Power System Protection and Switchgear
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Lecture 31
Protection of Busbars

Okay. So, let us discuss the next chapter that is known as the Protection of Busbars. So, we know that the busbar is a main junction point of electrical network where many transmission lines or sometimes distribution lines are also connected together. So, it is the area of the power system network where the magnitude of fault current is very high. Why? Because all the transmission lines are connected at one point that is at busbar. Similarly, all the distribution lines are also connected at busbar. So, if any fault occur, then the magnitude of current that would be very high.

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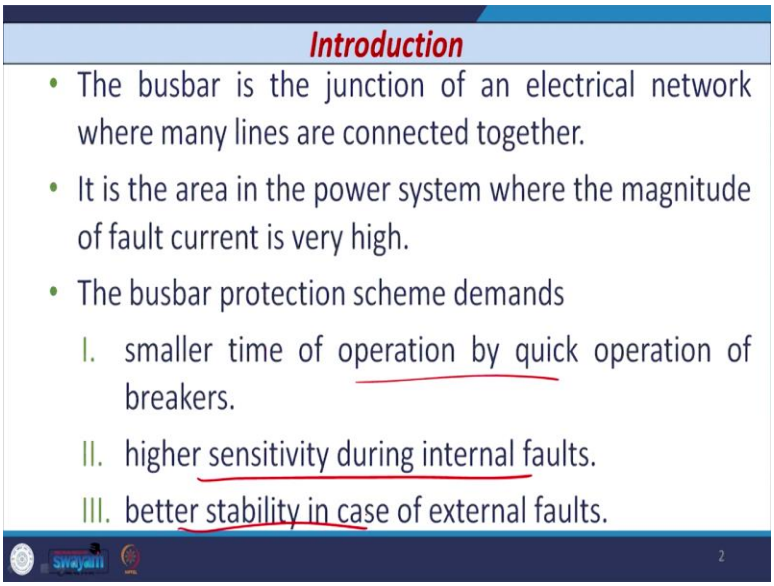

So the busbar protection scheme demands the first smaller time of operation by quick operation of circuit breakers. So, whenever bus fault occurs, we have to detect that fault. And not only that, we have to isolate the breakers in this condition with minimum time period. Higher sensitivity during internal fault. So, whenever any internal fault occur that means, whenever any fault occurs on the bus, maybe phase to phase or phase to earth or some other type of bus faults, then we need to detect that fault without any problem. And this third that is the better stability in case of external fault. So, if any fault occurs on the

line instead of bus, then busbar rely should not operate in that condition. So, this is the third requirement.

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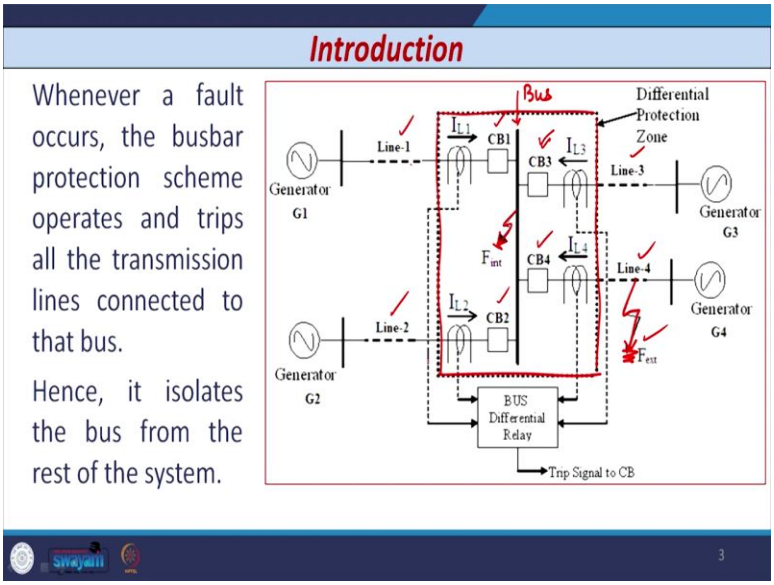

Now, whenever fault occurs on the busbar, the busbar protection scheme operates. So if let us say this is your busbar or bus. It is a single line diagram. However, there are three RYB for each phase, one bus is there. So, whenever any fault occurs on this bus, which is the interval fault on the busbar, then the busbar protection scheme detects this fault and operates in this situation.

And whenever this scheme, that is busbar protection scheme operates, you can see, I have also shown the zone of the busbar. So this is the zone of the busbar protection scheme you can see with dotted line. So, whenever bus fault occurs and whenever the busbar protection scheme operates then it is going to trip all the breakers associated with the lines connected at the busbar.

So, you can see that here there are two incoming lines that is Line-1 and Line-2 and for that circuit breaker one and circuit breaker two are there. Similarly, two outgoing lines are there that is the Line-3 and Line-4 for which circuit breaker three and circuit breaker fours are connected. So, whenever bus fault occurs, internal fault on the busbar occurs, all

the four circuit breakers from one to four that is going to be tripped by the busbar protection scheme.

So, it isolates the bus from rest of the system. So, it is very important to detect whether the fault is an internal fault on the bus or it is an external fault on the bus. Because if any external fault occurs on the line, let us say somewhere here, then it is outside the busbar protection zone, so busbar protection relay should not operate in this case. Otherwise, you are unnecessary disconnecting the other three lines that is Line-3, Line-1 and Line-2 on which there is no fault.

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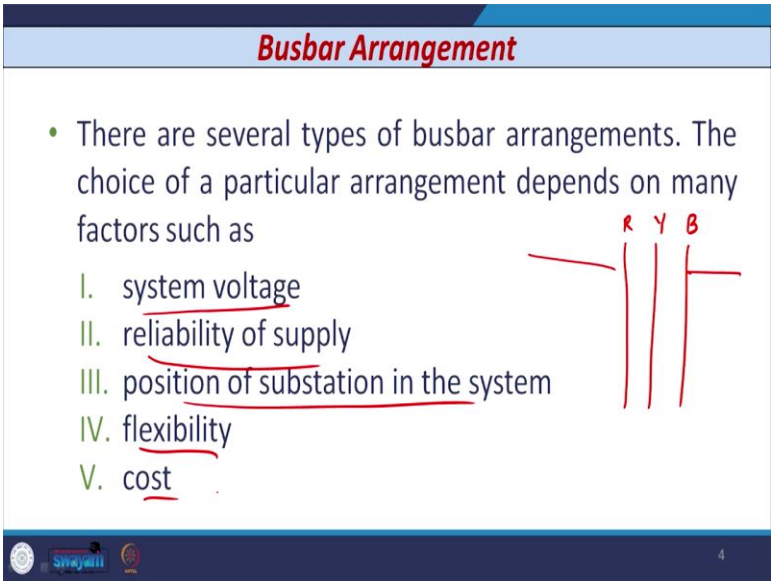

There are several busbar arrangements available, right. So, when I consider the three bus like this for each phase, then along with this bus in the substation different busbar arrangement schemes are available. So, this type of busbar arrangement schemes that depends on various factors. So, these factors are, what is the system voltage at what voltage level, whether it is 132kV, 220kV or 400kV. The second that is the reliability of supply, whether you want how much reliability of supply you required when you operate any of the incoming lines or when you connect any of the outgoing lines or anything happens on the line, then whether you want how much reliability.

The second is the position of substation in the system, whether your substation is very important in the particular network, then that is also going to decide the busbar arrangement. Flexibility and cost. As you increase the cost, flexibility increases. As you reduce the cost, flexibility also reduces. Flexibility means in terms of power. If any line fails connected to the busbar, whether you have any other arrangement through which you can supply the power to that line, so that is known as flexibility.

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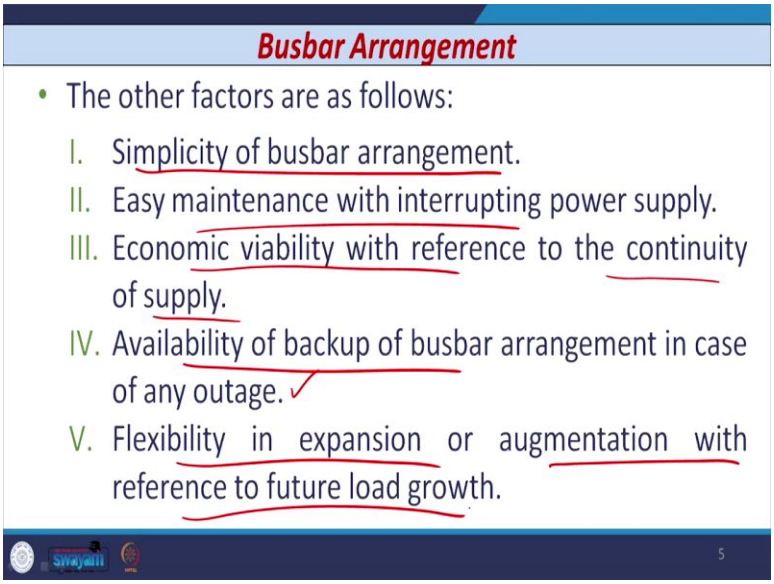

Now, the factors which are going to affect the busbar arrangement that is the simplicity of the busbar arrangement, whether you want simple busbar arrangement or complex. Easy maintenance with interrupting power supply, so whether you need easy maintenance whenever any line connected to the busbar trips, then what type of maintenance you required. Economic viability with reference to continuity of supply, so whether you want continuity of supply continuously or maybe if continuity of supply is not maintained for this much time period, then it is okay, fine.

The next is the availability of backup of busbar arrangement in case of any outage. So if any line trips or any outage occurs, if any line corrected with the busbar, if any fault occurs on that line and that line is disconnected, whether you have any alternative arrangement to fed the power that is also going to play an important role. And the last that is flexibility in expansion or augmentation with reference to future load growth, so

whether whatever busbar arrangement we use that is flexible in nature, so that in future after five years or 10 years, if load growth increases, then whether you can accommodate that load growth within the utilizing the same busbar arrangement or not. So that is also going to play an important role.

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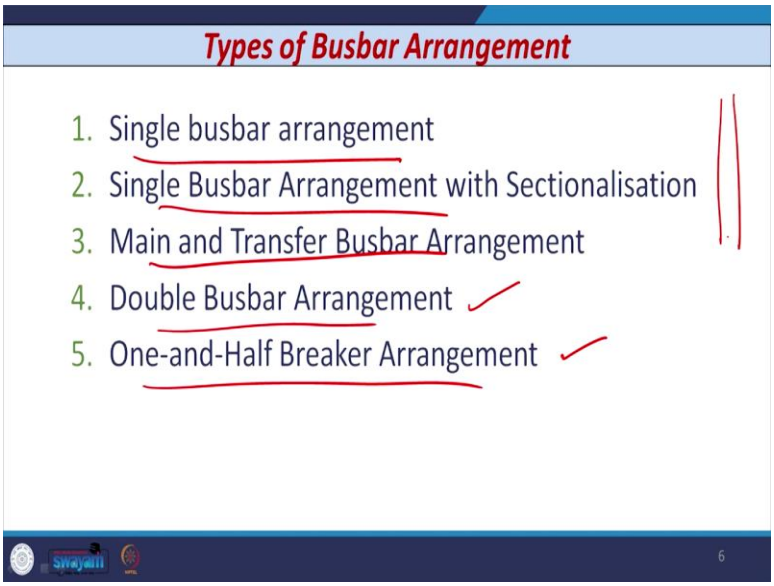

So, the different types of busbar arrangement available that is the single busbar arrangement; second that is the single busbar arrangement with sectionalisation; the third that is main and transfer busbar arrangement; the fourth that is the double busbar arrangement; and the fifth that is one-and-half breaker arrangement. Normally at high voltage substations EHV and UHV level, either double bus or one-and-half breaker arrangements are used, whereas the other three types, above three types of arrangement that is used at distribution or medium voltage level.

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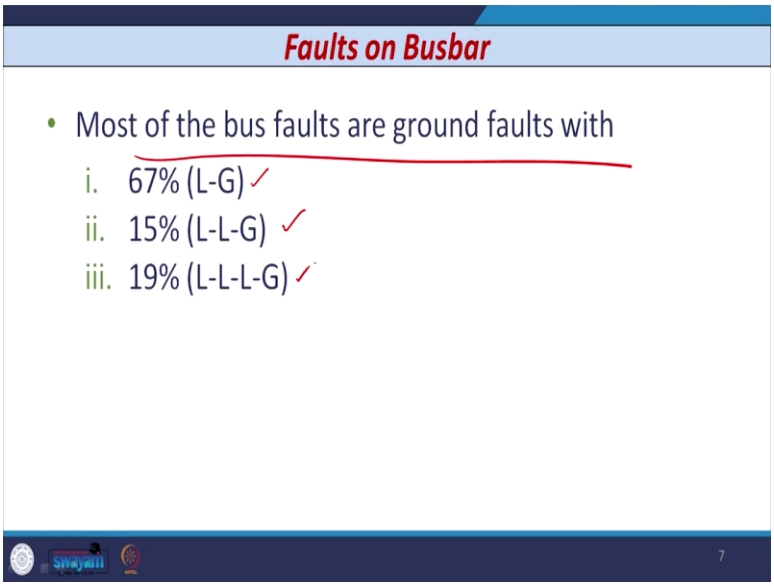

Now, let us discuss what are the faults that are possible on the busbar. So, most of the bus faults are ground faults. This is already details are given in the survey. So, if you just look out that then 67% faults are line-to-ground faults, 15% faults are double-line-to-ground faults and 19% faults are triple-line-to-ground faults.

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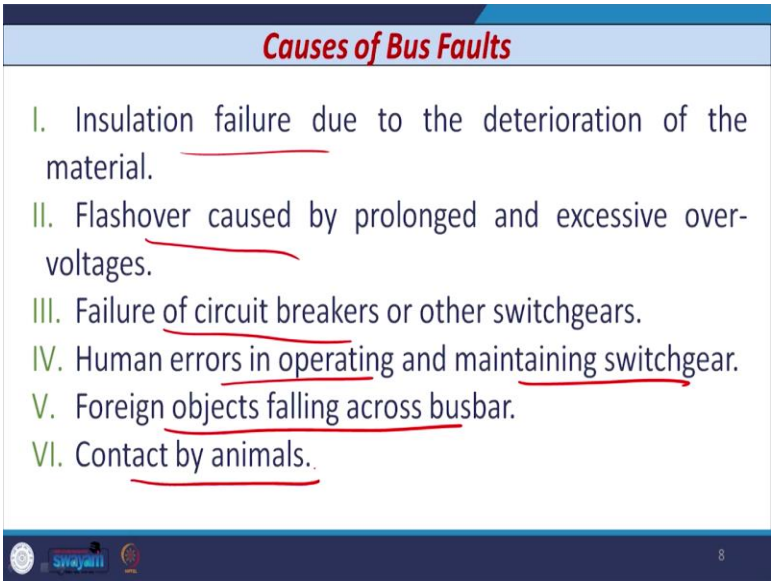

Now, let us discuss how, because of what reason faults that occur on the busbar. So, the first reason that is the insulation failure due to deterioration of the material. So, if any

insulation fails, but fault occurs. The second that is flashover caused by prolonged or excessive over-voltages. So, because of over-voltages if any flashover occurs, then that is also going to damage the insulation and hence the faults occur. The third that is failure of breakers or any other switchgears, because of that also there is a possibility of bus fault.

The human errors in operating and maintaining the switchgear, so when you operate the particular busbar arrangement and if any human error is there, then also there is a fair possibility of bus fault. Foreign objects falling on the bus, then also bus fault occurs. Or if any contact maybe by animals, then also this type of fault occur.

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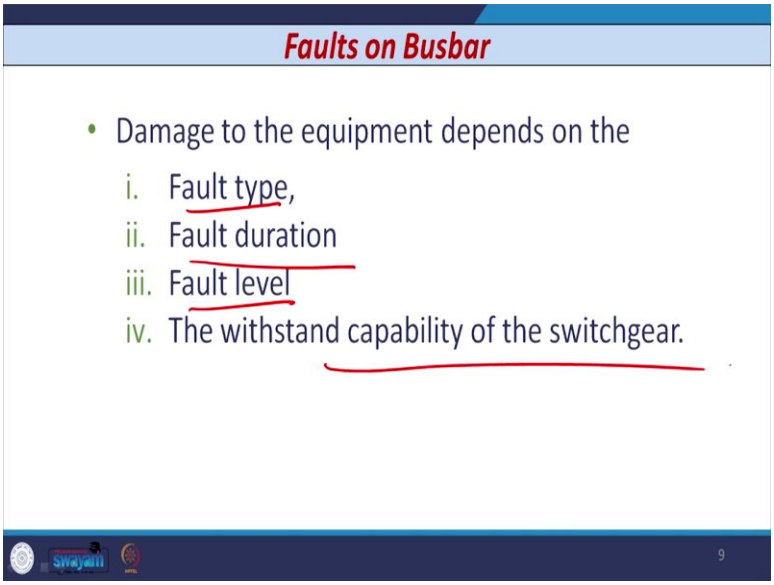

Now faults on busbar whenever occur, then whether how much damage that is going to create that depends on default type, what type of fault occurred -- was fault occurs, how -- for how much duration that fault occurs, what is the fault level of that bus fault and what is the withstand capability of the switchgear that is circuit breakers.

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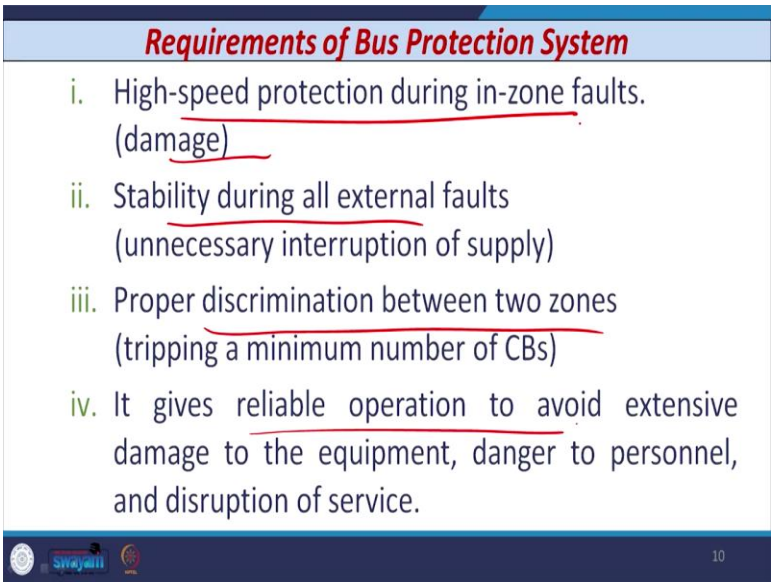

So, let us see what are the requirements of busbar protective scheme. So, the main requirement is the high-speed relaying in case of internal fault. So, if any busbar fault occur on the bus, then the relaying scheme should operate within a cycle. So, minimum damage that is going to occur. Stability during all types of external faults. So, if any faults occur on the line connected with the bus, then there is no unnecessary interruption of power because of the tripping of all the breakers.

Proper discrimination between two zones, tripping of the minimum number of circuit breakers. And it gives a reliable operation to avoid extensive damage to the equipment, danger to the personnel and disruption of service. So, these three are also very important.

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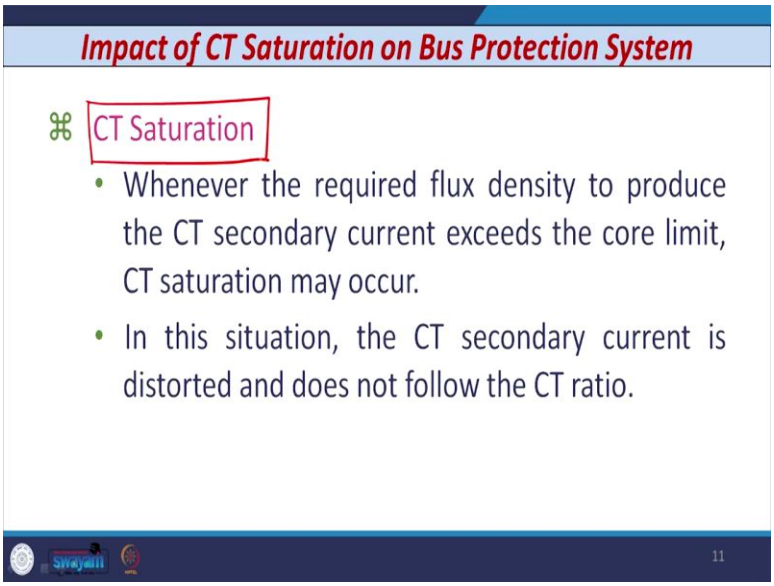

Now, before we proceed, what are the different types of protective schemes used in the buspar arrangement, let us discuss, first, the CT saturation phenomenon, because CT saturation phenomenon is very important as far as the busbar protection scheme is concerned. So, let us discuss the first what is CT saturation phenomena. So, whenever the required flux density D that is produced in the CT secondary current exceeds the core limit of the CT, then the CT saturation may occur. So, in this situation, whenever CT saturates, the CT secondary current that is going to be distorted and it is not going to follow the CT ratio. So, the -- when the CT is working in linear region whenever CT saturates, it enters non-linear region.

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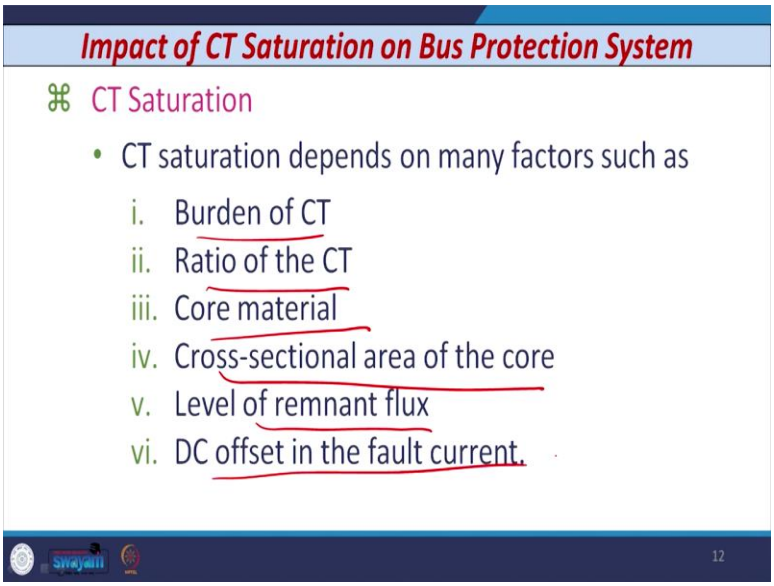

So, CT saturation depends on many factors and these factors are what is the burden of the CT, what is the ratio of the CT, what is the core material used in the CT, what is the cross-sectional area of the core, what is the level of remnant flux in the CT, and what is the DC offset in the fault current that is also going to affect the, whether CT saturates or not.

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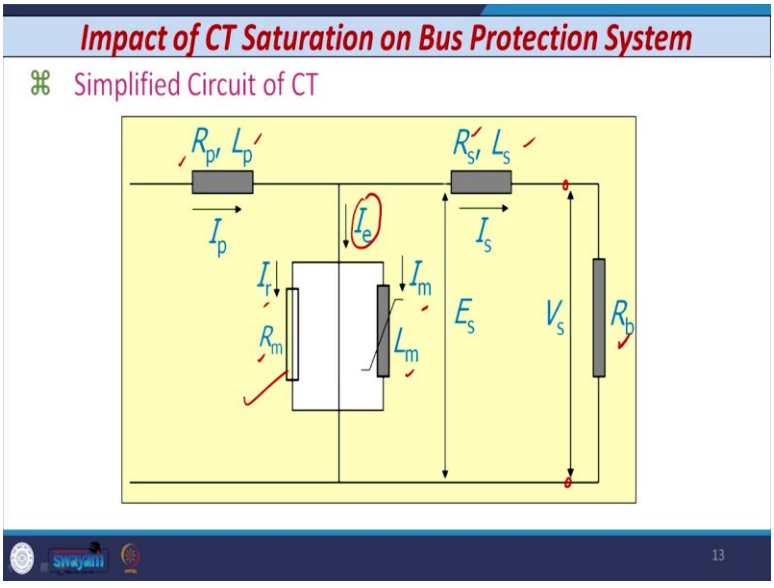

So, to understand the saturation phenomena in CT, let us consider the equivalent or simplified circuit of CT. So, you can see that this circuit looks like the equivalent circuit of the transformer. So, you have the one component that is here this component, where you have the exciting current Ie which has the two component magnetizing component Im and the other component that is the active component Ir. You have the Rm and Lm also. You have the other two resistance or impedances that is the Rp primary side and Lp primary side and Ra and Ls on secondary side. You have the load or burden impedance also. And across this you measure the voltage. So this is the Vs is the terminal voltage of the CT and Es that is the EMF used in the.

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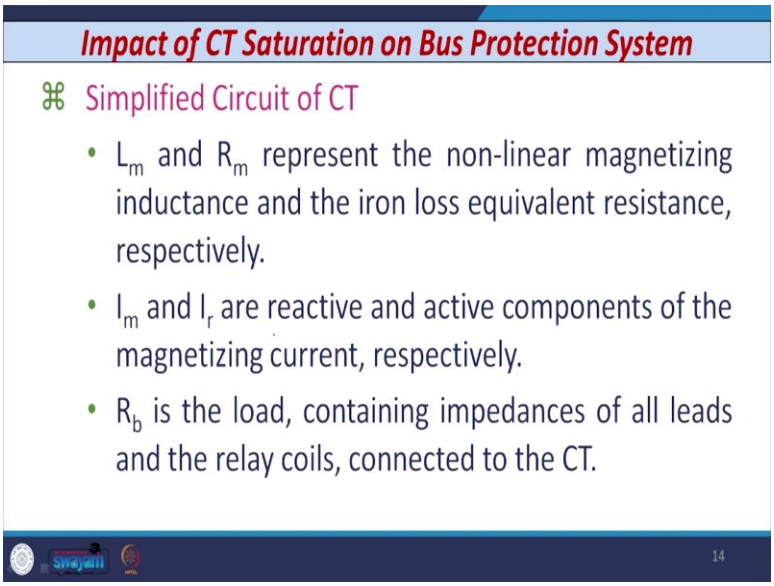

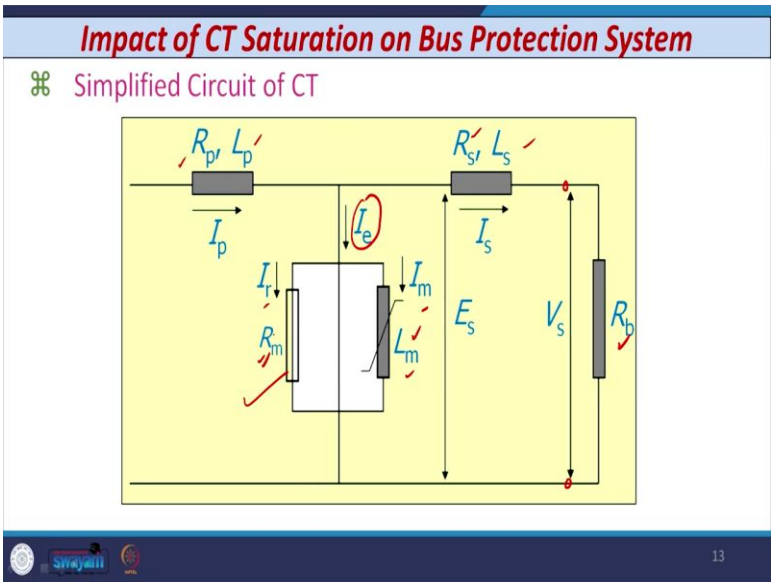

So, you can -- if I want to define then Lm and Rm that represents the non-linear magnetizing inductance and the iron loss equivalent resistance. So, these two Lm and Rm that is the non-linear magnetizing inductance and iron loss equivalent resistance. The current that flows through the Lm that is Im and the Ir that is through Rm that is the reactive and active component of the magnetizing current that is a total exciting current that is Ie. Rb is the load. Now, burden resistance, so burden resistance that is a combination of all the lead impedance, because see whenever you connect CT secondary, busbar is located somewhere in the switchyard. So, there from there you have to run the

wires and you have to connect it to the CT secondary. So, whatever you have connected lead resistance along with that the coil of the relay that is also connected across the CT secondary. So, its resistance or impedance that also comes in picture.

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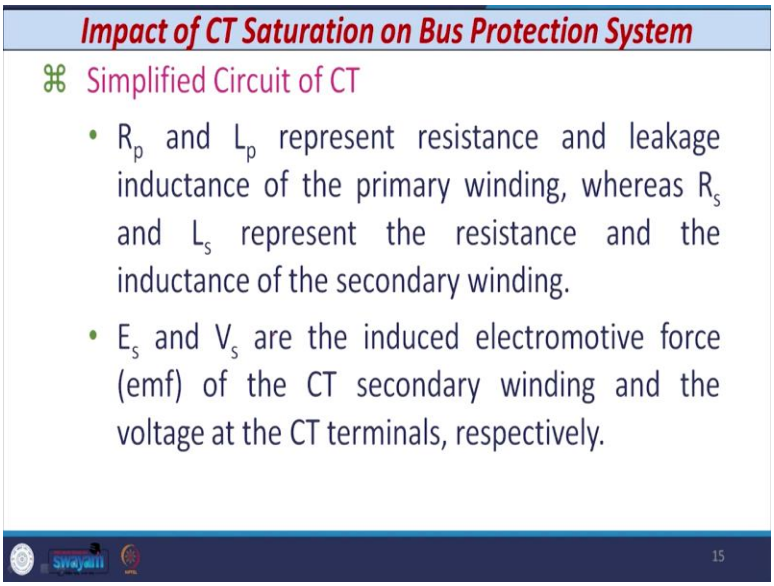

You have the Rp and Lp that is the resistance and leakage inductance of the primary winding, whereas Rs and Ls is represent the resistance and inductance of the secondary winding. Es and Vs are the induced electromagnetic force on the CT secondary and the terminal voltage of the CT secondary.

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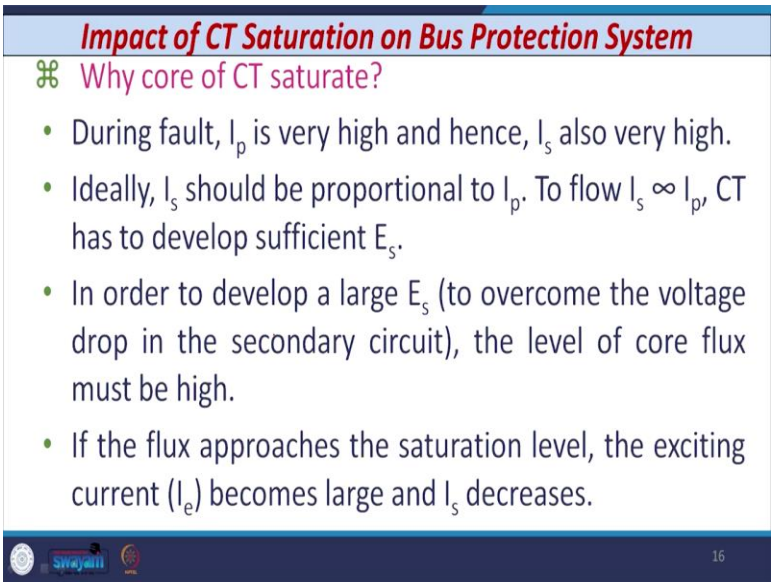

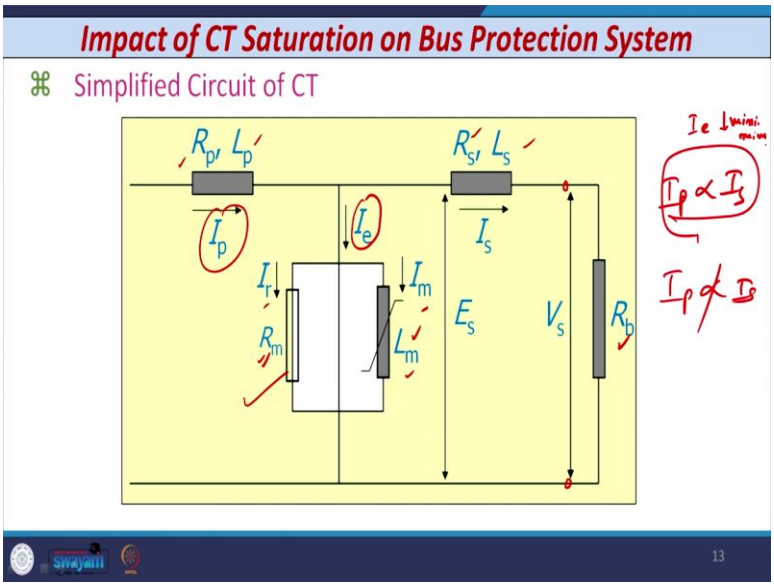

Now, whenever fault occurs, you can see that the primary current that is very high and because of that secondary current is also very high. So, ideally, if I consider, Is should be proportional to primary current Ip. And to flow the secondary current which is proportional to primary current, CT has to develop sufficient Es that is the induced electromagnetic force. In order to develop a large value of Es to overcome the voltage drop on the secondary circuit, the level of core flux must be very high. So, if this flux approaches saturation level, then the exciting current becomes large and Is decreases.

So, if you consider this equivalent circuit, when there is CT is not going to saturate, when CT is working in normal condition, then this Ip that is proportional to Is. So, whatever Es is there produced for that, whatever flux is required or flux density is required in the core of the CT that is within the limit. Whenever CT saturates, then Ip is not proportional to Is. That means, the value of exciting current Ie increases. So, in this case, when the CT is not saturated, Ie is very minimum or very small.

However, when CT saturates enter in the non-linear region, then Ip is not proportional to Is, why, because the value of Ie increases significantly. So, your secondary current Is reduces. And because of that, to produce the same value of Es, the flux density or flux that increases.

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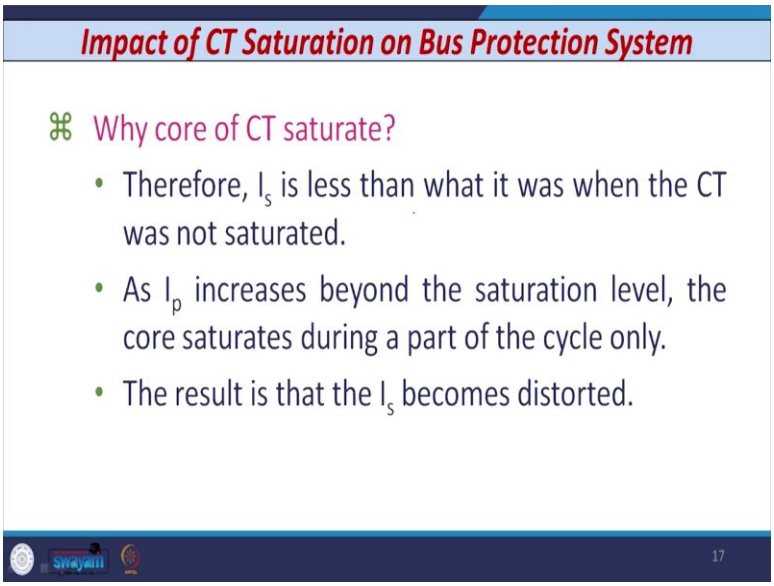

Therefore, as I told you, Is is less than what it was when the CT was not saturated. So, as Ip increases beyond the saturation level, the core saturates during a part of the cycle. So, within one cycle only, and hence, the secondary current that becomes distorted.

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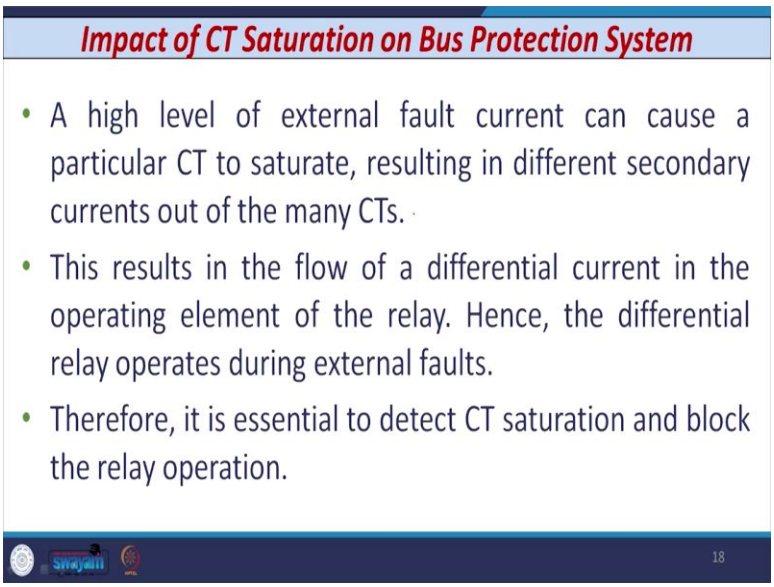

Now, a high level of external fault current that means if any fault occurs near on the line, transmission lines, and that fault current is known as external fault for the bus zone protection or busbar protection. So, that this type of fault can cause a CT to saturate

because of which the secondary current that can be different out of many CTs for other lines. So this results in a flow of differential current in the operating element of the relay, and hence, differential current may maloperate. Therefore, it is essential to detect CT saturation phenomena and block the operation of relay when such type of external fault occurs and when CT saturates.

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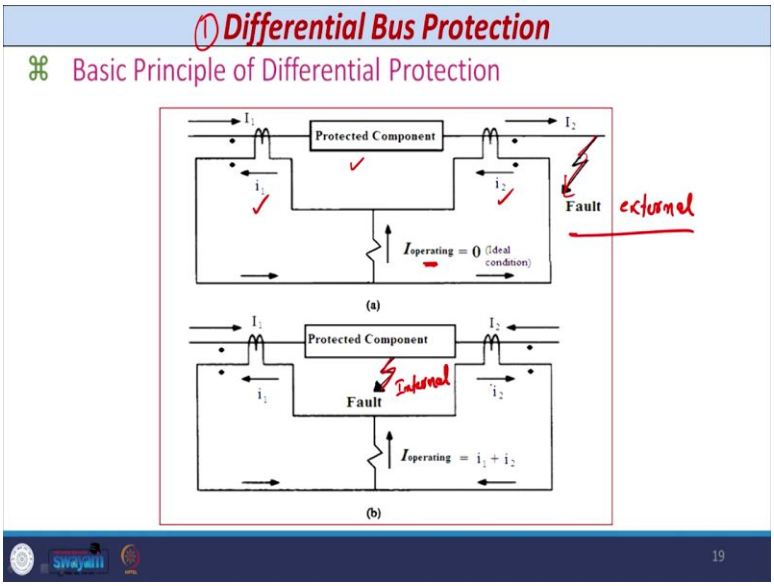

So, with this background of the CT saturation phenomena, let us discuss the different types of protection scheme used in the busbar. So, first type of protection scheme that is known as differential protection scheme. So, the first type of scheme that is known as the current differential protection scheme. So, as I told you earlier in case of transformer and generator, the main operating principle of differential protection scheme that is the current entering and the current leaving to the protected equipment that is to be compared.

So, I1 and I2 and hence the i1 and i2 on CT secondary side these two currents are compared. In case of external fault, somewhere here this is your external fault, in this condition these two currents are ideally zero, practically it is not zero because of reasons. So this current is ideally zero and hence relay is not going to operate. Whereas in case of internal fault, this is the internal fault in the bus or protected equipment, these two

currents I1 and I2 that is addition of that and hence the -- if this value exceeds the pickup of the relay and then relay operates.

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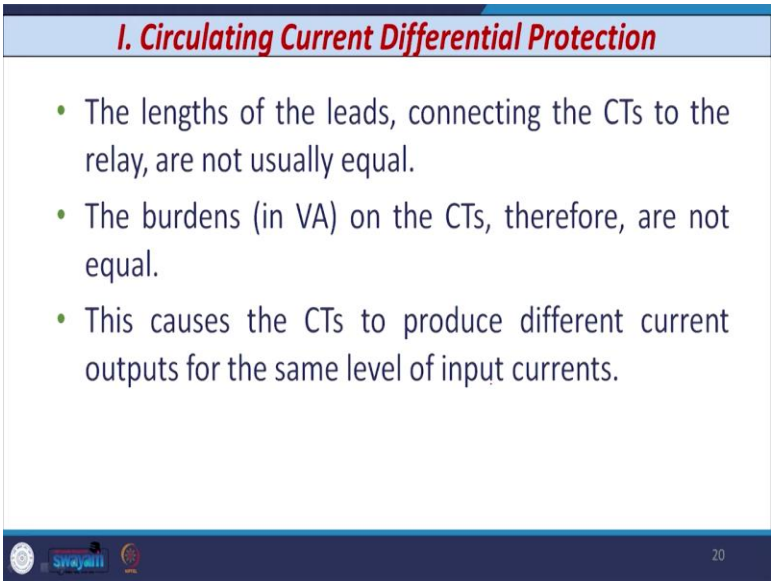

So, let us discuss first type of scheme in differential protection that is circulating current differential protection scheme. This type of scheme we have already discussed in case of generator and transformer protection. This scheme has only one coils that is the operating coils. However, this type of scheme maloperate because of two reasons. Number one, the length of the leads connected to the CTs to the relay that is usually not equal. So, burden of the CTs are unequal and because of that the some type -- some value of current that flows through the operating coil of differential relay, this current is known as spill current.

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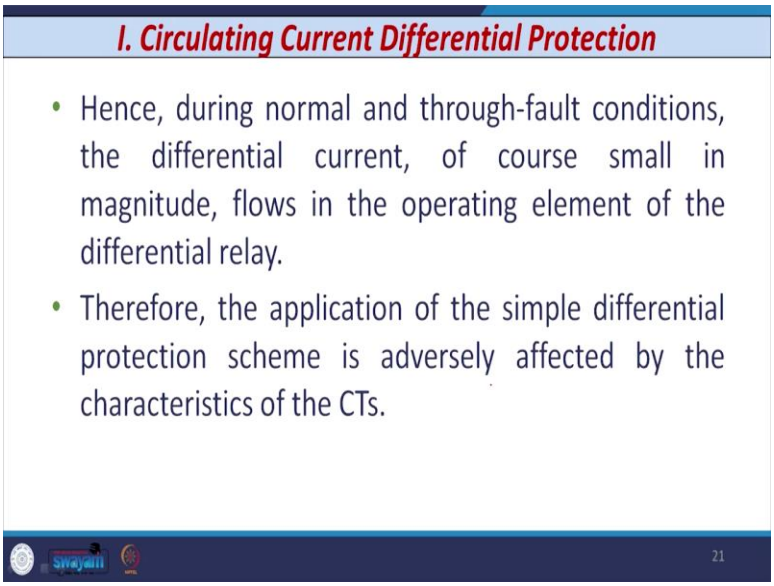

So, during normal condition and in through-fault conditions, the differential current, of course, of very small magnitude that always flows through the operating coil of differential relay and hence the application of simple differential protection scheme that is not actually beneficial when we consider the busbar protection.

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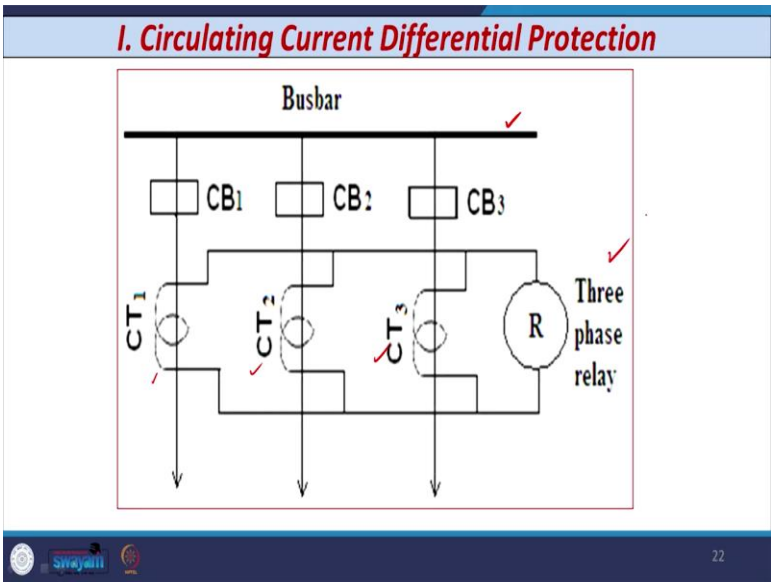

So, you can see here, if I wish to apply the circulating current differential protection scheme for busbar protection, this is your busbar and these three are the outgoing feeders,

you can see that on each feeder I have one CT and then whatever relay I use that is the three phase relay, which has only one operating coil.

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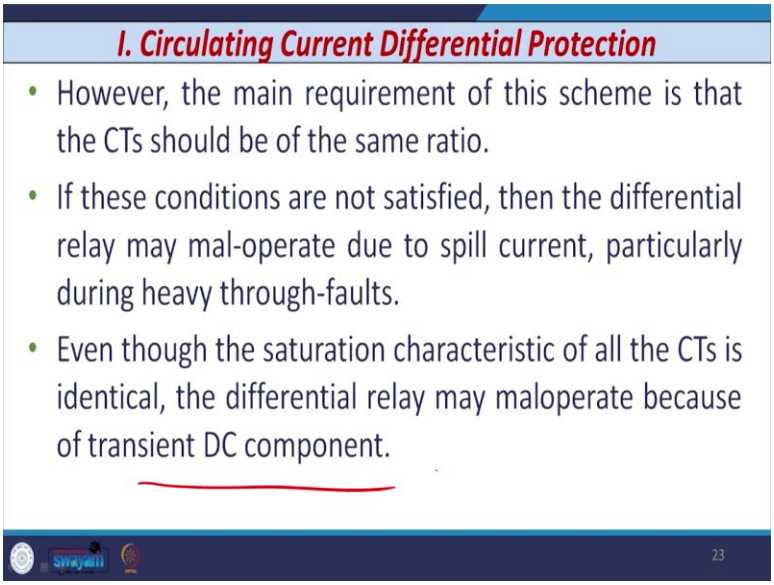

However, the main requirement of this scheme is that CT should have same ratio. If these conditions are not satisfied, then the differential relay mal-operate because of spill current. Even though the saturation characteristic of all CTs are identical, practically it is not possible even though the CTs are manufactured by same manufacturer. Then also differential relay mal-operate because of the transient DC component that present in the fault current.

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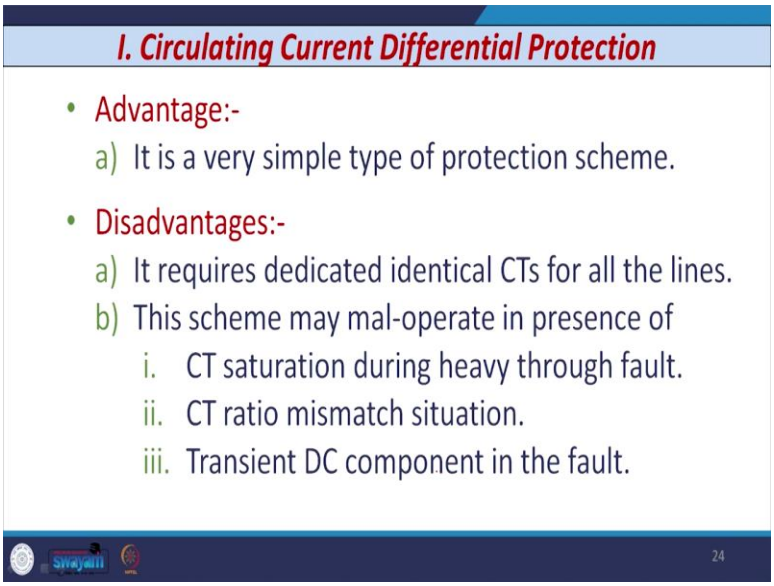

So, advantage of circulating current differential protection scheme is very simple scheme. However, there are many disadvantages. This type of scheme requires dedicated CTs for all the lines connected or emanating from the bus. This type of scheme may mal-operate because of the CT saturation in case of heavy external fault, CT ratio mismatch or if transient component or DC decaying component present in the fault.

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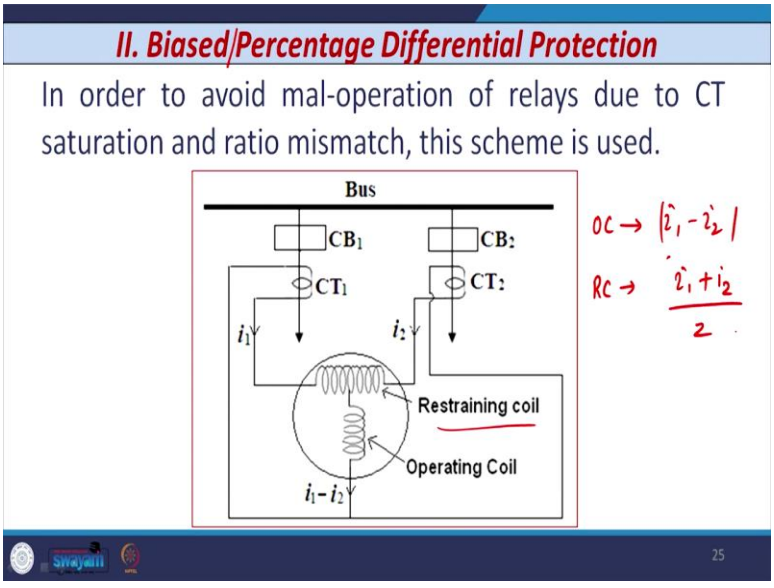

So to avoid this, to rectify this problem, biased or percentage differential protection scheme that is utilized. So, in biased or percentage differential protection scheme instead of operating coil -- along with operating coil, you have the another coil that is known as restraining coil. So, in operating coil, you have the current that is the difference of two i1 minus i2, let us take absolute value, and in restraining coil, the current that is i1 plus i2 by 2. So, average restraining current that flows through this.

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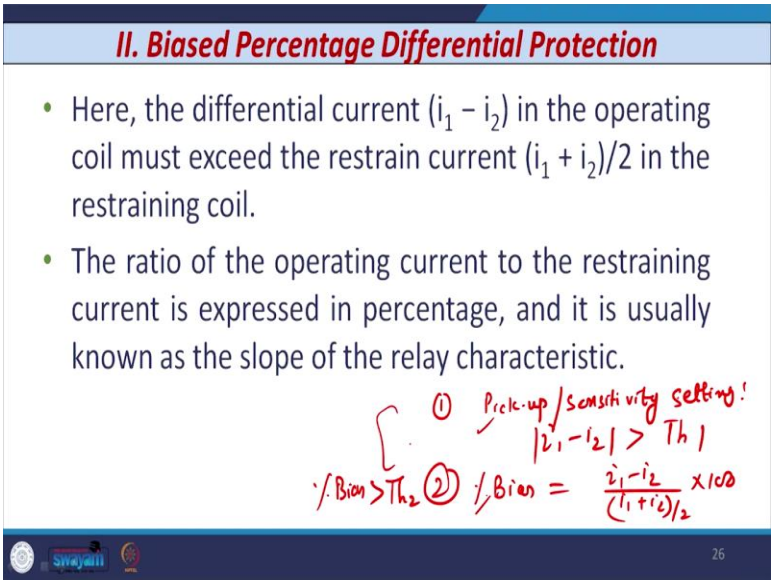

So, there are two types of settings available as I explained in case of generator. The first setting that is the pickup setting or sensitivity setting. So this setting is nothing but the i1 minus i2. If this value exceeds some threshold one, then relay operates. And along with and logic of the percentage bias which is nothing but the i1 minus i2 divided by i1 plus i2 by 2 into 100. So when these two values percentage bias greater than some threshold two, so when these two value exceeds then the relay operates.

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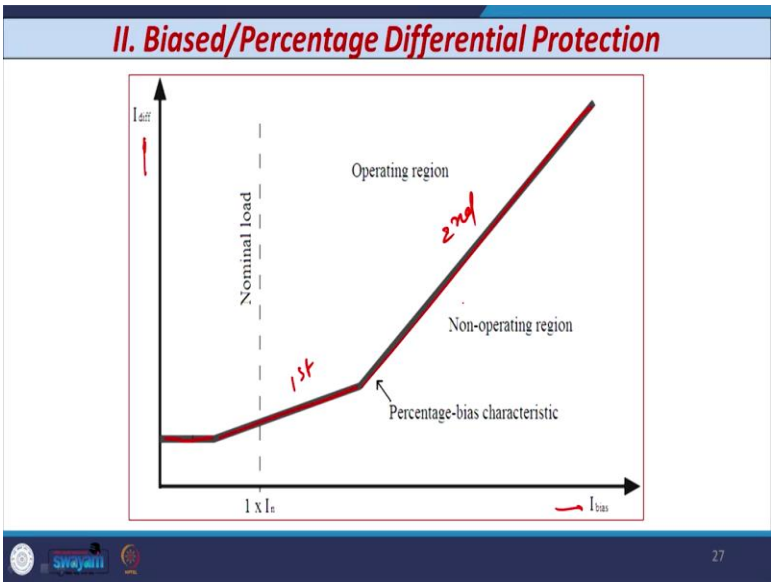

If I consider the characteristic of biased differential relay, then on x axis I have the restraining current i1 plus i2 by 2, on y axis I have the differential current that is i1 minus i2. And if you draw with the two slope characteristic, this is first slope and this is second slope, then you have any point falls on above this line that is the operating region or working region of the relay and if any point falls below this characteristic, then that region is known as the non-operating region or restraining region.

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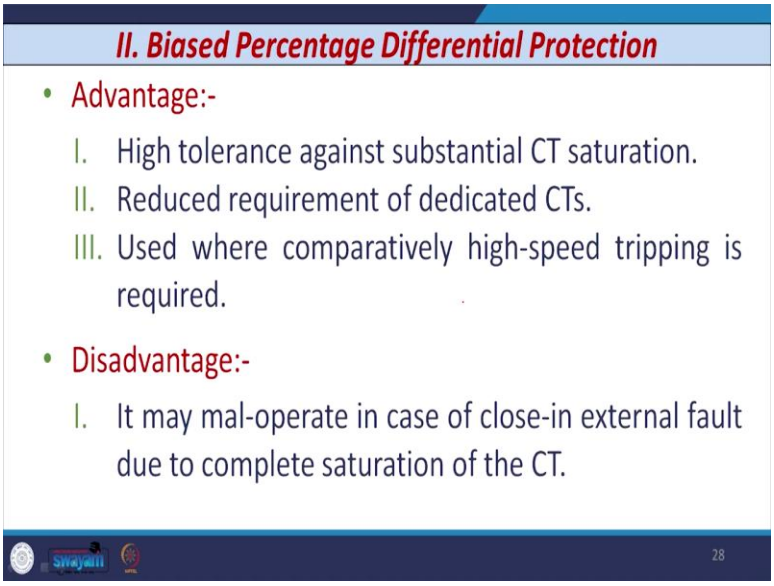

Now, the advantage of biased differential protection scheme is it has a high tolerance limit against the substantial CT saturation. It has a reduced requirement of dedicated CTs and it can be used comparatively for high-speed relaying. However, the main disadvantage of this type of relaying scheme is that it may mal-operate in case of closing external fault due to complete saturation of CT.

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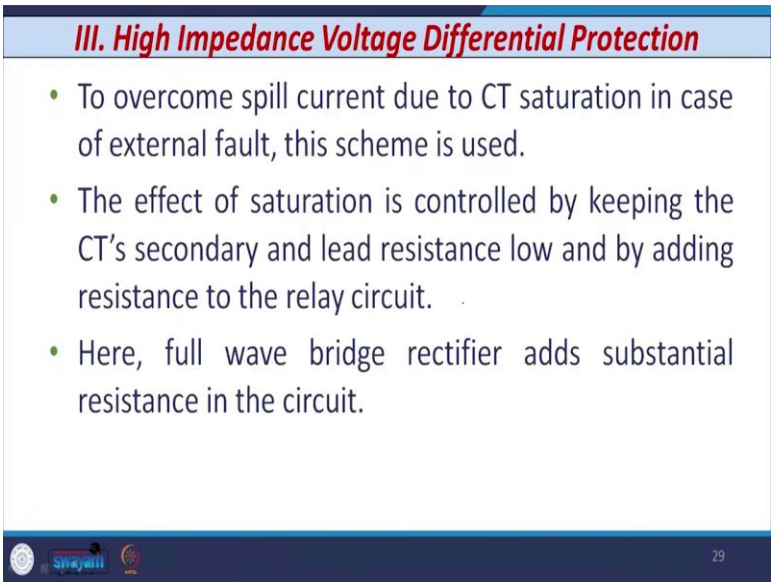

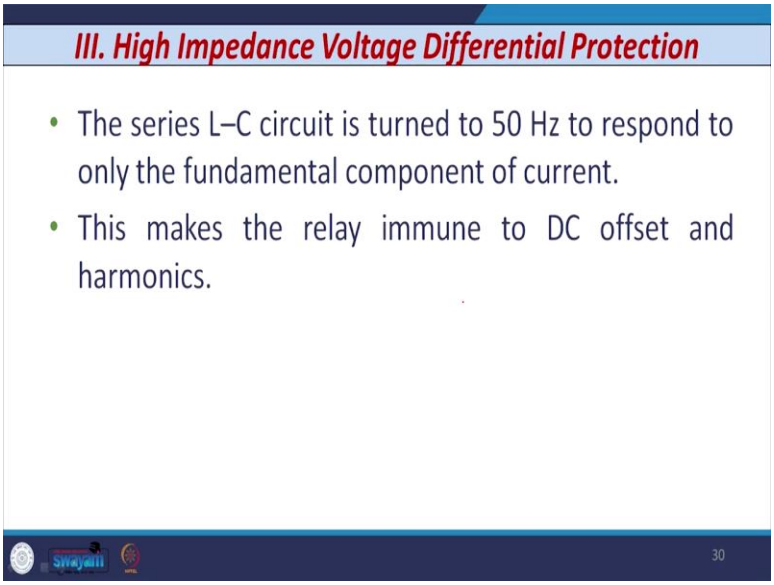

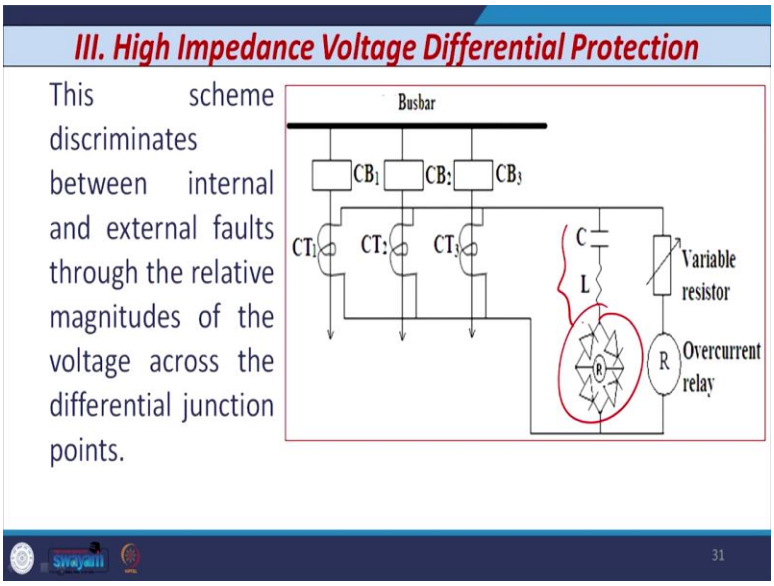

So to overcome this, the next type of scheme that is used as high impedance voltage differential protection scheme. So to overcome the spill current due to CT saturation in case of external fault, this type of scheme is best suitable. The effect of CT saturation is controlled by CT secondary and lead resistance and by adding resistance in the relaying circuit. Here, full wave bridge rectifier circuit adds substantial resistance in the circuit. And if I have that this point and along with this you have the L-C circuit and this L-C circuit is tuned to 50 hertz to respond only to the fundamental frequency component of current. So this type of scheme makes the relay immune to DC offset and harmonics.

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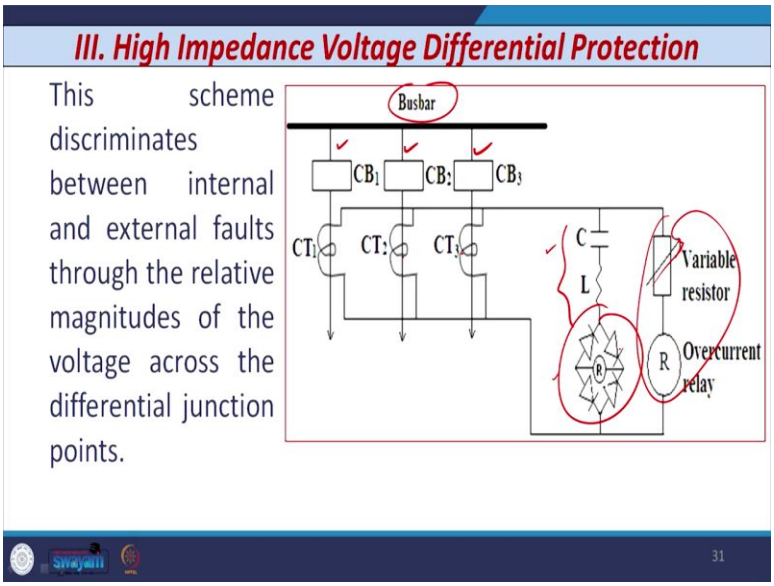

So, you can see it is similar to you have the three outgoing feeders from the busbar and along with this I have put three CTs and these three CTs are instead of connecting directly to the relay, I have connected through some variable resistor and in parallel with this I have connected the L-C circuit with the bridge rectifier circuit. So this type of scheme that is capable to discriminate between internal fault and external fault through the relative magnitudes of voltage across the differential junction point.

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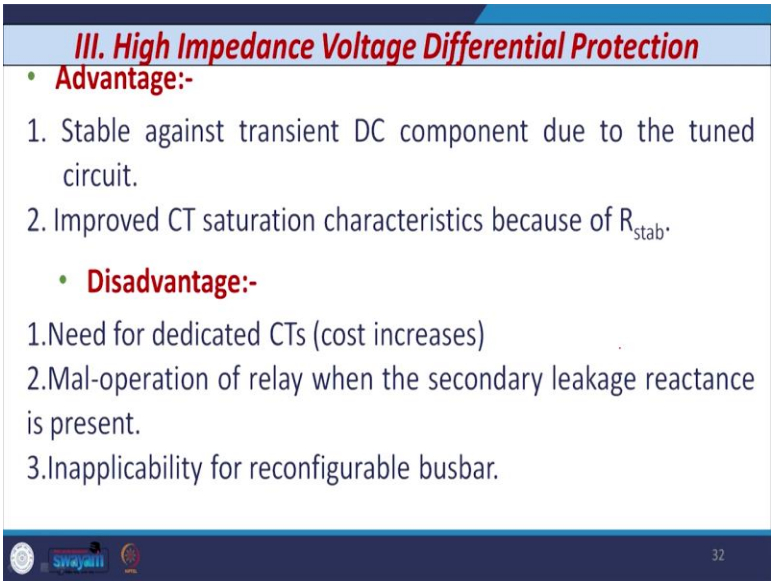

So, if I just take the advantage and this type of scheme that provides stability against the transient DC component that present in the fault and it has improved CT saturation characteristic because of Rstab. However, as I told you, whenever I use the stabilizing resistance in series with the relay coil, sensitivity of the relay reduces. So this is the main disadvantage of this type of scheme. Along with this, this type of scheme requires dedicated CTs, so cost increases and this type of relay also mal-operate when the secondary leakage reactance is present. And this type of scheme is also not applicable when the reconfiguration busbar arrangement is possible. That means, if I want to change the busbar arrangement, then retrofitting of this type of scheme is not possible.

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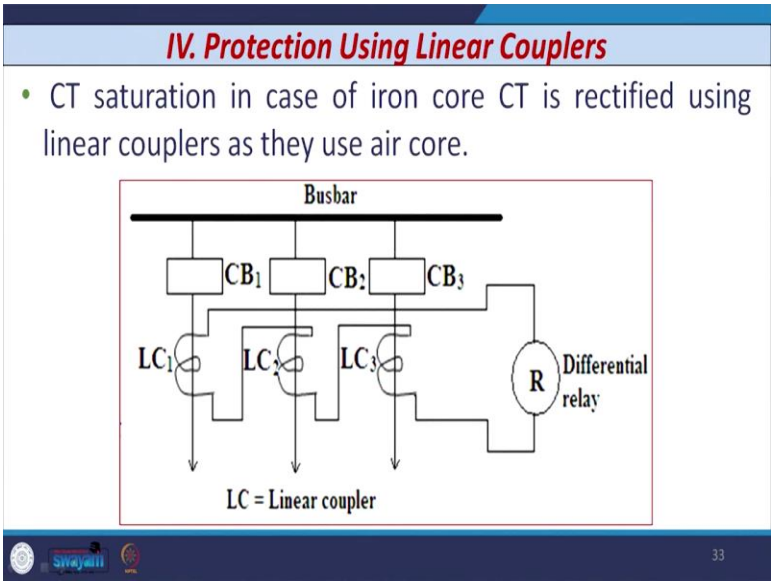

So the fourth type of protection scheme that is known as protection using linear couplers. So in this case, instead of utilizing conventional CT, you are going to use the air core CTs. So CT saturation in iron core CT that is again completely rectified using the linear couplers which is nothing but the iron core cities. So, these CTs are changed.

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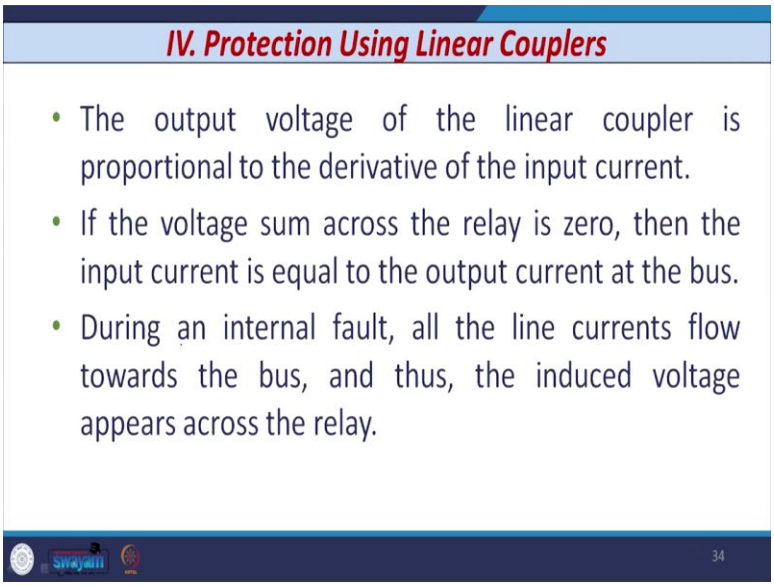

So, output voltage across the linear coupler that is proportional to the derivative of the input current. Summation of this voltage across the relay zero, then the input current that is equal to output current, so no fault on the bus. Whenever in case of internal fault, all the line currents flow towards the bus, so the induced voltage appears across the relay that is significant and if it exceeds some value, then the relay operates.

The linear couplers is a spatial device and it can be effectively used when CT saturation phenomena is very predominant. However, this type of scheme requires additional equipment to realize the benefit of the digital relay, so that increases overall cost of the scheme.

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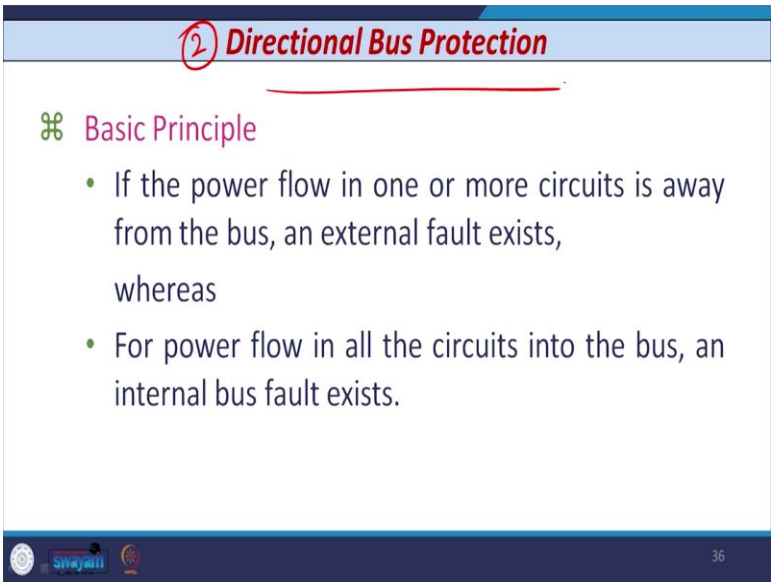

So the next type of scheme applicable to busbar protection that is known as directional bus protection scheme. So the basic principle in case of directional bus protection scheme is if the power flow in one or more circuit is away from the bus, then an external fault exists, whereas if power flow in all the circuit into the bus, towards the bus, then the internal bus fault exists.

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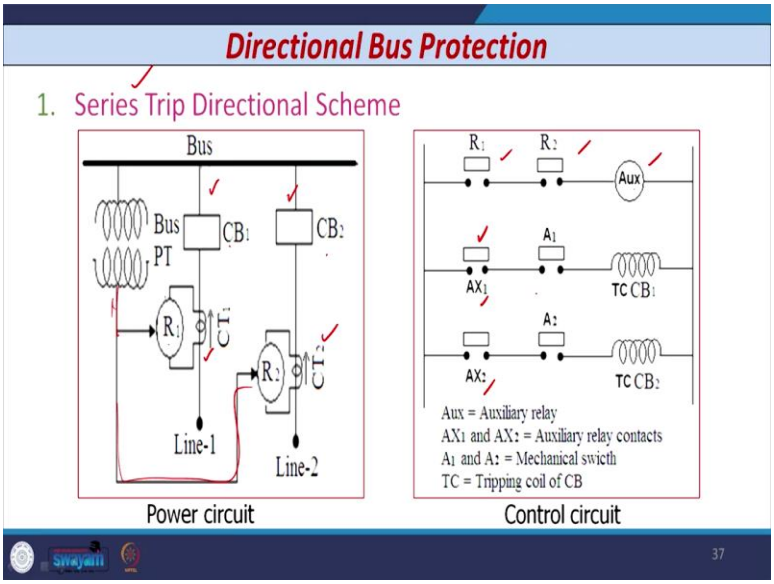

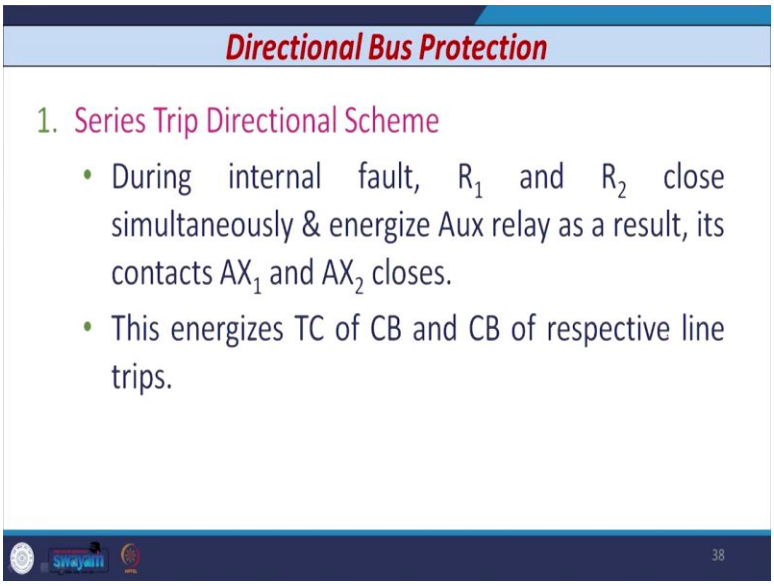

So, in directional bus protection scheme, first type of scheme that is known as series trip directional scheme, so you can see here, this is the bus and you have the two outgoing feeders where CB1 and circuit breaker one and two are connected and on this you have the CT1 and CT2 are connected and across secondary of CT1 and CT2 you have the relay one and relay two both are connected. As this is a directional relay, so the secondary of PT input that is also required to each relay.

And if I just look at the control circuit of this relay, the contact of relay R1 and R2 are connected in series that's why it is series trip directional scheme. So, whenever these two contact closes, the auxiliary relay energizes, which is going to trip its contact that is AX1 and AX2, and finally, the trip coil of circuit breaker that is energized.

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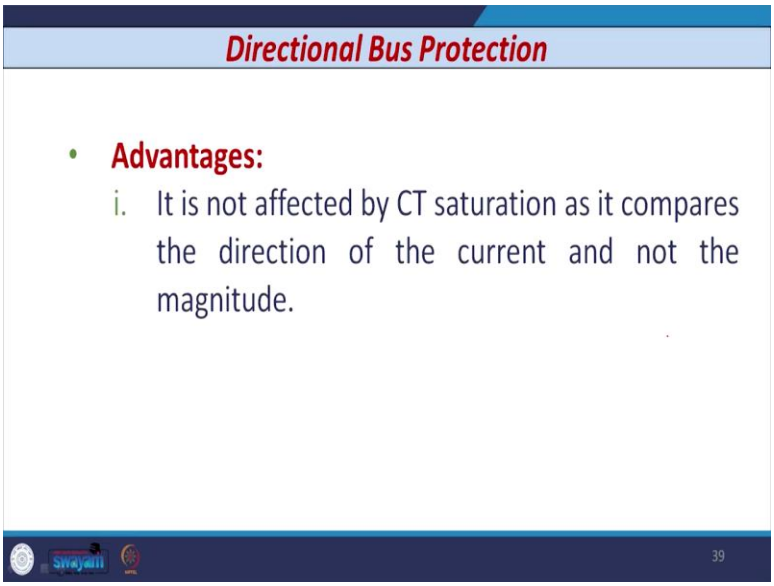

Main advantage of directional protection scheme is it is not affected by CT saturation as it compares the direction of current and not the magnitude.

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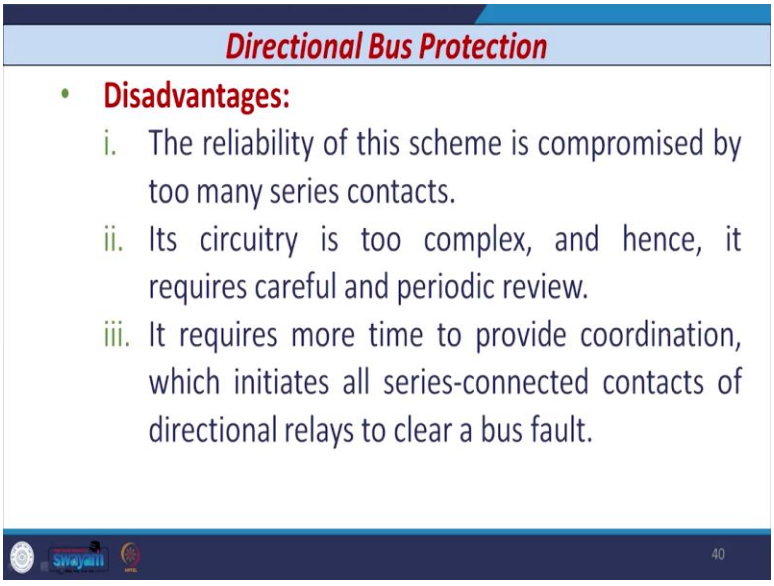

However, there are certain disadvantages of directional bus protection scheme. The first, reliability of this type of scheme is compromised by too many series contacts. Its circuitry is complex, and hence, careful and periodic assessment is required. And this type of scheme requires more time to provide the coordination and which is going to

initiate all series connected contacts of directional relay to clear the bus fault. So time of operation of this type of scheme is more than one cycle. So it is not used in actual or practical field.

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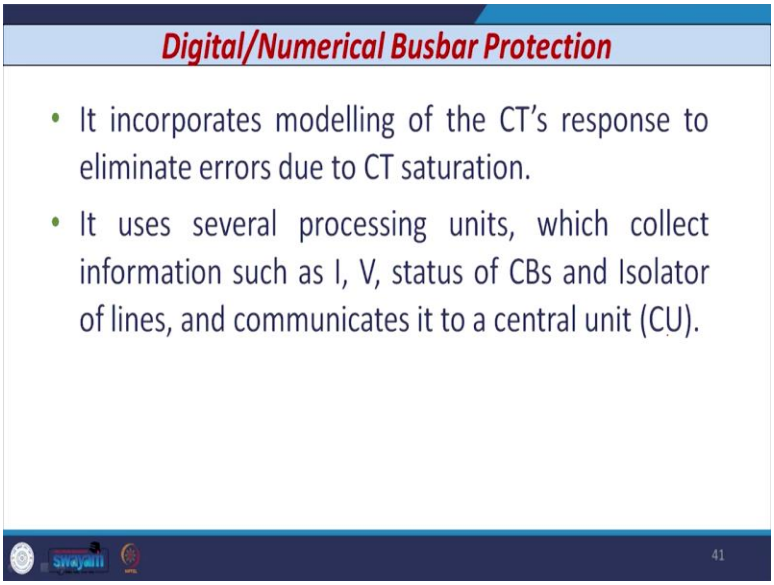

So, in practical field, the scheme or the relay used that is digital or numerical relay. This type of relay incorporates modeling of CT response to eliminate the errors because of CT saturation. It uses several processing units which is going to collect the CT secondary current, PT secondary voltage, status of circuit breakers and isolators connected with the line and then finally it communicates it to the central unit.

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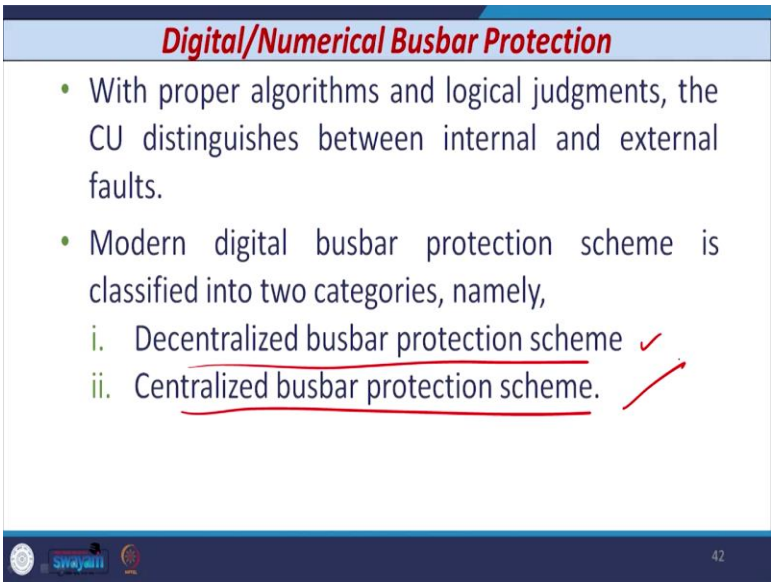

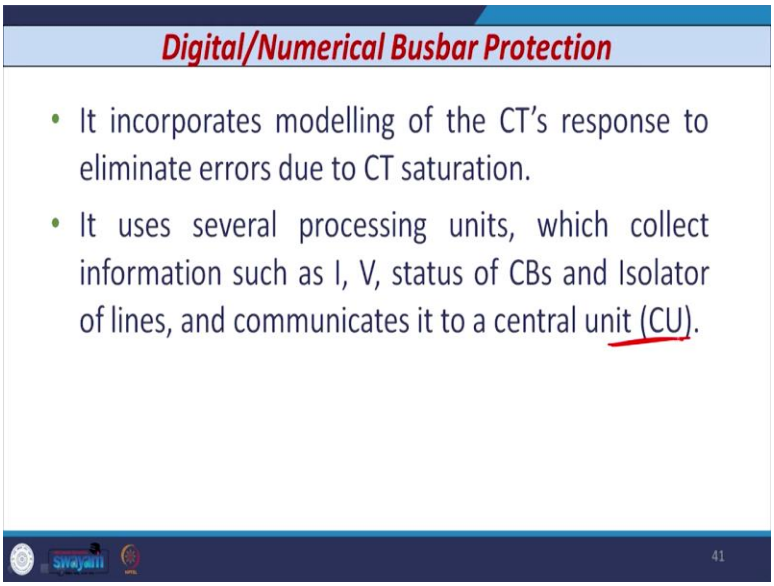

With proper algorithms and logical judgments, the central unit distinguishes between internal fault and external fault. The modern digital busbar protection scheme that is classified by two ways; the first type of scheme that is known as the decentralized busbar protection scheme; and the second type of scheme that is known as centralized busbar protection scheme. So, in both the schemes whether we use centralized busbar protection scheme or we use decentralized busbar protection scheme, this unit that is the central unit that is always there. Whether you use separate central unit for each line or feeder or you

use a common a single central unit, in this way the decentralized and centralized busbar protection scheme that is different.

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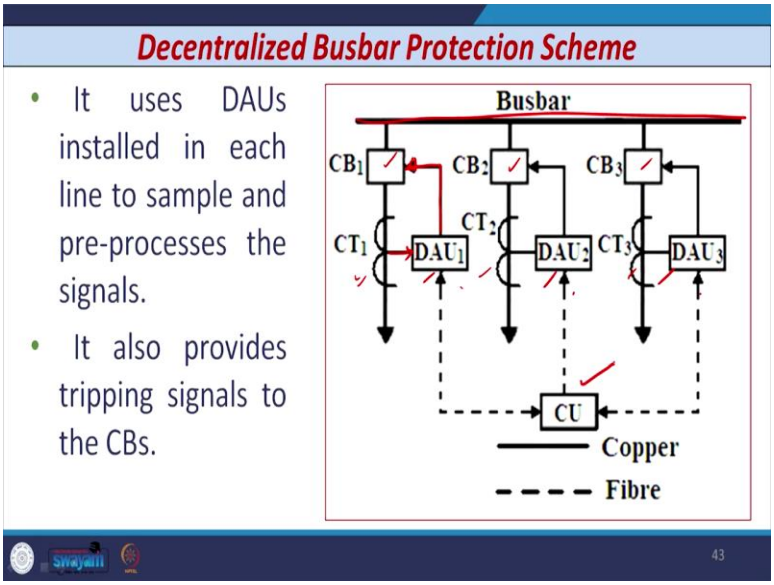

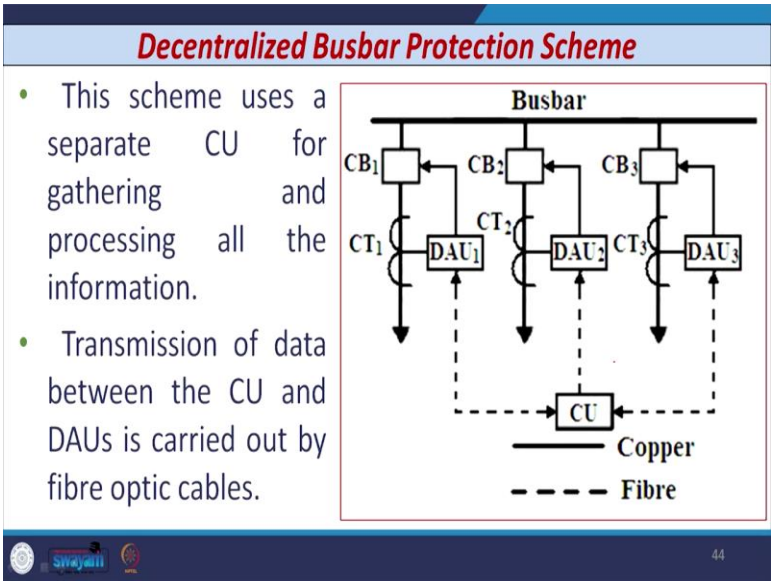

Let us see what is the decentralized busbar protection scheme. So you can see that this is a diagram of decentralized busbar protection scheme where you have the busbar and you have the three outgoing feeders. In each outgoing feeder, you have the three circuit breakers along with three CTs, 1, 2, 3, and you have the data acquisition unit connected across the secondary of CT, so each CT you have the data acquisition unit which is going

to acquire the data and is also going to give the signal to the circuit breaker, so that's why you can see this arrow that is given with each data acquisition unit it is going to acquire the signal and this each data acquisition unit that is controlled by the -- this central unit. So it all -- this type of unit also provide signal to the circuit breaker as I told you, and this type of scheme separates central unit for gathering all the processing. So transmission of data between the central unit and data acquisition unit that is usually performed by fiber optic cables.

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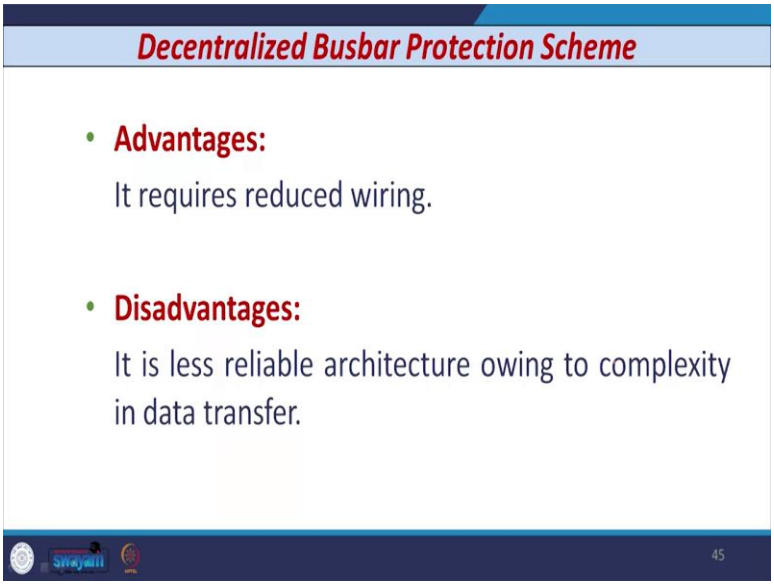

Now, if I consider the decentralized busbar protection scheme, then it requires reduced wiring which is the main advantage of this scheme. However, this type of scheme is required the very complex circuitry, and at the same time, the data transfer rate required from central unit to the data acquisition unit that is also sufficient. So, for that, the scheme utilized that is known as centralized busbar protection scheme.

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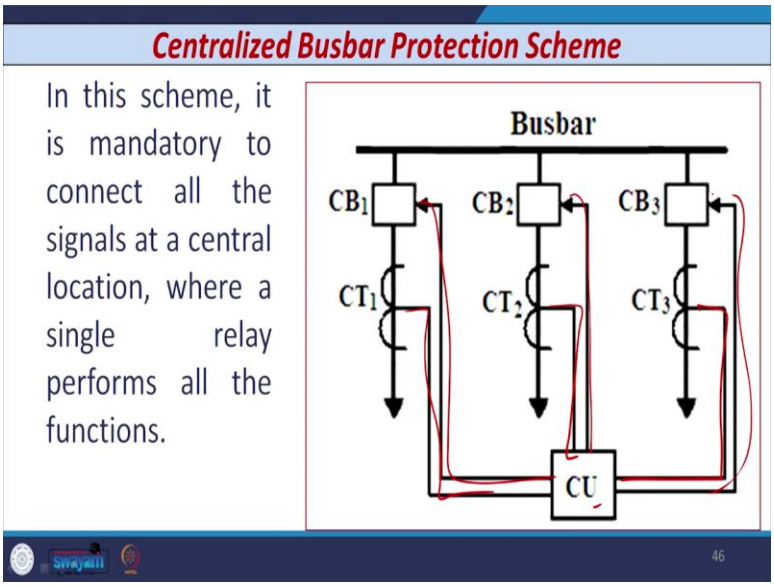

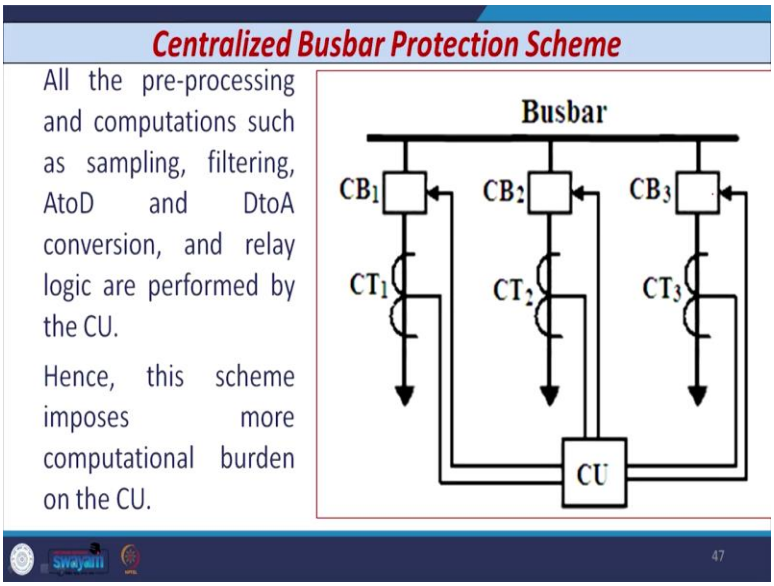

So, you can see observe the diagram of centralized busbar protection scheme instead of separate data acquisition unit which was there in decentralized busbar protection scheme, you have only a one central unit which is going to acquire the data from each CT you can see, at the same time it is also going to send the signal to each breaker. So, in this scheme, it is mandatory to connect all the signals at one central location, single relay performs all the calculations. All the pre-processing and computations such as sampling, filtering, analog to digital conversion or digital to analog conversion and the relay logic

that is all thing, everything all computations are performed in central unit. Hence, this type of scheme imposes more computational burden on the central unit.

So, with this, we have discussed, we started our discussion with the different types of busbar protection scheme, we started with the differential scheme, then we discuss the directional bus protection scheme and then we have -- we started discussion with the digital scheme or numerical busbar protection scheme, along with advantages and disadvantages. So, with that, I stop here. Thank you.