High Voltage DC Transmission

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Module No. # 06
Lecture No. # 01
AC- DC Power Flow

So, let us start the new module. That is module number Six and today is lecture number one. In this lecture, I will discuss about the AC-DC load flow or it is also known as a power flow. There is no difference between the load flow and the power flow. Some in some books, they call it as a power flow and some books they call it as load flow. Basically, this term came because we wanted to know, what is the power flow in the individual lines, branches. So, that is why, the power flow name basically came. So, to start this, we have to see why we are going for the load flow?

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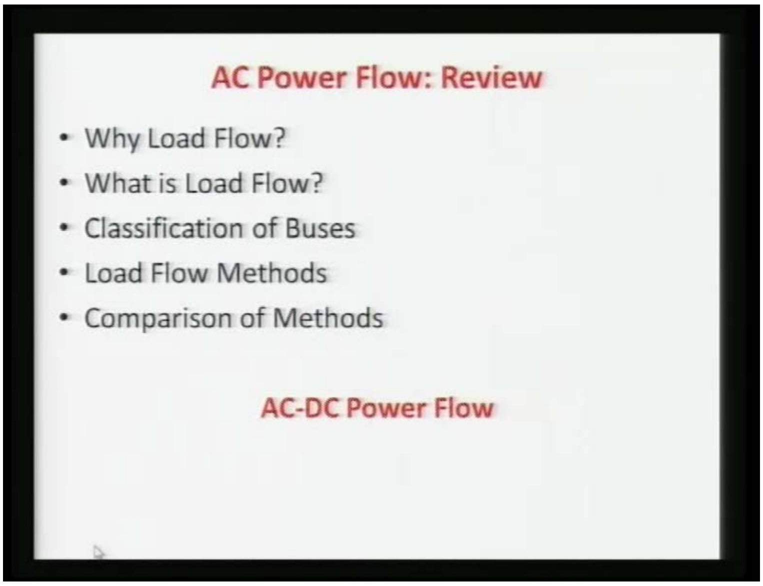

Because, this is a AC-DC load flow. So, first we will see the AC load flow, then we will see how we can incorporate. So, the AC load flow only, I will go for the review aspect. I will not go much in detail but, slightly I will discuss why, what is the AC load flow, what, how it is done, what are the various methods and what are the comparison, etcetera? Then, I will move to the DC load flow.

The question arise, why load flow? Basically, the load flow is required for the various applications as the planning stage, at your operational stage as well and sometimes after the post contingency or post outage, etcetera for the analysis purpose. In the planning, basically, we know that suppose you are having a power station to be constructed at someplace, then you should know what should be the transmission lines, what will be the capacity, what will be the voltage level? So, that, you can evacuate power from the generating station especially, you have to transmit it to the load center. So, we know that is what will be the power flow in the different branches existing line. If you are going to construct a new line, then what will be the power flow pattern of whole system, what will be the losses?

And at the same time, you also require to know what are the various compensating devices are ignited. The compensating devices, I discussed in the very first lecture, and first and two lectures, that we require the capacitors to improve the voltage profile of the power factor. We require reactors to control the over voltages during the off-peak hours. So, all these things basically at the planning stage we require that, although in the planning stage, there are set guide lines. For example, suppose you want to install existing system, you want to install a power plant at any individual location, now, that location also decided by several other studies. Once, it is decided that you want to put at particular near to the certain location, then you have to connect that generating stations to the grade with the help of transmission lines. Now, there are some thumb rules that is applied or adopted in the various countries for the different voltages levels. Suppose, you have this much x megawatt, then what will be the voltage level and how many transmission lines you are going to have.

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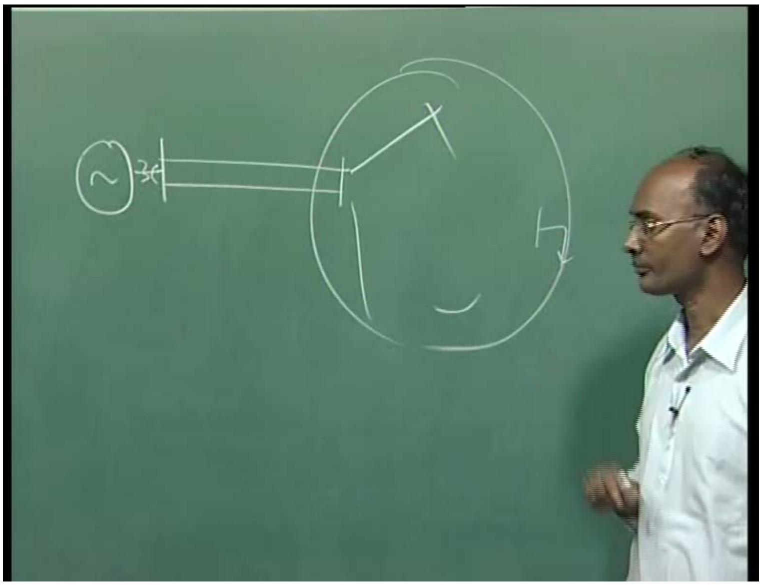

Always, for example, let us suppose, here I generating a station, thus, it is decided that it will be here and you have a network here; that is, your complete network having your all AC-DC and having generators, load, etcetera. So, here what we do normally, we the connect here with the two parallel lines. Again, you know the two, because we want to give the reliability. We never want that this should be, suppose there is some problem in one of the line, suppose only one line is there, we do not want to stop the generating station, because huge cost is involved here. So, if there is one problem, then another line can be taken. And normally, this parallel lines are used. So, there are some thumb rules, also what should be the voltage level. It decided, what is the power level of this? Depending on the power level, we know the surge impedance low heating of the lines, etcetera. So, the voltages levels are decided by this power, how much power. That is not only one unit, there are so many unit at that power plant. So, the total capacity of this power plant, then that decides the voltage level and then accordingly, we should have the generating transformer here. And then, we can evacuate and we can feed the power here. So, this is very simple because, these are basically based on the thumb rules.

You know how much power, you are just feeding in the grade. Now, in the grade, this is a, it is a complex network. This power is going to be injected here, because we require more power here. Once you require the power here, now the question is how the re-distribution of the power is going to take place here. And then, what will be the, because earlier it was also loaded, now, some of the lines will be over loaded may be, some voltage may be going under loaded lower limit or upper limit, depending upon the system criteria. So, we require certain new additions of the lines. We can go through a various compensating devices like reactors, capacitors, etcetera. And then, we have to go for complete, that is this planning studies. Then, you require the load flows.

Another, basically, we require for the online operation of the system. Normally, you have a power system right now. You know, what are the voltage in the system. How will you know? We have the remote terminal units of the various locations, we get the information and we know the, what are the voltage at the various buses in the system sitting in the your display center. You know there is a various hierarchy, we are normally power system operates.

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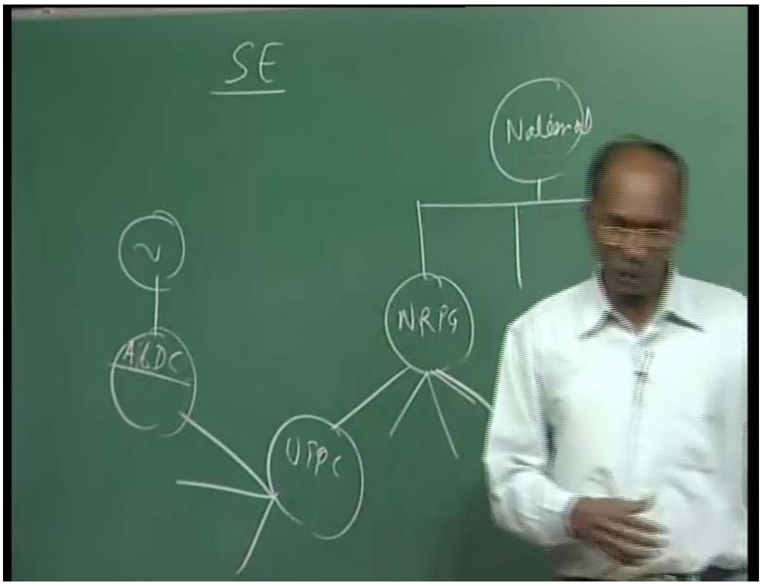

Here, basically at the national level, we have the grid which is connectional, that is conventional level. Then, we are having the various regions here, that is called the like, we are in the NRPG, Northern Regional Power Grid. And southern, western and eastern, non-eastern five regions we are having. Here, we are having in this various states, various states in that northern region, here I can say we are having UPPC here, UP power corporation limited. We are having Rajasthan, we have Haryana, Punjab, Srinagar, Himachal, all these are basically interconnected. So, this is here, we have the dispatch here, here, here. In this also, we are having the various again, the area load dispatch, because it is a very big state. So, we are having, that is called the area load, ALDC, dispatch centers normally are there. Like, we have been Panki, Muradabad, Mughalsarai, and one more, somewhere we are having. So, even though that is not sufficient. Here, in this system, we are having in each ALDC, we are having may be a generating station. So, this station is having its own control, the power plant control we call. Here, they are controlling the load. After that, this power corporation is looking all this here. Altogether, this NRPG is looking here and also its own generating stations, if they are having now it is a complex one. Here and finally, whole national grid is operated.

So, in the operation all these persons who are setting here, normally they are going for the load generation balance. They should know what are the voltage, what are the various frequency in the system, based on that they can go for the load generation balance. So, one option that sitting here, in whole system, we are having the remote terminal units; means at each sub-stations is having equipped with the monitoring device like CTS and PTS are there. That information is going to here and the person sitting here, he can see what is the power generated by generating units, what is the load taken by various, here the feeders. And also, what is the power flow voltages at the various known, that can be here through the state estimators.

Now, the question arise will come back here, what is the state estimation? So, that voltage, present voltage is known through the measurement. It is not through the calculation. But, the person who is here, he can see whether his system is secured or not. He can predict some contingency may occur. Because, right now, if your system is okay, you are very happy, but, there may be some outage of one of the line your system may go somewhere else and your system may be collapsed. So, what happens the person sitting here, he tries to monitor the security of the system; means, he can just predict, if this contingency is going to take place, then what will be the scenario. Then, what he will do? He has to run the load flow, because right now, that condition is not there. So, he has to calculate the load flow. Based on the current loading, etcetera and then, he has to know what will be the voltage at various buses, what will be the power flow? So, the load flow here, also require for the online operation of the system. We go for the contingency analysis means various outages, etcetera. Then, we go for, see the security of the system, whether our system is present, system is secured or normal or not. And then, that is called it is a normal operation, also require your load flow. You should also require this load flow for running the various things, like if you require your stability analysis. So, for the stability analysis, the first step is the load flow. Because, you know what is the current state then, from there, what is if the some fault is occurring. So, in the present online operation, we require the stability analysis. Then, we require the load flow. We require your security analysis. We require load flow. So, the in the as I said in the operational issues also, we required the load flow. Another is the post disturbance analysis, we require the load flow, because something has happened, you have the complete information, load, etcetera. Then, you can analyze a load flow and you can see what are the causes, what were the problem your contingency has occurred. So, this load flow require for the all the three stages: planning, operational and the post-analysis of the system that is required.

Now, then question arise, what is load flow? Load flow, as said in the beginning, the word the load flow seems that there is a some flow and we are talking about the power flow or load flow in the lines. But, the load flow basically, what we do? We want to calculate the state of the power system. States are those minimum set of information that is required to know all the other information from that. So, that is why, you can say in the load flow, what we do? We normally calculate the voltage and angle. You know the network topology. Topology means, you know the connectivity of the lines, transformers, generators, etcetera. Then, you know its parameters, means R x and your charging, etcetera if there. You know the reactor value, you know the capacitor value, all the parameter, we call the topology of the system is known to you; means, we are having the admittances, admittance matrix of the network. It is normally known as Y bus. So, here, this is a Y bus, you are having, this is given to you. Then, we require this V and angle. Based on what is your PGs, generations, what is your demand, what is your rate to power demand, etcetera. Then, we can calculate this in the load flow. So, we try to get the states based on the available information this. Available information, whatever the system information, that is load, that is varying, these are the varying quantities. This is a fixed quantity. Based on that, we calculate voltage and angle. And once, you are having the voltage and angle, then you can calculate all the information.

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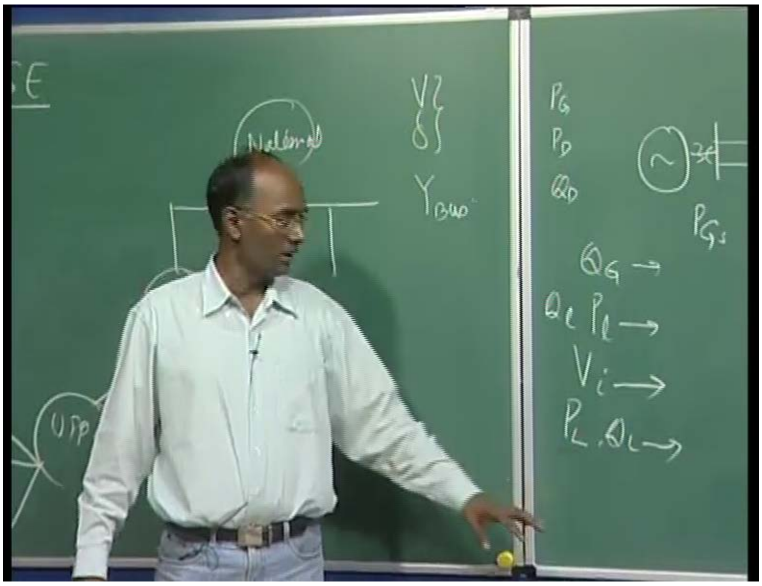

Like, you can calculate your reactive power generations, you can calculate the line flows, both real and reactive line flows in that way. You can also get, of course you are getting voltages at all the nodes. You can you can calculate this P loss and then Q loss of the system. So, all this things, you can calculate. You can also calculate the slack bus power. If loss is there, then slack bus power here, you can also calculate. So, all the information which is required you know, this and this information is known as the operating state of the system because, the voltage is keep on changing depending upon a load. The power flow is also changing and you should know, because they should these should not violate your limit. So, these are the operating states. So, that we can get. Loss, etcetera, we can get, again we should design specially that is required in the planning stage, we want to minimize the losses. We want to design our system that can give you minimum loss.

In operating state also, by changing the reactive power injection, we can minimize the losses. That can be also done online, that is even though, that we can also go for the cost minimization based on the scheduling of the generators; that is, you are again online and using the your load flow.

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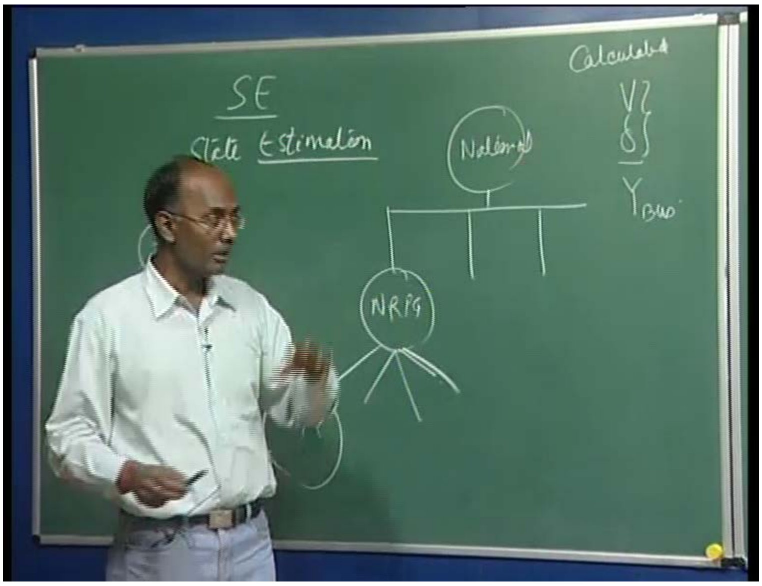

Now, here I am saying this, it can be calculated. I used another word here is called state estimation. Here, this is state estimation. Now, you know the difference in the estimation and the calculation. The calculation basically, the number of equations and your number of unknowns are equal, then you can calculate it; means, this is a simple calculation solving the algebraic equation. In estimation, what is happen? You have a lot of estimate datas. In that, you are estimating, you are again the state of the power system. Because, whatever you are having the data, that is measured data. There are having the error, etcetera. Based on that, we can using large number of equations, we are trying to minimize the error. That is measured and transmitted to your control center. So, the difference between the state estimation here, also we are estimating the state; that is voltage and angle. Here, we are doing the power flow. Here, this is a calculation I am calling. There is a, I am calling the state estimation. The only difference is this. So, here we are just calculating voltage and angle and thereby, we are calculating all the information of this the system. So, this is you done.

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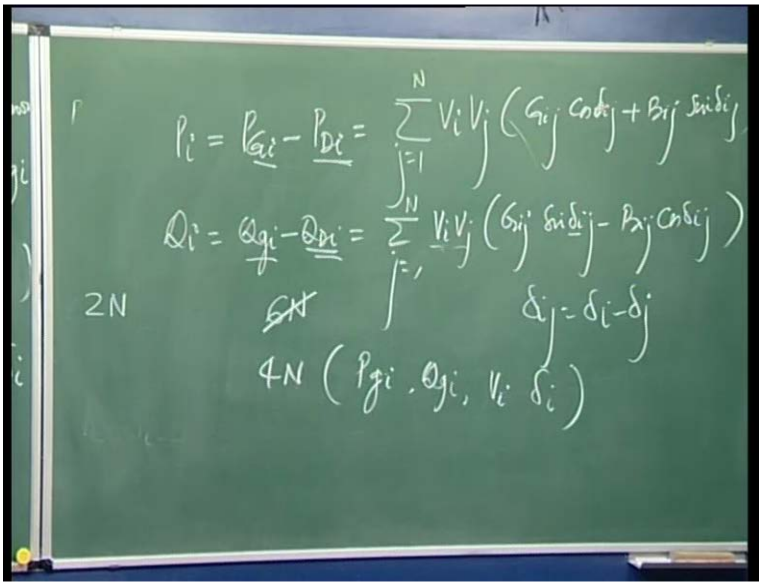

Now, if you write the power balance equation at the various node, again since it is reviewed, so, I am not going to derive those equations but, if you remember, here we derived the P i at real power injection at any bus. Here, that is, it is your P Gi, that is your power generation at that bus. And here, I can say minus your demand at that bus will be equal to your summation of yours V I, the magnitude I am writing here. And it is your G ij cos delta ij plus your B ij sin delta ij. Here, your j went to here. this is a real power balance equation we call and here, you can say terms of magnitude of voltage at bus I, bus j and the Gi and the B ij of the elements of here, that is your, of this bus matrix plus here j, B ij. So, this is a Y bus elements basically, the i. The real and imaginary component of this. Similarly, we can write here Q i. It is, I can write Q gi minus Q Di. Here, summation of j is equal to 1 to N, N is number of buses in the system. Here, V i V j. Here, G ij sin delta ij minus B ij cos delta ij. Basically, delta ij is nothing but, delta i minus delta j.

So, here these are the power balance equations. This is a real power, this is a reactive power and we are having the two equations at each node because we are having N bus system. Now, our total equations, we are having 2 N in number. But, if you will see, that is why, the question arise our number of variables are more, our variables are one, two, three, four, five, six. This is V, is only one because we require the voltage. This and we require the delta. So, we are having the 6 N variables; means at each bus, we require voltage. We require P real power generations, reactive power generations. So, one, two, three, four, voltage and the delta 6 variables are there. So, we cannot solve it. So, that is why, we go for the classification of buses; means, we believe and we assume this demand is known at all the buses in the system, which load is normally measured and it is solvable. So, what happens from this? Now, we have reached up to 4 N. Now, the 4 N, we have here, you can see, oh sorry. 4 N, it is nothing but your P gi at this bus, Q gi, V i and the delta i. So, we have the four variables, we have the two equations at each node in the system. So, the total we are having 2 N equations, we are having the 4 N variables. So, what we do? Now, we have to specify, we have to set the two values and then only, we can get the two value and that is why the classification starts.

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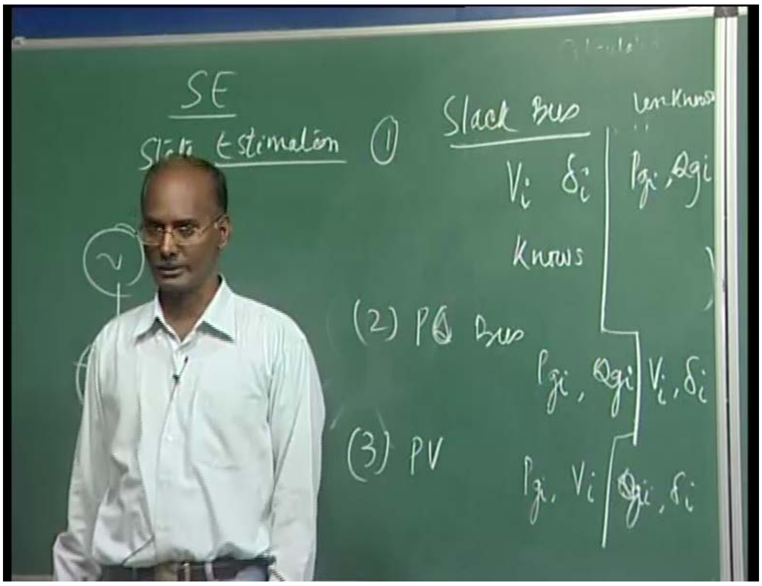

So, in the system, we defined that one bus should be a reference bus from where, we can angle can be relatively changing. So, that is called your slack bus or sometimes is called reference bus where, we fix the voltage and your angle. So, these are basically your non-values. this is a fix. So, we want to calculate here, what will be your P gi and your Q gi. So, this is your unknown. So, the slack bus is normally only one in a system where, this is the fixed. It is given to you and then, we calculate the real and reactive power generation at that bus and it is your slack bus or reference bus. Another is called your P Q bus, first side should we start P Q bus or it is also called the load bus where, your the P gi's and your Q gi are set, are given to you. Slack, slack bus are reference bus, it is also given. So, again, you cannot say this is first, this is second. This is, we are classifying basically. So, we classify the buses in terms of three buses: one is a P V bus, one is a P Q bus, and another is a slack bus. So, I said this is a first. So, it is this value. Now, here in this classification, we assume that the load buses are those buses where, generation real and reactive power are known. Once they are known, now the left out is your V i and delta; means, this is unknown and we should calculate.

Third one, we know it is a P V bus or also it is called generation bus where, this P g is known and the voltage is known. Then, we go for Q gi and your delta i is calculated. Why at the P V bus, we fix this? You know the P g is the real power, it is set by the turbine. How much steam you are flowing through the turbine, which you can control? The reason is there because, we can control the P gi there. Though, you can (( )) this value. The voltage you can also set because, you have the exciter and from the excitation you can control the V i but, these things are depending upon the network and how much it is connected. So, the voltage here Q is basically the V i and the network information will set your reactive power generation at that bus. So, this basically three buses are classified. Now, we are two fixed to known. So, we can solve this power flow equation. Infinite bus is the different concept at all where, we believe your voltage and your frequency does not change of the system that is known as the this one.

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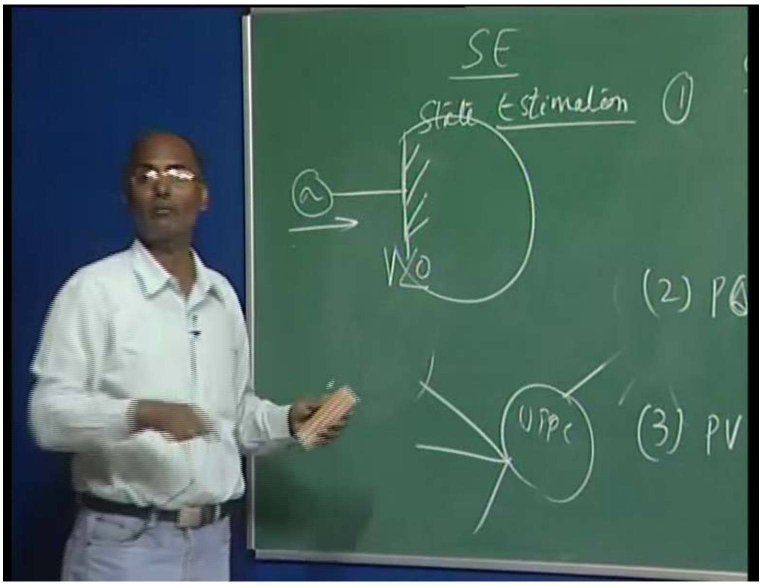

For example, infinite bus what we say, Let us suppose you are having a generator. Here, you are connecting with the system, this is called infinite bus. Here, the voltage and angle, we say it zero and whatever the power you are injecting here in the system, the frequency and the voltage of this system does not change. So, that is called infinite. Although, there is no infinite bus practically but a very strong grid can be treated or big bus can be treated as a infinite bus. This analysis normally used in your stability analysis because, we can equivalent whole your system as infinite bus and this generator behavior we can analyze it. So, especially, this is used in the stability analysis. So, this is a something different than this. Here, we are fixing, we are not worrying about the frequency, we are assuming the frequency of whole system is same and here the voltage and angle are thus, we are setting. Infinite also, I said here V angle zero. Zero, you can put or you can put any value. So, this is also sort of reference bus but, it is not that is treated in that sense, which I am talking here now.

Now, you can see, these two equations are highly non-linear. Because, you can have you can see that, the you are having here, the cosine and sine terms. If you will expand, you are having the large number of terms and it is a highly non-linear, I can say. So, again you have to go for the certain methods because, this is a you are having the set of equations at each node and you are having the set of unknowns, then you can solve. Again, you require the various techniques to solve these non-linear equations. Now, the question arises, as you know this is a non-linear equation. Any non-linear equation will have large number of solutions. if it is a quadratic equation it will have two, if it is a cubic equation then you are having three and so on, so forth. Now, what will be the number of solution for this? And also for solving this, if you are having higher order numbers, you require some initial guess. So, starting with a initial guess, you can solve this and you can have a large number of solution. Here also, you can get large number of solution.

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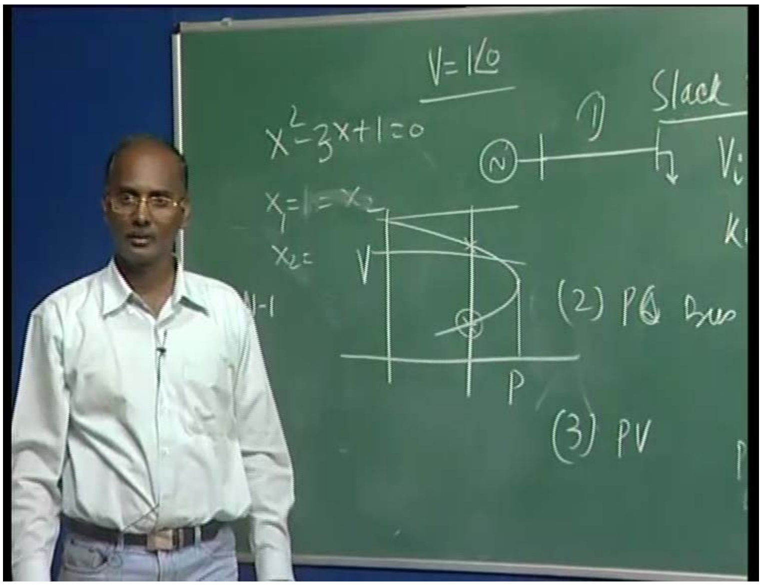

And for example, why I am telling this, you know this equation here 2 X plus 1 is equal to 0. Here, the solution is looks only X is equal to 1 but, it is not so, because the two equation are coinciding, two solution are coinciding each other; means, here X 1 and your X 2 is equal to 1. But, if you are changing here, something three, you are having both different here, X 1 and X 2; means, effectively you are having the two solutions but, at certain point they are going to converge and there is having only one solution.

If remember your P V bus, here as I said the P V curve, if two bus system you are having, just remember. The two bus here, we are having a generator, here, this is one bus and here, we are having a load. This is a 2 bus system. If you will draw this here, the voltage profile by the power which we are taking, the voltage here, it will be keep on changing. So, this is a system having two bus. Now, you can see if it is two bus, you are having the two solutions. For any given P, you are having the two voltages. But, once you are coming here, you are getting here at this point only one voltage. So, here also you are having the multiple solutions but, if the system loading keep on increasing, you can look some of the solutions are coinciding each other and finally, you are having only one solution and after that, there is no solution. You cannot have solution at all. So, beyond this, it is called unsolvable condition; means, you cannot solve even this non-linear equation but, if you are inside here, there is a possibility. Since, here the solution are here going to one point, you cannot get the converge solution. Solution is existing but, you cannot get the solution. So, that is called divergence of solution or unconvergence of the solution. So, you should mind it, there is a difference between the unsolvable case and the solvable with not getting solution. Means, beyond this point there is no solution but here solution exist but, you are not getting it. Based on it, again different methods may give, some methods may not give. So, that is called diversions of the solution. Here is a unsolvable case, you cannot solve it; means, there is no solution exist at all because, you will see sometimes Newton-Raphson, the Jacobean basically becomes similar.

Now, here once I want to tell you here, you can see this relation normally, the solutions here, the number of solution that exists for this is approximately, here 2 power N minus one. For the two bus system here the two solutions. Similarly, you are having N number of solution. Another thing, I want to tell you, we are least concerned about this solution because, your system is operating near to unity band. It is a one per unit approximately. So, that is why, we start our initial guess is called the flat start. With 1 0 we start because, we want, if you are starting with the very some extra voltage here, you may get the solution here, which is not of our concerned. Sometimes, it is required, those are analyzing the voltage instability and another analysis. So, that solution may also require. But, in the normal operating people they are only concerned about the solution because, this is the real practical solution; that is our operating condition which existing here. So, that is why, here we require the initial guess here, one angle normally zero; that is called flat start. Because, if you are starting here one, you will land up here before this. So, the flat start is called and thus, we go for the initial guess this.

Now, so, this is a non-linear equation, we are just going to get largest number of solution and this should be solved by the iterative procedures or we can have some approximation and then finally, we can get solution. Now, the question arise that here, we can land up the, what are the various methods of load flow? Now, we are classification is over. Now, thus go for the load flow. Now, in the load flow, already since it is a, I am only reviewing, I am not going much in detail of the various methods but, the most commonly used methods, you must be knowing that is called Gauss-Seidal load flow method.

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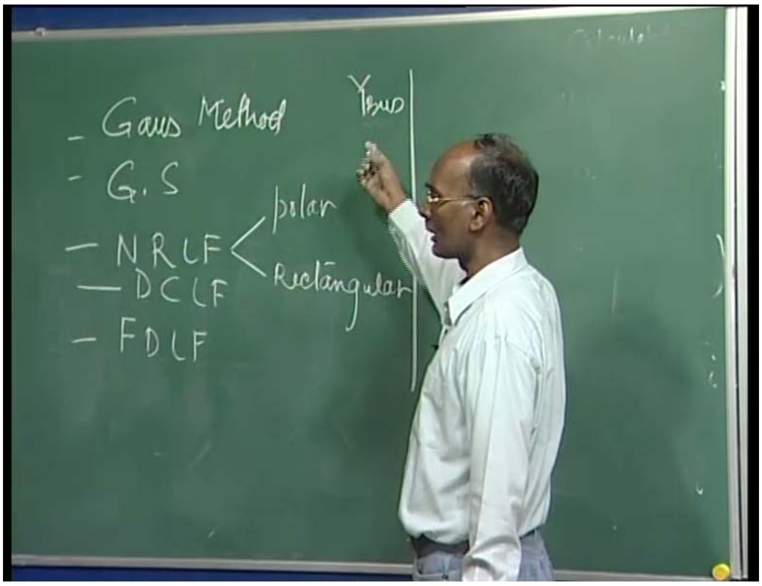

You know Gauss method itself is there. In Gauss-Seidal, means you are Gauss method, then you are having Gauss-Seidal, then you are having Newton-Raphson load flow method and then, you are having FDLF, Fast Decoupled Load Flow. In between also, many people say decoupled load flow because, in between this method derived from here to here, via this decoupled load flow.

Here, in the NRLF, we are having the two types. One is called the polar; another is called rectangular co-ordinate solutions. So, it is, if you are writing the equations in polar like, if you are writing this equation here, then it is a polar and another is in your rectangular rectangular coordinate method. Now, the gauss method basically and the gauss-Seidal method, there is no much difference. And these method basically, derived based on, why I am relating this because, we are going to use for the newton-Raphson. I will show you. Another concern, just I want to before going the method, we use this Y bus. Why not Z bus? You know it very well. Because, this Y bus is easily formed by looking even though network you can form the Y bus and also this bus, no doubt it is a complex matrix, having real imagery and it is highly espoused. So, earlier people were facing the problem of the storage because, the memory were not so cheap and it was very complex to store. So, espoused techniques were used and the matrix is highly espoused. You have to store very few elements. But, if you are going for the Z bus, it is a full matrix and that is why, it is not espouse. So, that is why, in starting from beginning, we started with the Y bus and this load flow, all the load flow methods are now basically running on the Y bus methods. So, we form the Y bus there is a different approaches are there, whether you are connecting a line, whether you are connecting a transformer, your Y bus is keep on modifying and then, you can have the complete one. So, there is a different techniques are there to form different way frequency approaches.

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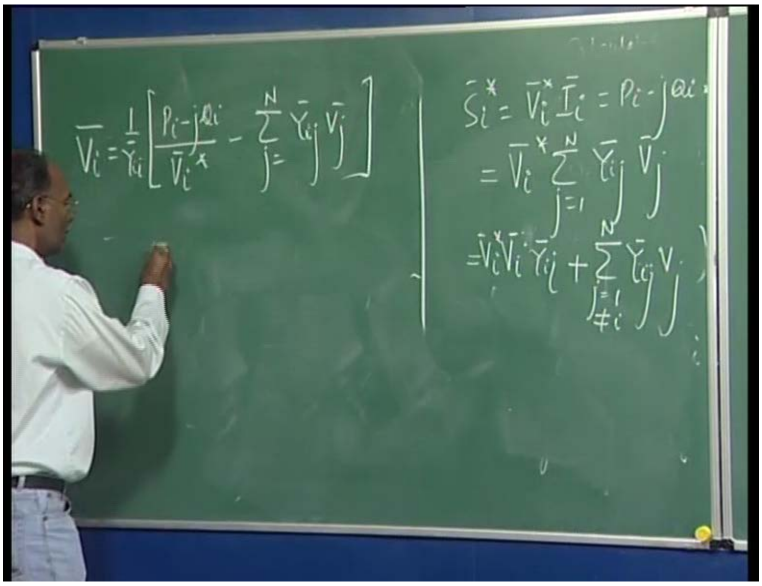

Now, this gauss method basically, we again arrive from the very simple principle here. This is your S i conjugate will be nothing but your V i conjugate into your I. These are the complex power. Now, this is equal to your P i minus j Qi. I am writing this power injection at ith bus. We can write in this format. Now, this i here, it is this I i. This here conjugate, I can write simply here, your Y ij into your V j. Here, j is equal to 1 to N. From the Y bus here, it is just based on basically nodal methods here. Here, this is admittance matrix. Here, you are this multiplying by j and if you are adding, you will get the I injection at that bus. Now, what happens here? This we can simplify, here we can write, this V i square Y i plus here, I can write, I think, I can write the V I, here conjugate, we can just take at this and then, here j is equal to one to N but not I. I can write here Y ij, these are the your V j.

So, in the gauss method, what we do? We solve this equation, by knowing P and Q, we try to determine the V i and these values are known; means, I can write I can write from again simplify here, from this value. I can write here, this P i minus j Qi divided by your V i conjugate, 1 over, this is Y i. From here, minus your summation of Y ij V j, j is equal to 1 to N. So, if you are solving this equation, it is called Gauss-Seidal method; means, you are calculating the voltage at all the P Q buses. You are calculating the angle of this voltage at all the P V buses. Knowing your P and Q at all the load buses you are knowing. At the P V buses, you do not know this Q. So, what we do? From the initial guess, whatever Q is there, you put it there and you can calculate the angle and it is it is ready process.

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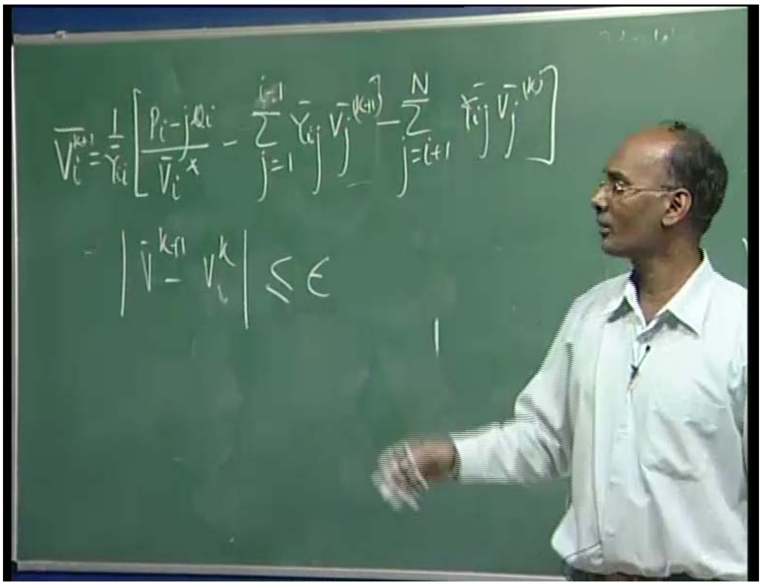

So, here we just calculate V k plus 1 minus V k, that is, all the buses should be less than certain absolvent and then, we say the solution is convinced. We keep on solving putting this value because, once first iteration, you have taken the initial values, you are calculating all the V i's, then you are again checking here, again putting this value and then, calculating. This is a iterative process. In the gauss-Seidal, what we do? Because, in each iteration, we are having some of the values calculated in the same iteration and if you are utilizing that, then it is called gauss-Seidal method. So, what we do here? We normally expand this, with the known in the same iteration and unknown in the another iteration. So, here I can say j is equal to 1. Here, it is your i minus 1, because you know this, minus summation j is equal to i plus 1 to N here your Y ij V j. So, what we do, if you want to calculate here, k plus one of this. Before, you are calculating, you are knowing this value here, it is j k plus 1 iteration value known to you, here you are using the already the just calculated; this means, in the same iteration you are you are these values are known because, before I, V are known. These voltage are known and remaining you do not know. So, this is called your Gauss-Seidal method.

This method is very simple, no doubt as you can see. But, only the problem here, the convergence problem because, this is very highly non-linear. If your system is highly loaded, system is very complex. This criteria is very difficult to get and finally, you cannot get the solution. So, that is called the diverged solution. Solution exists but, we are unable to solve by the given method. Here, we use some acceleration factors to accelerate the speed but, still that sometimes it is not possible. Then, people go for your another method, that is called Newton-Raphson methods. You know the Newton-Raphson methods, it is based on the tailors series expansion. And we take the first derivative terms, remaining second order and others, we can just remove it, ignore it. And then, we can solve. This is this is just like your function f x, we want to solve equal to 0. Because, this P i minus this value, just we are going to solve and that is, it utilize your Newton-Raphson method. Now, let us see in the Newton- Raphson method, it is no doubt, it is based on the Taylor series expansion.

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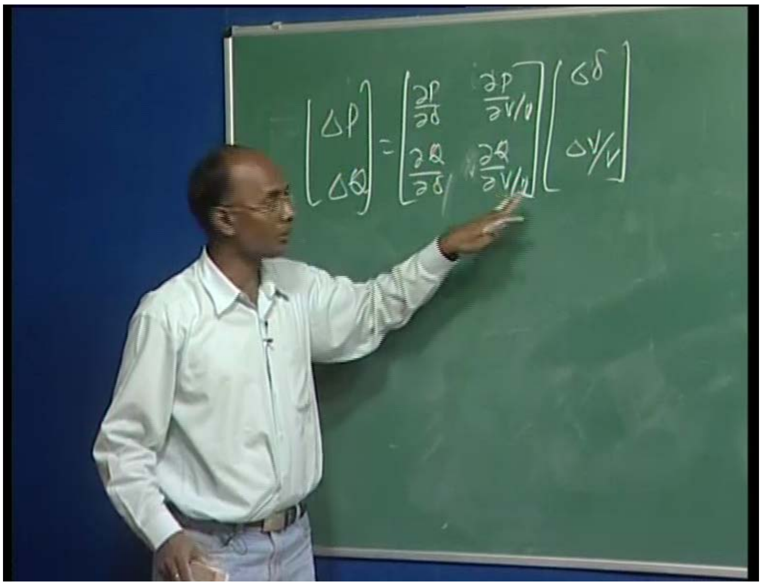

And we form the Jacobean and it is called, if the power injection here, for corresponding, I am writing in the vector form. Here, this is your Q. We take this is Jacobean, that is, the first derivative of this equation; means, this is related to your del P del delta del P del V. Here, del Q by del delta. Here, del Q over del V and here, we are having the change in angles and change in the voltages. And we calculate these values, Jacobean, we can invert it here. These values are known to you, you can calculate the change in the voltage and angle. So, this is basically in the your polar co-ordinate. Normally, here to make it say, more faster convergence, what we do? Instead of this, we divide here V, here we multiply, no, here by V, here we do V. This, by this will be alternatively multiplied. If you are doing the d V upon d V, it is the same. So, basically this V is going to be multiplied here. That is correct. Now, what we do here?

If you are differentiating here, we apply here to make this and this Jacobean quadratic. Because if you are differentiating with the voltage because, in this equation, you can say, this is only quadratic. So, once you are differentiating the voltage, you are having only with the one term, and if you are multiplying with this means, you are having the same because, if you are differentiating with a delta, this sine becomes cosine and cosine becomes sine and this is a voltage quadratic.

So, to make it here, it was found it is a more convergent, if you are using del V upon V. Because, this is also quadratic, this is already quadratic term, in terms of V i, V square and the cosine and deltas, this is also here, we are doing this. So, this is your Newton-Raphson method in the polar co-ordinate. Here, this Q is basically done for only the load buses. This P, we calculate for all the buses except slack bus. And then, its order here, decided by the number of your load buses. Because, load buses here, sometimes in the load flow, sometimes reactive power is heating. We also have the reactive power limits of the generators. If they are violating then, from the P V it is converted to the P Q and then again, if it is not heating then, it will be going back. So, this dimension of this matrix is a very dynamic but, it is very powerful and it normally, it is used at, can go up to, normally it converges in the five four to five iterations only. If it is not converging in the four to five iteration means, it will not converge.

So, it provides quadratic convergence. It is very fast, it is very reliable and it is widely used for the large power system as well. We have another one, that is to write this equation in the rectangle co-ordinate; means, here what we do? We write the voltage at any bus here i, it is magnitude V i angle delta i, we wrote. So, this is calling the polar coordinate representation. We can also have, it is e i plus here j f i, means real component and the imaginary component. Then, it is called the rectangle coordinate. Then, you can modify this equation accordingly. In that case, you can again, here, the modify this and then, then it will be called the Newton-Raphson in your the polar co-ordinate, a rectangle co-ordinate. Here, instead of this, we go for here del f, here this is changed, your changed in del E, here del f and here del f. In this case, the size of here is not equal. What we do? e and f, we require at all the buses. So, what we do?

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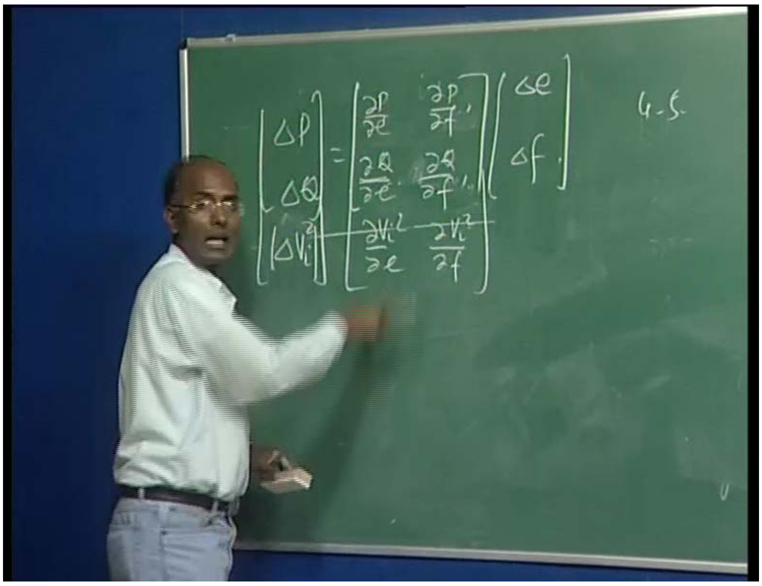

At the generation buses the voltage is specified. So, we add some more equation because, this is unsolvable. So, we require V square at the generation buses, e i square plus f i square. These equations are also added and we add here, this is for load buses, this is for your change in V i square and we just go for two more elements. Here, del V i square over del e del V i square over del f, we just add two, so, that it can a square matrix and then, you can invert it, you can calculate it. Here, this is Newton-raphson method in the polar co-ordinate. In Newton-raphson, it was found the polar co-ordinate, the off diagonal elements.

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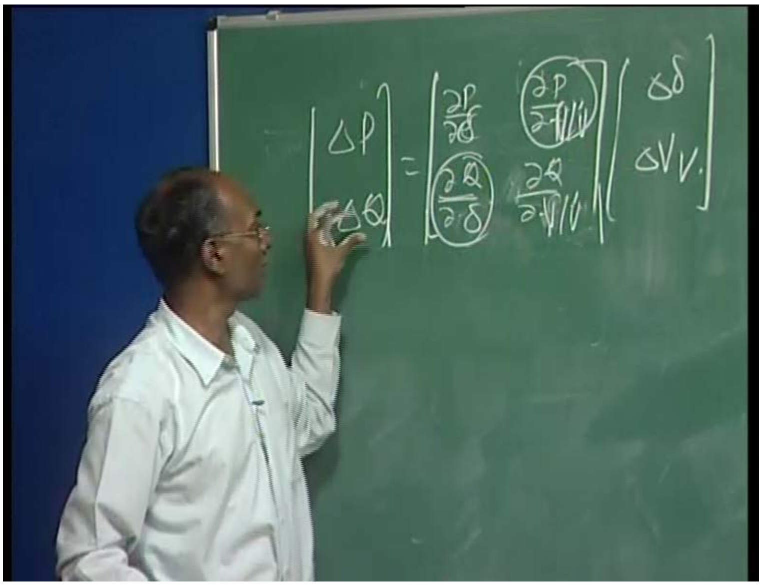

Now, I can remove this. And I only I we use del delta, here del V upon V. it was found that this Jacobean and your this Jacobean is very small. So, it was treated as zero and then, we can have the decoupled equations here. We can solve, this is a equal to this one, directly it is independent of this. Here, this is only dependent on this. So, this is a decoupled equation. Then, fast decoupled load flow came, we used this equation and we made certain assumptions that the sine delta here is equal to delta i j, if it is in radian. The cosine delta is treated as one and the multiplication of this here, with a delta here is very very larger than this. So, we can do some approximation and then, based on that FDLF method came. So, fast decoupled method is also used for the various application, even the also for the load flow and it has a various assumptions. Already, you can read the books for more detail. So, from the decoupled, the fast decoupled came and these are the basically, Newton-Raphson and the fast decoupled load flow methods are very widely used for all your applications. So, this is the comparison between this.

Now, I think we have to go for another one; that is, the DC. Now, looking at this, we have to now go for the various DC power flow methods. There are basically the three type of DC power flow methods can be categorized methods.

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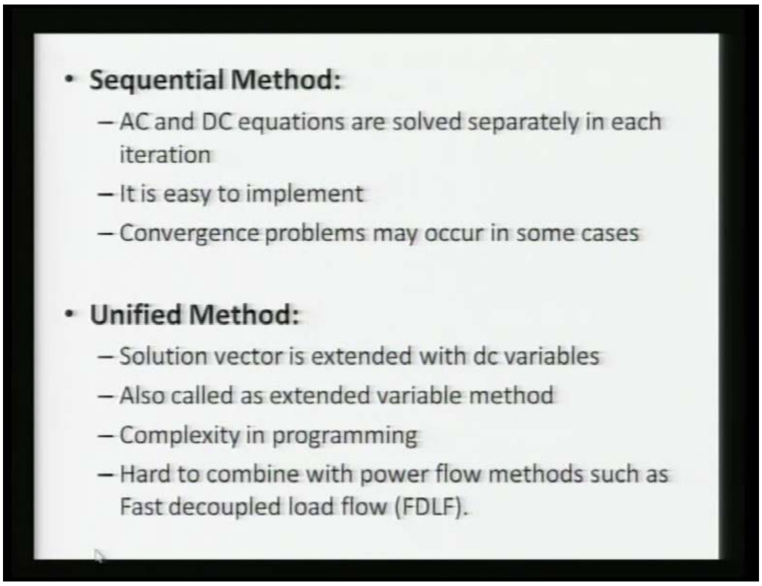

Here, one is called your sequential method; another is called your unified method. The two method is variedly, widely known. In the sequential method, what happens? You can see, it is AC and DC are solved separately, means you have to solve this AC, then you have to solve the DC because, this P and Q at the DC bus are basically known. Based on that, you can calculate your DC variables. So, the AC and DC equations are solved separately in each iteration. Only, you can see in the DC equations, AC variables are also there.

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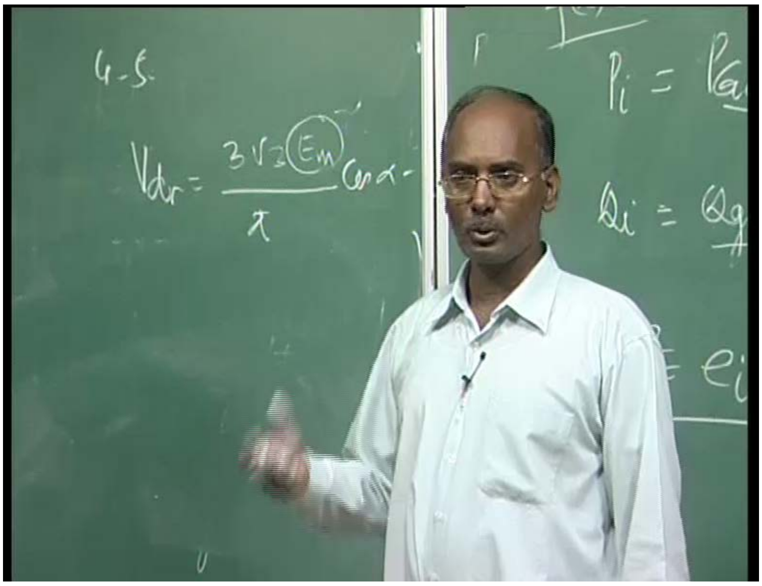

If you remember here, if you are writing this V d r, your 3 under root 3 E m, you are having by pi cos alpha minus 3 X c upon pi I d. Here, you are having, this is your AC voltage, the peak value or you can just make it to a rms value. So this, at that where it is converted is connected you are having the AC voltage. So, what you are doing? You are solving this, that voltage is coming here. You are calculating the DC variables. You are solving the DC equations. These variables, again you are just solving here and keep on, it is repeating. So, it is very easy and earlier it was used but, nowadays it is not used because, here the convergence becomes very difficult, because sometimes, it may be possible; that you are getting the oscillating solution, means your convergence criteria does not meet. Your convergence criteria here, it is your change in P. It is so, should be less than Epsilon value and change in Q in Epsilon value. Now, again here the question arise, since your fast equal method than the Newton-Raphson methods are based on the options. So, whether the solution is approximate solution or exact solution? To know to know this answer, you can see what is the solution?

Solution means we want f x for any equation, if we are not having f x is equal to 0, if you are getting x by any approximation, any assumptions, your this equation is satisfied for the given x; means this is the exact solution. So, in the Newton-Raphson and the fast decoupled methods, no doubt, we are having lot of assumptions.

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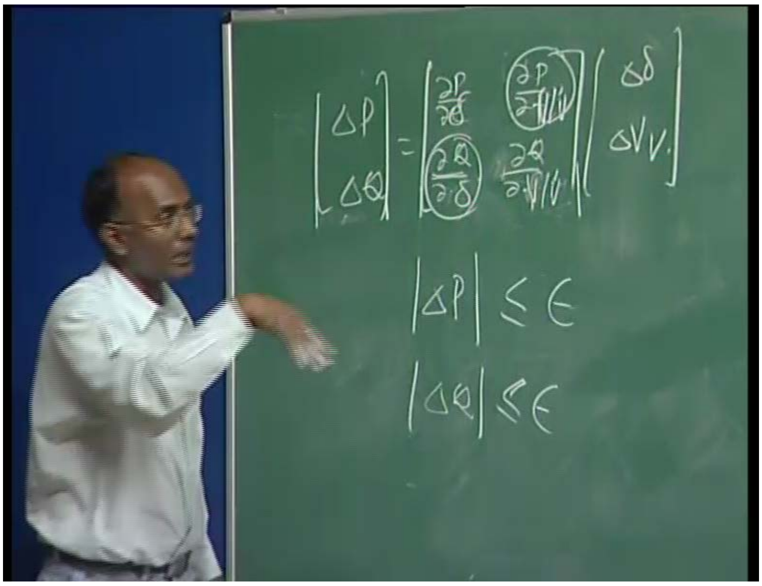

In spite, we have our convergence criteria. We are making del P and your del Q are less than or equal to your Epsilon. That is a very very small, if it is zero, this is the exact solution. So, your solution correctness, that is a based on your basically, I can say depending upon, is not based on your assumption, based on how much you are going to put your tolerance. If you are putting a high tolerance means, you are getting approximate solution. If you are putting the very tight means is equal to zero, you are getting the exact solution because, here this x is satisfying this equation. So, your whatever the criteria you are using, it is not required that one. We have to see the tolerance limit here. If you are putting very tight, it is called zero. If you are putting zero, it is very tight tolerance. If you are putting large value, it is very loose tolerance. And then, your correctness or exactness of solution is defined. So, another is called, here the I was talking, it is called your unified method. In this unified method, it is as name you are combining your AC and DC variables. In the sequentially sequence method, what we are doing? We are solving AC and DC separately.

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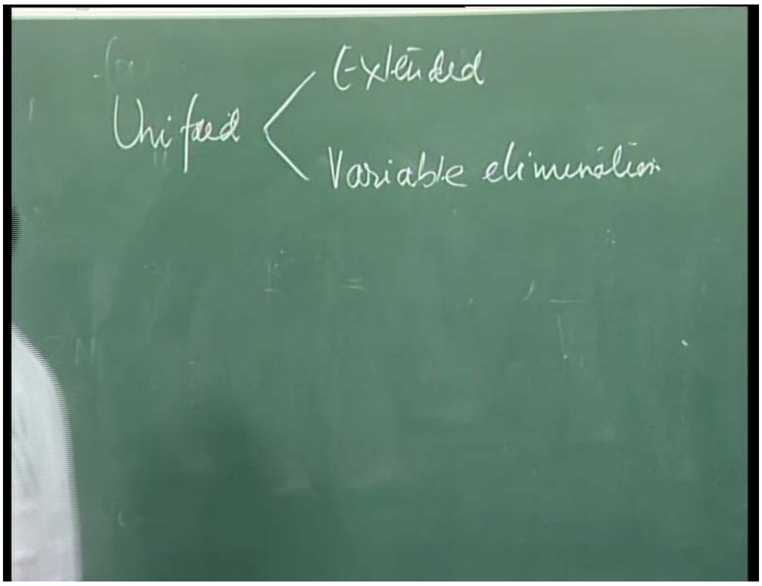

Here, in unified, again the unified, this method is of two type. One is called your extended variable method, another is called variable elimination method; means, your unified approach here. We are having the extended variable method and another is your called the variable elimination method. So, if you are here the solution vector basically is extended with the DC variable. Here, we are having P and Q, these are the AC variable.

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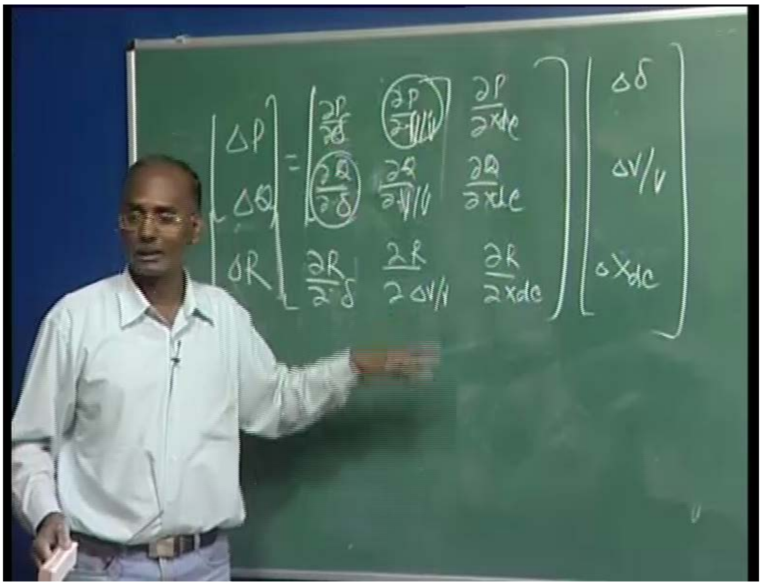

Now, if you are using some DC variables, equation corresponding to this and if you are having, here your variable that is x dc vector, then it is called extended, your Jacobean, you are extending it. We will see, what is R, what is x dc, what is the DC variables? And then, corresponding here, the elements are, those are modified; means here, we are adding del R over x oh sorry. So, we have to go for this extended, means it is not only adding here. We have to see here, del P x dc del Q x dc, here we are having del R, here it would be delta, del V, Why V? del R here, x dc. And now, here we are having our del delta del V upon V and here change in x dc. So, this is called your extended variable method. Because, we are extending this AC with the DC equations and then, we are solving in a unified way, not sequential way. Another, in unified way, that is I said the variable elimination method, what we do? We try to write these equations here, simplify in the such a fashion, that this equations can be substituted in the P and Q itself equations. And then, means the DC variables are eliminated. And then, we can just solve here, means they are inside, starting some value. And we can solve the voltage and angle and from there, we can calculate the x dc. It is called the variable elimination method and we will see later on.

So, if you are extending, it is called extended variable methods. Here, no doubt, your Jacobean sizes increased, the complexity in the programming are increased because, you are calculating some extra here the element, this element, this element, here, here and here. You are calculating the five more Jacobeans basically, I can say. And they are corresponding to various elements. Sometimes, it is very difficult especially in the extended variable methods. Now, you can say your FDLF does not work here. In FDLF, what we are doing, we are making this zero. But, now if you are making zero, still they are related to each other. So, you cannot have the decoupled equation and you cannot solve the unified equation. But, if you are having this variable elimination methods, you are having the same concept and then, you can even though try to apply that method as well for the various applications. So, in the variable elimination methods, the FDLF can be included, but if standard extended variable method, it is not possible. But, again both are very widely used because, if you are making here the elimination, you are making the complexity. Here, it is a very simply, you are adding the few equation, the DC equation and you are solving this Jacobean very simple. So, this is your unified approach.

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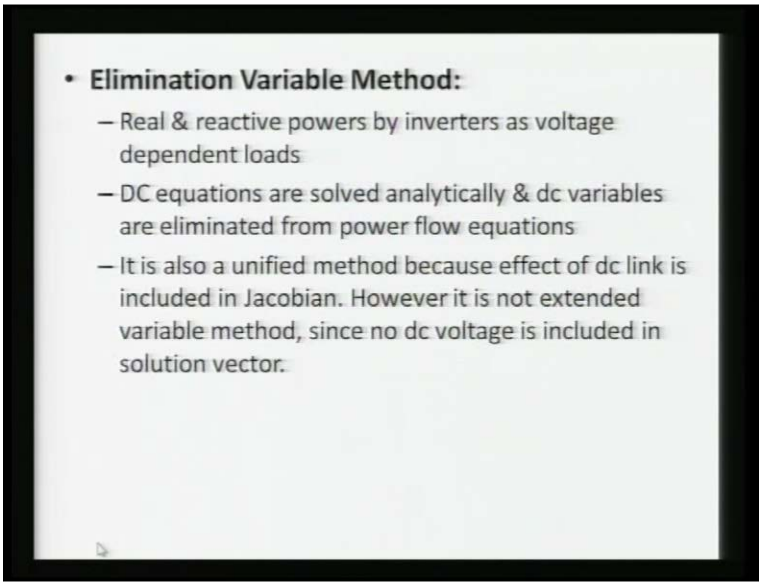

So, in these elimination variable methods, what we do? The real and reactive power by the inverters, we take as the voltage dependent loads. Then, the DC equations are solved analytically and the DC variables are eliminated from the power flow equations because, once you are taking load, here then, DC variables are solved and this variables basically included. It is also a unified method because, the effect of the DC is included in the Jacobean. Because, this extended method, here, it is also unified because, here in the Jacobean you are including this one. So, already this variables are there. No DC voltages include in the solution vector. Here, the DC voltage will see, we are not including in the just vector. What is the X dc, will see in the later on?

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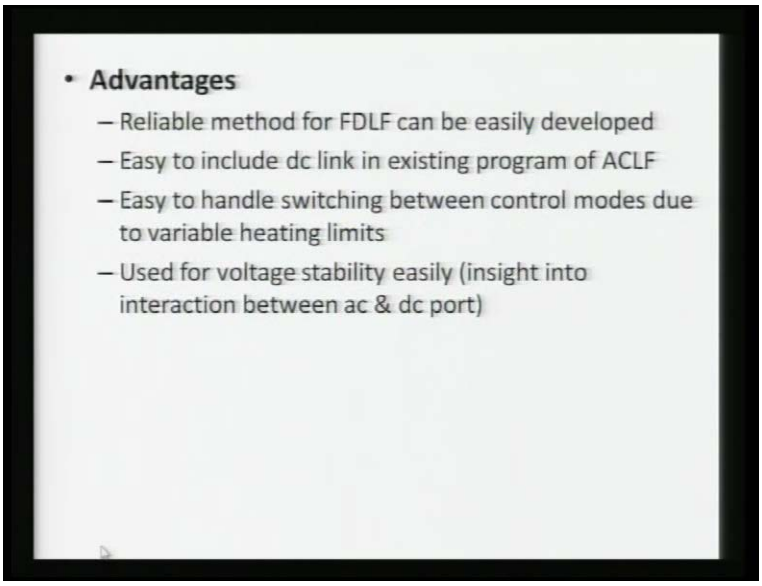

So, the unified, the variable method is a advantageous, that it can be this reliable methods. FDLF can be developed. It is a, it can be very easily incorporated in both your, already if you are having the this program code, you can very easily that put this value, the modify value here. In the unified scheme, you can very easily you can modify it. Only, your required will see, few elements will be changed, other will be not changed. Means, out of this, if you are having two terminal network, only this element corresponding to this node and this node will be changed, other will be as it is. So, in the unified that is a variable extended method, it is very easily to incorporate here only to modify the few elements. If you are going for extended variable method, you are using some more Jacobeans and then, it is slightly complex. Here, this is also very easy to handle the switching mode. Now, you know the converter characteristics remember, it is keep on changing.

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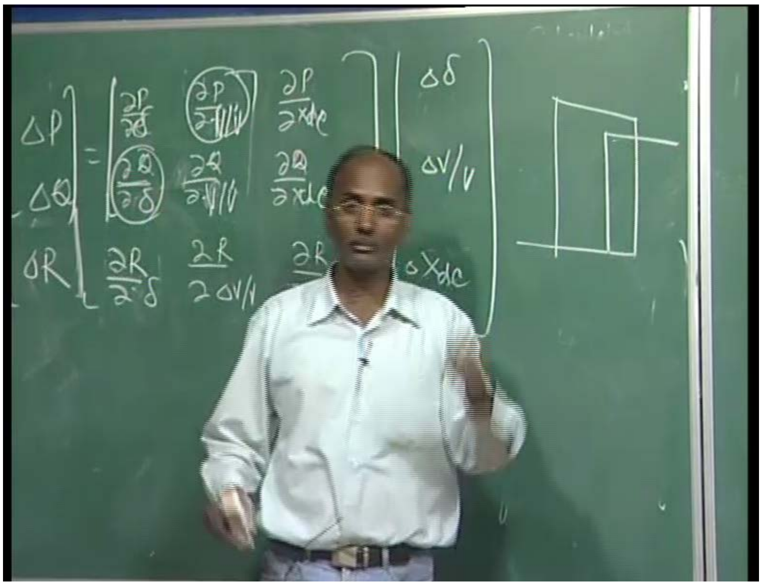

If you remember the converter characteristics here, it is not straight forward here, it is your like this. Now, we have to see where is a converter is operating? It is operating here or it is operating somewhere. So, the mode is where you are here, you are here, you are here or you are here. So, the modes are basically, keep on changing. So, in this also, you have to keep on changing your modes. We will see again. Now, it looks very complex but, once we will go and will analyze it. It will be very simple. It is also used very easily for the, if you are using the unified scheme with the variable elimination, you can again solve your same stability voltage, stability criteria and you can get it without any problem.

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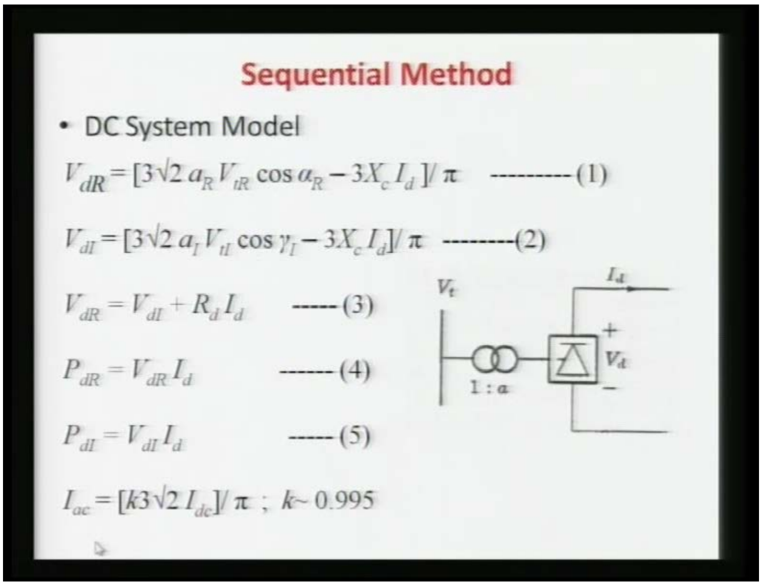

Now, here these are the five basic equations, we are keep on driving in the HVDC. Remember, here this is nothing but your the rectifier side voltage, this is I can say the rectifier. This is you can take as R, you can take this is aR because, the tapings of both side is changing. So, R is representing your rectifier and your I is representing the inverter. So, I can say here it is R, here is R, here I can say R. So, we have your the tap changers here. One is to a R, that is online as I said. The transformers are equipped with the online load OLTC, here it is having. This is your rectifier voltage. This is your AC terminal V dR voltage. So, already, we can write now, I am writing instead of E m, here under root 2 term is appearing. So, that we are writing the rms value. So, this is a terminal voltage, here you can say this is a simple, we were using this value. Now, here the V dR, you can say the 3 under 3 term under root 3 term is missing.

This under root three term is missing because, here we are taking in the per unit. If you are taking the per unit, again I will come later on that, what is the base quantities, what will be the base power, because the AC base is the different. We are having the base quantity because, load flow is solved in the per unit. So, similarly, we have to go for the DC side on the base. So, from the AC side base, we should have certain base for the DC. So, in the general sense, I can say here the this w R here, it is the rectifier delay angle minus here the reactance, this drop you have the inverter. This equation, basically is related with this equation in the other end because, there is a line impedance. Resistance is there and the inverter, this equation is there. The P R and the d I, we can calculate directly, this one. This AC will come, I will discuss later on. But, we are having the five basic equations. Out of these five, only three are the independent because, these are basically derived here. So, out of five, the three are the independent equation. One to three are basically here the R equation. We will see later. And these are again the here, we can solve the non-linear equations and then, we can incorporate in our either extended variable methods and the variable elimination methods. That, we will do in the next hour. So, with this I will stop it here and more the sequential method, will discuss on the next hour. Thank you.