Digital Protection of Power System
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Lecture - 33
Introduction to Phasor Measurement Unit – II

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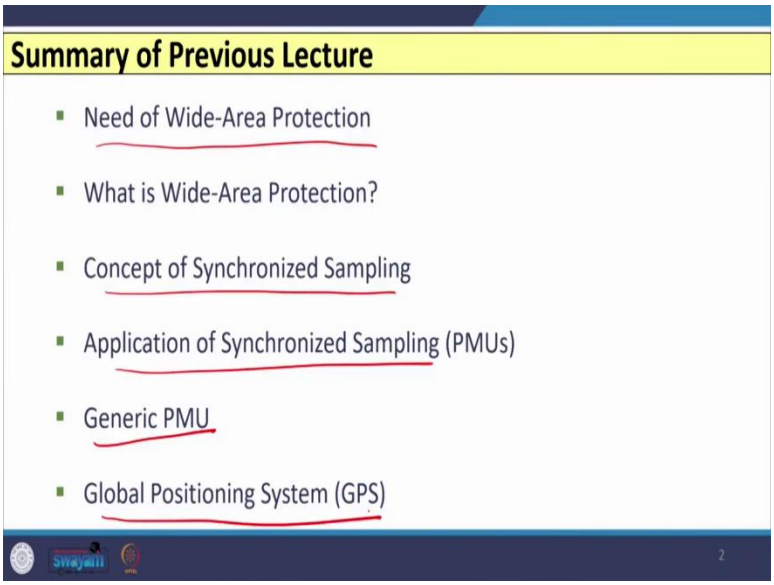

Hello friends, so in the previous lecture, we have discussed about the need of wide area protection concept or system. And we have discussed that wide area protection concept is a concept where we can have the protective device implementation using the data available from various buses instead of local measurements which is done in most of the protective device.

And, then we have discussed that if we wish to achieve wide area protection concept then we have to go for wide area measurements and for wide area measurements, we have to use the concept of synchronized sampling. And, then we have discussed that if we wish to apply the concept of synchronized sampling then we have to go for the utilization of a device known as Phasor measurement unit, which will give you as an output Phasor value of voltage and current estimate along with that some additional estimates are also possible like frequency and rate of change of frequency.

Then, we have discussed the basic block diagram of a generic PMU in which we have discussed that the acquiring of data that will be carried out and then it is processed by signalling unit, and then this is given as an input to the microprocessor block which is going to compute the estimate

of voltage and currents and which is at time stamped signals and this output will be again transmitted to the wire channel through some modem devices. And this time stamping is done by the system known as global positioning system.

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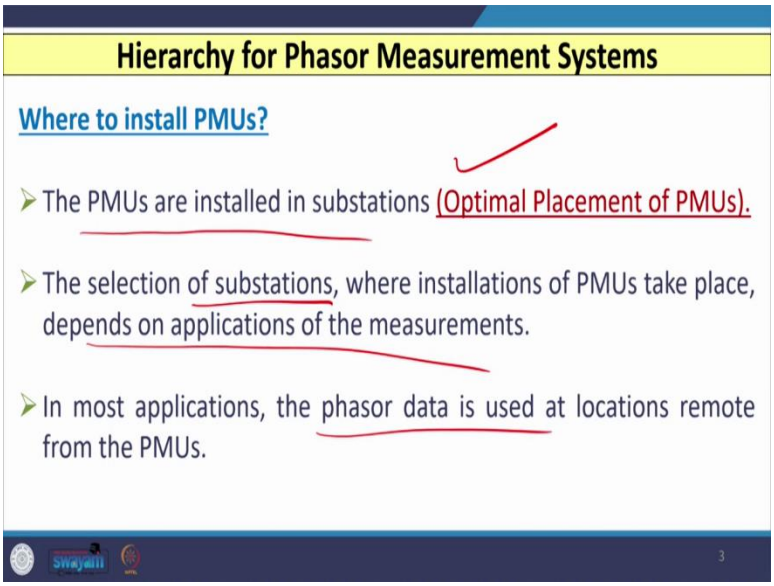

Now, let us see what is the hierarchy of Phasor measurement systems? So, the first question comes where to install the Phasor measurement unit or Phasor measurement devices? So, normally, the PMUs are installed in substations, however it is not possible to install the PMUs at all the substations, so for that the selection of substations where installation of PMUs can be taken place that depends on the application of measurement, for what purpose we are implementing the PMUs, whether we are implementing for post mortem analysis, or whether we are implementing to know the state of the system, so it depends on application. And in most of the applications the Phasor data is used at locations remote from the PMUs, so we will go for the algorithm which is widely known as optimal placement of PMUs.

So, using this con, optimal placement of PMU concept, we can find out that, if we install the PMUs instead of let us say 10 substations to the 7 substations, then whatever application for which we have installed the PMUs that will suffice, if we installed PMUs at only 7 substations, instead of 10 substations. So, which substations we have to install that will be given by the optimal placement of PMUs algorithm.

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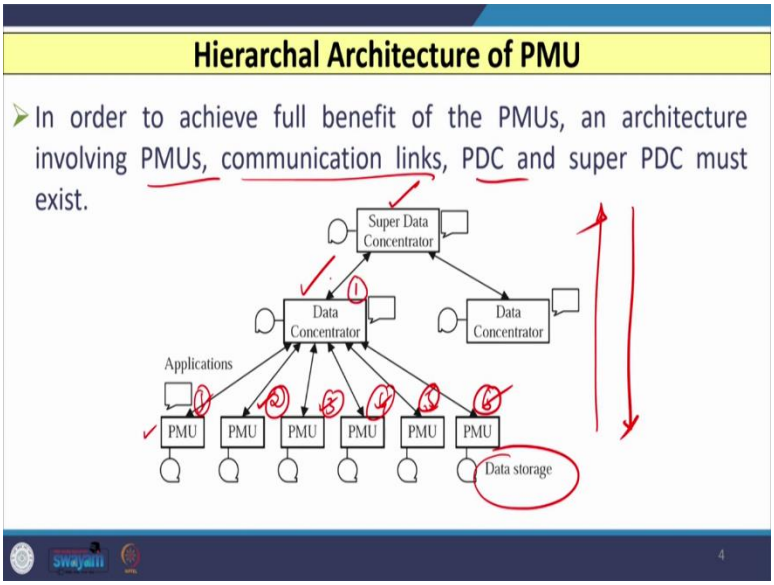

Now, if we consider the hierarchical architecture of Phasor measurement unit, then in order to achieve the full benefit of Phasor measurement units an architecture which involves Phasor measurement units, communication link, Phasor data concentrator, and super Phasor data concentrator, that will be exist in the hierarchy of this PMUs.

So, you can see in the figure that we have several PMUs installed at several substations and the output of this PMUs that will be again transmitted or given to the data concentrator which is known as Phasor data concentrator and for maybe at every 15-20 PMUs, we have 1 Phasor data concentrator. So, we have several Phasor data concentrators installed and this Phasor data concentrator can be region wise also, can be state wise also, can be province wise also.

And then, the output of this Phasor data concentrators that will be again given to the super Phasor data concentrator which is available at particular location. Let us say, we have national grid, then we have regional grid, then we have state level grid, so we have the region wise PDC, state wise PDC, and we have the national PDC also. So, the flow of this data that will move in upward direction. However, in certain cases, we also need a data flow in reverse direction that is in downward direction also that provision is also exist as per this diagram.

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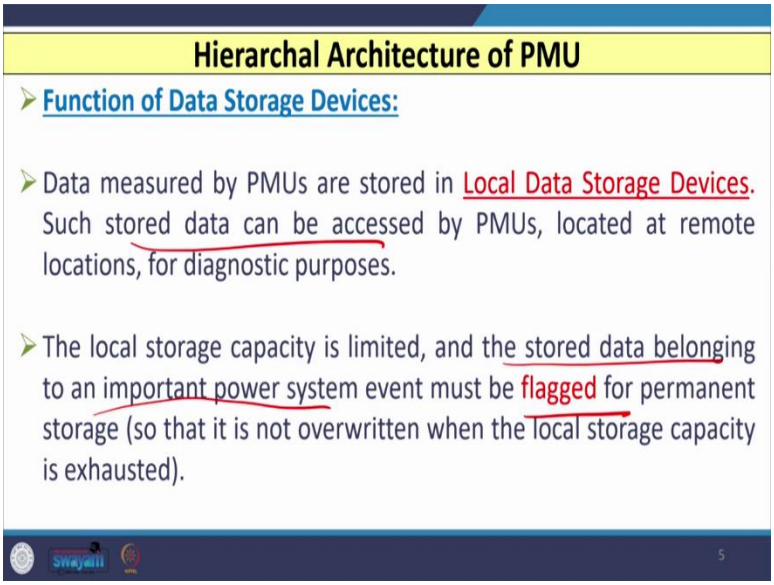

Now, let us see what is the function of this data storage? So, the function of this data storage devices is whatever data that is measured by PMUs that is stored by these devices. Such stored data that can be assessed by PMUs as and when required, located may be at remote location or maybe at local location, and this is again for the maybe some analysis or diagnostic purpose.

The capacity of this local storage devices is very limited, so these stored data belonging to a particular special event or an important event in the power system network that must be flagged for permanent storage, so that whenever the new data are available because of the limited storage capacity of these data storage devices, the remaining data that can be overwritten.

So, this is very important function as far as the data storage devices are concerned. So, important information or important event that can be flagged, so that can be stored permanently, whereas the remaining data that can be exhausted and the new data that is available.

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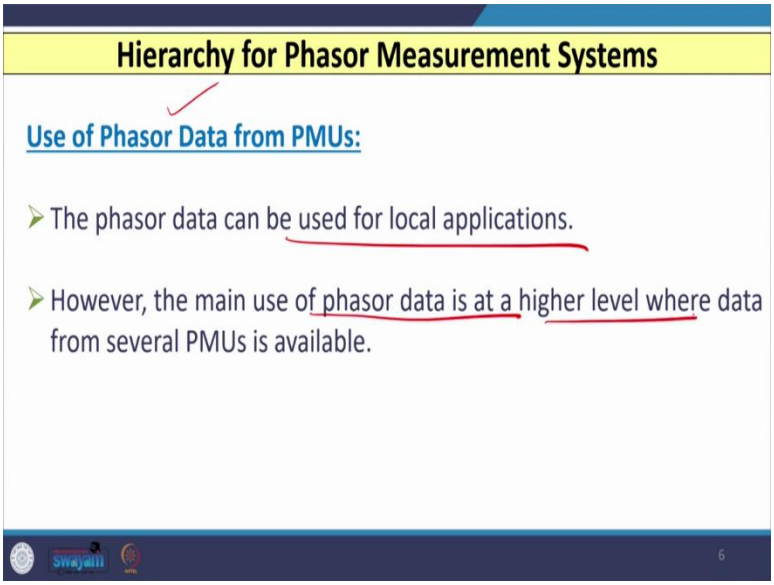

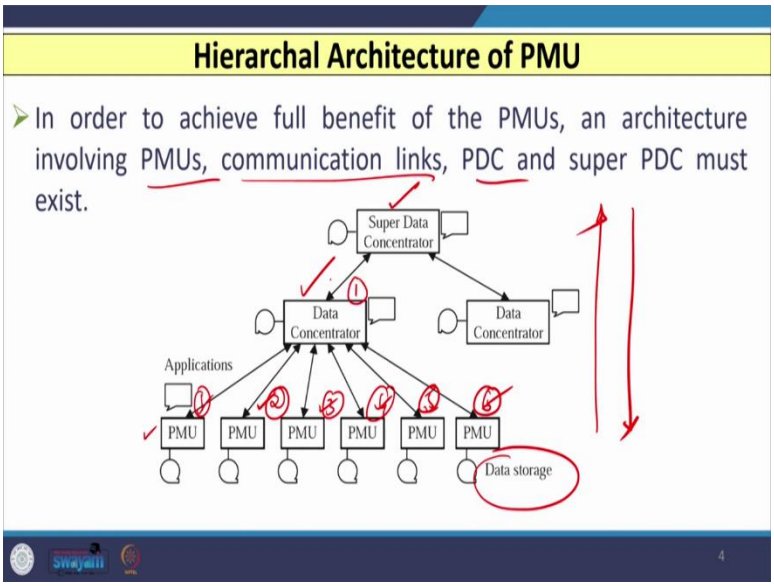

Now, let us see what is the use of Phasor data from the PMUs? So, the Phasor data that can be used may be for local applications, however the main purpose of this Phasor data, that is available from the PMUs that is at higher level, maybe at PDC level, where the data from several PMUs are available. So, as I told you, when different PMUs, let us say these are the PMUs from 1, 2, 3, 4, 5, 6, so the data of all these PMUs are available in this data concentrator. So, the main function of this Phasor data that is at higher level that is at PDC level.

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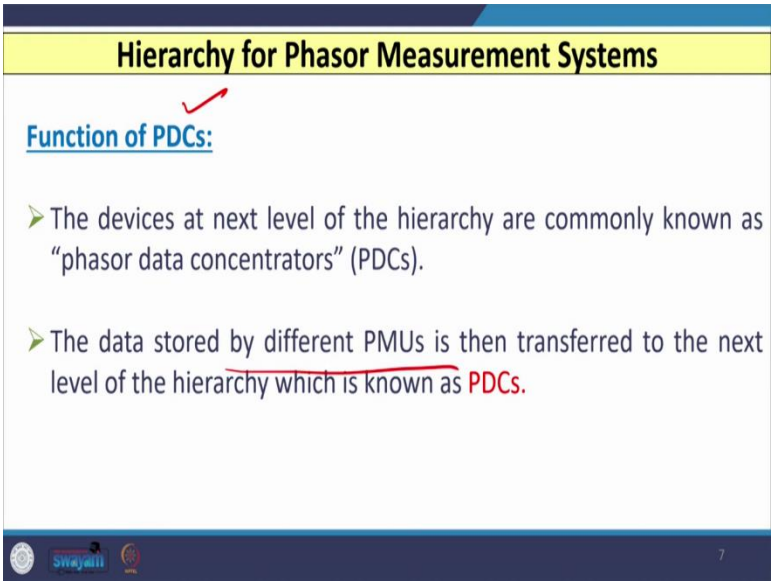

Now, let us see what is the function of Phasor Data Concentrator. So the device at the next level of the hierarchy that is normally known as the PDC or Phasor Data Concentrators. So, whatever data stored by different PMUs that is transferred at upward level that is the next level of hierarchy which is known as the Phasor Data Concentrators or PDC.

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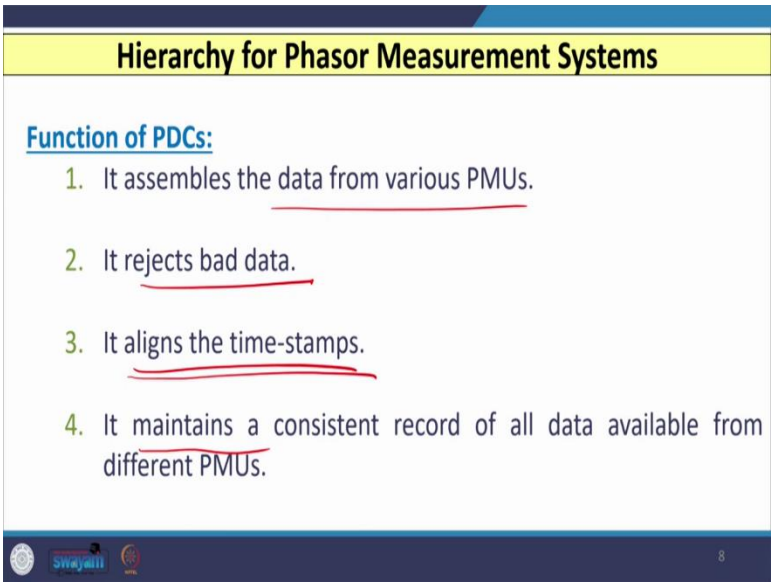

The function of PDC are following: it assembles the data from various PMUs, so let us say as I told you 15 to 20 PMUs you have 1 PDC, so whatever data are available from all 15-20 PMUs those are again assembled by this PDC. It rejects the bad data, if it is there in the PMU. It also

aligns the time stamps, because normally PMU located at different substations, they send the data in terms of packets. So, alignment in terms of stamping or timestamps that is also required. Moreover, PDC maintains a consistent record of all the data available from different PMUs that, okay, from PMU number 1, the datas are available at this instant, from this address, and so on, so this is also done by PDC.

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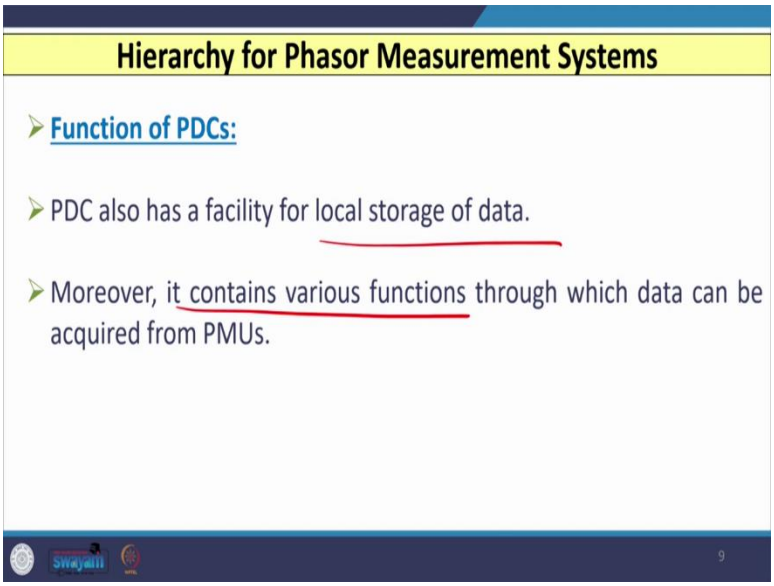

Moreover, PDC also has a facility of some local storage data, so some important data are there that can be also stored by PDC. And along with that, it also contains various functions through which data can be acquired from PMUs also. Now, as I told you in the hierarchical diagram of Phasor measurement systems, that in most of the cases, the normal flow of data, that is in upward direction.

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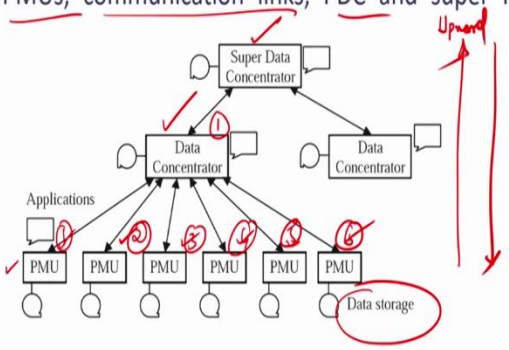
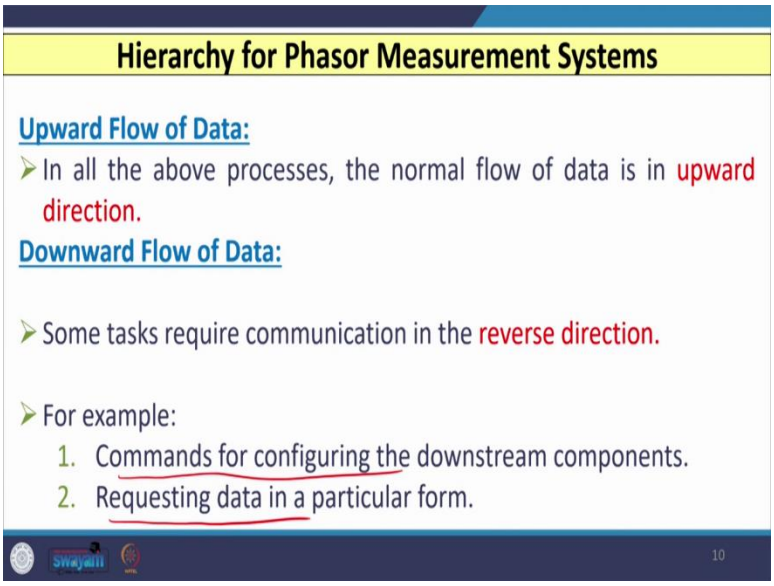
Hierarchal Architecture of PMU

- In order to achieve full benefit of the PMUs, an architecture involving PMUs, communication links, PDC and super PDC must exist.





So, as I told you here the normal flow of direction of the data, that is like this upward only. However, sometimes in certain cases, the reverse flow of direction of the data, that is also possible, particularly for example, the commands for configuring the downstream components is there, then in that case some reverse direction from PDC to PMU level or may be further that is also required.

The another example of the reverse direction where it is requesting the data in a particular form, let us say PDC wants a data from PMU in some different form and that message is given by the PDC to a particular PMU, then in that case the reverse or downward flow of the data that is also there.

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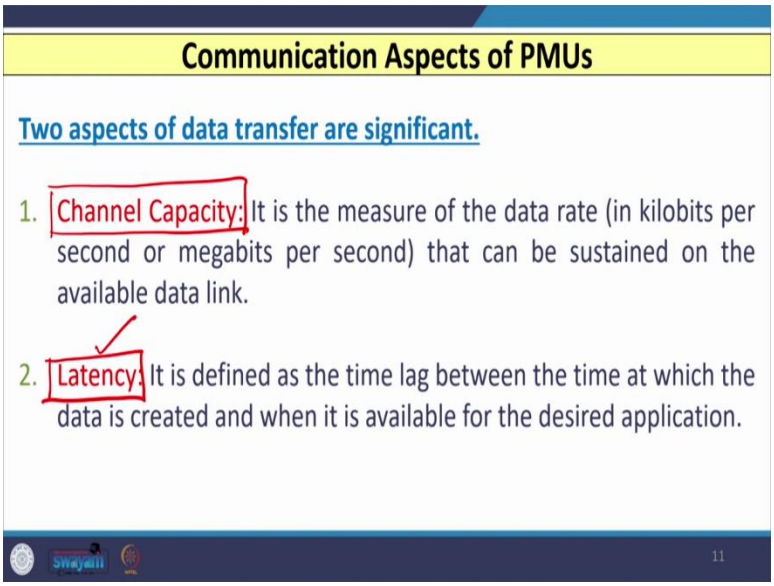

Now, let us see how the communication aspect of PMU that can be achieved? So, normally when we consider the communication aspects in any Phasor measurement unit, then 2 aspects of data transfer that is very significant. The first aspect is related to the channel capacity. So, normally channel capacity is nothing but the measure of the data rate, normally in kilobytes per second or megabytes per second and that can be sustained on the available data link.

The second aspect is known as the latency aspect, and latency is defined as the time lag between the time at which the data is created and when the data is available for a particular or desired application that time difference is known as the latency. So, these two expects are very important as far as the data transfer is concerned in the Phasor measurement units.

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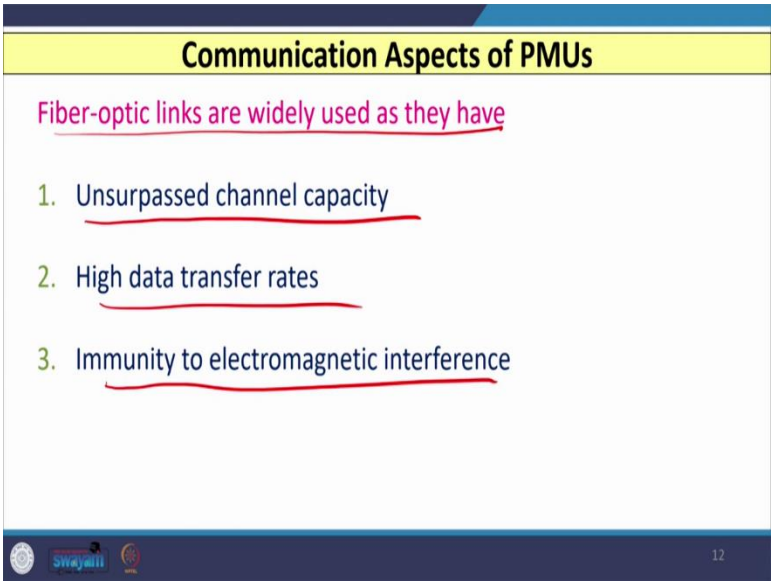

Normally, in most of the cases, Fiber-optic links or cables are used, because they have several advantages, such as they have unsurpassed channel capacity, they have high transfer data rates, and they remain immune to EMI that is electromagnetic interferences, and that is why in most of the cases, Fiber-optic cables are used. So, we can install the Fiber-optic link or cables on at different transmission structure in different way.

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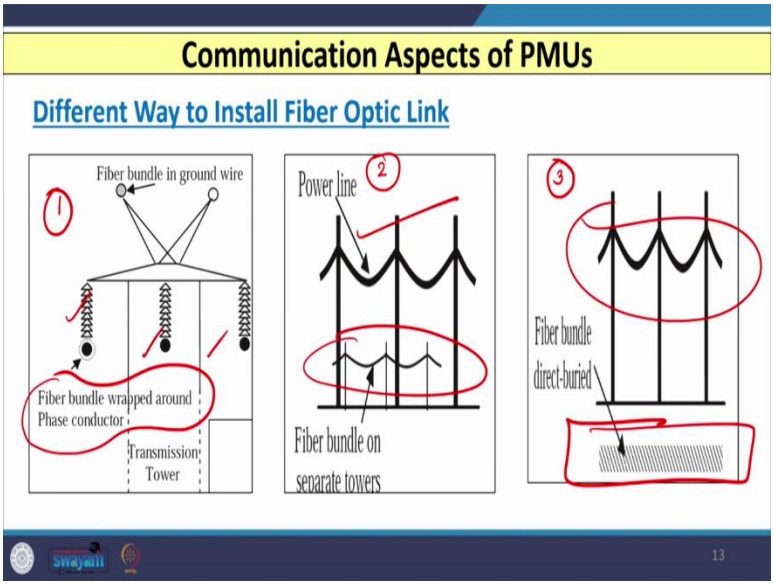

Let us say, one of the way you can see in the figure that is figure number 1, where you can use the Fiber-optic cables in the bundled form, you can wrap it around the phase conductor, so here, so that you can do it. In the second case you can see that the fiber bundles are installed on a separate towers, here, along with our original conductor or phase conductor or power line and the third possibility is the, we have the fiber bundles, that is buried inside the ground and we have the conventional phase conductors are there which is carried by the towers, so with any of the way, we can install the Fiber-optic cable, and we can communicate the whatever information we want to communicate.

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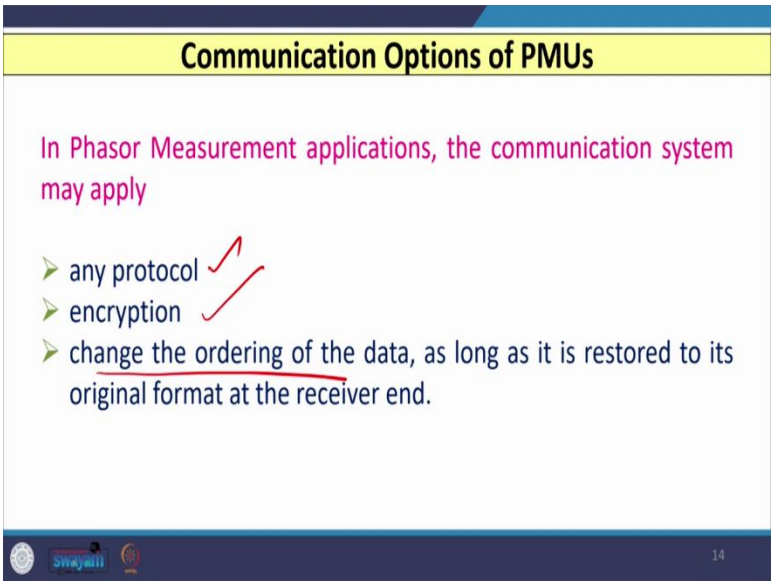

Now, in Phasor measurement applications the communication system may apply any protocol, so any protocol that can be used, any type of encryption that is also used and any change in the ordering of the data that is also possible as long as it is restored and the original format when it receives at particular end. So, any protocol is possible, any type of encryption is possible, and any type of change in the data ordering that is also possible, but this is subject to when this data are received then that will be received in original format as it is transmitted by particular transmitter.

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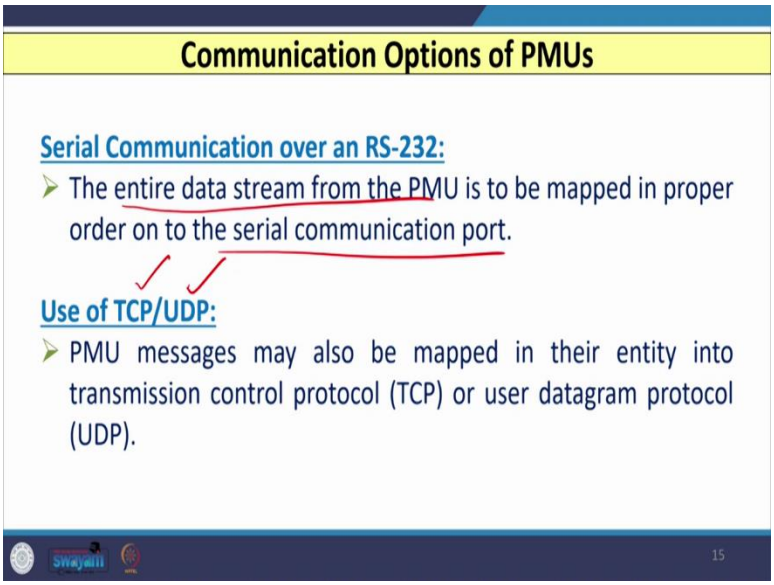

So, to achieve this, normally, we can go for the serial communication using RS-232 port, so the entire data stream from the PMU that is to be mapped in proper order on the serial communication

port. We can also go for the transmission control protocol that is TCP, or we can also use the user datagram protocol that is UDP, so PMU messages may also be mapped in their entire entity into the TCP or UDP, like this also the communication is possible.

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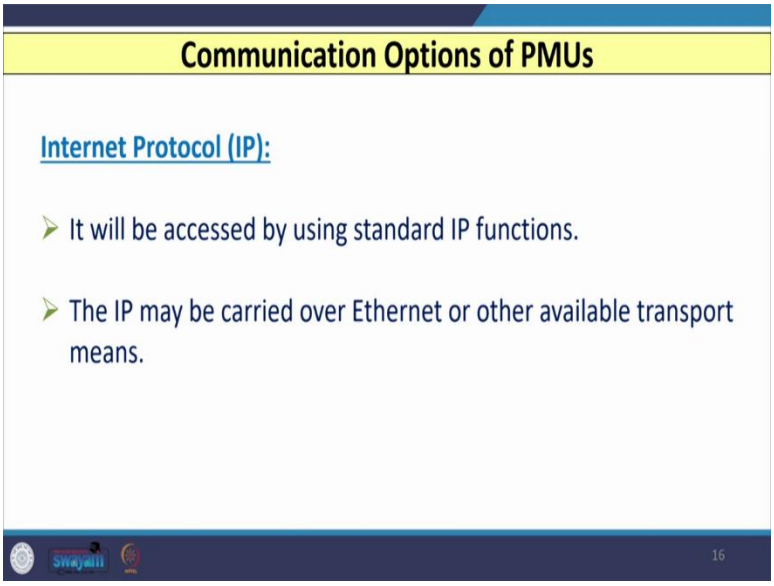

Internet protocol that can be also used, so it will be assessed by using some standard IP functions and the IP that may be carried out using ethernet or whatever the available other transport means are there, that can be also utilized. Let us see, what is the importance of standardization? So normally, in actual practice when we install the PMU in different substations this PMUs are provided by different manufacturers.

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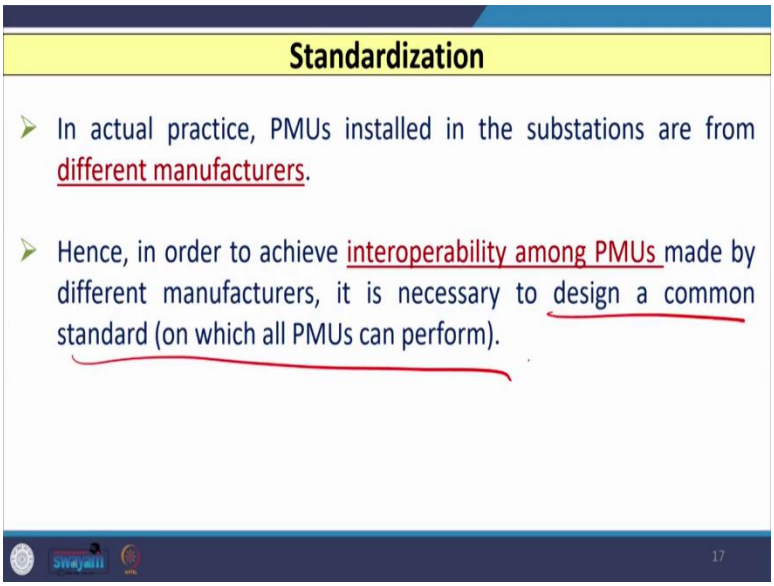

So, in order to achieve the interoperability among all the PMUs which is made by different or which is supplied by different manufacturers, it is necessary to design a common standard on which

all the PMUs can perform their work or they may transmit their signal using this standard, so that is why standardization in the PMUs that play an important role.

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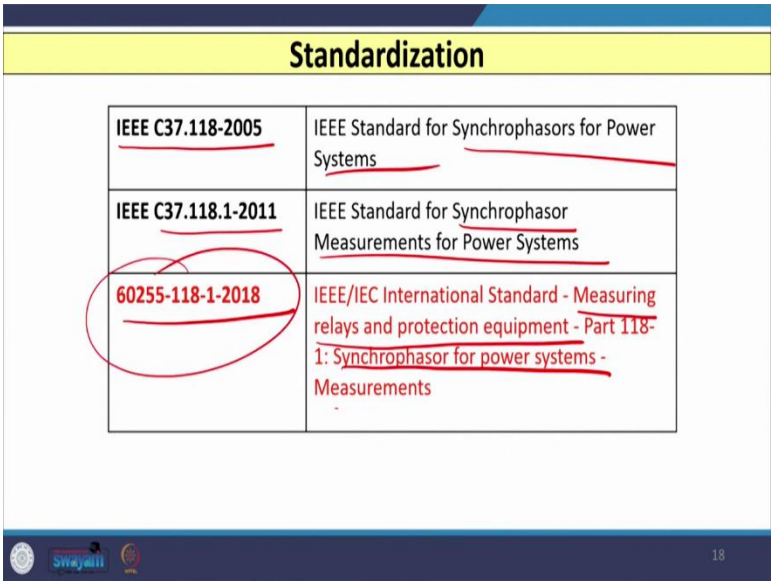

So, as far as standardization is concerned initially in 2005, IEEE has given a standard that is IEEE C37.118, which is given in 2005, and these standards are for Synchrophasor for power systems. This standard is amended by IEEE in the form of C37.118.1 in 2011, and the name of this standard is again Synchrophasor measurements for power systems.

And again, it is amended in 2018 in the form of 60255.118.1 and the name for this standard is again given as measuring relays and protection equipment Part 118.1 that is for Synchrophasor for power systems and that is for measurement purpose. So, these are the standardizations which you can refer as far as the communication in PMUs is concerned and we will see few aspects related to this communication in PMU with reference to this standard.

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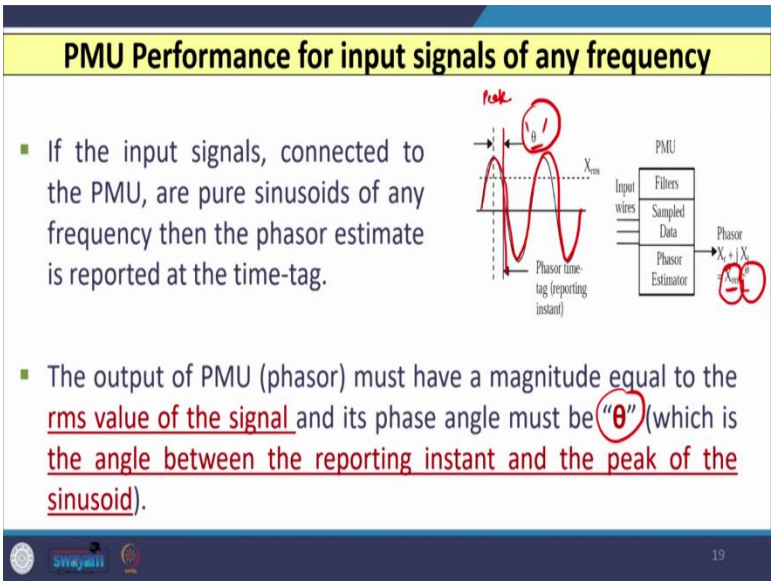

Now, let us see the PMU performance for input signal of any frequency. So, we know that if the input signals that is connected to the PMUs are pure sinusoids of any frequency, then the Phasor estimate is reported at the time stamps. So, you can see that (as shown in above slide) here I have shown 1 signal, and these signals that is I have reported, so this hard line is nothing but the reporting instant Phasor timestamps and this reporting instant is measured with reference to the dotted line which is a peak value.

So, whatever is the difference between the peak and the reporting instant, that is denoted as or denoted by the term theta, and when you give input to the PMUs, PMU has several filters, it is going to sample those acquired instantaneous data, they have some Phasor estimation algorithms as I told you, Fast Recursive Discrete Fourier Transform Algorithm is used and the output by the PMU that is given in terms of the magnitude and the angle that is e raised to j theta and magnitude that is in the form of rms.

So, the output of PMU in terms of phasors magnitude and angle that must have a magnitude which is equal to the rms value of the signal so that is why I have mentioned X_{rms} and its phase angle which is normally denoted by the theta, here you can see which is the angle between the reporting instant and the peak of the sinusoid.

So, this e raised to j theta that is again the output of the PMU in terms of Phasor. Now, the PMUs also contain a number of filters at the input state, so when acquired signals in the form of CT

secondary or CVT secondaries are given as an input to the PMU, these signals are passed through several filters.

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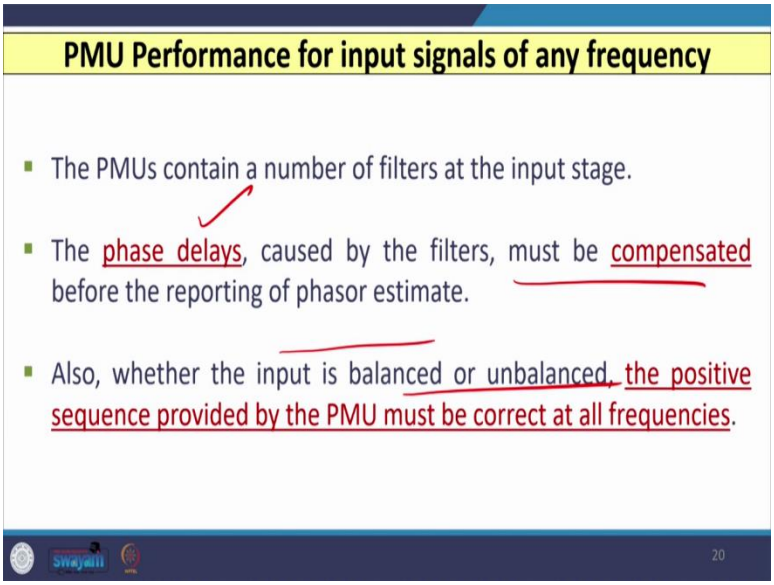

So, any phase delay that is possible when we use the filters must be compensated before the reporting of the Phasor estimate, that is to be carried out, so before the PMU will give Phasor values in the output form, this phase delays may be because of filters that has to be compensated. Also, whether the input is balanced or unbalanced, the positive sequence provided by the PMU must be correct at all the frequencies, so it has to consider all the frequencies and the positive sequence output provided by PMU that remains constant irrespective of whether my input is balanced or I received some unbalance in the input. Now, after this let us see what is the file structure of Synchrophasors or PMUs.

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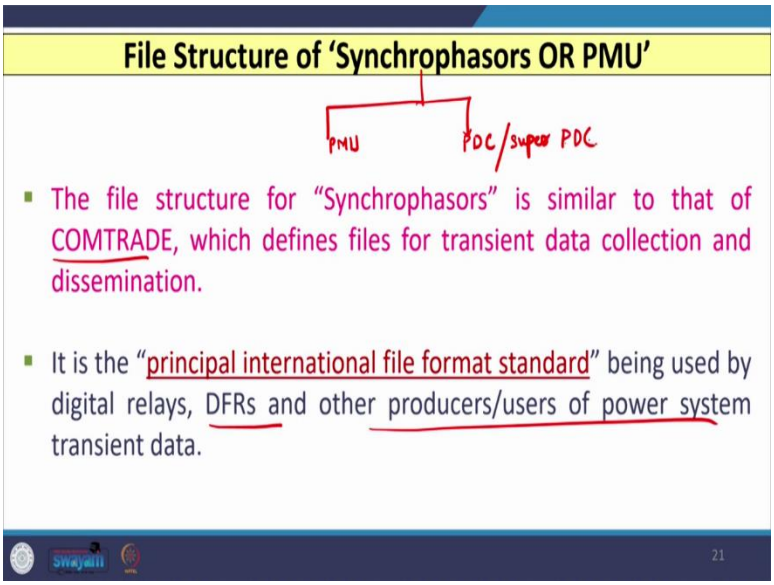

So, when we consider the file structure for Synchrophasors that is similar to that of the COMTRADE file, that which defines the files for transient data collection and dissemination, so a COMTRADE file is file which is meant for the transient data collection and dissemination, so this COMTRADE files will be used by most of the digital fault recorders, digital relays, so same concept same, that is also used by Synchrophasor or in PMUs.

So, it is the principle, international file format standard, that is being used by most of the digital relays, it is also used by digital fault recorders and other producers and users which are dealing with the transient data in power system network. So, the same concept, same format that is used by Synchrophasor also. When I say the word Synchrophasor, it contains either PMU or it can also contain the PDC or any super PDC, so this is very important point.

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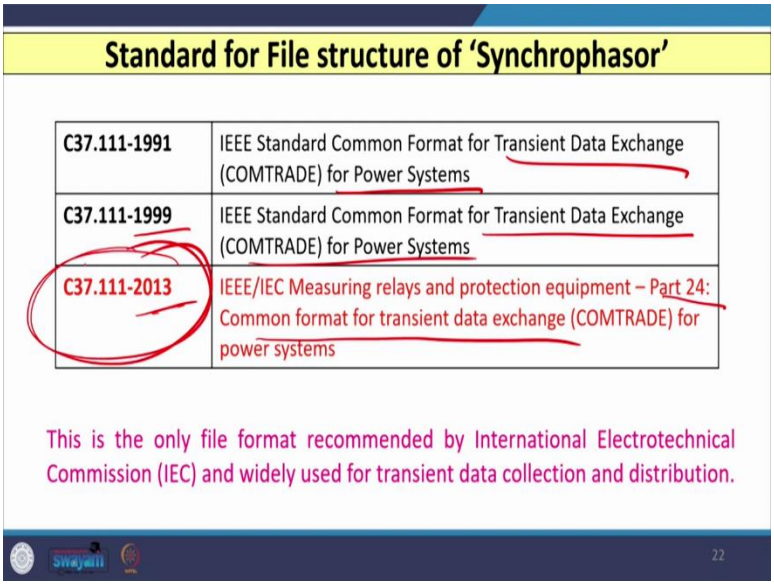

Now, let us see what are the standards which are related to the file structure of Synchrophasors. So, initially in 1991, C37.111 standard is given by IEEE and this is for the transient data exchange for power system, basically COMTRADE. Then it is again amended into 1999 and then it is again the format for transient data exchange for power system and again it will be amended in 2013 and then it becomes the part 24 common format for transient data exchange for power system.

So, we will again concentrate on this standard and we will see what is the file structure that is used in syncrophasers. So, this is the only file format as I told you that is recommended by the IEC which is International Electro Technical Commission and that is used for transient data collection, so we will concentrate more on as per this latest standard only.

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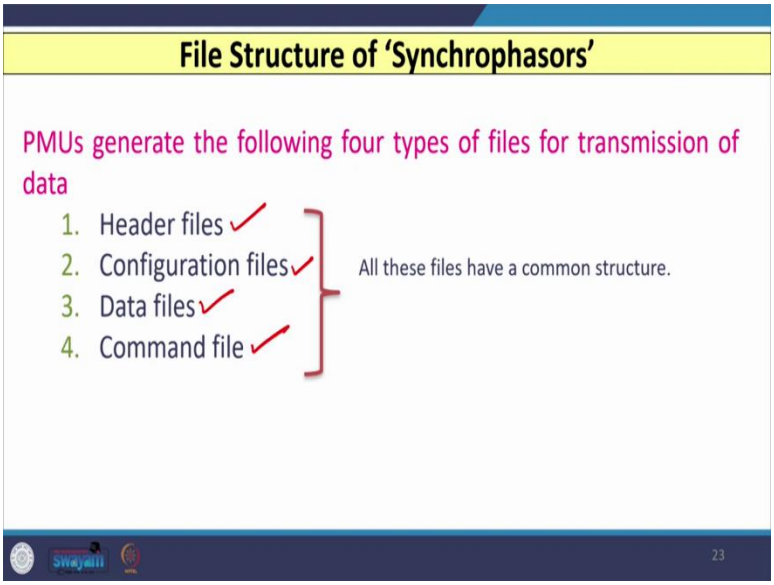

Now, let us see what is the file structure possible in Synchrophasors? So normally, most of the PMUs generate the following 4 types of files for transmission of data, and these files are the first is the header files, second is the configuration files, third is the data files, and four is the command files. Now, all these 4 files have a common structure, so that it can be easily communicated between 2 PMUs or maybe between PMUs and PDCs. So, let us see the importance of all the 4 files one by one.

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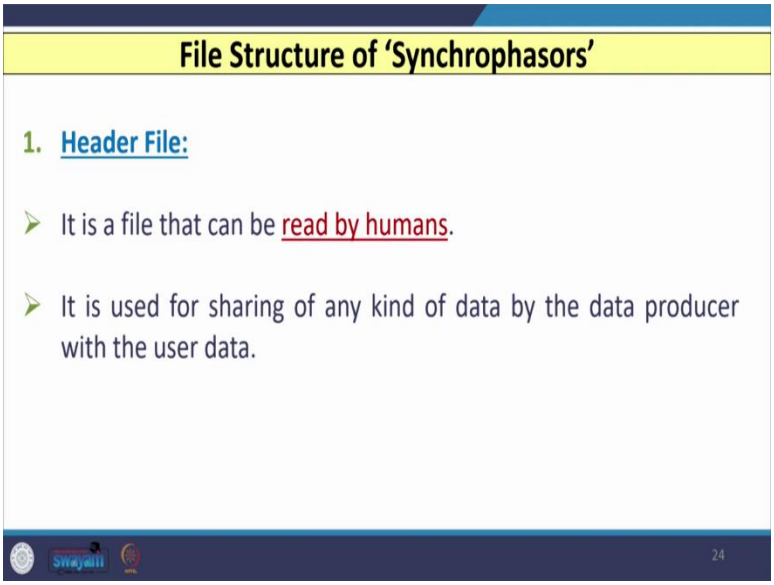

So, if we start with the header files, then header file is a file that can be read by any humans or maybe for operator. So, this file is used for sharing any kind of exchange of data between the operator and the data producer, so this file is very important.

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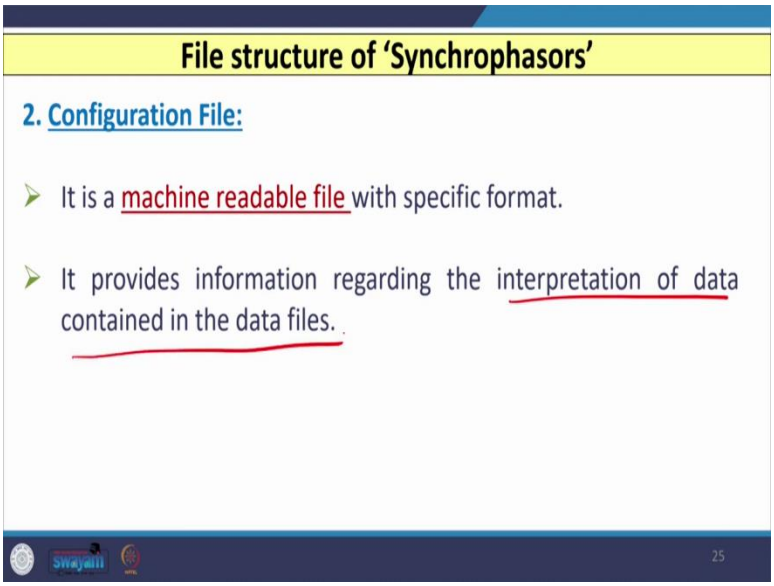

The second file format is the configuration file which is a machine-readable file and it is in specific format, so this file provides the information related to the interpretation of data that is contained in the data files, these data files are related to for what purpose, that information's are available in the configuration file. The third file is the data file this is also machine-readable file in specific format and it contains the output of PMUs.

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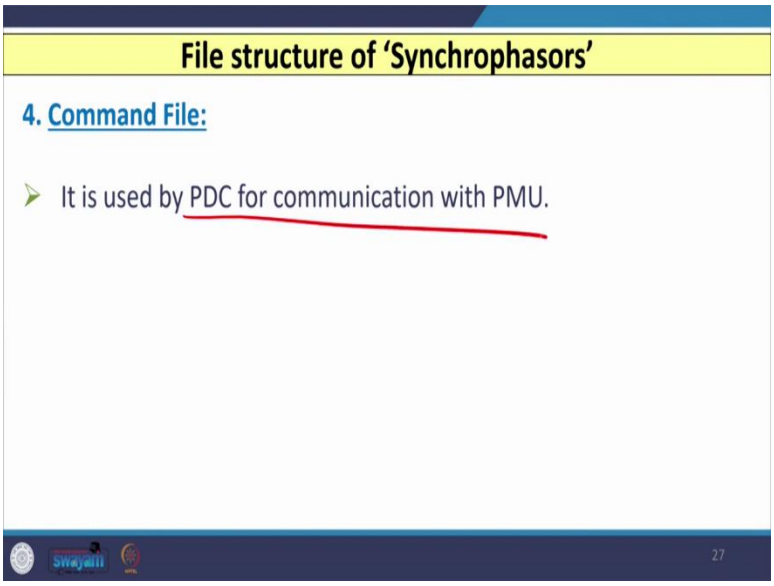
File structure of 'Synchrophasors'

3. Data File:

- It is also a machine readable file with specific format.
- It contains the output of PMU (i.e. phasor value of current and voltages along with "*f*" and "df/dt" which can be sent in rectangular or polar form).



So, we know that output of PMUs are in the form of phasors of voltage and current sometimes, we also wants frequency or rate of change of frequency, that is sent either in a rectangular or polar form, so this is contained by this data file. And the fourth file which is known as command file that is used by PDC for communication with the Phasor measurement units installed at different substations.

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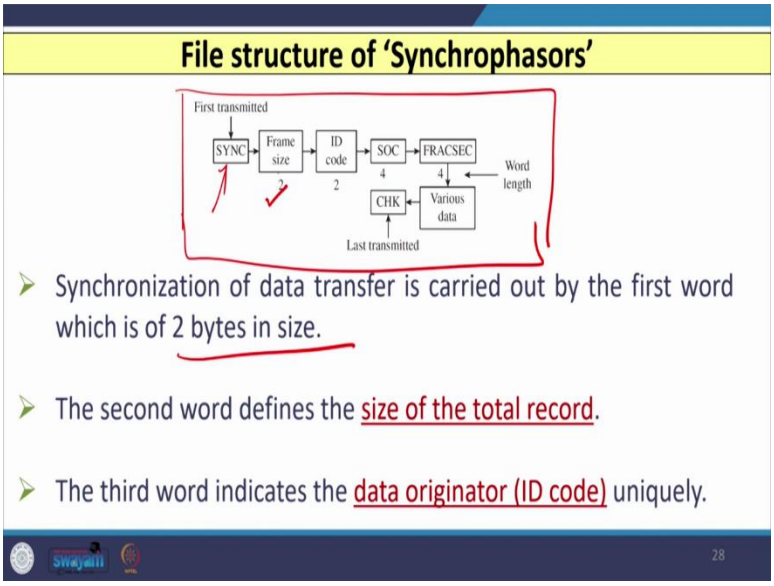

Now, let us see how the file structure of Synchrophasors works and how many bytes are required for each case? So, you can see here the diagram where I have shown the file structure, the processing of the each code with several bytes, so the first when file is transmitted by PMU it is

started with the synchronization command. So, synchronization sync is meant for the data transfer that is to be carried out by the first word which is of 2 bytes in size. The second, the frame size is the word which defines the size of the total record, so that is given in the frame size. The third file is related to the ID code and its word length is again 2 and that indicate the data originator uniquely and it is unique for a particular PMUs.

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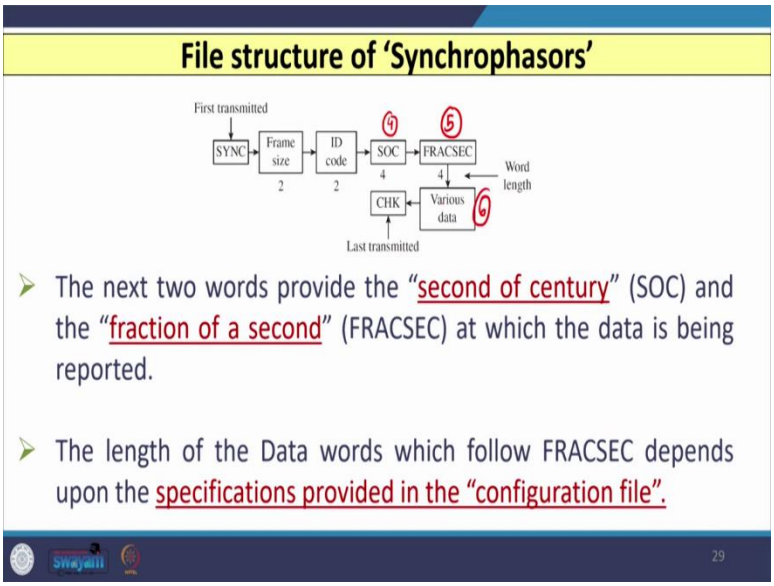

The fourth one and fifth one, that is this one Soc and fraction of seconds. So, SOC is nothing but the second of century and FRACSEC is nothing but the fraction of second, these two are the two words which provides a second of century command and fraction of second command at which the data that is being reported.

The length of the data words which follow the fraction of second commands that depends on the whatever specification is provided in the configuration file of the PMU. And then after that you have various data available may be current, may be voltages, 3 phase current, 3 phase voltage frequency, rate of change of frequency, so all are there in the data file.

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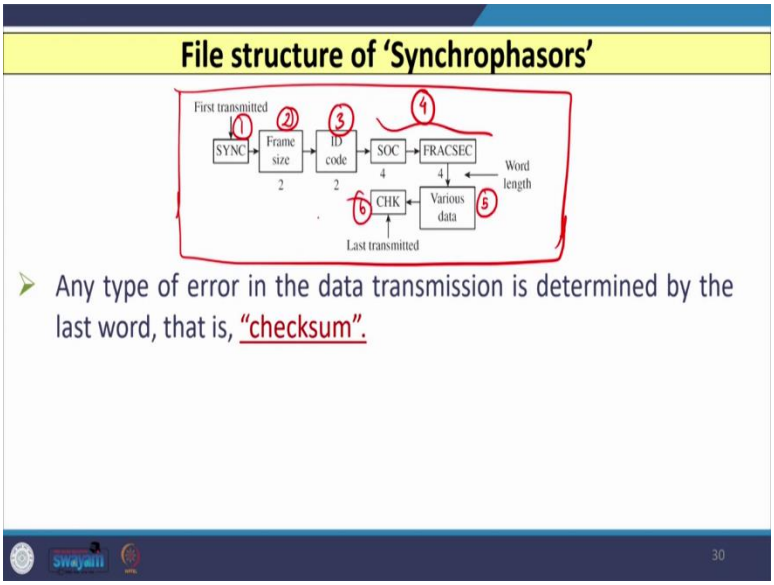

And after that any type of error in the data transmission that is determined by the last word, that is the checking or CHK command, so checksum command is also there. So here, we have discussed that this diagram is very important when PMU is going to transmit the file and in that the synchro frame size ID code, and then these 2 commands that is SOC, Second Of Century and fraction of second and along with you have the data, and last that is the checksum the 6 important aspects are there when any transmission of the file that is to be carried out by the PMU may be from PMU to PDC or at any level.

So, in this lecture we started our discussion with the hierarchy of the PMUs and we have seen that the normal flow of the transmission of data that is in upward direction from PMU to this PDC that is Phasor data concentrator and from PDC to the super PDC and so on. However, in certain cases, if let us say PDC wants the data in special format then the reverse direction that is downward direction of data flow that is also possible.

We have seen that how the communication in PMUs that is to be carried out and we have to use several standards. And finally, we discussed about the file structures in Synchrophasors and based on the latest standard, we have discussed that there are 6 important blocks which need to be considered where any file is transmitted by the PMUs, so this we have discussed. Thank you.