Introduction to Smart Grid
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Lecture – 39
System Analysis of AC/DC Smart Grid

Welcome you all for the NPTEL online course on Smart Grid, and today we will be talking about the analysis aspect of smart grid. Now as you see in almost during last 13 to 14 lectures, where we you know focused how to develop a smart grid, different components of smart grid and their hardware implementation and analysis ah. But if you take into a system level means you have a distribution system having few nodes few hundred of nodes and it one note the micro grid may exist means if the micro grid not necessarily to be established at each and every node of the distribution system, but certainly few zones of the distribution system.

Now the question is when we determined the line currents as well as real power flow, reactive power flow, the voltage at each and every bus then ideally we have to carry out a load flow analysis and based on which the potential it each and every node can be determined that will indirectly tell me the health of the system of state.

But when you establish smart grid or micro grid different locations of a distribution system, then the system analysis; especially when you determine the voltage at each and every node, and the algorithm need to be made more robust and which is slightly complicated compared to the classical load flow analysis.

Now the very standard load flow analysis which has been used in distribution system, let say it is forward backward swipe algorithm; where we have the any substation or the bus initial bus and then we have a load bus and in between there could be couple of buses. Now considering the system is purely redial and when we see that the load is of x kba, and the source is operating expected to operated 1 per unit for an example. And now what happens the voltage which is keep on dropping because it is radial and finally, the voltage is altogether different compare to my substation voltage.

So, if you start with 1 per unit in a radial system the last bus may experience a voltage which is close to a 0.85 or 0.88. Now the concern here how do you determine voltage because the system is altogether different, and the conventional Gauss Seidel Newton Raphson algorithms cannot be extended to distribution system being the system is of a i or by (Refer Time: 03:25) and those algorithms cannot be extended.

Means the transmission system load flow algorithms cannot be so, easily extended to distribution level of low voltages and hence we have to go for a new algorithm that is forward backward sweep as an example, where we consider that the voltage at the last node is same as my substation voltage. So, knowing the you know power requirement at that bus, assuming the voltage as 1 per unit, we can determine the current and further we can determine the voltage by adding the drop and further we can determine the voltage adding the drop and so and so. And when you reach back to your from the load point to the substation you will come to know the voltage is keep on adding 1, 1.1, 1.15 so and so.

And finally the substation voltage maybe at 1.25 or 1.3, because we had an assumption that the last bus will experience 1 per unit voltage but because my real voltage is expected to be 1 and because there is a mismatch from 1 to 1.25; the current is not acceptable to me; so what we do? We assume the voltage once again is 1 per unit at the substation. Based on the previous current we move further the voltage is known 1 per unit, the current which is being determined based on the previous step, and then you determine the voltage, voltage, voltage, voltage and you experience let us say 0.98.

And you keep on oscillating from the last node to the substation node and from the substation node to the last node and hence it is called forward backward sweep. And you keep on doing it repeat the exercise till the substation voltage is very close to 1 per unit or the difference between the voltage which has been determined after sweep must be very close to my substation voltage.

And then I can claim oh that is what the situation is all the voltages with respect to the last iteration assuming the substation voltage is 1 per unit solution will be my voltage solution of the network and these are, but now when you have a smart grid in place there are so many new devices, new converters those are not been model in my conventional load flow algorithm.

So, the cable modeling, the line modeling, the transformer modeling, the load modeling, the source modeling, are common, but the distributed generator modeling, PB modeling, storage modeling, and the converter modeling become the new components that a distribution system can experience in the presence of smart grid. So, now, the challenge is how do you simulate or analyze a system, a distribution system having smart grid, along with renewal generations, cables, converters, batteries etcetera.

And that grid could be a DC smart grid or AC smart grid or could be a combination of AC-DC smart grid. So, let us now move on to the system analysis of distribution system in the presence of smart grid. Now first of all we will just cover this portion with different steps like AC-DC distribution network, structure of AC-DC distribution network.

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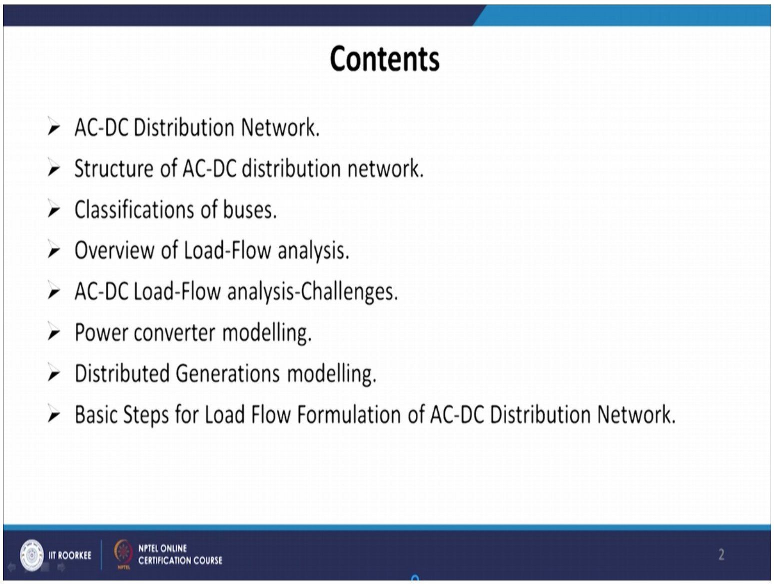

Classification of buses, overview of load flow analysis, AC-DC load flow analysis and their challenges, power converter modeling, distributed generator modeling and basic steps for formulating AC-DC load flow, because when you talk about a DC micro grid in along with the AC distribution system.

So, my system becomes AC distribution system and DC micro grid in place. So, then the scenario could be AC-DC distribution system. And we have to now have a load flow algorithm which is suitable for AC-DC system simultaneously. So, what is AC-DC distribution network? Now in the late 1883, exceptionally brilliant invaders Nikola tesla, George Westinghouse and Thomas Edison better over which electricity system whether it has to be alternating AC nature or DC in nature.

And which one has to be the standard for future, but due to numerous advantage of AC over DC; finally, AC found to be the victories one, and today we all use AC system in place.

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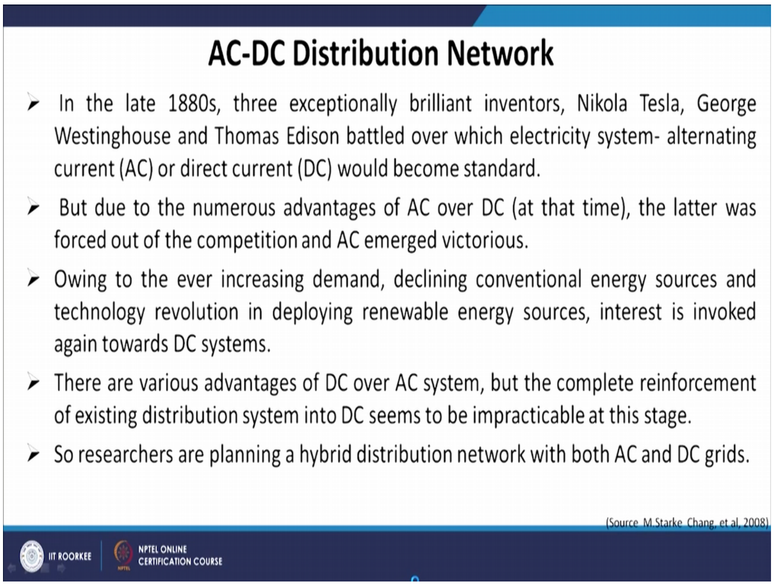

Going to the ever increasing demand declining conventional energy sources and technology revolution in deploying renewable energy sources interest is invoked towards DC grid again, though we have mention that the AC system is considered to be the victorious or the meritorious one, but looking into the current scenario of maximum renewal penetrates into the system; slowly the DC network or the DC grid taking upper hand over AC.

But being said that we cannot absolutely replace the AC system it is both they have to exist together and simultaneously. There are various advantage of DC over AC, but the complete reinforcement of the existing distribution system is next to impossible, and hence DC seems to be impracticable at this stage. So, what way to consider that the AC system is in place along with DC, a part of the distribution system could be of DC in nature, but the replacement of a AC system by DC is next impossible. So, researchers are planning a hybrid distribution network with both AC and DC grids.

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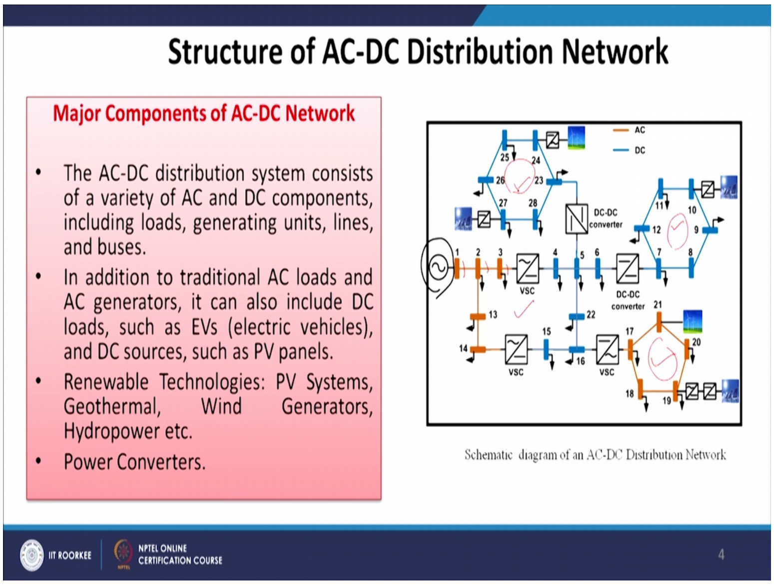

Now, if you look at the structure of a AC-DC system it may look like this. So, previously let us see the system is completely AC, where we have the source and further we have different buses. And let us see all it is radial in system; it goes this way, as well as this way and you can see few rings in between a loops. And all the buses are AC nature which was the initial stage, but now we are considering that there could be few DC micro grids in place, so most of the buses are not necessarily AC, but they could be DC.

So, all the orange color marked in this diagram are belongs to my AC bus and all the blue color represent my DC bus. So, we can see the this; these all are AC buses and this is a AC network, and we have DC buses, and DC network, and DC network. Now please try to understand when you talk about the loads those loads are not necessary to be purely AC or purely DC. And hence, loads can be connected means AC-DC loads can be connected at a DC bus; as well as at a AC bus. And because of that conversion from DC to DC DC to AC AC to AC and AC to DC is very, very common.

Now what are the major components of a AC-DC network and the AC-DC distribution system consist of variety of AC-DC component including loads, generation units, lines and buses. In addition to traditional AC loads and AC generators; it can also include DC loads and DC generators. And perhaps we can include electric vehicles PV panels etcetera, renewal technologies like PV systems, wind generators also can be considered in our system modeling.

Now power converters which is considered to be one of the very, very important part here because in our previous distribution load flow analysis; we ideally do not consider the modeling or power converters, but when you talk about smart grid certainly it has many converters and without modeling power converters your AC-DC load flow become has no meaning alright.

So, how do you classify? Because as you know in any system we ideally have actually three different types of buses, one is known as slag bus and whereas, you considered the voltage and angle at that bus is known to you and whereas, the P and Q requirement at that bus is not known to you.

So, out of all four parameters P Q V delta that is real power; reactive power, voltage at that bus and angle. Now two parameters those are V and delta are known to me where as P and Q which are not known to me is known as a slag bus. Now moving towards a AC PQ bus where the P and Q are known to me like a load where is V and delta is not known to be. And in case of a PV bus, where the P is known to me, real power output is known to me the voltage at the bus is known to me, but the Q and delta is not known to be. So, the main challenge for a load flow analysis how to determine the rest of the two parameters at each and every bus which is not known to me.

So, at the end of the day we can determine all the four variables like P Q V delta at each and every bus of the system. So, I can say the system analysis of AC system is clearer, but when you go for your DC buses now the reactive power is missing, the angle is missing. So, perhaps you have only P and V the real power and voltage because a DC system.

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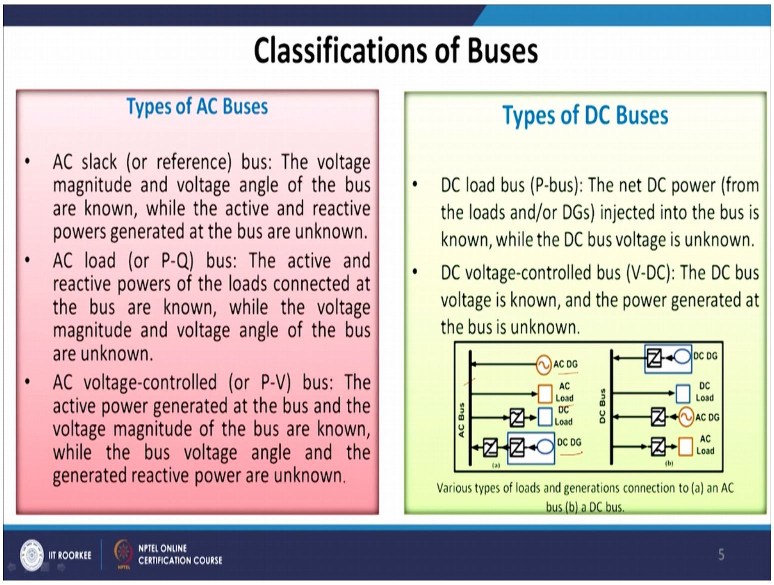

Now in DC bus we have a P bus where we we call it is a DC load bus or so called P bus where the net DC power injected into the bus is known while the voltage is not know the P is known, but the V is not known; so called DC load bus or P bus. Now we will have one more bus called as V DC bus that is DC voltage controlled bus, where the DC bus voltage is known, but the power generator generated at that bus is not known. First one is P known V is not known, the second one where V is known and P is not known.

So, we can clearly see now this is my AC bus where we can connect AC distributed generators, we can connect AC loads, we can perhaps connect DC loads and you can also connect DC distributed generators. Similarly, when you model a DC bus; I mean we can have DC distributed generators, we can have DC load, we can have AC distributed generators and you can have AC loads.

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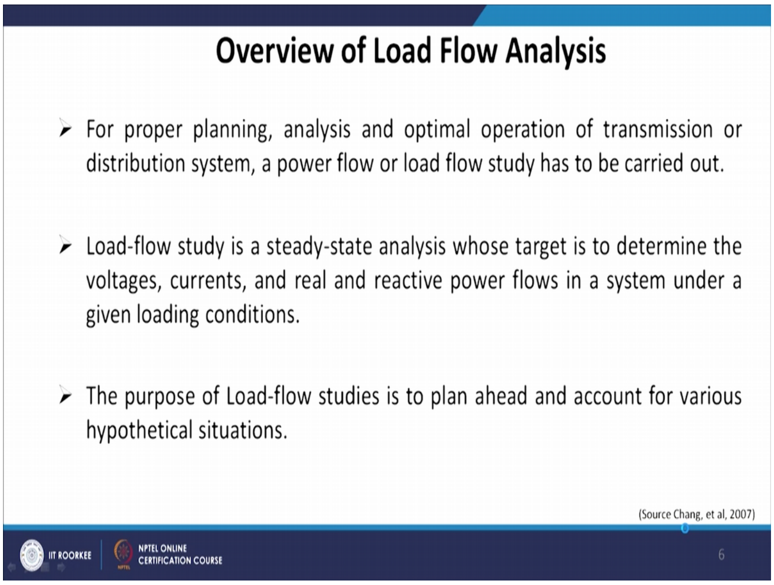

Now, very quickly the overview of load flow analysis; for proper planning analysis and optimal operation of transmission or distribution system, a power flow or load flow analysis become a must. Now load flow study is steady state analysis whose target is to determine the voltages, currents and real and reactive power flow in the system under a given loading condition.

So, if the loads unknown to me I must be in a position to determine, the voltage at each and every bus, the real power reactive power flow in each and every line need to be determined. Now the purpose of load flow studies is to plan ahead and account of various hypothetical situations, if the load scenarios are keep on changing; how do I plan my system so that the voltage at each and every node do not violate the permissible variation maybe 2 percent, 5 percent depending upon the utility.

Now there are well established algorithm for Newton's Raphson Newton Raphson load flow Gauss Seidel load flow algorithms, fast decouple and Boyden methods, but unfortunately the distribution system do have high value r by x ratio and they are weak in nature and mostly they are radial. And because of that those transmission system based algorithms cannot be simply extended as it is to my distribution system, they need to be updated and modified to suit to my current environment where the r by x ratio could be high, the system could be radial and it is weak in nature.

Now, the very important AC-DC distribution system is more complex compared to a AC distribution system; it is many elements like new generators, converters, whose input and output relations are extremely non-linear. And hence the modeling or developing algorithm for AC-DC system become a challenge. Now when you move to AC-DC load flow analysis what are the challenges? Proper modelings of various types of power converters in the load flow equations become important.

So, how do you incorporate those modeling into your system; so, to make it more generate and modeling of various types of distributed generators like PV systems wind generator etcetera. And modeling of storage and various DC loads, I mean the storage need to be model and the DC loads also need to be modeled and finally, taking care of prerequisite control objective by the converters in the load flow equations.

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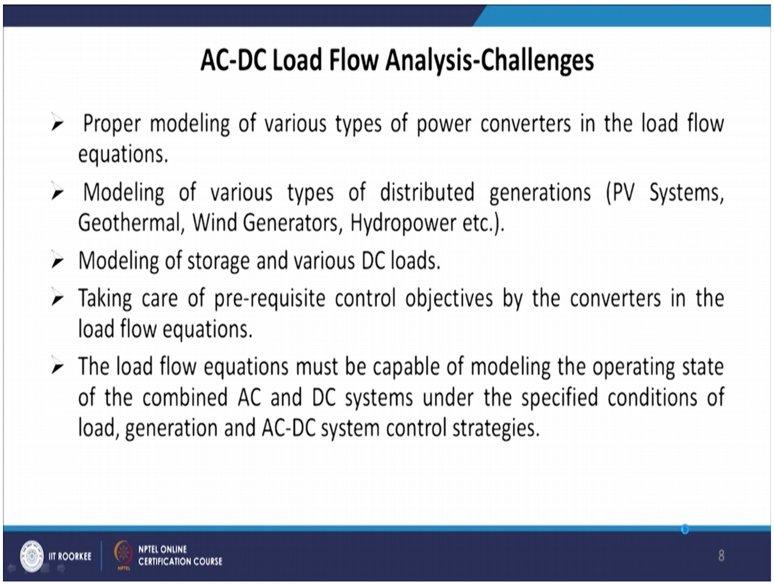

So control characteristic of those converters need to be embedded into my load flow; the load flow equations must be capable of modeling the operating state of the combined AC-DC system under the specified conditions of the load generation AC-DC system control strategies.

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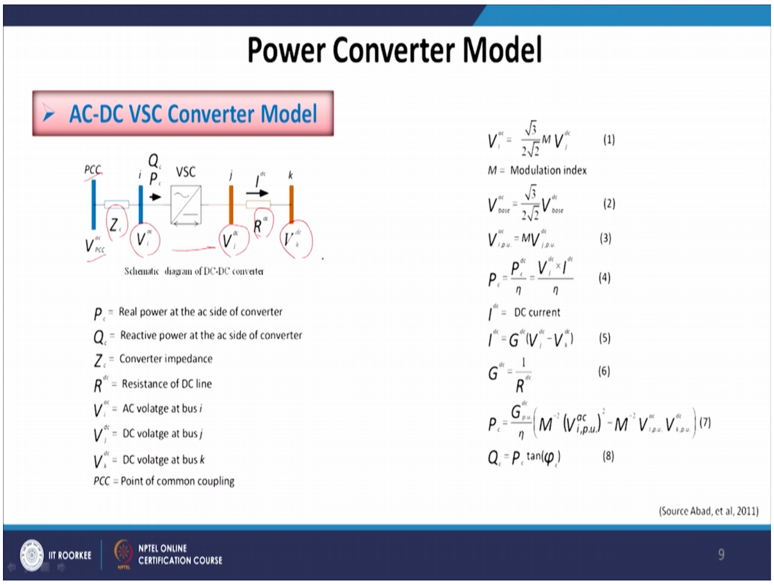

Now, there are two different important models that need to be developed; the first one is AC-DC VSC converter model where you can clearly see that is my point of common coupling, we have VP PC and the PCC, then we have the impedance and then the final output voltage in AC and then you convert to DC from AC to DC through a VSC. And finally, you experience the terminal voltage which is VDC and that could be a drop in my DC grid and finally, experience VDC.

So, what exactly happened that for the point of common coupling if the voltage is V and then different stages you know it get dropdown and then because of the line impedances and final you convert to DC. And there could be you couple of drops in the DC lines. So, DC cables and the terminal voltage could be VDC at gate bus.

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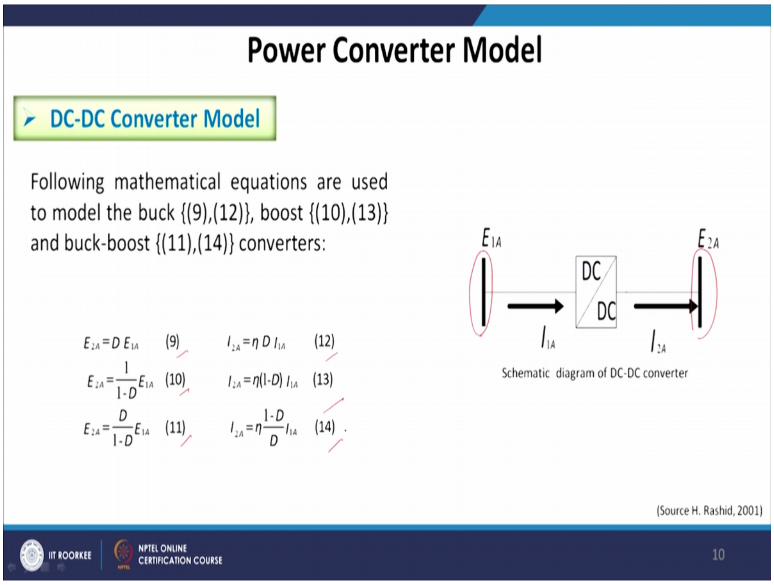

Now one more important model that is DC DC converter model where there are few equations where you see you can see that the DC-DC converter and the bus at 1 and you can experience the bus 2 with a new voltage through a DC-DC converter. And the following mathematical equations are used to model buck boost and buck boost where equation number 9 and 12 is being used for buck type 10 and 13 used for the boost type and 11 and 14 used for your buck boost converters.

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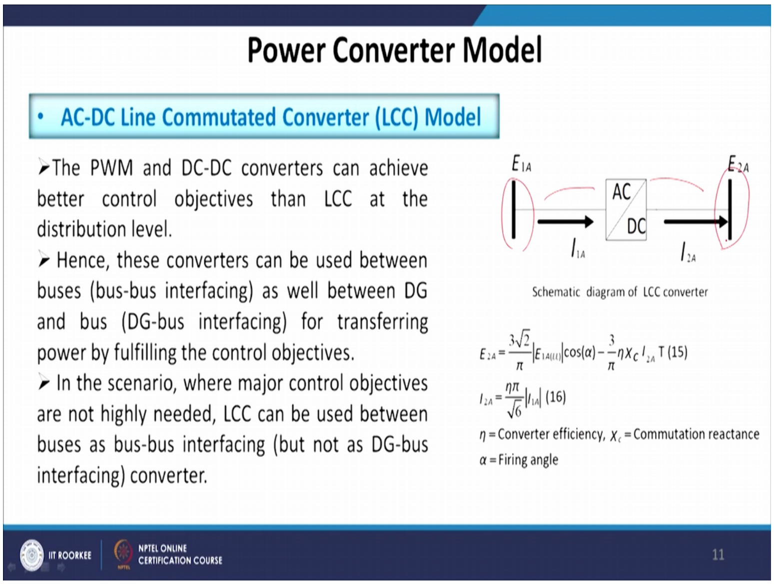

Now, there is one more important converter known as AC-DC line commutated converter that is LCC model. The PWM and DC DC converters can achieve better control objective then LCC, at the distribution level. Hence this converters can be used between the buses as well as between dg and bus for transferring power by fulfilling the control objectives.

But if you go for LCC because they are not, so precise or and in that scenario where major control objectives are not highly expected; if you are not looking for measure control objectives, then LCC can be used between buses as bus to bus interfacing, but not as a DG bus interfacing. So, if you are connecting between bus to bus please you can place LCC, but if it is between DG to bus then it has to be it is not be LCC that is what actually being recommended.

Now the pictorial diagram schematic diagram of LCC converter where you are converting from AC bus to a DC bus and from bus number 1 to bus number 2, and this is how the LCC being represented or modeled in our analysis.

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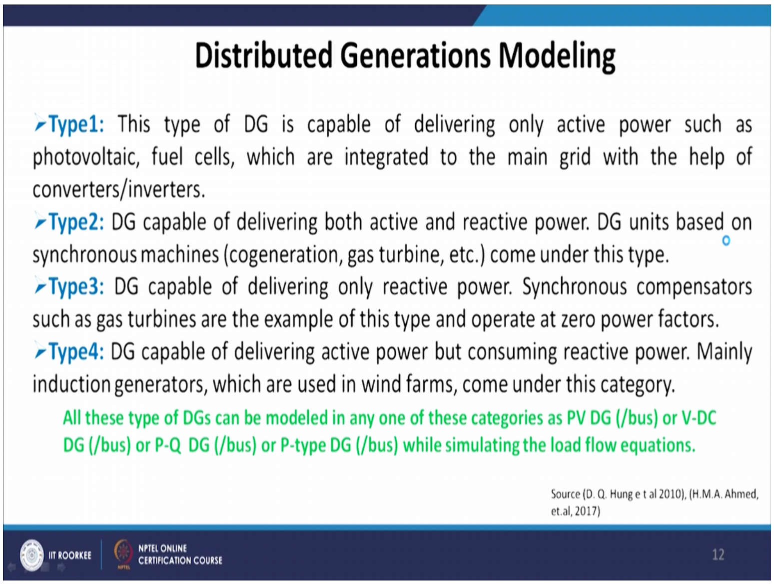

Now when you modeled the next level is distributed generator modeling; the model distributed generators based on four types there are type 1, type 2, type 3, type 4, modeling and type type 1 where this type of distributed generator is capable of delivering only active power such as photovoltaic fuel cells which are integrated to the main grid with the help of converters and inverters.

So, this kind of modeling we see only reactive real power injection which is of type 1, then we will have type 2 with the DG capable of delivering both active as well as reactive power. So, it is not simply P, but it is P as well as Q and we call it is type 2 and further we can move to type 3. DG capable of delivering only reactive power that is such a synchronous compensator such as gas turbine are the example of this type of where they operate at zero power factor. So, you only consider the reactive power injection and type 4 where you give the real power and take the reactive power out.

So, DG capable of delivering active power, but consuming reactive power is an example induction generators for the wind farms etcetera. So, to conclude all this type of distributed generators can be model in any one of these categories as PV DG or V DC DG or PQ DG or P type DG while simulating the load flow equation.

So, the what in excess we are projecting here compared to the existing literature is that the DG based on type 1, type 2, type 3, type 4, can be modeled different converters can be model and they can take care of my new components within the DC smart grid. And hence, I can simulate both AC distribution system along with DC smart grid simultaneously. Now what are the basic steps for load flow formulation of AC-DC distribution network? First one the mathematical model of both AC and DC distribution lines and cables is required.

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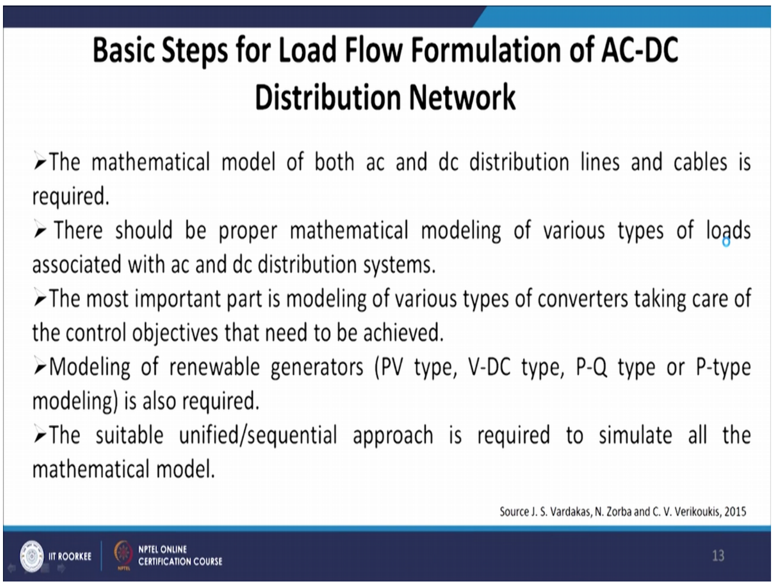

There should be proper mathematical modeling of various types of loads associated with AC and DC distribution system. The most important part is modeling of various types of converters taking care of control objective that need to be achieved, modeling of renewable generators like your PV, wind could be PV type VDC type PQ type or P type modeling is also required to represent you type 1, type 2, type 3, type 4, DGs.

And the suitable unified sequential approach is required simulate all the mathematical model and with this I like to conclude that the distribution system analysis in the presents of DC micro grid become an important issue. And we need to appropriately model those new components especially the distributed generators of type 1, type 2, type 3 type 4, along with different converters so that the voltage profile system planning for a AC-DC distribution system along with smart grid presents can be viable.

Thank you.