DC Microgrid and Control System

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Lecture - 05
AC and DC Microgrid with Distributed Energy Resources
(AC Microgrid Part)

Welcome to our lectures on DC microgrid and control system. Today we shall elaborate on AC DC microgrid with the distributed energy sources and this is a part of the hybrid as well as the AC microgrid.

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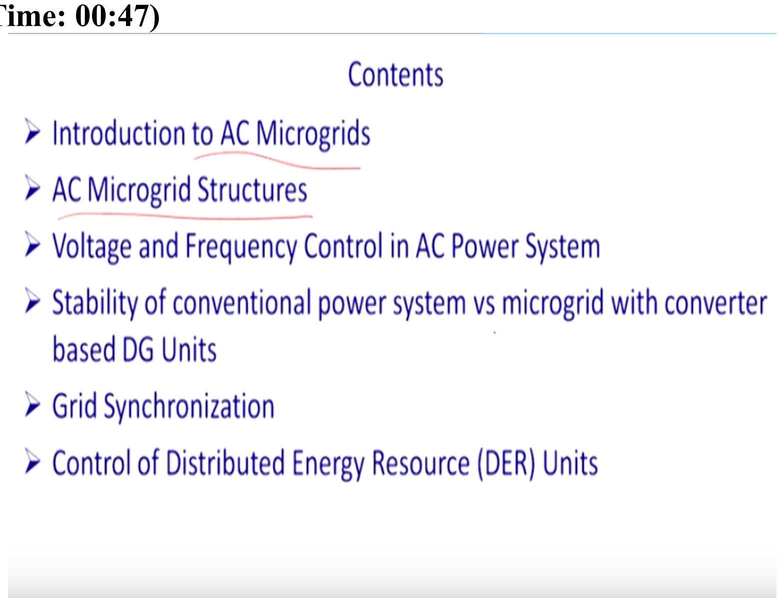

So, we shall discuss briefly about our introduction to the AC microgrid and we shall discuss the AC microgrid structures and voltage and the frequency control in AC power system, stability and conventional power system versus microgrid with converter based on the distributed generation units, grid synchronizations, control of the distributed energy and DERs.

AC microgrid we are discussing here because we require to understand, we are studying it, we shall see that what are the issues related to the AC microgrid because, we may come across as some portion of the microgrid maybe AC and we may continue to do that. So, we are not replacing totally the DC microgrid and replacing it by replacing the DC microgrid by the AC microgrid or vice versa.

Whichever is suitable for the particular area and location we shall go for that particular microgrid and for this reason, there can be a place where AC microgrid and there can be a place of the DC microgrid and they require to talk with each other as well as we can talk

about the AC and DC microgrid both it is called the hybrid microgrid.
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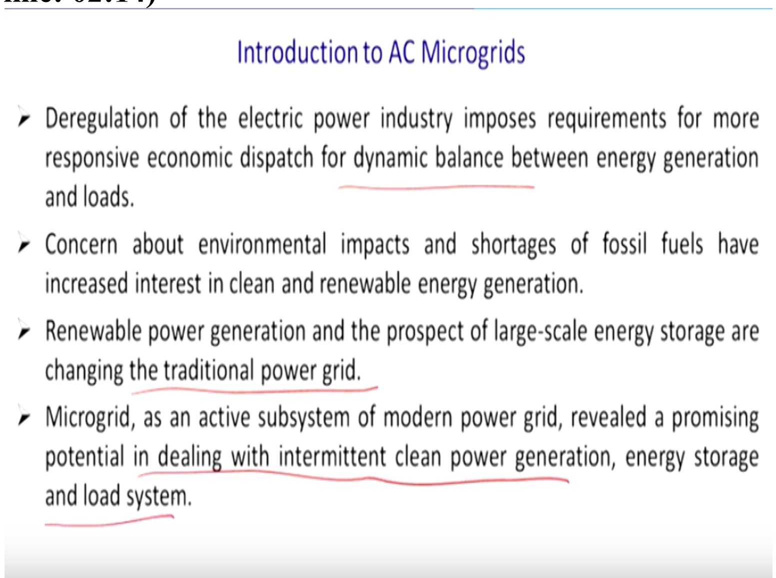

Now, why AC microgrids instead of the centrally dispatched power? Deregulation of the electric power industry imposes requirement for more responsive economic dispatch for dynamic balance between energy generation and the load. Ultimately, load is something we cannot say that it is a consumers prerogative. We have to limit our consumption based on the generation. That is our essence of the microgrid.

And thus some time you become a load and sometime you may become a generator. Concerned about environmental impacts and shortage impact and shortage of the fossil fuels have increased the interest of clean and the renewable energy generation and there microgrid fits into the picture very well.

Renewable power generation and prospect of large scale energy storage are changing the traditional power grid, where we have a problem of energy storage of the bulk power as well as there is a peak power management problem. Microgrid as an active subsystem of modern great revealed a promising potential in dealing with the intermittent clean power generation, energy storage and the load system. So far this reason gradually we are interested in the microgrids.
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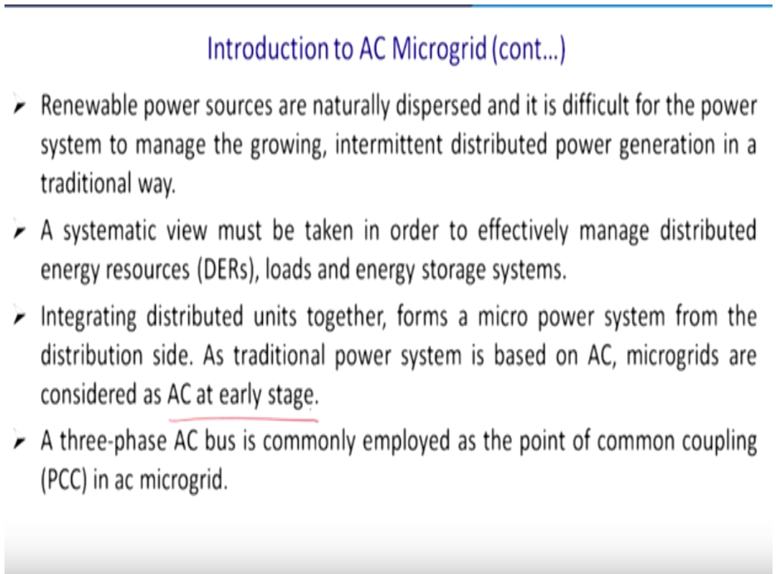

Now, renewable power sources are naturally dispersed, since solar is available everywhere and it is difficult for the power system to manage and the growing. Intermittent distributed power generation is a traditional way to look out the solution. The systematic view must be taken in order to effectively manage the distributed energy sources that comes with the not only the distributed generation also the storage element, these are called distributed resources.

This is consisting of load, energy, and the storage system. Thus every household may become or the DER that is distributed storage resources. Instead of looking at a load, you treat them as a resource. So, overall philosophy of looking at microgrid is different. Integrated distributed unit together form a micro power system from the distribution side.

Traditional power system based on AC microgrids are considered as a AC at a early stage. So those are the when we have came across from the DC transmission system with AC transmission system because of courtesy to the great scientists of Nikola Tesla. Three phase AC bus is commonly employed as the point of common coupling PCC in AC microgrid. A typical configuration of a grid interactive AC microgrid is will be illustrated in the figure 1.

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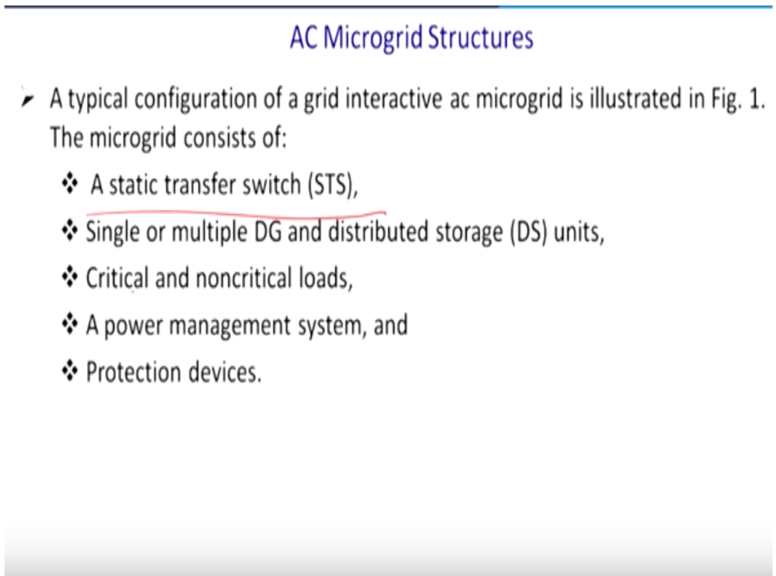

And this consisting of the static transformer switch, transfer switch, single or multiple distributed generations and distributed storage unit and critical and the non critical load, power management system and the protection devices. Critical loads are the load and require to be on always and a non critical load you can shade those loads when it for any generations any point of time when you do not have up to the marked generation then you can cut down a part of the critical load or fully critical load.

And you have a energy storage device you have to design in such a way that it can supply your critical load in case of the contingency that is if it is connected with the grid connected system, you will cut off the grid maybe for two days and it can be a non sunny day, then your battery backup can take care of the two days that is called the autonomy and that has to be designed in that way.

Thereafter power management system, you have to do your job when power is plenty. So, like in a sunny day we have to, when you have plenty of solar generation, then you may actually schedule your work in such a way like washing machine or whatever the battery charging or you can do that way. And for this reason you shall use the optimal billing cycle.

Of course, there is a it has to put some financial incentives and for this reason it has to be dynamically tariff controlled. And thereafter of course we have our protection devices. We have different kind of protection system in microgrids.

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AC Microgrid Structures

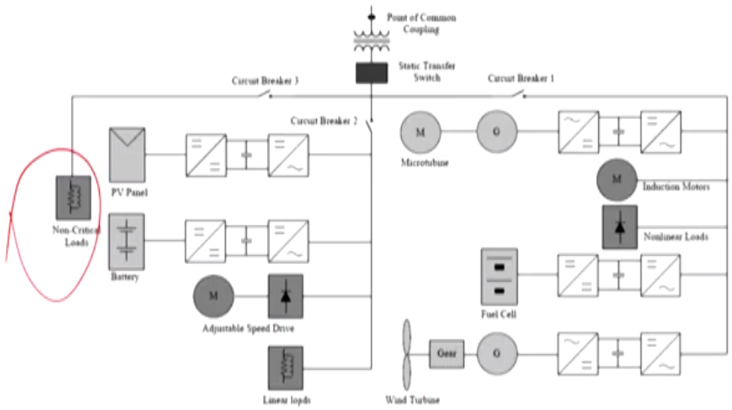

Fig.1: A Typical AC microgrid Structure.

Now, this is the structures of the AC microgrid. This is the point of common coupling. Thereafter we have a static transfer switch and from this is the circuit breaker and this is the circuit breaker 2. This is assumed to be the non critical load with a bulky purpose and this is the circuit breaker 1. Ultimately this is categorized as a generation unit. You may have a micro turbine fitted to the back by AC DC converter.

And ultimately you will give the power to this bus. You may have a induction motor directly connected to it and it can take the power and you may have nonlinear load induction machine fitted to the adjustable speed drive that becomes a nonlinear load. You may have a fuel cell. You may have a wind turbine and thereafter here also you may have solar panel.

So, from there you have a DC to DC thereafter DC to AC conversion and you fit the power to the grid. You have a storage element, that is AC to DC conversion and thereafter AC to DC conversion bidirectional. Then you may have a adjustable speed type like leaps and all those things and thus you have a, it can be a nonlinear load and you may have linear load and you may have a non critical load.

So for this reason based on that you require to design. These are the overall typical microgrid, AC microgrid structure.

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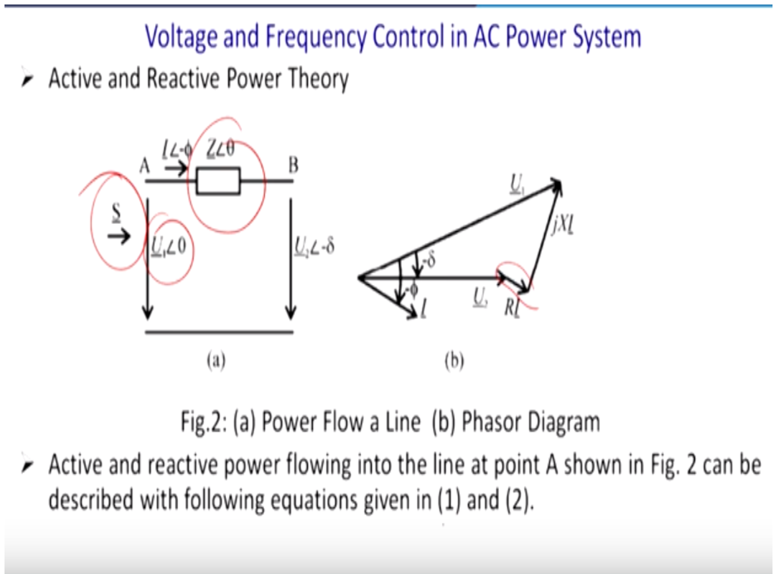

So, let us see that how voltage and frequency required to be controlled in case of the AC microgrid. So for this reason complexity is more in case of the AC microgrid. So, let us revisit and we will see that complexity then when we will discuss about the DC microgrid you will appreciate that this complexity has been diminishes So, active and reactive part theory.

So, what happen you know you send power that is S that consisting of P + JQ ultimately in the sending end your sending end voltage is zero and the receiving end voltage is minus delta and in between there is a impedance. Ultimately what will happen you got a sending in power that is U 1 and it has been delayed by this angle delta. There is a angle between voltage and is I.

And I will be actually there can be a resistive top that is RI and that is (()) (10:53). So, this is the Phasor diagram of this power flow line. And this active power flow into the line from the point as shown as A in the figure, and it can be described by the following equation given in the equation 1 and 2 in next slide.

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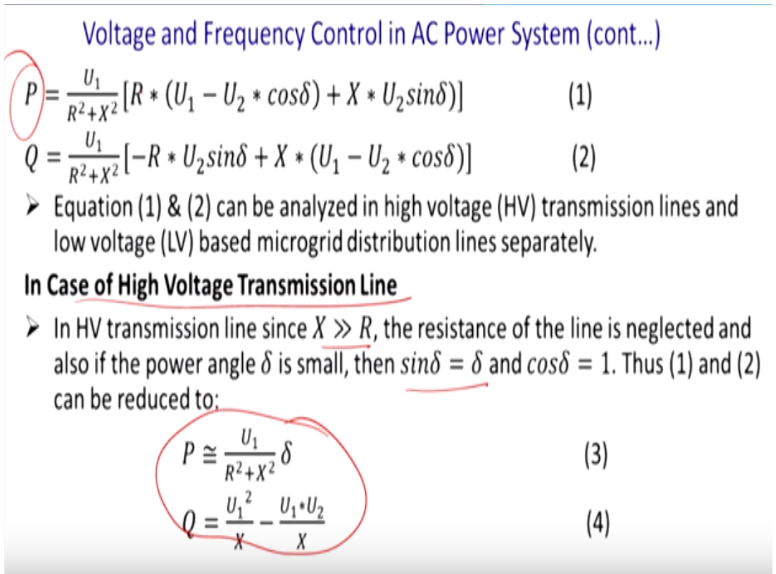

So, this is the power dispatch equation. So, this is U 1 by the R 2 into X 2. R square X square plus this is a multiplication of R into U 1 – U 2 cos delta + X. This is the regulations. Similarly, Q can be represented by U by R square X square – R into U sin delta + X U – U 2 cos delta. So, this equation 1 and 2 analyzed in a high voltage transmission line you might be aware of it and is a quite well familiar equations in power dispatch in the centralized power system same equation is taken here.

So, there will be some modification because you know you have a very short transmission line or you do not have any transmission line. So, the HV transmission line and the low voltage transmission line based on the microgrid distribution line separately. In case of high voltage line what generally happens, X is much greater than R because you have a very long transmission line and ultimately conductance is of copper.

So it does not give much value of the resistance, but it has a considerable value of the inductance. In HV transmission line X is much much greater than R the resistance of the line thus is neglected and also power angle delta is considered to be very small, and thus we can change sin delta equal to delta and cos delta equal to 1. So, thus you know this equation will be reduced here considering that R equal to zero. So, ultimately this is the power dispatch equations in case of the long transmission line.

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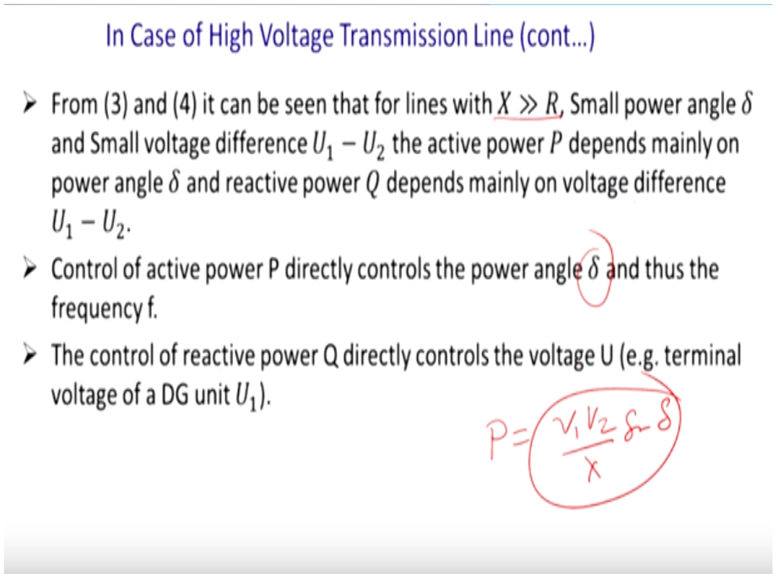

Now, from the 3 and 4 it can be seen that for the lines with X much greater than R and small angle delta small voltage difference U 1 U 2 the active power depends mainly on the power angle and reactive power depends on only the voltage difference. So, these are the thing. Again you can rewrite this equation P = V 1 or E 1 V 2 by X into sin delta is the power dispatch equation.

Considering that value of R is almost zero. The control of active power directly control the power angle delta and thus the frequency of the system. So you have to play around with the frequency. And what is another aspect? The controller reactive power Q directly control the voltage that with the terminal voltage DG of U 1.

So, you have to control the terminal voltage then only you can control the injections of the bar and you have to control the sine delta or delta. Then only you can have a control over your real power flow.

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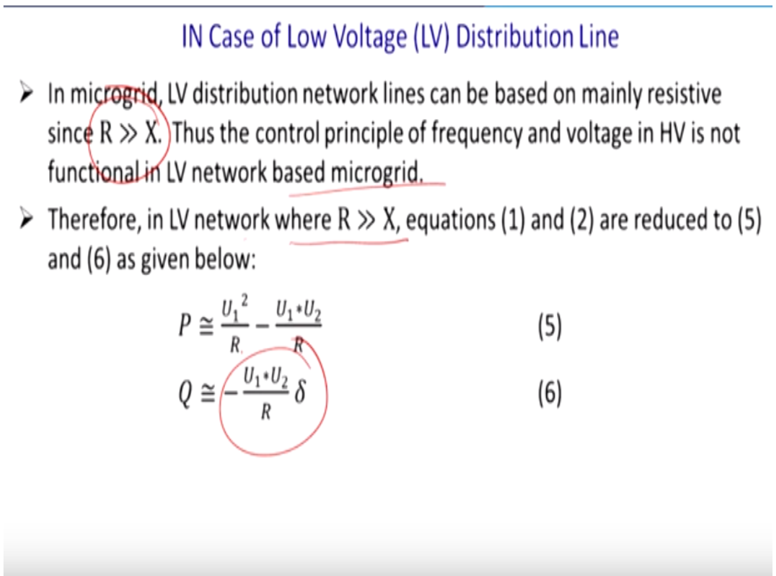

In microgrid but there is a challenge. LV distribution networks line can be based on mainly resistive load and thus all the situation will change. So what you have seen in case of the long transmission line and ultimately you may have you know X is less than R if it is not much less than R. Thus control principle of the frequency and the voltage in high voltage is not non functional in LV network based on the microgrid.

So, you have to revisit the equation 1. Ultimately we will find that suitable solution for the microgrid. Therefore, in the LV network where R is much greater than X the equation 1 and 2 is reduced to equation 4 and 5. You can revisit that equation. Ultimately it is U 1 square by R into U 1 U 2 by R and this value is again U 1 U 2 by R.

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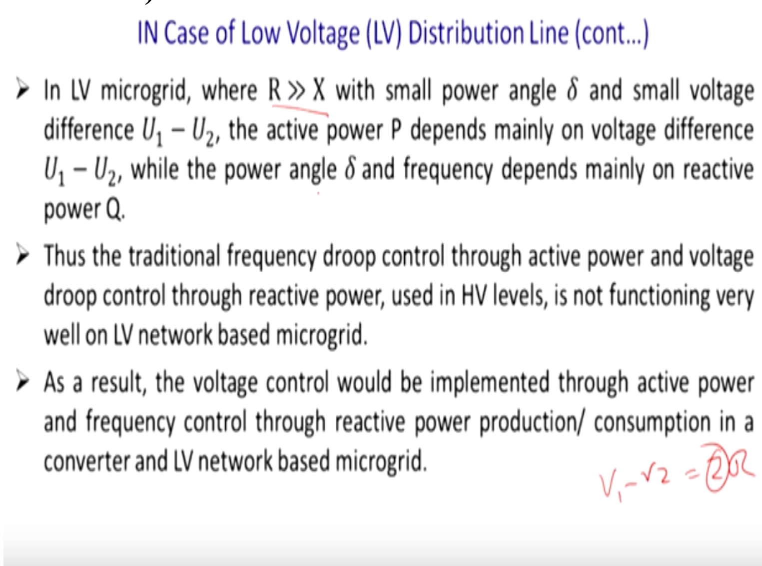

So in LV microgrid, where R is greater than X small power angle delta and small voltage difference that is the U 1 and U 2 the effective power depends only on the voltage difference U 1 and U 2. So, you have to see that basically V 1 – V 2 is basically I into R. So you can increase the I by simply increasing this actually the difference. While power angle and delta are independent while the power angle delta and the frequency depend mainly on the reactive power flow. So, this changes pattern.

We had in long transmission line mainly you control delta to control over the reactive real power and difference for the reactive power here it is different. Just difference will be for this real power and the delta will be for the reactive power. Thus the traditional frequency droop control through active power and the voltage droop control to the reactive power used in high voltage level or the long transmission line are not functioning very well in the low voltage network based on the microgrid.

So we require to have a separate strategy to control this microgrid. As a result, the voltage control could be implemented through active power and the frequency control through reactive power production or consumption in a converter in the LV network based on the microgrid.

And we may have to produce the reactive power into the system by different devices into the microgrid to take care of the reactive power because otherwise you will not be able to control the real power flow. So then see that if you do that what is what kind of problem you are going to face.

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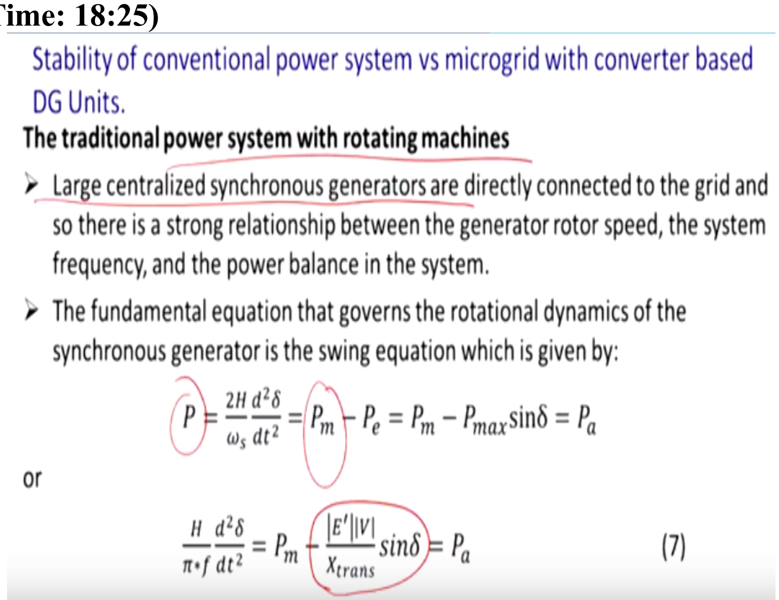

So we have to revisit again the stability of our traditional power system. Then from there we have to see that what are the changes in the microgrid. So stability of conventional power system versus microgrid converter with distribution unit. Traditional power system with the rotating machines, we have huge inertia. Thus you will find that large centralized synchronous generator are directly connected to the grid.

So there is a strong relation between generator rotor speed, the system frequency, and the power balance in the system. The fundamental equations that governs the rotational dynamics of the synchronous generator is a swing equation or the swing curve that is given by P equal to 2H by omega S. This is the actually the delta is the phase angle that is basically the difference between mechanical input minus P e and is said to be the accelerating potential.

So you can write P m = P max sin delta that is equal to P a. And thus in steady state H, H is inertia. It is actually MV megajoule you know it, you have learned it from the power system. H by 2 pi f 2 delta by d t 2 equal to P m minus this is the power transferred. That is E into V by transmissions of the network reactants of the network into delta that is the power available to you and this is accelerating power. So that is causing this actually to oscillate.

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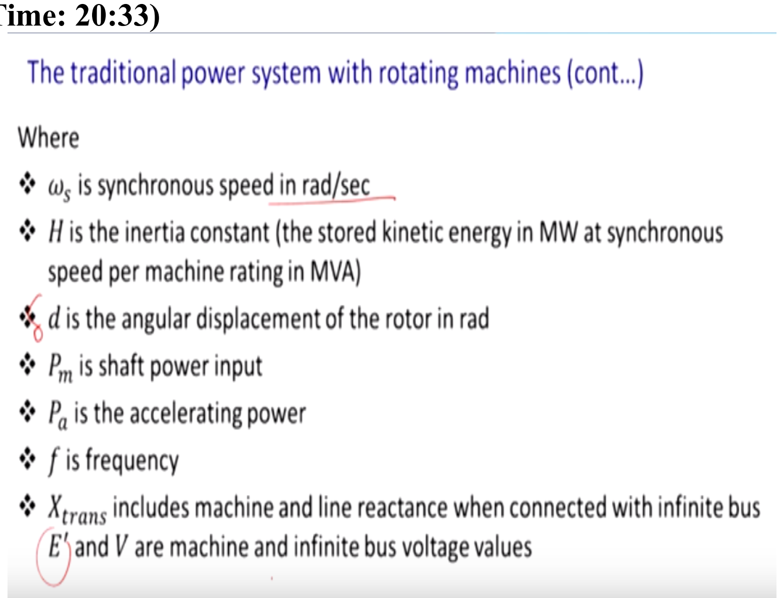

So traditional power system with the rotating machines where omega is the synchronous paid in radian per second, H is the inertia constant, is stored in the kinetic energy in MVA in a synchronous machine speed per machines rating in MVA. So, it is megajoule per MVA. D is the angular displacement of the rotor in radian or delta, we may write delta also. P m is the shaft power, mechanical input we consider generally.

P a is the accelerating power, f is the frequency. X trans include the machines and the line reactance when connected with the infinite bus where E prime and V prime are the machines and the infinite bus voltages.

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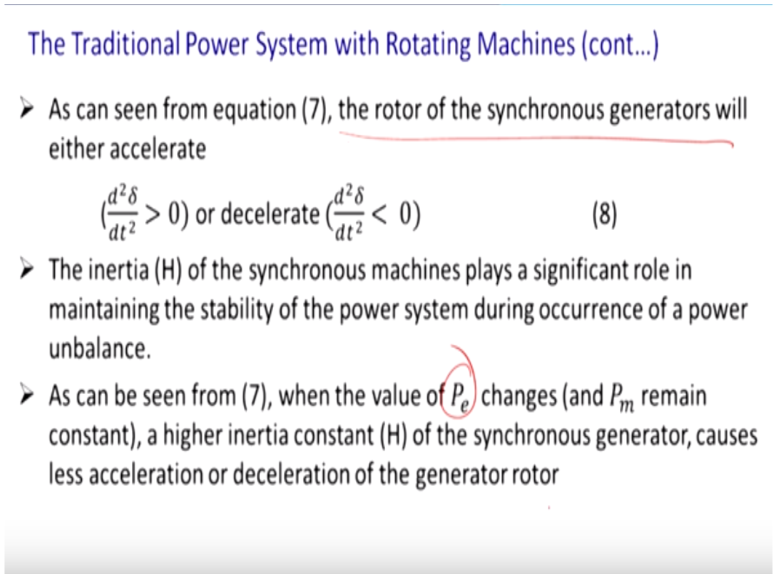

Now, we can see from the equation previous equation that is equation 7, the rotor synchronous generator either accelerate or decelerate depending on this value. If d delta dt 2 is greater than zero it will accelerate, if it is less than that the system with decelerate. The inertia of the synchronous machine plays a significant role in maintaining the stability of the power system during the occurrence of the disturbance.

Ultimately it will gradually damp out the oscillation. And it can be seen from the equation 7 when the value of P changes and let us assume that P m remains constant, the higher inertia constant H of the synchronous generator causes less acceleration of the less deceleration of the generator. It is something like you applied the same force and your mass is more definitely acceleration will be less.

So, from this discussions we can say that system frequency in a traditional power system is coupled with the rotor speed, speed of the directly grid connected large synchronous generator.

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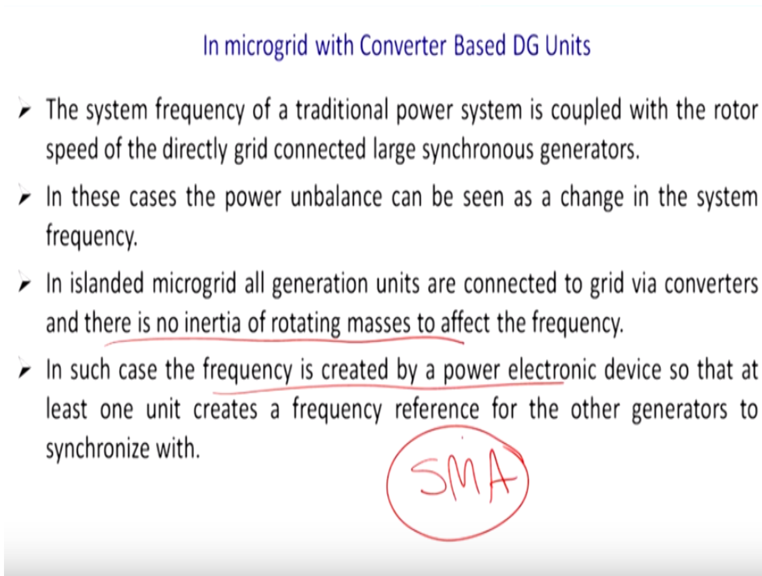

In these cases, the power unbalance can be seen as change in the system frequency. So you can map it that if there is accelerating power or decelerating power, you will note that change in frequency. In islanded microgrid all generation unit are connected to the grid via converter and there is no inertia or rotating masses to affect the frequency. So, it is a low inertia system or zero inertia system.

In such a case the frequency is created by the power electronics devices so that at least one unit that is something like pilot inverter we will say that creates the frequency reference to the other generator to synchronize with. You can refer to this SMA. There is a company called SMA and it has a off-grid inverter Sunny Boy. So, these are they synthesize their own microgrid and all the solar inverter required to be synchronized with that. That is the off-grid solution from the company like SMA.

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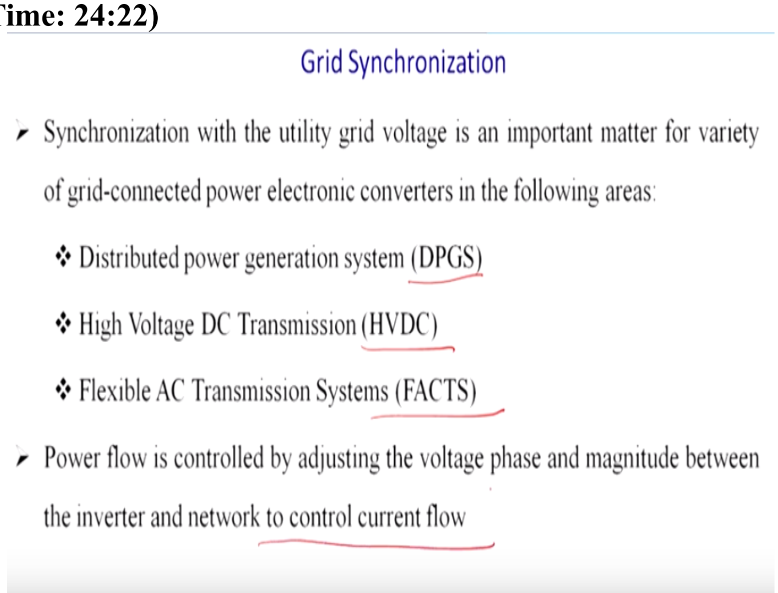

Synchronization with utility grid voltage is an important matter for variety of off-grid connected power electronics converter in the following areas. Distributed power generation system that is DPGS high voltage DC transmission that is HVDC and flexible AC transmission system that is fax. Power flow is controlled by adjusting the voltage phase and magnitude between the inverter and network to control current flow. Now, grid synchronization.

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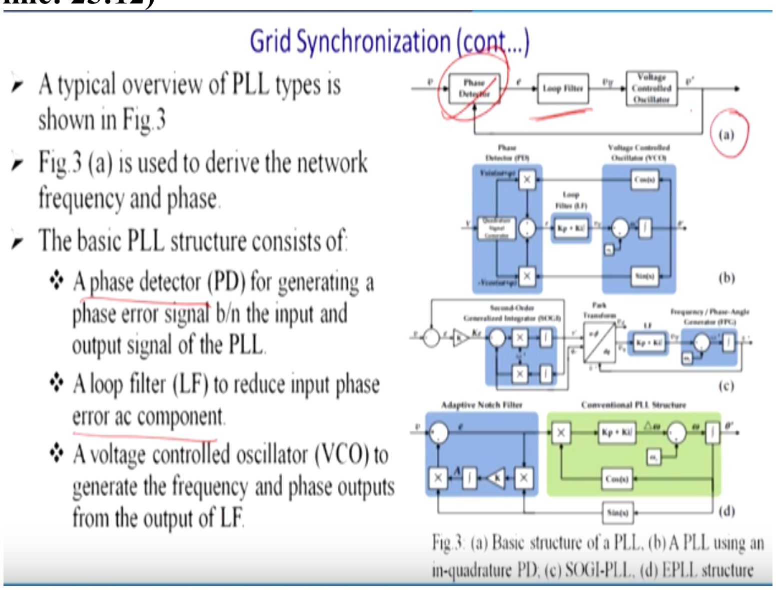

A typical overview of PLL is given, is shown in the figure 3. So, you have a voltage, you have a phase detector, you have the error and you have a loop filter. Then you have V1 f that is the voltage control oscillator. Ultimately you will find that actually that this is a stabilization loop. See that figure 3 is used to derive the network's frequency and phases. The basic PLL structure consisting of the phase detector, this one, for generating the phase error signal between the input and the output signal of the PLL.

They do filter to reduce the input phase error AC component. So for this reason you have to put the loop here. So high frequency noise will be eliminated. Voltage control oscillator VCO to generate the frequency that in phase outputs from the output LF. So, this is the description of finger a.

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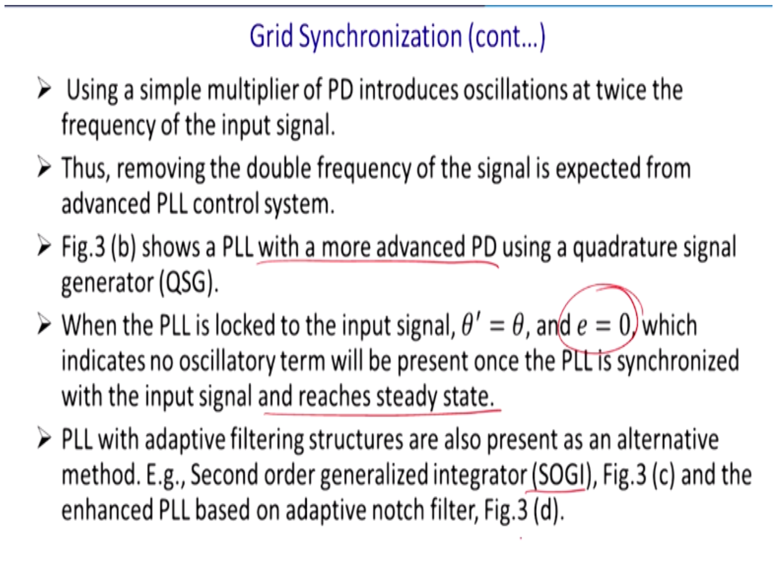

Now, using the simple multiplier of this phase detector introduces oscillation at twice the frequency of the input signal. Thus removing the double frequency of the signal is expected from the advanced PLL control. So it is sin and sin multiplied to sin 2 theta. And then the figure 3b shows that PLL with more advanced PD, phase detector using a quadrature signal generator QSG. So, let us go back.

So, this is basically the quadrature signal generation QSG. Ultimately you got sin theta and cos theta. Then you will multiply the sin theta cos theta and there is a PI controller then that will generate the loop. So, using a simple multiplier of the, using the quadrature controller QSGs when used where PLL is locked into the input signal that is theta prime equal to theta then the error will become zero.

Which indicates no oscillatory in terms of the no oscillator term in terms of once the PLL is synchronized with that input signal and it reaches the steady state. Let us try the different mode of PLL generationally then you will be able to appreciate the different methods. First method is simple, but it gives more error as in terms of the precision. Then there is an adaptive PLL.

PLL with the adaptive filter structures are also present as an alternative method. For example, the second order generalized integrated or SOGI in figure 3c and the enhance PLL best adaptive notch filter in figure 3d. So, these are different method of generating the frequency and the phases of the PLL. Students are welcome to study this because PLL is a very important concept in all the devices, in fax and other devices also.

Fax as well as the power quality and also in microgrid. So, I just wanted to have a detailed discussion little bit on the PLL here.

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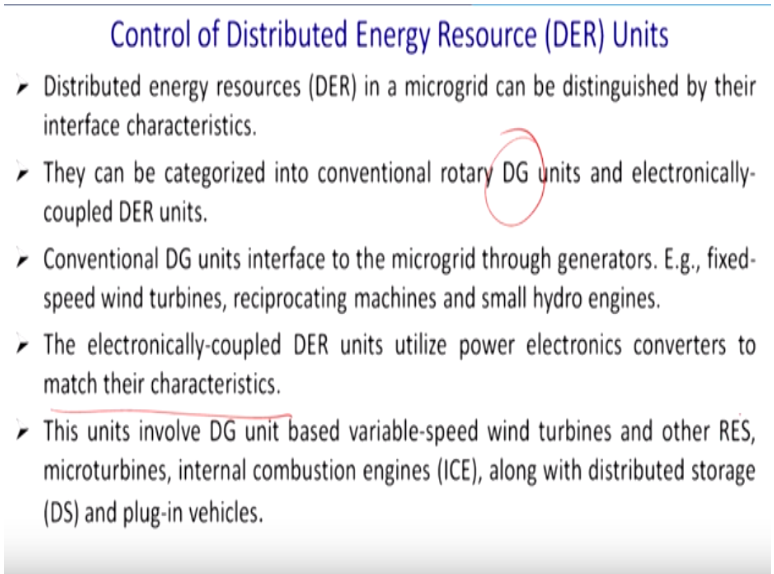

So, distributed energy resources in microgrid can distinguish their interference characteristics. They can be categorized into the conventional rotary distribution generated unit and electrically coupled that is distributed energy resources. Conventional distribution generation unit interface with the microgrid through generator fixed speed wind turbine reciprocating machines and small hydro engines.

The electronically-coupled DERs unit utilizes power electronics converter to match their characteristics. So, it is quite easy to match. Instead of inertia, you have to have a damping and other control unit to be placed. The unit involve DGs based on variable speeds wind turbines and other energy resources micro turbine internal combustion engine.

Sometime you may have a diesel generator that is basically ICE along with that distributed storage element that is will be the batteries and the plug-in electric vehicle. That may consist of the total microgrid system.

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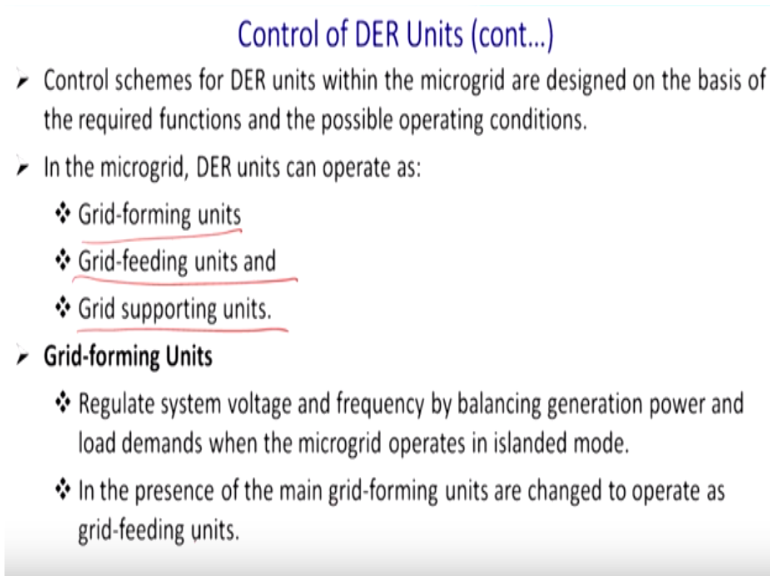

So, control schemes of DER unit within the microgrid is designed for the basis requirement and function of the possible operating conditions. That is in the microgrid DERs can operate as microgrid forming units, grid fitting units, and the grid supporting units. So, grid fitting unit is essentially the regulate system voltage and frequency by balancing generation power and load demand when microgrid operates in islanding mode.

So that mean whatever you want you can spend. In the presence of the main grid forming unit are changed and operate as a grid-feeding unit.

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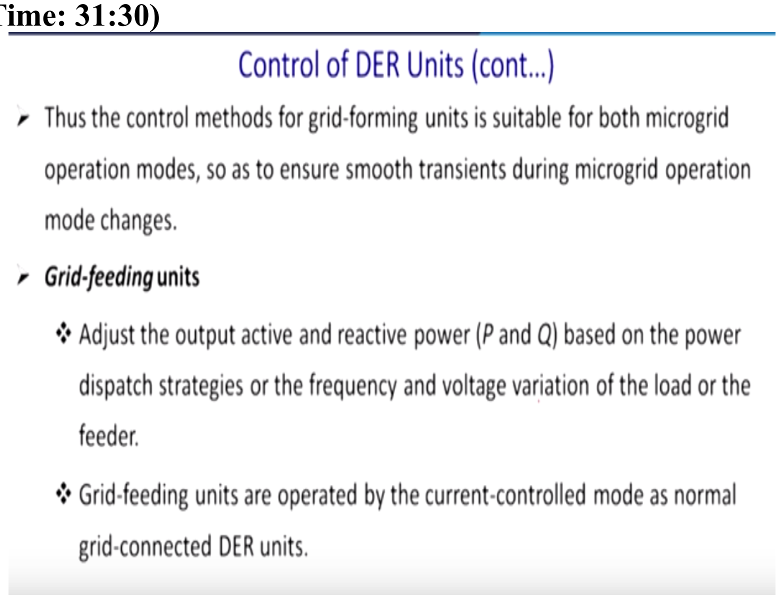

So, thus the control method of the grid-forming unit is suitable for both microgrid operation and mode so as to ensure smooth transients during microgrid operation change mode. And another mode is grid-feeding mode. Adjust the output activity reactive power based on the power dispatch strategies that we have explained in equation No. 4 and 5 to the frequency and the voltage variation in the load to the feeder.

Grid-feeding units are operated by the current control mode as normal grid-connected DER units. Thank you for your attention. We shall continue to our discussions with AC microgrid in our next classes also.