Power System Dynamics and Control

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Lecture No. # 39
Frequency/Angular Stability Programs
Stability Phenomena:
Voltage Stability Example

In today's lecture, we will introduce you to the concept of voltage stability, but before we go on to studying this phenomena, let me do a bit of shift of what we were doing; we were studying the simulation of our two machine system. And in the previous lecture, I gave you expose of angular stability and frequency stability of a system, that is the stability of the centre of inertia motion as well as the stability of the relative motion of the system.

In today's lecture in the beginning, we will just briefly review, what goes into making an angular or frequency stability program. Today's lecture is, initially focused on frequency in angular stability programs, and there after I shall introduce you to voltage stability example. Now, remember that one of the objectives, of this course was to introduce you to some simulation tools or power system analysis tools and one of the most important stability tools is what is known as a transient stability program. Now normally transient stability refers to the study of large disturbance, relative angular stability

Now, if you look at transient stability programs, they essentially focus on phenomena which are roughly between 0.1 hertz to around 10 hertz kind of phenomena. So, you are focusing on electro mechanical oscillations of this kind of frequency range.

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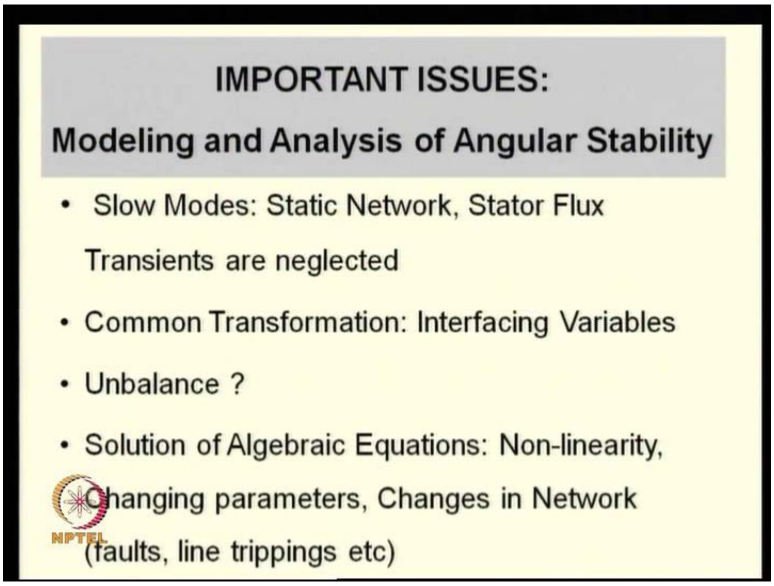

So, our modeling, as we did in our two machine example was suitable for this kind of a situation. If you recall, the key modeling issues, which are to be considered in the modeling analysis of angular stability or frequency stability as well, these are slow modes, they are slowly changing pattern in the system. So, you can represent the network by algebraic equation. So, that is what I call as a static network. So, recall that the network of course consists of the transmission lines, transformers, compensating capacitors and so on. So, that part of the network is represented by algebraic equations by effectively setting the d i by d t s and d v by d t s in the transform frame of reference.

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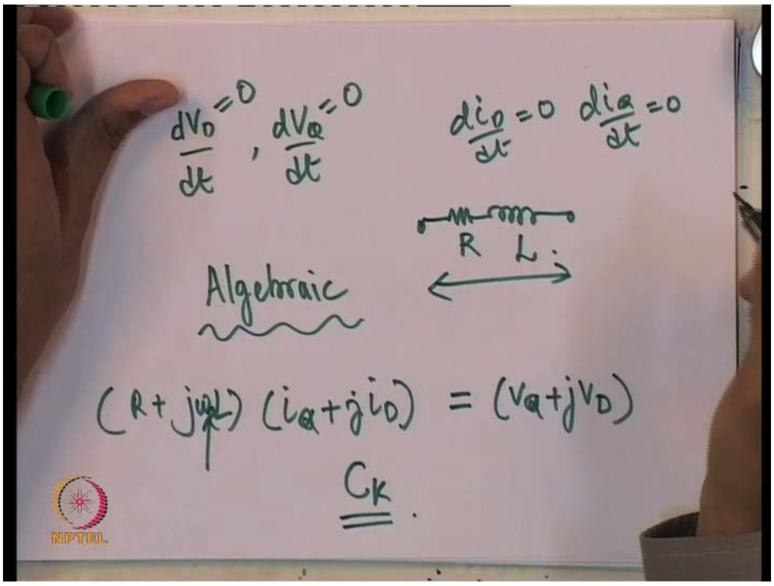

So, what we are doing is the voltage the transform voltages is d v are set equal to 0 in your equations of transmission lines and other components of the network. As a result, we will get algebraic equations. So, your network is represented by algebraic equations; and one of the interesting things, which we observe as far as transmission lines, which is also true of transformers etcetera is that you can represent balance network compactly by complex equations.

So, for example if you had a transmission line R and L, so we found out that, in case you neglect these d i d by d t for an inductive element neglect zero, in that case, an interesting representation of the network is the compact complex representation, which is nothing but R plus j omega L, omega is frequency of the transformation, which is used, we have talked of the transformation C k, which is a synchronously rotating transformation, say of constant frequency in that case is to be omega naught, and this is equal to the voltage across this; so this is the voltage across the inductive element. So, you can actually represent, this is a very compact notation and it is a familiar representation of the network. So, whenever you are writing down your algebraic equations of the network, you will find that effectively, you can represent the network by an admittance matrix.

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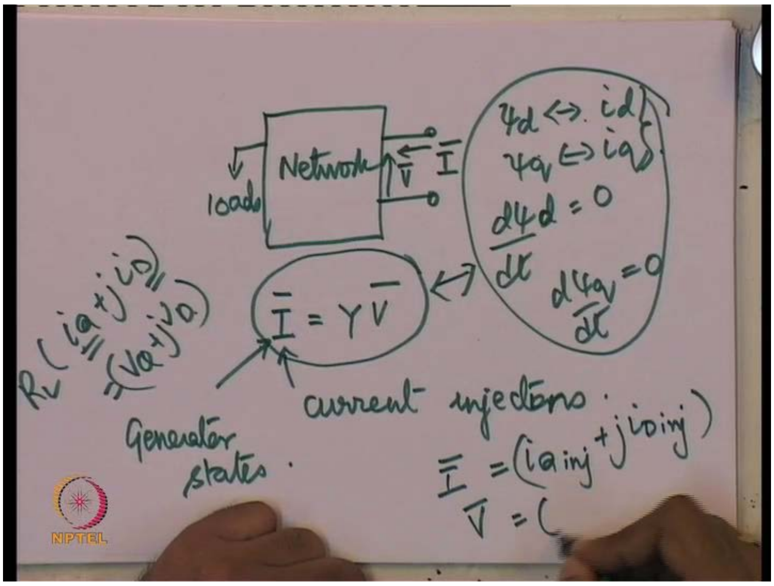

So, you can actually read the network as if you apply k v l, k c l to the individual elements or rather the topology of the inter connected network as well as the individual relationships of the elements, you will effectively get, that in case, so I will call this I bar and V bar, so the network can be represented by an admittance matrix. I as the injections, these injections are due to elements like generators etcetera. So, which are injecting current into the network? So, the network itself can be represented simply by I bar is equal to Y V, I bar being the current injections.

The current injections of course, are determined by the functions of the generator states. So, what you can do is gather all the algebraic equations corresponding to the generator as well as the network. In fact, if you look at the generator equations, if you neglect d psi d by d t is equal to 0 and d psi q by d t is equal to 0, then too, you will get an algebraic equation.

Then of course, there is also an algebraic relationship which relates psi d and i d and psi q and i q. So, these are all algebraic equations, which are obtained from the generator itself. So, you have got algebraic equations of the network, then you have got four algebraic equations per generator, obtained simply by the relationship between psi d and i d and psi q and i q as well as, because you have said d psi d by d t and d psi q by d t is equal to zero

So, these are the algebraic equations, which you have to combine with the network, now loads as well. So, if you have loads, they also may be represented algebraically, in some cases. For example, if you have got a purely resistive load, then the load current is simply i q plus j i d into r l is equal to v q plus j v d, this is the bus voltage, this is the load current. So, you can actually get various algebraic equations, depending on the loads and of course, the network is in the study of slow modes, slow a pattern is represented simply by an admittance matrix.

Remember, that i bar is nothing but the d q component of the current injections, these current injections are due to generators and other dynamical elements voltage, is the voltage at buses. So, remember that each element of the network will be represented by some equation of this kind, then all the currents and voltages are related to each other, depending on the topology of the network by kerchiefs of voltage and current loss. And, therefore you are going to get, what we commonly use as a admittance matrix of the network to represent its behavior.

Remember, that do not use the admittance matrix representation of a network in case you are interested in fast transients. So, anything faster than a few tens of hertz or may be 20, 30 hertz you may have to represent the network, by its differential equations and of course, if you are really interested in things like switching in lightening transient into represented, even in more detail, which is the partial differential equations or the travelling wave equations, which is the solution for partial differential equations. So, this is something you need to keep in mind and angular stability program will represent a network by algebraic equations. So, this is something you should remember and also stator transients are neglected. So, you have got four sets of rather four algebraic equations as a result of a generator.

Now, I cannot cover all dynamical elements, which are there in a power system. You have got things like a hpdc links and you could have fax devices, like static wire, compensators thruster, controlled series, compensators and so on. But remember the guiding principle in all these is that, represent the system by a model which is compatible with what transients are there of your interest. So, for example, if you are interested in very slow transients you may even representing devices like hpdc links etcetera. You can use the simplified notation as a controlled power flow in between two nodes

So, you have to really take that call, depending on what you want to really see. So, this is often matter of engineering judgment and of course, one way of verifying that what assumptions we make or what modeling simplifications, we make, are correct or not, is to actually compare at least for a few bench mark, examples the response we get by considering all details and the response, which we get by modeling simplification.

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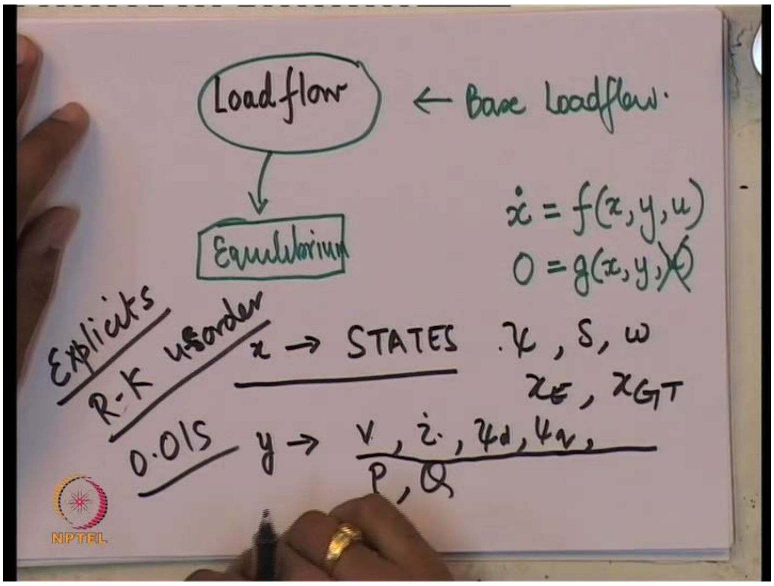

Now, getting back to our original problem that is talking of how you make a transient stability program or large scale transient stability program. What you would do first of course, is start of with some base case or what you want to study, some base case or base example. Remember that the whole idea of doing this kind of stability analysis, which you answer question select what if this happens? Does the system loose stability? In case this is the large disturbance. So, this kind of questions, if you have to answer, what you need to do first is, define first what your initial operating condition is.

So, usually whenever you do a transient stability program, you do not really start from the scratch, in the sense that you do not do the simulation of synchronizing of each individual generator to the grid and then you know lighting it up. What we usually assume is, that the system is operating at equilibrium at some 50 hertz kind of condition arts you know everything is normal and we operating the system at equilibrium. This is what the usual assumption, which is made. It does not mean that you cannot model things like synchronization, etcetera you can.

But remember one thing that if you are modeling a phenomena or rather the behavior of the system during synchronization of generator, remember that your frequency may be quite half nominal. So, some of the assumptions, we have made at omega almost equal to omega may not hold for that kind of study.

But typically if you are doing a transient stability study what you would like to do is assume that you are operating at a system certain equilibrium system condition, where certain load is being meant by certain generation and then your subject, the system to some credible contingency to see how the system behaves. So, that is what typically a stability program would like you to do.

So, first thing is think of a base case scenario that is do a load flow. Load flow of course, is a steady state kind of study, which tells you the flows and the voltage phases at various points in the network corresponding to certain specifications. So, if there is certain load generation configuration or a scenario, you can do a load flow and obtain all the voltage phases at all the buses from the voltage phases of all buses. The first step is computing the equilibrium values of all the states. We did this in a single machine infinite bus example, when we studied the a v r. So, you can look back few lectures you will really see how you can calculate initial conditions. So, an equilibrium condition of the state is computed from the load flow.

The next step is of course, define your contingency. Define what the disturbances you would like to study are, after that remember that your system is represented in general by equations of this kind x dot is equal to f x y and u and algebraic equations, because we are simplified and neglected several transients we get algebraic relationships x y and u.

Usually u will not appear in this, but it can and there is no reason for you can always have a situation, where inputs you could appear in this algebraic equations. What are these x y, x is other states. So, they are all the generator fluxes, deltas, omegas of all the generators, then all the states corresponding to the excitation system, governors and turbines. So, all these states are there depends you can also have other dynamical elements in your system you know you can have other controllers.

So, all that has to be substituted and brought on the states they are basically differential equations, y are the algebraic variables algebraic variables in the sense these are related to x through algebraic equations. So, examples are the voltage at all buses if you have neglected stator and network transients. So, voltage at all buses the currents through all branches you can also say power flows through to all the branches and Q’s they all related.

So, if you know v and i in all buses you also know p and q flows in the network then. So, y is usually consisting of voltages currents or P's and Q's then the d q fluxes in case you have neglected stator transients. What else, these are the basic algebraic variables. So, this is basically how your equations look like, if you are at equilibrium of course, if you have computed a equilibrium conditions correctly you will find that x dot will be equal to zero and everything stays where it is.

So, this is what really or the equations this is the form of the equations, now what you need to do of course, is to integrate these equations and numerically integrate them, using some integration method.

Now, one of the things which if you are formulated your equations and simplified the model by neglecting the fast transient, in some sense you are not faced with the problem of stiffness we have discussed what is the stiff system in the first the fifth to tenth lecture of this course. You would have seen that a stiff system is a system in which they are fast and slow transients.

So, the point is that, if I neglect or I make modeling simplifications and ensure that fast transients have been removed. In that case fine fast dynamic patterns are not visible in that case this system will not have fast patterns and as a result you can use explicit methods to integrate this system. If you feel you can integrate this set of equations using implicit integration methods as well, but explicit methods are easier, if they require lesser amount of computation eventually.

Now, explicit methods like R K fourth order are quite good. So, you can use Rungekutta fourth order to integrate this kind of system for angular stability studies. And one would expect, since we have neglected fast transients and we are interested in transients which says about 0.1 to 10 hertz. You can really take time steps of the order on ten milliseconds to one millisecond.

So, in this rough time step you will use, fix step explicit methods, if we had not neglected network transients and considered, all the fast transient, including the stator transients then one would have to use possibly there would not be any alternative, but you use implicit methods like trapezoidal rule or backward Euler otherwise you would have a problem.

But since you have removed the stiffness, you can actually use explicit method. So, what is commonly used and which is the convenient and modular kind of way, of simulating the system is to use the method like explicit method, like r k fourth order and basically this involves. So, you will basically discredit, the equations corresponding to the differential equations as well as the algebraic equations. In fact, the algebraic equations are simply something like this.

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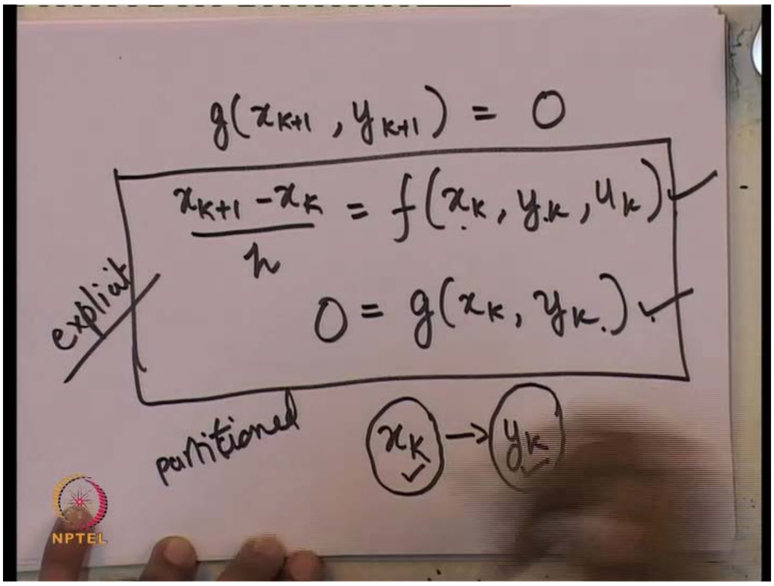

And suppose I have discredited, our differential equation by Euler method, this is what I would have had. Euler method is not a very good method for integrating, its not very accurate and very poor for stiff systems. But I am just showing you, what the equations would like? You would basically have to solve for x k plus 1, from x k using these equations. In fact, you can in fact, represent this is also true. So, if you take these two, all you have to do is of course, plug in the Keith value of these variables and get the k plus north value.

So, this is how an explicit method like Euler would look like Euler is not very accurate even though, you have removed the stiffness, from the system is not very accurate, its good, if you use an explicit method like r k fourth order

Now, this is how you would do it. What you can do? In fact, do a kind of partition solution. So, what you can do is for example, if you have x k get y k from this equation. So, if I have the previous value of the states I can get y k from this algebraic equation. As soon as, I get y k yap, but both x k and y k you plug it into this, in order to get x k plus one.

Similarly, now get y k plus one and repeat this procedure. So, this is called the partition solution where you are actually, solving this equation alternately. So, you plug in x k get y k, then use x k y k to get x k plus one and so on. So, this is called the partitioned explicit method. So, what is easy to implement, you have to simply plug in things and get the values, but there is one thing, which may take some extra time, is this particular equation. Now, this equation, if you look at it, it says it is an algebraic equation relating x k and y k, but in order to get y k from x k you will have to solve this algebraic equation and if this algebraic equation is non-linear, you will have a problem.

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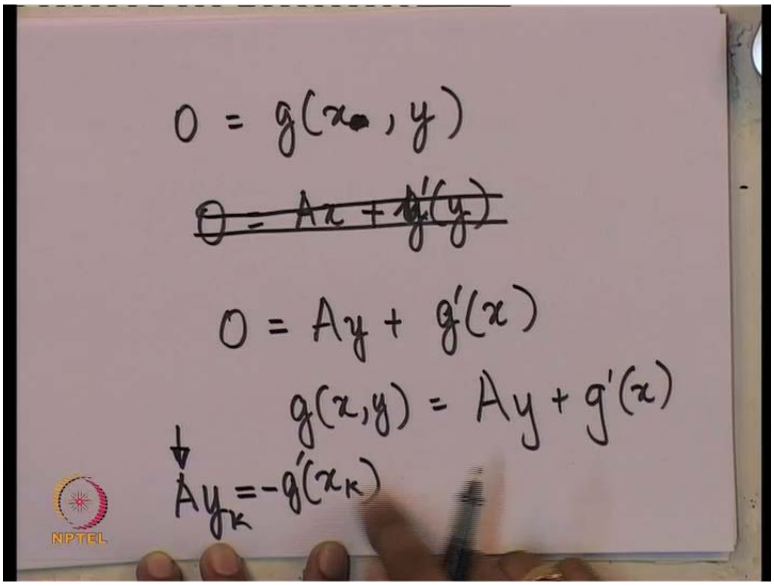

However, you have this. So, instead of having 0 is equal to g x y, suppose this is your algebraic equation, if it is of this form, rather this can be written as a into y plus g of g dash of x, suppose this particular algebraic equation has this form, that is the non-linear part really appears here, but the equations in the y themselves are simply a matrix into y. So, y appears in the equations in this form. So, suppose g of x y can be written in terms of a y plus g dash x. Our problem to some extent is solved, because if I know the Keith value of x in that case all you have to do is solve a y is equal to g dash x k. So, in that case you can directly do a linear solution. They will not require any iteration. So, you can use. In fact, you can solve this equation a y k is equal to g dash x k minus g dash x k to directly get y k.

So, you can get a direct solution for y k without doing and iterative kind of solutions. Of course, in a realistic situation this can be very large. So, you have to use special methods for linear system solution. But the point is that, the solution becomes simple. You do not have to use iterative solutions in order to get y k from x k. So, this happens, only if your g x y s of this form. So, this actually may be the case in some situations for example, the two machine example which, we solved sometime ago.

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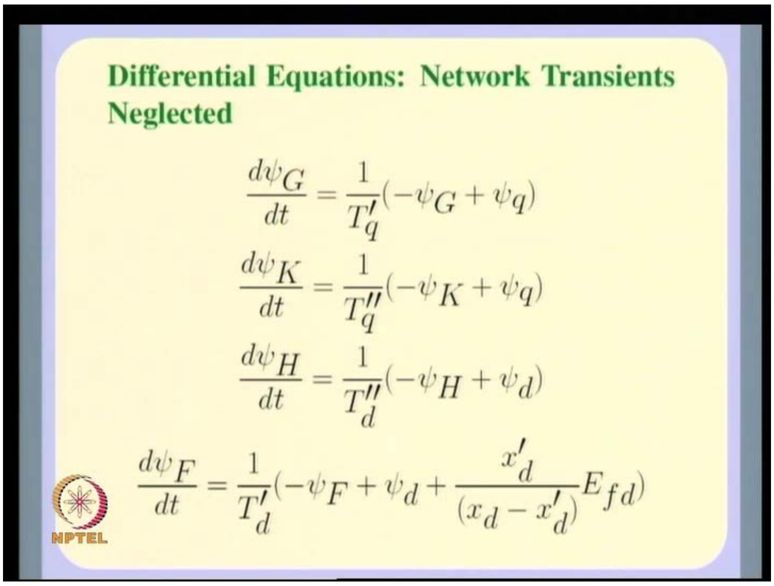

If you recall what our differential equations were?

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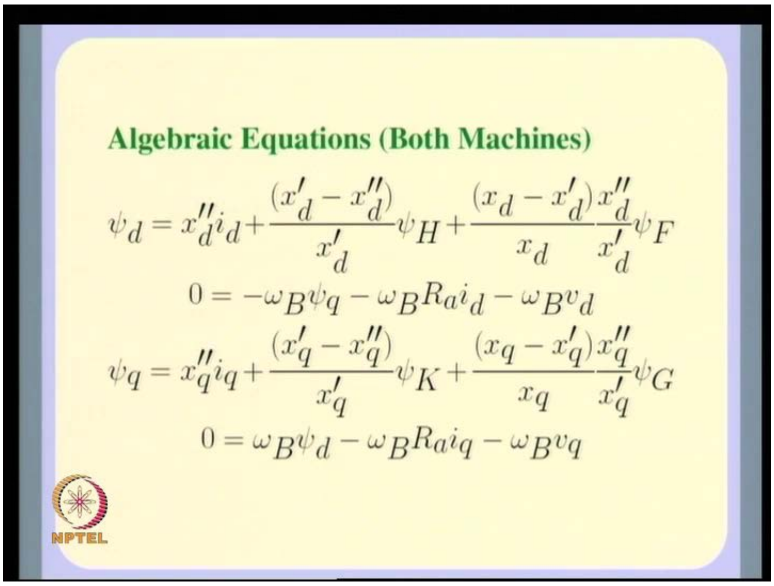

For the generators, were looking like this and the algebraic equations were like this.

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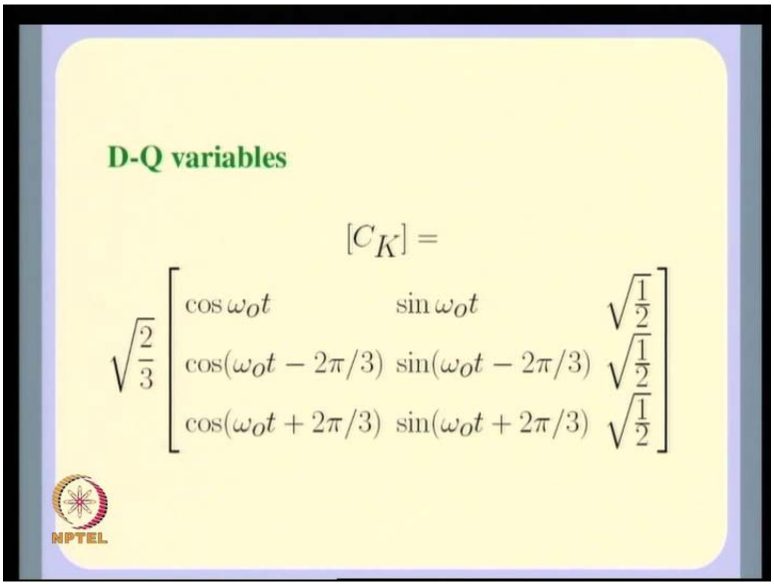

Since, we have to interface the equations of both machines, we converted the interface variables i d i q v d v q and psi d psi q using a common transformation c k. This is what we did and the algebraic equations of the network, which are supposed to be interface with the network equations.

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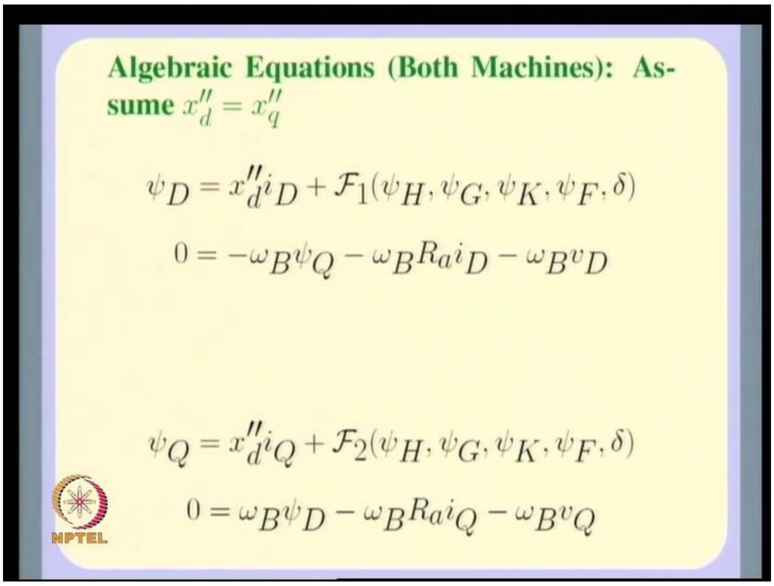

And the algebraic equations of the other machine to get the whole set of algebraic equations was looking like this. So, the first second third and fourth algebraic equation, of every synchronous generator look like this. In this case of course, we studied two synchronous machine. So, you would have similar equations here.

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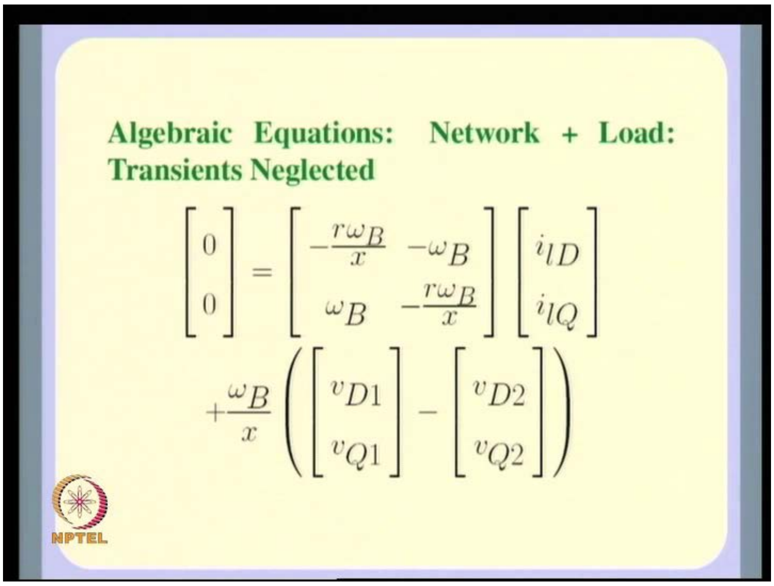

If you look at the network equations with transient neglected, they look like this.

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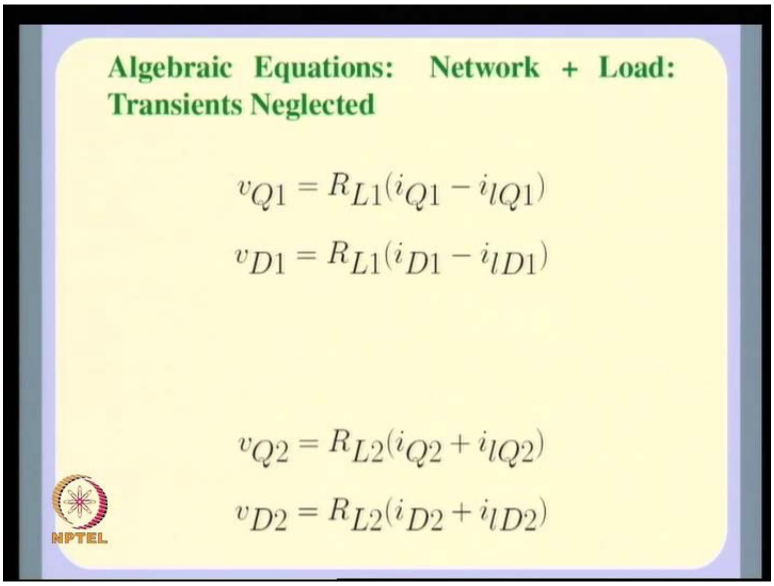

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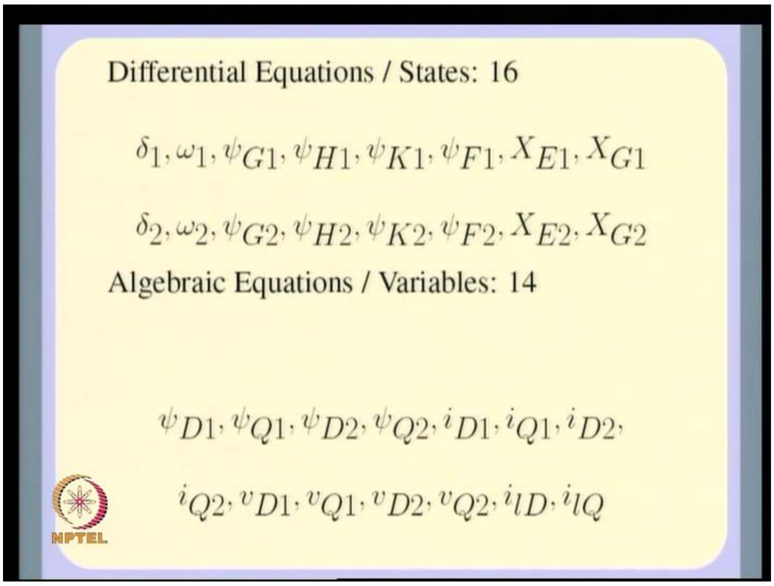

So, actually when you put all the algebraic equations together in fact, you would notice that a y this would actually have this form, where y would have been these 14 variables, which are seen on your screen.

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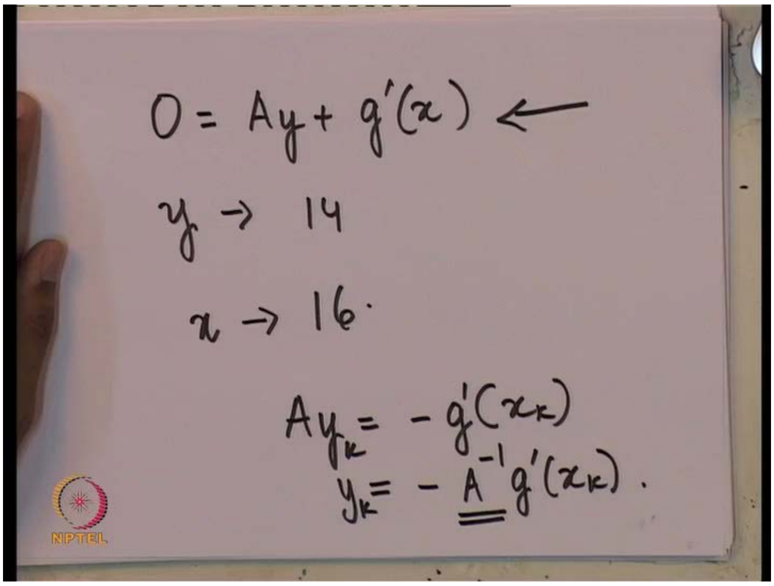

So, fourteen variables which you are seeing on the screen would be y and the differential equations would be 16. In fact, this form resulted, because we made one important assumption here that x t double dash is equal to x q double dash. So, if you look at this set of equations, the algebraic equations will come out to be of this form, only if x t double dash is equal to x q double dash. So, it is certainly not true, that your algebraic equations would always be of this from. So, this is something you should keep in mind.

So, in a partitioned explicit solution, what you would do is, in case your g of x would be of this form to solve for this equation and the interesting thing is that, if it does not change, when you are taking out the solution of this set of linear equations, you need not actually do this solution fully. Every time, what do I mean by that? Suppose, I have got basically g of x and at every time step you have to get y k from x k.

Now, what you would get, is a inverse g this is x k. So, if you could take out this inverse before hand and keep then at every step, all you have to do is multiply. This is the inverse, which you have already computed and stored with this g dash x k.

So, this is what you do at every step of course, there is a small issue here, that explicitly computing the inverse and storing, it is not a good idea. When you have got very large systems, because this is a matrix, even if a is a sparse matrix, a inverse is likely to be a full matrix. So, if you have got a network consisting of thousands of nodes, you will find that a is a large matrix, but which also sparse normally. The admittance matrixes of the network are in fact, sparse

So, this matrix, when you take out the inverse, is not necessarily sparse, it will be usually a full matrix. So, storing this a inverse again becomes a big issue. So, instead what we do is, you store the l u factors. You would have done in a previous course, on r system computation, that solving an equation can be done by computing the l u factors of the same matrix and then doing backward and forward substitution

Now, it turns out, that you can by appropriately ordering your variables y get reasonably sparse l u factors. So, the thing is that, instead of storing a inverse, you store the l u factors of a and then you just do backward and forward substitutions. This of course, requires, you to know little bit about linear system solution. So, I request you to look at any book and matrix computations, which will invariably talk of how to solve linear equations using this l u factors and backward and forward substitution

Then, what I am trying to tell you will become clear, the fact remains that, if a is constant, you can store the l u factors and if a is the small matrix, you can store the inverse as well before hand and at every time step in your numerical integration all you have to do is, actually do some simple calculations in order to get y k from x k you do not have to again at every step compute a anew

So, this is the advantage, in case you can get the algebraic equations, of your system in this form, this will not be true for example, if x t double dash is not equal to x q double dash, unfortunately or if you have got non-linear loads which cannot be represented as simple linear relationship between the current and the voltage.

So, this is something, which you should keep in mind. So, your algebraic equation formulation can be done in the way I mentioned and then you do a partitioned solution, you solve the algebraic equation to get y the variables y then use both x and y to get the new values of x by some numerical integration technique. So, since you have removed the stiffness, by modeling simplifications you can use explicit methods, which have quite accurate like Rungekutta fourth order.

Only in an academic sense, when you do it for the first time use Euler method, but then you will have to constrain your time step to quite small and you would get quite an inaccurate solution otherwise. So, what all transient stability programs do is, basically solve the differential algebraic equations. Algebraic equations arise because you neglected the network or the stator transients and of course, transients associated with any other fast acting device in the system.

So, the fast acting device in the system is depended on, what study you have. You may have things like hpdc links in also a other polyclone devices, which you may decide to model, but by algebraic equations instead of differential equations because the transient associated with them are quite fast.

Now, somebody, may ask that let us not neglect the fast transients, retain all the differential equations, can we actually study the system by considering both the fast and slow transient? The answer is yes. So, if you want to capture both fast and slow transients you will not make this modeling simplification. You would instead, use a more detailed model and then use a variable time step implicit method like backward Euler

In case you want to capture both fast and slow transients, it is a good idea to use a variable step implicit method. But since you have neglected fast transients and made the modeling simpler. We can use an explicit method implicit method in this case. Remember, they are more complicated because they will require you to solve non-linear algebraic equations in every time step. In case, you have got a non-linear system.

So, the differential equations in a synchronous machine are non-linear and if you want to use implicit methods, very honesty then you would have to solve the algebraic equations using iterative methods within every time step. So, that becomes real pain.

So, I would suggest of using a partition explicit method, at least the first time you try to program a transient stability simulation. Now, there are situations where you want to study slow tar which I mentioned may be appropriate for example, if you want to study relative angular motion which is around at a 0.1 to 1 hertz or 2 hertz, but you also may be interested in longer time dynamics, in that case you have to model system by using a transient stability like assumptions, but remember that once the fast transient in this case of the swings and the relative angular movement have come down, you can think of increasing time step

So, you can actually use a transient stability program for long term, transient behavior as well, but remember if you are studying long term behavior you have to make appropriate modeling you know you have to model a system appropriate for example, do if you are doing a long term simulation. You may have to model turbine boiler and other controls in more detail.

If it is a very long term simulation, you may have to model things like tap changing, stanch tap changing, transformers and so on. You may have to model things like you know the action of over excitation limiters in excitation system controllers and so on, which are relatively, slower acting kind of devices.

So, remember that, there is a distinction made between different kinds of programs required to study different kinds of phenomena, but if you use variable time step, implicit methods you can use a common model and use variable time steps to capture both the fast and slow transients.

In fact, now a day’s it is written in that way. Of course, there is one important point which you should remember, that suppose I have modeled the system, in which fast transients are modeled and I would like to use a variable time step implicit method.

Now, in case your system, which is modeling fast transients has got priding periodic switching’s like for example, in a hpdc system, you have got, what is known as the twelve pulse thruster bridge, you will have switching’s occurring every twelfth of a cycle and if you want to capture every switching. In that case, if you use a variable time step implicit method, you will not be able to increase your time steps because you will be forced to capture every switching every time. There is a kind of an event which you have to capture and that occurs at every twelfth second of a cycle, for a twelve pulse convertor.

In that case it would be a good idea, to use complete model of the system, with no simplifications for the study of both fast and slow transients. It is better to use a program which models switching’s and everything to study. Fast transients have a separate program and have a simplified model which uses larger time steps and possibly explicit methods and removes the stiffness out of the system, use that for studying other phenomena. So, you have two separate programs.

That is why in this course, I have talked a special program called a transient stability program. Otherwise you may say that, you model the whole system in detail and use variable time step implicit methods, do not make a distinction between fast and slow transients, but given the example which I gave you things like hpdc links etcetera. Where you are constraint, to keep the time step small, you will never be able to increase it because you are capturing every switching. In that case it does not make sense to have one over hatching kind of program, which models everything because you will not be able to increase the time steps because you have captured every switching event.

So, there is no point in modeling switching's, in case you are interested in long term dynamics. So, it is a good idea to make a separate program for long term dynamics, a separate program for transient stability and a separate program for studying very fast transients like switching's in polyclonal devices. So, this is one thing which is a general principle, which should guide you, when you are developing programs.

Now, we have discussed one stability tool called the transient stability tool. We can use this to stimulate a larger system consisting of many machines and so on. So, we move on to study the new phenomena, for some time we took a diversion we studied a analysis tool par system, analysis stability tool

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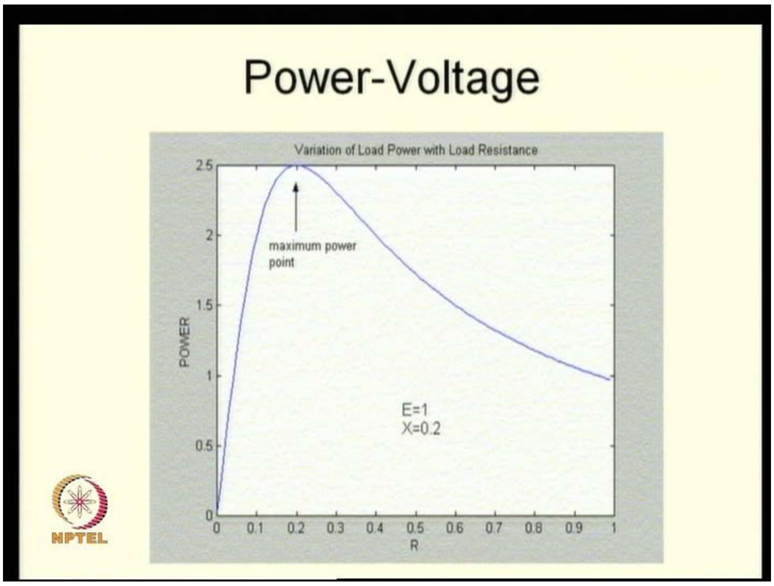

Now, we move on and try to study a phenomenon called voltage stability

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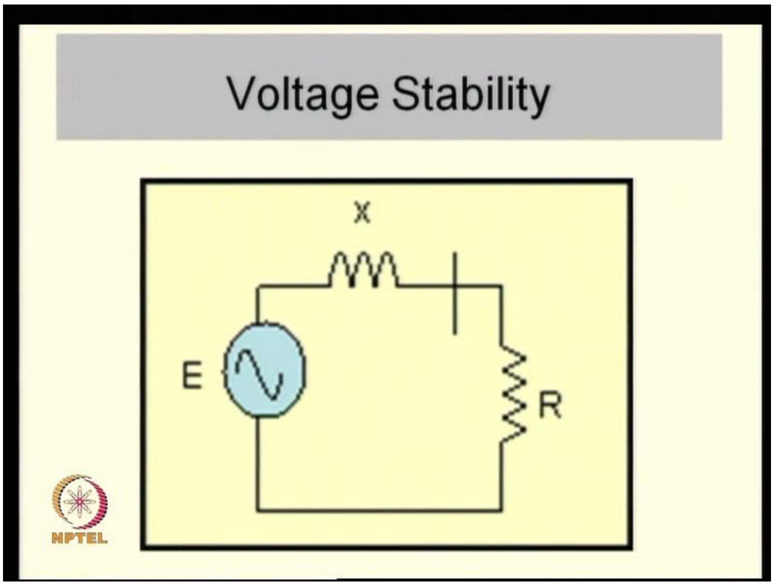

Now, when I introduce you to the topic of voltage stability, a very popular example is, this single source connected to a single load. So, they have got a voltage source sinusoidal voltage source, which is connected to load through an impedance which is in fact, the source impedance x and if you look at the characteristics of the system for a variable r its quite interesting. If you look at the voltage power and voltage characteristic, rather this is not the power and voltage characteristic. In fact, it is the resistance and power characteristics. So, you have got resistance in the x axis and power dissipated in the load or the load power on the y axis. So, it is a variation of load power with load resistance.

We assume e is equal to 1 and x is equal to 0.2 and now we plot the steady state power as a function of the resistance you will find that resistance is reduced from infinity, to open circuit condition. You will find that the power starts increasing. So, if I reduce the resistance, power increases, but there is a point. In fact, this is the maximum power point at which you will find any reduction in the resistance, actually causes the reduction in the power. This is because the reduction in resistance eventually causes the voltage drop to be. So, significant that power such dropping, but this occurs only after r is equal to x which is the maximum power point.

Now, what is the significance of this is, that if I go on reducing the load resistance your power increases, but after a point it decreases now the reason, why I show you this graph is that, it is certainly not true, that if you reduce resistance, power will increase always. If your r is beyond this point you will find it actually reducing r, decreases the power

So, this is an interesting point which you should remember, but of course, this is not expected to occur for example, unless r is near about equal to the source reactance. So, normally, this will not occur. Usually, the source impedance is much, much smaller than the load resistance that you will put. So, if you put a heater in your room and its winter and you want to increase the temperature of your room. So, connect a heater into a room, you connect another heater in parallel to it, we expect that the total power output will increase.

So, you take a heater, connect it to your plug point, you will find that the heater dissipates some amount of power, which is heating the room. You take another heater ,put it in parallel, with that heater also lights up and you will find the room becomes warmer quickly, but if the source impedance is very high, which is normally not the case, in that case putting another heater would cause such a voltage drop, that eventually your load power decreases. So, this does not occur normally and. So, this is something, which you normally do not encounter in our daily life.

This is another way of looking at this graph; this is the plot of the load voltage on the y axis with load power. So, this is what really, I wanted to say, if I decrease my resistance I will find that the load power is increasing, but beyond the point, decrease in r causes the reduction in the load power and interesting the voltage drops very significantly beyond this point. So in fact, take the resistance below this point, the amount of load power you will find at the voltage dropping. So, substantially the load power starts decreasing, when you decrease R. Remember that load power is v square by r voltage across the load divided square divided by r

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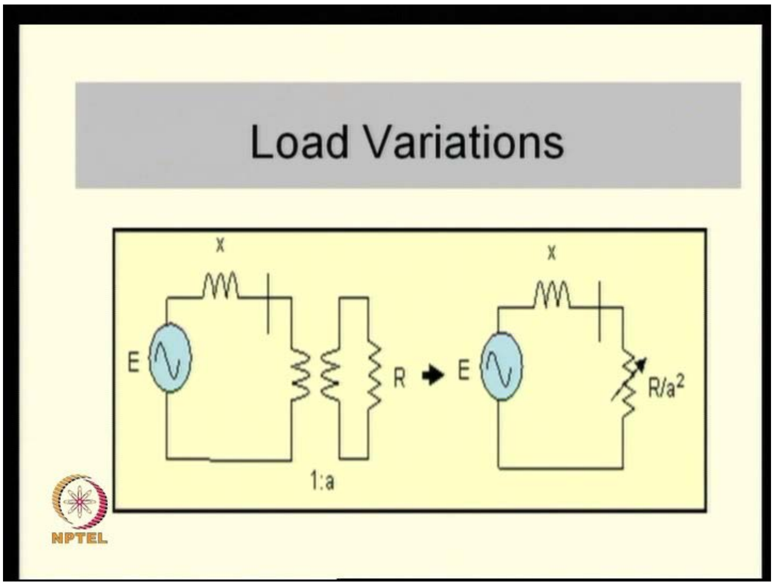

Now, normally this would not be a problem in the sense that we do not go on decreasing load the way I showed you, rather you do not decrease the resistance, the way I showed you. In fact, you have devices which implicitly do this; however, for example, consider what you see on your screen you have got the same system, except that, this resistance is failed wire transformer, which has got the turns ratio 1 is to a. So, if a is equal to 1, we are back to the old system because you can refer the resistance to the primary and that is simply R itself. So, if you have got of course, a tap ratio normally1 is to 1 transformer, but half nominally you have a tap ratio, then the resistance gets reflected on to the primary side as R by s square.

So, the thing is that suppose I have got a scheme load transformer in which I can change the tap setting and therefore, I can change a. So, that I try to regulate the voltage at the load. So, what I do is that, in case I find this voltage to be low, I increase the tap voltage which appears here would be, a into v. So, if I find voltage dropping here is low, here I can change the tap ratio and I show that you get whatever voltage or rather the voltage is the nominal voltage here at low, but from a system point of view for the source the source starts seeing the resistance which is R by a square. So, if a is greater than one, the resistance is low.

So, I can have a scheme of regulating load power. So, load in the sense that if the voltage decreases I still want to draw the same amount of power. So, what will I do is, voltage decreases on the primary side of the transformer, I increase the tap ratio a and reduce the resistance which is seen by the source and draw the same roughly the same amount of power. So, the moment I see the voltage decreasing I effectively reduce my resistance. So, this is what I would call as a dynamic load and I have called a selfish load at that, who tries to keep his load power constant by changing the tap ratio.

Now, this can sometime lead to a runaway situation, where you may have instability picture the voltage on the primary side of the transformer drops and I as a selfish load increase the tap a. So, that in spite of the fact that the voltage dropped here, I get the nominal voltage v, here as a result, I will draw the same amount of power. But because I have changed the tap ratio the system is seeing the lower resistance and therefore, the voltage may decrease. Further, this may become a runaway process in case this x is large.

Normally, reduction in a r will cause a reduction in r, effectively will cause load power to increase the amount of power dissipated in the load will increase, but of course, if this r starts approaching x, in that case a decrease in R, may cause load power also to decrease. So, you may have a runaway situation in the sense that I change the tap A, that decreases the effective resistance seen by the source that reduces the voltage. Further the drop in voltage results in again increasing A, that reduces the resistance seen by the source again that further reduces the voltage and that becomes a runaway process and the voltage collapses. Of course, it would not really collapse, because real tap changing transformer, would have limits, but the point is that your tap. So, go on increasing and the voltage will go on decreasing to a point of very low voltage.

So, the normal source impedance is not very large. So, it is certainly not true and the normal situations, that if you reduce your load resistance tap for example, you have got one bulb on your home, if you switch on another bulb, it does not cause the voltage collapse ,it is unlikely to do happen. But how can source impedance increase for example, a line trip occurs there are several parallel lines in a transmission network and one of the lines trips then x will increase, but even so, the source impedance is usually much lower than the load resistance. So, you will never have a situation happening, a transmission line, usually will not result in x been so large because they have the other parallel paths.

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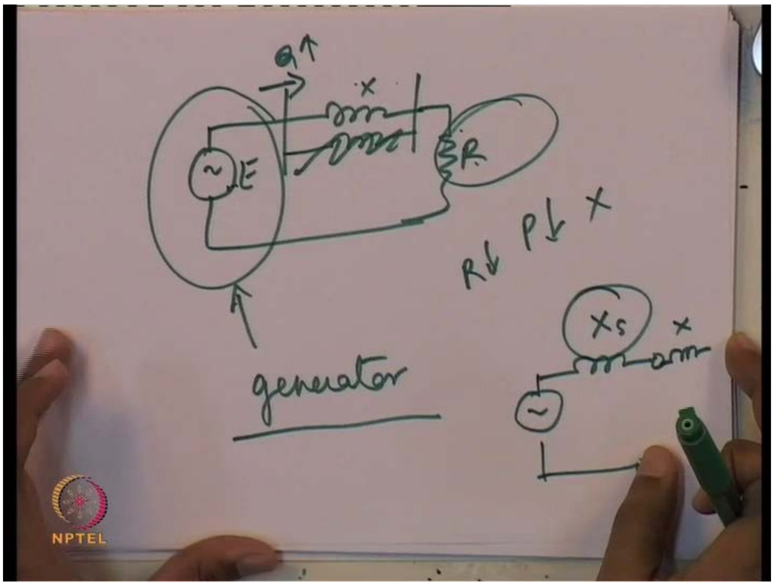

So, typically this will not happen, even after weakening the transmission network, but this can happen in case the source e itself has the source impedance. Now, think of the situation the source e is usually a generator this is a transmission network, the transmission network source impedance is normally much smaller than whatever load or typical load you will put on this network. So, even this transmission line is made out of two lines a even if you trip one transmission line, normally will not have a situation where reduction in r results in reduction in load power, this typically does not occur. But one more phenomena which you should remember, which can occur is relating to this source is equivalent of generator is not strictly speaking a stiff voltage source, but it can be made like a stiff voltage source. You can keep its magnitude at thermal constant because we can change the field voltage, which is applied to a synchronous generator

So, typically a synchronous generator, although it has got extremely poor voltage regulation, you can still make it as stiff voltage source because you can increase the field voltage every time the loading on the synchronous generator change. So, if the loading increases, you increase the field voltage and something which we have discussed in the modeling of a static excitation system is that, typically there is a very large margin there is a large range or large ceiling voltages provided in an excitation system.

But even if you starts loading the synchronous machine, you will find that the field voltage will go on increasing, but beyond the point you will not be able to do that because the field voltage would have hit its limit or the field current would have hit a limit, after which the field will start getting hot or rather heated up beyond the rating of the machine.

So, even although a synchronous generator field can be controlled so, as to regulate the terminal voltage and therefore, have practically a constant e at the terminals there is a limit. So, for example, you have got a two transmission line, you trip this transmission line and now the reactive power loading on the machine increases, in that case you may have encounters situation, where this synchronous machine hits its field voltage limit in trying to regulate the voltage, it hit its limit.

In such a situation you no longer have a well regulated source here, but instead you will have something like this, the full force of the synchronous reactance of a synchronous machine will come in series with the transmission line reactance and remember that this impedance can be quite large a synchronous reactance of a synchronous machine may be two per unit on its own base near about two per unit on its own base.

So, this can be really very large and under this situation you may encounter a very large source impedance effectively and thereby coming to a situation where reducing the resistance, actually reduces the load and therefore, you may have go into a voltage reductions spiral. If you have got a controlled selfish load, which reduces or increases the a in case of voltage drops.

So, this is the reason why you may have under certain circumstances a pure voltage collapse scenario. Though rarely, it can occur in case you have got a weak transmission network coupled with some of the synchronous machine heating the elements

You can have other situations, fast voltage collapse occurring for example, if you have got induction machines connected to very weak lines. So, if there is sudden disturbance which causes the slip of a induction machine to deviate like you got of fault or you connect another induction machine in parallel and the voltage dips, you can have induction machine stalling. So, this is also example of faster voltage collapse where induction machine draws more current because which slip increases that causes the further drop, which further causes a larger current to be drawn by the induction machine. Because its slip deviation is become large and you will find the complete voltage collapse, on all induction machines, at a bus stall this is also an example of voltage in stability.

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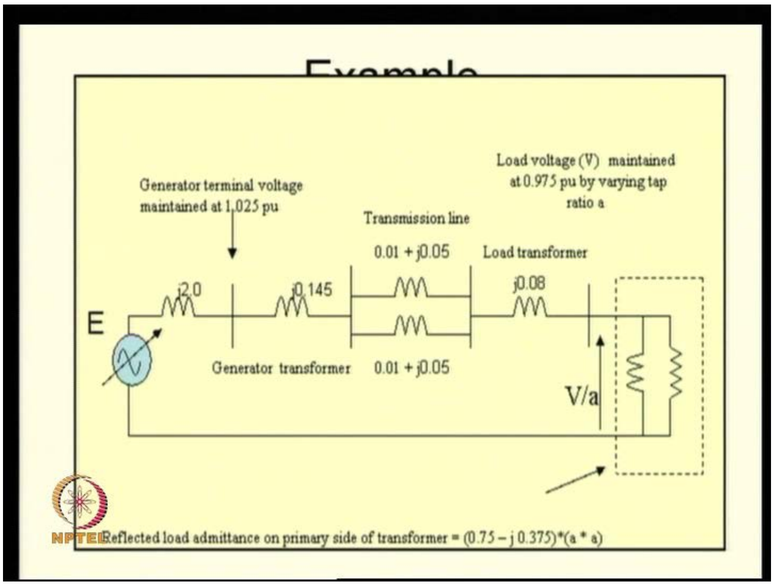

So, in the next class we will have a simulation of a system like this, and we will try to see what happens and try to simulate the situation it show that the tap changing actions of a transformer in order to maintain regulate voltage at the load bus in order that the load regulates the power. So, if you regulate the voltage at a load bus effectively regulating the power, you have becoming a selfish load. So, you are drawing the same amount of power in spite of the fact that the voltage is reduced. In fact, the system would be happy, if you were responsive load in the sense that the voltage drop you draw lesser power.

But in case of your tap changing transformers, you have got a control, which tries to over write this voltage dependence and tries to draw the same amount of power in spite of a reduced voltage. So, we will take an example and show you that under special circumstances, this can lead to a voltage collapse. So this is something we will do in the next lecture.