Power System Protection
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Lecture No. 52
Wide Area Measurement for Protection

Welcome to the power system protection course. We will be continuing with wide area measurement based protection.

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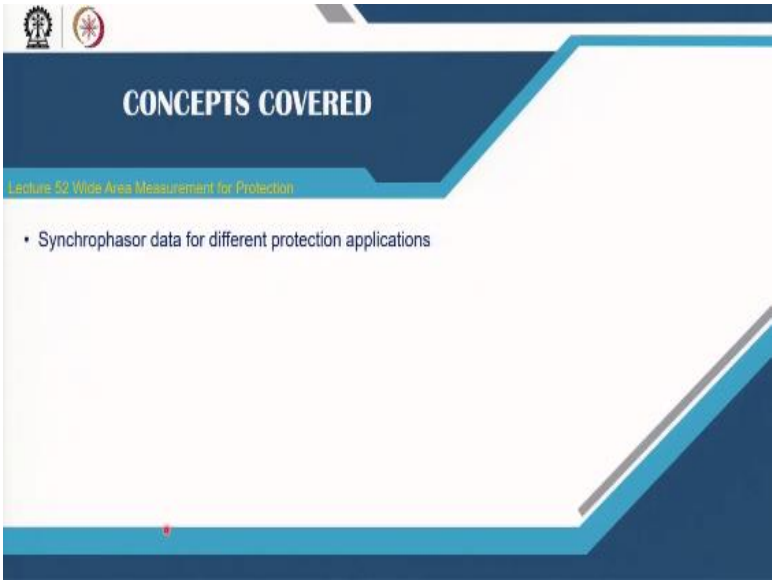

In this lecture, we will see different applications how synchrophasor data can be used. In the last class we discuss on to avail synchrophasor data from PMUs or relays with GPS or like other devices, data recorders and so in a substation. These time synchronized data gives powerful applications which is of relevance to the grid in grid operations for reliability and for better management.

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We discussed about data from PMU. This is a phasor data of voltage and current phasors in our laboratory collected from different PMUs through a PDC which shows different instant of time, different instances, different seconds in between consecutive time to seconds also we can have several collection of such phasor data. So, this talks about frequency, voltage, magnitude and angle of phase - A current like that for phase - B and phase - C voltage and currents.

So, such synchronized data at any instant of time gives a scope for numerous applications in the power system in particularly for protection. In protections applications such synchrophasors can be applied in two aspects you can broadly divide offline and online. Offline means relay setting perspective which requires parameters of the lines say distance relay, impedance of the line and so which can be obtained from this synchrophasor data.

So like that offline application we can have real time applications on protection decision perspective, but the difference here is that these wide area measurement system which is associated with PMU data have latency and this latency has different aspects and components as discussed in last class in the PDC level (phasor data concentrator), at the PMU level itself also with the communication infrastructure. So, the total latency of the system from data to the process is compatible to a particular protection application or not that has to be first check and as you see here with the associated latency such protection from wide area measurements are mostly for the backup arrangement. So, we have individual protection through the relays as we have already discussed in several lectures earlier. Line protection with distance relay, line protection with differential relay and so on, but now what we are discussing is on how the synchrophasor data can be applied which has latency issues. So, this is an independent platform which can collate, integrate data and then make a decision as fast as compared to the primary protection. So, this can supplement the protection decision in general. Now if one-to-one two PMUs are communicating or PMUs in a substation we can have very low latency of few milliseconds, but if the PMUs several PMUs are being integrated in an area or at central level it can be associated in terms of larger latency 100 ms to as 1 s also. So, this big difference between the conventional protection schemes and the latency associated has to be seen in the perspective of different applications.

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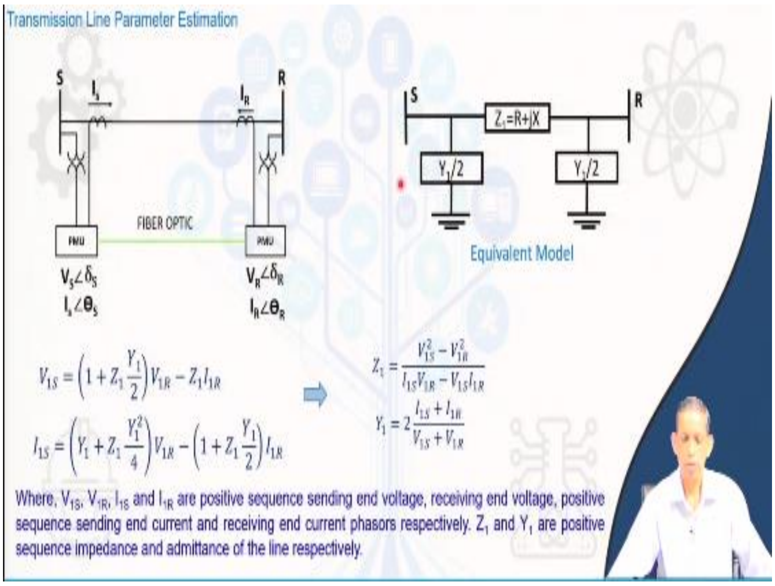

Let us come to different applications we will go one by one. First one is transmission line parameter estimation using synchrophasor data (synchronized data), data from the PMU. Note that these we have already address that these synchronized data or the phasor measurement unit data which can be availed from the relays with GPS facility.

So, this is a transmission system having sending and receiving end. We have current and voltage measurements through this PMU at sending end, another PMU at the receiving end and then they have dedicated communication systems for any other applications, then how we can avail the data for parameter estimation of this line we will try to see it. So, let us model this corresponding transmission line in terms of the п- model.

Here you see that this is the Z_1 = R + jX the series part and the shunt path with $Y_1/2$ and $Y_1/2$. So, like we talk about R and L and the corresponding capacitor and the conductance. So, our measurements here from the sending and side is $V_S\angle\delta_S$ and $I_S\angle\theta_S$. From receiving end $V_R\angle\delta_R$ and $I_R\angle\theta_R$ at any instant of time for any loading condition. So, then we can express the sending end voltage (V_{1S}) and currents (I_{1S}) in terms of receiving and currents and voltage.

$$V_{1S} = \left(1 + Z_1\frac{Y_1}{2}\right)V_{1R} - Z_1 I_{1R}$$

$$I_{1S} = \left(Y_1 + Z_1\frac{Y_1^2}{4}\right)V_{1R} - \left(1 + Z_1\frac{Y1}{2}\right)I_{1R}$$

So, that we know from this we can say that model. Then with this two expressions we can get this two unknowns here Z_1 and Y_1 in terms of the known values of V_{1S}, I_{1S} and the V_{1R} and the I_{1R} given by

$$Z_1 = \frac{V_{1S}^2 - V_{1R}^2}{I_{1S}V_{1R} - V_{1S}I_{1R}}$$

$$Y_1 = 2\frac{I_{1S} + I_{1R}}{V_{1S} + V_{1R}}$$

From this we talk about a positive sequence voltage and current and associated positive sequence impedance for this purpose. On that perspective this model belongs to the positive sequence equivalent model. So, associated positive sequence voltage and currents are being dealt with and we get this relations.

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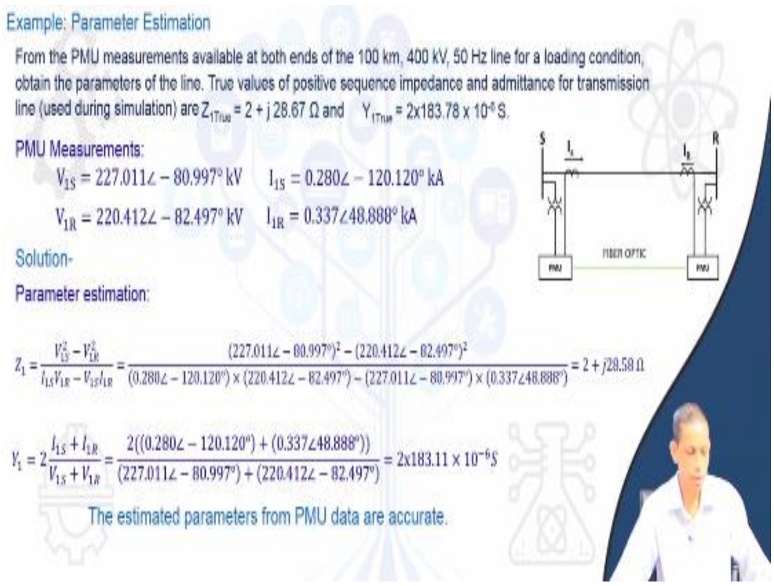

Now see this how this corresponding parameter estimation with the π model we can extend it to the other model also including long line model, ABCD parameters etc. Let us see here how this parameter estimation can be done from the phasor measurement data.

Example: Parameter Estimation

So, we have this to a system of 100 km, 400 kV, 50 Hz line at a particular loading condition

PMU measurements

$V_{1S} = 227.011\angle -80.997° \, kV$ $\qquad$ $I_{1S} = 0.280\angle -120.120° \, kA$

$V_{1R} = 220.412\angle -82.497° \, kV$ $\qquad$ $I_{1R} = 0.337\angle 48.888° \, kA$

We have to estimate the parameters using the expression as is derived in the last slide. True values of positive sequence impedance and admittance for transmission line (used during simulation) are $Z_{1True} = 2 + j\,28.67\ \Omega$ and $Y_{1True} = 2\text{x}183.78 \times 10^{-6}$ S.

Solution: Substituting these values from the synchronize data we get the corresponding positive sequence impedance (Z_1) and admittance (Y_1) as

$$Z_1 = \frac{V_{1S}^2 - V_{1R}^2}{I_{1S}V_{1R} - V_{1S}I_{1R}}$$
$$= \frac{(227.011\angle -80.997°)^2 - (220.412\angle -82.497°)^2}{(0.280\angle -120.120°) \times (220.412\angle -82.497°) - (227.011\angle -80.997°) \times (0.337\angle 48.888°)}$$
$$= 2 + j28.58\,\Omega$$

$$Y_1 = 2\frac{I_{1S} + I_{1R}}{V_{1S} + V_{1R}} = \frac{2((0.280\angle -120.120°) + (0.337\angle 48.888°))}{(227.011\angle -80.997°) + (220.412\angle -82.497°)} = 2\text{x}183.11 \times 10^{-6} S$$

So, it is clear that the estimated parameters using the PMU data or synchronize data are pretty accurate. It means that such line data can be used for relay applications or any other applications for the system.

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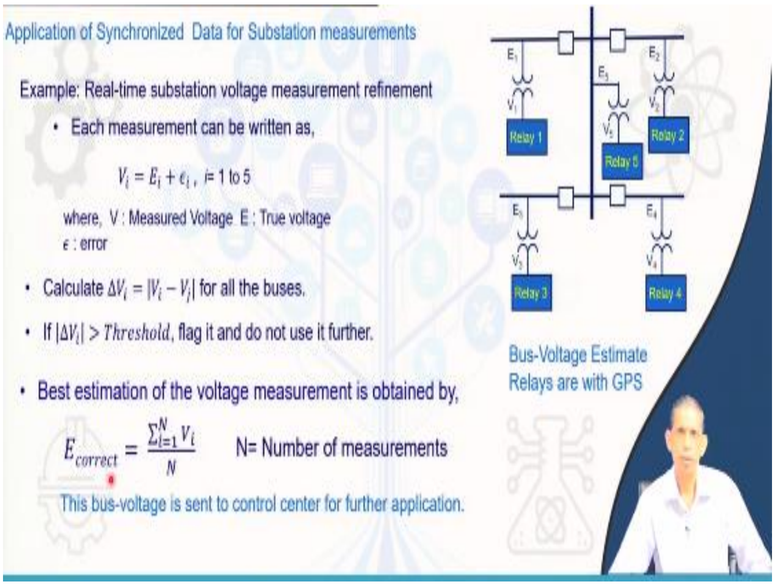

Now furthermore in second application we will see how synchronized data in real time can be used for substation measurements for the accurate information at the substation levels. Two aspects, one is the voltage another is the current. So, first we will see that how voltage measurements can be obtained in a better way at a substation.

We know a bus at a substation there are several measurements including that for the voltage also. These relays have their corresponding voltage measurements through the PT or CVT connection and they compute the phasors and if these relays are having GPS we can provide synchrophasor also. Assuming these are corresponding synchrophasor platform or equivalent to that PMU. Let us say here 5 relays are there. These relays provide us also the synchrophasor data and now consider this for the voltage measurements.

So, at this one because they are measuring the same voltage therefore, all the voltages would be same, but because of this PT and the associated computational process and the performance of the relay or the PMU, the accuracy will be of different in nature and therefore we can say that we will have even though we are measuring the same voltage, we will have different measurements as shown by this relays or PMUs.

Let us say here each measurement by this devices can be expressed in terms of

$$V_i = E_i + \epsilon_i\ , \quad i = 1 \text{ to } 5$$

Where, V: Measured Voltage, E : True voltage, ϵ = error

So, what we will do that we will calculate $\Delta V_i = |V_i - V_j|$ where i, j are the respective measurement devices. Thus the corresponding deviation to all the devices for all the bus measurements are calculated. Now if $|\Delta V_i| > Threshold$ we flag it, note it and discard it further. Note that there is some erroneous measurement in the system we have to discard those erroneous measurement measurements to get the best estimate by averaging the corresponding correct measurements

$$E_{correct} = \frac{\sum_{i=1}^{N} V_i}{N}$$

Where, N= Number of measurements. Such average measurements becomes more accurate value for the further application in the substation or any near remote end. Therefore, this processing leads towards bad data rejection. So, simple level of computation and also an accurate value of voltage phasors it provides at the substation level which can be dispersed at any control center for further application.

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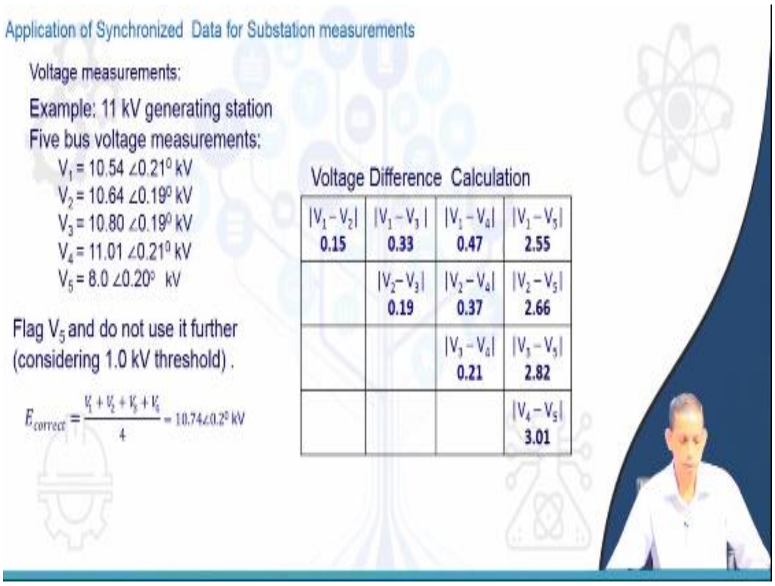

We will see an example on voltage measurement at 11 kV generating stations we have 5 bus measurements like that what we see. So, these 5 meters, relays, PMUs they provide V_1, V_2, V_3, V_4, V_5 at one instant of time one loading conditions are given by

$V_1 = 10.54 \angle 0.21^0$ kV, $V_2 = 10.64 \angle 0.19^0$ kV, $V_3 = 10.80 \angle 0.19^0$ kV, $V_4 = 11.01 \angle 0.21^0$ kV

$V_5 = 8.0 \angle 0.20^0$ kV

If you observe these five measurements there is a large difference between V_5 and rest of the measurements. So, as you see there is a chance of error with the fifth measurements. So, what we will do that as already mentioned in the earlier slide we find the voltage differences. Therefore, calculate like this

$\|V_1 – V_2\| = 0.15$	$\|V_1 – V_3\| = 0.33$	$\|V_1 – V_4\| = 0.47$	$\|V_1 – V_5\| = 2.55$
	$\|V_2 – V_3\| = 0.19$	$\|V_2 – V_4\| = 0.37$	$\|V_2 – V_5\| = 2.66$
		$\|V_3 – V_4\| = 0.21$	$\|V_3 – V_5\| = 2.82$
			$\|V_1 – V_2\| = 3.01$

So we have 1, 2, 3, 4 columns for these differences. Now, what you notice is that out of these we check here that V_1 - V_5, all these V_2 - V_5, V_3 - V_5, V_4 -V_5 all these different values are significant as compared to the other differences. So, this gives us a score to check that whether V_5 is common in all the differences. So, we doubt over the V_5 and if this V_5 is flag is set because the difference is significantly high. Let us in this case we have considered a 1 V threshold and this crossing 1 V threshold in all the differences so we flag V_5 and discard this measurements. Therefore, the corrected value after discarding the V_5,

$$E_{correct} = \frac{V_1 + V_2 + V_3 + V_4}{4} = 10.74\angle 0.2^{0}\, kV$$

So, this value should be used at this substation level or should be dispersed to the other centers. This gives us a refinement perspective for the substation voltage and gives a scope to discard bad voltage measurement. Thereby you can suspect the associated PT or the device itself and then we can have the correction for that.

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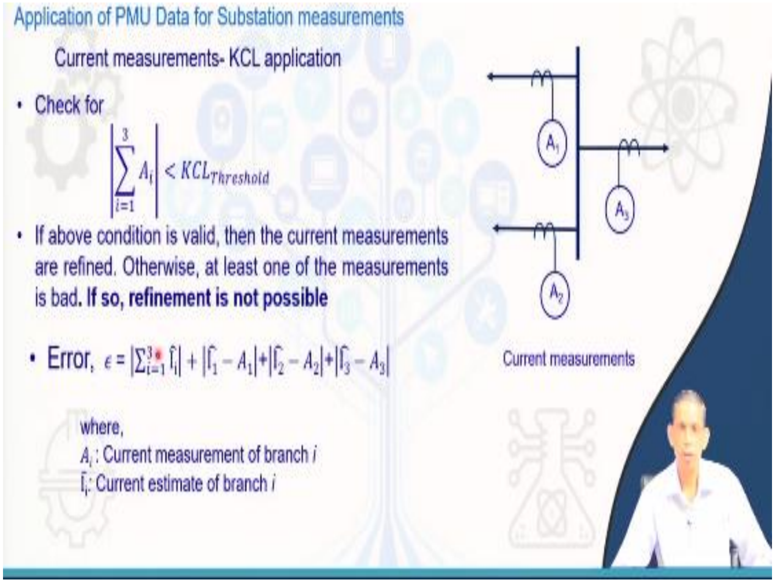

Similarly, in a substation we can have this corresponding current measurements and in current measurements we can apply Kirchhoff's current law, then this current law can be used for checking whether measurements are correct or not. So, some of the current measurement at a bus with all measurements coming to this bus. Ideally, this summation is close to 0 and is less than a threshold, then we declare that the measurements are okay, otherwise we suspect.

$$\left|\sum_{i=1}^{3} A_i\right| < KCL_{Threshold}$$

If above conditions is valid then the current measurements are refined or goes to the further refinement or we can do process something. Otherwise, at least one of the measurements is assumed to be bad so refinement is not possible unlike that in voltage what we see. So, we define error here as ε is equal to

$$\epsilon = \left|\sum_{i=1}^{3} \hat{I}_i\right| + \left|\hat{I}_1 - A_1\right| + \left|\hat{I}_2 - A_2\right| + \left|\hat{I}_3 - A_3\right|$$

Where A_i : Current measurement of branch i $\hat{I}_i$ Estimated current of branch i . So this gives us the corresponding error part for individual branch and then we have summation of this current as you see from KCL this will be close to 0.

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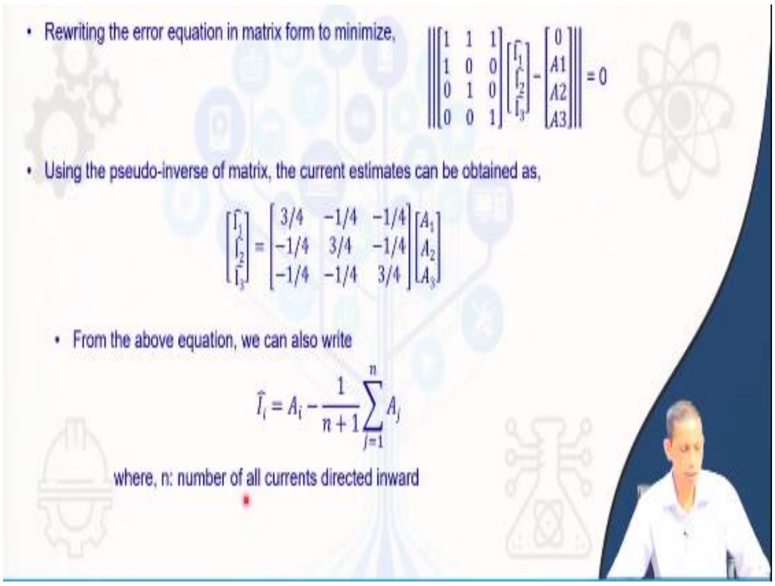

So, with that error if we write that corresponding error equation in matrix form,

$$\left\|\begin{bmatrix}1&1&1\\1&0&0\\0&1&0\\0&0&1\end{bmatrix}\begin{bmatrix}\widehat{I_1}\\\widehat{I_2}\\\widehat{I_3}\end{bmatrix}-\begin{bmatrix}0\\A_1\\A_2\\A_2\end{bmatrix}\right\| = 0$$

Using the pseudo-inverse of matrix, the current estimates can be obtained as,

$$\begin{bmatrix}\widehat{I_1}\\\widehat{I_2}\\\widehat{I_3}\end{bmatrix}=\begin{bmatrix}3/4&-1/4&-1/4\\-1/4&3/4&-1/4\\-1/4&-1/4&3/4\end{bmatrix}\begin{bmatrix}A_1\\A2\\A3\end{bmatrix}$$

Therefore, that I_1, I_2, I_3 can be obtained from this pseudo inverse of this matrix. And then we have A_1, A_2, A_3 so that leads to situation we can say that from the above equation we can simply mention also that individual current to be estimated by

$$\widehat{I_\iota} = A_i - \frac{1}{n+1}\sum_{j=1}^{n} Aj$$

Where, n: number of all currents directed inward. So, this is a straight forward relations and all currents directed inwards then only the KCL becomes a valid perspective.

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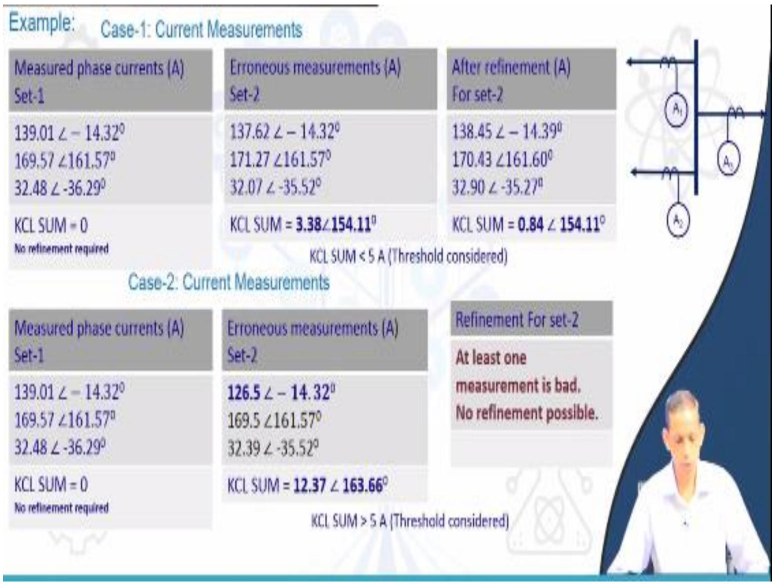

Now we will see example for this case three measurement system. So, let us see A_1, A_2, A_3 are the measurements in the first set so these is case 1 and we see the corresponding measurements in this process the KCL sum becomes equals to pretty small value. So, we say that no refinement is required. Now what you see here in the second set that these are modified measurements where intentional errors are being put into this data and we see now from the corresponding KCL this becomes equals to $3.38\angle154.11^0$and then we have a threshold as already mentioned in the earlier slide. The KCL summation becomes less than 5 A. So, this is acceptable so we can go for this refinement.

So, from this set 2 which are having little erroneous data as compared to the set 1, for the same condition, then we see that the corresponding currents after the refinement using that relation of matrix as pseudo inverse or the refined current becomes this and we found that the KCL summation becomes equals to $0.84 \angle 154.11^0$as compared to 3.39 in the actual measurement perspective. So, therefore we see that the refinement reduces the error in that perspective.

We have another case of current measurements from the same A_1, A_2, A_3, three measurements these are better measurements and now we added error into this and there is significant difference between the A_1 and the first measurements here. So, this shows that if we go for the KCL, this becomes significantly high $12.37\angle163.66^0$. So, this crosses the corresponding 5 A threshold. So, it means that there is a bad data here and that bad data in that case we cannot have a refinement perspective because you have to apply KCL So, this shows two cases, in one case we have a bad data and in one case refinement is possible.

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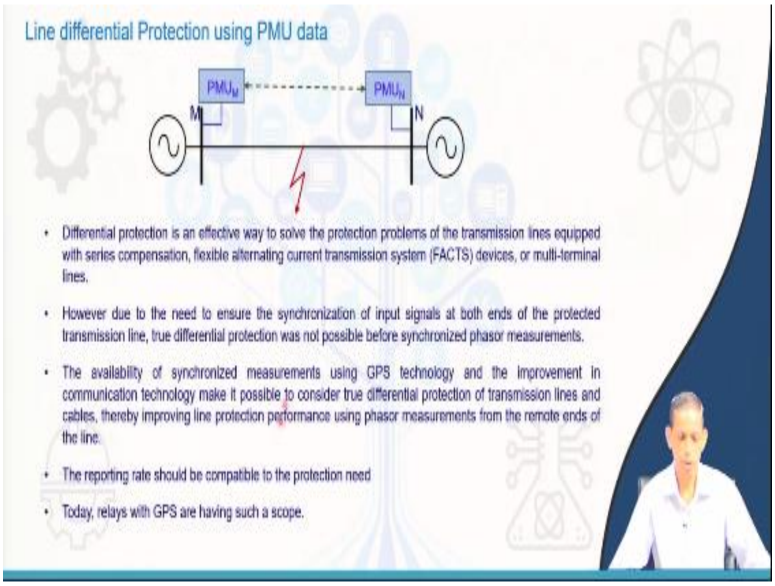

Now furthering our application perspective on line differential protection using synchronized data we have seen this application in line differential perspective and already we have covered in earlier lectures. So continuing with that, if we have PMU data either directly or in a wide area measurement system perspective, then we can use this PMU data for this line differential protection perspective. This can act as a backup or also normal with GPS technology and all these things we can have synchronized data and you can use as a primary protection also. So, this if you have indirect way of collecting these data for any other applications if the PMUs are available, so this can act as a backup also. So, synchronized measurements gives us that I_1 - I_2 otherwise, we cannot do as only pointed out the concept of synchrophasor. So the only thing is that if the reporting rate and the corresponding and associated latency are compatible to this particular protection requirement, then this can be directly applied.

The advantage of such a differential protection is that this line is having capacitor having FACTS devices or multi-terminal lines, then we can explore such facility for accurate protection. So, multiple lines may be emanating from a different points. So, in that case the best solution will be the differential protection and if we go for synchronized data, then it becomes easier and more accurate.

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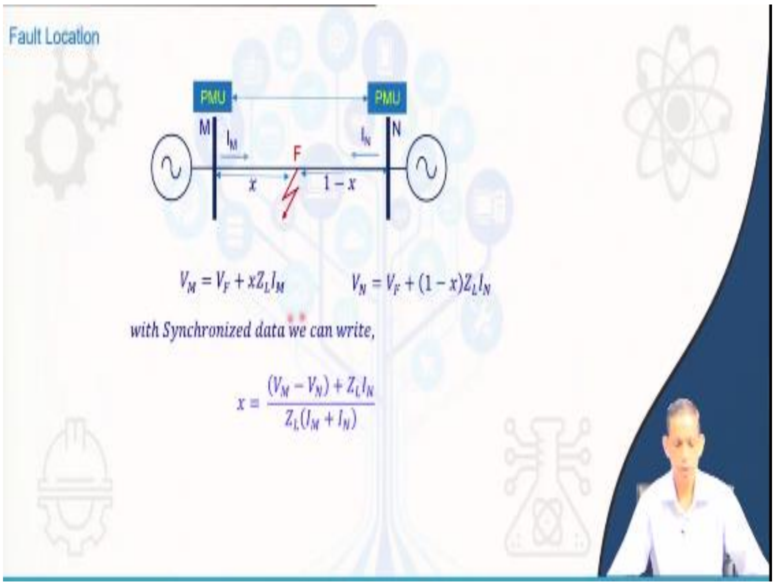

Fault location we have seen in travelling wave perspective so there also we mentioned about if we have synchronized data at both the ends from PMUs application, fault location is offline business there is no issue of speed. So, in this case, if we have a fault at *x* so then we can write down this side single phase synchronized basic equation if you write and then we can extend to three phase concept also. The voltage and current relation at bus M can be written as

$$V_M = V_F + xZ_L I_M$$

Similarly for bus N

$$V_N = V_F + (1-x)Z_L I_N$$

Now fault location x can be represented by the synchronize data at both ends V_M and V_N as

$$x = \frac{(V_M - V_N) + Z_L I_N}{Z_L(I_M + I_N)}$$

So using the voltage and current measurements and the line parameters the fault location can be accurately estimated.

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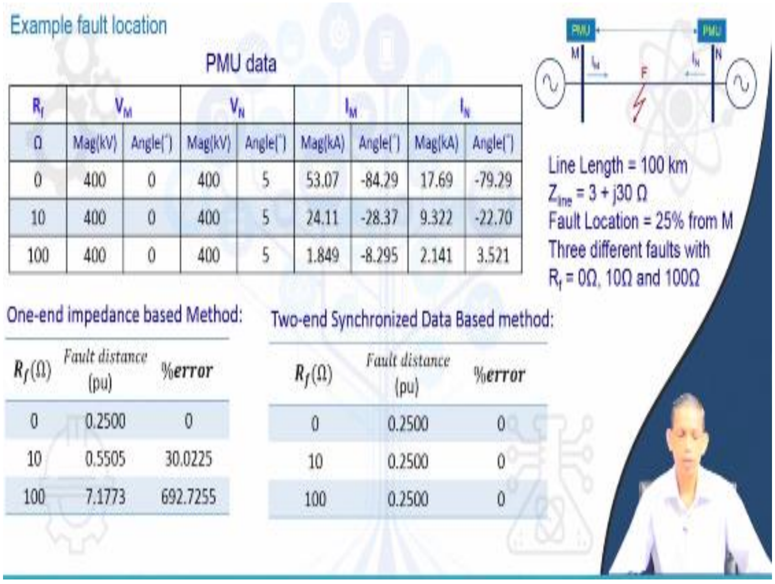

So, this is for the two bus line 100 km line, the line impedances are like this and we say that R_f the fault resistance variations of 0 Ω, 10 Ω and 100 Ω for 3 different fault situations of phase A to ground fault and then we have got the V_1, V_2, I_1, I_2 of both these sides measurements and then we apply this from one end if you could do the calculation then the corresponding fault was having 25 km from this side.

So, we got the per unit distance to be 0.25 for 0 fault resistance, but with increase in fault resistance, the impedance based approach gives us erroneous fault distance, but with two end synchronized data the formula we used in the last slide. Using that we can say that in all the cases we are getting 0.25 because the V_F fault voltage does not influence the corresponding accuracy. So, this is the strength of synchronized data being used for fault location application also.

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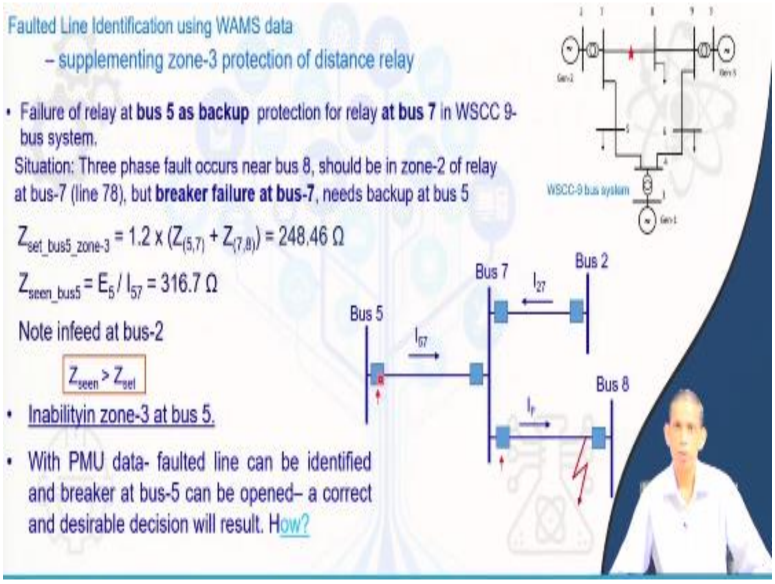

Now next we will go for another applications in real time perspective how the corresponding PMU data can supplement the zone 3 protection for better decision. In this perspective we say faulted line identification. So, what do you see that any line having a fault in this 9 bus system can be identified from different measurements of the PMUs, then we can use that for the backup protection also.

Let us consider a situation here how that can be extended. Now see failure of relay at bus 5 as backup protection for relay at bus 7. So, from this one this part is taken care. So, we see here failure at bus 7 so the relay at bus 7 fails to protect for this fault let us say three phase fault that is towards the end in zone 2. If this breaker does not operate this breaker must operate. So, that means that for this it will be a zone 3 fault. Now what happens to the situation? So the zone 3 settings for the relay at bus 5 will be

$$Z_{set\_bus5\_zone\text{-}3} = 1.2 \text{ x } (Z_{(5,7)} + Z_{(7,8)}) = 248.46\ \Omega$$

So, that becomes equals to let us say for this case is 248.46, but the impedance seen at a given instant of time because of the infeed from bus 2 happens to be 316.7 Ω. So, that leads to a underreach situation because this setting is 248 Ω only and now its apparent impedance is 316 Ω so this relay at zone 3 will not pick up. So, the fault will continue because breaker at this point is not able to clear the fault. So, the inability of this zone 3 at bus 5 leads to dangerous situation. So, with PMU data if we can identify the faulted line and then this Z at bus 5 breaker can be opened from the independent protection arrangement that can supplement the valuable protection schemes then it will be better. Now the question is how that can be implemented?

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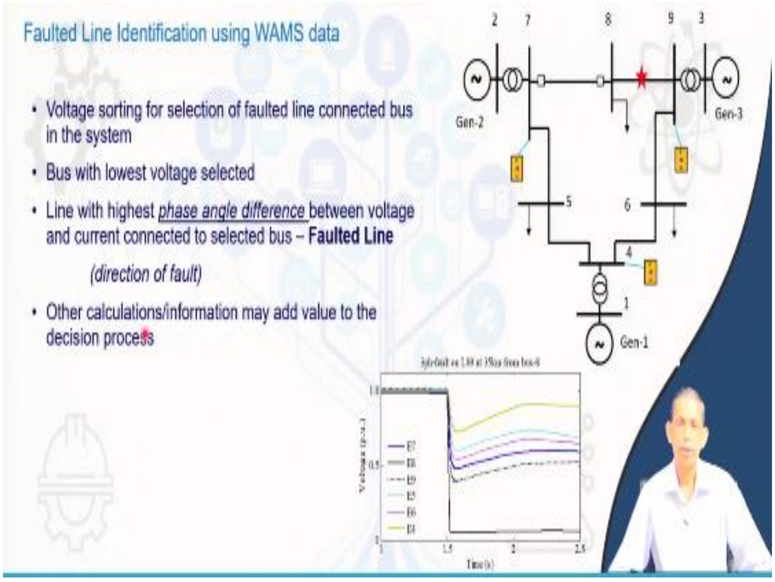

So, for that perspective, let us see in this 9 bus system we have few PMUs at bus 7, bus 9 and bus 4. Now how this data can be used for faulted line identification and then how we can supplement the zone 3 protections that we like to put as an example. So, we see this fault in line 8, 9 and in that case the corresponding voltage everywhere dips and as you know that the voltage dips to a greater extent at the adjacent buses. So, bus 8 and 9 should be affected. Now we can say that the corresponding E_8 is this one that goes to significantly low and this side is the generator due to that reason voltage is little bit higher. What we like to say that if we see this magnitude and dip in these voltages from one PMU, it is clearly observed and further in the corresponding bus the dip will be smaller and smaller.

Thus from the voltages to identify the faulted bus with lowest voltage and selecting the line with highest phase angle in the current respect to that bus voltage indicates the faulted line because the phase angle will indicate the direction. In that perspective this phase angle will be in negative direction. So, what we like to say that the PMU data here can be useful for decision process which add value to the protection scheme.

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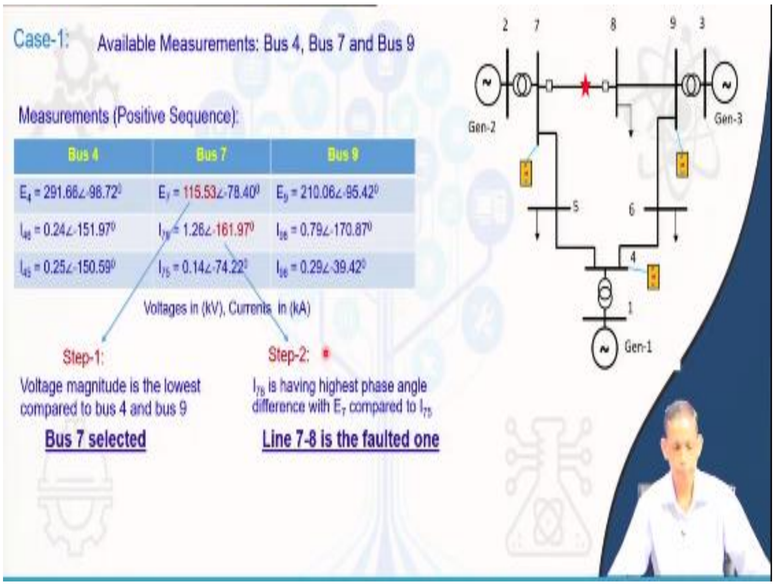

Now let us see an example here what is being done? So, we have three PMUs and a fault happens to be there between bus 7 and 8. So, at that time we collected data in the simulation process so at bus 4, bus 7, bus 9 these are the PMU data, positive sequence data three phase fault happens to be there. So, E_4, I_{46}, I_{45} are the corresponding line at bus 4 we have two lines 45 and 46. So, these are the currents associated at bus 7 we have two lines this line and this line the currents are there and bus 9 we have two lines 98 and 96.

So, all currents associated with that PMUs are also available including the voltages. So, three voltages 291, 115 and 210 so the minimum one is 115. So, bring out this corresponding bus 7 as the choice of low voltage bus so that is why bus 7 selected in this case. So after this bus 7 we say we consider at bus 7 the corresponding currents are I_{78} and I_{75}. And then we check with this voltage at bus 7 which current is having larger angle. So, the highest phase angle difference between E_7 and I_{75} which happens to be there. So, therefore, line 7, 8 this is I_{78} so with this we can say that angle tells about lines 7, 8 is the faulted line.

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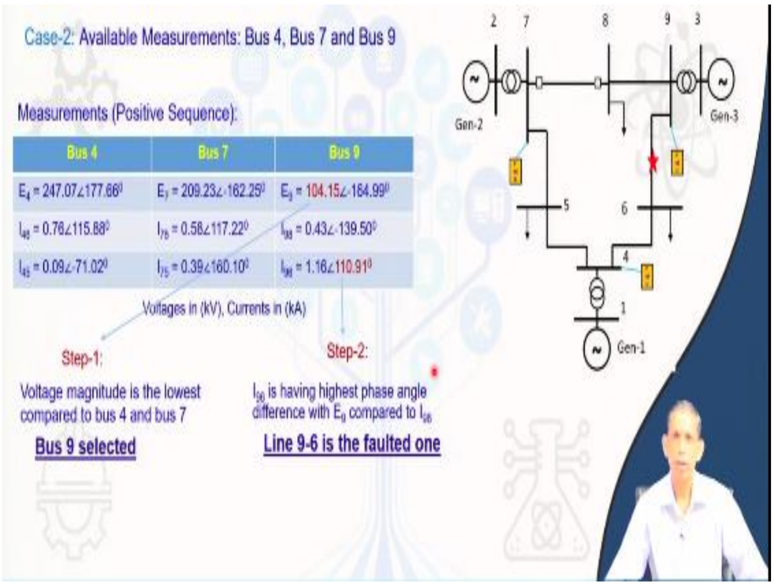

Another case we see here fault is created between 9 and 6 and the measurements are this so in this set positive sequence voltages and current we say the minimum voltage comes out to be 104 so bus 9 is selected. Two lines are there 98 and 96 the angle between this voltage and this current that happens to be significantly high. So, the corresponding 96 line is that is the correct value. So, in both the examples we see that from the PMU data if available we can find the faulted line correctly and this faulted line can be useful for further influential processing.

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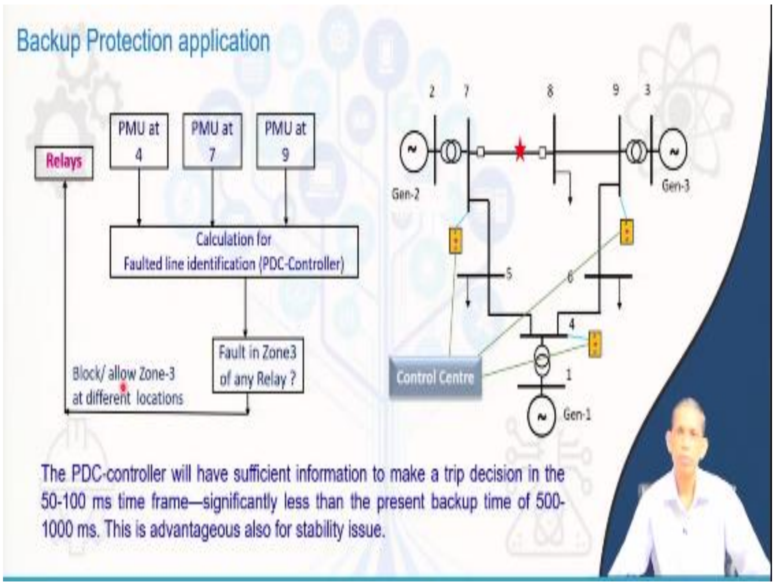

Now what do you see that this is the 9 bus systems and we have PMUs we collect at a control center to this PMU and this control center can process the corresponding PMU data, align them in terms of the times alignment and then it can be used. So, we have this three PMUs and then we calculate the corresponding faulted line, identify the faulted line perspective using this PDC and the controller level this level. And once it is done you can calculate whether the fault is in zone-3 or not. So, we calculate for different relays at this centralized levels we calculate that is the corresponding fault is any zone 3 of any relay here? If it is yes then the corresponding relay should remain active otherwise we can say it should be blocked. So, common issue from here also through the relays at different points to activate the corresponding breaker in this stipulated time without waiting for that.

So what is the advantage of this that such a platform can give us trip decision between 100 ms and therefore, we may not have to wait for 500 ms to 1 s which the conventional zone 3 operates. So, that will speed out the process of decision because it will be able to know that it is the decision with zone 3 when zone 1 is not operating. Therefore, we can say that all zone 2 is not operating there is a failure. So, it can go for the protection decision at the faster rate. Thus we see that PMU data can be used as a backup arrangement, as a supplementary arrangement to the zone 3 protection perspective which seems to be compatible from latencies also.

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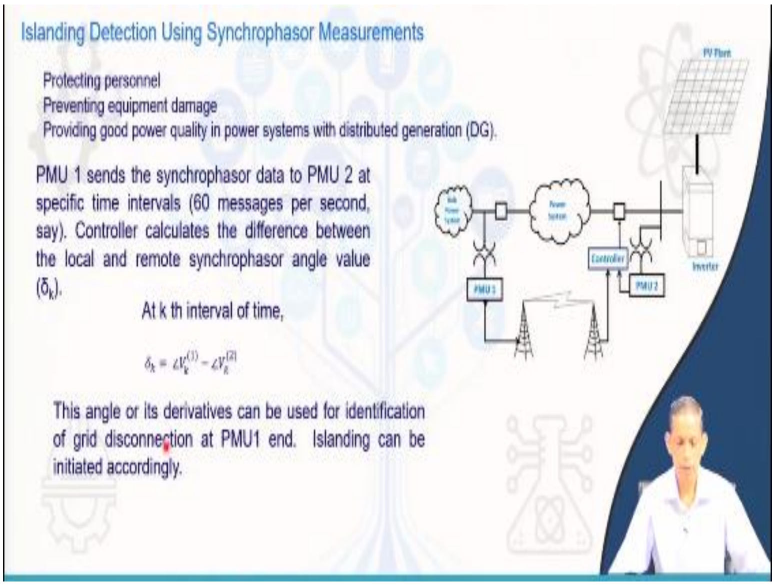

Islanding detection for the larger system we talk about out of step protection where the rest of grid side is having problem, then to retain this local area we can have an islanding situation. In that case the local area should manage the corresponding load and generation or it should shut down all its generations to bring it to a standstill. In a distributed generation systems we require also Islanding detection that we do generally from the frequency information or voltage information perspective.

But we can also use the corresponding PMU data or synchronized data. Like this is a power system connected to this local power system is connected to the corresponding PV plant and so any renewable resources or DG this side you can say to the bulk power plant. If this corresponding bulk power plant connections is disconnected, then this local system may not be able to manage at this corresponding PV plant or renewable generation.

So in that case an Islanding detections the DG plant will be disconnected because otherwise it will lead to issue with the safety of the personnel, equipment damage locally and also the power quality issue. So, for that reason the island detection becomes an essential one and in that case the local islanding detection schemes can be useful and if that fails also the PMU data are available it can supplement that in the high voltage side or in the distribution system also.

Further, the angle between the two voltages this side and that side that angle is indicative in case of this islanded system, if this breaker is opened the angle drifts independently between these two. There is no synchronization between them and therefore, it drift to any forward or backward direction. So, that angle is indicative of the corresponding situation normal situation when grid is connected these delta angle becomes smaller and it will be consistently having closer value to the steady state value. So, therefore this corresponding angle is indicative of in terms of the islanding situation, its derivative or double derivative can be faithfully used for such detections.

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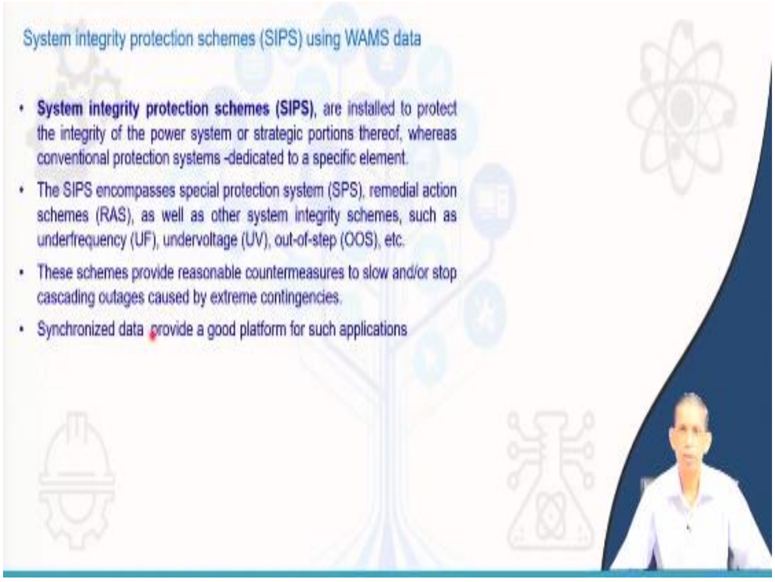

System integrity protection scheme is a concept which is already there in the system. Most of the system integrity protection schemes used this SCADA data also. Note that system integrity protection scheme is different from the conventional protection address individual element like differential protection for transformer, line protection with distance relay or differential arrangement for individual line distribution system and so generated protections.

These are individual protection we talk about, but system integrity protection schemes are installed to protect integrity of the power system or strategic portion was thereof whereas conventional protection is for element wise element specific protection. This is to retain the system intact its integrity particularly from possibility like large scale disturbance or blackout and so.

This SIPS encompasses special protection scheme, remedial schemes any integrated schemes and it also includes under frequency, under voltage and out of step functions to retain the integrity of the system. This schemes provide reasonable countermeasures to slow and to stop cascading effects for varying possible large scale disturbances. Synchronized data provides a good platform for such applications. So, we will find many applications today in different grids on that perspective. This cedar system which was catering this SIPS can be supplemented with wide area measurement systems because that gives us a better scope for such applications.

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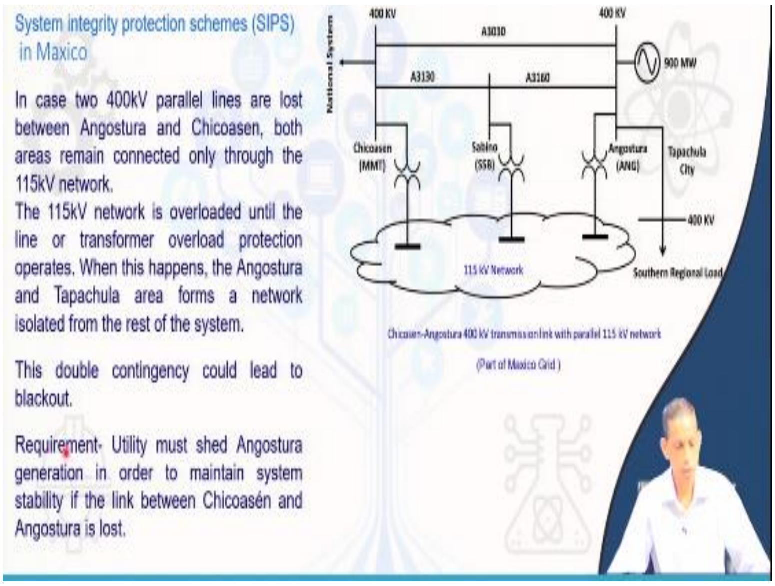

Let us see an example how in Maxico grid SIPS using synchrophasor data is being implemented. So, this is a part of Maxico , Angostura and Chicoasen, this 400 kV line they are parallel lines, double circuit lines and there are number of connections for the 100 kV line and that 115 kV network. So, what happens that this 900 MW generations possess power to the national grid and other portion of the system through double circuit line and also there is a connection of 115 kV line also.

Now what happens in case of any of the lines trip in this 400 kV line so the rest of the power will be dispersed through the 115 kV line. In that process, the 150 kV line get stress and there is a possibility of this 115 kV line at different portions can be overloaded and overloading operations will go and that leads to different several outages of this line and make cascade events may go and that leads to more stress in the system from this generation units to the national grid level. When both the lines are out it is more severe in nature and then there is a chance that this region can be out from the national system level case. In that case this to avoid this situation particularly the contingency of double circuit line outage at 400 kV level and so the requirements becomes the utility must set this generator to reduce the generation or to withdraw all the generator at this location.

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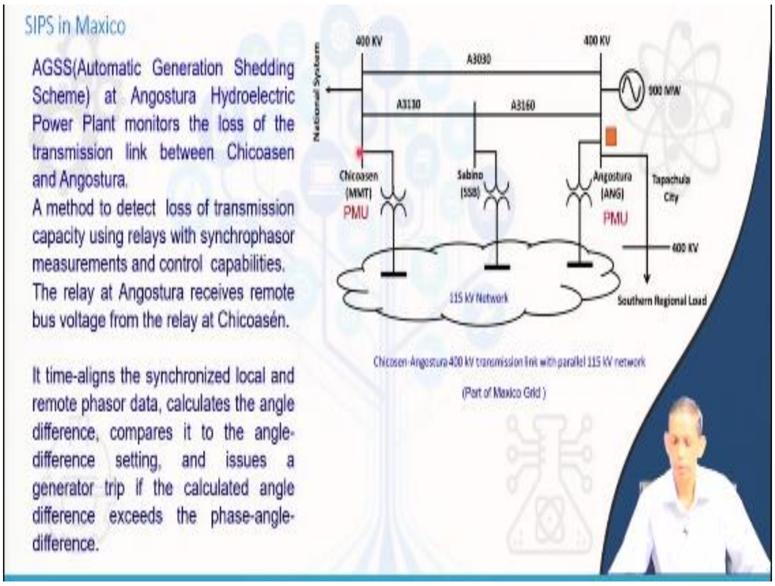

So, what is being done we see here that we have a PMU place at this end and we have PMU at this end through available region with GPS facility. Now this PMU sends data information to this one in real time to communication system and the corresponding voltage data here and voltage data are here they align and then from the alignment the processing processor here does sees that what is the angle deviation between this side and this side.

Note, when the corresponding angle in general is in a limit where 400 kV both lines are there. One line is out the angle between this side and that side goes to the higher value and when both angles are out, the angles becomes further higher. So that is being noticed so in this automatic generator shedding scheme that hydro plant giving 900 MW or so. Therefore, a method to detect loss of transmission capacity is by this angle measurement between this two sections. So, that is being used.

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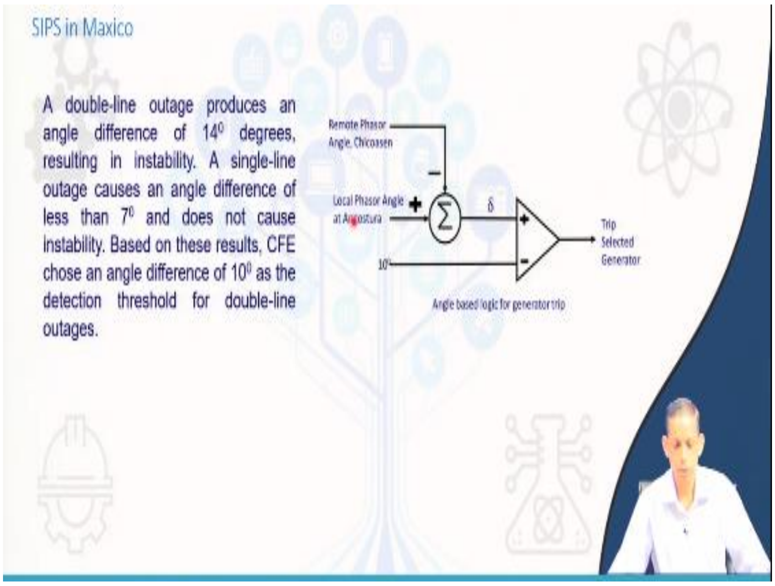

So, what is being done here that the double line outage produces 14^0 angle between these two sides and one line outage provides around 7^0 angle difference between both ends. So, a threshold of 10^0 is being selected and then we can say that between these two phasors. Angle between these two voltage phasors one at the generating station side and other at the remote one. So this two angle differences gives us δ and if the δ is greater than 10^0, then it is a drifting of selected generator is to be accomplished. This gives that once the generator stations reduces generation or the generators are out, then the stability of the system can be retained and the cascade tripping can be avoided in this perspective. So, this gives a systematic protection schemes using phasor measurement needs at remotely placed PMUs.

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So, in overall we say that synchronized data from PMUs, from relays with GPS facility can be used for different applications. We have real time applications as well as offline application of relevance to the protection perspective that you see like SIPS for online applications, differential protection and quadrilateral identification for zone 3 application perspective and also for offline perspective for parameter estimation and so.

But in real time application, latency is the challenge, the late arrival of data, if that is compatible the corresponding synchronized data through wide area measurement systems can be a good addition for system level protection including element level protection as a backup or supplementary. Emerging technology this field is and newer and newer applications are coming in different grid application. Such technology is not only limited to protection, this is also going on for the control applications of the power system and also for monitoring applications.

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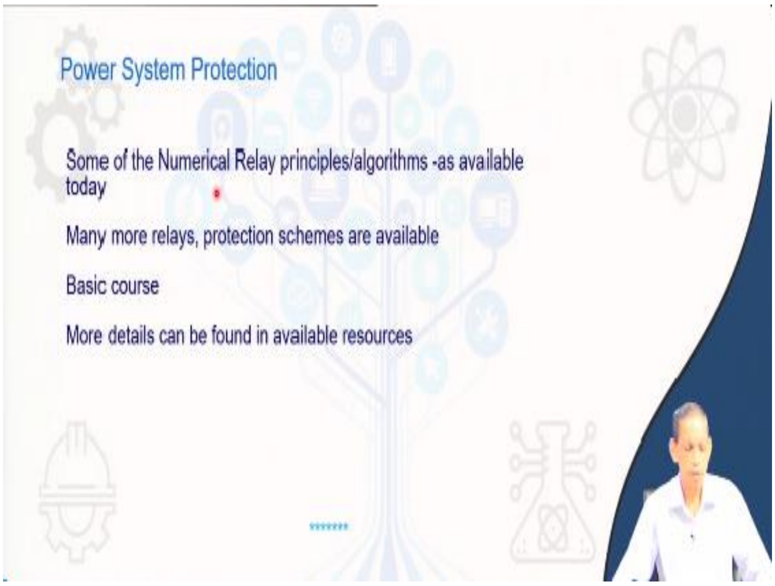

So, this is the last lecture we have for the power system protection course. Our focus was on numerical relaying principles algorithm which are available today and are being used in different applications of the grids. Many more relays are available, many different protection schemes are available like generator protection and so. This is beyond scope of this course. This course deals dealt with the basic in nature. If anyone desires to be more details on this lot of resources are available.

Hope you enjoyed the course any remarks, comments is always welcome. There is definitely some errors. If you can point it out and communicate to us it will benefit all of us. Thank you best wishes.