Power System Protection
Professor. A. K. Pradhan
Department of Electrical Engineering
Indian Institute of Technology, Kharagpur
Lecture No. 29
Power Swing Detection Techniques: Part 1

Welcome to NPTEL course on Power System Protection. We are discussing distance relay. In this lecture, we will continue on Power System swing issue.

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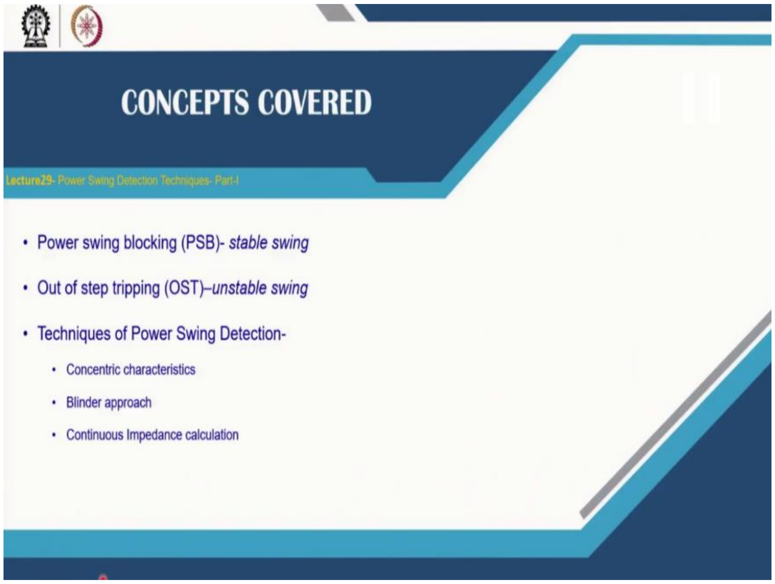

CONCEPTS COVERED

Lecture29- Power Swing Detection Techniques- Part-I

- Power swing blocking (PSB)- *stable swing*
- Out of step tripping (OST)–*unstable swing*
- Techniques of Power Swing Detection-
    - Concentric characteristics
    - Blinder approach
    - Continuous Impedance calculation

In this lecture, we will discuss about Power Swing blocking and out of step tripping. These are all swing issues and then we will discuss on three techniques on detection of power swing and also that on out of step tripping.

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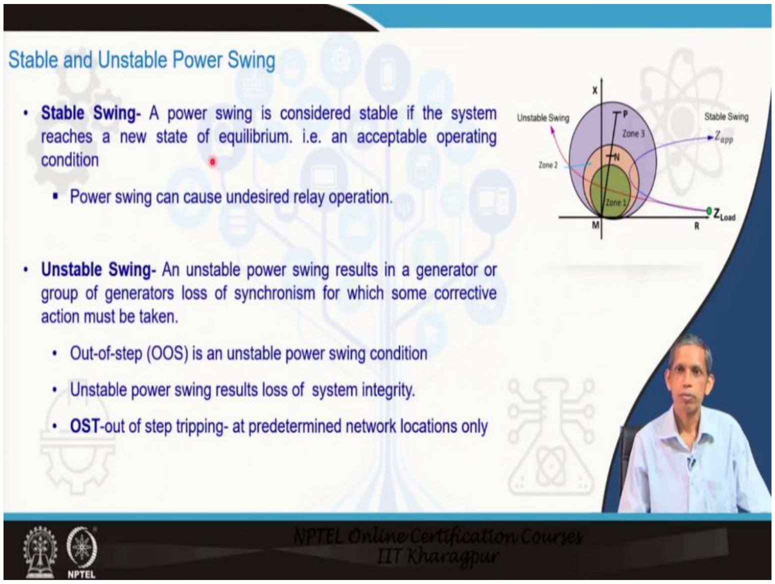

Stable and Unstable Power Swing

- **Stable Swing-** A power swing is considered stable if the system reaches a new state of equilibrium. i.e. an acceptable operating condition
  - Power swing can cause undesired relay operation.
- **Unstable Swing-** An unstable power swing results in a generator or group of generators loss of synchronism for which some corrective action must be taken.
  - Out-of-step (OOS) is an unstable power swing condition
  - Unstable power swing results loss of system integrity.
  - **OST**-out of step tripping- at predetermined network locations only

In the last class, we are discussing on how power swing creates problem to distance relay. There we saw that the impedance trajectory during swing enters into different zones and that may lead to unwanted tripping in the distance relay. So, distance relay is vulnerable in this case during power swing. Then how to overcome it? The solution for that will be discussed in this lecture.

So, in the last lecture, we talked about also on stable swing and unstable swing, let us have a more elaboration on this. A power swing is considered as stable if the system reaches a new state of equilibrium, an acceptable operating condition, but these as you know in this impedance plane may lead to an unwanted tripping element because the trajectory may enter into the different zones.

Unstable swing on the other end results in generator or a group of generators’ loss of synchronism and they may fall apart. So, corrective actions must be taken, otherwise the system may collapse. So, that leads to out of step situation and resulting in system integrity challenge. So, we call it out of step tripping is the option so, that is being incorporated into the distance relay perspective.

In case of stable swing, we see that this is not an issue in terms of system stability or integrity. So, the relay must be blocked to prevent unwanted tripping during this situation unless it is being done so, during this stable swing it will lead to unnecessary further issue in the system which may result in further stability challenges.

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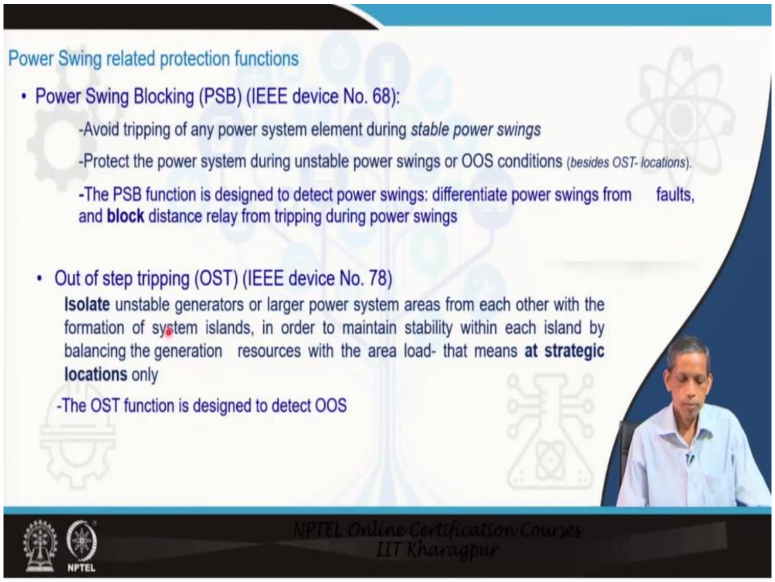

Power Swing related protection functions

- Power Swing Blocking (PSB) (IEEE device No. 68):
  - -Avoid tripping of any power system element during *stable power swings*
  - -Protect the power system during unstable power swings or OOS conditions (besides OST- locations).
  - -The PSB function is designed to detect power swings: differentiate power swings from faults, and **block** distance relay from tripping during power swings
- Out of step tripping (OST) (IEEE device No. 78)
  - **Isolate** unstable generators or larger power system areas from each other with the formation of system islands, in order to maintain stability within each island by balancing the generation resources with the area load- that means **at strategic locations** only
  - -The OST function is designed to detect OOS

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So, as mentioned, we have solutions for power swing issues. One perspective on power system Power Swing Blocking (PSB) device number 68 in IEEE device number. Now this is to avert unwanted tripping during stable power swing. The PSB function is designed to detect power swings, its objective is to distinguish swing from faults.

Note its objective is to distinguish swing from faults because during fault also the impedance trajectory will enter into the zones and then the corresponding zone will take the decision accordingly. With that philosophy, we started with the distance relay, but now, we find that during the stable power swing also or unstable also the impedance trajectory enters into the zones and that creates problem.

So, therefore, now the point is any swing happens to be there the relay must be able to distinguish whether it is a swing situation or fault situation. And if it is a stable swing there is a block even in situations in places at a steady look at different locations in the system, the relay also should not go for trip decision it should be in the block mode even during unstable power swing also.

Out of stripping device number 78 isolate unstable generators or large power system areas from each other with the formation of islands in order to maintain stability in order to maintain integrity in the system where now these are done at strategic locations, predefined buses only where the load and generation can be balanced in an area.

So, after the fragmentation or isolation of a portion of the system that portion should be able to maintain load and generation balance. So, therefore, the out of step tripping is only being accomplished at strategic locations in the system. Unlike the PSB function, it is generic. So, it should be supplemented with all distance relay to distinguish swing and fault.

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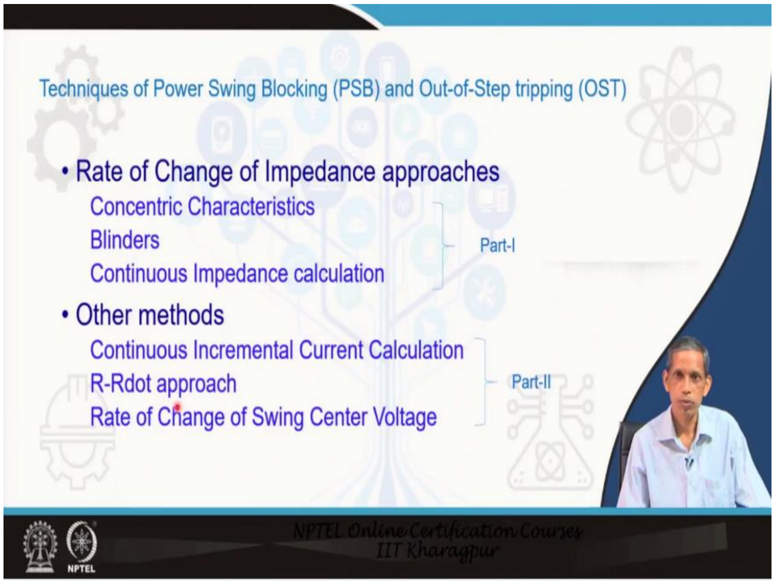

Techniques of Power Swing Blocking (PSB) and Out-of-Step tripping (OST)

- Rate of Change of Impedance approaches
  - Concentric Characteristics
  - Blinders
  - Continuous Impedance calculation

  Part-I

- Other methods
  - Continuous Incremental Current Calculation
  - R-Rdot approach
  - Rate of Change of Swing Center Voltage

  Part-II

Now, the techniques for power system blocking and out of step tripping are by and large same. So, we will discuss these two in with both simultaneously. In today's lecture, we will discuss 3 techniques and they fall in the category of Rate of Change of Impedance approach. We say the impedance plan the trajectory traverses by a swing or fault goes through changing impedance.

So, therefore, there is an associated rate of change of impedance with that, as features there are 3 techniques available one is called Concentric Characteristics, the other one is Blinders techniques and third one is Continuous Impedance calculation approach. So, these 3 we will discuss in this lecture, the other methods available also being used to in relays Continuous Incremental Current Calculation, R-Rdot approach and Rate of Change of Swing Center Voltage. So, we will have this one in a next subsequent lecture.

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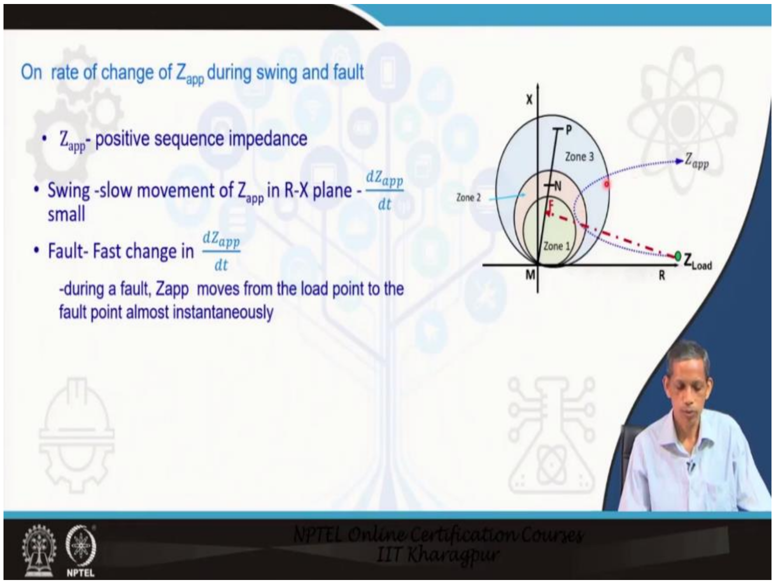

On rate of change of Z_{app} during swing and fault

- Z_{app}- positive sequence impedance
- Swing -slow movement of Z_{app} in R-X plane - $\frac{dZ_{app}}{dt}$ small
- Fault- Fast change in $\frac{dZ_{app}}{dt}$

  -during a fault, Zapp moves from the load point to the fault point almost instantaneously

Now, coming to different techniques on rate of change of impedance. So, the impedance we wish to talk about in the distance relay, the Z_{app} which is being calculated or seen by the relay is the positive sequence impedance and that refers to the positive sequence impedance up to the fault point. If it is a fault, that is what we have learned.

But now in a swing situation, the voltages and current oscillate, so, current may be very high times and voltage may be low. So, the apparent impedance becomes seen by the relay becomes maybe much smaller and it may enter into the zone. So, with that we say that in case of swing the apparent impedance happens to be a slow movement it means dZ/dt will be small in case of fault it is almost instantaneous and therefore, the dZ/dt will be very high.

So, that gives us a clear feature, which you can distinguish, fault to swing. So, we say here in this figure, that in case of a trajectory like this, maybe a swing which may enter and again go back to the original system because load will be in this side also. And in case of a fault from the load, it reaches to the particular zone almost instantaneously.

Now, that is what , we say however, if the corresponding fault happens to be in zone 2 or zone 3 the decision will be delayed, but from load to the fault it becomes almost instantaneous. So, that in the impedance plane we see that the rate of change of apparent impedance seen by the distance relay will be very high for a fault and it will be small for the swing issue.

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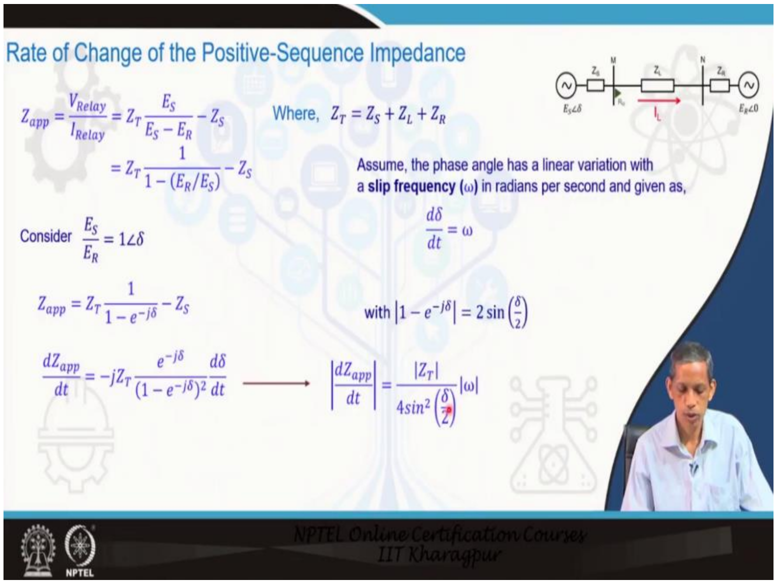

Rate of Change of the Positive-Sequence Impedance

$$Z_{app} = \frac{V_{Relay}}{I_{Relay}} = Z_T \frac{E_S}{E_S - E_R} - Z_S$$
$$= Z_T \frac{1}{1 - (E_R/E_S)} - Z_S$$

Where, $Z_T = Z_S + Z_L + Z_R$

Consider $\frac{E_S}{E_R} = 1\angle\delta$

$$Z_{app} = Z_T \frac{1}{1 - e^{-j\delta}} - Z_S$$

Assume, the phase angle has a linear variation with a **slip frequency** (ω) in radians per second and given as,

$$\frac{d\delta}{dt} = \omega$$

with $\left|1 - e^{-j\delta}\right| = 2\sin\left(\frac{\delta}{2}\right)$

$$\frac{dZ_{app}}{dt} = -jZ_T \frac{e^{-j\delta}}{(1 - e^{-j\delta})^2}\frac{d\delta}{dt} \longrightarrow \left|\frac{dZ_{app}}{dt}\right| = \frac{|Z_T|}{4\sin^2\left(\frac{\delta}{2}\right)}|\omega|$$

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Now, let us analyze what this Rate of Change of Impedance reveals. So, we have a two bus system as usual and a current flowing from left to right from bus M to N. So, this is swing situation we are talking about, not a Fault situation. $Z_{app} = \frac{V_{Relay}}{I_{Relay}} = Z_T \frac{E_S}{E_S - E_R} - Z_S = Z_T \frac{1}{1-(E_R/E_S)} - Z_S$ where $Z_T = Z_S + Z_L + Z_R$. So, that we have seen in our earlier discussion in last lecture.

So, we see here that the if we $\frac{E_S}{E_R} = K\angle\delta$ that we considered in last lecture. If K becomes equals to 1, both voltage magnitudes having similar value, only that one with an angle of δ, $Z_{app} = Z_T \frac{1}{1-e^{-j\delta}} - Z_S$. Then, derivative of this Z_{app} becomes $\frac{dZ_{app}}{dt} = -jZ_T \frac{e^{-j\delta}}{(1-e^{-j\delta})^2}\frac{d\delta}{dt}$.

And then if you say these two that dZ/dt magnitude becomes equal to $\frac{|Z_T|}{4sin^2\left(\frac{\delta}{2}\right)}|\omega|$ where Z_T is the total impedance of this system and omega is the slip frequency with the substitution of $\left|1 - e^{-j\delta}\right| = 2\sin\left(\frac{\delta}{2}\right)$. So, we got that the Z_{app} during a swing situation also which magnitude of this rate of change of Z apparent will be $\left|\frac{dZ_{app}}{dt}\right| = \frac{|Z_T|}{4sin^2\left(\frac{\delta}{2}\right)}|\omega|$.

So, we see that it depends upon the slip frequency to tell the impedance of the system which includes also the source impedances and the angle between the two equivalent sources.

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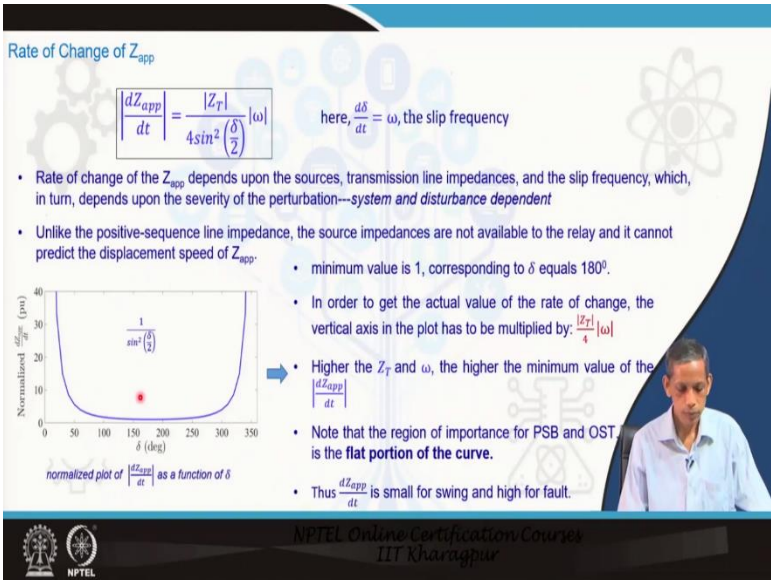

Rate of Change of Z_{app}

$$\boxed{\left|\frac{dZ_{app}}{dt}\right| = \frac{|Z_T|}{4sin^2\left(\frac{\delta}{2}\right)}|\omega|}$$

here, $\frac{d\delta}{dt} = \omega$, the slip frequency

- Rate of change of the Z_{app} depends upon the sources, transmission line impedances, and the slip frequency, which, in turn, depends upon the severity of the perturbation---*system and disturbance dependent*
- Unlike the positive-sequence line impedance, the source impedances are not available to the relay and it cannot predict the displacement speed of Z_{app}.

normalized plot of $\left|\frac{dZ_{app}}{dt}\right|$ *as a function of* δ

- minimum value is 1, corresponding to δ equals 180^0.
- In order to get the actual value of the rate of change, the vertical axis in the plot has to be multiplied by: $\frac{|Z_T|}{4}|\omega|$
- Higher the Z_T and ω, the higher the minimum value of the $\left|\frac{dZ_{app}}{dt}\right|$
- Note that the region of importance for PSB and OST is the **flat portion of the curve.**
- Thus $\frac{dZ_{app}}{dt}$ is small for swing and high for fault.

Now, moving further on this same term, so we said that the Rate of change of Z apparent depends upon the sources, transmission line impedance, slip frequency and the severity of the perturbation and so. Unlike positive, positive sequence impedance of the line that is line parameters source parameter at a time is generally not known to the relay because, that is also varying and that two other and source, source parameters also.

But, therefore, this Z apparent prediction or so, during this swing is not possible in general for the distance relay. Now, if you plot the corresponding dZ/dt and normalized value what I mean to normalize value you can see that these value divided by this term of $\frac{|Z_T|}{4}|\omega|$. So, that becomes you can see that normalizing that we got to , that part becomes equal to $\frac{1}{sin^2\left(\frac{\delta}{2}\right)}$.

So, if you plot this $\frac{1}{sin^2\left(\frac{\delta}{2}\right)}$for different values of δ, in degree, then you get a plot against that like this. This is a normalized plot. it has a minimum value of 1 and for δ equals to 180^O. It means that the two sources are one phase apart anti phase. In order to get the actual value we can say that the corresponding y axis value dZ/dt we have to multiply this parameter to with $\frac{|Z_T|}{4}|\omega|$.

Now, the point is that higher the Z_T and ω, the higher the minimum value of the Z apparent. So, this minimum value what is we say here 1 with the normalized 1 because that is that will multiply with these. So, if you have you ZT and omega becomes higher then this term also will be higher. But note that, from the perspective of power system blocking and out of step tripping, the flat portion is of relevance because it is in this region the corresponding δ will be in operational and therefore, these on swing perspective, we are only concerned about the flat portion of this one.

But during fault the angle change may not be very quick because of the inertia of the system. So, that lead us to that the, the clear picture that faults will be not being that large angle and so, so, that is the dZ/dt is small because in this portion dZ/dt is small as compared to this portion. So, dZ/dt is small during swing, because it is in this region as compared to the fault and that is clearly evident from this plot of $\frac{1}{sin^2\left(\frac{\delta}{2}\right)}$.

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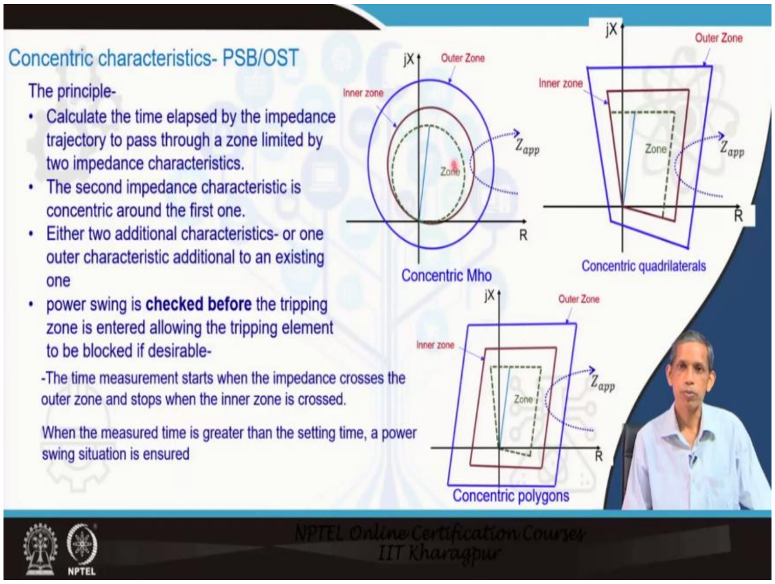

Concentric characteristics- PSB/OST

The principle-

- Calculate the time elapsed by the impedance trajectory to pass through a zone limited by two impedance characteristics.
- The second impedance characteristic is concentric around the first one.
- Either two additional characteristics- or one outer characteristic additional to an existing one
- power swing is **checked before** the tripping zone is entered allowing the tripping element to be blocked if desirable-

-The time measurement starts when the impedance crosses the outer zone and stops when the inner zone is crossed.

When the measured time is greater than the setting time, a power swing situation is ensured

Now, they we will different techniques based on that we learned from the last slide that dZ/dt for the distance relay is indicative to distinguish fault to power swing. Now, how that is being used in different techniques we will learn so, first one is concentric characteristics. So, what is being done here, if you see the mho characteristics here, so, this is a zone which is of concern the point is that these zone needs to be protected from power swing.

So, during power swing take the relay this, this zone should not function relay associated this one should not go for trip. So, that must be blocked to block it to block it what is being done two concentric circles inner one and outer one. So, this is beyond the outside the corresponding zone which you are concerned maybe zone 1 maybe zone 2 or zone 3 whichever your concern at.

So, this is inner zone and this outer zone to the zones are concentric there and they are being used for this for system blocking. So, that is why I talk about concentric characteristics similar in the quadrilateral also, this is the zone we are concerned with for the relay and these are the the inner and the outer zones in the concentric quadrilateral and they are concentric also in the polygons also this is the relay characteristics for the assigned zone, particular zone concern and this are the concentric inner and outer characteristics in the concentric polygon perspective.

So, what is being done here that the relay during swing traverses into this get it into the expected and into characteristics and may create problem. So, because this is outside, it also will traverse we can see that this out these you can see that concentric characteristics which are outside it may traverses. Say intersect one you of this one it may not intersect if does not intersect do not bother.

However, if it comes to inside this outer zone it crosses the outer zone then what is being done that in this portion of ΔZ, ΔZ traverses the inner almost perpendicular to the line impedance.

So, this portion is the two impedance value ΔZ suppose then the corresponding time elapse between these two concentric characteristics by the trajectory, Z_{app} trajectory is to be noted and that is indicative of the corresponding fast swing a corresponding slow swing aspect or the fault aspect. In case of fault the momentum is very rapid and case of swing it will be slow. That we have already, we are already aware of.

So, that is what the calculate time elapsed by the impedance trajectory to pass through zone limited by these two trajectory to characteristics, any of these and both are concentric. Power swing is checked before the tripping zone is entered means this zone of concern is to this these, these outside, that is why outside.

The time measurement starts when it enters to the outer zone and the time measurement stops when it touches the inner zone. When the measured time is greater than the setting time, the power swing situation is ensured. Once again when the measure time to cross the outer zone and touching inner zone is greater than these setting time then it is a swing, swing situation is ensured at a blocks the corresponding relay which may be vulnerable.

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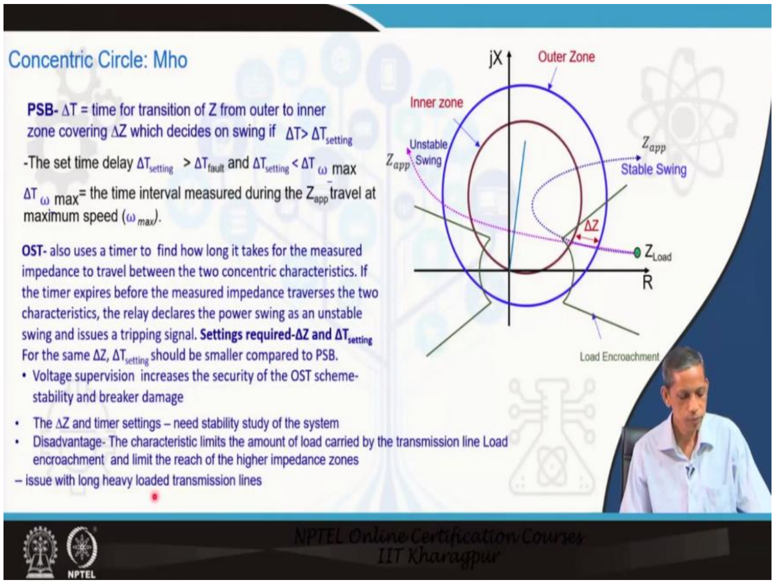

Concentric Circle: Mho

PSB- ΔT = time for transition of Z from outer to inner zone covering ΔZ which decides on swing if $\Delta T > \Delta T_{setting}$

-The set time delay $\Delta T_{setting} > \Delta T_{fault}$ and $\Delta T_{setting} < \Delta T_{\omega\ max}$

$\Delta T_{\omega\ max}$= the time interval measured during the $\bar{Z}_{app}$ travel at maximum speed (ω_{max}).

OST- also uses a timer to find how long it takes for the measured impedance to travel between the two concentric characteristics. If the timer expires before the measured impedance traverses the two characteristics, the relay declares the power swing as an unstable swing and issues a tripping signal. **Settings required-ΔZ and $\Delta T_{setting}$**
For the same ΔZ, $\Delta T_{setting}$ should be smaller compared to PSB.

- Voltage supervision increases the security of the OST scheme- stability and breaker damage
- The ΔZ and timer settings – need stability study of the system
- Disadvantage- The characteristic limits the amount of load carried by the transmission line Load encroachment and limit the reach of the higher impedance zones

– issue with long heavy loaded transmission lines

Now, more details on this. So, what we say that the PSB function passes pass power swing blocking function. So, we have ΔT time of transition of Z from outer to the inner covering, so ΔT the measurement. So, when the apparent impedance traverses this kind of path during swing, so, this is our ΔZ the impedance difference between these which are fixed for this setting.

So, to traverse from this point to this point, how much time is being taken by the relay during that process in the calculation process is our ΔT if this ΔT is greater than the $\Delta T_{setting}$, then it is confirmed a power swing and the relay can go for the blocking. The set time delay ΔT, $\Delta T_{setting}$ should be higher than the ΔT fault like if you analyzed for a fault it will be very rapid.

So, that is why the ΔT required very small, so it must be accurate, then ΔT fault situation and the ΔT settings should be should be smaller than the $\Delta\omega_{max}$ where the ω_{max} is ω your slip frequency we have $d\delta/dt$. So, that slip frequency particular higher value slipped you can see typically some 7 hertz to 10 hertz that depends upon the system and system studies required for that one.

So, we say that we power system blocking can be accomplished by having a ΔZ, two characteristics concentric characteristics and then we fix a $\Delta T_{setting}$ depending upon the ΔT_{fault} and the $\Delta T_{\omega max}$ and then if these corresponding at a given instant of time during swing, if the relay records a time which is greater than the δ setting the relay ensured that this a swing situation and power swing blocking can be invoked.

Similar to that out of step tripping, as we have enumerated that out of step tripping is that at static locations only to avoid against their system integrity laws. So, in that case, out of step tripping also does in a similar way. So, what is being done that it also uses a timer time recording like for the ΔT that the relay records how long it takes to measure the impedance travel between the concentric one.

If the timer expires, before the measured impedance traverses the two that we have mentioned that in the ΔT is greater than $\Delta T_{setting}$ then the relay you can say issues a trip signal. This is a OST out of step tripping. Agree earlier one we talk about power system blocking. So, this is a trip signal is being generated issued and thereby it is ensured that this is an unstable swing situation from that perspective.

So, here we require settings you can see that in terms of the ΔZ if you are using the same ΔZ that is the same concentric circles. So, the $\Delta T_{setting}$ is different and it should be generally smaller than the $\Delta T_{setting}$ for what we have for the power swing blocking it will be smaller than that one.

In addition to that, it is required see here because the corresponding angle goes on increasing more and more δ angle towards this portion. So, therefore it is from the possible damage of the breaker and so and also system stability perspective also. In many cases it is being referred to have voltage support supervision base to secret voltage supervision phase approach to OST.

So, that possible breaker damage can be avoided and all things. So, the correspond even the tripping concern is being detected, it has been delayed against that, till the corresponding δ becomes smaller. So, that possible breaker damage can be avoided. The ΔZ and the timer settings need stability study what will have ΔZ will fix and to which characteristics which relay characteristics we are concerned with.

So, that is a part of this design process of this approach whether PSB or OST in addition to the corresponding ΔT sitting and we know from the earlier derivation that in this case, we can say that the dZ/dt of this approach kind of thing depends upon the Z_T the total impedance of the system that including this source and all this thing. So, it requires detailed stability study, so, that it becomes a challenging thing that is a disadvantage in that perspective.

Furthermore, the other disadvantage is that, because of this the characteristics become outside the relay characteristics. So, it may encroach to the load area and therefore, the corresponding load of that line will be limited and if it is a long heavily loaded line then the corresponding and to get into that the sufficient space for the RX this two characteristics may be difficult then if you have to reduce the corresponding load aspect and so, that we become still in use we have to compromise some perspective.

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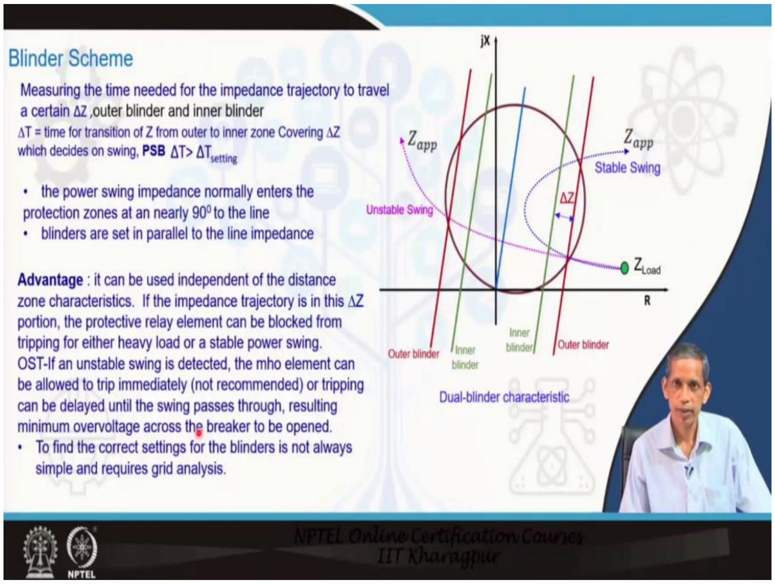

Blinder Scheme

Measuring the time needed for the impedance trajectory to travel a certain ΔZ ,outer blinder and inner blinder

ΔT = time for transition of Z from outer to inner zone Covering ΔZ which decides on swing, **PSB** $\Delta T > \Delta T_{setting}$

- the power swing impedance normally enters the protection zones at an nearly 90^0 to the line
- blinders are set in parallel to the line impedance

Advantage : it can be used independent of the distance zone characteristics. If the impedance trajectory is in this ΔZ portion, the protective relay element can be blocked from tripping for either heavy load or a stable power swing. OST-If an unstable swing is detected, the mho element can be allowed to trip immediately (not recommended) or tripping can be delayed until the swing passes through, resulting minimum overvoltage across the breaker to be opened.

- To find the correct settings for the blinders is not always simple and requires grid analysis.

Dual-blinder characteristic

The second method is on Blinder Scheme similar to that one based on same principle of dZ/ dt and so, what is being done here here we can say that blinders outer blinders, inner blinder and to this sides also inner blinder and outer blinder. So, here also what you do that this is your ΔZ. So, these blinders are generally parallel to the line impedance and they can be positioned not necessarily outside that is the advantage of this approach.

So, what happens that here also the corresponding trajectory during the swing it process these blinders so, it touches outer blender and then that goes to as you can say inner blinder. So, the corresponding time recording between these two points of crossing is indicative of we can say that whether ΔZ slow phenomena or a phenomena for the fault case also similar to what we have discuss for the, the concentric characteristics.

So, the time transform from Z from outer to the inner zone covering the ΔZ which decides on the swing. So, PSB we at option power swing non blocking option is it the measure ΔT is greater than

$\Delta T_{setting}$ and it goes for blocking. The advantage of this one is that as already mentioned it can be used independent of the distance zone characteristics it can be taken towards the the zone characteristics.

If the impedance trajectory is in this ΔZ portion they particularly can be blocked from the tripping for either heavy loads, that heavy load issue which was there in the concentric characteristics can be avoided against that in many cases and OST unstable swing is detected if the mho can, can be allowed to trip immediately or, or the tripping can be delayed on, until swing passes through the to further till the corresponding voltage becomes overvoltage in the breaker becomes to a lower one.

So, that no possibility of breaker damage can be there. To find the current settings for the blinder is always not simple and requires also here also stability analysis of the grid like concentric circle.

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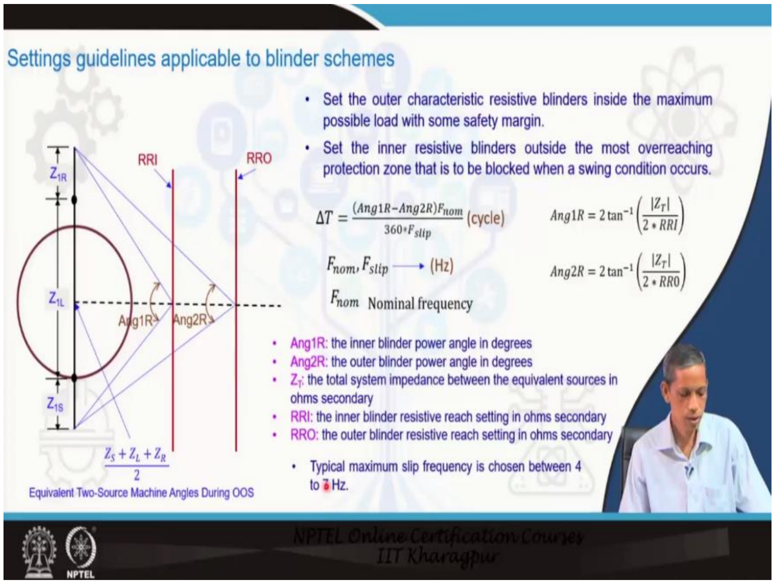

Settings guidelines applicable to blinder schemes

- Set the outer characteristic resistive blinders inside the maximum possible load with some safety margin.
- Set the inner resistive blinders outside the most overreaching protection zone that is to be blocked when a swing condition occurs.

$$\Delta T = \frac{(Ang1R - Ang2R)F_{nom}}{360 * F_{slip}} \text{ (cycle)} \qquad Ang1R = 2\tan^{-1}\left(\frac{|Z_T|}{2 * RRI}\right)$$

$$F_{nom}, F_{slip} \longrightarrow \text{(Hz)} \qquad Ang2R = 2\tan^{-1}\left(\frac{|Z_T|}{2 * RRO}\right)$$

F_{nom} Nominal frequency

- Ang1R: the inner blinder power angle in degrees
- Ang2R: the outer blinder power angle in degrees
- Z_T: the total system impedance between the equivalent sources in ohms secondary
- RRI: the inner blinder resistive reach setting in ohms secondary
- RRO: the outer blinder resistive reach setting in ohms secondary

- Typical maximum slip frequency is chosen between 4 to 7 Hz.

Equivalent Two-Source Machine Angles During OOS

Now, some of the guidelines for applications to blinder schemes is that if you can see that this is about resistance reach outer and the inner what we have discuss. Suppose a blinder is here and if you see the total impedance of the system source, remote side, local side and this is the line in if you see that from this here suppose here the traversing point you can say operates at here and the way we discuss in the earlier also.

So, then you can see that the angle here corresponds to δ angle. So, that δ angle you can see that if you see here, let us say this is angle 2R, angle 1R for this case this outer and inner. So, if you see the angle goes on increasing, and when it reaches to you can see it here that is 180^O apart and vary your electric, electric center or swing center we talk about. So, we see are in this case, we define the time which is crossing $\Delta T = \frac{(Ang1R - Ang2R)F_{nom}}{360 * F_{slip}}$.

So, the nominal frequency divided by 360^O. So, this gives you, the ΔT how much time it will take us from this to this if we know the corresponding slip frequency at that instant of time. So, that the ΔT will be depending upon the slip frequency. So, the set the inner resistive blinders outside the most overreaching portion zone that is to be blocked when is swing condition occurs. Set the outer characteristics resistive blinder inside the maximum possible load with this safety margin.

So, that is why we can say that how much load are for that line is concerned and then we the value to we can find the corresponding ΔT if we take the corresponding slip frequency to be higher then this will be smaller. So, that about that highest possible swing frequency can be for the system can be taken to consider to set the corresponding ΔT setting perspective and so. So, that is the maximum slip frequency is chosen between 4 to 7 hertz that depends upon the system perspective.

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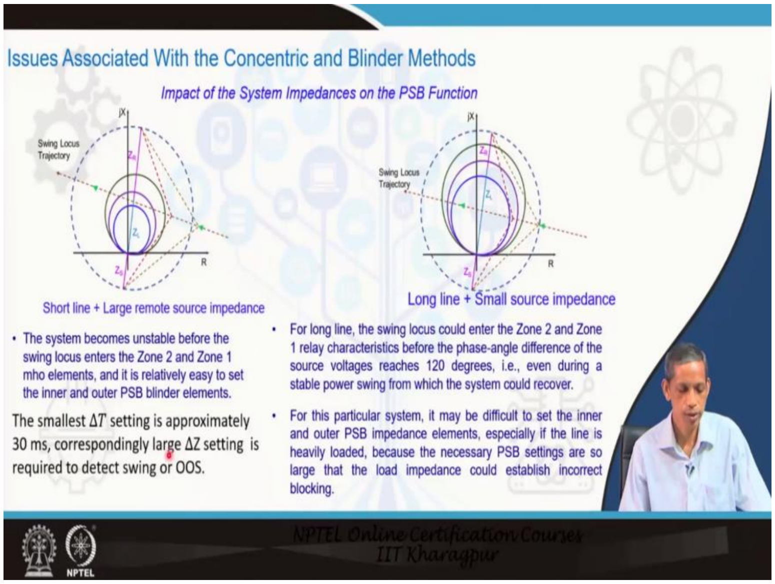

Issues Associated With the Concentric and Blinder Methods

Impact of the System Impedances on the PSB Function

Short line + Large remote source impedance

- The system becomes unstable before the swing locus enters the Zone 2 and Zone 1 mho elements, and it is relatively easy to set the inner and outer PSB blinder elements.

The smallest ΔT setting is approximately 30 ms, correspondingly large ΔZ setting is required to detect swing or OOS.

Long line + Small source impedance

- For long line, the swing locus could enter the Zone 2 and Zone 1 relay characteristics before the phase-angle difference of the source voltages reaches 120 degrees, i.e., even during a stable power swing from which the system could recover.
- For this particular system, it may be difficult to set the inner and outer PSB impedance elements, especially if the line is heavily loaded, because the necessary PSB settings are so large that the load impedance could establish incorrect blocking.

Now, some of the issues also with the Concentric Blinder Concentric or Blinders both are manner similar perspective. So, what do you see that when the corresponding trajectory traverses like this, then the angle goes on increasing. Now, let us see the situation short line large remote source impedance. Line is short. So, this impedance is small and large remote source impedance and the source impedance locally.

In this situation, because these trajectories traversing through the electrical center when K equals to 1 we have studied earlier. So, what you see here the system becomes unstable before the swing locus enters to zone 2 or zone 1 in this situation if you see this, this this one, so, these you can say these are the concentric circle perspective the outer one. So, here it reaches to these that the angle you can say is so, high now, more than 120^{O} in this stability assessment perspective.

Before you can say it enters to consider zone 2, and zone 1 also. So, that clears problem that the relatively easy to set the inner and outer PSB blinder elements here. So, because you can see that before it returns to you can make a clear decision in the outer side perspective , but for long line small source impedance, impedance sources if you can see the angle now, even though you can see that it is inside into that zone 2 also, the angle as compared to this situation is not that high.

So, it means that it has not reached to an instability point to it as per the definition of this one. So, for a long line the swing locus could enter zone 2 and the zone 1 relay characteristics before the phase angle become before the phase angle becomes 120^{O} or so. So, even during a stable swing is a stable swing from which the system could recover.

For this particular system, this kind of system, it may be difficult to set inner and outer boundary element especially if the line is heavily loaded that you have already observed in case of this kind of thing. So, the challenge, long line some small source impedance and if the line is heavily loaded, then the corresponding boundary setting for corresponding concentric circle setting is difficult.

Note that the smallest ΔT setting is ΔT setting in these blinders and the corresponding concentric circles is approximately taken around 30 millisecond and accordingly you can say the ΔZ being set for this perspective and so, or even for the PSB or OS, out of step tripping.

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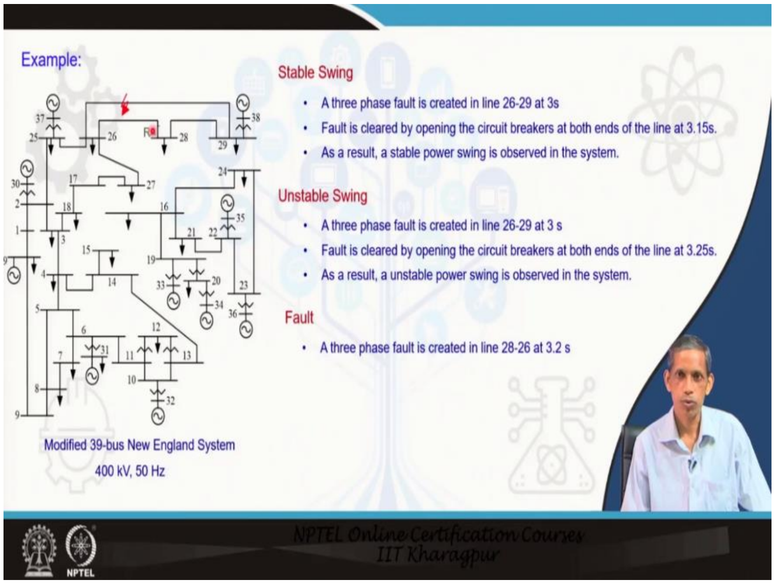

Example:

Modified 39-bus New England System

400 kV, 50 Hz

Stable Swing

- A three phase fault is created in line 26-29 at 3s
- Fault is cleared by opening the circuit breakers at both ends of the line at 3.15s.
- As a result, a stable power swing is observed in the system.

Unstable Swing

- A three phase fault is created in line 26-29 at 3 s
- Fault is cleared by opening the circuit breakers at both ends of the line at 3.25s.
- As a result, a unstable power swing is observed in the system.

Fault

- A three phase fault is created in line 28-26 at 3.2 s

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And take an example, a 3 phase fault is created in here there is fault in this line and that is being removed in this 39 bus 50 Hz system 400 kV. So, then what happens there once the line is removed a fault is cleared by opening the circuit in both and say line and as a result stable swing is observed in this by this relay in the system. So, this is a stable case swing. Now for an unstable swing like in our earlier example in our earlier lecture we have done so, the corresponding fault delayed and then cleared.

So, as a result you can say unstable swing is observe by the relay and then without this fault we create against a 3 phase fault in line 28 to 26 at 3.2 second. So, there are the 3 situations which the relay will see this relay and then how the corresponding relay will be able to distinguish swing and then unstable swing or the fault.

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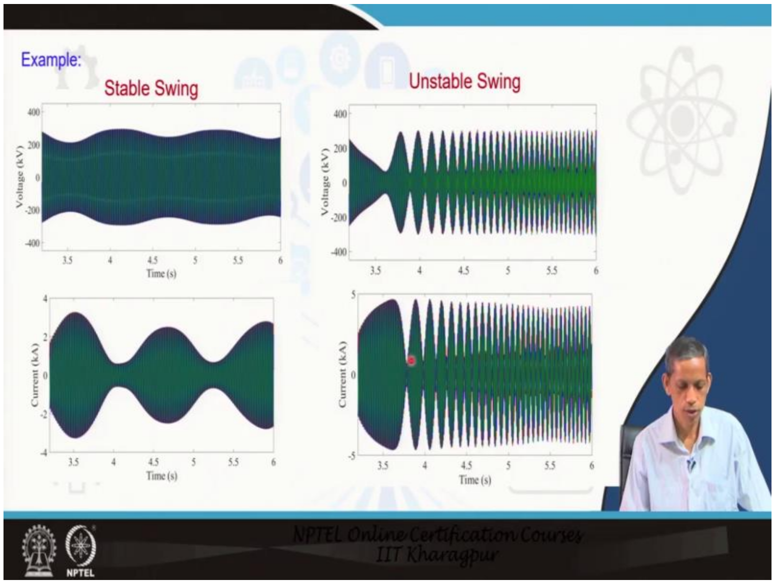

Example:

Stable Swing

Unstable Swing

So, this is the situation of stable swing voltage and current patterns and the unstable swing the corresponding voltage and current pattern this is clearly visible as the distinction.

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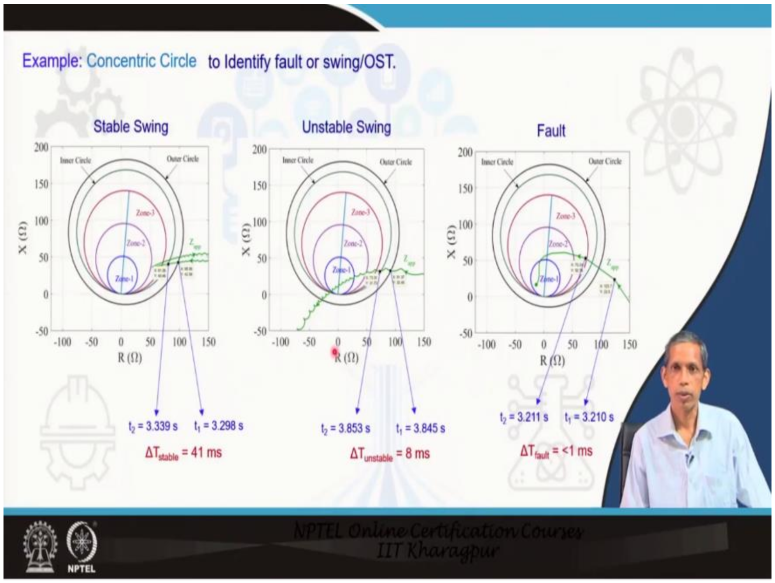

Example: Concentric Circle to Identify fault or swing/OST.

Stable Swing

Unstable Swing

Fault

$t_2 = 3.339$ s $t_1 = 3.298$ s

$\Delta T_{stable} = 41$ ms

$t_2 = 3.853$ s $t_1 = 3.845$ s

$\Delta T_{unstable} = 8$ ms

$t_2 = 3.211$ s $t_1 = 3.210$ s

$\Delta T_{fault} = <1$ ms

What the relay does now, for these 3 cases that this is stable swing case first case using the voltage and current we obtained the corresponding Z_{app} and V/I for any phase and then we have the concentric circles here the outer and inner. So, when it goes to the enters, so, that touches the outer circle, then the time recording starts and then only touches the inner circle the time recording stops.

So, that ΔT is obtained. So you see here T1 and the T2. So, the ΔT concern becomes equals to 41 millisecond the ΔT recorded for this stable case is 41 millisecond.

Now come to the unstable swing case the second case. So, in this case, you can see that with the same set of characteristics here both including the concentric circles. So, the T1 is here is 3.845 second it touches here and to the inner one it touches you 3.853 milliseconds. So, the ΔT becomes equals to 8 millisecond much smaller than this. ΔZ remaining same the corresponding time recorded by the relay for the unstable swing case is much smaller than that for the stable swing.

Now, come to the fault in that line. So, if we see you, a trajectory. Now if you can see that the corresponding two points because this time is very fast. So, we record one point here that becomes 3.2 and here are these are quite more against their larger value then the ΔZ because fault is pretty instantaneous. So, we found that still you can say it is less than 1 millisecond.

So, compare it to stable and unstable case fault is pretty faster. And that is you can see there too in our earlier discussion, we told that a dZ/dt is an indicative of classifying identifying power swing than fault and also we said that if you will have the corresponding ΔT time setting proper one a smaller one then you can distinguish you can say this is a unstable swing also from stable swing. So, either applying concentric circle or applying a blinder.

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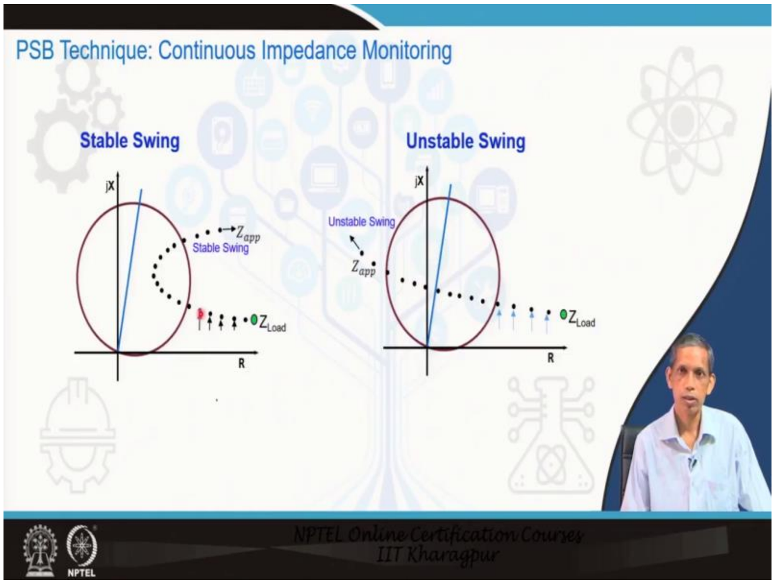

PSB Technique: Continuous Impedance Monitoring

Now, to go to the third technique in this impedance calculation perspective continuous impedance monitoring. So, what is being done here that the apparent impedance traverses like this. So, we go on monitoring considering the corresponding apparent impedance and then we can start to require some calculation. So, in case of a stable swing it traversal like this.

So, these are the points , that, that interval typically 5 milliseconds or so, we go on against that on computing the corresponding Z and then we will find the ΔZ against that to decide on the stability stable swing or unstable swing or this swing versus fault identification issue.

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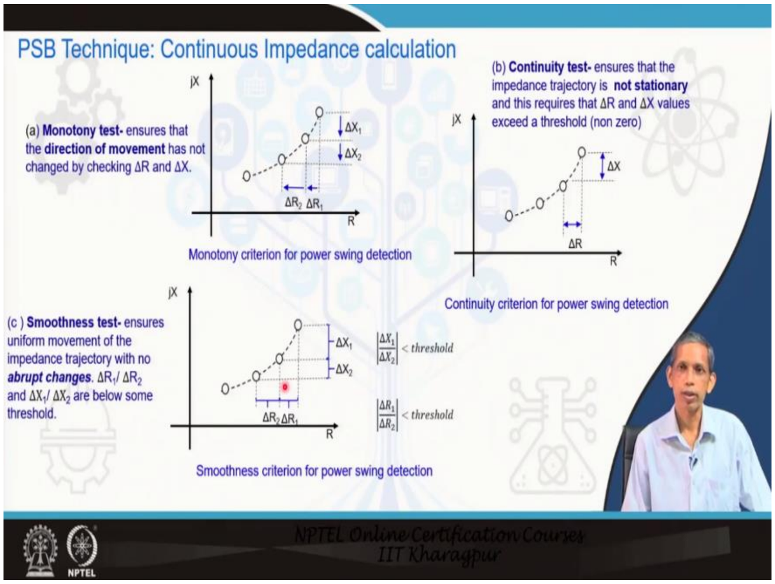

PSB Technique: Continuous Impedance calculation

(a) **Monotony test-** ensures that the **direction of movement** has not changed by checking ΔR and ΔX.

Monotony criterion for power swing detection

(b) **Continuity test-** ensures that the impedance trajectory is **not stationary** and this requires that ΔR and ΔX values exceed a threshold (non zero)

Continuity criterion for power swing detection

(c) **Smoothness test-** ensures uniform movement of the impedance trajectory with no ***abrupt changes***. $\Delta R_1/\Delta R_2$ and $\Delta X_1/\Delta X_2$ are below some threshold.

$\left|\frac{\Delta X_1}{\Delta X_2}\right| < threshold$

$\left|\frac{\Delta R_1}{\Delta R_2}\right| < threshold$

Smoothness criterion for power swing detection

What has been done here that the continuous impedance calculations as already mentioned, 3 things are being checked Monotony test, Continuity test and Smoothness test, these 3 tests are being checked by the relay and from these 3 it then confirms whether to swing or a fault. In monetary test, what is being done there to the direction a moment has not changed, you can see that has not changed that is being checked from ΔR and ΔX.

So, what is being done there it consider that at each point find the corresponding ΔX and ΔR and the corresponding ΔR and ΔR that is from Z we find. The real part and the imaginary part so, these ΔX_1 and ΔX_2 so, you can see that are they going in the same direction or not that is being tested to it to the monotony test.

The second test is a Continuity test. If they know stagnancy means not at a lower point or so, to have that whether ΔR and ΔX are having significant value or not that is being checking the continuity test. Third test is Smoothness test, it is to ensure that you there is no abrupt change like in fault also. So, so, the $\Delta R_1/\Delta R_2$ or $\Delta X_1/\Delta X_2$. This must be take smaller value not very large, so, there must be less than a threshold value. So, once the 3 tests are being carried out, then only the relay will be able to detect and show that whether there is a swing or not so, you can say in terms of that.

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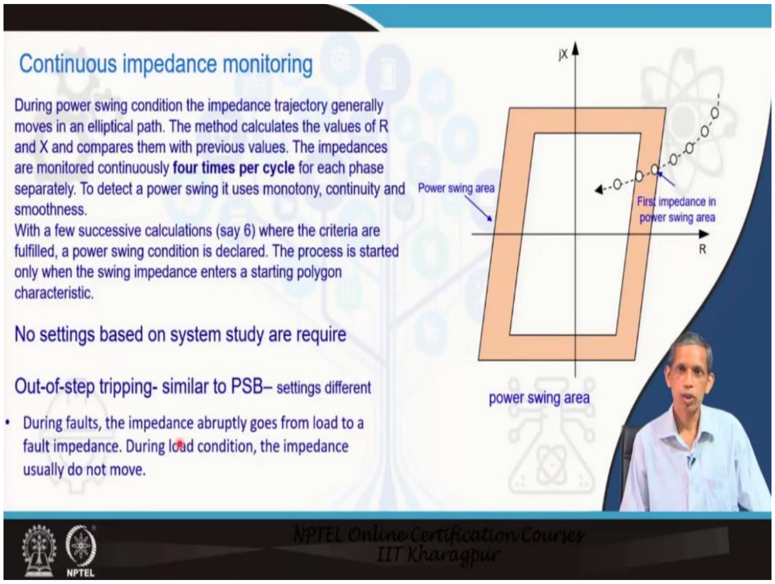

Continuous impedance monitoring

During power swing condition the impedance trajectory generally moves in an elliptical path. The method calculates the values of R and X and compares them with previous values. The impedances are monitored continuously **four times per cycle** for each phase separately. To detect a power swing it uses monotony, continuity and smoothness.

With a few successive calculations (say 6) where the criteria are fulfilled, a power swing condition is declared. The process is started only when the swing impedance enters a starting polygon characteristic.

No settings based on system study are require

Out-of-step tripping- similar to PSB– settings different

- During faults, the impedance abruptly goes from load to a fault impedance. During load condition, the impedance usually do not move.

For that what is being done a a power swing area is being assigned like we talk about concentric circles and so, and once it starts entering to that the process of against that the corresponding impedance calculations the 3 tests against that what to mention in the earlier slide are starts beginning and then the relay you can say dot the said calculations 4 times per circle circle or circle per 50 Hz systems you can assume 5 milliseconds kind of thing.

And it could consider and then you can say these dots are the calculation process of those three tests to it typically, some 6 times also successively to ensure that it is a swing or fault also. So, to test those things, so, these are does not require any settings you can set based on the system study on or so, so, that is where we ensure that the strength of this approach. Out of step tripping is similar to the PSB what you narrated here.

Only that says settings of thresholds are different the threshold, threshold settings for the different three test. During faults the impedance abruptly goes from load to a fault impedance and during load conditions the impedance usually do not move. So, they do not qualify in those three tests and therefore, the relay able to say that becomes able to distinguish sequence that from fault to swing or load situation.

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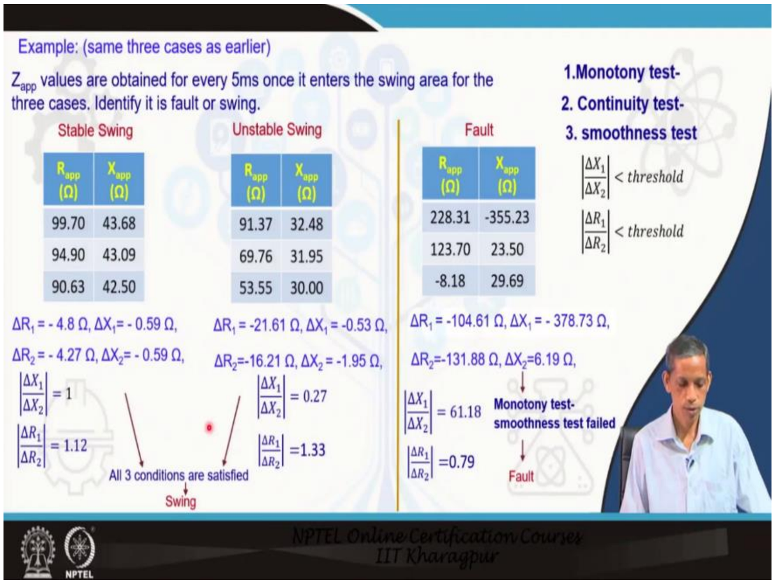

Example: (same three cases as earlier)

Z_{app} values are obtained for every 5ms once it enters the swing area for the three cases. Identify it is fault or swing.

1.Monotony test-

2. Continuity test-

3. smoothness test

$\left|\frac{\Delta X_1}{\Delta X_2}\right| < threshold$

$\left|\frac{\Delta R_1}{\Delta R_2}\right| < threshold$

Stable Swing

R_{app} (Ω)	X_{app} (Ω)
99.70	43.68
94.90	43.09
90.63	42.50

$\Delta R_1 = -4.8\ \Omega$, $\Delta X_1 = -0.59\ \Omega$,

$\Delta R_2 = -4.27\ \Omega$, $\Delta X_2 = -0.59\ \Omega$,

$\left|\frac{\Delta X_1}{\Delta X_2}\right| = 1$

$\left|\frac{\Delta R_1}{\Delta R_2}\right| = 1.12$

Unstable Swing

R_{app} (Ω)	X_{app} (Ω)
91.37	32.48
69.76	31.95
53.55	30.00

$\Delta R_1 = -21.61\ \Omega$, $\Delta X_1 = -0.53\ \Omega$,

$\Delta R_2 = -16.21\ \Omega$, $\Delta X_2 = -1.95\ \Omega$,

$\left|\frac{\Delta X_1}{\Delta X_2}\right| = 0.27$

$\left|\frac{\Delta R_1}{\Delta R_2}\right| = 1.33$

All 3 conditions are satisfied

↓

Swing

Fault

R_{app} (Ω)	X_{app} (Ω)
228.31	-355.23
123.70	23.50
-8.18	29.69

$\Delta R_1 = -104.61\ \Omega$, $\Delta X_1 = -378.73\ \Omega$,

$\Delta R_2 = -131.88\ \Omega$, $\Delta X_2 = 6.19\ \Omega$,

↓

$\left|\frac{\Delta X_1}{\Delta X_2}\right| = 61.18$

$\left|\frac{\Delta R_1}{\Delta R_2}\right| = 0.79$

Monotony test-
smoothness test failed

↓

Fault

Now, let us take the example for this same we can say an example which we have you have considered three cases stable swing, unstable swing and the fault situation. So, for these stable swing the corresponding Z which are being calculated three points are given us here. So, the corresponding R and X are given here at time T_1, T_2 and T3. So, we say from this ΔR_1, ΔR_2 are calculated. ΔX_1, ΔX_2 are computed. So, it means that they are not having same values. So, that means that they qualify the corresponding continuity. Monotony means we will say they are the same sign. So, that is also true and now, you have $\Delta X_1/\Delta X_2$ is 1 and $\Delta R_1/\Delta R_2$ is this. So, they are not that very large value.

So, it means that this this situation qualifies for the all the tests Monotony, Continuity and Smoothness and that is why this is a ensure that this is a swing situation. Come to unstable swing case, case two, here also the corresponding R and X values are available. So, again calculate ΔR_1 and ΔR_2 and ΔX_1 and ΔX_2. And so, you can see that here also the continuities maintain and that is now they are non values of significance.

And then also you can see that the, the corresponding monotony is also maintained because you see the signal symbol as the corresponding changes in sign third thing is that this smoothness if we find the value $\Delta X_1/\Delta X_2$ is 0.27 and $\Delta R_1/\Delta R_2$ is 1.33. So, seems to be pretty smaller. So, this also confirmed that this is the monotony the all the 3 conditions are being satisfied. So, it is ensure also a swing situation which is correct. So, both stable and unstable swing are being confirmed that they maintain they, they satisfy the, the 3 conditions

Now, come to the fault now, so, in this case we see the R rapidly changes. And so, the X also rapidly changes at T_1, T_2, T_3 time; ΔR_1, ΔR_2, ΔX_1 and ΔX_2. So, if you see you can see that here, then the $\Delta X_1/\Delta X_2$ it is having a negative sign and the $\Delta R_1/\Delta R_2$ is having positive sign. So that, the makes us to the monotonic test not being satisfied and even continuity being maintained and the corresponding smoothness test, the value up here will become 61.18 as compared to 1 and 0.27 for the earlier cases that says a very large value.

And that means that we will cross the threshold against that, which is required for this smoothness test and all these things. So, that ensures that you can see that this is not a swing situation. So, that is against the as a fault situation. So, that means that if it is not swing, the relay will not block for this case, but the relay will go for blocking the situations. So, this is about the continuous monitoring of the impedance calculation.

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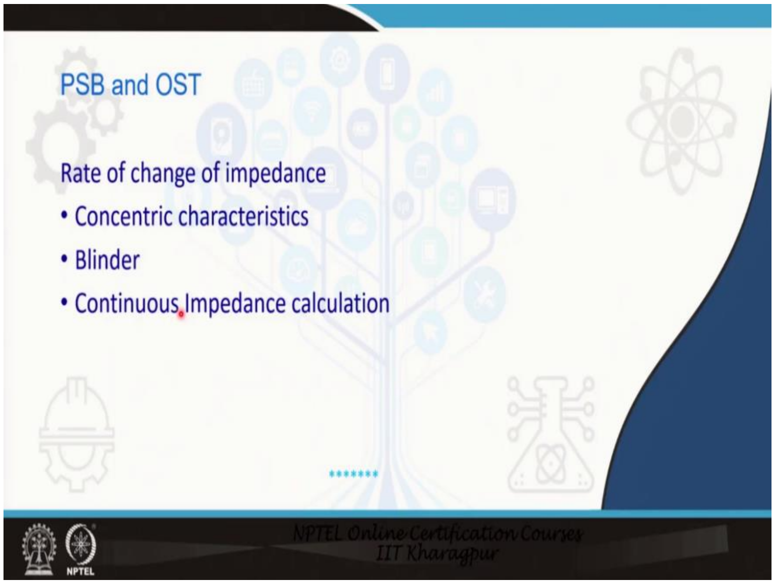

PSB and OST

Rate of change of impedance
- Concentric characteristics
- Blinder
- Continuous Impedance calculation

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So, in this lecture, we mentioned about power swing blocking and out of step tripping and we address on the three techniques based on rate of change of impedance principle, the concentric characteristics, the blinder and the continuous impedance calculation, the merit of the continuous impedance calculation why is that being used. So, in many relays, you can see that in numerical relays, that advantage, it does not depend upon any system, a system stability study.

Thank you.