Power System Protection
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Lecture - 30
Power Swing Detection Techniques
Part - II

Welcome to Power System Protection course. We are discussing on distance relaying. In this lecture, we will talk on Power Swing Detection Techniques, continue with that.

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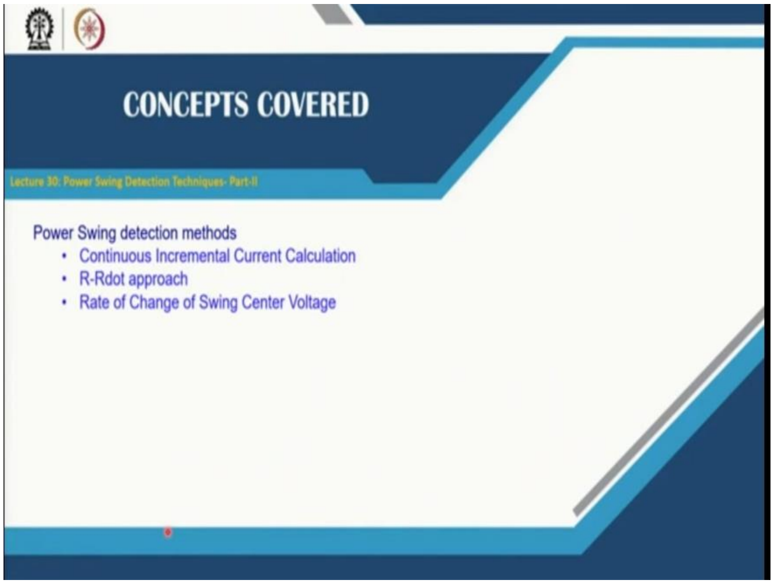

We will be addressing the other techniques on power swing detection methods, three techniques; continuous incremental current calculation, the R-Rdot approach, and the rate of change of swing center voltage techniques for this perspective.

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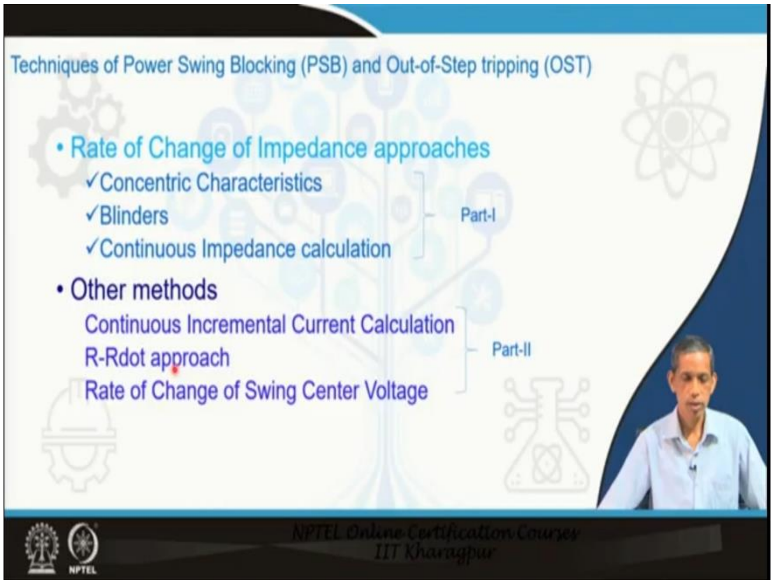

So in the last lecture, we discussed about three techniques based on the rate of change of impedance; the concentric characteristics, blinders, and continuous impedance calculation. We discussed what both power system blocking and out-of-step tripping and we demonstrated examples on stable swing, unstable swing, and fault; how the relay is able to distinguish them.

We will continue that with more methods available in this domain which are being used in different relays. So first one is your continuous incremental current calculation, only current based. Second one is R-Rdot that is a derivative of resistance, and the rate of change of swing center voltage; the swing center voltage, we will define that, and then we have its rate of change.

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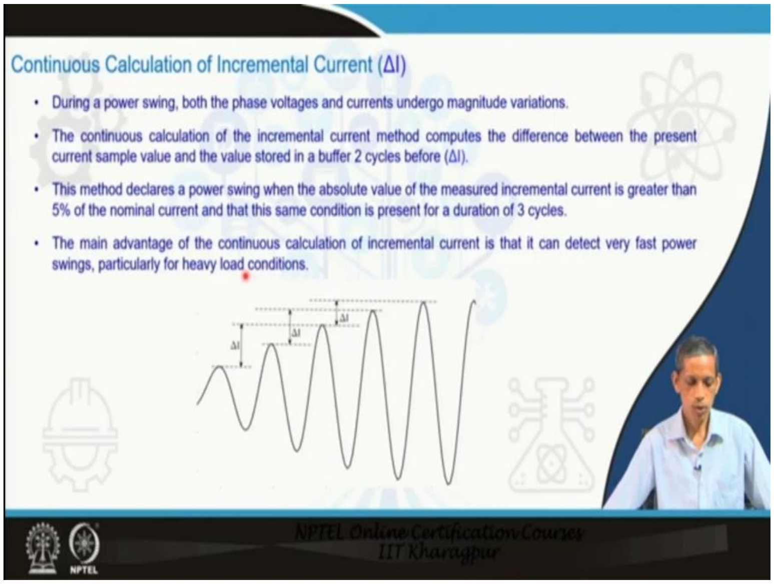

So let us start the first one, continuous calculation of incremental current. So we know that both voltage and current varies, they vary significantly during swing situation. All the 3 phases observe this. The continuous calculation of the incremental current, ΔI, incremental current, or literature says about superimposed current also. The method computes the difference between the present current sample value and the value stored in the buffer two cycles earlier. The two cycles earlier value and the present value, they are being compared and you compute the, calculate the ΔI for each sample.

Like here, we see here this point, and this point 2 cycles, so that is why this and this compare ΔI. So this point and this point so then this becomes your ΔI and like this. So this swing situation, swing trajectory and we find the ΔI to be significant. Normally, the ΔI will be steady-state so magnitude will be same. So it will be 0. But during fault also the ΔI is expected to be higher but once the fault persists then the δ will be negligible, we will see that perspective.

What the method does that the method declares a power swing when the absolute value of the measured incremental current, its absolute value of ΔI is greater than 5 percent of the nominal current of the system, that this same condition is present for duration of 3 cycles. So if the consecutive 3 cycles, 50 Hz system, 60 millisecond around, if this situation persist then the ΔI magnitude becomes more than 5 percent of the nominal value of current, then the relay declares this as a swing situation otherwise not.

The advantage of this continuous calculation of incremental current is that it detects very fast power swings and also the corresponding particularly for heavy load condition, including heavy load condition also because it is superimposed component-based.

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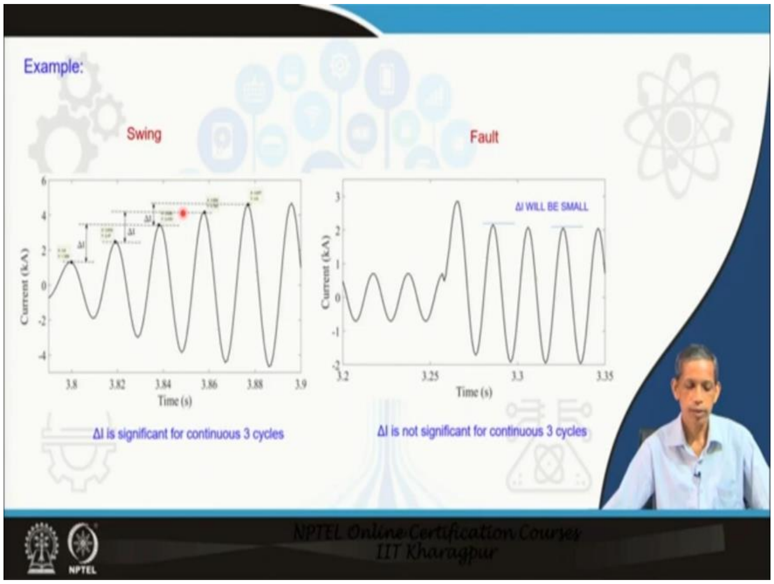

Now let us see this situation as an example. So this is a swing situation, swing trajectory for the current. So we go on ΔI computing from the 2 cycles. So this one, 2 cycles will be for this, so this to this, so this is ΔI value we go on calculating the ΔI value. You see this magnitude of ΔI so that can bring down here, for 3 cycles you can do like this.

Now, this is a fault situation, and suddenly the current jumps so at this point we have computed the 2 cycles, this becomes significant but if you see this point here inside the fault because due to decaying you see it will die down and then it goes to the steady region. Then this point and earlier to 2 cycles you see here the ΔI becomes negligible as compared to this swing situation side.

So this clearly shows that if you find the corresponding ΔI for a period of time like we mentioned about 3 cycles, then the swing can be clearly identified from fault situations. So this is what being used in this approach of many relays used at this principle to distinguish, to identify power swing.

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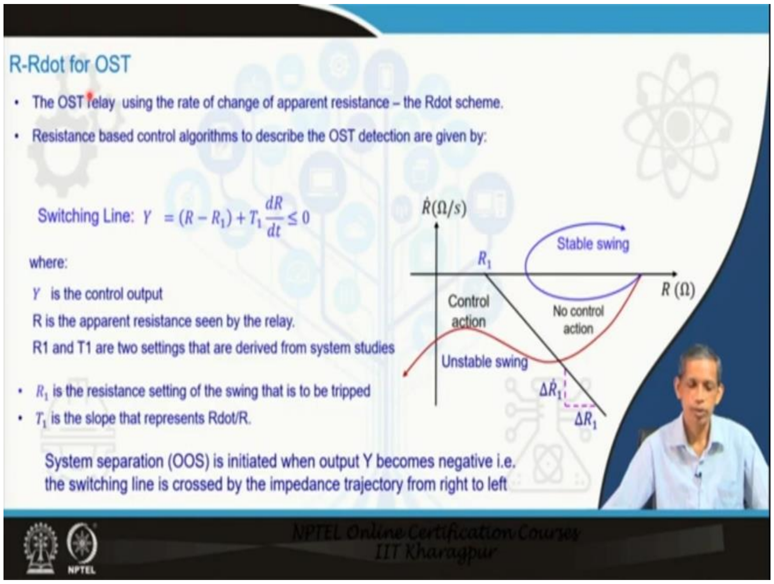

The R-Rdot approach is used for out of step tripping specific utility only. So we know that when the apparent impedance becomes smaller than a value, then the distance relay should go for a trip decision. So with that philosophy that if the Z is smaller than X value, then the relay will trip.

With that concept, this principle is being taken from, so this is to identify unstable power swing. So for that what is being done, a dZ/dt also be taken into consideration including that $Z - Z_{setting}$ also. Note $Z - Z_{setting}$ becomes negative when the apparent impedance is inside the characteristic. That results in a trip decision.

Now, what is being done $Z - Z_{setting} + k\frac{dZ}{dt}$, rate of change of impedance to accommodate in the corresponding swing perspective is being added. In furthering that theory, what is being done that instead of the impedance, the real part of that gives you the resistance, and thus, the approach is just in that perspective.

So what is being done in the line, a straight line is defined in the Rdot, Rdot means the dR/dt and the R. R is in X-axis; dR/dt in Y-axis. A straight line is defined based on the same principle what take mention on the impedance. R- R_1 like Z – Z_1, the Z setting; $Y = (R - R_1) + T_1\frac{dR}{dt}$. So if this is less than 0 means negative then the corresponding thing is called an unstable swing situation.

So this is the straight line which we are trying to define and its slope is based on this T_1 is dR/dt. So then, we say here, so this X-axis intersection point is R_1. So what happens here that this Y, the output of this control output for this equation so continuously you can find out the dR/dt from the real part of this impedance and then R_1 is the setting value, T_1 is setting value, so then you can compute this Y. When Y becomes negative in this zone then the system we declared here is unstable.

Stable swing traverses path in this region and unstable goes through this. So it will go to the negative. So thereby the corresponding relay can decide very quickly on the perspective of the unstable swing that is out of step tripping perspective. System separation initiated when the output Y becomes negative and the switching line is crossed by the impedance trajectory from right to left subject that it traverses this path because this is the load area. So in the load area, it traverses like this on stable swing and it will not cross the line in case of stable swing. So this is the simple approach being used for the out-of-step tripping perspective.

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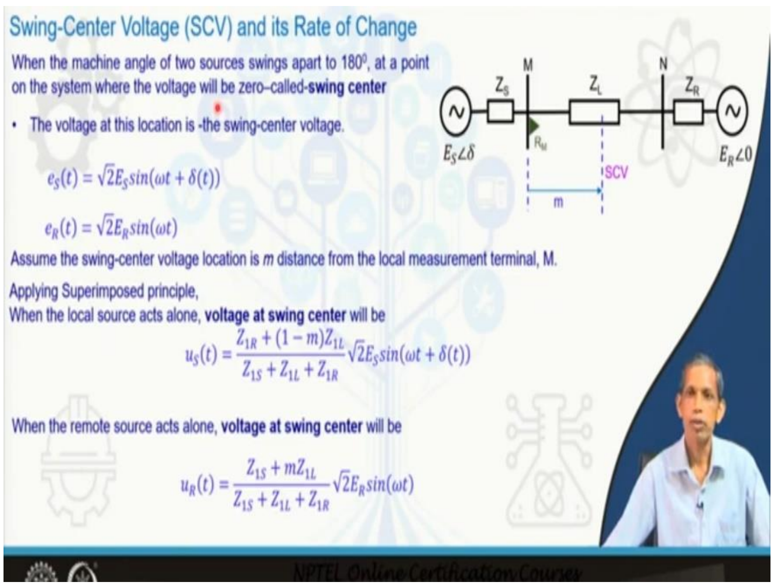

Now we go to the last method, swing center voltage approach. So on this, we will define swing center voltage and then we will proceed further. Let us consider a system like this and we have a source impedance local Z_S, and the Z_R is the remote, and the line impedance is Z_L. So earlier, we have define what its electrical center. So same concept we are again continuing here.

So when the machine angle of the two side sources are 180^O apart, at a point in the systems, the voltage becomes 0 and that is called the swing center. That point where the corresponding angle becomes 180^O and the voltage vanishes, that we call swing center. We talk about electrical center in the earlier discussion. The corresponding voltage of that center at different situations is the swing center voltage. Once again, we point out that what is the swing center point in the impedance plane where the corresponding voltage becomes 0 during the 180^O and now, the corresponding voltage at different situation of the δ is called the swing center voltage.

Let us define the E_{st}, this side source is expressed in terms of the sinusoidal thing; and the E_{rt}, this side source voltage becomes this sinusoidal thing. We consider the power is flowing from left to right with an advancement angle of δ by this source as compared to the right-hand side source. Let us assume that the corresponding swing center is m distance from this Z_L per unit distance from this m bus and this falls on the line impedance Z_L.

Now, we will apply this superimpose principle. So each source applying one by one, one after the other. So when this first source us swing is there, so we say that the voltage at the swing center m distance from this R_M relay. So the voltage at the swing center contributed by this, only this source is short-circuit area at the time. So that becomes equals to $u_S(t) = \frac{Z_{1R}+(1-m)Z_{1L}}{Z_{1S}+Z_{1L}+Z_{1R}}\sqrt{2}E_S sin(\omega t + \delta(t))$.

So we are applying this voltage and we are trying to consider what is the corresponding voltage of this point, so that from this side because this is sorted, so this side this voltage will be this one. When the remote sets acts alone and this side is sorted, the voltage at the swing center again from this side will be this side sorted. So that will be $\frac{Z_{1S}+mZ_{1L}}{Z_{1S}+Z_{1L}+Z_{1R}}\sqrt{2}E_R sin(\omega t)$.

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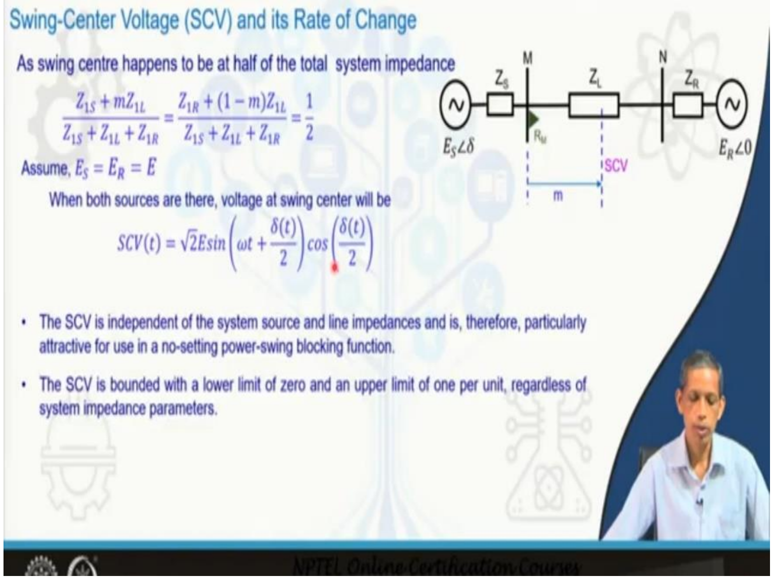

Now, what we see, that we know earlier also that this location is half of from both the sides. The swing center or electric center is half of the total impedance of the line, $Z_S + Z_L + Z_R$. So that gives us that these 2 impedances which we are looking from this side or that side what we have calculated in the earlier slide, $\frac{Z_{1S}+mZ_{1L}}{Z_{1S}+Z_{1L}+Z_{1R}} = \frac{Z_{1R}+(1-m)Z_{1L}}{Z_{1S}+Z_{1L}+Z_{1R}} = \frac{1}{2}$ because it points to that point only.

So if we assume E_S equals to E_R equal to E, same voltage simplicity, then the swing center voltage at any instant of time T, $SCV(t) = \sqrt{2}Esin\left(\omega t + \frac{\delta(t)}{2}\right) cos\left(\frac{\delta(t)}{2}\right)$. So we got that both the sources are there that is superimposing these two, whatever voltage is obtained at the endpoint and with this the relation of half with algebraic manipulations we will get that this side source and that side source, combined them, add them, we will get the voltage to be $\sqrt{2}Esin\left(\omega t + \frac{\delta(t)}{2}\right) cos\left(\frac{\delta(t)}{2}\right)$.

So this term if you see here it is this magnitude of the corresponding swing center voltage and this is about the sine of this angle, the δ(t) also. So the corresponding swing center voltage is a function of δ(t); swing center voltage is independent of the system's source and line impedances, no impedance, nothing. There is only to the √2E and the δ perspective, and ω is frequency, a system frequency, sine ωt, 50-hertz system or so.

So, therefore, particularly attractive for use in no setting power perspective and that is the beauty of this approach. Furthermore, this swing center voltage is bounded because it is sinusoidal and this cos term we considered this, is 0 and upper limit to 1 per unit, if you make it a per unit if we have a 0 to 1 so that is why I can say that another from the calculation perspective, simplify the thing.

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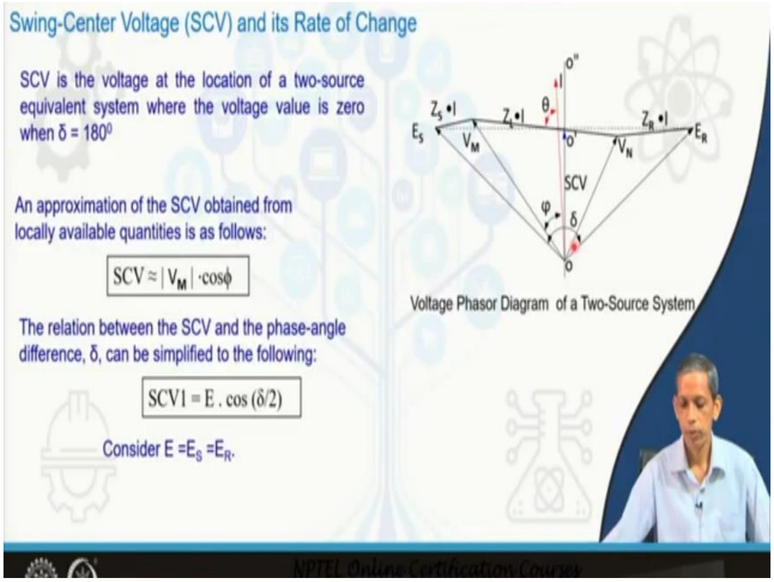

Now, I will move forward. In our earlier discussion also, we have this kind of diagram on the impedance. Now, to this impedance, if we multiply I, then we get the voltage. So then this becomes also the voltages. So this is source voltage E_S, this is V_M and this is Z_SI, the Z_LI, and this Z_RI. And this straight line, as we have discussed earlier, is nothing but the total impedance of the line, so ZI, you can say the dotted line.

Now, if this is the operating point at any instant of time, so this voltage is E_S, this voltage is relay voltage, this set is E_R set voltage, and this is the other voltage bus perspective. Now, let us consider the midpoint is O'. So this is swing center, so the corresponding swings under voltage is SCV is this one, O to O'.

Now, if you see this, SCV have a similarity that this δ, when it traverses in makes 180^O here if the trajectory comes on this path when k equals to 1. We have discussed earlier. Now, if you see this you can see there is similarity here, this V_M with is the relay bus which is measurable, this φ the corresponding current with respect to this V_M at the relay bus during any instant of time where the angle between these two sources is δ.

So now $V_M$cos φ on this perspective so that becomes equals to very close to SCV with little difference. So an approximation of SCV obtained from the local evaluated quantities, locally we are trying to commit approximations that this VM cos φ becomes this. Note the θ, this I Z and θ because line impedance is more than 85^{O} with an angle or so, then the theta will be close to 90^{O} and that leads to a situation in that perspective that the V_M cos φ at this point will be very close to the swing center voltage.

Any discrepancy or so does not matter much because of the further discussions would like to have. The relation between SCV and the phase angle δ can be simplified to the following. So what we see here, if you see this, further this diagram, φ the angle between V_M and the corresponding I at that point; for δ is the angle between E_S and E_R. Now, this φ is almost δ by 2.

So if we take this, the corresponding E equal to E_S equals to E_R perspective, then the corresponding V cos φ, so this E cos (δ/2), if you take this one then this is also an approximation to the swing center voltage. We have distinguished SCV here to SCV1 because of this approximation. So the swing center voltage can be approximated from this measurement. What is measurable? V_M and the corresponding φ and from that you can calculate swing center voltage, but this can be related to this swing center voltage where it is related to this angle δ.

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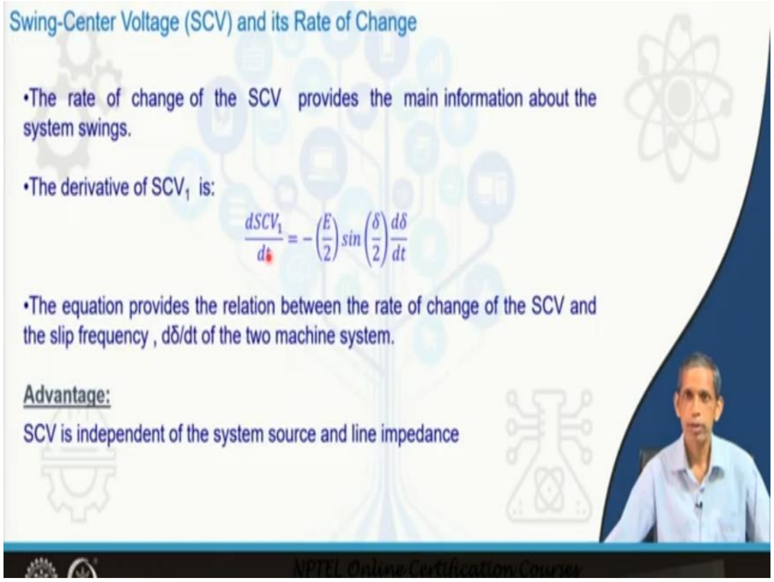

What we will do now that with that swing center voltage SCV1 if we take the derivative of that one, $\frac{dSCV_1}{dt} = -\left(\frac{E}{2}\right) sin\left(\frac{\delta}{2}\right)\frac{d\delta}{dt}$. So this shows that the derivative of the swing center voltage is having only in terms of the δ terms and the voltage. The equation provides the relation between the rate of change of swing center voltage and the slip frequency dδ/dt for the two-machine equivalent system.

What are the advantages? The independent of source and line impedances which are difficult to get unlike in the earlier lectures on concentric circle or the blinder approach which where we required to use Z_T impedance and total impedance of this system or so. So this shows that the derivative of this can be easily obtained from this one and that will be indicative of the situation of distinguishing swing versus fault and the unstable swing and swing perspective, so what logic is being followed.

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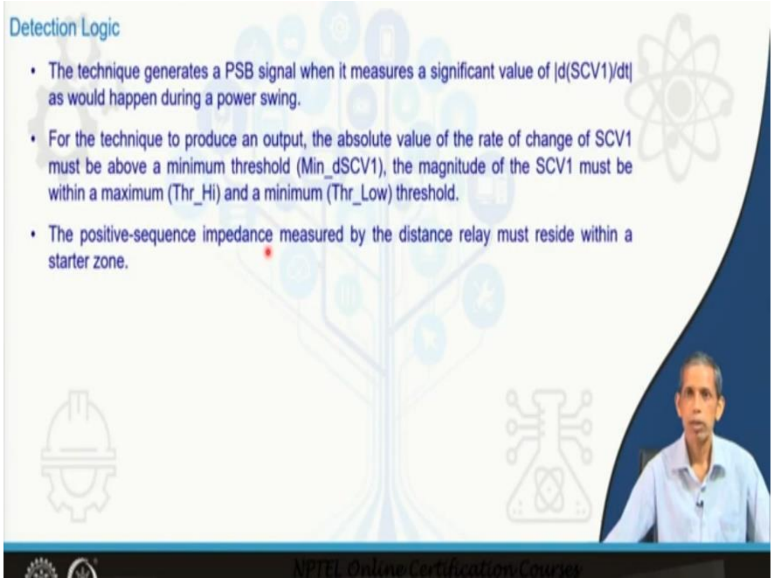

The technique generates the blocking signal, power swing blocking signal when it measures a significant value of swing center voltage say, derivative dSCV1/dt. Dδ/dt, I am saying that from that one if you calculate the corresponding dSCV1/dt then we will find that it will be very significant one power swing.

For techniques to produce an output, the absolute value of the rate of change of SCV1, we have to ensure that SCV value is of good value is there to check its experience that this swing is passing through. And it must be minimum threshold of, minimum value of rate of change of voltage and the magnitude of SCV1 must be within a limit, maximum, and minimum.

Furthermore, the positive sequence impedance measured by the distance relay must be within a starter zone like the, we talked about concentric circles and so. So these are being satisfied means the corresponding power swing blocking function can be invoked. It will ensure that this is going to be a swing business and the relay has to be blocked. So we saw from the earlier discussion that the derivative of that one is having a dδ/dt at the swing frequency perspective.

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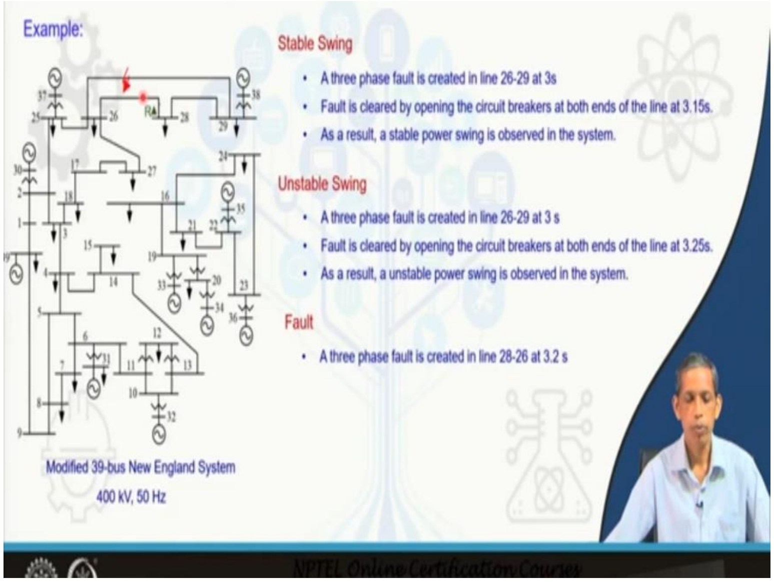

Now, let us consider take the same system and examples what we have discussed in our earlier lecture also, stable swing, unstable swing, and fault, which are to be distinguished by this approach. So what will be there for this stable swing, we created a fault and then we cleared this line, and then, this relay observed swing.

Second case, unstable swing; we delayed the clearance of this fault. So then this observes the unstable situation. And then, we create instead of this fault, we created a fault in this line, line between 28 and 26, and then we created fault. So these 3 situations are to be distinguished by the swing center voltage approach and its rate of change of swing center voltage.

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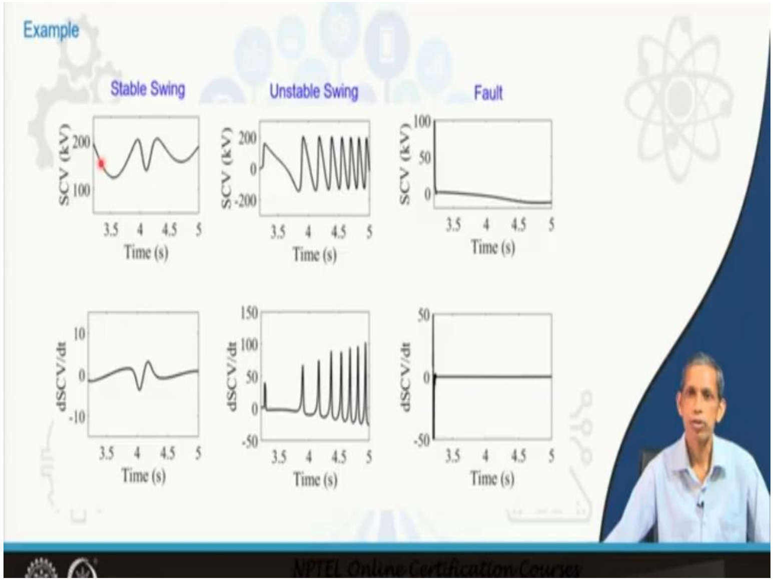

Now you see that the swing center voltage, how do you compute this? V cos φ. We have this V measurement at the end bus, at the local bus, relay bus, and the corresponding φ angle between voltage and current. So that V_M cos φ gives us a swing center voltage. So we have plotted this one for this swing center.

The derivative of this one gives us dSCV/dt, so we have this one. So now from this for this stable swing, we have a positive value of swing center voltage and this is going down some negative value and then this perspective. Unstable swing, we know this unstable swing center voltage pretty oscillating, large value also and it crosses the 0 or the derivative of that one is having like this, pretty high value as compared to the stable swing case.

Now during fault. Swing center voltage, small value, derivative is almost constant. So the derivative is almost negligible so we see here swing center voltage is negligible and small amount is there means fault. Swing center voltage, derivative of swing center voltage is significant and swing center voltage oscillates at 0, then this is unstable.

Swing center voltage smaller value and this derivative of swing center voltage is smaller value and swing center voltage is having a positive value, then we say this is stable swing. Thereby we say that the swing center voltage approach can be applied to distinguish fault from swing and stable and unstable swing for out of the tripping business. The beauty of this method is that it does not require any system study in the setting perspective.

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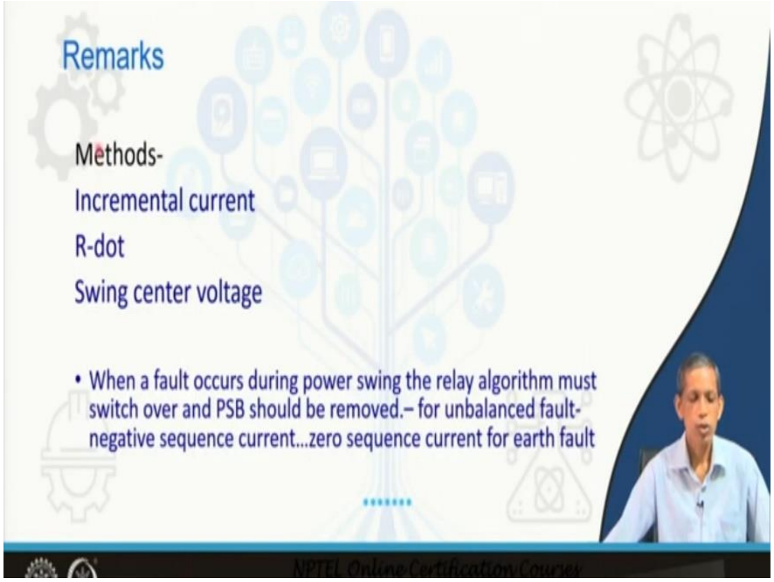

So in general, we saw in this lecture 3 methods. Incremental current, only from the current signal; the R-dot approach to have out of step tripping business; and then finally, swing center voltage approach and its derivative we talked. The derivative gives information on that whether it is to distinguish swing from fault and whether it is a stable swing and unstable swing in supplement with the swing center voltage decides.

Now, however, we launched many techniques on to distinguish swing from fault decision for the power swing blocking, and for out-of-step tripping, we have to identify whether it is unstable situation or not. And the out of step tripping is being accomplished at strategic locations only which are predefined and not at all locations for the distance relay.

Note, there is a probability also that if fault may occur during power swing situation. Because power swing is an elongated process, disturbances are there in the large systems many times in a day or so. So swinging situations will be observed by the relay frequently but the power swing blocking will not be allowed to go for trip decision unnecessarily, thereby retaining the system stability.

But the point is now if a fault happen to be there in the system during power swing, if the relay is blocked then it becomes challenging. So, therefore, the blocking has to be removed during that situations to clear the fault otherwise, there will be possible damage, which is not desirable from the protection sense.

Say, if unbalanced fault happens to be there during power swing blocking, then power swing blocking; now what will happen that power swing is 3 phase phenomena, balanced phenomena, 3 phase. Unbalanced fault like line-to-ground or phase to-phase fault or double-phase-to-ground fault happens to be there. That means their negative sequence component will be significant, which will not be found in case of swing or so. So by computing the negative sequence component as compared to the positive sequence component, we can distinguish this is as a fault situation.

And if it is a phase-to-ground fault, if the fault is involved with the ground, then zero sequence component also will be significant. So they can be used to adjust the fault situation and thereby the corresponding blocking functions can be removed from the relay. So this is all on power swing blocking issues with distance relay. Thank you.