Digital Protection of Power System
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Lecture - 11
Digital Protection of Transformer-I

Hello friends. So, today we are going to discuss on digital protection of transformers. So, we will see that how if we use digital or numerical relays or IEDs, then how we can protect the transformer. And what are the changes we need to do, if we wish to use digital or numerical relay for the protection of large or power transformer. So, if we consider the transformer or basically power transformer; then three types of faults are possible in power transformer. The first type of faults are known as incipient faults.

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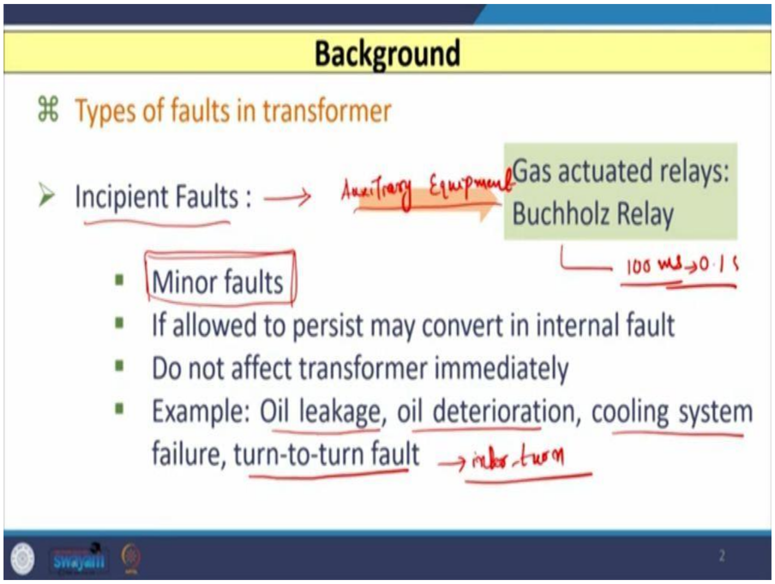

And these faults are basically going to occur in the auxiliary equipment connected with the power transformer. So, if any auxiliary equipment are connected with the transformer and if any fault is going to occur, then those faults are treated as incipient faults. Sometimes these faults are also known as the minor faults; so, that means we need to clear this fault. If we do not clear this fault, and if we are allowed to persist this fault for a longer duration, then these type of faults maybe converted into major faults or electrical faults or internal faults. So, we have to detect these faults and we have to clear this fault, and we have to isolate the transformer also if required in some cases.

So, if I consider such type of incipient or minor faults, then this type of faults occur in the auxiliary equipment of the transformer. And these faults occur basically because of many reasons. The first reason is the leakage of oil in the transformer. So, we know that if there is a leakage of oil in the transformer, then the level of oil that is going to down; and because of the reduction in the oil level in the transformer, oil level indicators are there.

So, these indicators are going to give the indication that there is a leakage of oil; and because of that oil level indicator shows that there is a reduction of oil. And if we allow, then whatever bushings and windings are available inside this transformer those are exposed; and maybe the winding temperature increases.

The second reason for the occurrence of incipient faults are the deterioration of oil. So, we know that with the transformer conservator tanks are used and inside the conservator tank, the air that is going to be served by using the dehydrating breeder. And this breeder when he takes the or sucks the air to avoid the content of moisture, they normally use oil cub along with that silica gel. So, if moisture content are again allowed, then there is a deterioration of dielectric strength of the oil; and that is going to again damage the insulation or winding of the transformer.

The third reason, because of which the incipient or minor faults occur, because of the failure of cooling system. So, failure of cooling system that is because of the maybe blockage of radiator or maybe failure of the fans; so, because of that the temperature of oil increases. And if temperature of oil increases, then we have to detect this condition; and we have to again take the proper or appropriate action.

The fourth reason for the occurrence of incipient faults are turn-to-turn fault; sometimes it is also known as inter-turn fault. So, inter-turn faults are going to occur because of the shorting of few turns on a particular phase or winding. So, when shorting of few turns that is going to take place in particular phase or windings. Then the current entering to the winding and current leaving to the winding remains same. So, our conventional relay or differential relay is not capable to detect this.

But circulating current is going to flow because of shorting of turns, which is going to increase the heating. And finally the temperature of the winding increases and that is may damage the winding or insulation of the transformer. So, we need to detect these type of faults, which are known as incipient faults. The second category of faults are known as the internal faults.

Now, before we proceed for internal faults or we can also call it electrical faults; these incipient faults are detected by two devices. One is known as the gas operated relays. So, in gas operated relays, we use either Buchholz relay or we use sudden pressure relay. However, when we use such type of Buchholz relay or sudden pressure relay, because there is a fundamental difference that we use Buchholz relay, when we have a connecting pipe between the conservator tank and main tank; and if that is not there, then we have to go for a sudden pressure relay.

But, whatever maybe the case, if we use either of these Buchholz relay or sudden pressure relay, the operating time of this relay that is of the order of 100 millisecond; or, you can say 0.1 second. So that means this will give the delayed operation. And sometimes if there is a mechanical vibration is going to take place, then this type of relay, they may mal operate because mercury that is used inside the Buchholz relay.

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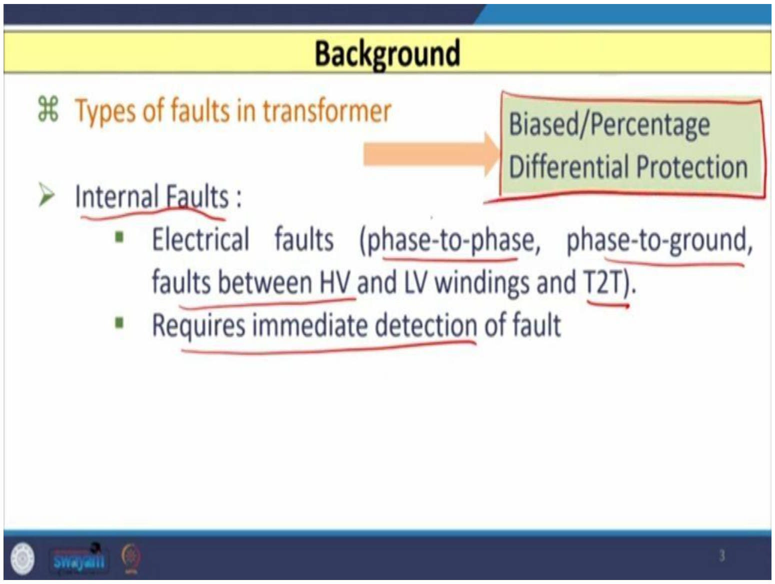

The second category of fault as I told you these are known as electrical faults or internal faults. And these type of faults are going to occur, because of the failure of insulation between the two windings; or because of the failure of insulation between the winding and the core of the transformer.

So in this case, the phase-to-phase faults are possible; phase to ground faults are also possible. Sometimes faults may occur between HV and LV winding and in some cases turn-to-turn faults are also possible. These type of faults are known as internal faults. And as the magnitude of fault current in any of these fault case is very high, maybe almost 10 times, 15 times the full load current of the transformer, either on the LV or HV side.

So, it this requires immediate detection of fault as well as isolation of the transformer by operating the associated circuit breaker connected with the transformer. This type of transformers when we use and when we detect internal faults, this can be detected by percentage differential protection scheme or biased differential protection scheme.

And most of the utility, they use either electromechanical relay, those are based on biased or percentage differential protection scheme. However, relative advantages and disadvantages of percentage differential protection scheme we will discuss in due course of time. The third category of fault are known as external faults or maybe sometimes also known as out of zone faults.

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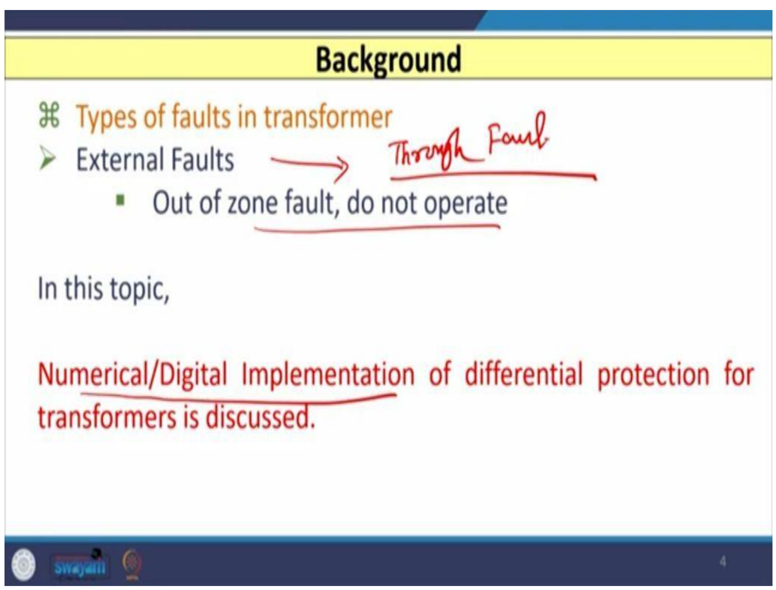

Sometimes in some cases they are also called as the through fault. So, whenever such type of fault occurs outside the range of the CT of the transformers connected on both sides of the winding of the transformer, then this relay should not operate in this case. So, we want stable operation of the relay in this situation. However, in this lecture we are going to concentrate more on digital or numerical relays; and how we are going to implement this relay for differential protection of power transformers, so that we will discuss in this lecture.

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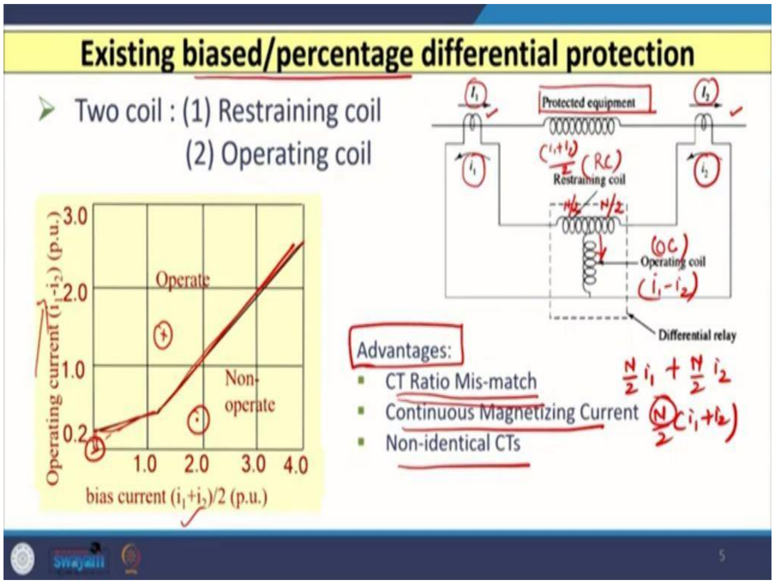

Now, before we start the importance of digital differential relay for the protection of transformer, let us see or discuss the conventional percentage or biased differential protection scheme. So, here you can see I have shown a single line diagram of one winding of the transformer. So, this is the winding of the transformer of one phase which I need to protect. And if I wish to use differential protection, then you can see I have put one CT on each side of the winding; and secondary of the CT are connected with the two coils. One is known as the operating coil and another that is known as the restraining coil.

So, the arrangement is done in such a way that current through the operating coil. You can see that the primary current is I_1. And again, the other side of the winding, the primary side current of the CT is I_2. And when this is transferred on CT secondary on each side of the winding, the current will be i_1 and i_2.

And if you connect the operating coil in this fashion, then the current through this operating coil is nothing but the difference of this i_1 and i_2. And your operating coil is connected at the middle of the restraining coil, so that half of the turns that will be available on the restraining coil; and whatever current that flows through the restraining coil that will be N/2 times i_1 + N/2 times i_2.

So, if you take this N/2 common, then the current will be i_1+ i_2. And as the number of turns of the restraining coil that is constant, so the current through the restraining coil that is $(i_1+i_2)/ 2$. So, if I using this current that flows through the operating coil, which is i_1- i_2, and the current that flows through the restraining coil, which is $(i_1+i_2) /2$. If I use these two currents and plot the characteristic of the differential relay, then the characteristic looks as shown in this screen.

So, on x-axis, I have considered the restraining current; sometimes also known as bias current, which is $(i_1+i_2) /2$. And on y-axis, I have considered the operating current or differential current, which is known as i_1-i_2. And you can see that if I plot this characteristic, then I will have the characteristic like this.

So, here you can see that this curve that is going to start from slightly above the origin; it does not start from the origin, so, this curve that is not going to start from here this point. The reason is we need to give some amount of current, so that relay should not operate if there is a spill current inside the operating and restraining coil of the relay.

Further, you can see that these two slopes are also there. And if any operating point falls in this region above this characteristic, then relay should operate. Whereas, if any point that is going to come in this region, then relay should not operate. So, this discussion you already know because this is the main features of the percentage or biased differential protection scheme. However, there are certain advantages of this biased or percentage differential protection scheme. The first and foremost advantage is that this scheme remains stable, or does not operate in case of if any mismatch of the CT ratio exists on each side of the transformer.

We know that as transformer voltage ratio that is different on LV and HV side; so whatever currents we have that those currents are also different on both the side. So, accordingly CT ratio we need to select, those ratios are also different. So, if there is a mismatch in the CT ratio, then also this relay does not operate and it gives correct operation. The second advantage is, if continuous magnetizing current is present which is there, when we deal with the power transformer, then also this relay remains stable.

And even when the CTs are not identical, we know that CT saturation characteristics are not identical of both the CTs or both side CTs, even though they procure from the same manufacturer. So in that case, there will be a spill current inside the operating coil of the relay; then also this relay does not operate and it gives correct operation. However, I have considered the single line diagram considering only one phase winding.

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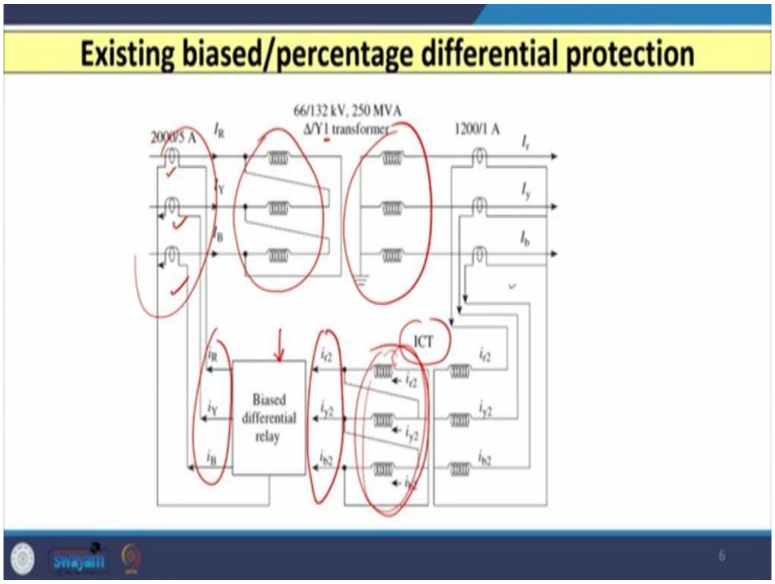

Now, if I consider the three phase diagram and if we look at the how the biased or percentage differential protection scheme, that is implemented in actual field by the utility. Then you can see I have consider here Delta-star with some winding phase shift exist. So here the one is given; so this phase shift is again lagging. Here, you can observe that on one side of the winding, this is Delta connected and other side of winding that is Star connected. And you can see that on when the winding is Delta connected, we have connected the three CTs in Star fashion; and when you have the Star side winding, we have connected still the CTs in Star fashion.

But, we have used another inter posing transformer, which is a basically low voltage transformer, one of the winding of the ICT that is connected in Delta. So, if you connect any Delta winding, there if you connect CTs in star; and for Star side winding if you connect the three CTs in Delta, then whatever is the phase shift exist or inherent phase shift exist, I would say between the primary and secondary side quantities that can be easily compensated. So, the objective when we deal with biased or percentage differential protection scheme, that is we need to compensate the secondary current given to the relay, either from one side of the winding and other side of the winding.

So, these currents and these currents whatever we wish to give to the relay or coil of the relay, they should be equal in magnitude; there should not be any phase shift, and there should not be any zero sequence existing between these two quantities. So, if you connect these CTs that is in Star fashion for Delta winding, and these CTs in Delta for Star winding; then this can be easily obtained. And this is done by most of the utility when we use electromechanical type biased or percentage differential protection scheme. However, there are certain issues when we are dealing with this type of biased or percentage differential protection scheme.

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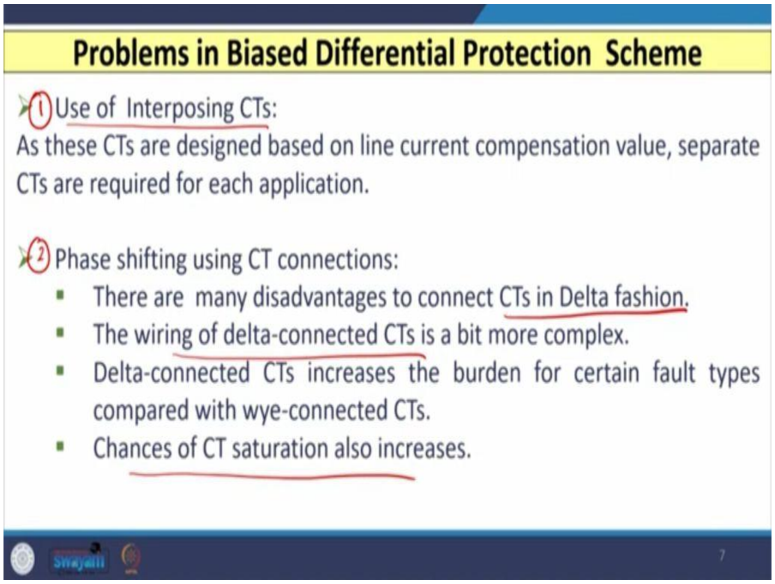

The first issue that is related to the use of interposing current transformers or ICT's. Now, whenever all these interposing current transformers are designed based on the line compensation value, so for each specific application we need special or specific interposing current transformer.

So, if I have one configuration of transformer, then I need one ICT of particular value or design. If I change that, then I will need the another type of ICT design; so, that is the main disadvantage of the biased or percentage differential protection scheme. The second disadvantage of this biased or percentage differential protection scheme is regarding the connections; so this is related to the CT connections.

Now, if I connect the CTs in Delta fashion, then there are certain disadvantages. And the first disadvantage is wiring of Delta connected CTs is quite complex. And if I use the Delta connected CTs, then the burden of the CT increases, for certain types of fault compared to the. If I you connect the CTs in Star fashion, and if the burden of the CT increases, then the chances of CT saturation also increases; because your operating point may shift from linear region to the saturation region. So, these are the disadvantages of the biased or percentage differential protection scheme.

Moreover, if I use the tappings on the transformer and we know that most of the power transformers are equipped with tap changing mechanism.

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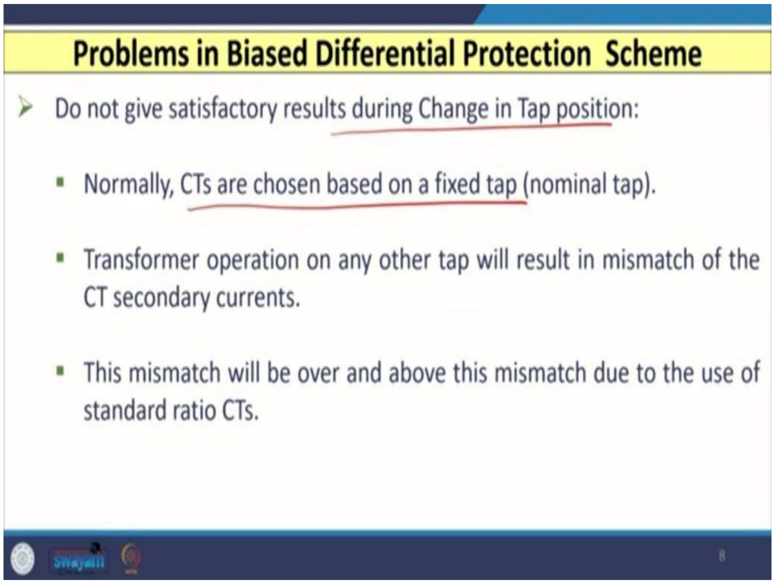

So in that case, the performance of biased or percentage differential protection is not up to the mark. So, because normally, the CTs are basically chosen and considering the fixed or nominal tap. So, when transformer is operated other than the nominal tap, then obviously mismatch will exist on the CT secondary side current; and this mismatch is over and about the mismatch that is going to be exist because of the CT ratio. So, that is why the spill current will increase and it may possible that for different tap position other than the nominal or fixed tap, the relay may mal operate.

So, if we wish to avoid all these things; because we have discussed that there are three important disadvantages of biased or percentage differential protection scheme. First, that is the if I go for Delta connected connection of CTs, because and that we have to do in order to avoid the inherent phase shift. So, if I go for that, then the burden of the CT increases and chances of CT saturation also increases.

The second disadvantage we have discussed is its performance. When tap changing mechanisms or facilities are provided, its performance will be deteriorated compared to when tap is connected at nominal or fixed tap.

And the third thing is that we have to go for specific ICT; so that is interconnecting transformer. Of course, these transformers are low voltage, but still we need to use those ICTs if we go for conventional electromechanical biased or percentage differential protection scheme. If we wish to avoid all these disadvantages, then we have to switch over or shift from this electromechanical relay to the digital relay or numerical relay.

So, if I shift or if we move or if we switch over from electromechanical relay to the digital relay, then we will have several advantages. So, the important advantage is that is we will have all the functions clubbed or combined together in a single unit. Let us see what are these functions available in a single unit, when we use digital relay for the protection of power transformer.

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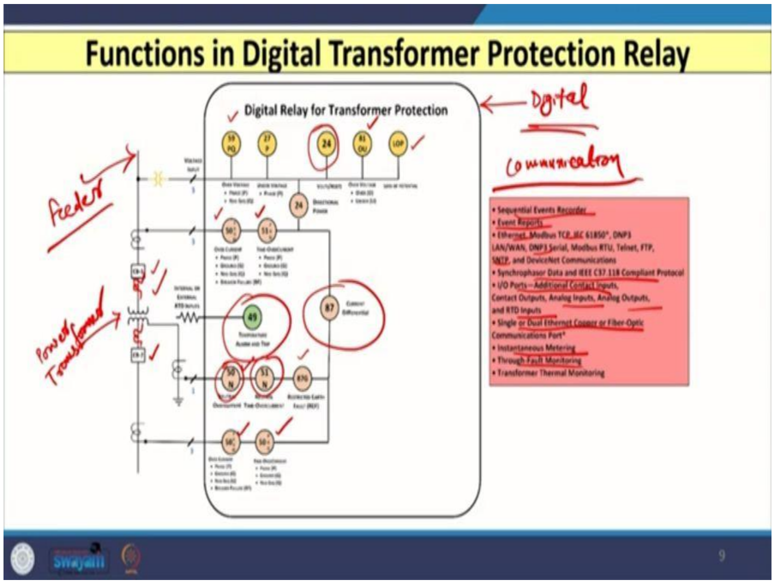

So for that, you can see I have shown here one feeder which is connected with the transformer. So, this is our power transformer, which is under consideration or for which we want protection. And on each side of the transformer we have two circuit breakers; so that if any fault occurs on one side, this circuit breaker will open. And if any fault occurred on other side, the other one will take care of that. However, when we wish to disconnect we have to disconnect a transformer from both the sides. Now, you can see that we can connect the CT somewhere here (as shown in above slide), and then accordingly whatever protection we want, we have to acquire the data.

So, here if I use digital relay or numerical relay, then the first advantage we have that is the differential protection itself; that is number is given 87 that is possible, and it is based on current which we have discussed. The other protection we obtained that is the overcurrent and timed overcurrent that is 50 and 51, which includes both phase negative sequence, and the ground also, and the breaker failure also. So that will be provided on each side of the transformer windings. So on this side also, we have the 50 and 51; and on this side also, we have 50 and 51 both are available on this side.

So, both that is available. So, for providing the overcurrent protection on both the side of the winding of the transformer is if my differential relay fails, then I need some backup protection. The other protection we have that is related to the neutral. So, we have the protection of neutral overcurrent and neutral time over current, along with the restricted or fault protection, which is basically on one side of the winding of the transformer.

Then, we also have the temperature monitoring and that is connected with your resistor temperature detector. So, if I have any inbuilt RTD, if I want to use for digital relay, we can use; or if external RTD we wish to install, and we can connect the output of that external RTD to the contacts of this relay that also we can do. So, this is also there.

The other things are we do have the protections like the over voltage and under voltage, both for phase and negative sequence. We do have the over frequency and under frequency protection that is also possible in this unit; and we do have the loss of potential. So, if a voltage drops below certain value, then also for that we have loss of potential protection; and along with that we have the volts per hertz that is over fluxing protection. So, that is also provided in the same unit. So, all this you can see this is my digital relay or numerical relay, and all these settings or all these protections are available inside this single unit.

And this is one group setting; as I told you another group settings are similar to that that is also available. So, it is up to the user that which group of settings they want to use. Along with this, there are possibility of the event recording facilities also there inside this digital relay. So, you have the event recorder and reporting of those events are also there. So, if I want let us say what events took place in last five years, so those facilities are also possible. This relay has another feature that is this is connected with the communication mediums; so all communication protocols are there.

They support like if we consider the Ethernet, TCP, or maybe we can say DNP3 or SNTP; any type of communication protocols that is supported by this relay. Along with that it is also going to support the ICC 37.118; so it is also compliant with this. And along with that several input output ports are also provided; and these output ports or maybe analog input and output, and maybe some RTD inputs are also possible. So, we do have the facility of if I want to connect fiber optic cable for communication purpose, so that is also possible. And along with that this unit will also work for measuring purpose.

So, if I want to measure some quantity, then instantaneous measuring and through fault monitoring that is also possible. So, that means this unit will act as a protection, monitoring, communication and control, everything is possible in this unit. So that is why we want to switch over from the electromechanical relay that is used for the protection of the power transformer to the digital relay, which is again used for the protection of power transformer with enhanced facility. So, in this class, we started our discussion with the what are the different types of faults that is possible inside the transformer; and we have discussed that incipient faults, internal faults and some through faults are there.

After that we have discussed that what are the main scheme that is used for the protection of power transformer, and most of the utilities will use biased differential or percentage differential protection scheme. And we have seen that the advantages and disadvantages of biased or percentage differential protection scheme.

And then we have concluded that if we switch over from electromechanical relay to digital relay, then most of the functions including monitoring, metering, protection and communication; all those are available in single unit, if I wish to protect the power transformer. So, that is why we will be in use or in touch with the digital relays. And in the next class also we will discuss more about the digital relays. Thank you.