Digital Protection of Power System
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Lecture - 01
Introduction to Phasor Measurement Unit – I

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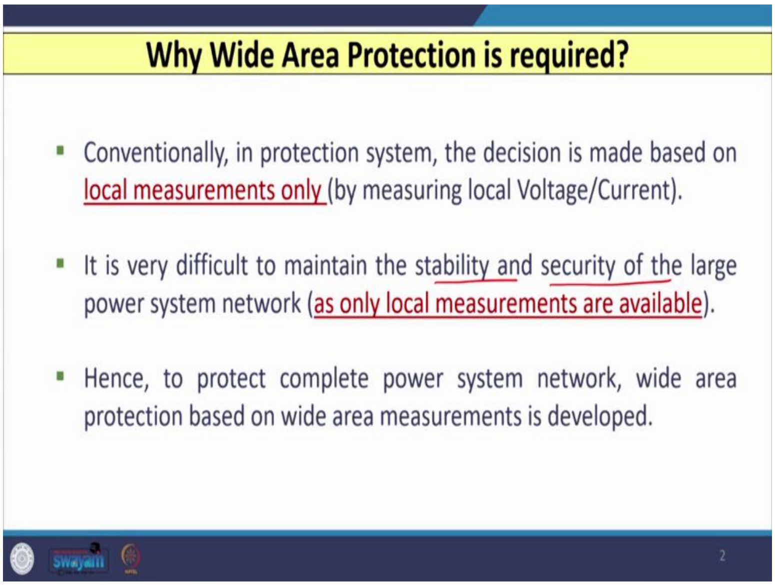

Hello friends, so in this lecture, we will discuss about the introduction of Phasor Measurement Unit which is an important equipment that is used in most of the substations nowadays. So, before we start introduction of Phasor Measurement Unit, let us see what is wide area protection and why it is required? So, we know that in protection system, conventionally, the decision has been made based on local measurements. So, by measuring the let us say three phase voltages or 3 phase currents at local end or sending end or whatever protective device, we have utilized or we have installed that device will take the decision based on these local measurements.

If any protective device is installed which is used only the local measurements and which will take the decision based on local measurements only, then it is very difficult to maintain the stability and security of the entire power system network. Hence, to protect the complete power system network wide area protection is required and this wide area protections are based on, the wide area measurements that is carried out in the entire power system network using Phasor Measurement Units.

Now, let us understand first what is wide area protection system. So, the wide area protection system is based on wide area measurements where the measurements are available or carried out from local end that is sending end as well as several remote buses, so this wide area protection works in coordination with the conventional protection system, so we are not at all eliminating the conventional protection system or conventional protection device, let us say distance protection, maybe for transmission line, so it is already there. Along with that, we are going to use another one that is wide area protection system.

Wide area protection system performs online security analysis may be in case of post fault or maybe in case of post disturbances and it can also take care of the system, whenever any blackout is there, may be full blackout or partial blackout or maybe when any outage is there, then this wide area protection system is capable to take care of this. So, if we wish to achieve a wide area protection concept, if you want to realize this concept, then we have to go for the concept of synchronized sampling, so let us see what is the meaning of synchronized sampling.

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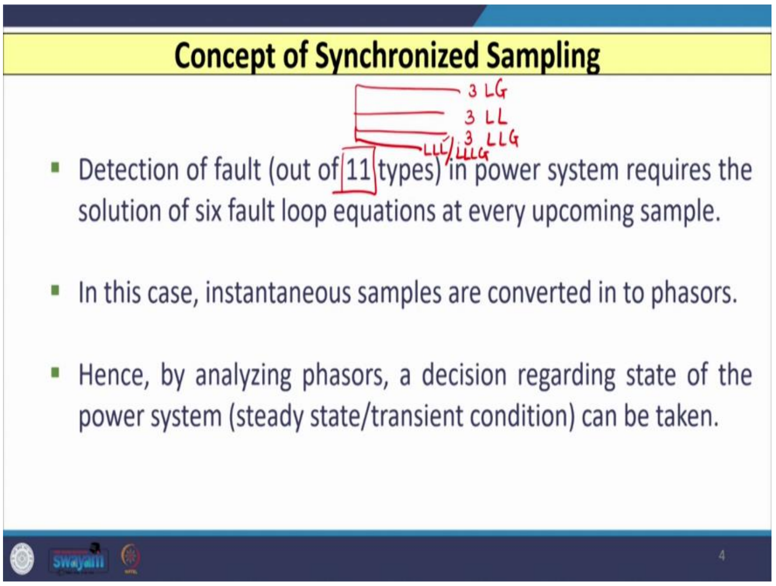

So, we know that if we wish to detect all types of faults in a power system network, we know that total 11 types of faults are possible in power system network covering 3 single line to ground faults, 3-line to line faults, again 3 double line to ground faults, and 1 either triple L, or triple L G fault. So, if we include these 2 also, then total 11 types of faults are possible in any power system network, and if we wish to detect all these faults, then we have to write 6 loop equations at every upcoming sample or every sample which we are acquiring.

Now, in this case instantaneous samples are converted into Phasor values using some Phasor estimation algorithms, maybe we can use DFT or LES method and by analysing the Phasors, maybe whatever quantities we are acquiring, let us say voltages or currents, so by analysing the Phasors of the voltage or current, a decision can be made, whether the state of the power system is stable, or maybe some transient condition is there that is going to occur in the power system, so that decision can be considered or can be carried out or can be taken if we analyse the Phasors.

So, if we use symmetrical component theory, or the concept of symmetrical components or maybe certain quantities or features derived from these symmetrical components, then we can detect all 11 types of faults using a single equation and this is really an advantage compared to the previous philosophy.

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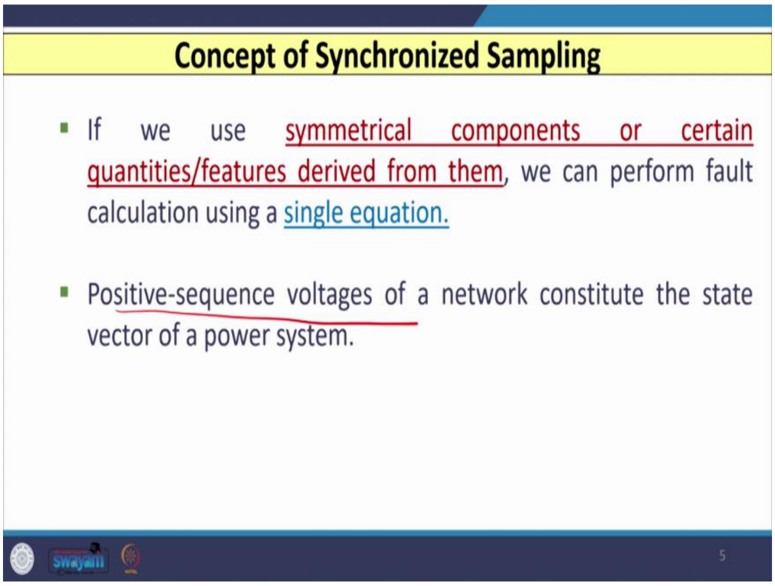

So, positive sequence voltages of a network that constitute a state vector of the power system and by monitoring that, we can say that, whether the system is stable or some other emergency transient or dynamic condition is going to occur in the system or not.

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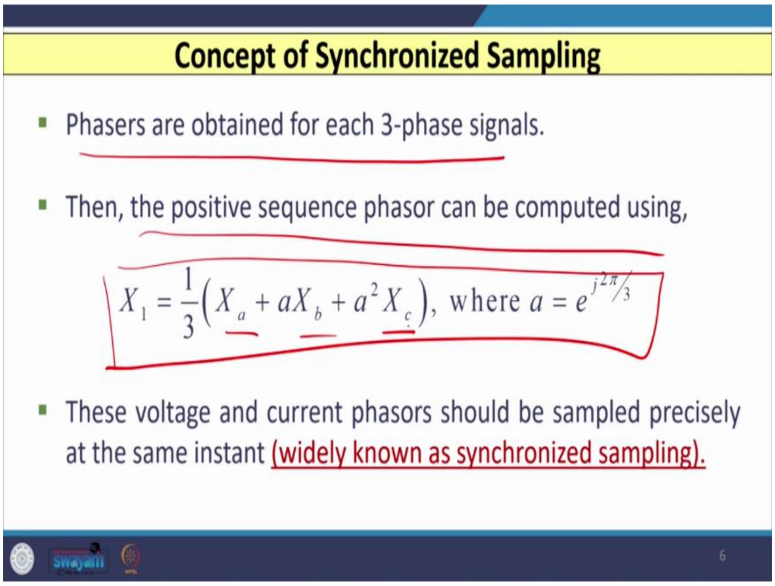

Now, to understand the concept of synchronized sampling we have to take or we have to obtain the Phasor values of the, let us say voltage signals or current signals and once we have the Phasor values, the positive sequence Phasor can be obtained using this equation

$$X_1 = \frac{1}{3}(X_a + aX_b + a^2X_c), \text{ where } a = e^{j\frac{2\pi}{3}}$$

where the positive sequence Phasor is the X_1 which is given on left hand side, and X_a, X_b, X_c are any values, let us say voltage or current and a is the operator which is given by 1 angle 120. So, this voltage and current Phasors should be sampled very precisely particularly considering the same sampling instant and when we wish to have all the Phasors at same sampling instant, then that is obtained with the help of synchronized sampling.

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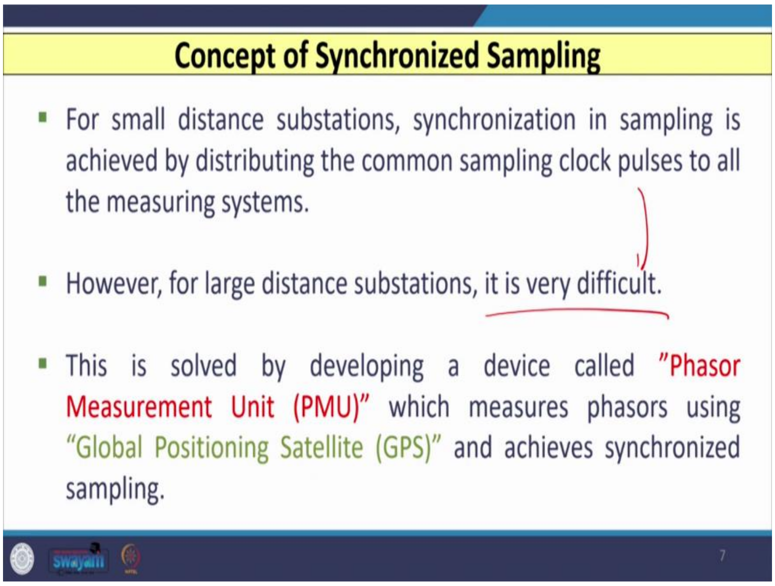

So, if we wish to implement or if we want to obtain synchronized samples at different substations, then for small substations, synchronized sampling can be easily achieved by distributing the common sampling pulse at all the measuring systems, but when we have large substations then this implementation of this concept is very difficult, so in that case we have to go for the utilization of a device known as Phasor Measurement Unit, which measures the Phasors using the global positioning system and it also achieves the synchronized sampling. So, let us see what are the applications of synchronized sampling?

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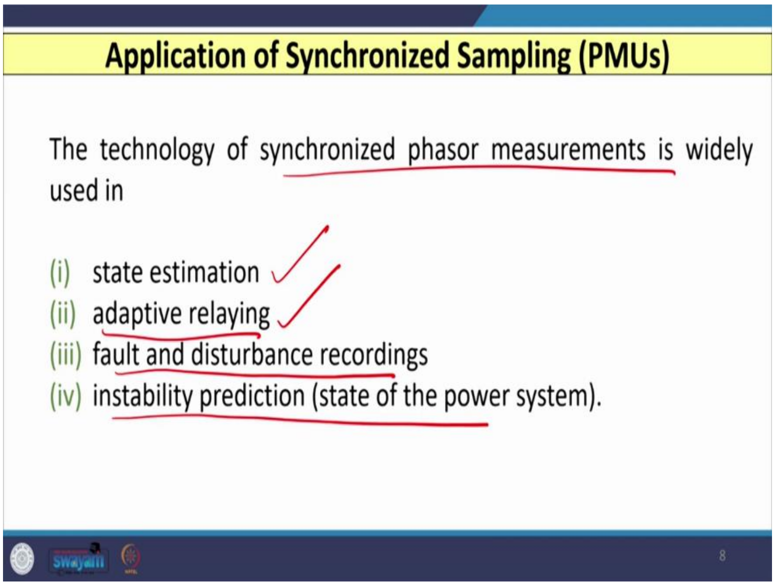

So, the technology of synchro phasor measurements, that is widely used in state estimation, so if we wish to estimate the state of the system whether the system is in stable state or normal state or whether it is in emergency state, so that we can easily obtain. If we wish to have the concept of adaptive relaying, that means adaptive relaying is a philosophy in which the protection system is capable to adapt the changes that is going to occur in external system conditions.

So, if any external parameter changes, then whatever change is required in the settings of the protective device that can be automatically done by the relay or ID itself. So, that is nothing but the concept of adaptive relaying. It will be also helpful in case of fault and disturbance recording, so if any post-mortem analysis is required, then that can be also possible with the help of the synchronized sampling, and if we wish to monitor the state of the power system, that means for instability prediction, we can also use the concept of synchronized sampling.

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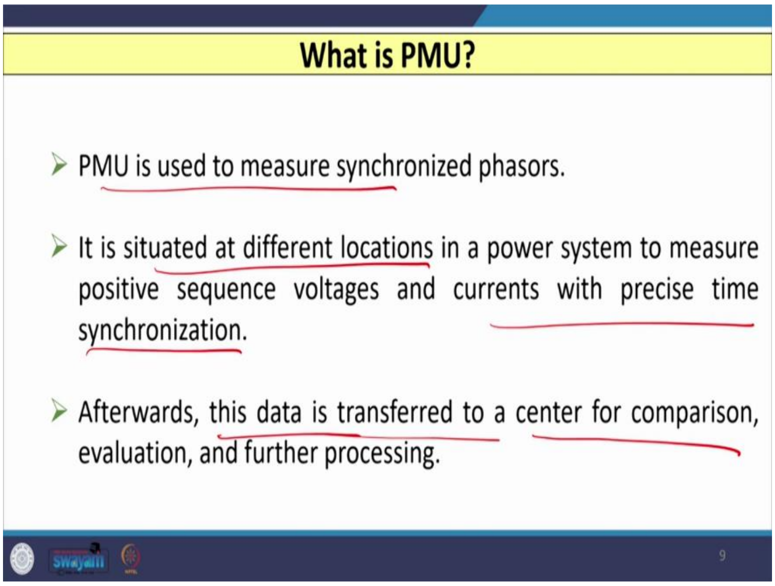

Now, let us consider what is PMU?. So PMU is nothing but the Phasor Measurement Unit which measures the synchronized Phasors, so which calculates the synchronized Phasors and the output of PMU is nothing but the Phasors. So, this PMUs are situated at different locations in a power system network to measure the positive sequence voltages and current with precise time synchronization.

So, basically PMU is nothing but a device which takes input in the form of instantaneous values of let us say voltages and currents and the output of this that is in terms of Phasors and this Phasors are again time stamped, that means they are taken at very precise time synchronization, and once this is done, the data whatever PMU you have, the PMU's are going to transfer this data at higher level, that is maybe at a particular control centre, where the comparison evaluation and further processing on those data that will be carried out.

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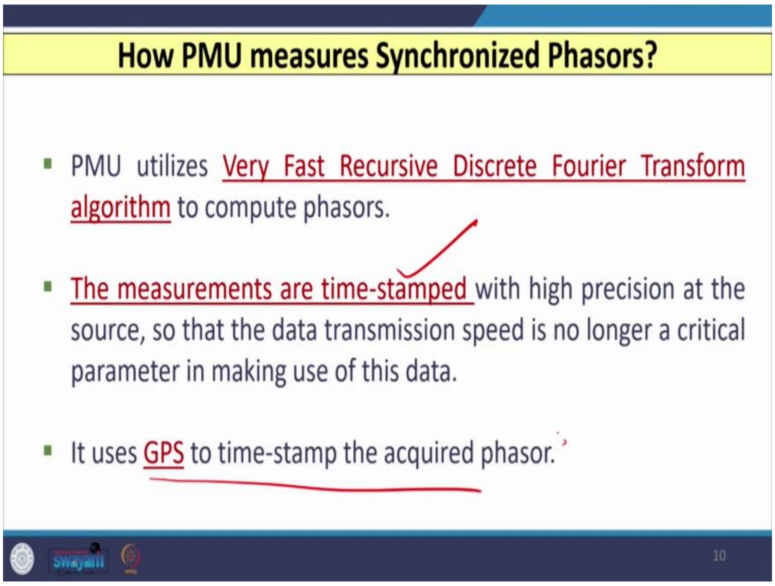

Now, let us see, how PMU measures synchronized Phasors? So, PMU utilize very fast recursive discrete Fourier transform algorithm to compute the Phasors. The measurements are time stamped as I told you, with high precision at the source, so that now transmission speed of those data at which we are we are going to transmit from one end to other end in a transmission system, that is no longer a critical parameter for this synchronized sampling. It also uses a global positioning system to time stamped the acquired Phasor.

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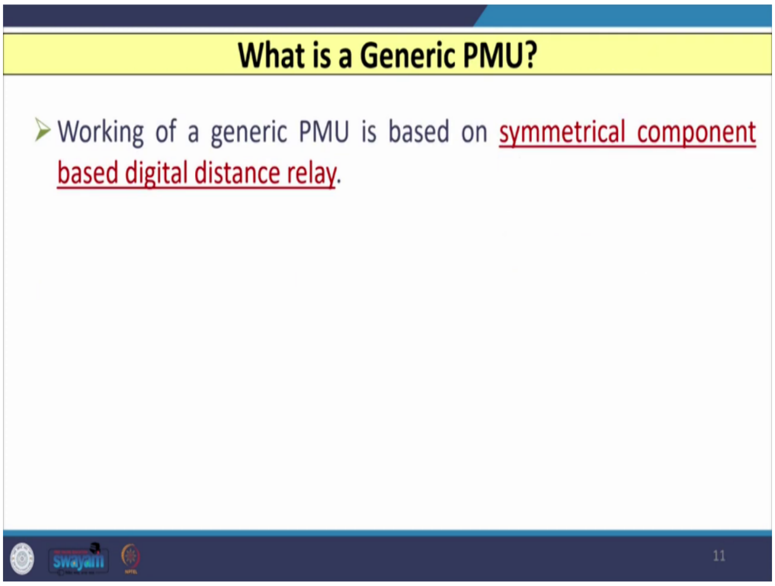

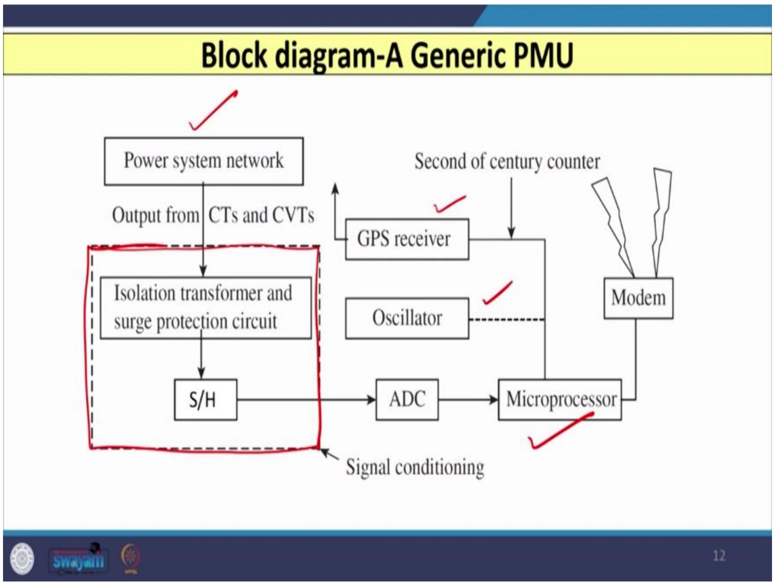

So, let us consider what is generic PMU? So, working of generic PMU is based on the philosophy of symmetrical component based digital distance relay. So, let us see what is the block diagram of generic PMU. So, if we consider the block diagram of generic PMU, you can see on the screen (as shown in above slide), we have the power system network from which we are going to acquire these secondary parameters of the currents, let us say from CT secondary and voltage parameters from either PT or CVT secondaries.

Once we have the secondary parameters from CT secondary and PT or CVT secondaries, the isolation transformer and surge protection circuit is there, and analog to digital converters are also there, and this entire unit that is known as the signal conditioning block, which we have discussed in case, when we have discussed the block diagram of digital or numerical relay. Once we have the digitized value of the acquired signals from the output of ADC that will be given to the microprocessor and microprocessors is going to do some computations or calculations and then through modem, it will communicate these signals.

These microprocessors is connected with the GPS receiver, output of this GPS clock is given as one of the input to the PMU and along with that separate oscillator is also required. If sometimes, if say GPS signal or satellite signal is not available, then using this oscillator, the time of this PMU that can be fixed.

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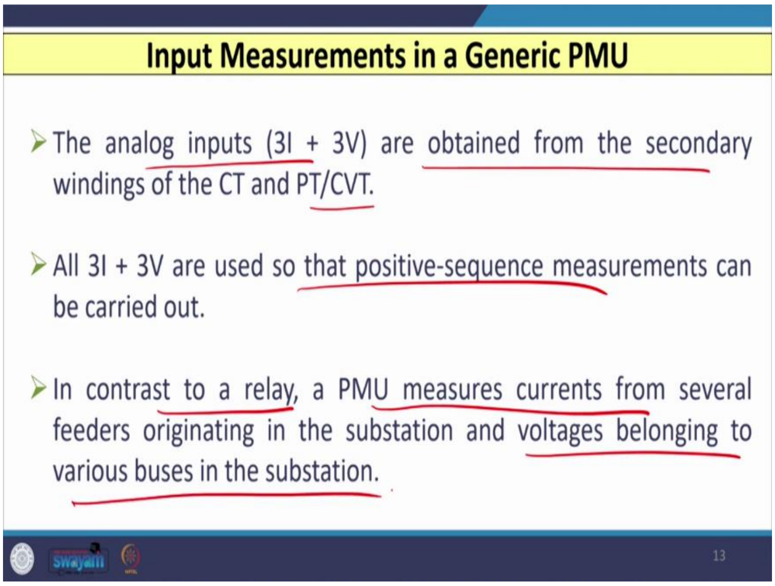

So, as I told you, the analog inputs, let us say in terms of 3 currents, and 3 voltages or maybe if at one particular bus, let us say 3 feeders are there, each having 3 current, so 9 currents and 3 voltages like that these are obtained from the secondary of CTs and CVTs. All these 3 voltages, and 3 currents or maybe whatever values are there are used, so that positive sequence measurements that can be carried out.

Now, what is the difference between PMU and the relay? So, if I have a particular digital or numerical relay, then I have to installed separate for particular feeder or line, so this relay will acquire 3 currents and 3 voltages for that feeder only. Whereas, if I used the PMU, then PMU's will acquire the currents of several feeders, those are connected at particular bus in the substation and at the same time it will also collect the data of voltages those are belonging to the buses of the substation. So, this is the fundamental difference between a relay and the PMU.

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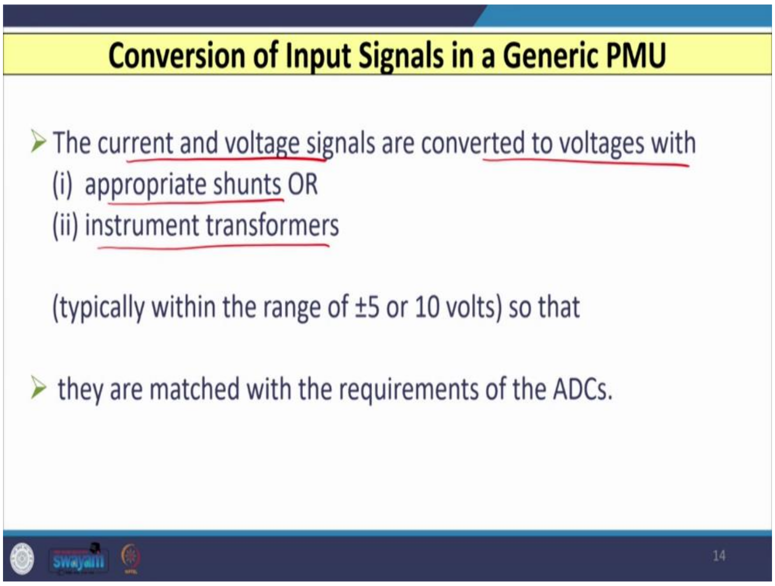

Now, let us see how the conversion of input signals is carried out in generic PMU. So, we know that once we have the currents and voltage signals available from secondary of CTs and CVTs. These signals are converted into equivalent voltage signal using either appropriate shunts or we can also go for some instrument transformers, and these signals are converted typically, within the range of plus or minus 5 volt or maybe 10 volts, so that their ratings are matched with the requirement of analog to digital converters.

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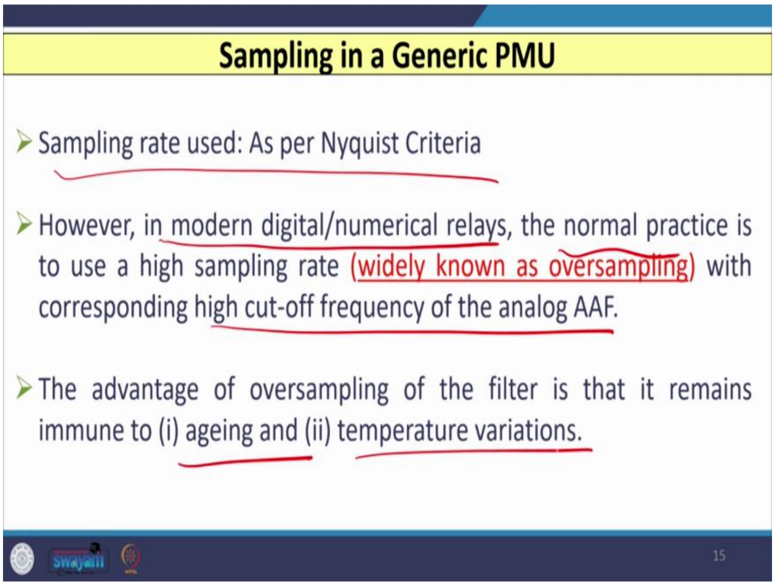

Then the important part comes that is the sampling, that is to be carried out in generic PMU. So, normally, as we have discussed the Nyquist Criteria, sampling rate whatever we used, and that is also used in PMU that is based on Nyquist Criteria. However, in most of the modern digital or numerical relays, most of the manufacturers, they provide or they use the very high sampling rate and this rate is along with the high frequency cut off with the analog anti-aliasing filters. So, when any digital or numerical relays, they use very high sampling rate to acquire the current or voltage signals. This concept is known as over sampling. However, there are certain advantages of over sampling of the filter and the main advantages are remains immune with reference to aging and temperature variations, so there is no effect of this.

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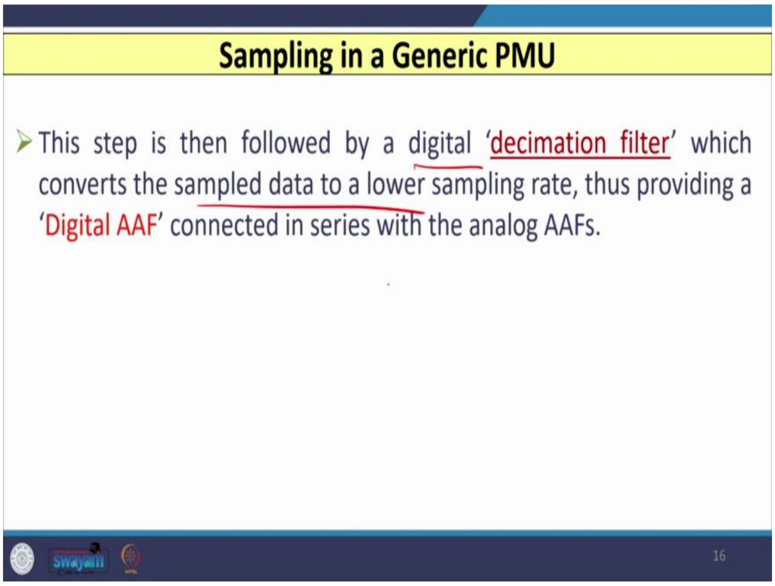

However, whenever we use or whenever we acquire the signals with very high sampling rate, means whenever we use over sampling, then this is always followed by digital filters known as digital dissemination filters, which converts the sample data to a lower sampling rate, so that this digital anti-aliasing filters that can be easily connected or concatenated with the analog anti-aliasing filters.

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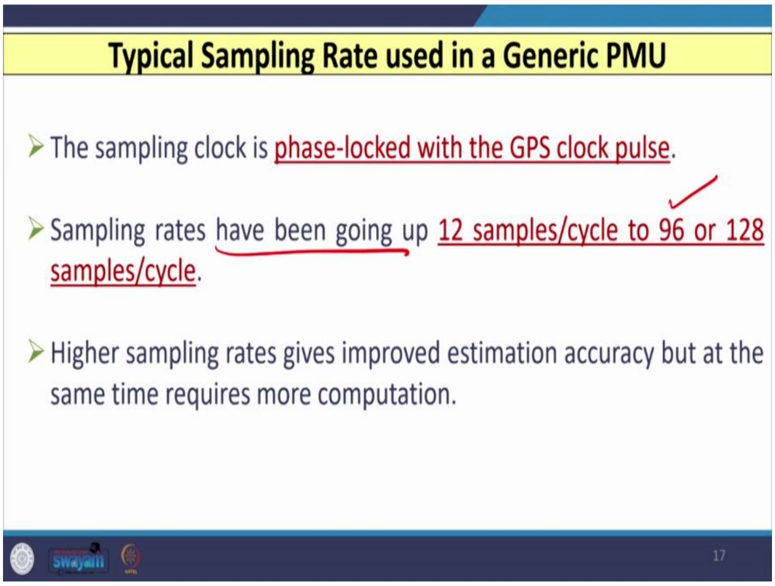

Now, let us see what are the typical sampling rate given by most of the PMU manufacturers? So, normally the sampling clock is phase locked with the GPS clock pulse and that is why time stamping is carried out. The normal sampling rate that is given by most of the manufacturers that is 12 samples per cycle, and it may go up to let us say 96 or 128 samples per cycle, and we know that higher the sampling rate we will have better accuracy, but at the same time we have to go for more computation, so we have to again estimate between these 2 things.

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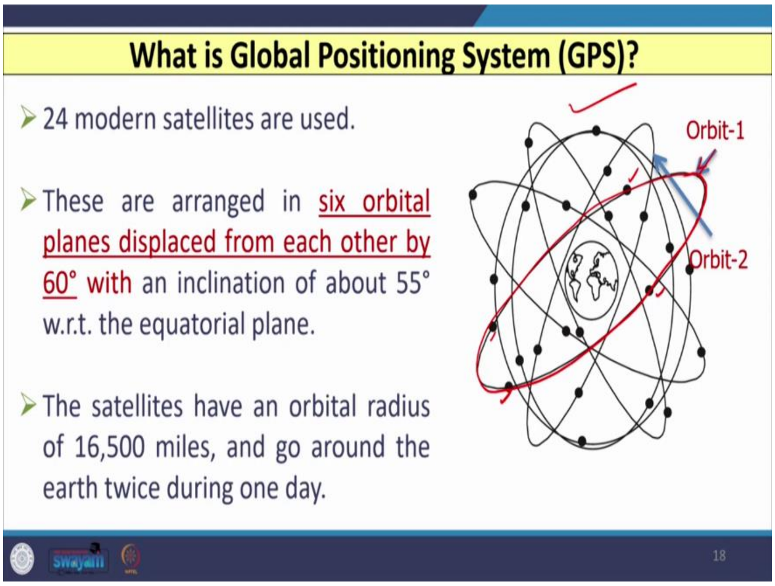

Now, let us see what is GPS or global positioning system. So, in 1994, 24 satellites were installed in the sky, and these satellites are arranged in 6 orbital planes from each other by 60 degree with an inclination of about 55 degree with reference to the equatorial plane. So, you can see in the figure (as shown in above slide) that different orbits are shown here, you can see this is the orbit 1, so this has 1 orbit, and you can see when I say this orbit, then here in this orbit, you can see four satellites are there. So, similarly you have different orbits, six orbits are there, in each orbit you have four satellites, so total 24 satellites are covered in this orbital plane. And these satellites have an orbital radius of 16,500 miles, and that will go around twice in a particular day.

So, these satellites are arranged in such a way that at least 6 satellites are visible at most locations on the earth and often as many as 10 satellites may be available for viewing. So, synchronization using this global positioning system that provides continuous precise timing of the order of almost 1 micro second. So, this PMU will use this satellite as an external input from this GPS, and so that time synchronization can be effectively done with a precise timing of almost 1 micro second.

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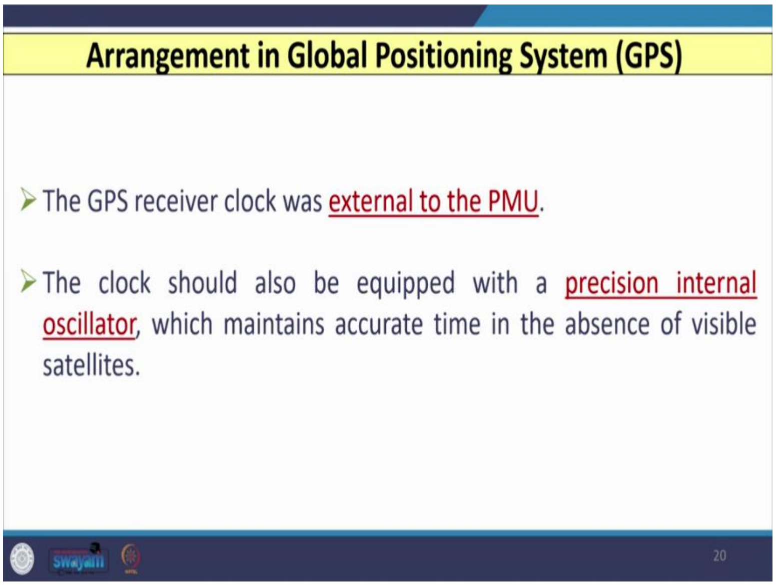

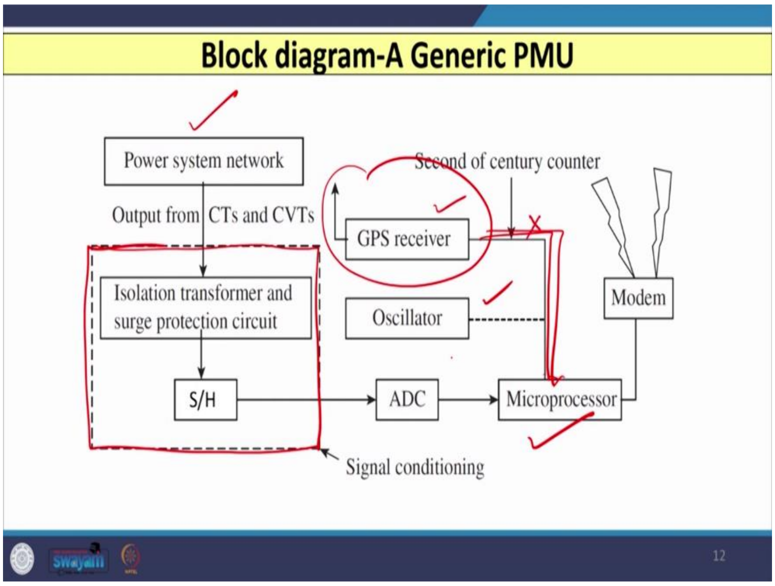

Now, let us see what is the arrangement in global positioning system? So, normally a GPS receiver clock that is used or as an external device and the output of this GPS clock is connected to the PMU. So, you can see in the generic PMU diagram, here, the output of this GPS clock that is given as an input to the PMU. So, this signal is externally given as an input to the Phasor Measurement Unit, or this PMU device.

Now, the clock that should be equipped with a precision of internal oscillator. So, I told you that normally GPS signal is available from the satellite and it is given as an input to the PMU. But somehow, let us say, if I assume in worst case this satellite signal is not available from GPS, then this internal precise oscillator that is used, which is again capable to take care of when satellite signals are not available as an input to the PMU device.

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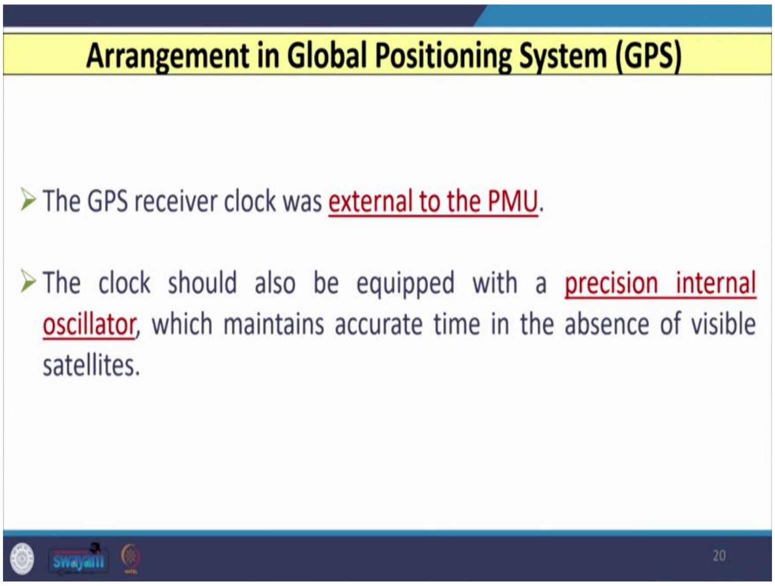

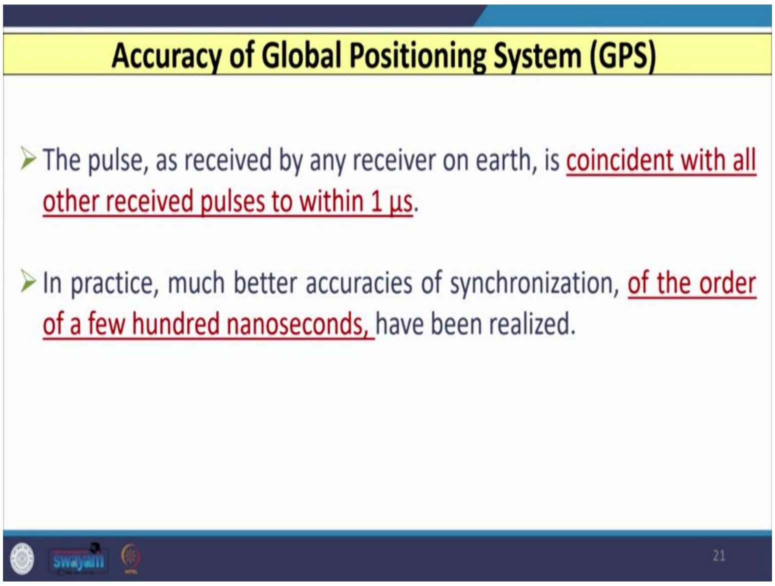

So, using that we can effectively maintains the accurate time in the absence of satellites, or in the absence of signal from the external unit. Now, let us see what is the accuracy of global positioning system? So, the pulse as received by a receiver on earth, that is coincident with all other received pulses to within 1 micro second. In normal practice, much better accuracies of synchronization of the order of let us say, few hundreds of nano second that can be realized, if we consider the accuracy of GPS.

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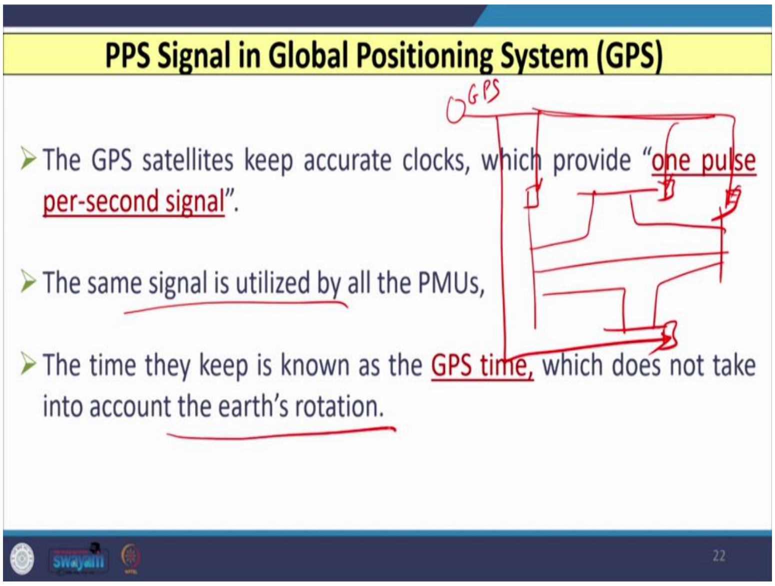

Now, what is the pulse per second signal in global positioning system? So, we know that GPS satellites keep accurate clocks, and this will provide 1 pulse per second signal, and this signal is given to the PMU. The same signal is utilized by all the PMU's which we have installed. So, let us say, if we have system like this, and if we have installed let us say the PMU's at this bus, and other 2 buses, then what is the meaning of this that GPS clock signal is given to all the PMU's that is installed in a particular system as an input, so that we will have the time stamping of all the signals acquired by this PMU's. So, the time they keep that is known as the GPS time, and this time does not take into account the earth rotation. This is also very important point; we need to remember.

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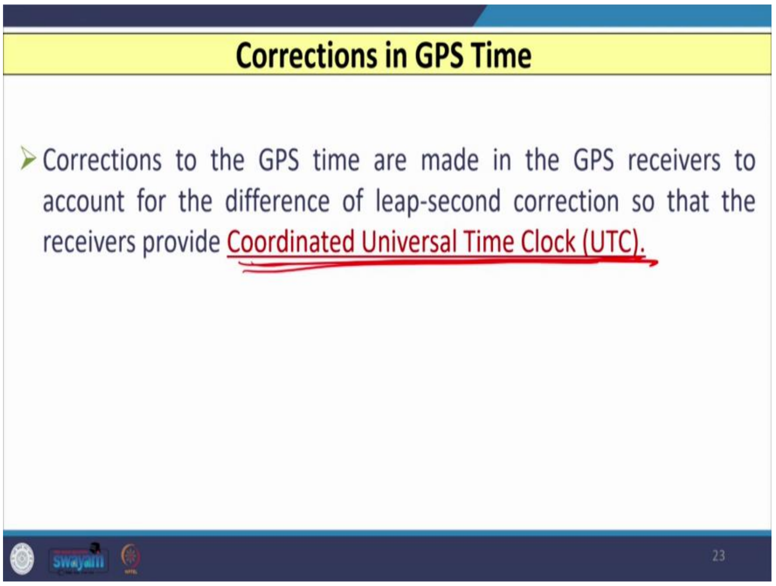

Now, what are the corrections required in GPS time? So, the corrections to the GPS time are made in the GPS receivers to account for the difference of leap-second correction, so that the receivers provide the coordinated universal time clock. So, this clock is very important as far as the GPS is concerned. So, whatever corrections are required that is to be carried out and the, so that output of the receivers that will take care of all these errors and finally this signal that is coordinated universal time clock signal is available from the GPS which is given to the all the PMU's available or installed in a particular network.

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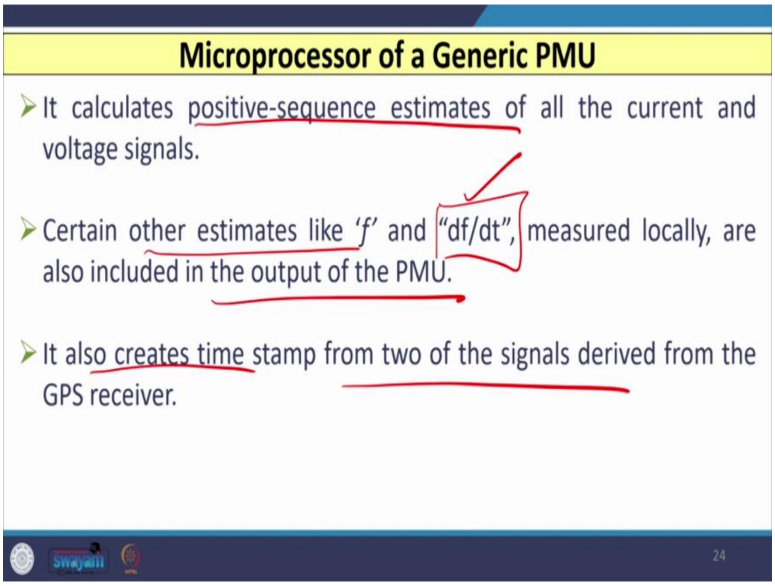

Now, let us see what is the function of microprocessors that is available in a generic PMU? So, the function of microprocessor unit or block is that it calculates the positive sequence estimates of all the currents and voltage signals. So, we know that as an output it will give Phasors, so the processors have some algorithm as I told you, the very fast Discrete Fourier Transform Algorithms are available and using that these Phasor values are calculated and positive sequence estimates of all the acquired voltage and current signals that is given as an output of this.

Certain other estimates, if it is required let us say frequency, we required as an output from the PMU, sometimes let us say we also need the rate of change of frequency because we know that if we have installed the PMUs, and we know that in particular network or region, if let us say some island is formed, then in that case, change in frequency is very important.

So, that we, the operator can know that, there is some phenomena is going to happen, and island is formed, now operator has to take certain measures based on reduction in the frequency, so that is why df/dt, signal as an output from PMU that is also available and PMU will also provide this as another additional output whenever it is required. These microprocessors in a generic PMU also creates timestamp from 2 of the signals derived from the GPS receiver.

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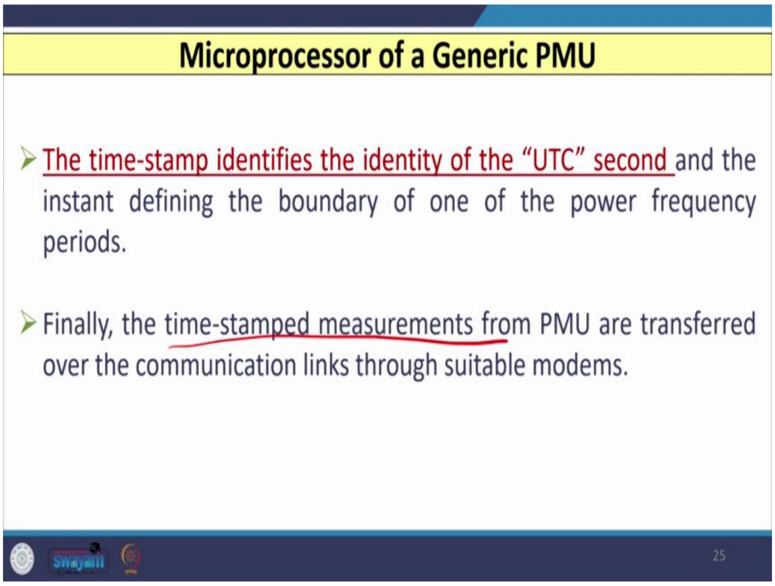

So, the timestamp identifies the identity of the universal time clock second and the instant defining the boundary of 1 of the power frequency periods. So, finally the timestamp measurements which are available from the PMU, as an output of PMU, they are transferred to the communication link through suitable modems.

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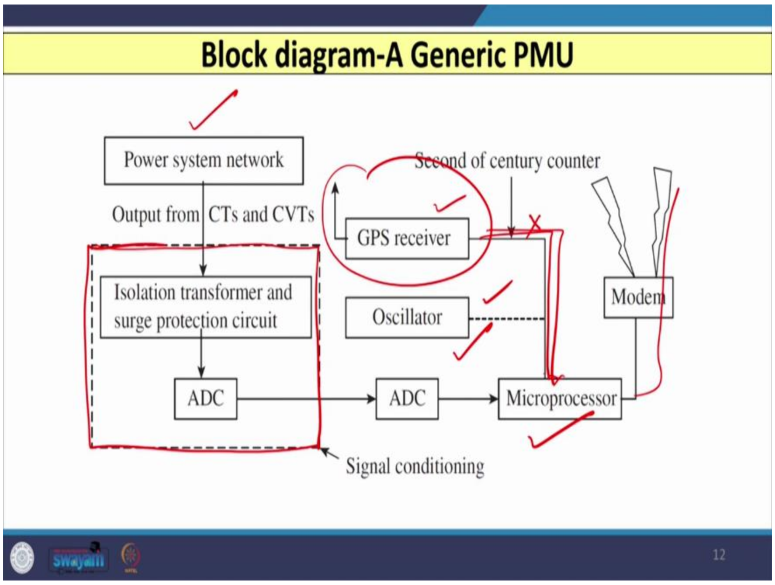

So, you can see that, when we saw the diagram of this generic PMU (as shown in above slide), so in that we have discussed that output of this PMU that is time stamped signals of voltages and currents that is transferred or that is given to the communication channel and that is again pass-through suitable modems, so that that can be further transmitted at different ends. We will discuss later on hierarchy of PMUs in which we will see that the output of each PMU that is given to the its upper device known as the data concentrator.

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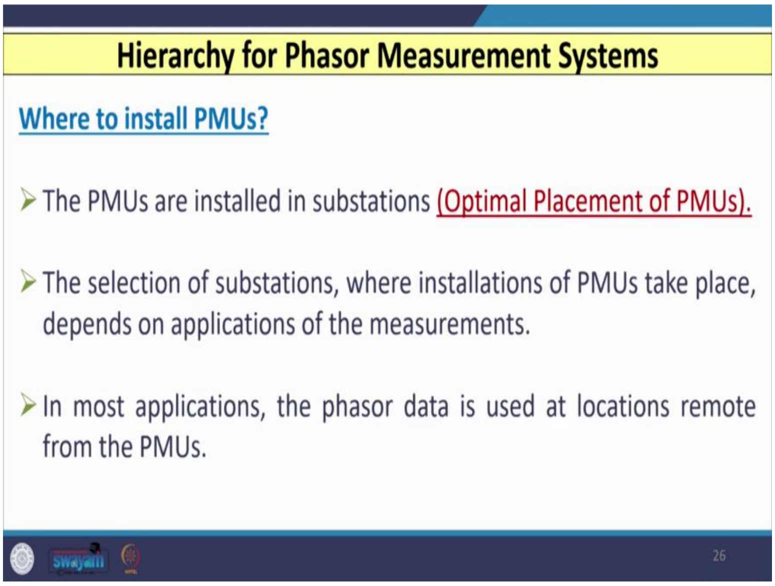

So, in this lecture we started our discussion with the concept of wide area protection, and we have discussed that if we wish to achieve wide area protection for any system or network, then we have to go for wide area measurements, and wide area measurements we can obtain by two ways, either we can go for unsynchronized sampling or we can go for synchronized sampling. So, the best option is we can go for synchronized sampling and synchronized sampling can be easily achieved by synchro Phasors, that is nothing but the PMU's.

So, we then, we have started our discussion with the what is PMU? So, PMU is nothing but the device which acquires the signal, let us say current voltage, and it gives the positive estimates of those signals in Phasor forms, and additionally PMU is also capable to give you some other estimate like frequency, rate of change of frequency, and those signals are again transmitted at the higher order or higher level to the data concentrator using some modems. So, in the next class we will discuss more about the hierarchy of Phasor Measurement Systems. Thank you.