times the rated current. But keep in mind this starting of induction motor is not a fault. There is a difference between fault in induction motor and starting of induction motor. So your protective device should be capable to discriminate between fault and starting phenomena in the induction motor.

The third point regarding discrimination is the, for transformer. So for transformer, your protective device should be capable to discriminate between fault that occurs inside the winding of the transformer, whether phase to phase, phase to core, and the other phenomena that is known as inrush. So whenever you switch on the transformer, depending upon at what voltage instant point of waves, it is known as point of wave switching.

You switch on the transformer and normally when we switch on the transformer, secondary side of the transformer is open-circuited or lightly loaded. So, whenever you switch on the transformer, transformer is going to carry a very high level of fault, high level of current compared to it is rated current. But this is not a fault, inrush is not fault. So, your protective device should be capable to discriminate between fault that occurs inside the winding of transformer and the inrush phenomena that occurs in the transformer. And for, inrush phenomena is more severe in case of power transformer than the low capacity of the transformer. So, this is all about the discrimination.

The next criteria or requirement of protective system that is known as the stability. So, what is stability? So, stability means a protective system should be able to distinguish between fault and loading condition when the minimum fault current is less than the maximum full load current. Now, what do we mean by this?

So, this means that your system should remain stable in case of any abnormal condition occurs for example, in if we consider the transmission line, then faults are always, they are always occur in the transmission line overhead conductors, but whenever some other type of phenomena occurs like power swing, then your system should be able to discriminate between the fault and the power swing phenomena. So, your system should remain stable in case of power swing or some other conditions which looks like a fault, but which is not actually a fault.

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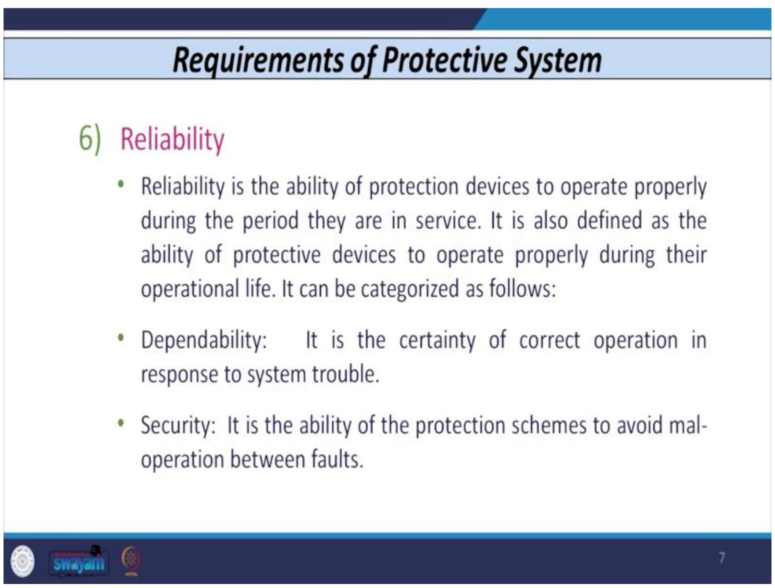

The next type of, next requirement of protective system that is known as reliability. So, what is reliability? So, reliability is nothing but it is the ability of protective device to operate correctly or accurately during the whole lifespan of the device, whatever you have installed.

So, suppose any protective device we installed in the substation, it has certain lifespan say, 10 years, 15 years, 20 years. So, during the whole lifespan whether your protective device, how much, how many times your protective device is capable to operate correctly in case of fault condition. So, this is nothing but the reliability of the protective system. Sometimes reliability of the protective system is also defined as inverse of the probability of failure.

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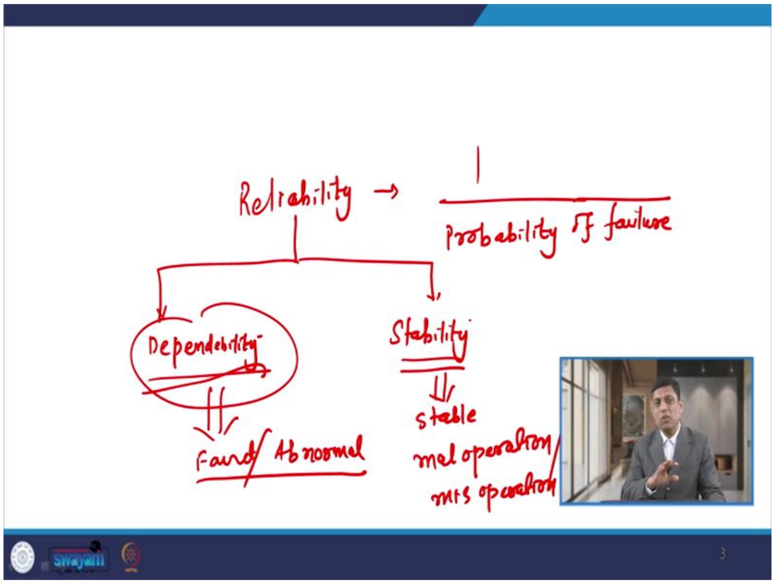

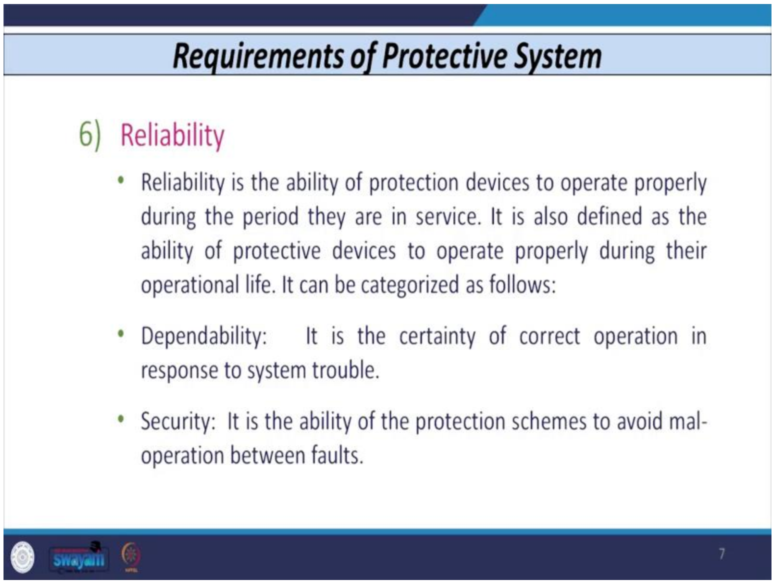

So, if I define what is reliability, then reliability is nothing but the inverse of the probability of failure, probability of failure. So mathematically, we can define this term. Now, when we consider the reliability, basically there are two points we need to consider. One is dependability and another is security. So, when we say that my system is reliable, so, reliability that can be categorized as dependability and the other one that is the stability. So what is dependability?

Dependability means it is the ability of the system that operates correctly for any abnormal condition or if any fault occurs inside the system, your system should be capable to operate for that event. So, that means, dependability is very important and it comes in picture when any fault occurs or any abnormal condition occurs, then your protective device should be capable to operate or respond against this fault or abnormality.

On the other hand, stability means your system or protective device should remain stable for any mal-operation. So, any mal-operation or any misoperation occurs, then in that case or in that condition, your system should remain stable. So, both the things are contradictory and one has to balance between these two conditions. So, that is all about security. The next and last requirement that is the economics of protective system.

Now see, we have discussed the six requirements of the protective system, starting from selectivity, speed, discrimination, reliability, selectivity, and the last one that is economics. So, as a protection engineer what we want? We want maximum number of protective features that is included in the relay and at the same time, we also want its cost should be minimum. So, we want maximum features, protective features in the relay, and with minimum cost. So, this is not possible because both are contradictory. So, we have to always optimize between how much features we want and against that how much cost we want to spend on that protective device.

Usually, when we decide or select the protective device, we have to consider on for what application we are utilizing that protective device. So, if we use the protective device for low voltage applications, then the number of features included in the relay, that is less important and if we consider that we use the protective relay for the device which is located on high voltage system or important to equipment like power transformer, then we need more number of features in that. So, in that case, cost, we have to optimize between the cost and the number of features we want.

So we can compare with this economics as far as when we purchase any new mobile, then we know that the number of features available, more and more features are available as we go with higher version of mobile. But at the same time, we have to pay the more amount. So, we have to optimize what we want, whether we want higher cost or whether we want higher or more number of features in the protective device.

So, with this background, there is also a statistics given. If we consider the cost of the whole system, say, 100 percent. Say, for example, let us, we want that we want to protect a particular power transformer and its cost is let us say, 100 percent. Then what are the cost of different components used to protect that transformer?

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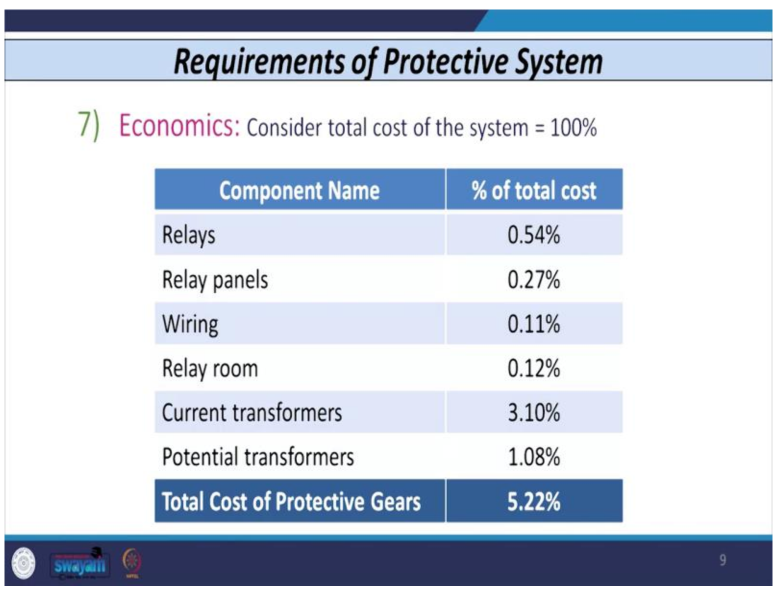

Component Name	% of total cost
Relays	0.54%
Relay panels	0.27%
Wiring	0.11%
Relay room	0.12%
Current transformers	3.10%
Potential transformers	1.08%
Total Cost of Protective Gears	5.22%

So, if I consider relay, then its cost is roughly 0.5 or 0.6 percent of the total cost. If I consider panels, then it cost is 0.2 to 0.3 percent. If I consider wiring and relay room, then its cost is 0.11 to 0.15 percent and if I consider CTs, then it cost is roughly 3 to 4 percent, and for similarly, for PT also its cost is 1 to 2 percent. So, if I summarize or combine all these the total cost of protective gears that comes out to be 5 percent to 7 percent.

So, that means if I want to protect a transformer whose cost is 100 percent, then whatever protective device I put or install on the transformer for the protection of transformer against all types of faults and abnormalities, its cost should not be higher than maximum 10 percent of the total cost of the equipment to be protected. So, these statistics is very important and we need to consider when we use or utilize or when we want to decide any protective device for a particular equipment.

So, with this background, we have consider the all these seven requirements of the protective system. Now one more requirement, which I have not listed here, that is also sometimes comes in picture and that is known as the simplicity. So what do we mean by simplicity?

Simplicity means the, whatever protective device we select or we use for a particular device or equipment, those device or those protective relay that contains the that does not contain any complex system. So that, that means whenever we wish to carry out setting of any protective device, we can easily carry out, the system should not be very complex. So, this is also one of the requirements of the protective system other than the seven requirements, which we have discussed.

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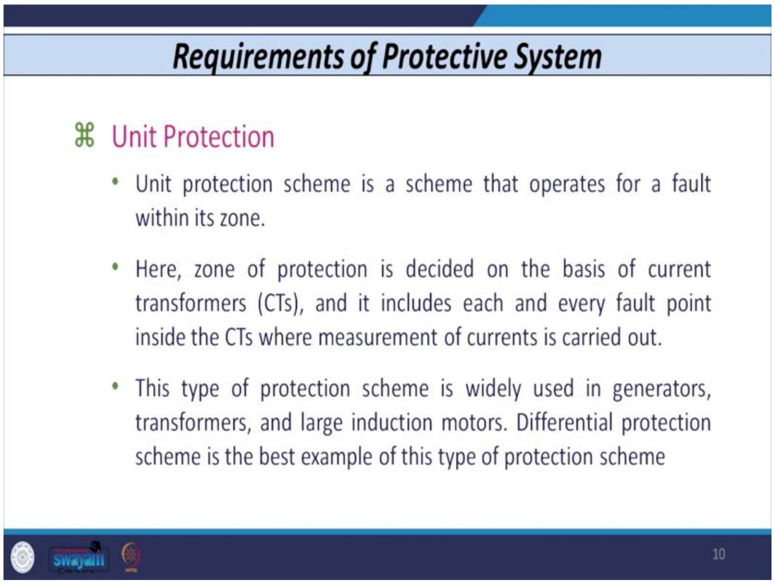

So, we have already discussed the seven requirements of protective system. So, now, the next topic is known as Unit Protection. So, what is unit protection? So, unit protection scheme is a scheme that operates for a fault within its own zone. So here, means that the zone of protection is decided considering at what point or location we place the CT.

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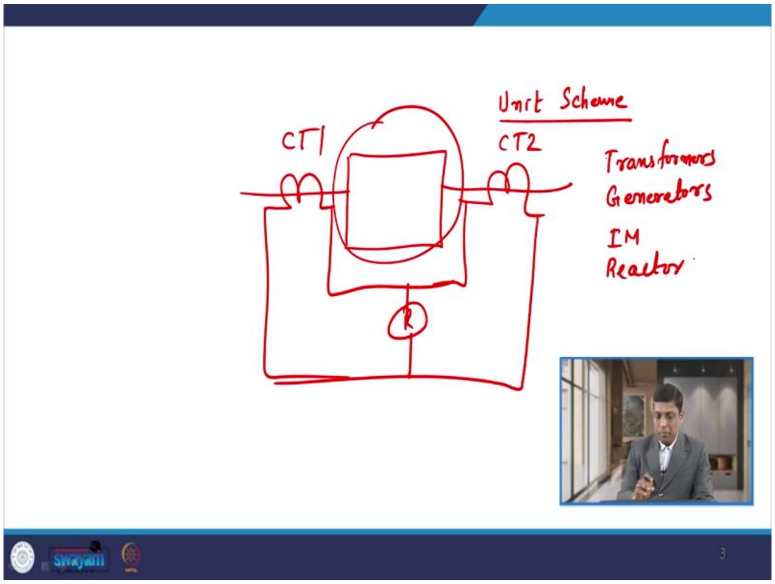

For example, if we place, if we consider any winding of the equipment and if you place the CT on each side of this equipment and if we connect this like this with relay, we put like this, then this scheme is known as unit protection scheme, unit scheme. Why? Because in this case, any fault occurs inside this equipment, winding of the equipment. So, that means any fault occurs on the left-hand side of this CT2 and any fault occurs on right-hand side of the CT1 that is taken care by this protective scheme. So, that is why it is known as unit protection scheme.

Usually this type of schemes that is used for protection of the transformers, it is also used for the protection of generators, it is also used for the protection of induction motors and sometimes reactor also. So, this is known as unit protection scheme. The other type of protection scheme that is known as Non-unit Protection scheme.

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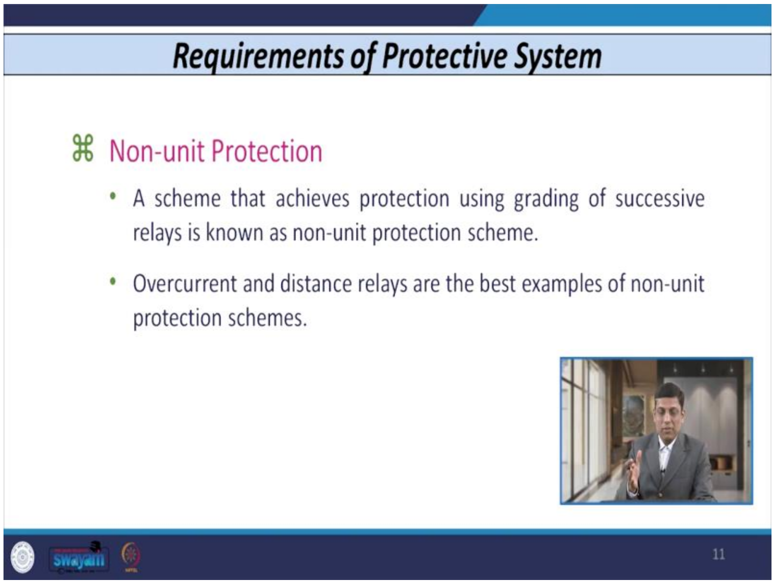

So, in this type of scheme the protection that is achieved by grading of different relays located at different bus.

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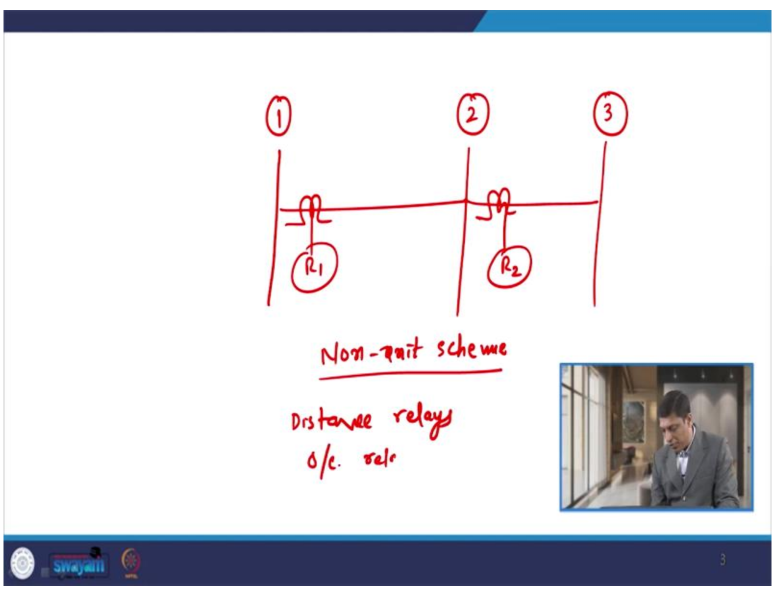

So, if say, for example, relay is located at bus number 1, let us say and then there is a transmission line connected to bus number 2, and then we have another line connected with bus number 2 and bus number 3. Then if we want to achieve a non-unit protection for relay, different relays located in line 1 connected between 1 and 2, and line 2 connected between bus 2 and 3, then this can be achieved by proper coordination or grading of this two relay, R1, and R2.

So, this is known as non-unit type of protection scheme. So, this is known as non-unit scheme and this type of scheme that is widely used for the protection of let us say, distance relays and the other one that is known as the overcurrent relays.

After this background, the next topic that is primary and backup protection. So, we know that normally, whenever we use any protective device, that protective device, if fault occurs in that zone, then that protective device operates instantaneously or according to the characteristic of the relay. If that device fails to operate, then we need some other device which will provide sufficient backup to that relay. So, to understand this, let us consider one simple example.

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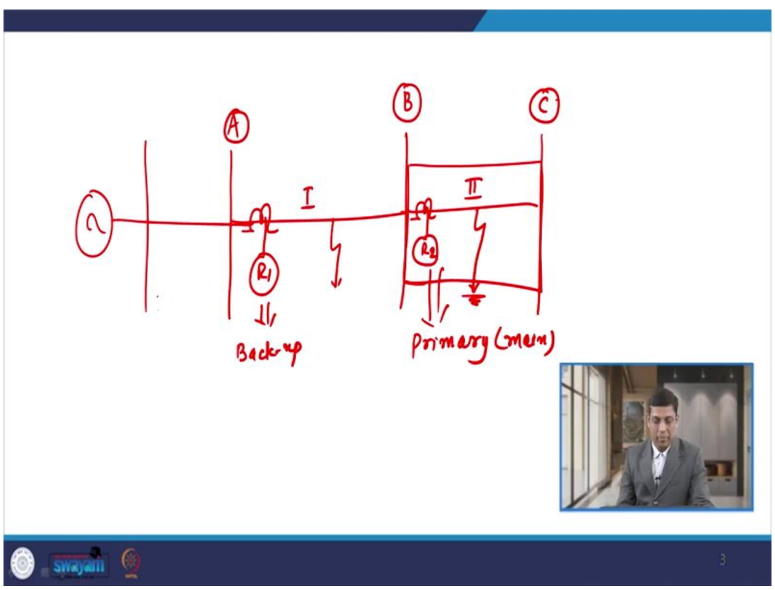

Say, we have a bus A and bus B, and in between that we have a line connected. Let us also consider the another line connected between bus B and bus C. So, line 1 that is connected between A and B, and line 2 that is connected between bus B and C. So now, if any fault occurs in line 2, obviously, the zone of protection for this line, whatever relay we use to protect line 2, let us say, we use relay R2 to protect any faults in line section 2.

So, the zone of protection of this relay R2 is like this. So, any fault occurs in this zone, relay R2 operates primarily.

By means, because of some reason, because of failure of relay or maybe some other reason, if relay R2 fails to protect for a fault at this point, then we need some other relay or device which will provide backup to this relay. So we need some another relay here, let us say, R1, in line section 1, which operates only when there is a failure of relay R2 for a fault in lines section 2.

So, this type of scheme that is known as the primary and backup scheme. So relay R2 act as a primary relay or main relay for any fault inside the line section 2, whereas relay R2 that will act as a backup relay for any fault inside the line section 2. Of course, if any fault occurs in line section 1, R1 also acts as a primary relay and the other relay located towards the source on this side somewhere here further that will act as a backup relay. Now, this primary and backup protection of any protective device or any equipment that can be achieved by different ways.

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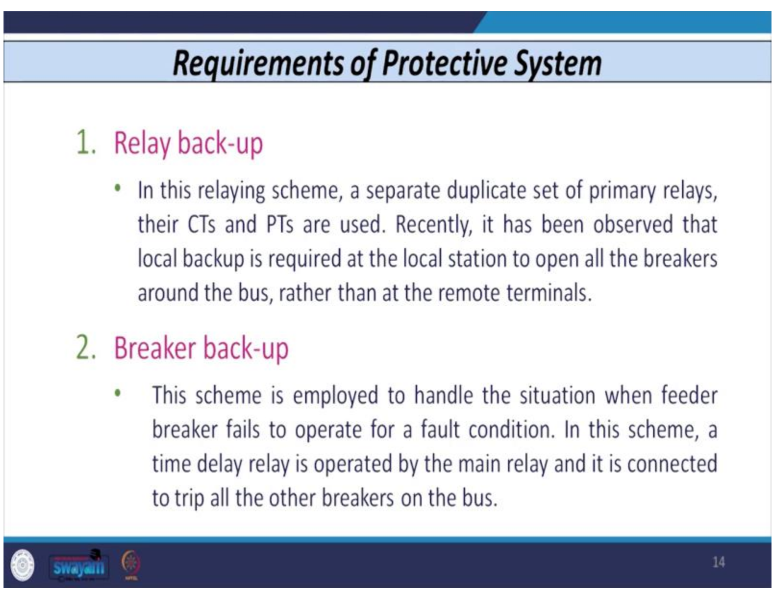

So different ways that can be taken care that is, there are three types, one is known as relay backup, another is known as breaker backup and the third one is known as remote backup. So these three are the types by which we can achieve primary, which we, using which we can define the primary defense and secondary line of defense. So, let us start with relay backup.

So in relay backup, the separate or duplicate primary relays, CTs, PTs, all are there. So, if any one relay fails, then the other relay will provide backup. However, this type of scheme is not used in actual practice because we need to require all the relays, CTs, PTs doubled than the actual requirement, which increases the cost.

The second type of backup that is known as breaker backup. In breaker backup scheme, whenever a fault occurs on a feeder, on which the breaker is installed and if that feeder breaker fails to operate, then that fault virtually becomes the bus bar fault. So in this case, a time delay relay is operated by the main relay due to which all the breakers emanating from the bus bar that is installed on all the feeders, those are going to trip if the main breaker fails to operate in this situation.

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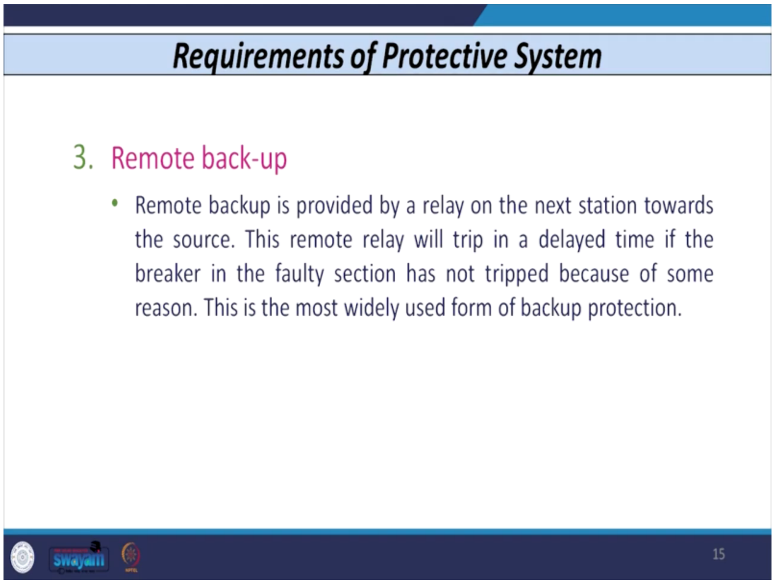

So, third type of scheme that is known as remote backup scheme. So in this scheme, the backup is achieved by the bus located towards source end. So any relay located near the load end, if that relay fails to operate for fault in its own job, then the other relay which is located towards the next bus, towards the source, that relay will act as a backup and that will be taken care, fault will be taken care by that relay. So, this is all about the primary and the backup scheme of the protective system. So, with this background, we will consider the other topics in the next class. Thank you.