Electrical Distribution System Analysis
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Lecture – 25
Applications and Modeling of Capacitor Banks

In the last lecture we have seen modeling of distributed generation and in today's lecture we will see Modeling of Capacitor Banks. So, let us before going to the capacitor bank, let us see what we have seen in the last class. As I told you we have seen distributed generation modeling in case of distribution system.

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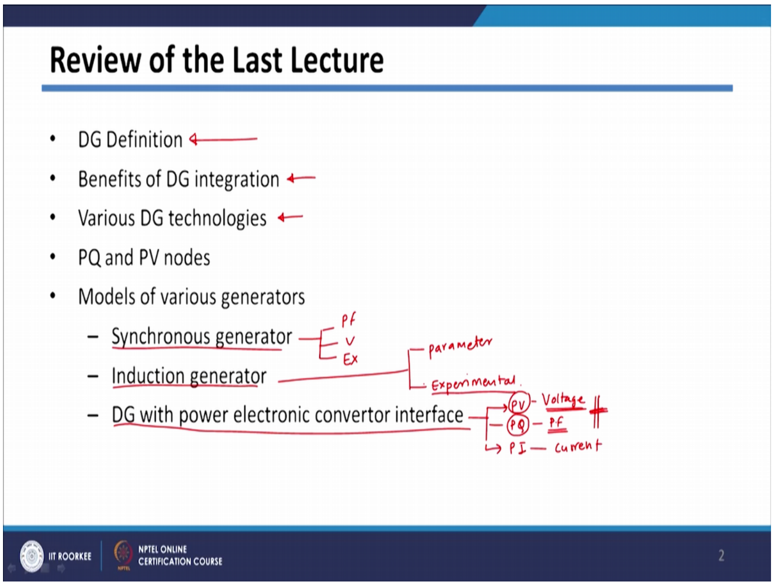

In that basically we have seen various definitions of distributed generation. So, we have seen that small scale generation or small scale generators which are connected to the distribution system are called as DGs. And then we have seen various benefit from loss reduction to voltage profile implement to releasing the system capacity, there are many benefits of distributed generation and we have seen all those benefits of distributed generation.

Then we have seen various technologies and when we are interfacing these sources of renewable energies with distribution grid, there are basically interfacing generators and for different types of energy sources we have seen what kind of distributed generators are used. So, in case of fuel cell and solar PV system we have seen that we need power electronic interface, in case of wind generator, if it is DFIG then you need power turning interface to interface with grid. If it is induction generator can be directly interfaced with grid and in that case the speed will be maintained based on your gear boxes which will be provided with wind generation. Then there will be gas turbine, micro turbine, internal combustion engine and various generators use for those technologies we have seen in case of various DG technologies.

Then we have seen that when we want to interface this DGs with grid or when you are using this DGs in various analysis like load flow analysis, they will be treated as PQ or PV node. So, in case of PQ node your real power and reactive power will be specified and we have seen how to calculate it and in case of PV node real power and voltage will be specified. Then in case of various generators we have seen three types of generator that is synchronous generator, then induction generator and then DGs with power electronic converter interface.

So, in this case we have seen three types of DGs, one is where power factor is controlled, another is where voltage is controlled and third is where excitation is controlled. Then induction generator type we have seen two types of DG modeling, one is based on parameters of the generator and another is based on experimental data which is obtained from various experiments on distribute generation. That is basically reactive power generated by this generator with respect to your real power that experimental data is use to model induction generator.

And then finally, we have seen this DGs with power electronic interface, in this case we again we have seen three types, that is it can be modeled as PV or PQ node. So, if we are controlling PQ so, basically you are controlling the power factor and here we are controlling the voltage, in case of PV node and then there is final that is called as PI node where current is controlled. So, these modeling of distributed generators we are seen in the last class.

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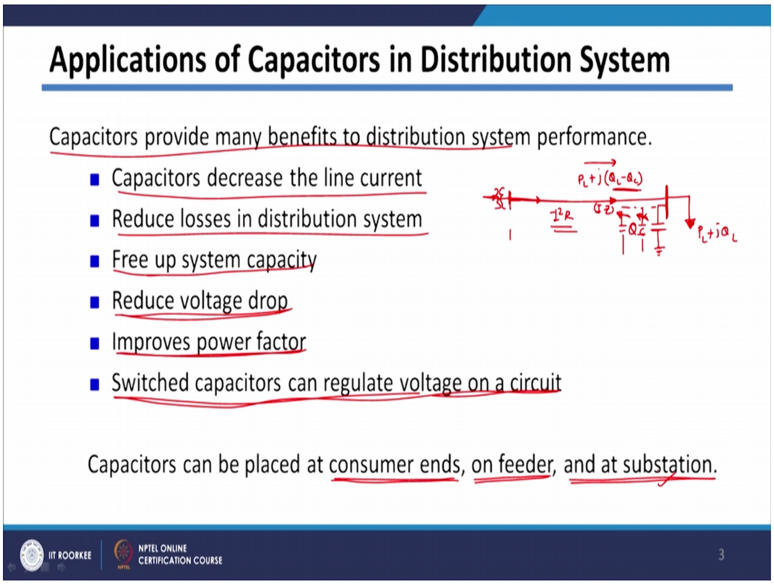

Now, let us see what are the applications of the capacitor and how we can model the capacitors in load flow studies or distribution system analysis. like in case of DGs capacitors also provide many benefits to the distribution system performance. It is similar to your distributed generation like suppose you are having distribution feeder here and then there is load connected at this end say this load is pl plus jql and then if you connect the some capacitor here which is having Q c.

So, before connecting the capacitor whole real as well as reactive power will be flowing through this feeder, but when we are connecting capacitor real power flowing through this will be same plus your reactive power will decrease that is ql minus Q c. So, overall kVA or apparent power which is flowing through this feeder will decrease which will decrease basically current which is flowing through the feeder. So, it will decrease current flowing through the feeder which will reduce the losses in the distribution system because losses are basically I square R. So, when say current is decreasing losses will get decreasing.

Similarly we can say the power which is flowing through this transformer lines which is getting decrease. So, total kVA which is coming out of the transformer or flowing through the feeder which is going down. So, there is free of some kV capacity available which can be used for giving some more connections or some to feed some more load. So, this speed capacity can be use for that purpose, then it reduces the voltage drop in this case also seen the current through the feeder from here to here it is decreasing. So, we can see that since the current is decreasing voltage drop which is basically I multiplied by Z will decrease.

So, it reduces the voltage drop improves the power factor. So, basically if you see this power factor at this end it will get improved because reactive power we are providing locally, then main purpose of capacitor also to provide the reactive power and to improve the power factor. So, basically when we have providing capacitors in your distribution system it will improve overall power factor of system.

The capacitor, if it is switched capacitor then it can regulate the voltage on a circuit. So, if there are switch capacitor bank if we are providing. So, there will be number of capacitor and switch are connected in parallel and they are switch. So, depending upon the real or reactive power requirement of this load, number of capacitor can be switched on to the system and to control the voltage at this particular bus. So, whenever the load is increasing voltage at this bus will get decreased and to improve that voltage we can switch on number of capacitors which are connected in parallel, which are connected to this bus. So, if this is switched capacitor bank then it can regulate the voltage on a circuit.

Now, this capacitors can be placed at various location the distribution system most preferred location is actually consumer end because there will get maximum benefit because locally we are providing your reactive power. However, it is not possible to provide the capacitor at each load end, though there was sometimes capacitors will be provided on a feeder on a pole at some location on feeder or at the substation. If it is switched kind of capacitor or controlled kind of capacitor it is always bettered to be used at substation. So, there are various locations where capacitors can be placed.

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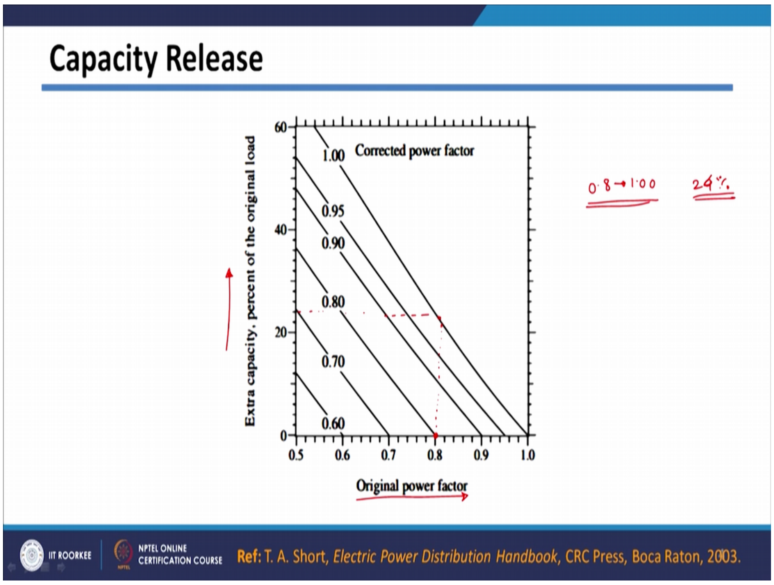

Now, this graph which shows how much release of capacity can be happened when we when we improve the power factors. So, here on the x axis there is original power factor and on y axis there is extra capacity or capacity which can be which is available for further connection. So, whenever we improve the power factor some capacity will get released and this shows this capacity here.

So, if you see, here if you consider earlier your power, original power factor is 8 and if you improved this power factor to say 1. So, we can see that about 24 percent capacity will get release by improving that power factor from 0.8 to 1 unity power factor if we do this you will get actually 20 percent, 24 percent capacitor release. So this 24 percent capacity can be used for any other purpose.

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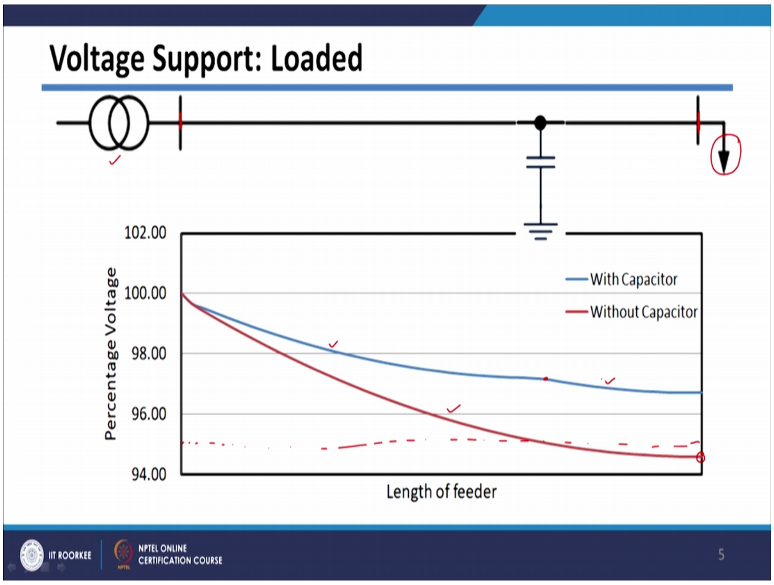

Now, let us say how the capacitor banks provides the voltage supports. So, in this case two cases I have drawn. So, this is your feeder say this is substation transformer and then feeder is starting from the substation bus to the your load bus. So, this is feeder here and I have plotted the voltage of this feeder from the substation end to the consumer end. So, it will be varying like this. So, if the if this capacitor is not there this will be a depending upon the load on the system this will be varying like this.

So, this is actually your voltage profile which is decreasing with respect to your length of the feeder, length of the feeder is longer this decrease is very less, means it will cross the limit of say if it is 5 percent limit is there then it will cross the limit it will go below that. By providing the capacitor you can see that, after putting the capacitor the voltage profile improvements happened means at these junction you can see that voltage profile has increased and overall performance if with capacitor, if you see it will be like this.

So, it provide the if you are providing the capacitor bank on the feeder it is providing you voltage support; however, this is the case when the feeder is loaded.

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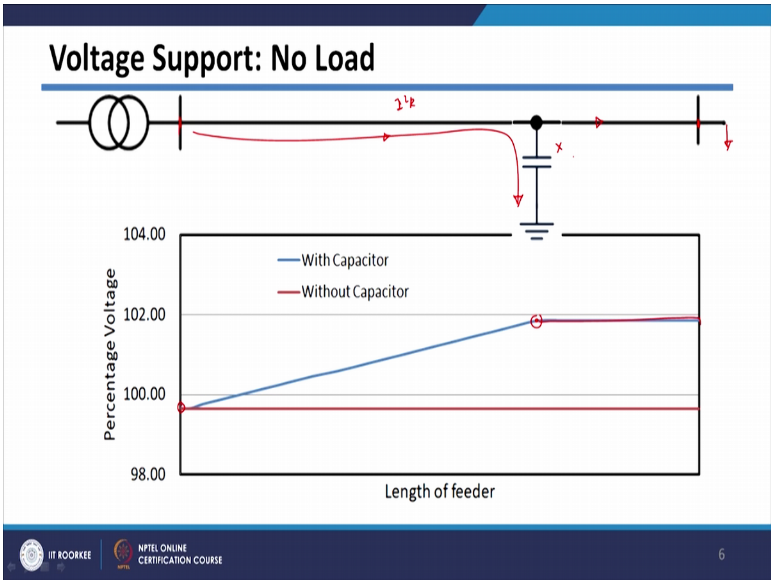

However if the feeder is unloaded means if there is no load in case of if there is no capacitor then voltage profile will be flat, means whatever voltage at this end the same voltage will appear at this end. But when the capacitor there capacitor will draw some power from here and basically this is reactive power, leading reactive power it will draw and because of that voltage till this point will raise to this point and then a since there is no load which is flowing to this one current is 0 same voltage will appear till the end, so same voltage will appear till this point.

So, voltage profile with capacitor with no load we will be something like this, means voltage will go above your rated value and because of that this leading KV r will constitute some kind of current because of that there will be I square r losses also. So, even though there is no load losses are happening means in this case we can see that voltage support which is required during the loaded condition; however, this disadvantage of connecting the capacitor on the feeder if there is no load.

So, this capacitor need to be disconnected if there is no load condition and this should be connected when there is loaded condition.

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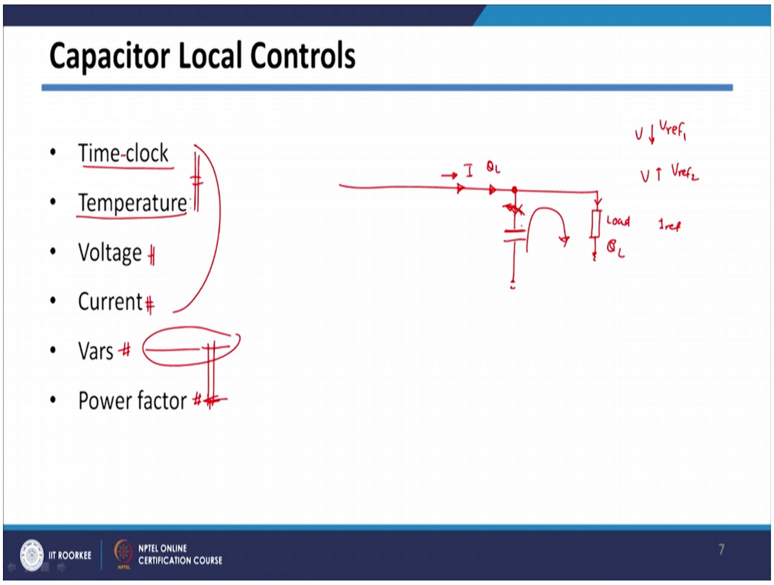

So, there are, there are various ways we can control this capacitor which is based on various controls, one is time clock. So, depending upon loading conditions in your distribution system capacitor can be switched and on and off. So, generally we know that at some particular feeder the load is highest from say 5 pm in the evening to 9 pm. So, your capacitor will be switched on at 5 pm and switched off at 9 pm. So, this is called as time based. So, clock will be set according to that, similarly in case of some feeder which are providing power to the some industry load will be highest during the day time. So, capacitor will be switched on at say 9 o' clock in the morning and switched off at 6 o' clock in the evening.

So, this is time based; however, if there is some kind of holiday or some kind of weekends are there in that case if this time is not set properly then there will be voltage raise problems will happen in this, if it is time clock based capacitor control. Another way is actually controlled by using temperature range, means if the temperature is more there will be more air conditioning load which will be happening on some of the feeder. So, to provide reactive power support to this feeders your capacitors will be controlled by temperatures.

So, if the temperature is same more than 30 degree Celsius the capacitor will be on, if it is less than 30 degree Celsius capacitor will be off because where here considering that on that particular feeder during the summer time the air conditioning load is more. So, this is called as temperature based control and these are two simplest way of controlling it. We do not need to give any measurement to this one, only temperature will be measured and another is just based on clock.

Third control is based on voltage so, if there is feeder and if the some capacitor is connected at this place. So, it will measure the voltage at this point, if the if this voltage is less than some reference voltage then the capacitor will be switched on, if this voltage again more than some reference two this is reference one because we need band here, otherwise it will keep on chattering. So, there will be some band of reference one and reference two. So, if this voltage is more than reference two then we can actually switch off the capacitor.

In case of another control which can be use is actually basically currents. So, in this case current which is flowing to the feeder will be measured. So, current is proportional to your load which is connected at the end of this feeder. So, if the load is large, if the loading is large current will be highest and in that case voltage drop will be highest. So, to give the now voltage support we need to switch on capacitor in that case. So, if the current is in this case current reference will be used, if the currents is higher than some value the capacitor will be switched on otherwise switched off.

The and then there is var and power factor based control, these are the most proper control as compared to other this 4 controls, this var based and power factor based are based control available. So, in this case we are basically measuring how much vars flowing through the feeders and based on this var. So, if this is ql and then those switching on there will be some same Q L will be flowing through the feeder and if this Q L is more than vars reference which is set for this capacitor then capacitor will be switched on.

And similarly here there will be power factor based control where the power factor of, power factor of the system will be measure and based on system power factor the capacitor should be controlled. So, these are the various capacitor local controls are used. Then let us see how we can model the capacitor. So, now, the capacitor banks which are generally connected in star or delta fashion.

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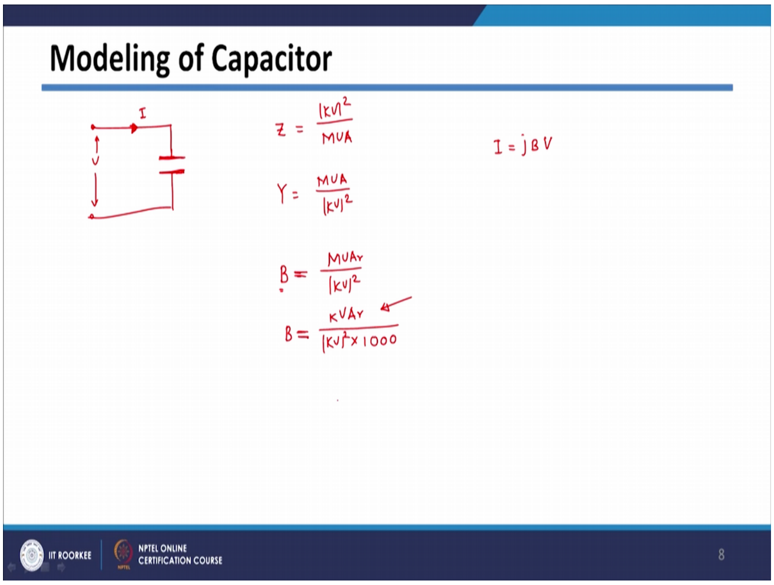

So, before going to that say let us see we are having this capacitor here, single phase capacitor which is like this and then there will be current say I the current which is flowing through the capacitor which will be used as the load in case of load flow studies. So, capacitor load so whenever connecting the capacitor we need to calculate how much current it is drawing.

So, to calculate this current; however, this capacitance will act as a constant suscept and device. So, we need to calculate the susceptance from rating of the capacitor and then use that capacitance as a constant and then each load flow iteration depending upon voltage current will be calculated. So, in this case we know that a any impedance of the system will be calculated by KV square upon MVA.

So, admittance then it will be MVA divided by your KV square and since it in case capacitance are maintenance will be just susceptive in nature that is B. So, B will be equal to your MVA rating of the capacitor divided by KV square. However, we know that capacitor rating generally give given in KVAr instead of MVA because that large capacitance we do not use it or capacitor bank, each capacitor or be KVA are rating.

So, in that case MVA can be converted into KVA. So, this will be since we are considering susceptance it will be MVAr. So, it will be KVAr, I am just writing this MVr in terms of KVr. So, KVr will be KVr divided by thousand and KV square will be as it is. So, we can get the from the rating of the capacitor that is KVAr we can get the susceptance of it and this susceptance is remaining constant. So, whenever we are calculating the current which is flowing through this one, it will be j beta into voltage across this terminal. So, we say this voltage is v then it will be j beta jB into V. So, this b will be calculated like this and it will be kept constant.

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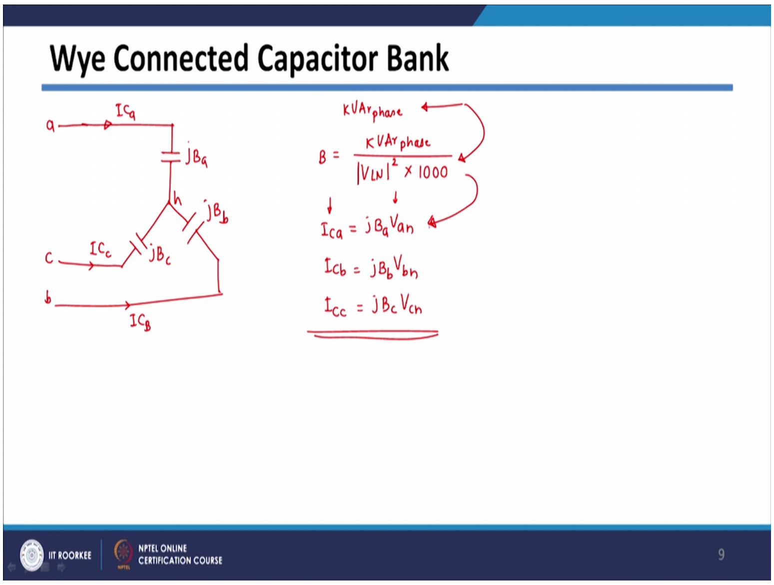

So, let us say if you are having wye connected capacitor bank. So, in case of wye connected capacitor bank the capacitors will be connected like this, 3 phase capacitors and there will be currents I can call this is IC a this is IC B and this will be IC c this is phase a, b and c and this will be jB a, jB b phase, jB c phase 3 phase capacitances. So, in this case I can, I can calculate the capacitor value if you know the KV r rating of per phase capacitor that is say KVAr phase is known they can, I can calculate jB will be equal to your KVAr per phase divided by voltage across this capacitor, in this case it will be v line to neutral voltage and its square multiplied by 1000.

So, this will give me beta B value and not it is not jB it is just B value and from this B value I can calculate the various currents. So, this currents are I ca will be equal to j B into V an this is n terminal. So, V an is voltage of phase a I Cb will be equal to jB. So, this is I can to represent phase a susceptance, phase B susceptance, V bn and I Cc will be equal to jB c susceptances c phase multiplied by Vcn. So, this will give current. So, capacitance will be model like this from the KVr rating of the capacitor which is connected in the phase you have to calculate its capacitive susceptance and it should be kept constant throughout the load flow iteration. So, load flow iteration if whenever voltage is changing the currents flowing through the capacitor will be changing and those currents which are flowing through the capacitor can be calculated based on the voltages.

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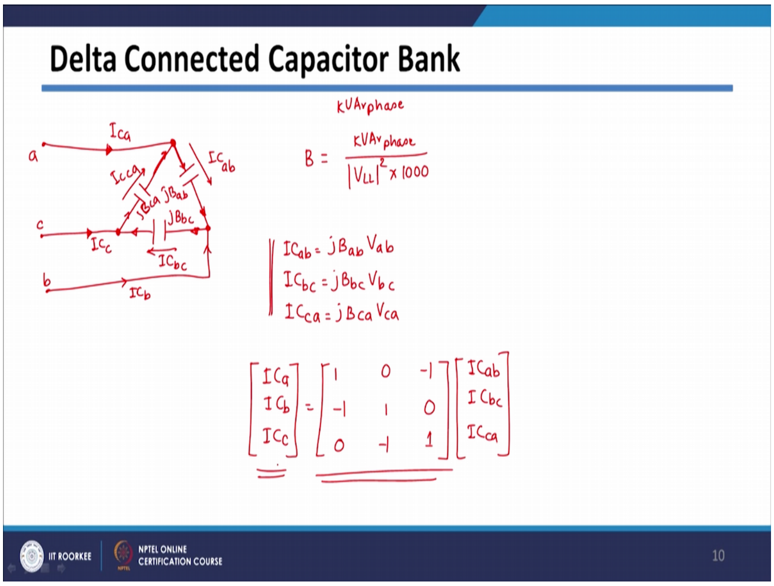

Now, let us say your having delta connected capacitor. So, in this case the capacitors will be connected like this delta connected branch here, this is your b phase, this is your c phase and say this is your a phase. This current is again I Ca this current is I Cb and this current is I Cc. Now, what will happen is there will be current which are flowing through the delta branches which will be directed like this. So, this current will be IC ab this current will be IC bc this current will be IC ca.

Now, in this case if you know per phase capacitor. So, KVAr phase if it is known in this case capacitive susceptance will be calculated like this, B will be equal to KVAr of phase which is known divided by in this case voltage across the capacitor is line to line voltage. So, V line to line its square multiplied by 100 will give me susceptance and then by knowing the susceptance of each phase I can write your IC ab will be equal to jB ab. So, this is actually jB ab this susceptance is jB bc and this capacitive j jB ca.

So, jB jB multiplied by V ab IC bc will be equal to jB c, jB c into V bc and IC ca will be equal to jB ca into V ca. Now, we have got this, these this delta currents which are IC ab, IC bc and IC ca which need to convert because finally, in load flow studies or any other studies we need this line currents here. So, this needs to be converted into line currents that can be converted into line currents like this. So, line currents are IC a, IC b, IC c will be equal to some matrix here multiplied by your currents IC ab, IC bc and IC ca.

So, if you apply k cell at this junction IC ab will be equal to this current this current which is flowing to this 1 minus this current. So, it will be 1 0 minus 1, if you apply k cell at this point it will be this current which a, this current will be equal to this current which is going out minus this current. So, it will be 1, this 1 0 and if you apply k cell at this point this current which is going in this direction and this current is coming like this. So, it will be 0 minus 1 and 1. So, we can get this convergent matrix and we can calculate currents, line currents and which can be used in load flow studies.

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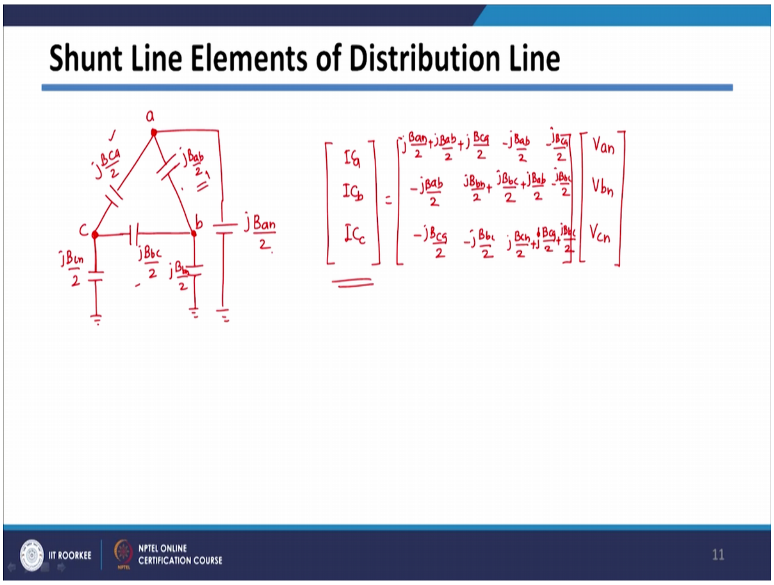

Moreover sometimes we have seen that if your using pi model of distribution feeder then we need to connect the capacitances of the distribution feeder and we need to connect them have as each of the end. But in case of three phase line this admittances or capacitances will be divided into half and there will be capacitance between each of the conductor and there will be capacitance with respect to ground.

So, in this case the structure will be something like this. So, if you are considering the shunt elements of distribution line when you are using pi model the capacitance will be connected at the lower end like this. So, at one end the capacitor will be connected like this we already seen how to get this, cabc matrix which is basically 3 by 3 matrix. So, it will be like this.

So, suppose this is conductor a, this is b and this is c. So, this will be jB ab by 2 because half we are connected at sending end half we are connecting at receiving end it will be jB bc by 2, this will be jB ca by 2, this will be jBcn by 2 this will be jB an by 2 because it is with respect to ground and this will be jB bn divided by 2. So, in this case we can calculate currents injected. So, currents in 3 base matrix we can say I a, I can, IC a, IC b and IC c that will be equal to some matrix which is basically made up of admittances and then it will get multiplied with respect to voltages. So, this voltages are V an, V bn and V cn.

Now, this is admittance matrix. So, if you apply the wye, if you find out wye bus of this particular node since there will be all the 3 elements are connected. So, diagonal entry will be addition of all the three elements, that is j B an by 2 plus j B ab by 2 plus j B ca by 2 which will get multiply with respect to van and then there will be between a and b there is jab by 2. So, minus j B ab by 2 and then between cn that is this is B ca so, minus j B ca divided by 2.

Then, if you write for this node b there are 3 impedances which are connected so diagonal element will be addition of all the 3 elements that is j B bn divided by 2 plus this element here that is j B bc divided by 2. And then this element is there that is j plus j B ab by 2 and element corresponding to van will be just, so negative of this one. So, negative of this one will be minus j B ab by 2 and corresponding V cn negative of this. So, it will be minus j B bc divided by 2.

Then in case of third row, in case of this c node the three admittances which are connected are addition of them. So, the j B cn divided by 2 plus j B ca divided by 2 plus j b B bc divided by 2 and then between bn say it is minus j B bc divided by 2 and minus between a and c it will be minus j B ca divided by 2. So, to get the currents corresponding to shunt element which is modeled like this.

So, in the summary of today’s lecture we have seen modeling of capacitor in distribution system. So, first we have seen various benefits which were going getting from the capacitor banks, then we have seen various graphs where we have seen how capacity is getting released by placing the capacitance distribution system. How the capacitor provides voltage support in distribution system and then we have seen modeling strategy of distribution system and we have seen that capacitor will be modeled as constant susceptance. So, from the rating of the capacitor we need to first calculate susceptance of the capacitor and that susceptance would be kept constant. So, whenever voltage is changing your current will be change based on just susceptance of that capacitor.

Thank you.