Introduction to Smart Grid
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Lecture - 12
Wide Area Monitoring Systems- II

Good morning to all of you, in this particular lecture we will talk about the WAMS Applications. If you will see that nowadays we are using wide area monitoring based systems for different applications like for the generation sector, for the transmission sector, for the distribution sector.

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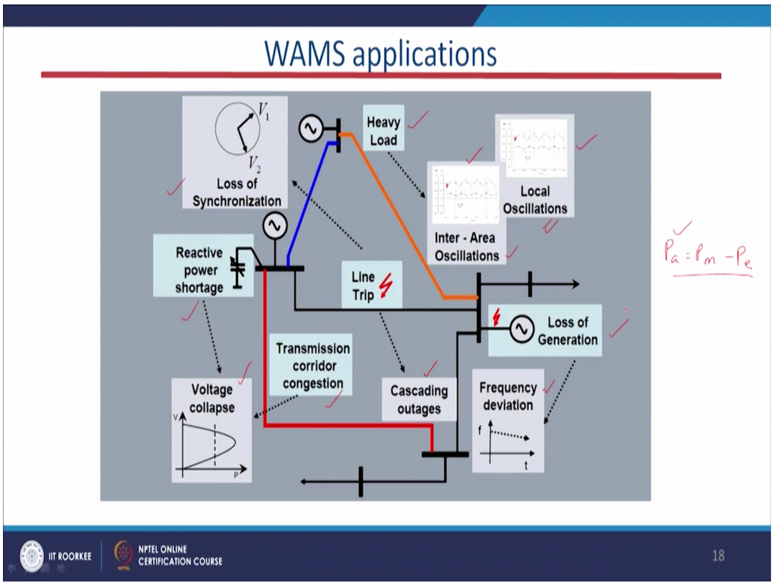

And if you see this, this particular slide where I have just mentioned about the different sectors.

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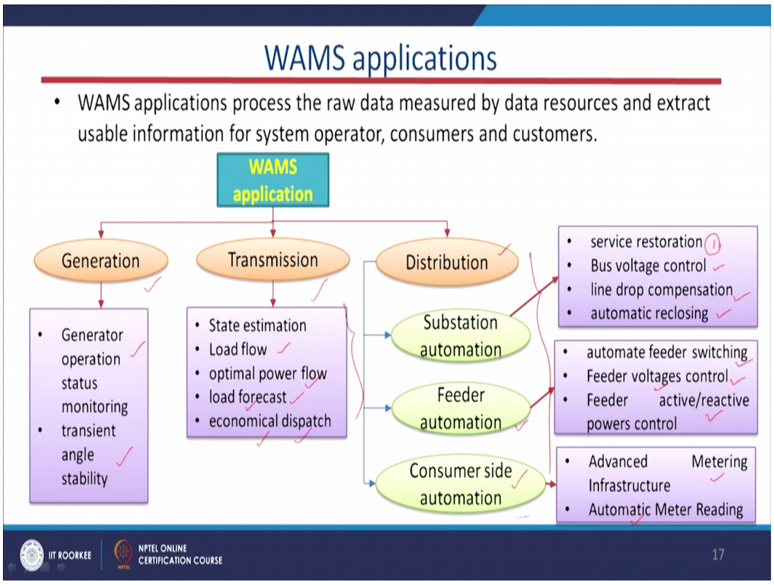

Like if will take a generation here we can go for generator operation status and monitoring. Let us say in particular generating station, we have large number of like generating power plants; I mean more number of generating power plants and we have to monitor the corresponding voltage frequency and the current output power output. So, there are many parameters which are basically require monitoring system what is the direct status. So, for that purpose of course, we can use the WAMS application like Wide Area Mentoring System, the second one is the transient angle stability.

In case of generating stations, we have like different stability issues voltage stability then we have angle stability we have frequency stability. So, keeping on that mind different type of stability issues can also be monitored using this WAMS structure. Now, coming to the transmission part like state estimation, load flow, optimal power flow, load forecast, and economical dispatch; these are different operating parts operational parts of the transmission system and how to basically help the load flow the conventional load flow conventional test estimation process.

So, there also we can embed the information from the WAMS technology and we can improve it to a higher version, where this thing will be more realistic and more accurate and more reliable for further process. And the this one is also very important like load forecast; if you can forecast the load free hand like what is happening how much power we have in our hand next 1 week or 2 days or 1 day ahead then in that case we easily we can go for the power dispatch; how much power we can supplied to that particular customers or to that particular area, that can also we can decide easily.

And also we can do the economic and economic dispatch part; coming to the distribution part we have like a substation automation, feeder automation and the customer side automation. And this is in fact the distribution part is the customers end where the utilization the power takes place. And obviously, the more interaction is going to be at the customer side and that is why this smart grid aim is to improve wise or to make the distribution system more smart in nature.

And lots of applications are lying down where there is a grid scope; if you can apply this WAMS technology for the distribution side. And it is already tested for the transmission side where we are just spacing the PMUs for as transferring the data to the PDC that is we have already discussed the data concentration centers and then it is going to the national PDC, national level data concentration centers.

And there from there we can take any decision we like, but in the distribution side also we have to take care and the same technology can be applied for accurate and reliable operation of the distribution system. Coming to the first part the substation automation part the first component is the service restoration. See sometimes what happens after the fault inception, we have to reconnect the circuit to the main circuit or we have to basically bring back the service should be restored so that the customers will get supply after certain time peroid.

So, those type of service restoration techniques can also be improved using this WAMS technology. And the second one is the bus voltage control at certain buses we could see that that the voltage profile is going down or the voltage is going to be collapsed due to the lack of reactive power compensation or reactive power supply. So, those are remedial controls or remedies we can act from the WAMS technology.

So, that is what we can control this bus voltage and the line drop compensation also we have this automatic reclosing facility; this automatic reclosing facility also we can draw from this WAMS. Now coming to the feeder automation part we could do this automatic feeder switching then this feeder voltage control and again also we have this facility active reactive powers control. So, this active reactive power control is very important as well as the feeder automation is concerned, where the load changes time to time, the load is not static in nature it is dynamic in nature.

So, in that case; obviously, the active reactive power is going to be changed they are going to be changed. So, that is why this feeder automation part this voltage control active reactive power control are important. Customer side automation we have advanced metering infrastructure and automatic meter reading. So, this two are already we have discussed in our during our substation automation part that what is this advance metering infrastructure, using this infrastructure we can monitor basically the major the power at the customer premises for the analysis; this is how this automatic meter reading also does.

Now, I will just show some examples that how these particular WAMS technology help to us. How this particular warms technology helps to us. The first one if you will see the loss of synchronism, what is the meaning of loss of synchronism? That in a particular network; we have two 3 generators and if the generator is going out of order due to certain problem or some fault or some maintenance so or some other difficulties. So, this is the generator is disconnected to the network; so that condition is known as loss of synchronism.

Now that by taking the voltage magnitude and phase angle information we can always say that what is the status of this generator; whether the generator is connected to the network or not. So, that is what the technology this WAMS technology will help to us. Now, we have also this reactive power shortage; if any at particular bus we do not have sufficient reactive power to supply to that particular volt I mean the bus to maintain the voltage profile.

So, always we can send some control command from the control centre to enhance the reactive power supply by switching on certain reactive compensation devices. And that is it is quite possible using this WAMS technology and also we can always by this corresponding. As we said by looking the voltage profile of each bus we are just monitoring time to time just in real time platform using this WAMS technology. Then always we can see the voltage profile whether it is going to collapse at certain buses in the network that is; what is voltage collapse status.

And also we have heavy loading practice; if in some areas we have excess load which are now connected and this load is this basically the load is drawing huge amount of power then that is known as heavy loading of the network. So, that due to that we may have some oscillations, you know that basically in the power network when the load increases or decreases; it means the electrical power of the generator decreases or increases, but keeping in mind that at that condition or mechanical input to the generator remains constant.

So, as you know that if the mechanical power remains constant and the electrical power varies; so obviously, there will be change in this two powers that is P a is equal to this P a is equal to P m minus P e that is our accelerating power, mechanical power minus the electrical power. So, this accelerating power accelerates the rooter of the machine. So, due to that we may have some oscillation in the current and voltage waveforms this is what it is shown here in the power finally, the power will also oscillate. So, those kind of inter area oscillations between two areas or within a single area; we could have some oscillations at different buses. So, those oscillations always we can tap from the wide area monitoring system and we can take corresponding remedies or some control actions we can apply.

Now coming to this transmission corridor congestion; so if we are supplying some; I mean power. So, through the particular transmission line from one bus to other bus; so that there is the chance that that line that particular line may be overloaded. So, that maybe some congestion I mean; so in that case how to maintain it how to divert the power? Unless until you know the status of the line. So we cannot take any decision; so that particular decision can be taken from the WAMS technology.

Now we have another factor that is cascading outages we have frequency deviations already we have discussed loss of generation. So, these are the focused areas where this WAMS technology can be basically utilized or I can say in other word it can be like properly justified. And we can exploit this particular technique for our betterment or better operation of our network or smart grid system.

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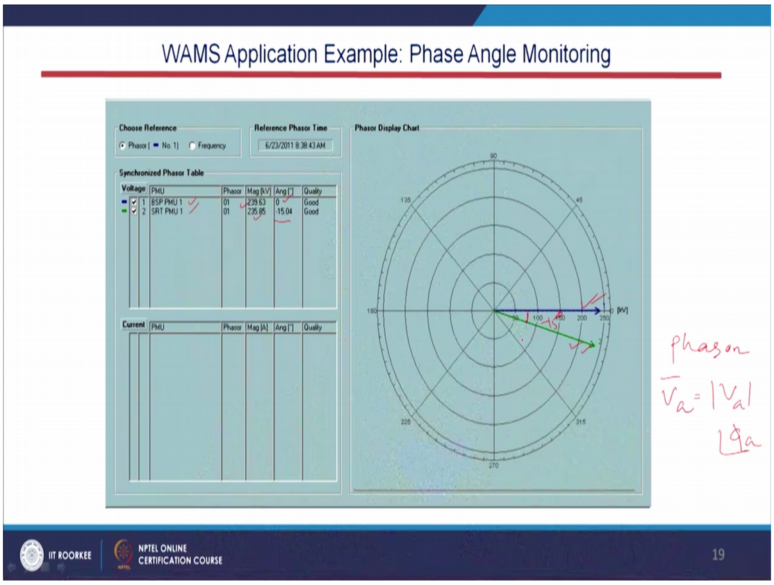

This is one snap shot that WAMS application for phase angle monitoring that you could see here that there are two buses two buses. So, we have placed PMU 1 and this 2; so, for that particular one PMU; the voltages and magnitude is 239.63 and angle is 0 degree and this is the phasor position. If you could see in this will this circle and here the second part the voltage let us the magnitude is 235.84 and the angle is minus 15.0 degree and here is the phasor positions.

So, phaser means it has the phasor word itself indicates the V a if it is a phasor voltage then it has a voltage and also it has a angle phi. That is what this voltage V a is 239.63 kV and the angle is 0 degree and here is this phasor position and when this angle is minus 15 degree. So, this angle is basically minus 15 degree; so this is how we can take the snap shots from the wide area monitoring system technology. And easily we can locate where is this particular phasor is lying we can see always the phasor position of particular bus of a particular power network.

Now, if we will come to the WAMS application like voltage stability monitoring.

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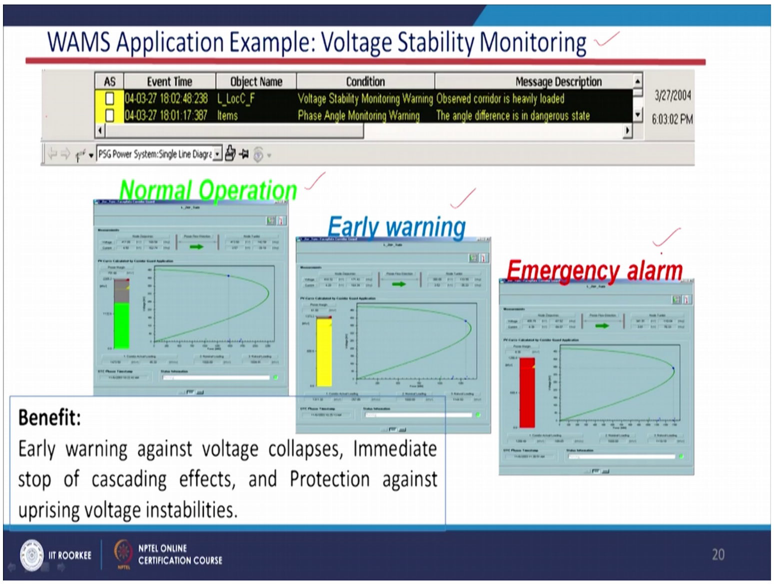

Here also we can see from the wide area monitoring system that if it is green; it is a basically normal operation of the system; that means, the voltage is in stable condition. If it is like yellow; it is a early warning condition; now if it is rate it is emergence alarm system.

So, these are basically the symbols or colours we use to detect whether my system this voltage is stable or it is in on stable mode. So, of course if this is the condition; so we can take some control measures or control action that is what is our target. First of all we know; what is a status, then we can take the corresponding actions. Now this is what this power oscillation monitoring part and if some areas like between two areas; the tie line basically connects two areas; if any oscillation occurs within this tie line; so we can monitor from this wide area monitoring system facility.

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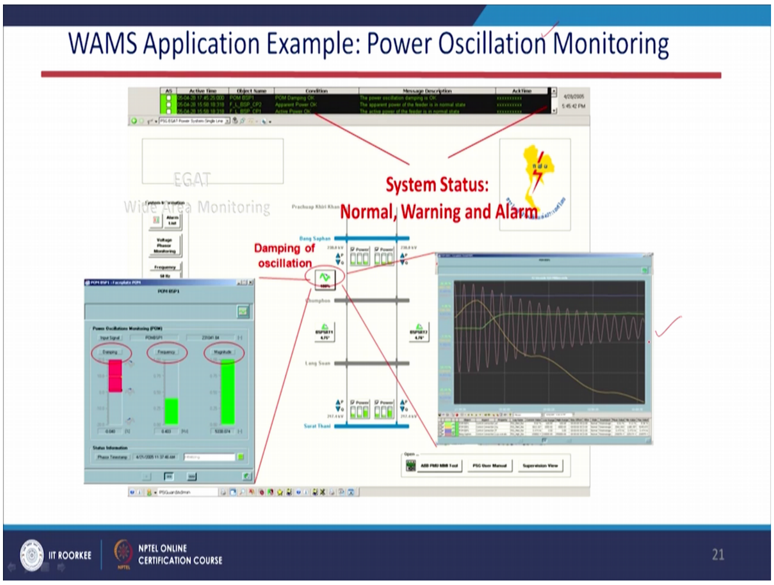

So, from there we can take some decisions. These are some examples I said; so there are lot of many applications we can do from this wide area monitoring system structure. Now already we have discussed when I started this wide area monitoring system lecture that we have discussed that the there are 3 components of this wide area monitoring system.

The first one is a the data acquisition, second one is the communication part and the third one is application. So, already we have seen application part as per the data concerned we have already discussed the synchronize measurement data that is the operational data. And other part is non operational data those non operational data we can obtain from this one of the device this is the digital fault recorder.

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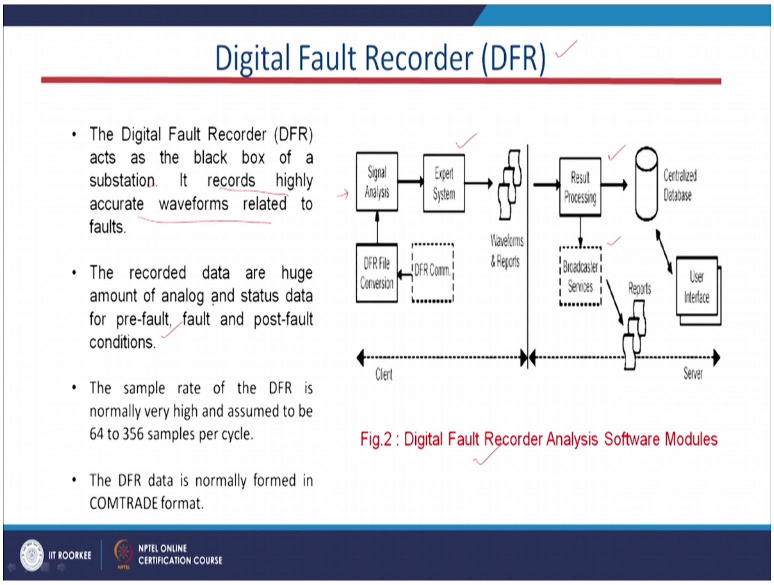

It is known as FR; DFR; so what are the basic block diagram for this; will accure the signal will accure the signal and we have expert system and from the expert system we can store the data or we can process the data for further actions. So, it will just this digital fault recorder acts as a black box of a substation and it records highly accurate wave forms related to the faults. It is basically records the voltage current wave forms during the fault inception period. So, it will just say at what accurately at what point the fault was there? The fault was incepted in the particular line or in a particular device or transform or generator or you can say feeder or so any load so wherever.

So, we can always record the voltage current data using this particular device and this are the recorded data huge amount of analog and status data for pre fault, fault and postpone conditions can be also used for further analysis that particular device will help us.

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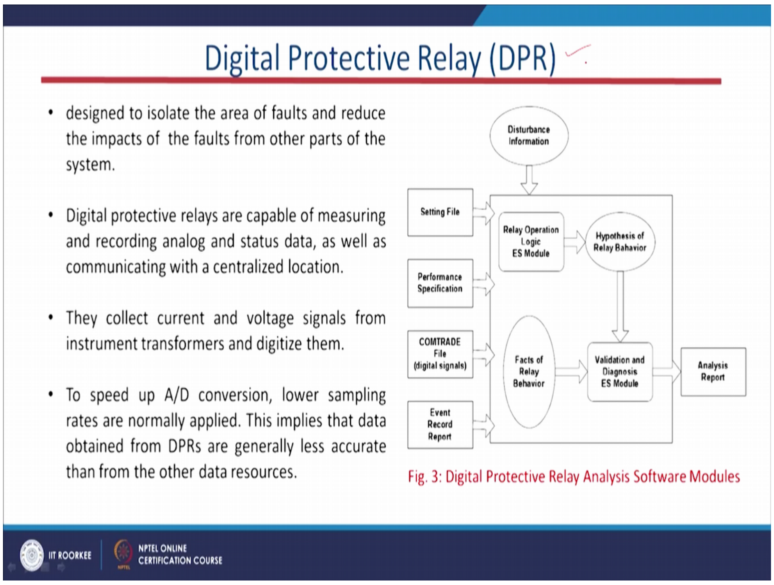

Now we have another device that is the digital protective relay. We will discuss more about in our subsequent classes when we will took about I will just take about the protection part of the smart grid system that this digital protective relay also takes a very good decision and it will just try to protect every equipment in fact, the generates or generators, transformers, transmission line, feeders, loads.

So, every equipment basically protected by one digital relay and this relay digital relate x the voltage current information and it basically operates with certain signal processing techniques and it gives the trip signal to the second breaker. And also we have third one that is the circuit breaker monitoring device.

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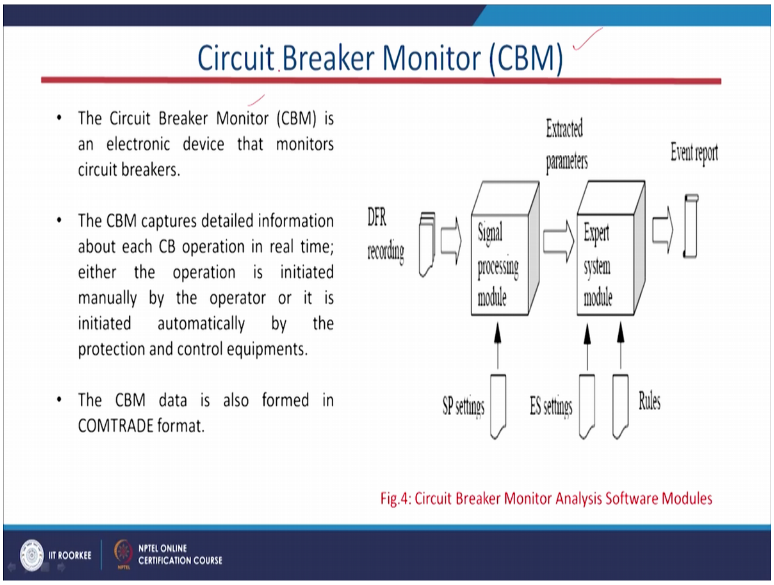

It will just this particular device this monitor this monitoring device will monitor the status of the second breaker which is present circuit breaker which is present inside the circuit; it may be in the transmission level or it may be in distribution level. So, we can always extend even if suppose it is a related to the distribution level always we can extend this technology to our other level also.

So, to facilitate the smart grid technology and also to have a better visualization of the circuit or network; for understanding what is happening inside the circuit so that any disturbance any event is going to be going to be happened inside the circuit. So, we can takes some major action before going to have some cascading failure of the circuit or some blackouts or brownout. So, in that case these devices I mean data which are obtained from this devices are very very important. I will just come to the very important part of this a wide area monitoring system that is phasor measurement unit.

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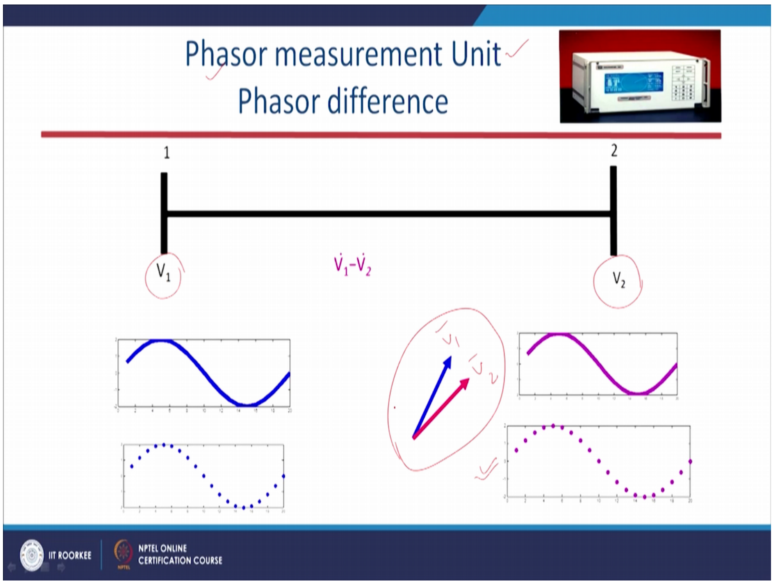

And. In fact, this PMU is the heart of our wide area monitoring system. So, without this PMU the wider area monitoring system has no meaning. So, this PMU stands for Phasor Measurement Unit and basically as the name suggest that phasor; it measures the phasor of the voltage and current. If let us say these are two busses where we have this V 1 is the voltage magnitude or phasor of bus 1 and this V 2 is the voltage phasor for bus 2.

Now, how to know this phasor position of these two buses? As already we have discussed in the scalar system the magnitude of the voltage of each bus basically is known to us, but not the phase angle. But nowadays if you could see our distribution system or even the transmission system or network or distribution network are becoming basically from passive to active network. Why? It is why? Because due to the integration of renewable sources like small hydropower plants and wind turbines solar system; so, this network is becoming now from passive to active.

Now the distribution system is also is having the facility to generate the power from any corner of it; that means, because we are connecting the solar and wind small hydro stations at nearest to the our load terminals; so, we are generating the power. So, in that case with magnitude information it is not sufficient to visualize to control the network or to protect the network or the smart grid system.

So, it is necessary to have this both the information like magnitude of the voltage and angle of the voltage or maybe the magnitude and angle of the current. So, that is what this PMU device helps to us providing this magnitude and phase angle of the voltage and current. If this is basically the bus 1 phasor this blue one; so this is my V 1 phasor position of the voltage and this rate one is the phasor position of the V 2; that is our bus number 2.

And we have a very good facility that with a advancement of this computer facilities and also signal processing techniques. We could like we are able to estimate the phasors of the voltage and current the real time platform. We use basically the DFT; Discrete Fourier Transform for this at the inside the PMU the algorithm runs. And using that we can always estimate the phasors of the voltage and current for further analysis. And that is how this phasors notation or phasor positions, we can always obtained using this PMU device which are basically installed inside the power network.

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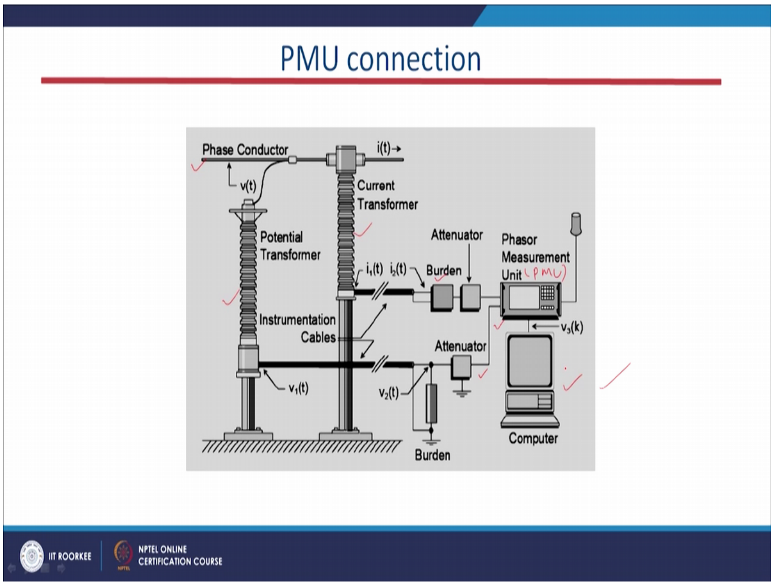

Now, this is the one of the PMU connection snap shot where this phase this is our phase conductor or the power conductor. And this is our potential transformer and this is our current transformer and here is our PMU the Phasor Measurement Unit; PMU and this current transformer is connected to the PMU terminal through this burden. And we have also this instrument transform which is also connected through this attenuator to the voltage terminal of this PMU device. And we have always this computer is connected to the interface to the PMU to analyze the data and what are the voltage current phasors or instantaneous values or even sometimes this PMU; also if it is customize properly it can also record the frequency and the rate of change of the frequency. So, this computer basically records or it displace the voltage current data.

Now, this is how this I will discuss about the PMU scenario in India.

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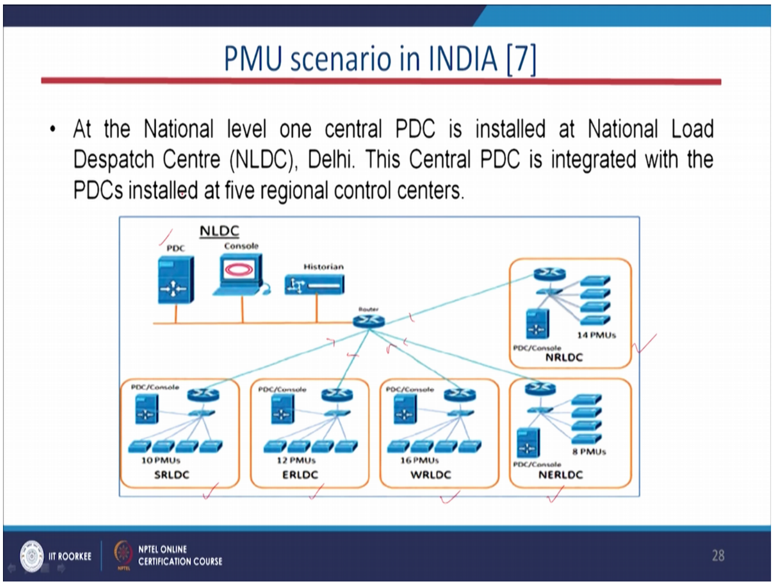

That we have different SRLDC means southern part of this load despatch centre and this is a eastern region this is western this is north east and this is northern region. And we have total 5 load despatch centres and at every load despatch centre, we have PDC the phasor data concentrator stations and from there the data has just passed to the our national load despatch centre that is we have a national PDC.

So, where we will just received all the PMU data from all the national grids 5 national grids. And we have also PMU; pilot projects are upcoming and is also some PMUs are installed. It is also in operation and Government of India also planning for more PMU installation in our transmission network.

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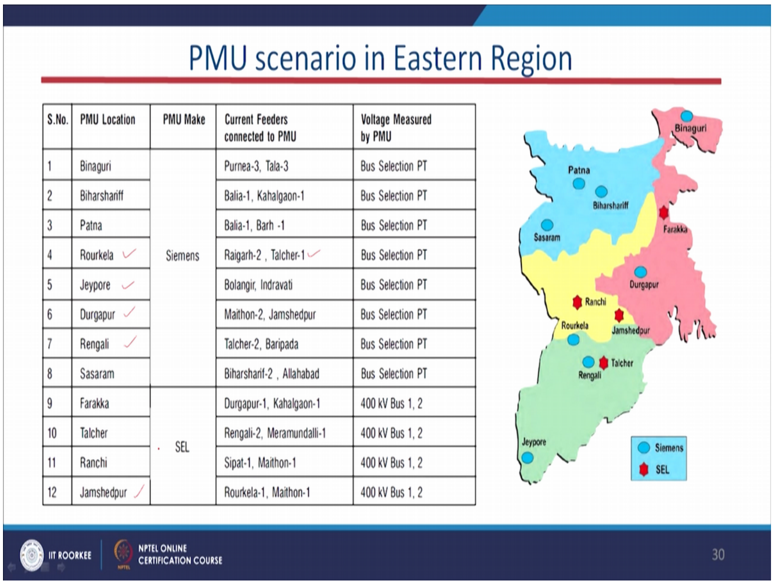

S.No.	PMU Location	PMU Make	Current Feeders connected to PMU	Voltage Measured by PMU
1	Binaguri	Siemens	Purnea-3, Tala-3	Bus Selection PT
2	Biharshariff		Balia-1, Kahalgaon-1	Bus Selection PT
3	Patna		Balia-1, Barh -1	Bus Selection PT
4	Rourkela		Raigarh-2 , Talcher-1	Bus Selection PT
5	Jeypore		Bolangir, Indravati	Bus Selection PT
6	Durgapur		Maithon-2, Jamshedpur	Bus Selection PT
7	Rengali		Talcher-2, Baripada	Bus Selection PT
8	Sasaram		Biharsharif-2 , Allahabad	Bus Selection PT
9	Farakka	SEL	Durgapur-1, Kahalgaon-1	400 kV Bus 1, 2
10	Talcher		Rengali-2, Meramundalli-1	400 kV Bus 1, 2
11	Ranchi		Sipat-1, Maithon-1	400 kV Bus 1, 2
12	Jamshedpur		Rourkela-1, Maithon-1	400 kV Bus 1, 2

And if you see this PMU scenario in eastern region these are some of the data we have collected Rourkela, Jeypore and Raigarh; too, the current feeder connected to PMU and Talcher 1 and Durgapur, Rengali and these are some places Ranchi, Jamshedpur; so we have eastern region. So, these are the places where we have the PMU connection.

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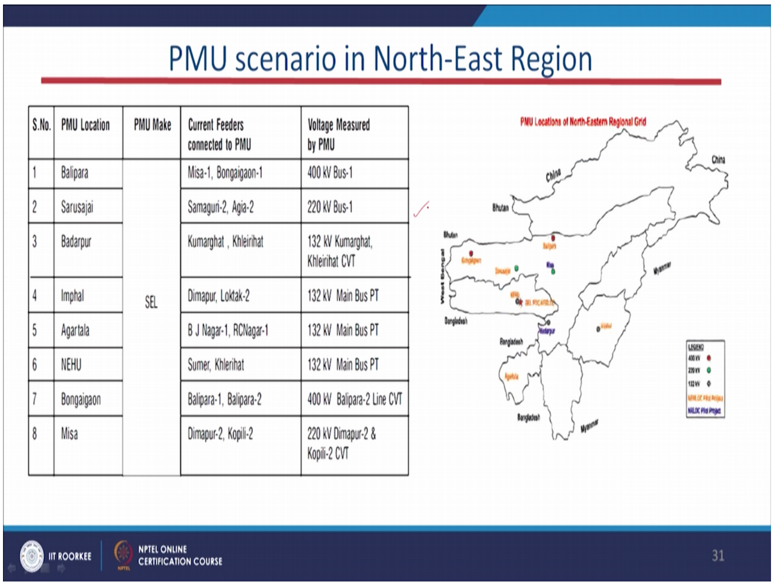

S.No.	PMU Location	PMU Make	Current Feeders connected to PMU	Voltage Measured by PMU
1	Balipara	SEL	Misa-1, Bongaigaon-1	400 kV Bus-1
2	Sarusajai		Samaguri-2, Agia-2	220 kV Bus-1
3	Badarpur		Kumarghat , Khleirihat	132 kV Kumarghat, Khleirihat CVT
4	Imphal		Dimapur, Loktak-2	132 kV Main Bus PT
5	Agartala		B J Nagar-1, RCNagar-1	132 kV Main Bus PT
6	NEHU		Sumer, Khlerihat	132 kV Main Bus PT
7	Bongaigaon		Balipara-1, Balipara-2	400 kV Balipara-2 Line CVT
8	Misa		Dimapur-2, Kopili-2	220 kV Dimapur-2 & Kopili-2 CVT

Similarly, we have northeast region where the PMU connection also there.

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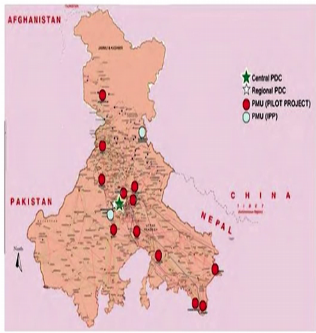
PMU scenario in Northern Region

S.No.	PMU Location	PMU Make	Current Feeders connected to PMU	Voltage Measured by PMU
1	DADRI	SEL	Inter-connecting lines Dadri AC and HVDC S/s	400 kV Bus 1
2	KANPUR		Ballabgarh-1	400 kV Bus 1
3	MOGA		Bhiwadi-1	400 kV Bus 1
4	AGRA		-	400 kV Bus-1, 2
5	VINDHYACHAL		Singrauli-1	400 kV Bus 1
6	HISSAR		Bawana	400 kV Bus-1, 2
7	BASSI		Agra-1, Agra-2	400 kV Bus-1, 2
8	K'WANGTOO		Abdullapur 1, Abdullapur2	400 kV Bus-1, 2
9	KISHENPUR		Moga-1, Moga-2	400 kV Bus-1, 2
10	MEERUT		Muzaffarnagar, Koteshwar	400 kV Bus-1, 2
11	BALIA		HVDC interconnector(AC) I,II	400 kV Bus-1, 2
12	RIHAND		HVDC interconnector(AC) I,II	400 kV Bus-1, 2
13	BAWANA		Mandola, Mahendragarh	400 kV Bus-1, 2
14	MOHINDERGARH	SIEMENS	Dhanonda 1, Bhiwani 1	400 kV Bus-1, 2



And this is for the northern region part this is our Dadri, Kanpur, Agra. So, these are the places where we have PMUs at 400 kV bus system you could see here the bus voltage is 400 kV.

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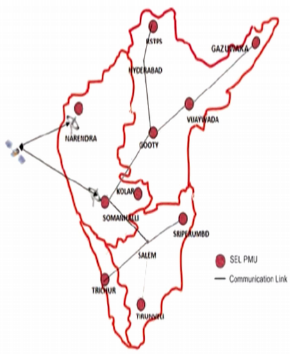
PMU scenario in Southern Region

S.No.	PMU Location	PMU Make	Current Feeders connected to PMU	Voltage Measured by PMU
1	Ramagundam	SEL	Nagarjunsagar-2, Chandrapur-1	400 kV Bus-1
2	Somanhalli		Salem, Gooty	400 kV Bus-1
3	Narendra		Guttur-1,Kaiga-1	400 kV Bus-1
4	Vijaywada		Nellore-1,VTPS-1	400 kV Bus-1
5	Sriperumbadur		Chitoor, Kolar	400 kV Bus-1
6	Trichur		Palakkad-1,Bus-1 extension CT	400 kV Bus-1
7	Gazuwaka (South Bus)		Vijaywada,Shimhadri-1	400 kV Bus-1, 2
8	Gooty		Raichur-1,Nelmangala	400 kV Bus-1, 2
9	Tirunlelveli		Trivendrum-1,Udumalpet-2	400 kV Bus-1, 2
10	Kolar		Hoody-1,Sriperumbdur	400 kV Bus-1, 2



And similarly for the southern region also at the 400 kV level; we have install the PMUs for our further processing.

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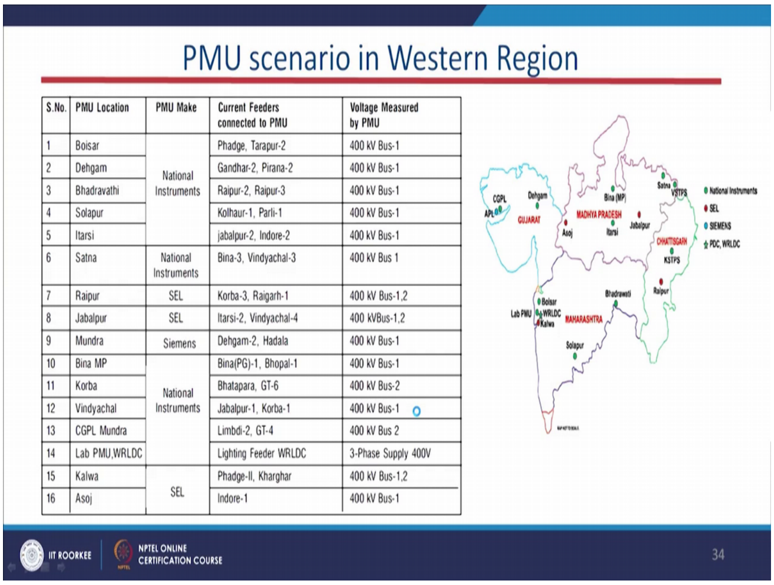

S.No.	PMU Location	PMU Make	Current Feeders connected to PMU	Voltage Measured by PMU
1	Boisar	National Instruments	Phadge, Tarapur-2	400 kV Bus-1
2	Dehgam		Gandhar-2, Pirana-2	400 kV Bus-1
3	Bhadravathi		Raipur-2, Raipur-3	400 kV Bus-1
4	Solapur		Kolhaur-1, Parli-1	400 kV Bus-1
5	Itarsi		jabalpur-2, Indore-2	400 kV Bus-1
6	Satna	National Instruments	Bina-3, Vindyachal-3	400 kV Bus 1
7	Raipur	SEL	Korba-3, Raigarh-1	400 kV Bus-1,2
8	Jabalpur	SEL	Itarsi-2, Vindyachal-4	400 kVBus-1,2
9	Mundra	Siemens	Dehgam-2, Hadala	400 kV Bus-1
10	Bina MP	National Instruments	Bina(PG)-1, Bhopal-1	400 kV Bus-1
11	Korba		Bhatapara, GT-6	400 kV Bus-2
12	Vindyachal		Jabalpur-1, Korba-1	400 kV Bus-1
13	CGPL Mundra		Limbdi-2, GT-4	400 kV Bus 2
14	Lab PMU,WRLDC		Lighting Feeder WRLDC	3-Phase Supply 400V
15	Kalwa	SEL	Phadge-II, Kharghar	400 kV Bus-1,2
16	Asoj		Indore-1	400 kV Bus-1

This is for the western region. If you could see that more or less India is also progressing towards its forms technology and in near future we will also extend this technology towards the distribution sector to the distribution part. So, that our whole network will be smart both transmission distribution together.

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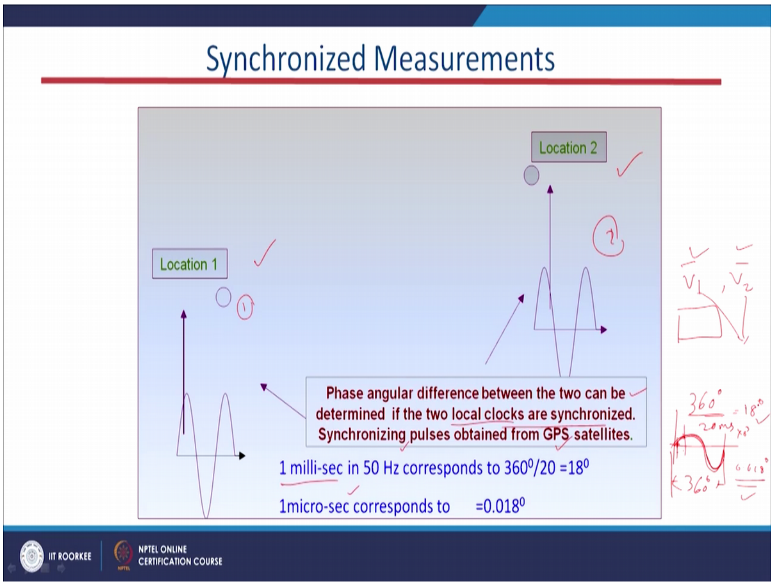

Now, I will just come quickly the again to this PMU part how it measures the synchronized data; synchronize the synchronized phasor, voltages and currents. Now this is one location in the network, this is location 2 that these two locations are apart from each other, but still at the control centre the data the voltage V 1 from this location the phasor and V 2 the voltage data voltage phasor will get from location 2 will be in same timestamp. So analyzing these two data; we need this two voltages should be synchronized, then only we can analyze otherwise it will be difficult to analyze these two phasors. So that particular work is done in WAMS technology using the PMU device.

Now, the angular difference between these two can be determined if the two local clocks are synchronized. See here also we have one local clock and here also we have one local clock. So, if these two clocks are synchronized together then; then only these two phasors can be compared together that is what the meaning of synchronized measurements. And this synchronizes this synchronizing process pulses are obtained from the GPS satellite; the GPS satellite will supply the synchronizing clocks or synchronizing pulses. So, with help of which these two data two phasors are going to be coordinated or going to be synchronized at a common time frame and if we are just synchronize the time stamp; if we have like the angle of 360 degree here it is and our sampling basically footage 1 millisecond base.

So, what is the angle between two corresponding samples? It will be 360 degree divided by 20; because we have 20 milliseconds within 50 hertz a 1 cycle signal; so this 20 milliseconds. So, if we will divide; so within 1 millisecond; so it is going to be have 18 degree between two samples, two corresponding samples the angle difference is going to be 18 degree. And if we will just correspond to 1 microseconds how much it will be?

So, it will be if it will just divide again 10 to the power this 3; so it will be 0.018 degree. So, the precision is better the resolution I mean if suppose we have some error between two samples. So if we will take like 1 microsecond resolution; so it will be much better here than this 18 degree difference.

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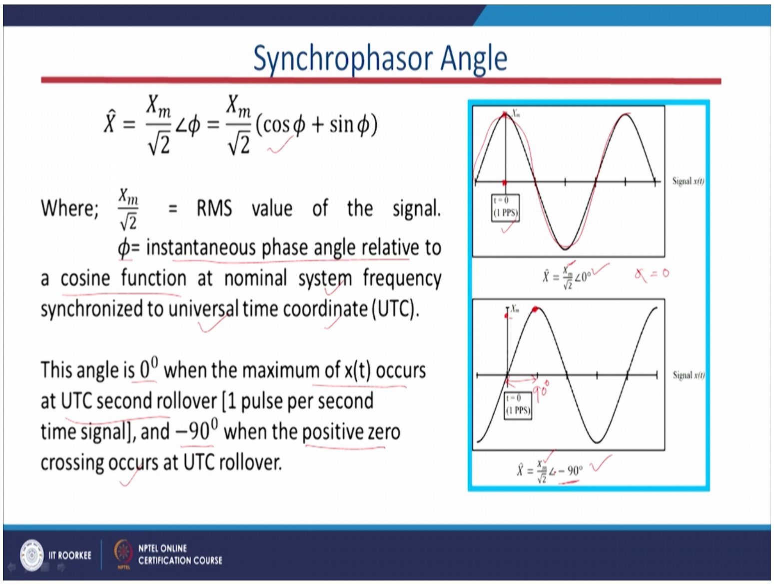

So, these are the concepts of Synchrophasor angle measurement; so this 1 pulse per second, 1 PPS corresponds to this t equal to 0, when this cosine function is having the peak value. This is what the definition by the IEEE standard that how to standardize this synchronized angle; universally this angle should be synchronized.

Then therefore, that we have some format, we have some standard like we have to take one cosine function that is what here this phi this is if this is my signal this phi is a instantaneous phase angle relative to a cosine function; this is our cosine function, this is our cosine function. At a nominal system frequency at nominal system frequency that is our 50 hertz signal frequency synchronized to the universal time coordinate; this is important.

So, if I will get the pulse 1 pulse per second from the satellite from the GPS system; so in that case. So, if it is a t equal to 0 at the peak value; so then in that case my phi is equal to 0 because it starts from 0; and how to write this particular phasor? V this I max or X max divided by root 2; angle of 0 degree. X stands for either voltage or current it may be a voltage signal or it may be a current signal. Now if suppose the real some other part this angle is 0 when the maximum x t occurs at UTC second rollover. Now and minus 90 degree when the positive 0 crossing occurs; if suppose let us say this particular peak is move to this point; that means, what is the difference between the phase difference between these two points? 90 degree.

So, this is this point is lagging to this point by minus 90 degree; it is lagging by 90 degree see here. So, this is our 90 degree; that means, this is this point is lagging to this point by 90 degree. So, while we will express this particular instantaneous signal in phasor form. So, we will write this is the magnitude and this is the angle part minus 90 degree. So, we have basically standardized this using this PPS 1; pulse per second that should be the strategy for to synchronize the voltage current phasors at different buses in a particular smart grid system.

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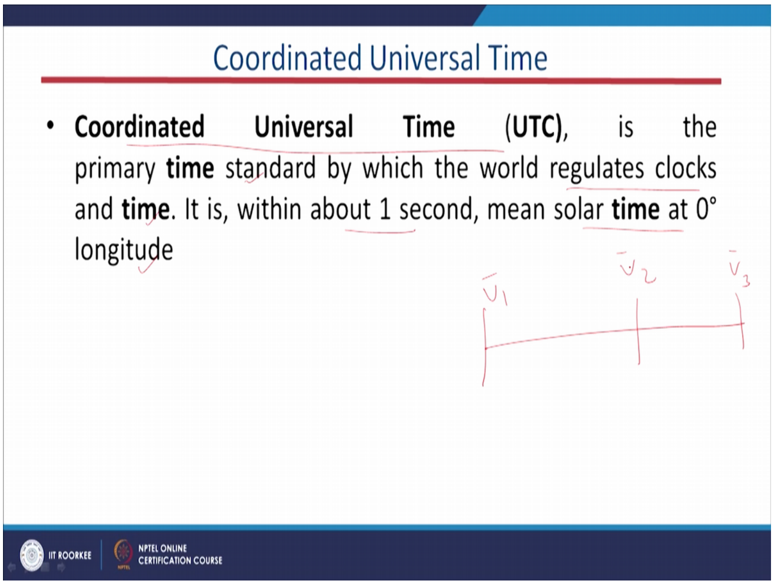

This UTC stands for basically the Coordinated Universal Time that is the primary time standard by which the world regulates clocks and time and it is within 1 second mean solar time at 0 longitude.

So, this is important. This using this UTC concept we can synchronize the basically we if we have different number of buses in a network. So, this V 1 phasor this V 2 phasor or V 3 phasor; all together they can be synchronized globally.

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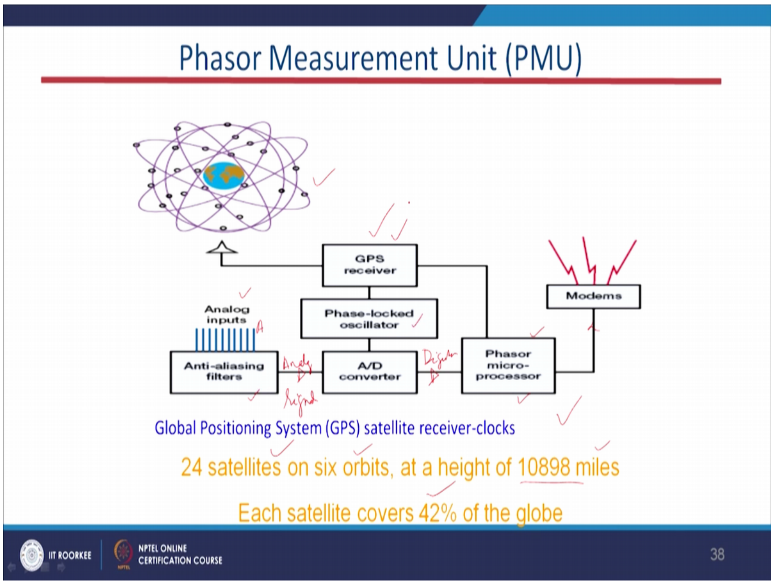

This is basically the basic block diagram of the PMU; we have first the analogue inputs the analogue inputs means the voltage current signals. And these voltage current signals will pass to the anti aliasing filters. We will discuss about this; what is the function of this anti aliasing filter. Then it will go to the ADC converter the data and here still this is analogue this signal is analogue here.

And even the signal status at the output of this analogue I mean anti aliasing filter is also analogue in nature. Now these analogue signal this analogue signal is going to be converted to digital platform using this ADC converter that is Analogue to Digital Converter. And after that this will go to the phasor microprocessor, where the phasors are going to be calculated or estimated using the Discrete Fourier Transform technique.

Now, after that it will go to the modems for communication purpose to the PDC; the Phasor Data Concentrator and from the Phasor Data Concentrator, we can applied to other devices like relays or some circuit breaker; wherever we like the to utilize the PMU data, we can always apply. And this is how the other part that is our this is our Global Positioning System; that is GPS we have the global positioning clocks like 24 satellites on 6 orbits at a height of 10898 miles.

And each satellite covers 42 percent of the globe, we have 6 orbits and 24 satellites and this satellites rotates around the earth. And it will this GPS receiver receive the signal from the satellite and it will just supply to the phase locked oscillator.

So, this phase locked oscillator will generate or it will lock the sample frequency according to the GPS receiver signal; 1 pulse per second will be received by this I mean this GPS receiver and it will send to this GPS unit and from there this ADC will start sampling the voltage current signal and then it will sent to the processor. This is what the word sampling at 1 millisecond; let us see we will discuss about the sampling part.

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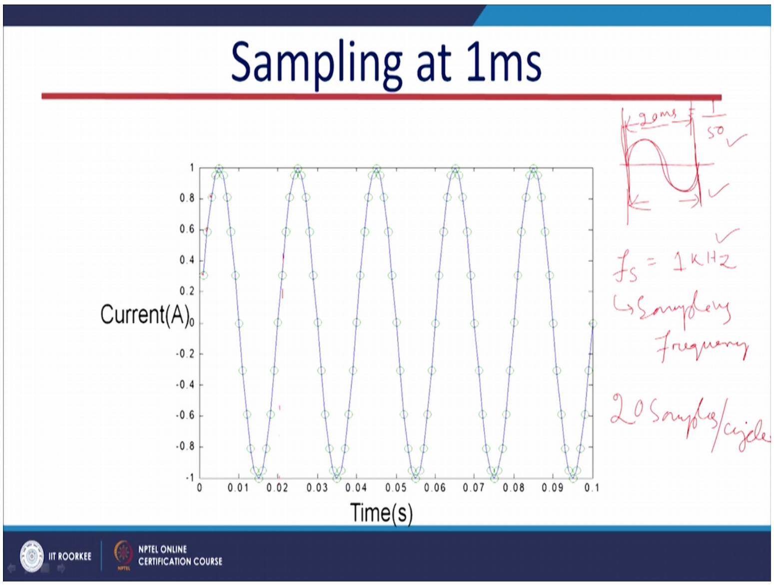

If we have voltage waveform then for riling purpose for protection purpose, the sampling rate is basically safe side we took basically 1 kilo hertz; 1 kilo hertz, that sampling frequency we denote by f s; this f s is known as sampling frequency. Now if this sampling frequency is 1 kilo hertz and we have a 50 hertz signal let us say voltage signal.

So, what is the time period for this particular signal? That is 20 milliseconds; how it is? 1 divided by 50 hertz because 1 upon frequency is our time one period that is t s. So, this fundamental time period is 20 milliseconds, fundamental frequency is 50 hertz. And for this particular signal we are taking 1 kilo hertz as sampling frequency. The meaning is we are sampling the analogue signal at rate of 1 kilo hertz. So, after every millisecond 1 millisecond we are getting the samples; the digitalized signal of the analogue signal. If you could see this particular signal, we have 1 kilo hertz sampling frequency after every 1 millisecond we have samples. So, overly we have 20 samples per cycle if you can count here, so we will have 20 samples per cycles; so we write like this 20 samples per cycle.

So, within 1 cycle we will have 20 samples, within 2 cycles we will have 40 samples and within 3 cycles 60 samples so on. Now if we will just take another sampling rate.

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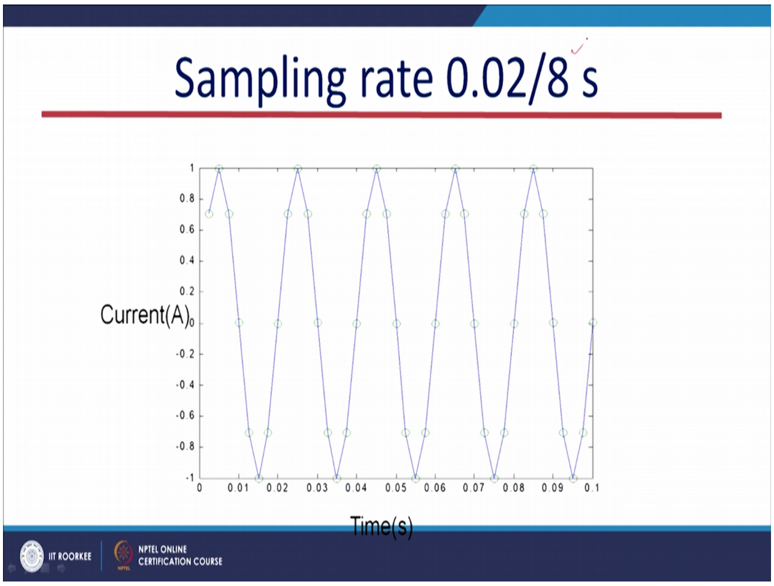

That is 0.02 by 8 means 8 samples per cycle and in that case; you can see here the signal is not approximated at to actually to our actual signal, the approximation is less here. You can see here it is better because we are just taking more number of samples within 1 cycle, but here the number of samples decreased that is why the approximation of the exact signal is not possible. Now if we will increase the number of samples per cycle more like here we have taken 64.

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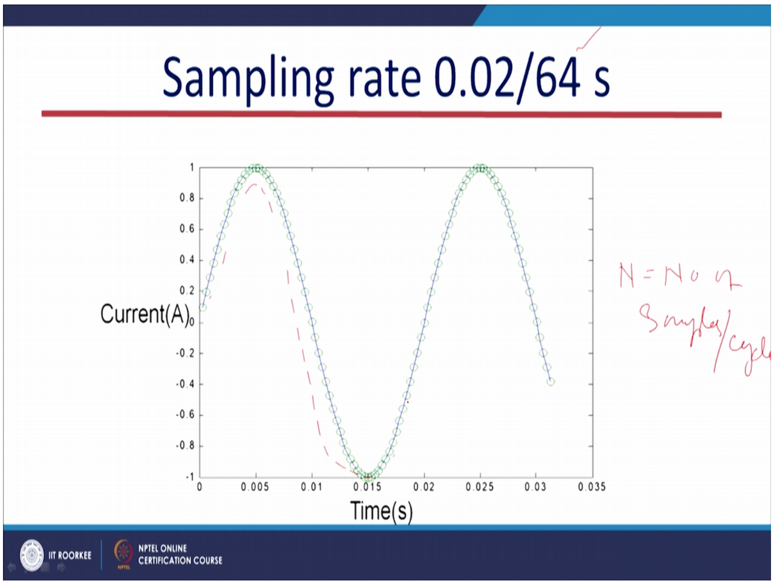

N we denote capital N; N basically stands for number of number of samples, samples per cycle. So, if we have increased here the number of samples per cycle to 64. So, in that case we have better resolution better approximation to our original signal. That means to have a better approximation or exact if you want to extract or we want to convert the exact analogue signal to digital. That means, we have to increase the sampling frequency.

But of course, however, we have some certain limitation for this. So, what should be the sampling frequency so that our signal should not be affected? I mean the digitalized version of the analogue signal should be proper for further processing through the microprocessor or DSP processor inside the PMU. During this sampling or we have one impact that effect that is aliasing effect.

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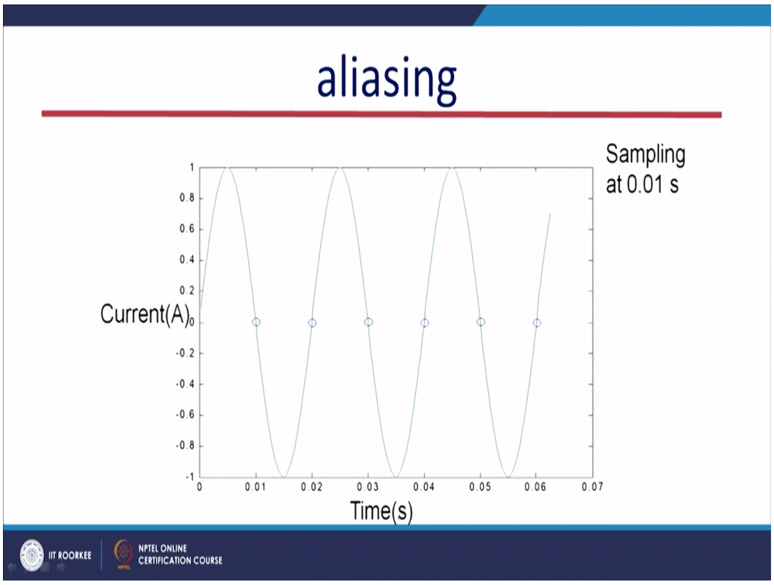

This aliasing effect means if a fundamental basically we have let us say 50 hertz signal, but during the power system operation; we have like higher fundamental higher frequency components like other harmonic frequency components, second harmonic, third harmonic, fourth or 5th harmonic components are present; so those are higher frequency components.

In that case, what happens due to this aliasing effect the higher frequency components; will behave like a small signal low frequency component or fundamental frequency component. So, that effect is not desirable for (Refer Time: 35:57) or PMU operation; so in that case we have to remove this effect using different concepts. So, if you just if you will take a 5th harmonic component which is a must with our fundamental frequency then in that case if I am sampling at rate of 8 samples per cycle.

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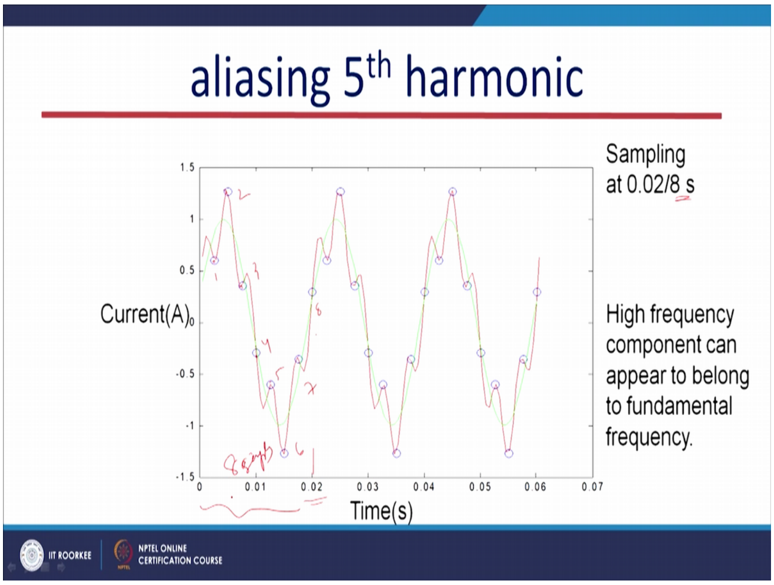

So, if you could see here these are the samples we have taken that is 1, 2, 3, 4, 5, 6, 7, 8. So, here is our cycle ends 0.02 second means 1 cycle; so within 1 cycle we have 8 samples present. So, in that case if I just taking this 8 samples per second; so, this particular 5th harmony component of the signal will behave as just like I am the fundamental frequency component; so please take me. So, in that sense the aliasing effect is see we here; so we have to remove this. So, what we do for this case? We basically do this is one more example; I just want to also explain this waveform.

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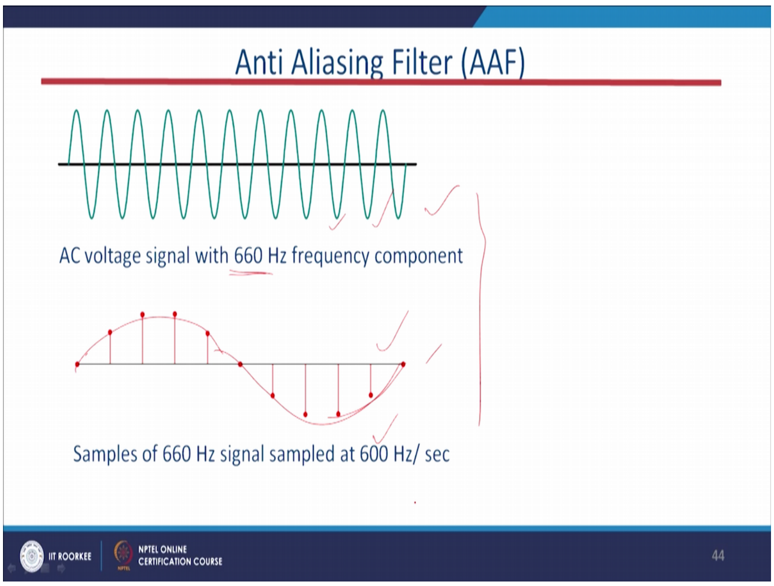

That this particular waveform is having 660 hertz frequency component and if you are just sampling this particular waveform at a rate of 6000 hertz per second. So, we will get the signal like this here.

So, this particular waveform will behave just like a 60 hertz component signal; this signal will behave just like a 60 hertz signal component; that means, this high frequency component will behave like a small frequency component or fundamental frequency components. So, this effect is known as aliasing effect.

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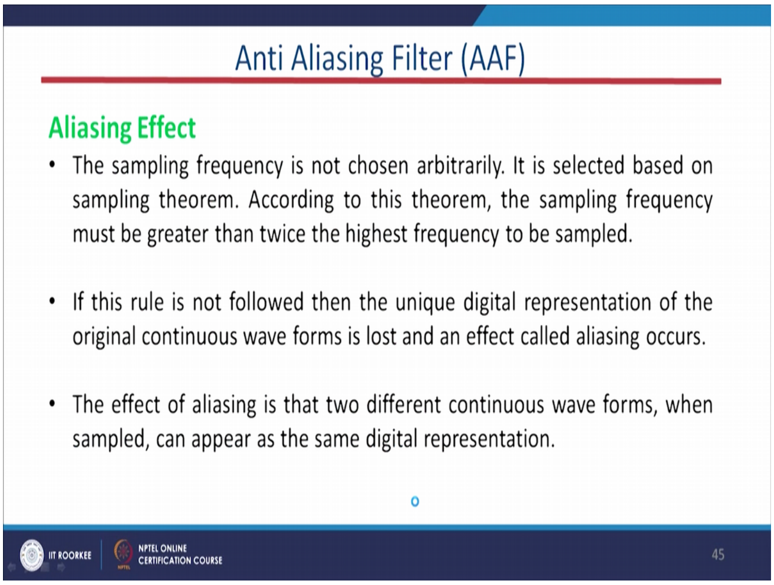

To overcome this particular problem we have anti aliasing filter.

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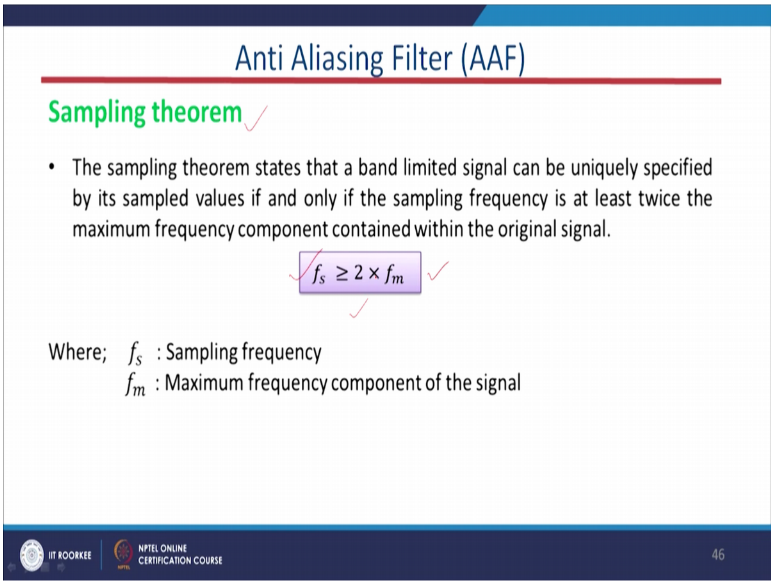

This anti aliasing filter; first we maintain one theorem that is sampling theorem and Shannon's theorem; what we have to do? We have to maintain the sampling frequency in such a manner that it should be greater than twice of the higher frequency component of the signal. Let us say we have certain high frequency component which is present in a particular signal. So, our sampling frequency should be two times of that particular signal it should be greater than that or equal to that.

So, in that since we can overcome this aliasing effect that is what here this sampling theorem tells.

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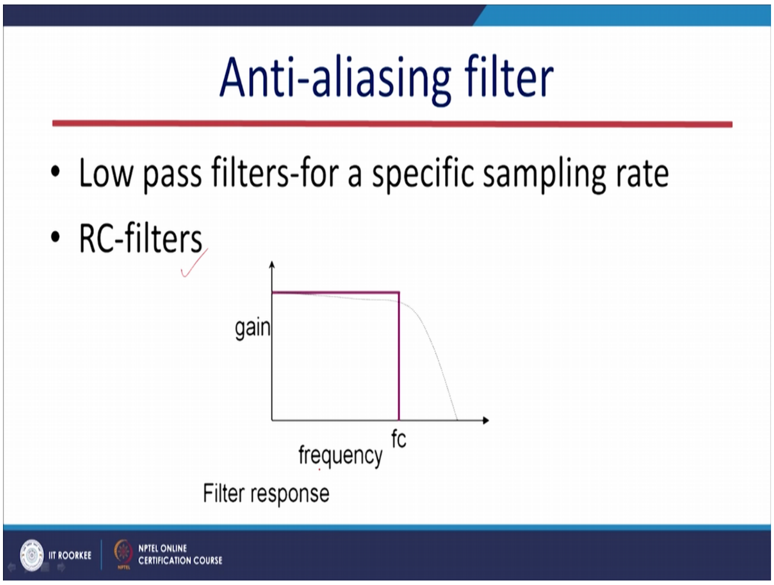

Now, also we maintain low frequency like low pass filters where will just remove the higher frequencies and will just passed the low frequencies and also our fundamental frequency for our application purpose. Basically in this case we use the RC filters and sometimes we you can see that some other low pass filters are also used.

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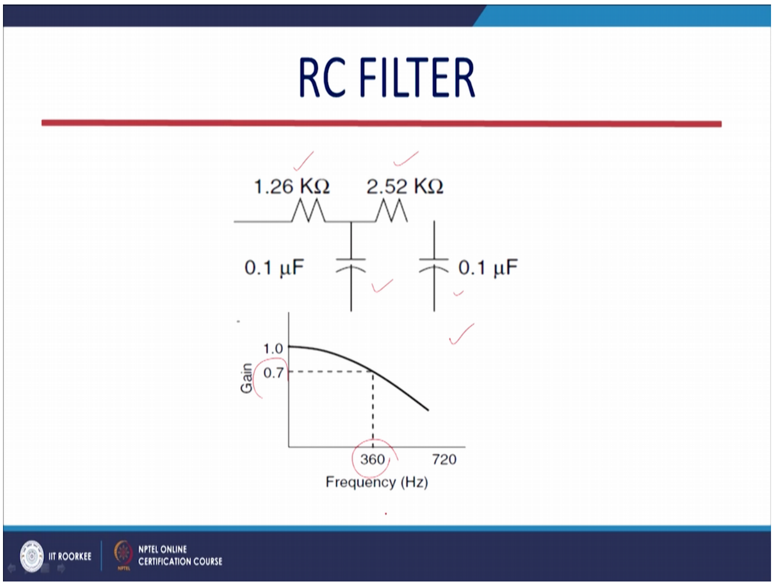

Now, this is one specific example where the RC filter is shown that these are the resistances values and these are the capacitance values and this is how this gain here present and this is how 360 is the cutoff frequency. So, there are lot of resource is also resources are trying to have this design of this RC filters for removing this higher frequency components when the signal is passing from one domain to analogue domain to digital domain. Now also next we use the ADC in case of PMUs.

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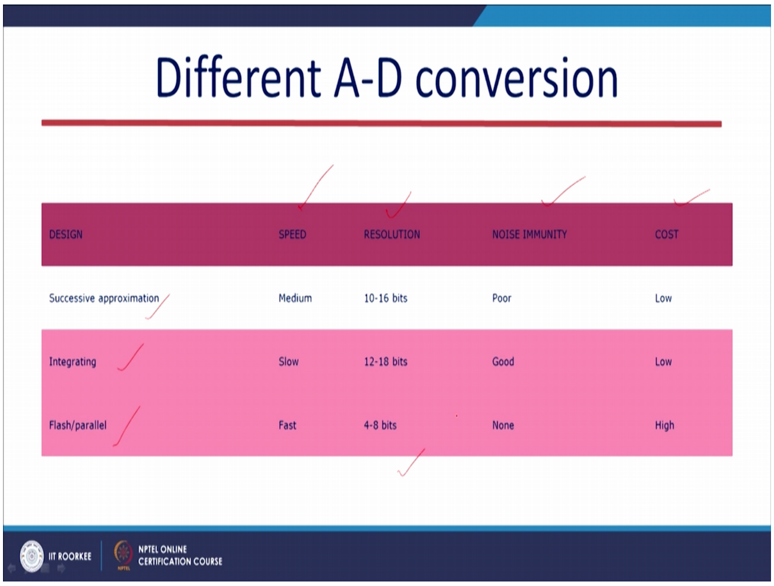

And we have different type of ADCs like successive approximation integrating flash or parallel. So depending on their resolution, speed and also noise immunity and cost; so this is a table how this particular all different types of AD: ADC vary in their operation.

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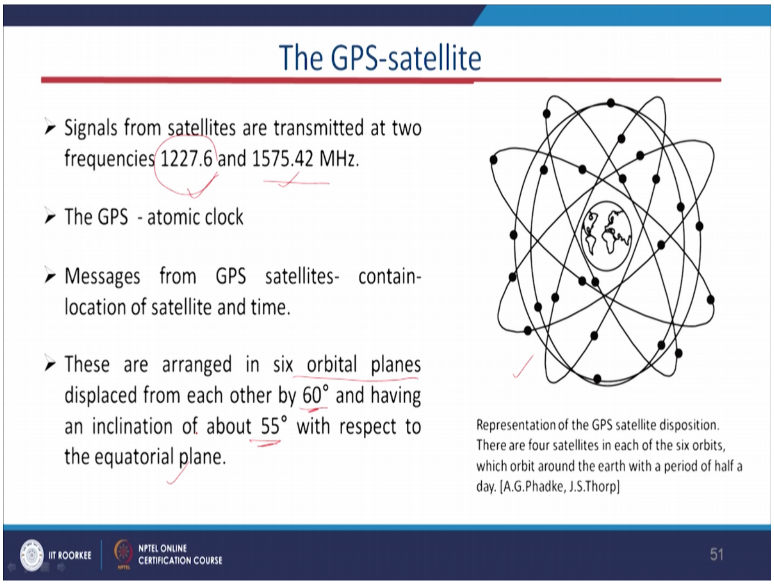

And this GPS already we have discussed that GPS transmits basically two frequencies; the first one is 1227.6 and second one is 1575.42 mega hertz. So, this two frequencies are the transmitted frequency by the GPS technology and if you will see that there are these are arranged in 6 orbital planes and displaced from each other by 60 degree and having a inclination of 55 degree with respect to the equatorial plane.

So, this there is some certain arrangement for this GPS so that we can cover the whole network nicely and properly and for our operational point of view.

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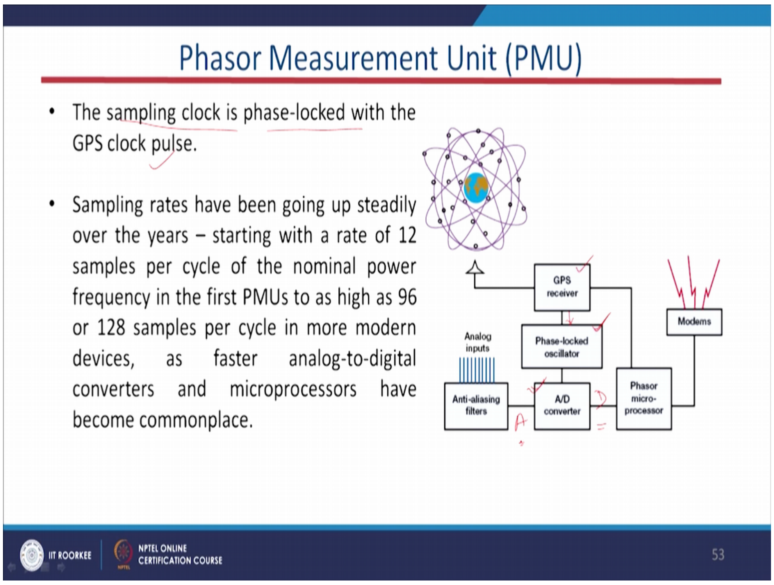

Now this if you see this PMU gets this clocks all this sampling clock is phase lock with the GPS clock pulse; this is very important. This phase locked oscillator and the GPS clock together they are locked, then only this ADC will start converting; I mean sampling this analogue signal to digital domain. It will just start sampling this analogue signal to digital domain.

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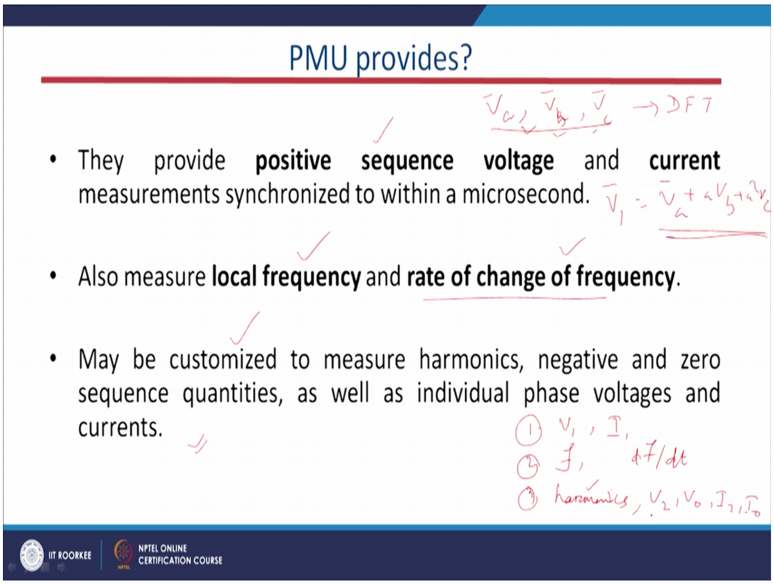

Basically among question comes here that what are the data or voltage information which are provided by this PMU? This PMU provides positive sequence voltage and current also now; if we have inside the PMU we have discussed that we measure or we estimate this voltage like V a maybe V c phasors using the DFT; the Discrete Fourier Transform technique. By using this phases; so we can always calculate the positive sequence component of the voltage that is V a plus a V b plus a square V c.

So, this process sequence component of the voltage can be estimated or calculate inside the processor of the PMU; using the phasors of corresponding voltage signals instantaneous voltage signals. And it also possible to measure the local frequency and rate of change in the frequency; this is also important. First of all it provides V 1, I 1 positive sequence voltage and current and second one it provides a frequency and also DF by DT; the rate of change of frequency.

And the third one is very very important; if it can be customized. So, it can also measure or provide harmonics this is very important because nowadays in smart grid system. We have many inverter based generating stations we are its coming up basically solar wind or we have (Refer Time: 42:36) or we have like other devices where we have electronic devices or electronic interfaces are present.

So, in that case there is a good chance of harmonic injection to the network. So, for that this PMU can be customized properly to estimate the harmonic components of the voltage and current signal. And also it can provide V 2, V 0 that is the negative and 0 sequence components of the voltage and also I two I 0; the negative and 0 sequence components of the current. So, these are the output data or output information we got from the PMU; this is how this PMU transfers the voltage current signal.

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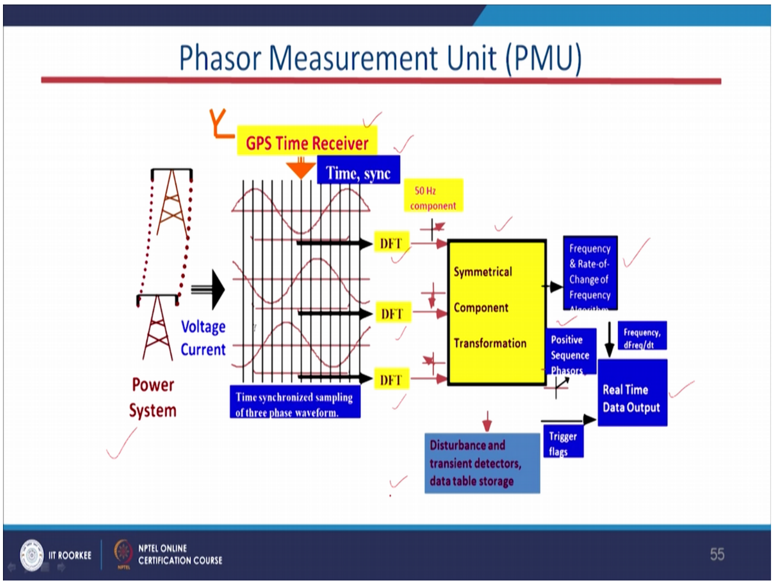

This is the GPS receiver time is synchronized at what time you want to start the sampling of this particular signal. And after the getting the sampled values of the voltage or current will apply the DFT to estimate the phasors and we will get the symmetrical component transformation technique; using that will get positive sequence components and further also we can get negative and 0 sequence components. And then also we can calculate the rate of change of frequency and further we can apply for the real time application or some disturbance transient detectors whatever the application we want to do we can do using this data.

This is how these sequence components are calculated already we have discussed here.

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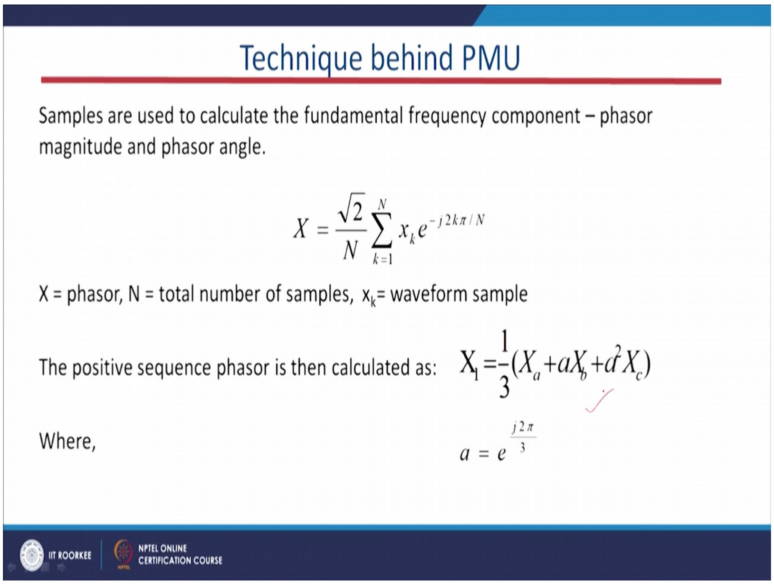

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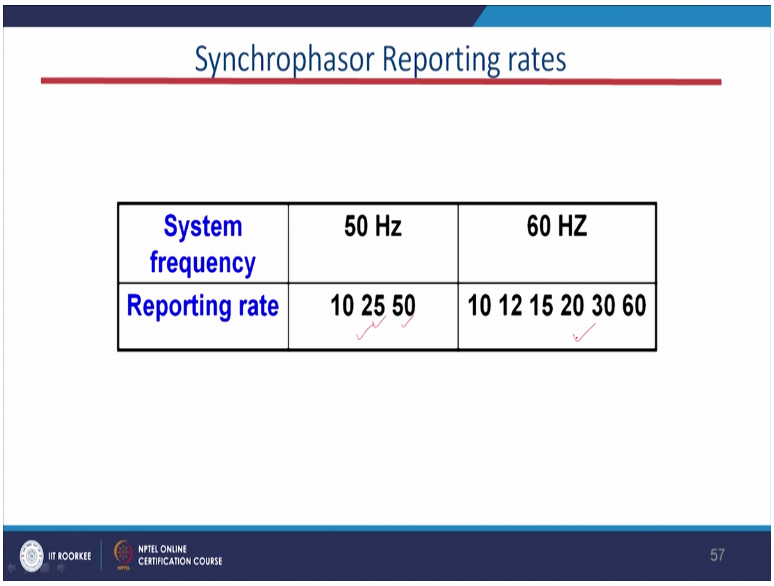

And this is the synchrophasor reporting rate this is for 50 hertz, 10 samples per cycle; 25 here, 50 here and for 60 hertz these are the figures this is IEEE standard basically. And this is the basically the file structure of synchrophasor standard.

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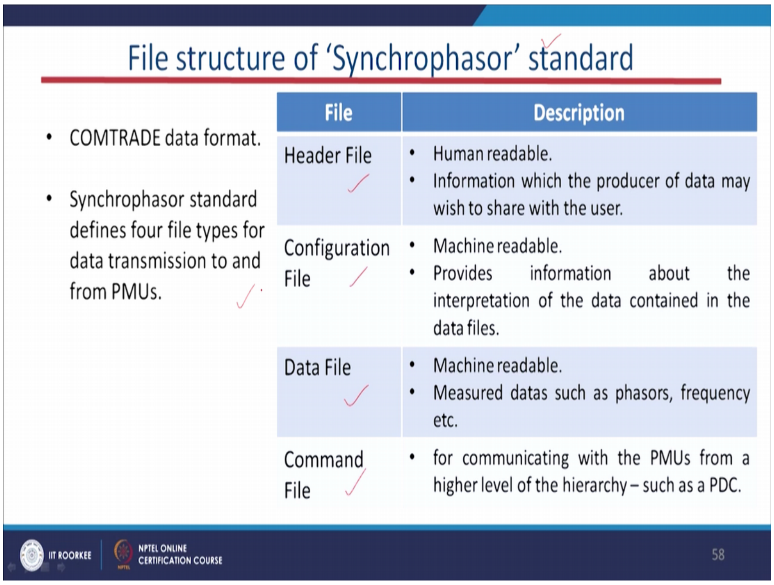

The header file, the configuration file, data file and command file; so these are the files which are present inside the PMU. And those files I mean the data file are sent to the PDC. We have already discussed how this data file are sent to the PDC for further application that the PDC will basically provide one command that you send the data file, then the PMU will just will be triggered and it will supply the data files to the PDC. And then the PDC will again send one stop file then the PMU will stop the data from the PMU to the PDC.

These are the format this is one of the PMU kit.

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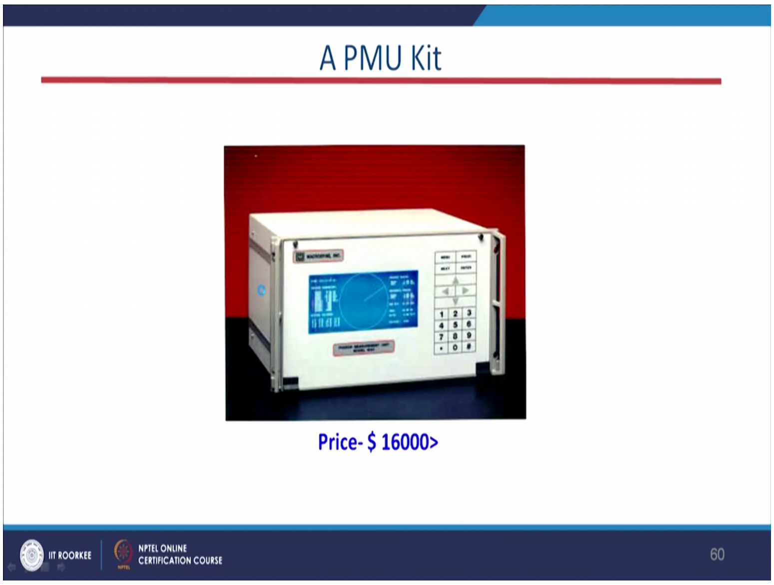

And in Indian context within 4 to 5 lakhs also we can just purchase one PMU for our network application. So, in this particular class we have discussed about the wide area monitoring system applications. And then we just started with what are the application areas like to monitor the angle variation or stability issues or angle oscillation also.

And after that we just discussed the PMU part; the PMU also important component of the wide area monitoring system, where we have discussed how this data is basically synchronized and data are passing form one PMU station to other stations and what is the GPS clock dyes and many other parts.

Thank you all.