Power System Protection
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Lecture – 44
Busbar Protection

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NPTEL ONLINE CERTIFICATION COURSES

Power System Protection

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Module 08: Differential Protection of Transmission Lines and Busbars

Lecture 44: Busbar Protection

Welcome to NPTEL course on Power System Protection, we are with module eight on differential protection of transmission line and busbar.

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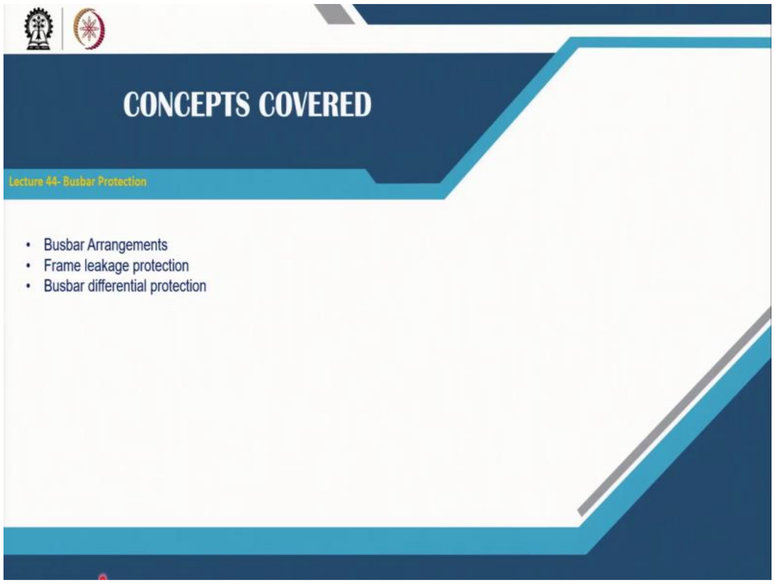

CONCEPTS COVERED

Lecture 44- Busbar Protection

- Busbar Arrangements
- Frame leakage protection
- Busbar differential protection

In this lecture we will discuss on the protection of busbar, where we will see different arrangements for busbar and then the different perspective of busbar protection including frame leakage and the differential protection.

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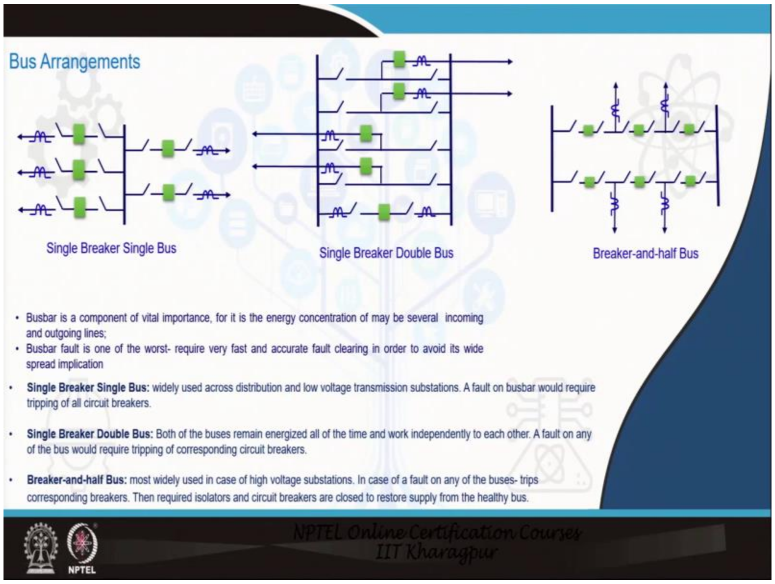

Bus Arrangements

- Busbar is a component of vital importance, for it is the energy concentration of may be several incoming and outgoing lines;
- Busbar fault is one of the worst- require very fast and accurate fault clearing in order to avoid its wide spread implication
- **Single Breaker Single Bus:** widely used across distribution and low voltage transmission substations. A fault on busbar would require tripping of all circuit breakers.
- **Single Breaker Double Bus:** Both of the buses remain energized all of the time and work independently to each other. A fault on any of the bus would require tripping of corresponding circuit breakers.
- **Breaker-and-half Bus:** most widely used in case of high voltage substations. In case of a fault on any of the buses- trips corresponding breakers. Then required isolators and circuit breakers are closed to restore supply from the healthy bus.

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Busbars can be arranged in different ways, so if you see different substation in power system we will find different combinations of isolators, circuit breakers, and line connections to busbars. Single bus, multiple bus and there are other options. One way of categorizing the busbars is that it can have single breaker single bus, single breaker double bus, or breaker and half bus where we have two buses connecting lines and in between we have three breakers.

So, most widely used in high voltage substations the breaker and half and the single breaker single bus widely used across distribution or low voltage system perspective. The bus arrangements are not limited to these three, there are other options available also. Point to note here is that busbar is very vital element in the substation or power network where the energy concentration of several incoming and outgoing lines happens to be there and a fault in busbar leads to worst situation and that requires very fast and precise fault clearing in order to avoid widespread implication on the power system stability issue.

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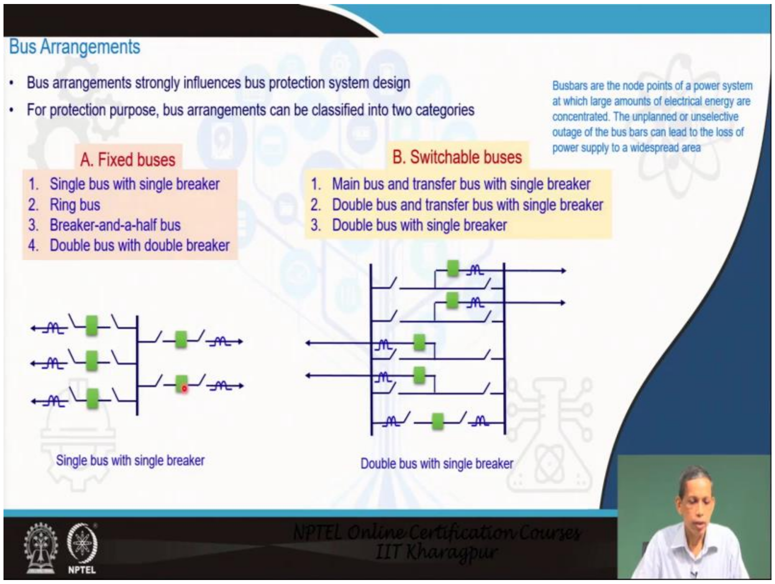

Bus Arrangements

- Bus arrangements strongly influences bus protection system design
- For protection purpose, bus arrangements can be classified into two categories

Busbars are the node points of a power system at which large amounts of electrical energy are concentrated. The unplanned or unselective outage of the bus bars can lead to the loss of power supply to a widespread area

A. Fixed buses

1. Single bus with single breaker
2. Ring bus
3. Breaker-and-a-half bus
4. Double bus with double breaker

B. Switchable buses

1. Main bus and transfer bus with single breaker
2. Double bus and transfer bus with single breaker
3. Double bus with single breaker

Two categories can be observed on the protection aspects, we say fixed bus approach and the switchable bus approach on the protection perspective and so. So, in the fixed bus approach single bus single breaker, ring bus breaker and half, double bus with double breaker and in the switchable bus we have main bus and transfer bus, double bus and transfer bus, double bus and single breaker, these are the different classes you can talk about here.

In the fixed bus approach like here you have a bus and the corresponding the switches, isolators all are connected to the particular bus and so. In the switchable bus we can have an auto switch options available. So, the corresponding protection arrangement all these things depends upon whether it is a fixed bus approach or it is a switchable bus approach into the system and already mentioned that busbar protection is critical and then the protection schemes depends upon the particular arrangement of the buses.

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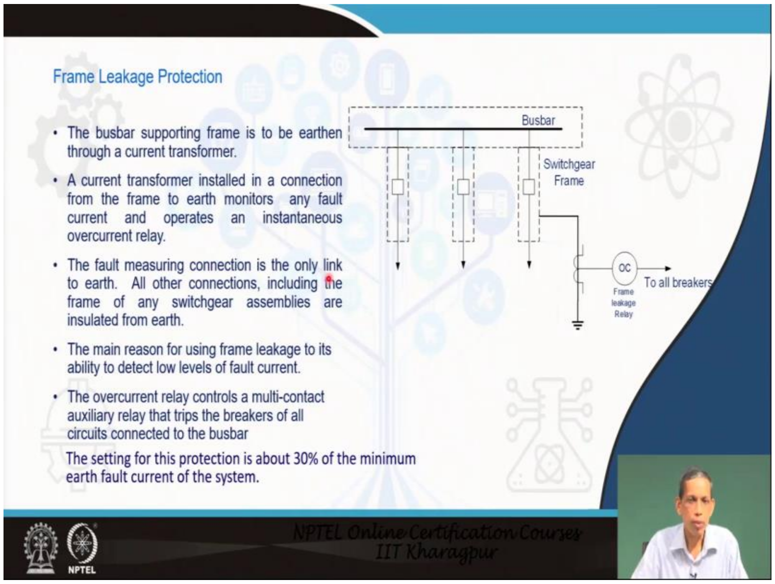

Frame Leakage Protection

- The busbar supporting frame is to be earthen through a current transformer.
- A current transformer installed in a connection from the frame to earth monitors any fault current and operates an instantaneous overcurrent relay.
- The fault measuring connection is the only link to earth. All other connections, including the frame of any switchgear assemblies are insulated from earth.
- The main reason for using frame leakage to its ability to detect low levels of fault current.
- The overcurrent relay controls a multi-contact auxiliary relay that trips the breakers of all circuits connected to the busbar

The setting for this protection is about 30% of the minimum earth fault current of the system.

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One simple approach which is being used is for the frame leakage protection perspective. So, if you see this connection diagram here we have a CT connecting to the leakage frame to the earth and on that path this CT connects to an over current relay and in case of failure of insulator or so this path has sufficient current to operate the corresponding over current relay perspective. This is very simple and this can use an instantaneous over current relay itself and the particular setting of this protection scheme is around thirty percent of the minimum fault current of the system and because this is related to the earth fault therefore this relay is pretty sensitive to the earth fault perspective of the busbar fault.

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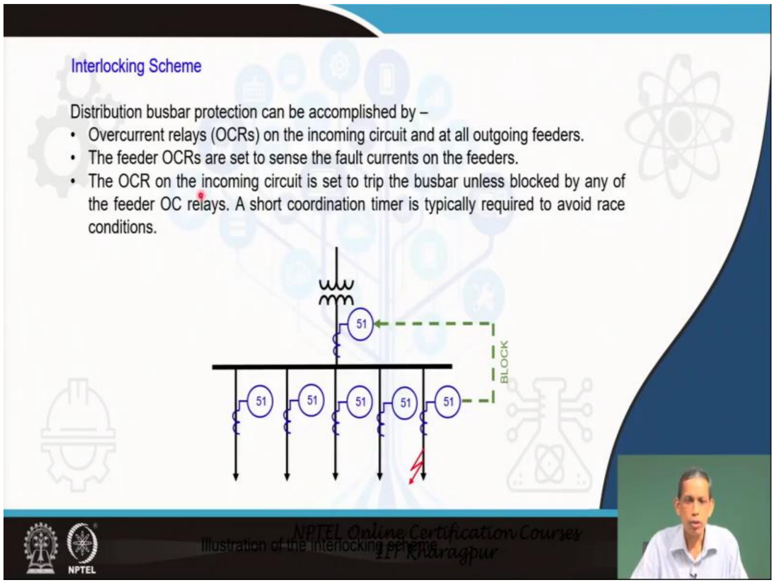

Interlocking Scheme

Distribution busbar protection can be accomplished by –

- Overcurrent relays (OCRs) on the incoming circuit and at all outgoing feeders.
- The feeder OCRs are set to sense the fault currents on the feeders.
- The OCR on the incoming circuit is set to trip the busbar unless blocked by any of the feeder OC relays. A short coordination timer is typically required to avoid race conditions.

Illustration of the interlocking scheme

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There is another simple approach on interlocking scheme where over current relays are there for the outgoing feeders and also to the incoming feeders. Now, what is being done that in case of external fault or a fault in the any of the line the corresponding relay takes the decision through that signal, this the incoming bus relay is being blocked. Whenever any of these relays does not find a fault then this will not be blocked ensuring that there is an internal fault to the busbar. So, this is about the simple interlocking scheme based on the overcurrent principle, only one point here is that a short coordination timer is required between these outgoing over current relay and this incoming bus, incoming over current relay.

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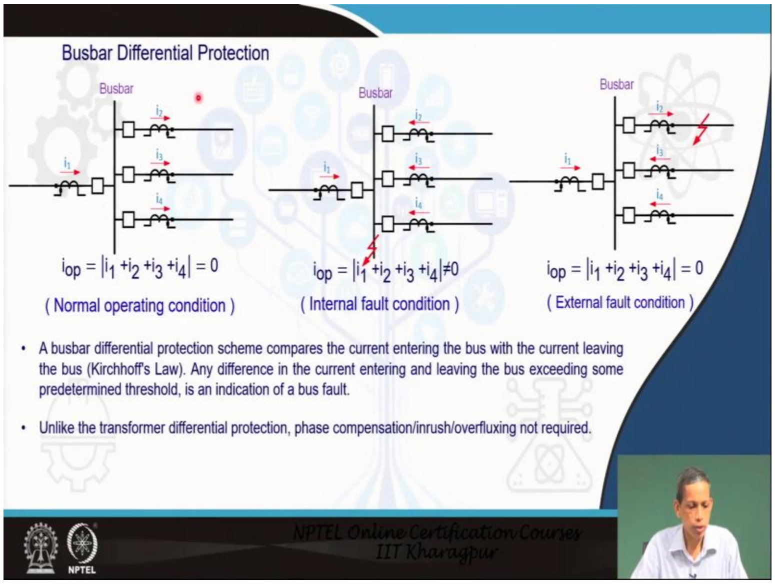

Busbar Differential Protection

$i_{op} = |i_1 + i_2 + i_3 + i_4| = 0$

(Normal operating condition)

$i_{op} = |i_1 + i_2 + i_3 + i_4| \neq 0$

(Internal fault condition)

$i_{op} = |i_1 + i_2 + i_3 + i_4| = 0$

(External fault condition)

- A busbar differential protection scheme compares the current entering the bus with the current leaving the bus (Kirchhoff's Law). Any difference in the current entering and leaving the bus exceeding some predetermined threshold, is an indication of a bus fault.
- Unlike the transformer differential protection, phase compensation/inrush/overfluxing not required.

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Widely use in for the busbar protection is the differential protection. So, in differential protection, for that perspective we have already learned on transformer protection and in earlier lectures we have learned how transmission lines protections can be there. In Busbar protections we do not have issues like inrush current, overfluxing or phase compensation and so, it is pretty simple and based on simpler KCL applications, applications to the system.

So, like earlier the CTs are connected such that the operating current (i_{OP}) expressed by

$$i_{op} = |i_1 + i_2 + i_3 + i_4| = 0$$

becomes 0 for normal operating condition, but for internal fault all the currents enter and the CT connections are such that the i_{op} becomes significantly high and that is nothing but the fault path current, that we already know for the internal fault condition. For external fault conditions similar to the normal operating condition the corresponding summation of all the currents should be 0, but this may not happen in case of CT saturation or so.

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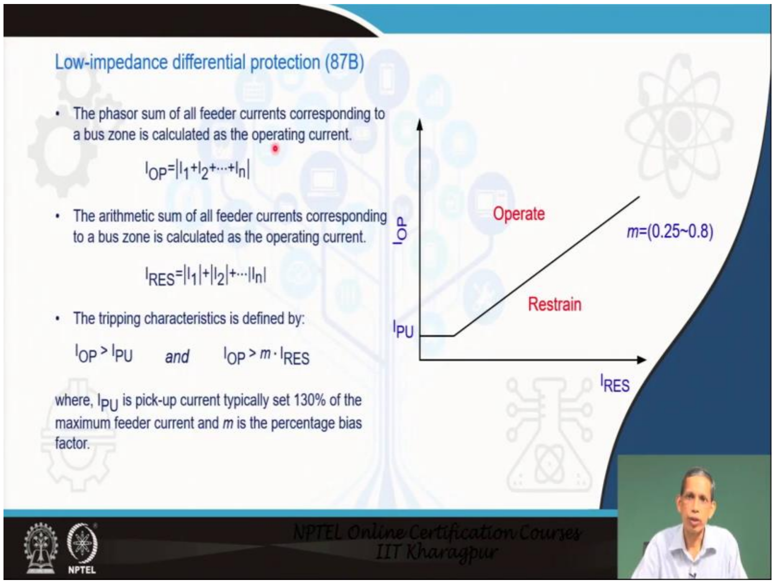

Low-impedance differential protection (87B)

- The phasor sum of all feeder currents corresponding to a bus zone is calculated as the operating current.

$$I_{OP}=|I_1+I_2+\cdots+I_n|$$

- The arithmetic sum of all feeder currents corresponding to a bus zone is calculated as the operating current.

$$I_{RES}=|I_1|+|I_2|+\cdots|I_n|$$

- The tripping characteristics is defined by:

$$I_{OP}>I_{PU} \quad \text{and} \quad I_{OP}>m\cdot I_{RES}$$

where, I_{PU} is pick-up current typically set 130% of the maximum feeder current and *m* is the percentage bias factor.

Two approaches for the differential protection for busbar. One is called the low-impedance, the other is called the high-impedance. First, the low-impedance differential protection approach for the busbar protection 87B. So, as already mentioned the operating current is expressed as

$$I_{OP}=|I_1+I_2+\cdots+I_n|$$

Restraining current is given by

$$I_{RES}=|I_1|+|I_2|+\cdots|I_n|$$

The tripping characteristic just like simple differential relay

$$I_{OP}>I_{PU} \text{ and } I_{OP}>m\cdot I_{RES}$$

So, this slope remains typically between 0.25, 0.8 and may be higher also, and the I_{PU} is the pick-up current typically set 130 % of the maximum feeder current and m is the percentage bias factor, so 130 % of the maximum feeder current, there may be multiple feeders, so we have to consider the in which feeder we have the maximum current.

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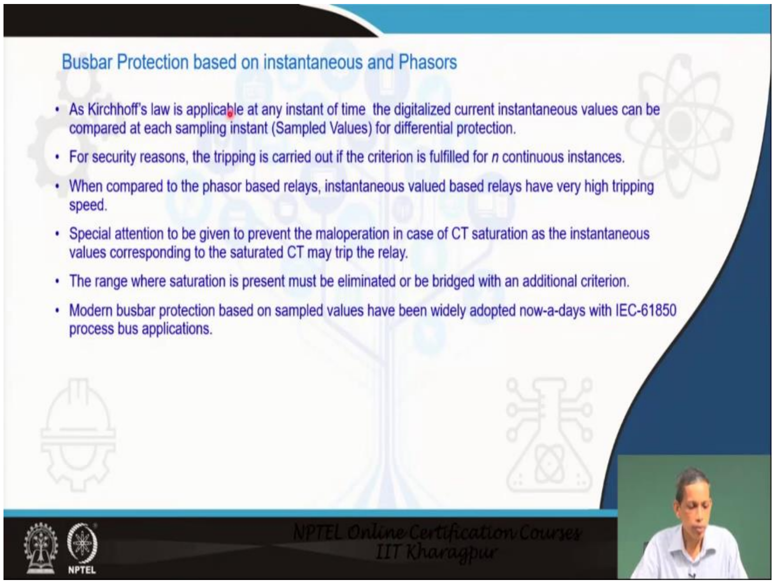

Busbar Protection based on instantaneous and Phasors

- As Kirchhoff's law is applicable at any instant of time the digitalized current instantaneous values can be compared at each sampling instant (Sampled Values) for differential protection.
- For security reasons, the tripping is carried out if the criterion is fulfilled for *n* continuous instances.
- When compared to the phasor based relays, instantaneous valued based relays have very high tripping speed.
- Special attention to be given to prevent the maloperation in case of CT saturation as the instantaneous values corresponding to the saturated CT may trip the relay.
- The range where saturation is present must be eliminated or be bridged with an additional criterion.
- Modern busbar protection based on sampled values have been widely adopted now-a-days with IEC-61850 process bus applications.

Again in the same low-impedance protection perspective, we categorize into two, one is that instantaneous approach and the other is phasor approach. So, earlier we have learned for the line protection for the transformer protection also, how phasors can be applied because busbar is very critical element in this system from stability perspective, the protection should be as fast as possible, so relays also use instantaneous or the sample based approach for the protection using the differential principle.

So, here sample values are used to ensure that the fault is internal to the systems, so *n* continuous instances are being checked to check the consistency of the decision. When compared with the phasor based approach, instantaneous value have high tripping speed. Special attention to be given for the CT saturation detection for external fault as differential current will be significant during the situation of CT saturation. So we have to incorporate the algorithm for detection of CT saturation during the external fault. Modern busbar protection based on sample value approach being widely adopted satisfying IEC-61850 versus bus application and so.

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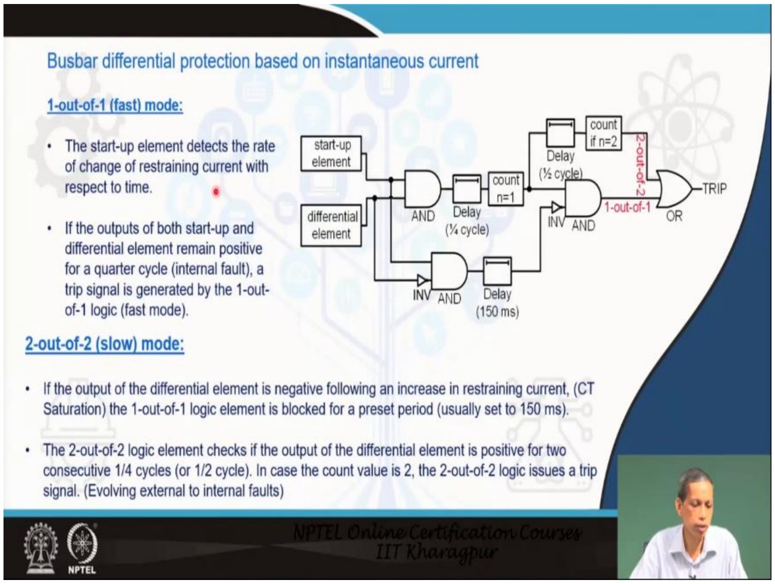

Busbar differential protection based on instantaneous current

1-out-of-1 (fast) mode:

- The start-up element detects the rate of change of restraining current with respect to time.
- If the outputs of both start-up and differential element remain positive for a quarter cycle (internal fault), a trip signal is generated by the 1-out-of-1 logic (fast mode).

2-out-of-2 (slow) mode:

- If the output of the differential element is negative following an increase in restraining current, (CT Saturation) the 1-out-of-1 logic element is blocked for a preset period (usually set to 150 ms).
- The 2-out-of-2 logic element checks if the output of the differential element is positive for two consecutive 1/4 cycles (or 1/2 cycle). In case the count value is 2, the 2-out-of-2 logic issues a trip signal. (Evolving external to internal faults)

So, what is being done in the instantaneous or sample based approach, two modes are there: 1-out-of-1 (very fast mode), and 2-out-of-2 (slow mode), so this is broadly the corresponding scheme what are being applied, so we have a start-up element which detects the rate of change of restraining current based on the rate of change of restraining current and you have differential relay element based on the operating current.

Now, what is being done, if we see here if both level is high say 1 and 1 then AND operations that will say high, so checks for one fourth of a cycle upon the consistency, then if it satisfies then count becomes 1, so if this is 1, this becomes 1 or high. Now, check this parallel path, if this is high or 1 at a given instance, negation of that, this becomes 0 or low, therefore 0 or low output here.

So, this becomes no delay and this becomes again inverted, so this becomes again 1, so this is already 1 in this path and this is 1. Therefore that AND operation gives 1 so this is one out of one then OR operation and TRIPS. So, once again for an internal fault this becomes high, this becomes high, both are high, so this becomes high, and delay for consistency checking becomes one fourth of a cycle, so this count becomes 1, so count becomes n = 1, so this becomes high.

Then come to this path because of the negations this becomes 0 at that time for the internal fault so this becomes 0, so this negation of becomes 1, so 1 and 1 or the high and high these two 1-out-of-1 approach.

Now, see the other 2-out-of-2 mode, in this case what happens if the output of the differential element is negative, that means operating current is not significant, in that case this will be 0 or low so therefore inverted means this becomes high, so this will be with the start-up elements providing high then this becomes high.

So, this will lead to a delay of 150 ms, so with this delay 150 ms if this becomes still high, so therefore this becomes 0 and then this 1-out-of-1 will not provide any output. However, if you see this path now, if the corresponding differential is high and this is also high for a consistency of *n* = 1 and then *n* = 2 for half cycle so then this count becomes n=2, so this is 2-out-of-2 path and then because OR operation this becomes TRIP.

So, this is when happens what in case of typically a situation of evolving external fault then final resulting into an internal fault and this delay helps in doing that particular perspective and the corresponding half cycle delay may give us this option of tripping for such a situation.

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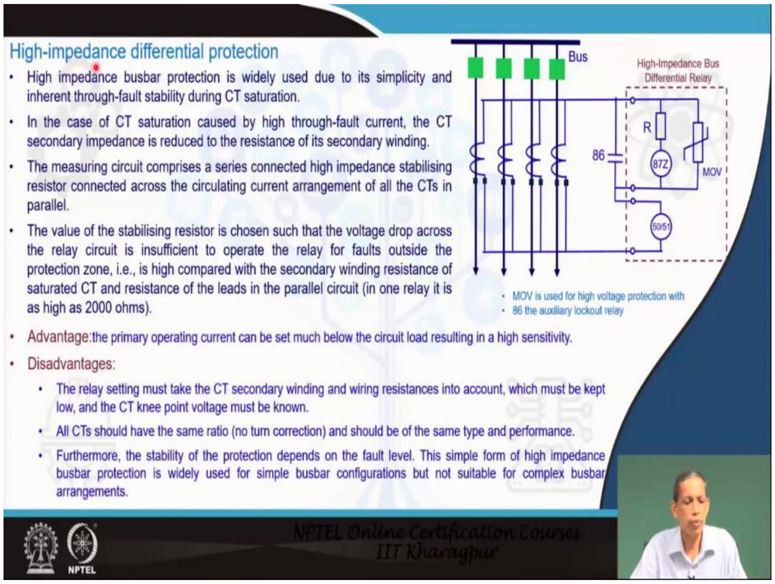

High-impedance differential protection

- High impedance busbar protection is widely used due to its simplicity and inherent through-fault stability during CT saturation.
- In the case of CT saturation caused by high through-fault current, the CT secondary impedance is reduced to the resistance of its secondary winding.
- The measuring circuit comprises a series connected high impedance stabilising resistor connected across the circulating current arrangement of all the CTs in parallel.
- The value of the stabilising resistor is chosen such that the voltage drop across the relay circuit is insufficient to operate the relay for faults outside the protection zone, i.e., is high compared with the secondary winding resistance of saturated CT and resistance of the leads in the parallel circuit (in one relay it is as high as 2000 ohms).
- Advantage:the primary operating current can be set much below the circuit load resulting in a high sensitivity.
- Disadvantages:
  - The relay setting must take the CT secondary winding and wiring resistances into account, which must be kept low, and the CT knee point voltage must be known.
  - All CTs should have the same ratio (no turn correction) and should be of the same type and performance.
  - Furthermore, the stability of the protection depends on the fault level. This simple form of high impedance busbar protection is widely used for simple busbar configurations but not suitable for complex busbar arrangements.

- MOV is used for high voltage protection with
- 86 the auxiliary lockout relay

The other one is high impedance fault, a high impedance differential protection approach, the scheme happens to be like this and the connection diagram is different then what we saw for the normal differential protections with low impedance approach. Here we have high resistance value which is connected to an overcurrent relay having high sensitive over current relay, so this is the arrangement for the 87Z, Z for the high impedance path.

So, this resistance value can be few kΩ also and then it is connected in MOV across this for the protection aspect and if required over current relay can be also connected in this fashion. So, what happens here in this case is that in case of an external fault if any of the CT saturates for the external fault that path becomes a low impedance path and thereby the corresponding current flows through that path because this all you see here CTs are connected to the common point. Thereby the corresponding current through this high resistance path where the corresponding relay is being connected the amount of current becomes insignificant but for internal fault case even though one CT or multiple all CTs may saturate though the corresponding output voltage becomes very high and in that case the corresponding through this path even though the resistance is high the current becomes significant to drive the corresponding over current, here you can say that at 87Z. That results the corresponding relay to operate for internal fault case.

However, in this arrangement the corresponding CTs need to be specially designed or in that perspective so that the corresponding for this requirement of satisfaction of this happens to be there but note that in case of internal fault the corresponding voltage may be very high and that may be detrimental for the gadgets like the high resistance, the resistor and other accessories here and to protect from that the Metal Oxide Varistor is being added in parallel with these circuits. The 86, the auxiliary lockout relay which helps in the tripping mechanism.

The advantage of this one is that the primary operating current be set much below the circuit load resulting in a high sensitivity. Disadvantages are the relay setting must take the CT secondary winding and wiring resistance into account which must be kept low and the CT knee point voltage must be known and that is what I like to say that in the design process they need special CTs and detailed information of the CTs also.

All CTs should have the same ratio, this is another typical requirement and should be also the same type of performance and so. Furthermore, the stability of the protection depends on the fault level and this simple form of high impedance busbar protection is widely used for the simple busbar configurations but not suitable for complex busbar arrangements. So, we will see many applications in this oriented but this has special requirement in the application perspective.

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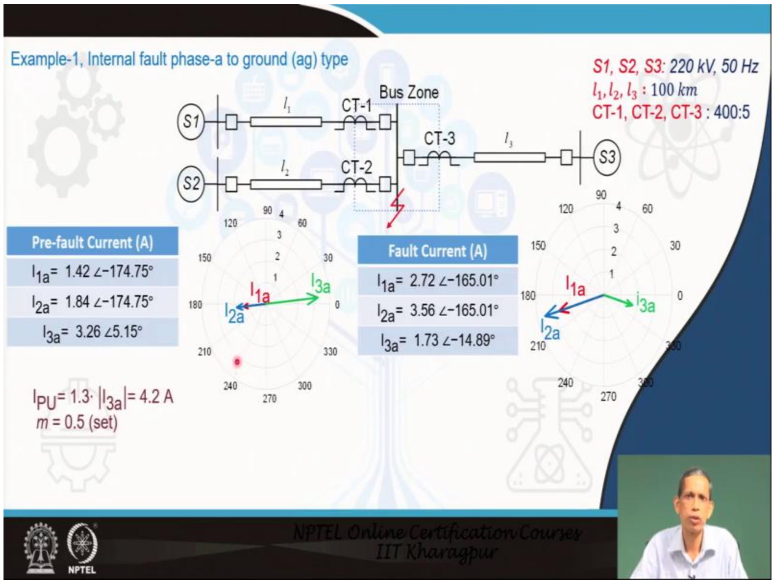

Example-1, Internal fault phase-a to ground (ag) type

S1, S2, S3: 220 kV, 50 Hz
l_1, l_2, l_3 : 100 km
CT-1, CT-2, CT-3 : 400:5

Pre-fault Current (A)
$I_{1a} = 1.42 \angle{-174.75°}$
$I_{2a} = 1.84 \angle{-174.75°}$
$I_{3a} = 3.26 \angle 5.15°$

Fault Current (A)
$I_{1a} = 2.72 \angle{-165.01°}$
$I_{2a} = 3.56 \angle{-165.01°}$
$I_{3a} = 1.73 \angle{-14.89°}$

$I_{PU} = 1.3 \cdot |I_{3a}| = 4.2$ A
$m = 0.5$ (set)

We will see two examples, the first one is internal fault and second one is on external fault related to busbar. So, this is a busbar and we have three lines connected to the busbar and an internal fault happens to be there in this busbar and the fault is of *ag* type in phase A only. So, the associated CTs groups connected 1, 2, 3 that corresponds to the corresponding line 1, 2 and 3 feeder lines.

In the pre-fault condition, we have I_{1a}, I_{2a} and I_{3a} these are the three line currents in phase A and then if we apply KCL then the phasor shows that this sum will be 0. So, for this perspective as we already mentioned for the low impedance protection arrangement we have

$$I_{PU} = 1.3 I_{max},$$

I_{max} is the maximum current happens to be there in the third line connected to the bus that is 3.26 A, so

$$I_{PU} = 1.3 \times 3.26 = 4.2,$$

We have selected m the slope (m) of the line of the percentage by differential relay to be 0.5, this is about low impedance percentage by differential relay. For internal fault the current level not though significant but it clearly shows that there is an unbalance in the system here and if we see the corresponding phasor positions so the summation becomes non-zero and that is what the KCL governs.

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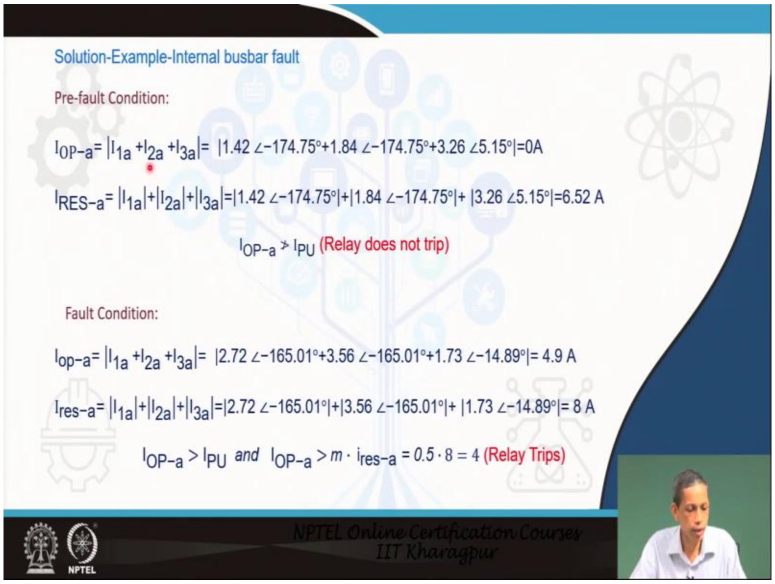

Solution-Example-Internal busbar fault

Pre-fault Condition:

$$I_{OP-a} = |I_{1a} + I_{2a} + I_{3a}| = |1.42\angle{-174.75^\circ} + 1.84\angle{-174.75^\circ} + 3.26\angle 5.15^\circ| = 0A$$

$$I_{RES-a} = |I_{1a}| + |I_{2a}| + |I_{3a}| = |1.42\angle{-174.75^\circ}| + |1.84\angle{-174.75^\circ}| + |3.26\angle 5.15^\circ| = 6.52\ A$$

$I_{OP-a} \ngtr I_{PU}$ (Relay does not trip)

Fault Condition:

$$I_{op-a} = |I_{1a} + I_{2a} + I_{3a}| = |2.72\angle{-165.01^\circ} + 3.56\angle{-165.01^\circ} + 1.73\angle{-14.89^\circ}| = 4.9\ A$$

$$I_{res-a} = |I_{1a}| + |I_{2a}| + |I_{3a}| = |2.72\angle{-165.01^\circ}| + |3.56\angle{-165.01^\circ}| + |1.73\angle{-14.89^\circ}| = 8\ A$$

$I_{OP-a} > I_{PU}$ *and* $I_{OP-a} > m \cdot i_{res-a} = 0.5 \cdot 8 = 4$ (Relay Trips)

Now, if we apply the additions, the operating current in phase A, there is a phase A to ground fault we are checking phase A only here. So, this summation becomes of these three phasors becomes 0 A during pre-fault condition, the restraining current becomes significantly high 6.52 A, so therefore the relay will not go for operations during pre-fault condition.

For fault condition, to know whether it is internal or external the operating is summation with those values what we have seen in the earlier slide, if we add all these things they become

$$I_{op\text{-}a} = |I_{1a} + I_{2a} + I_{3a}| = |2.72\angle\text{-}165.01° + 3.56\angle\text{-}165.01° + 1.73\angle\text{-}14.89°| = 4.9\ A$$

The restraining current becomes

$$I_{res\text{-}a} = |I_{1a}| + |I_{2a}| + |I_{3a}| = |2.72\angle\text{-}165.01°| + |3.56\angle\text{-}165.01°| + |1.73\angle\text{-}14.89°| = 8\ A$$

As

$$I_{OP\text{-}a} > I_{PU}\ \ \textit{and}\ \ I_{OP\text{-}a} > m \cdot i_{res\text{-}a} = 0.5 \cdot 8 = 4$$

Therefore even a small value of internal fault situation the relay is able to detect the fault correctly.

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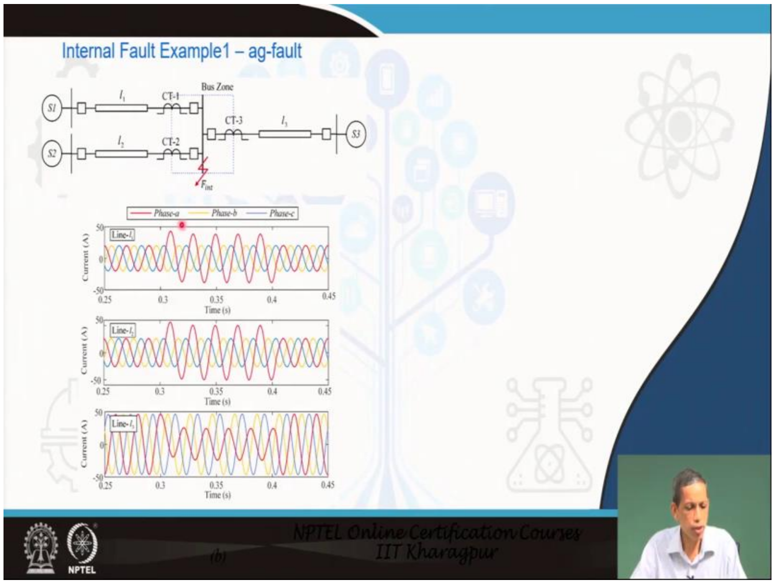

Internal Fault Example1 – ag-fault

In oscillograms, if we see the situations, if we see here this phase A current is high after this following the fault inceptions at this point so this we notice in all the l_1, l_2 and l_3, all the three lines.

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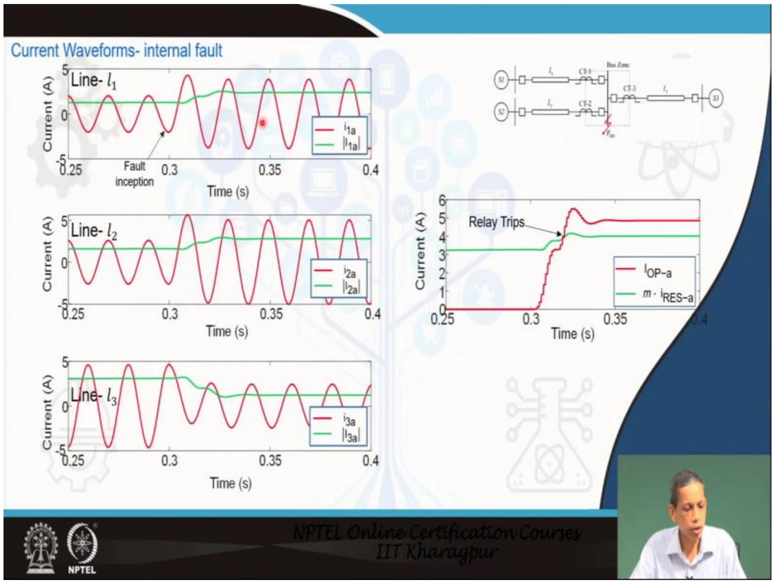

Current Waveforms- internal fault

Then you can say that if we go to the corresponding particular phase, the corresponding current magnitude increases during the fault situation, in all the three phases the corresponding current happens to be this way and then if you see the corresponding dynamic plot of this one then you see the operating current (I_{OP_a}) to be the red one and the restraining current mi_{RES_a} becomes this one. So, because the $I_{OP\_a} > mi_{RES\_a}$ so the relay will go for trip basis and that is what the dynamic plot also such that the relay will consistently find the fault as internal fault.

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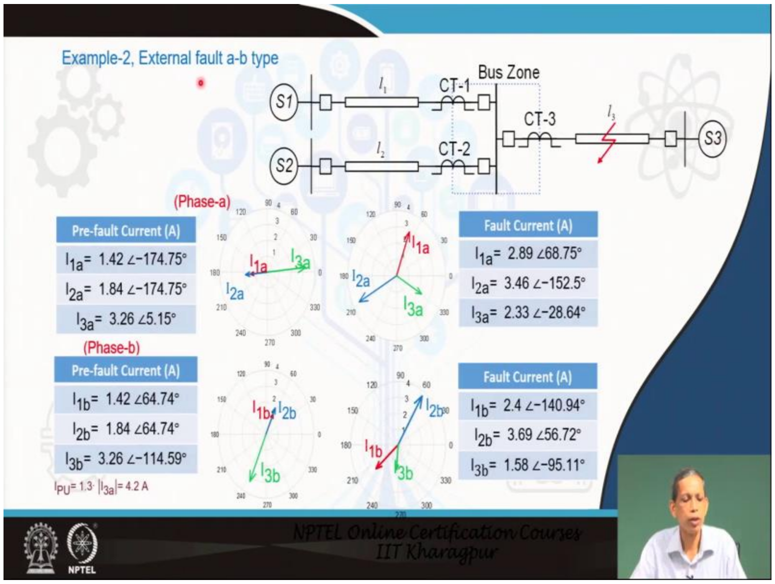

Example-2, External fault a-b type

(Phase-a)

Pre-fault Current (A)
$I_{1a} = 1.42 \angle -174.75°$
$I_{2a} = 1.84 \angle -174.75°$
$I_{3a} = 3.26 \angle 5.15°$

Fault Current (A)
$I_{1a} = 2.89 \angle 68.75°$
$I_{2a} = 3.46 \angle -152.5°$
$I_{3a} = 2.33 \angle -28.64°$

(Phase-b)

Pre-fault Current (A)
$I_{1b} = 1.42 \angle 64.74°$
$I_{2b} = 1.84 \angle 64.74°$
$I_{3b} = 3.26 \angle -114.59°$

Fault Current (A)
$I_{1b} = 2.4 \angle -140.94°$
$I_{2b} = 3.69 \angle 56.72°$
$I_{3b} = 1.58 \angle -95.11°$

$I_{PU} = 1.3 \cdot |I_{3a}| = 4.2$ A

This case is for external fault, in busbar the fault can be either insulator failure or an external element faults on the buses and there are numerous regions of faults and all these things. So, consider a fault of *ab* type in this case and external fault, this fault may be in this case in the line fault beyond the corresponding busbar.

Pre-fault condition phase A current, phase B current in all the three lines that what will be the corresponding CTs will provide to the busbar and then this is the fault current which are for phase A and phase B because this fault is involved in phase A and B so that is why we are showing here these two phases. Similarly, we can notice for the phase C also and these phasor positions for this pre-fault and the corresponding fault are shown here. So, in pre-fault the summation will be 0, and in case of here also this is by enlarge 0 in this case because of the balance nature of the for the external fault cases.

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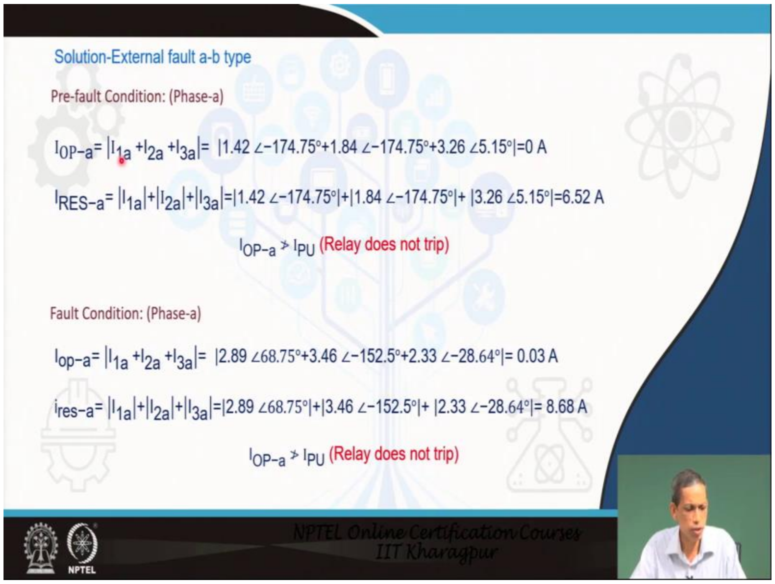

Solution-External fault a-b type

Pre-fault Condition: (Phase-a)

$I_{OP-a} = |I_{1a} + I_{2a} + I_{3a}| = |1.42 \angle -174.75° + 1.84 \angle -174.75° + 3.26 \angle 5.15°| = 0\ A$

$I_{RES-a} = |I_{1a}| + |I_{2a}| + |I_{3a}| = |1.42 \angle -174.75°| + |1.84 \angle -174.75°| + |3.26 \angle 5.15°| = 6.52\ A$

$I_{OP-a} \ngtr I_{PU}$ (Relay does not trip)

Fault Condition: (Phase-a)

$I_{op-a} = |I_{1a} + I_{2a} + I_{3a}| = |2.89 \angle 68.75° + 3.46 \angle -152.5° + 2.33 \angle -28.64°| = 0.03\ A$

$i_{res-a} = |I_{1a}| + |I_{2a}| + |I_{3a}| = |2.89 \angle 68.75°| + |3.46 \angle -152.5°| + |2.33 \angle -28.64°| = 8.68\ A$

$I_{OP-a} \ngtr I_{PU}$ (Relay does not trip)

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For calculation pre-fault again the I_{OP_a} in phase A this becomes 0 and restraining current becomes significantly high 6.52 A. So, $I_{OP-a} \ngtr I_{PU}$ that is why it will not go for operation. Fault condition phase a when we say, in phase *a* the corresponding fault current is pretty small 0.03 A as compared to the restraining current 8.68 A, so the relay does not satisfy I operating greater than I_{PU} and that is why this will not go for operation, this is correct because this is an external fault situation.

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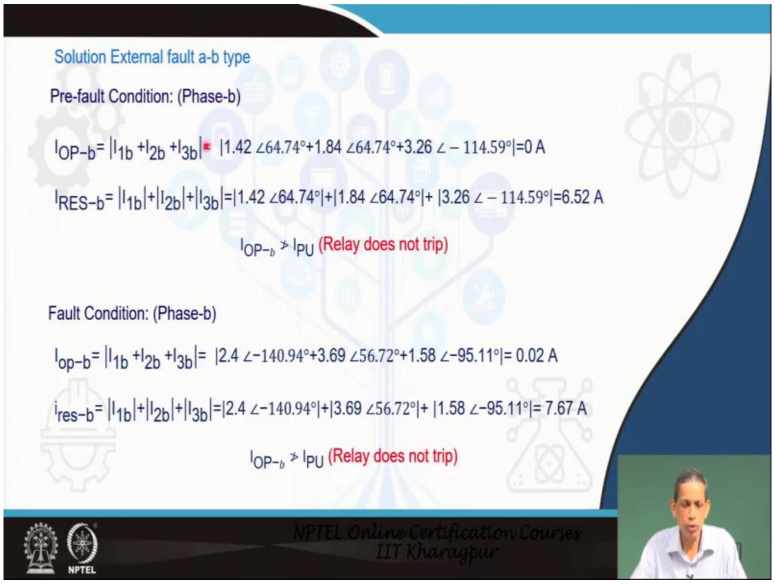

Solution External fault a-b type

Pre-fault Condition: (Phase-b)

$I_{OP-b} = |I_{1b} + I_{2b} + I_{3b}| = |1.42 \angle 64.74° + 1.84 \angle 64.74° + 3.26 \angle -114.59°| = 0\ A$

$I_{RES-b} = |I_{1b}| + |I_{2b}| + |I_{3b}| = |1.42 \angle 64.74°| + |1.84 \angle 64.74°| + |3.26 \angle -114.59°| = 6.52\ A$

$I_{OP-b} \ngtr I_{PU}$ (Relay does not trip)

Fault Condition: (Phase-b)

$I_{op-b} = |I_{1b} + I_{2b} + I_{3b}| = |2.4 \angle -140.94° + 3.69 \angle 56.72° + 1.58 \angle -95.11°| = 0.02\ A$

$i_{res-b} = |I_{1b}| + |I_{2b}| + |I_{3b}| = |2.4 \angle -140.94°| + |3.69 \angle 56.72°| + |1.58 \angle -95.11°| = 7.67\ A$

$I_{OP-b} \ngtr I_{PU}$ (Relay does not trip)

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For phase *b* also if we observe similar situation happens to be there the corresponding pre-fault condition is 0 A for phase b and restraining current is 6.52 A so restraining the corresponding pre-fault condition does not operate. For fault condition in phase *b* this is also the corresponding value of operating current is pretty less insignificant as compared to the restraining current of 7.67 A. So, in the phase *b* differential also, it is being observed that it does not satisfy $I_{OP\text{-}b} \ngtr I_{PU}$ it implies this is an external fault.

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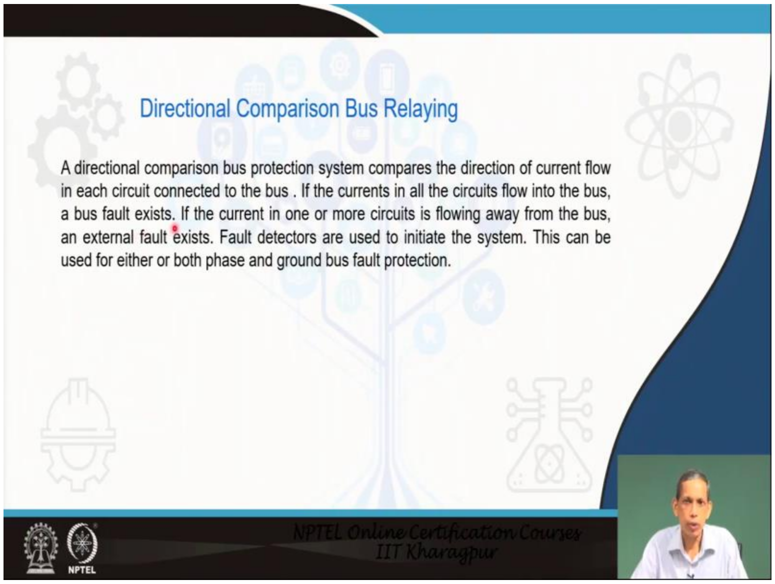

Directional Comparison Bus Relaying

A directional comparison bus protection system compares the direction of current flow in each circuit connected to the bus . If the currents in all the circuits flow into the bus, a bus fault exists. If the current in one or more circuits is flowing away from the bus, an external fault exists. Fault detectors are used to initiate the system. This can be used for either or both phase and ground bus fault protection.

Now, there are also other arrangements, other protection schemes available in this one. A directional comparison bus relaying, a directional comparison bus protection system compares the direction of current flow in each circuit connected to the bus. If the currents in all circuits flow into the bus, a bus fault exists. This is based on the direction information, directional relaying principle we have learned in earlier also in details using differential principle including negative sequence and so. If the current in one or more circuits is flowing away from the bus, an external fault exists. Fault detectors are used to initiate the system and this can be used either or both phase and ground faults protections and also these such different protection schemes for the busbar also can be integrated and they can be combined to make a more reliable decision also.

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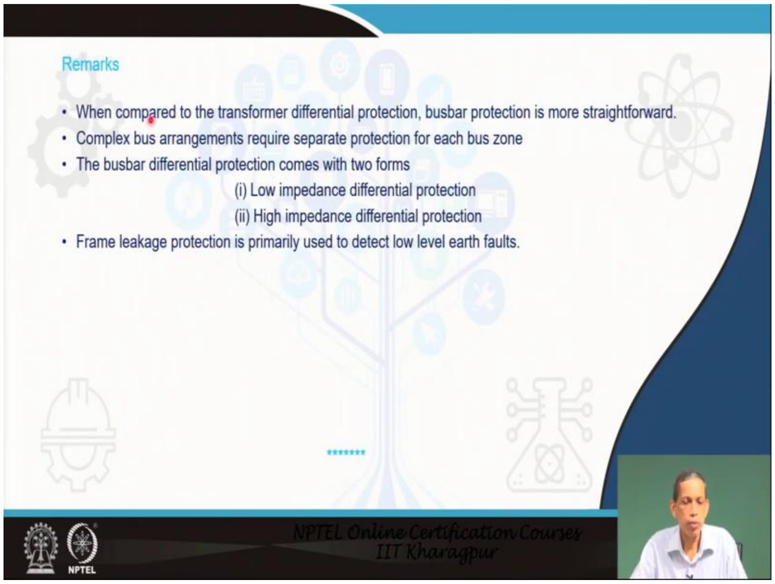

Remarks

- When compared to the transformer differential protection, busbar protection is more straightforward.
- Complex bus arrangements require separate protection for each bus zone
- The busbar differential protection comes with two forms
  - (i) Low impedance differential protection
  - (ii) High impedance differential protection
- Frame leakage protection is primarily used to detect low level earth faults.

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The overall remarks on this perspective is that, when compared to transformer differential protection, busbar protection is more straightforward but complex bus arrangements require separate protection for each bus zone that we observed in very beginning. Busbar differential protection can be categorized into two, the low impedance differential protection and the high impedance differential protection.

High impedance differential protection is widely used but it requires special CTs for its applications. We also saw frame leakage protections which is sensitive to earth fault perspective. So, busbar protection is critical to the power system operation, it should be clear as fast as possible so that system stability is not being hampered. Thank you.