Electrical Distribution System Analysis
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Lecture – 24
Modeling of Distributed Generation

In the last lecture, we have seen various load models. Basically we have seen various types of models, I will just revise this now those are basically constant, real and reactive power model.

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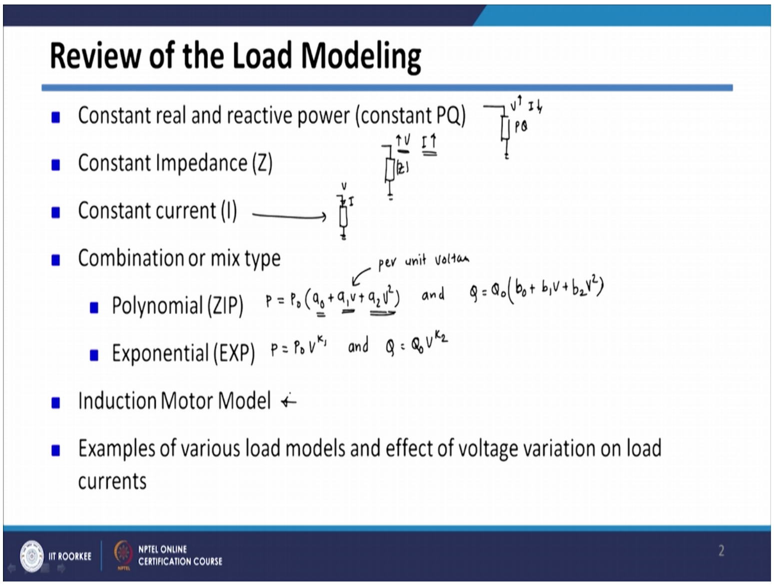

Constant impedance model, constant current models; we have seen that these models we have considered different type of this model, because they behave differently with respect to applied voltage. Means if you see this constant real and reactive power model, if the voltage across this increases, it will draw a less current to keep power constant.

So, however, in case of a constant impedance load, impedance is constant. So, whenever voltage across this constant impedance increases your. So, volt if the voltage increases your current through it is also increases in case of constant impedance model. However, in case of constant current it is independent of voltage whatever voltage across that particular device, your current through this device remain constant. So, we can see that in case of constant PQ load, if it is PQ kind of load if the voltage increases your current goes down. In case of constant impedance model when the voltage increasing, your current is also increasing and in this case it is not in case of constant current, it is independent of your applied voltage.

So, even if the voltage changes current through the load will remains same. So, that is why even though ratings of this devices maybe same, but if the voltage applied across it changes, the current drawn by this devices changes that is why we have classified this load models into three different types. And then this three different types can be combined into combination or the mixed type of load, because actual load in distribution system we will be actually mixed type.

So, it to model actual load practical load we need to consider these mixed types of load models. So, here you have considered 2 types of load model, where which is actually basically combination of all the three types of load. So, where first it is a ZIP model, where you have considered P 0 into a 0 plus a 1 V plus a V square where V is per unit value of actual voltage. And similarly we can get Q which is equal to Q 0 into b 0 plus b 1 into V plus b 2 into v square.

So, this considers combination of various loads. So, this is a 0 corresponding constant power load and a V square corresponding to your constant impedance load and this is corresponding to constant current load. Similarly in case of exponential model we have a model data like this. So, it is P 0 into V raised to k 1 here again V is per unit voltage. So, V raised to k 1 and your Q of the load will depend upon related Q 0 multiplied by V raised to another factor k 2.

Then specifically for induction motor, generally induction motor is modeled as a constant PQ load; however, if you want it more accurately we have seen detailed model of induction motor also. And then we have taken one or 2 examples which explains the effect of load models or effect of voltage variation on load currents of this load models. In today’s lecture, we are going to see modeling of distributed generation. So, before going to the modeling of distributed generation let us see what is distributed generation is.

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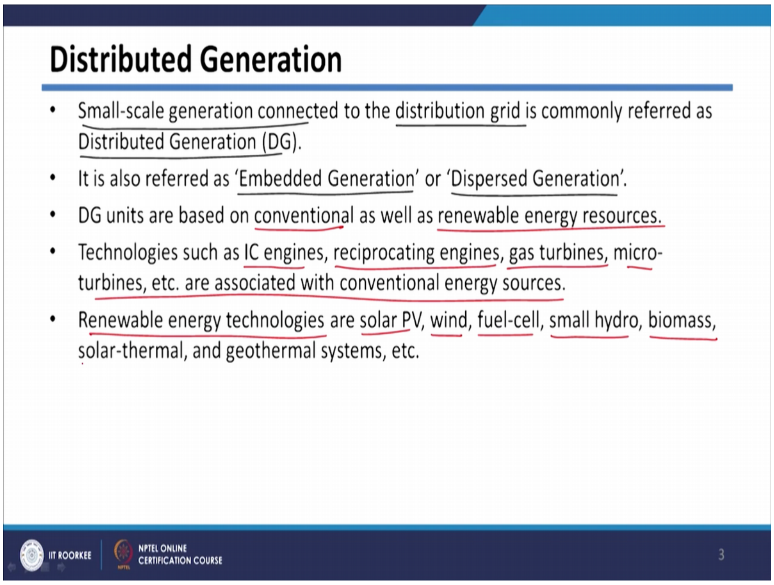

So, this is generally small scale generation connected to the distribution grid. So, generation which is connected to distribution grid, we call it as a distributed generation. Now these are basically a small generators connected over the or spread over your distribution area, and it is commonly known as distributor generation. So, small scale generation connected to distribution grid is referred as a distributed generation.

It is sometime also referred as embedded generation or dispersed generator generation also. These are basically if these DG units are based on conventional as well as renewable energy sources. So, if; so they are conventional as well as a renewable energy sources; so conventional technology based on IC engines, reciprocating engines, gas turbines, micro turbines they are associated with conventional energy sources that was consider as conventional DG. And then there are renewable DG technologies which are basically solar PV, wind fuel cells small hydro, biomass, solar thermal and geothermal etcetera are called as renewable energy technologies or DGs which are connected to renewable energy sources, we can call it as a renewable DG sources.

Now, let us see what are the benefits we are getting from DG integration? So, why we need to integrate DG in distribution system? So, first is when you are integrating DG whatever it is conventional or a non conventional renewable; you will get reduced line losses.

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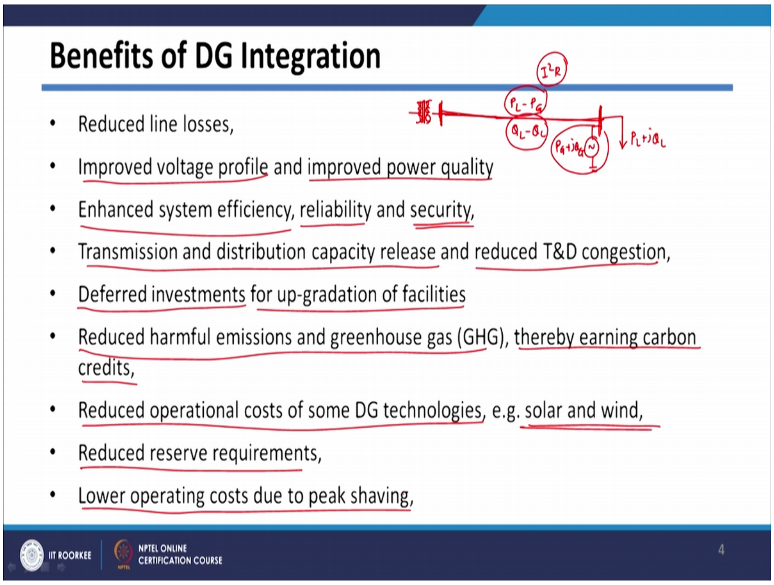

So, this is basically happening because you are connected some relative load at load end. So, here this is PL plus jQL which is load is connected at the end and if you are connecting some DG here, which is generating PG plus jQG then real power flowing from this one be PL minus PG and reactive power will be QL minus QG.

So, we can see that real power as well as a reactive power, which is flowing through the line is decreased which decreases the corresponding current and which basically decrease corresponding losses, which are basically I square losses in the line. So, line losses will get reduced also if you see since the current which is flowing through the feeder is decreasing. So, since the current is decreasing voltage drop across from here to here, the voltage drop also will decrease. So, basically volt your voltage profile over the feeder will get improved. Power quality will also get improved because of presence of DG in a distribution system.

There will be less sags and swells which will occur in your distribution system means, your power quality will get improved. Then your enhance system efficiency you can have a DG can be used to feed critical load whenever there is shutdown; which is improving your reliability of the system, similarly many degrees which are based on a renewable technologies. So, security of your energy is increasing. Also you can see that the some capacity is getting released because if you see this transformer here, which need the kV which is flowing through this transformer here is basically getting deceased.

Because some kV is actually provided locally here through this DG therefore, your transmission and distribution capacity release is happening here.

As well as the congestion which is happening in the lines as well as your network elements, it is getting released. Then since your generation itself is required low now. So, you can defer your putting large generating plants or building long transmission line. So, the some investment in transmission system and generation system can be deferred as well as up gradation of this facilities can be degrade deferred. If you are using renewable technologies, it will reduce your a carbon emission. So, your reduced carbon emission greenhouse gas reduction will happen; some carbon credits can be also earned by owners of DG as well as distribution system owners.

Then there will be reduced operational cost in some DG technologies, if you are using solar or wind DG operational cost is almost nil, therefore, operational cost will get reduced our the initial cost is very high in case of solar and wind. Then reduced reserve requirement, reserve requirements also will get reduced lower operating cost due to peak saving this also happen because during the peak period the power, you can say cost of power is higher. And if your DG is supplying during those periods, your decreasing your operating cost during that period. So, we are actually getting some savings here.

Now, let us see various DGs and their generate n technologies which are used. So, here first DG I am considering say fuel cell. So, fuel cell we know that a chemical energy stored in fuel cell, will be converted into electricity and this electricity will be in a DC from and because of that we need some kind of static power converter to convert into AC and then it can be connected to your power system.

Similarly solar (Refer Time: 10:28) I will take. So, it will be converting solar energy to electricity and in this case also the energy, which is generator will be generated will be DC and we need to convert into AC.

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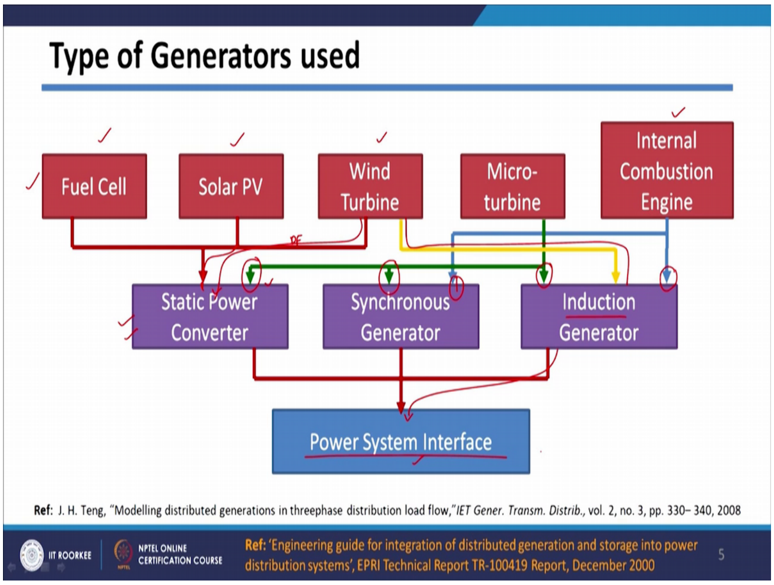

So, we need some kind of power electronic converter here to convert it into AC which can be connected to power grid or distribution grid. In case of wind turbine there are 2 types is one is variable speed and one is constant speed. So, in case of variable ts speed DGs we use basically a DFIG with some kind of power tonic interface.

So, here if you are using DFIG, then we need power electronic interface to connect to grid and if you are using DGs which is having fixed speed in that case we can use induction generator, and that can be directly connected to your grid. So, here the speed of this is controlled by gear boxes which are provided along the short of your wind turbine. And then you are having this micro turbine ah. So, in case of a micro turbine is similar to your gas turbine, only thing is speed of operation is higher in case of micro turbine.

So, therefore, many times it is with micro turbine we use power electronic interface or maybe sometimes you can use your permanent magnet synchronous generator or induction generator also. So, most of the time it is through power electronic convertor; and then in case of internal combustion engine, it can be connected to synchronous generator or it can be connected to induction generator, mostly it is connected to synchronous generator and then it will be connected to it will be directly connected to your a power grid.

So, these are the various technologies and type of generators, which are used for various sources of energy, which are been converted into maybe DC to AC and some generators of directly interfaced with your power system.

Now, let us see how we can model these synchronous generators before going to actually modeling the synchronous generator let us see, how what are the general types of these nodes means buses in distribution system how we can model them. We have seen in case of transmission load flow generally we divided them in slag bus PV plus and PQ bus.

In this case also the buses can be modeled as PQ node ah.

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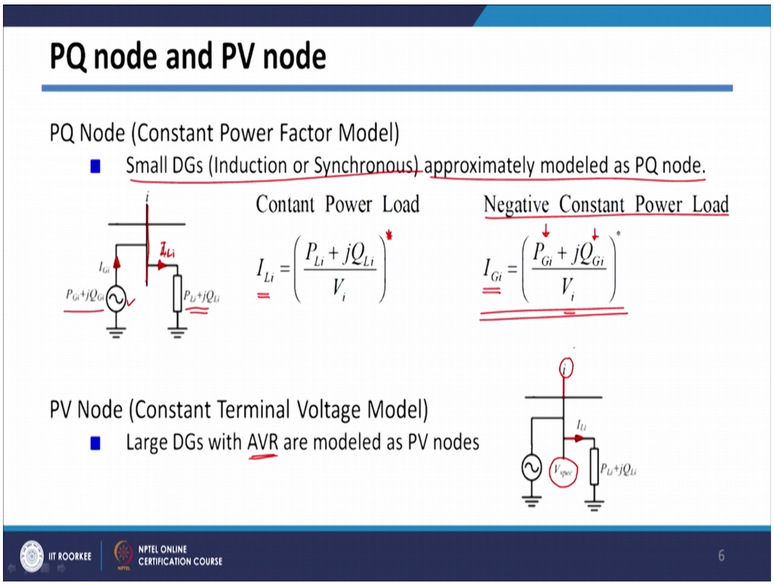

Generally in case of small DGs maybe it is synchronous or induction generator it is approximately modeled as PQ node. So, in case of PQ node, we model them as a negative loads. So, if you see this diagram here this DG is connected at I th bus the load at this I th bus is say QLi PLi plus jQL qLi and generation at this bus is PGi plus j QGi the current which is generated by DG is fed through the fed to the grid and the current taken by the load is shown by iLis.

So, we have seen that during the constant power load model, the current through the load is calculated like this. So, it will be PLi plus lQLi divided by V i and its star here. So, this actually you we know that this is the current in case of constant power load; exactly similar way we can model this a small DGs with which is having PQ, which we which is considered as PQ node as negative constant power load. So, in this case also injected current by this DG will be calculated like this it will be PGi plus zQGi divided by Pi. So, the PG is real power generated by DG reactive power generated by DG voltage at I th bus will give the current; however, the current direction is opposite in this case current is going towards the bus IGi.

And in this case in case of load, current will be coming out of that bus ah. So, accordingly you need to consider the plus sign or minus sign in case of load and generator model. So, PGi the current injected can be easily calculated using this in case of PQ model. And as I told you many times generators are small either it is induction or synchronous, and most of the time during the load flow studies, this small generators are a modeled as a PQ node and the currents will be calculated like this.

However in case of large DGs with automatic voltage regulator, AVR is a automatic voltage regulator can be modeled as PV nodes. So, in this case your terminal voltage is remaining constant. So, this DG is connected to this bus here the same load is there; however, because of this DG the voltage of this bus is getting fixed with voltage specified. So, during the iteration we need to fix the voltage of this bus to the specified. And then we will see if there are this 2 types of DG models how we can consider this case during the load flow studies.

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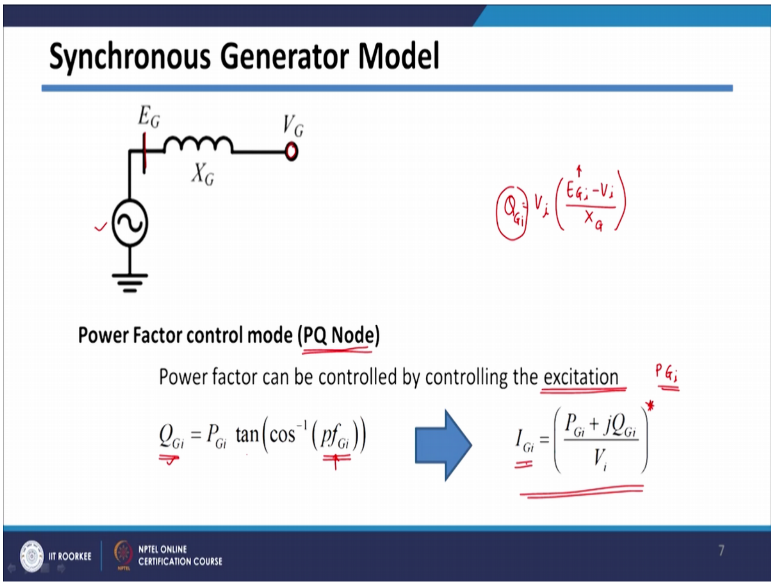

We start with first synchronous generator; synchronous generator can be modeled as simple like this you are having generator, this is generated voltage beyond the synchronous beyond before the synchronous reactance and this is nothing, but your terminal voltage. And this synchronous generators can be run into three types of modes; one is called as a power factor control mode, where the power factor of this DG will be controlled to some value some constant value may be.

So, we can control this power factor at of this generator by controlling the excitation. So, by controlling the excitation of this, we can control the power factor because the excitation, we will change your reactive power fed by this generator. So, we know that Q is actually equal to V i divide multiplied by EGi minus V i divided by your XG. So, QGi. So, here by changing your excitation Ei EGi can be changed which will basically change your reactive power of generator and which will change your power factors.

So, if you keeping see power factor constant you are controlling the power factor, then you can easily calculate your reactive power generated by the generator by just by taking this equation here. It will be so, if this is your power factor then cos inverse of it and tan of it will give multiplied by PGi will give me reactive power generated by this generator. So, PGi multiplied by tan of cos inverse of power factor. So, once you know this PGi and QGi. So, PGi specified and QGi we are calculated from the power factor. So, that is case you can consider it as a PQ node, and PGi and QGi will be just injected power of this particular bus.

Therefore injected current to that bus can be easily calculated from the equation which you are discussed earlier, that is apparent power divided by your voltages at the bus and you need to take star of this to calculate the injected current. So, here we can get the injected current in case of power factor control mode. Another mode these generator can be operated generally in case of large synchronous generator; this can be done easily. So, in case of large generator, this can be operated in voltage control mode.

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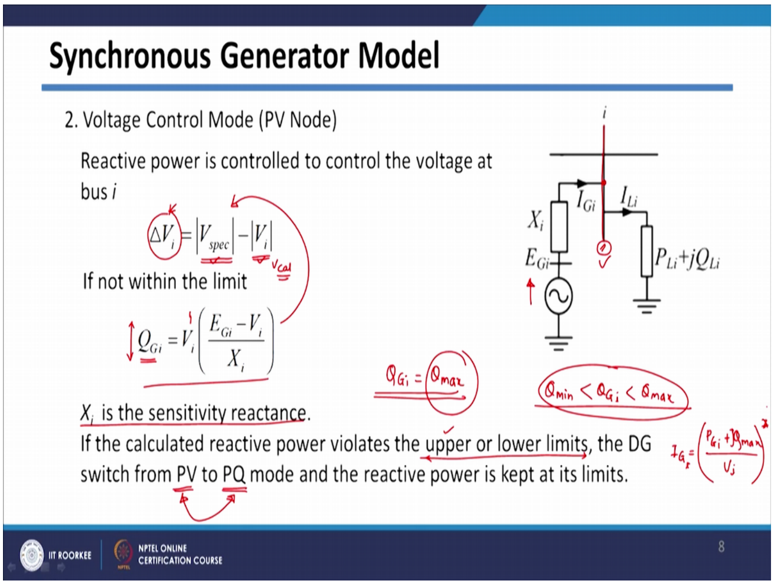

Means we can actually control the voltage of this particular bus to specified a value and this specified value.

So, during the iteration of say during the load flow iteration, you can have this specified value and this is nothing, but your calculated value. So, this is your calculated at any iteration. Now if this specified and calculated, there is large difference between specified and this one voltage specified and voltage of the particular bus if there is a large difference, then you need to change the reactive power generated by this generator by changing the reactive power voltage of this terminal will be changed, and which will be then brought up to the specified layout limit which will actually decrease delta Vi.

So, if this delta V i comes within specified tolerance limit, we can go ahead with that particular iteration. If it is not in within limit we can again change your reactive power injected by this generator till we get the this voltage at this bus in specified limit ah. So, here we can see that this QGi is given by this expression, where this X i is called as sensitivity reactance.

Now, we can afraid this we can increase or decrease this QGi till your upper and lower reactive power limit of this DG. If you are violating this limit or if you are going beyond a upper limit you cannot control if this QGi go beyond your upper limit we can have control your voltage. So, in that case your Q will be fixed. So, QGi will be fixed to Q max of that generator, and then it will go to the PQ mode. So, till QGi is within the Q min QGi and Q max within this limit if this you operating, we can control this voltage here if this limit is getting violated means if the reactive power is going beyond this limit, we cannot increase reactive power more. So, in that case your P bus will be converted into PQ bus, and then it will be actually then current will be calculated based on your Q max.

So, in that case your IG current will be PGi plus j JQ max divided by V i and its star. Now third mode of operation is called as constant excitation mode. So, here the excitation is constant which is keeping this EGi constant.

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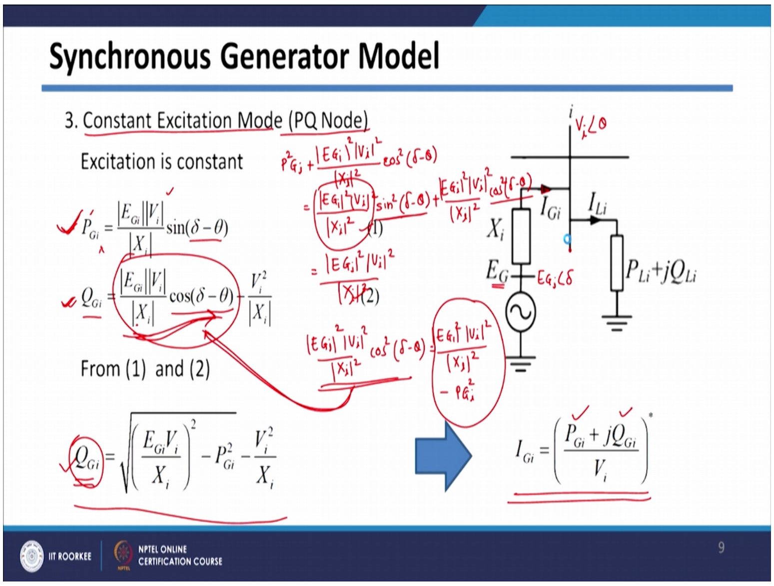

So, whenever the voltage at this bus is changing your reactive power generated by this generator will change. So, since excitation is constant you can keep this EG constant here and whenever this is change in their terminal voltage, there will be change in the reactive power supplied with generator

So, this 2 rearrange reactive power supplied by this generator, will be given by this 2 equations. So, PGi real power given by these generator will be EGi. So, this is your EGi and its angle is delta and this voltage is V i and its angle is theta. So, it will be EGi multiplied by V i divided by X i into sin delta minus theta, and then your QGi will be EGi multiply by V i divided by X i into cos of delta minus theta minus v V i square divided by Xi. So, this will give me real power real power and the reactive power supplied by this generator.

We can just this is equation number 1 and 2 we can just simplify it to get this equation. So, what we have doing it here ah. So, in this case we can just say PGi plus EGi into Vi. So, I am just squaring it. So, I am just adding this term here into cos square delta minus theta, which will be equal to. So, here on this side I am just squared it. So, this will be this will get squared. So, it will be EGi square into V i square divided by X i square into sin square delta minus theta.

And this since I am adding one term on left hand side same term need to be added on write hand side also. So, that is EGi square into V i square divided by X i square into cos of delta minus theta cos square delta minus theta. So, here cos square delta minus theta and sorry sin square delta minus theta and cos square delta minus theta, we can take this term common out and sin square theta delta minus theta and cos square delta minus theta it will become1.

So, it will be basically EGi square into V i square divided by X i square into 1 and on this side it is actually PGi square plus this particular term here. So, I can easily say this will be equal to. So, this particular term will be equal to that is EGi; from this I can easily write EGi square into V i square divided by X i square cos square delta minus theta will be equal to EGi square, V i square divided by X i square minus PGi square.

So, instead of this cos I can put root of this particular cos delta theta term of instead of this term I can put this term here into this expression. So, finally, your expression for QGi will be like this. So, PGi we can get it here QGi we can get it here. So, in this case also whenever there is constant excitation mode, it can be considered as PQ node and in that PQ node your current delivered or injected by DG will be PGi which where we got in be getting from this equation and QGi which we are getting from this equation divided by a voltage at this particular bus.

So, this I have synchronous generator with constant excitation mode is modeled. So, we have seen three modes for synchronous generators, that is in case of constant power factor or power factor control mode, and then we have seen voltage control mode that is PV node and then we have seen constant excitation mode that is third mode.

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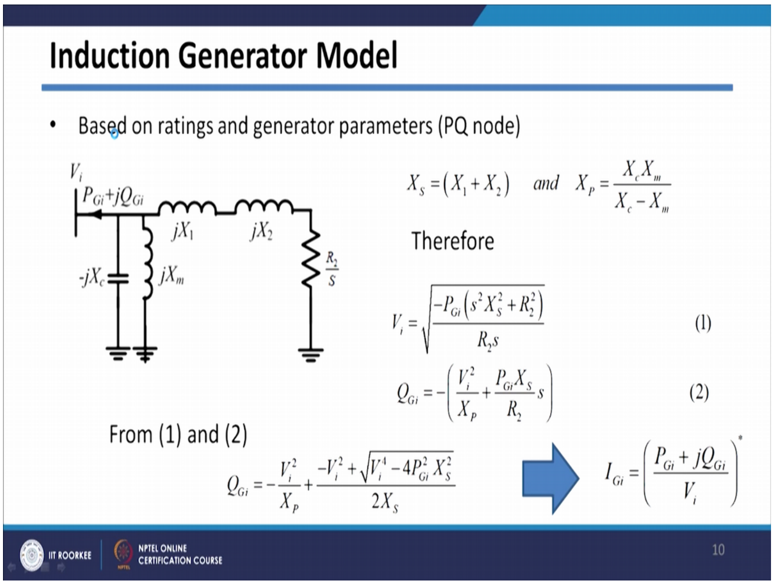

Now, let us see how induction generators will be modeled. So, first case we are considering; if it is modeled based on ratings of the generator as well as if the generator parameters if they are available, they can how they can be modeled. So, generally they are modeled induction generator are generators are modeled as PQ node. So, here is the simplified model of induction generator this is stator reactance stator leakage reactance, this is rotor leakage reactance this is excitation reactance and this is nothing, but your reactance of capacitor bank, which is connected to supplied reactive power to this induction generators.

So, this is capacitor bank reactance and this is nothing, but your rotor resistance which is depend on your slip value. And this PG and QG are actually real power and reactive power which is generated by this generally the reactive power is negative in this case of induction generator. So, this induction generator will basically absorbs the reactive power from the grid and capacitor bank which is provided at the terminal. So, in this case we can just simplify it your these 2 reactance X 1 plus X 2 I can say Xs.

So, these are series reactances. So, this is totally Xs and this reactance which are in parallel, I can take the parallel combination of this I can then call Xp. So, these 2 reactances which are in parallel Xp will be equal to Xc multiplied by Xn divided by xc minus Xm here. So, this is total reactance of this parallel combination which is here and series. Then what we can do we can write the equation that is PGi plus j QGi will be nothing, but v square divided by jw circuit and then the calculating equivalent impedance of whole of this circuit seen at this particular terminal we can get this equation.

And if you simplify this equation I can write the in terms of terminal as well as in terms of reactive power. So, we can get the. So, solving this circuit in terms of voltage and reactive power we can get this 2 equations here and from 1 and 2 we can get the equation for reactive power for this particular case. So, this is nothing, but your reactive power equation for the of the induction generator, if the parameters of the induction generator they are known is. If you know the X 1 X 2 Xn and r 2 parameter as well as the ratings of your generator you can actually get this one.

So, we can see that reactive power absorbed by this induction generator depends upon your terminal voltages and the basically real power delivered by the generator. And once you know the PGi and QGi we can get the current I considering it as a PQ node and we can calculate current delivered by this or you can say injected current by this induction generator, which is given by this equation.

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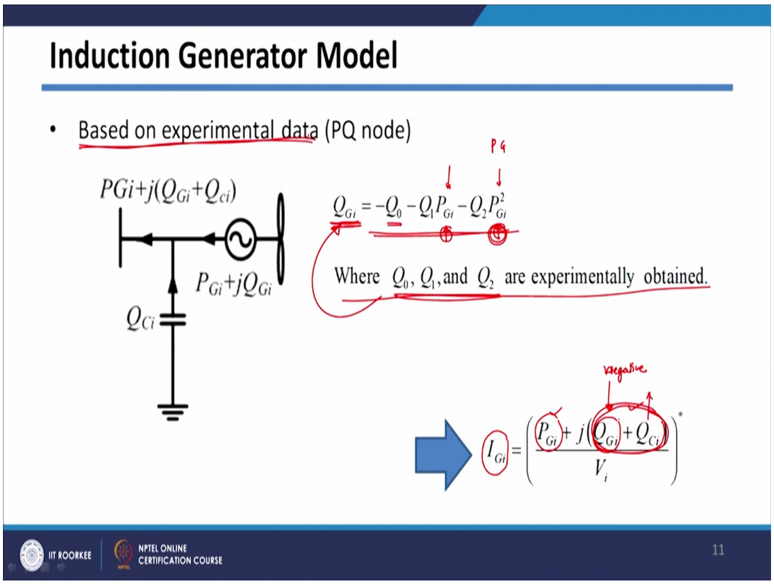

Another method of modeling induction generator is basically experimental based. So, many times the data is not available. So, we can modeled by model through experimental data. Experimental data is will be modified like this means it is getting from the reactive power is basically depend on the real power and as well as real power square, and there will be a some relation between this real power which is having some part, which is proportional to square of it some part, which is proportional to this one and some part of this reactive power which is constant.

So, this function can be modeled as minus Q 0. So, reactive power absorbed by this induction generator can be modeled as minus Q 0 minus Q1 into PGi which is proportional to real power generated as a terminal, minus Q 2 into PGi square which is basically real power square generated at the terminal. And this values of Q 0 Q 1 and Q 2 can be calculated from the experimental data means for different real power delivery we can get the reactive power values also and by after plotting this real values of power and reactive power we can get values of Q 0 Q 1 and Q 2 experimentally.

So, once you get this values of Q 1 Q 2 and Q 3 sorry Q 0 Q 1 and Q 2 experimentally you can get the values of QGi for different values of PGi. And once you get PGi and QGi values this is basically total reactive power which is coming from the grid will be nothing, but real power which reactive power which is supplied by a capacitor and this will be basically negative reactive power which is absorbed by this generator. So, this value will be basically negative, and then once you get PGi and QGi you can get the current which is supplied by induction generator, which is basically injected current which is required for load flow calculations.

So, this how we can model induction generators. So, 2 ways of modeling of induction generators we have seen, that is based on ratings of the equipment of generator and based on the experimental data of the generator.

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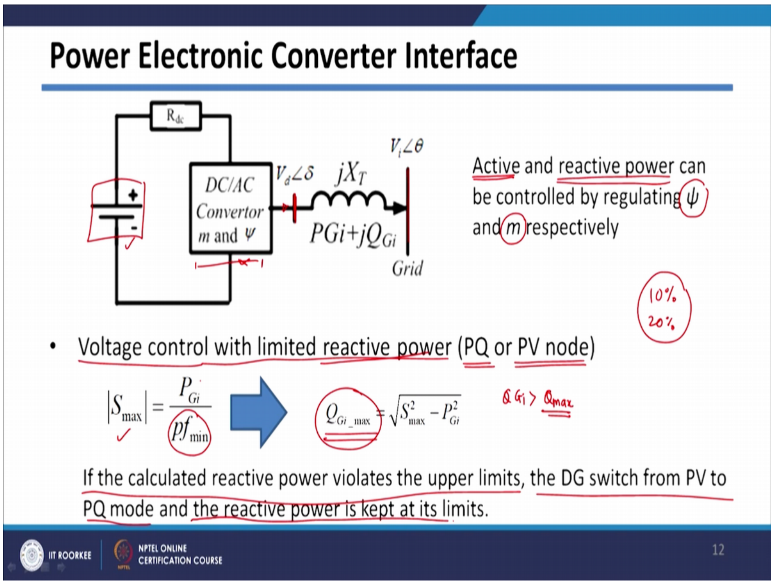

Now, let us see how we can model if some sources which are interfaced with power electronic based converters. So, here basically in case of fuel cell or in case of solar protocol type or in case of battery which can be represented here. So, this is DC source which is may be renewal solars like solar PV or fuel cell and it will be then there will be DC to AC converter, and this will be the voltage at this bus will be AC voltage.

And then this is actually voltage at the grid bus and which will be connected through this reactant here. Now this converter there will be there are many control strategies which are available to control this converter, and most widely adopted strategy will be control the active power and reactive power separately. So, generally they were active power will be controlled by phi that is nothing, but firing angle of these converters and their reactive power will basically convert controlled by m which is modulation inducts of this converter.

So, reactive power can be used to control the voltage. So, limited voltage control capability available because these inverters generally have limited reactive power capability may be 10 percent or 20 percent of real power capability. So, therefore, limited voltage control capabilities available. So, this till limited till that time within the limit if the reactive power is within the limit, you can modulate as a PV node and if this limit is getting violated means if this Q max with QGi is more than Q max then it will shift to your PQ node.

So, that limit is actually this QG m max can be calculated like this. So, this actually will be some minimum power factor depend upon reactive power capability of this generator. So, it will be PGi divided by minimum power factor, which will give me which will give me maximum apparent power that can be fed magnitude of apparent power and from this I can get the maximum Q, which can be supplied by this source.

As I told you, if the calculated reactive power violates the upper limit the DGs which from PV to PQ mode; so earlier till reactive power limit is within the required limit you can consider as a PV node that when this limit is getting violated you can shift to the PQ node.

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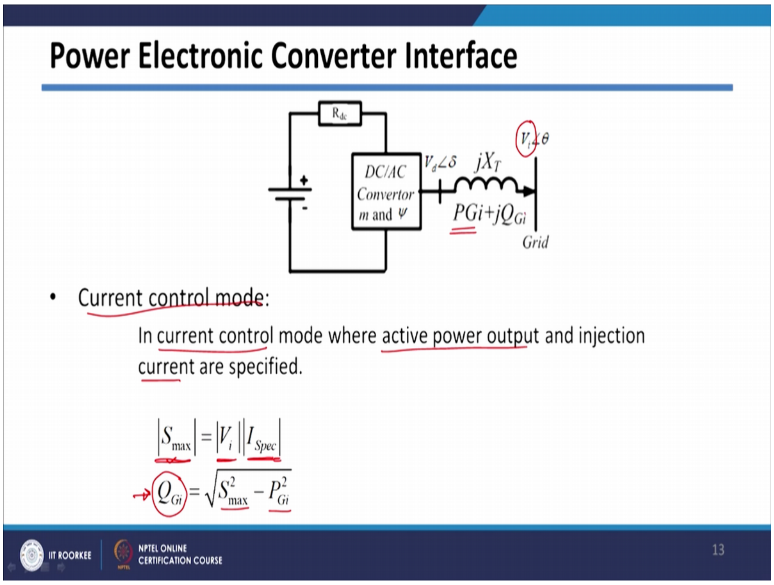

Then another mode of operation of this is generally used is called as current control mode most of the time current control mode is used. So, in the current control mode your active power output and injected currents are specified. So, in that case your S max. So, s max will be equal to your V i multiplied by I specify. So, V i is actually nothing, but your voltage at this bus and I specified means I specified current, which is you want to keep it constant current. So, you are controlling the current.

So, control current control mode. So, S max will be defined here and then in that case QGi will be calculated S max square minus PGi square. So, this will give me the reactive power which is supplied by this generator. So, PGi is already specified and then QGi will be calculated. So, here we can see that the power electronic based converter can be operated or can be considered in all the three modes, that is PQ mode PV mode or third mode is actually current control mode.

So most of the time it is current control mode; so, in summary of today's lecture we have seen the definition of DG, then we have seen various benefits of DG integration.

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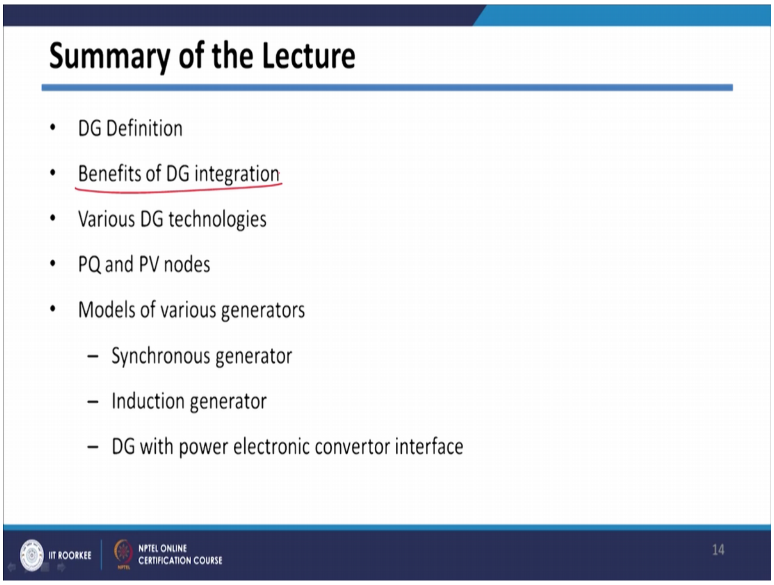

So, there are many benefits which we get apart from cost of DG otherwise there are many benefits. Then we have seen various DG technologies and the generator technologies, which are used to interface with the grid. Then we have seen definitions of PQ node and PV nodes and then we have seen models of various generators that is there are synchronous generator, you have seen there are three modes of operation that is first is a constant power factor mode second is PV node or third is constant excitation mode.

And as I told you most of the time it will be constant power factor mode in case of small DG synchronous generator based DGs. Then we have seen induction generator if the parameters of the equivalent network they are available then we can model it as a actual generator with this parameters; however, many time this parameters generally not available in that case you can use experimental data to fix the function between generated real power and reactive power and using that function, you can get the reactive power value at particular real power value.

And then we have seen DG with power electronic converter based interface, in that case also we have seen all the three modes of operation can be possible that is PQ node PV node or third is current control mode. So, here we complete the modeling of DG and in a next class we will see how to model the capacitor, and what are the applications of the capacitors in distribution system.

Thank you.