Power System Operations and Control
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Module - 2
Lecture – 09

Now, we have reached on lecture number nine of module two. In this lecture, we will see that the transient stability for the multi machine system. In previous lecture, we saw that is a equal area criteria for the single machine connected with the infinite system infinite bus system and also we saw the various way to improve the transient stability. Those methods for those were methods for improving transient stability that is a equally valid for multi machine system as well.

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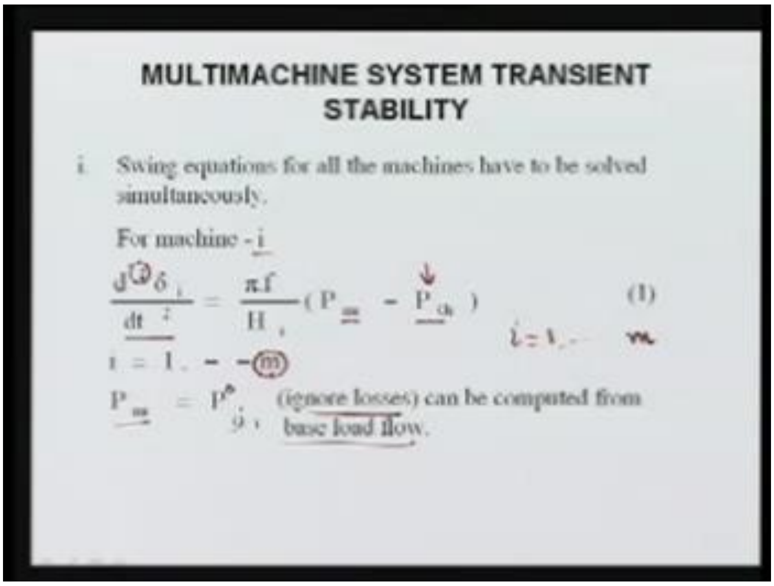

So, in this we can as suppose in multi machine system the n number m number of buses having n bus system. So, if your generator is connected at the various method busses and they are in m in number. Then, we can write the differential equation the swing equation for all the machines like here it is a double differentiation of delta with respect to time this that will be equal to your P i f divided by H i.

H i is the inertia constant of i th machine, that is multiplied by the difference of your mechanical power input to i th machine minus the electrical power output of that machine. So, this is the general swing equation for any i th machine, so we have to write the differential equation this is the second order differential equation. So, this i here will be starting from 1 to number of there are m machines, so we have to write m equation. Now, this E mi to know this value, this value is equal to your pg not g i means that is your initial power generation from the load flow that can be obtained ignoring the losses in the system.

So, the pm that is the mechanical input to the generator at the internal voltage of the generator it will be calculated by taking the P gi not that can be obtained using your base case load flow that will be P mi. So, we had seen that this P m that is mechanical power input to the alternators that is assumed to be constant during your transient stability program. So, this value is one fact and this P gi, which keeps on changing and that depends because basically this P gi is your output of your alternator and that depend upon the topology of the network.

So, now we have seen that that equation that swing equation here it is your order 2. We have also seen the various methods to calculate or to solve this differential equation, we have to have the single order differential equation.

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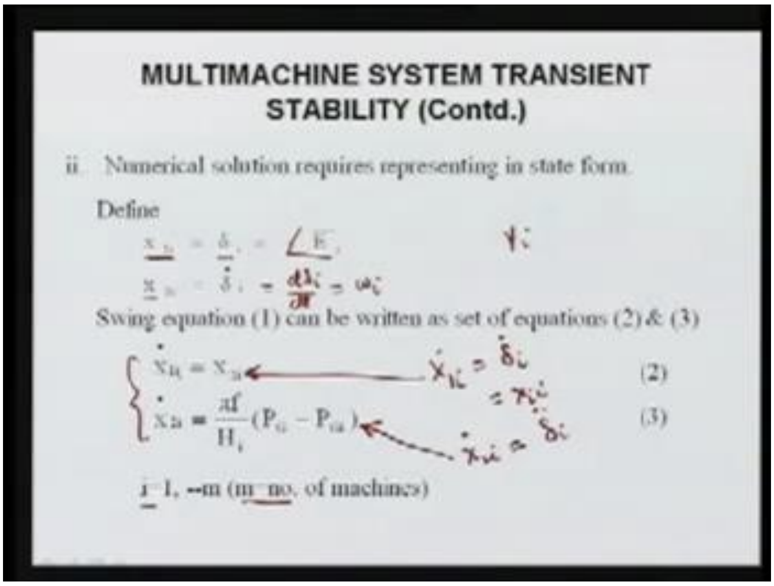

So, we can just convert that differential equation into the two differential equations of the first order and that can be done, that we can take one variable that is x 1 i here because for every i, we are calculating i, means number of generators. If it is m in the system, there will be m variables corresponding to x 1 i and this x 1 i just we have taken as the delta i. That delta i is nothing but it is your angle of your E i that is the internal induced EMF of highest generator, this is a angle of that one. Your second variable that is x 2 corresponding to i th machine that is a x 2 i will be the derivation of your delta i, means this is nothing but your d delta i over d t and this is we know this is nothing but it is your omega i.

Now, swing equation one can be written as the set of equation 2 and 3 and 2 is nothing, one I can write what is this? This delta i here, this is your delta i, so I can write here x 1 i, if you are diff differentiating this, so we are getting your x here. You can understand x i dot will be equal to your delta i dot that is the differentiation of delta, and this delta i already we have form the here, we can say this is nothing but your x 2 i. So, we have our differential equation corresponding to this one, another one if you are differentiating your x 2 i that will be nothing but your double differentiation of your delta i. This is nothing but the differential equation that the swing equation here this is nothing but this equation.

So, we can here write that x 2 i will be giving you this equation, so this is for all this machines you are going to get two differential equations if you are taking machine as a classical model. If you are taking it, again very accurate modeling of generating system then the differential equation will be changed, then it will be of the different order. So, here you are getting the two differential first order differential equations corresponding to each machine that is alternator. So, if it is m in number, then you have to write for all this nodes there, so to solve that that, we have taken the classical machine model.

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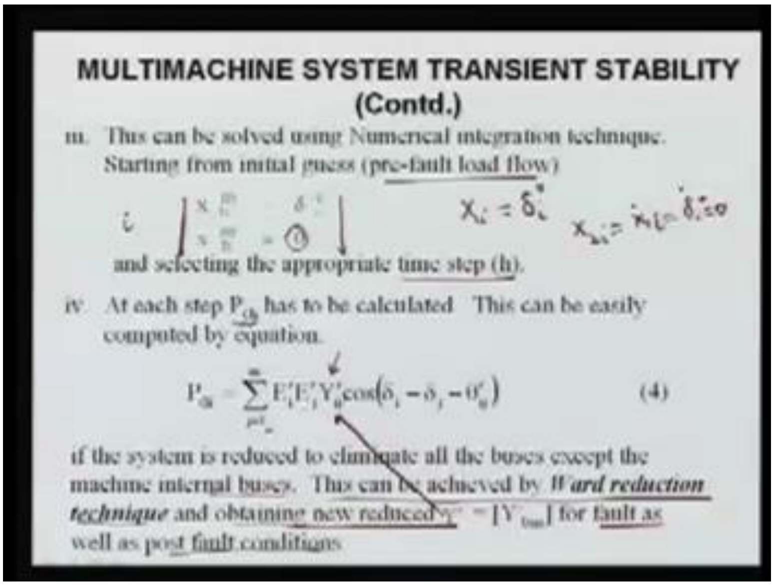

So, this can be solved using the numerical integration technique as already I have discussed that we can solve either by modified Euler methods Runge-Kutta methods or trapezoidal integration method. To start with, to start any numerical integration technique we require some initial guess. That initial guess that we can have the initial guess for our transient stability program, means your x 1 i is nothing but your delta and delta that is delta naught. This delta not is nothing but the initial that you are getting from the load flow, this delta of individual machine that is highest machine that is your 0 that is not, so it is a pre fault load flow that you can get.

We also know that here, since this delta i is a constant, so your x 2 it is nothing but your x 1 i dot that is a d x upon d t and this is here your d i naught differentiation, means this is your 0, so this value will be 0. So, starting with for all the machines here, I am talking for i and this i is true for all the machines and that is in m in your number. At the same time, you have to also select the appropriate time step of your integration as I explained in the previous lecture that, this time step is very important because this time step gives sometime less accurate. If you choose, you are choosing this h in the different way, your solution maybe unstable and the same time you may get inaccurate result as well.

So, the choice of this is also very important, if your step is very small, it may take more CPU time or computational time. So, you have to judge and it depends upon system to system.

So, at each step the P gi has to be calculated this P gi that is the electrical output of i th machine that can be easily calculated using the y bus. This is nothing but your P gi is equal to your summation, for all the buses here m and here E i prime E j prime V ij cos delta i minus delta j minus theta ij. Here, this is your V ij is a y prime, I have written this y prime is calculated from the y bus system, in this case what we do? Normally, we eliminate all the buses except the generating buses for the different conditions means pre fault, post fault and the during fault condition. So, if the system is reduced to eliminate all the busses, except the machine internal buses, this can be achieved by ward reduction technique that is very popular technique.

Based on that, we can reduce we can only keep the internal buses of the generating units and the remaining bus, we cannot just eliminate. Then, we can obtain the new reduced y prime bus y prime and that is here the element V ij is the element of this one. So, it is for the fault as well as the post fault condition, so we have to get for the pre fault post fault and the during fault conditions to see how we can get this y prime matrix.

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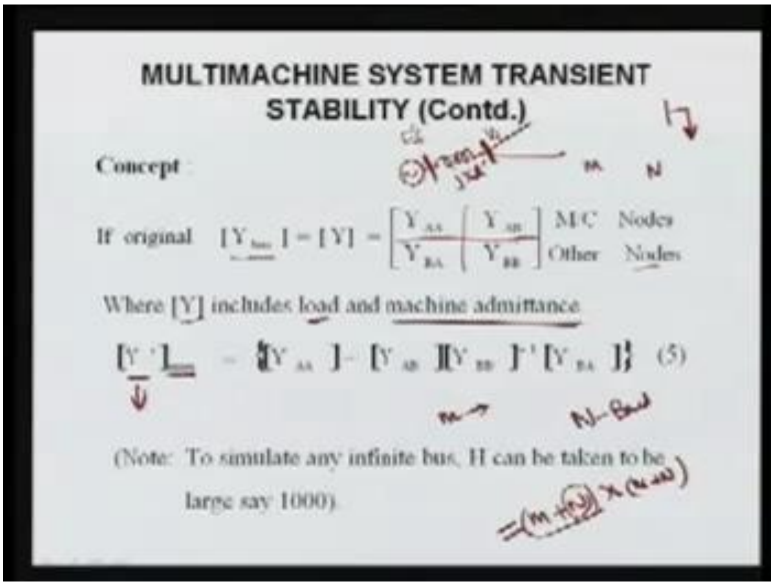

If your original matrix that is your y bus is here, I can again categorize because in your system, let us suppose you have n bus. So, in this n, you have m machine internal nodes and remaining are your other nodes, so we can write this y bus in here like this.

So, this matrix AA corresponding to the all the internal nodes of the machine and here AB is between the other nodes with the internal and so on so forth. So, we can from this y bus as usual that is using the power flow analysis. Only the difference in the y bus here as well as in the load flow normal load flow, that is why bus includes load and the machine admittance as well. In this, as you know in the load flow we only take the impedances admittances of the transmission line transformer and the science. We never take the machine admittance as well as the load admittance, we take load as a P Q, we take machine as a injection of the power at the terminal buses.

So, here of a single machine, let us suppose your machine here, this is your generator, now this generator will have some reactance and this is your V t. So, we are having another node here that is called your E f or E prime that is your excitation voltage. So, this impedance is also included in y bus and this is your j x d prime. So, that is included here, but in the normal y bus of the load flow, we never include, but here we are including that one. So, now if your n bus system your system is having let us suppose n bus and it is having m machines. Then, this y bus matrix here, just you are forming it is nothing but your m plus n bus matrix because here this is your number of buses in the system, where generator is connected we have extended one more internal bus.

So, it is a total number of y bus order will be this cross this matrix so that I am just emphasizing that here we are including the internal, this machine admittance as well as the load admittance. If your load here for example, at this bus is load is there, so we have to include this load into its admittance form and that will be again taken into the account. So, now our intension is to reduce this matrix to keep only these m buses that is m cross matrix means we are only trying to keep these internal buses of all the generating system and even all the buses of the system.

So, we have to eliminate this n matrix, so what we can do this matrix element, Y AA minus Y AB here, then inverse of this multiplier multiplied by BA that will give your Y prime m cross n matrix and that is called your reduced bus. That is keeping only the internal load nodes of machine, in whole simulation if there is any infinite bus is return for that h can be taken very la large very huge value and that can be even though taken as 1000. Now, to see the transient simulation program, how it will move, then you have to go for this.

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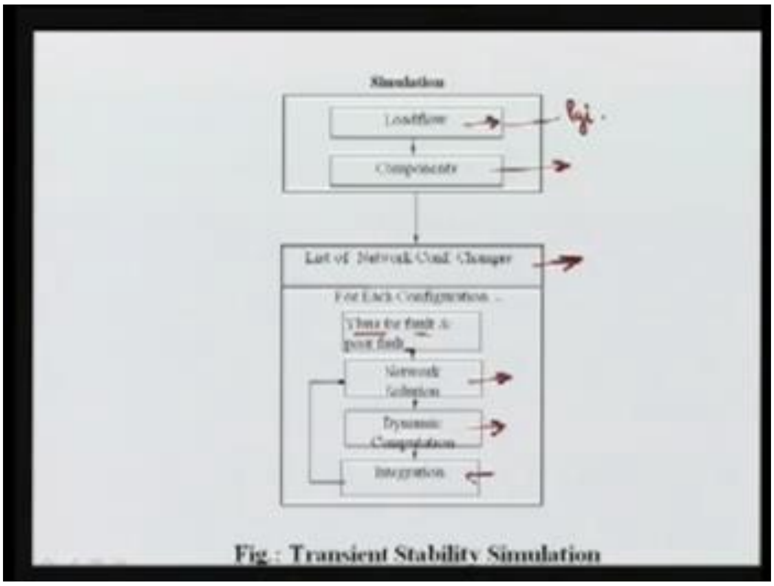

First, you have to run the load flow and from the load flow you can get this Pgi's at already generating stations. So, after getting this P gi, then you have to model the components the various components in the system. Then, you have to list what are the configuration network changes, means during fault post fault and the pre fault conditions and for each configuration, you have to form y bus for fault and the post condition. Then, you have to solve the network solutions, and then you have to go for the dynamic solution of this whole dynamics of the system using the integration techniques. Then, you have to keep on doing till your final conversation and final the time domain where you are going to simulate this.

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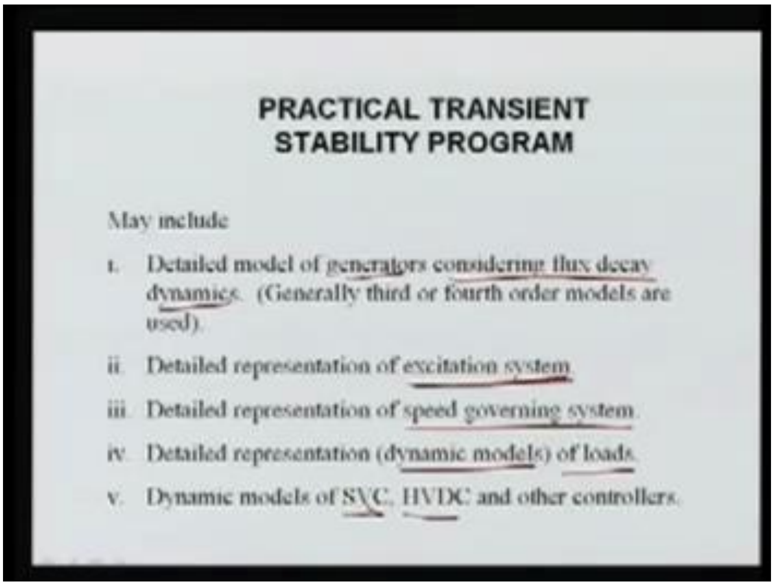

So, the practical transient stability program should have detailed model of generating stations or generators including the flux decay dynamics, generally third or fourth order models are used. So, even though there is higher order for machine dynamics can be also model, but normally we can go up to second or third dynamics of system, also we have to represent excitation system in detail. This excitation system will have a different type of excitation systems are used for the different type of machines. So, that will be also included in your practical transient stability program because it is not only that you can model the classical model, where we never model the excitation system, only we model the machine without taking its inertia.

So, in the detail and practical transient stability program, we have to model the generators in detail. We have to model the excitation system, we have to model the speed governing system also as well and we have to also go for the detailed representation of the loads because in the loads, there will be two type of loads. One maybe your static loads, another maybe dynamic load, dynamic load such as the motors. So, the motor dynamics will be also included if it is a static load simple your P and Q loads. Then, you can modelize the static, but the most of you know the 8 percent of loads in power system is the induction motor loads and that is a dynamic in nature.

So that dynamic should also be included in the practical transient stability programs if your system is having some other devices. For example, let us suppose FACTS controllers, it may have your SVC, it may have your TCSC that is the thyristor controlled series compensators, it may have the static synchronous series compensation it may have the unified power flow controller. So, we have to model these devices as well accordingly and we have to take the dynamic model of these devices to see the transient stability program.

If your system is having HVDC, then you have to also model the dynamic of HVDC accordingly and this HVDC modeling, again you have to take the dynamic along with their controllers. We know this SV, the FACTS controllers are very important to enhance the power system stability. It can enhance all type of stability, it can be improving your transient stability, it can improve your dynamic stability, it can also improve your the voltage stability. So, these devices are now coming into the practical power system and they must be model accordingly so that we can see the detail impact of the stability on the system dynamic model, let us see the dynamic model of synchronous generators.

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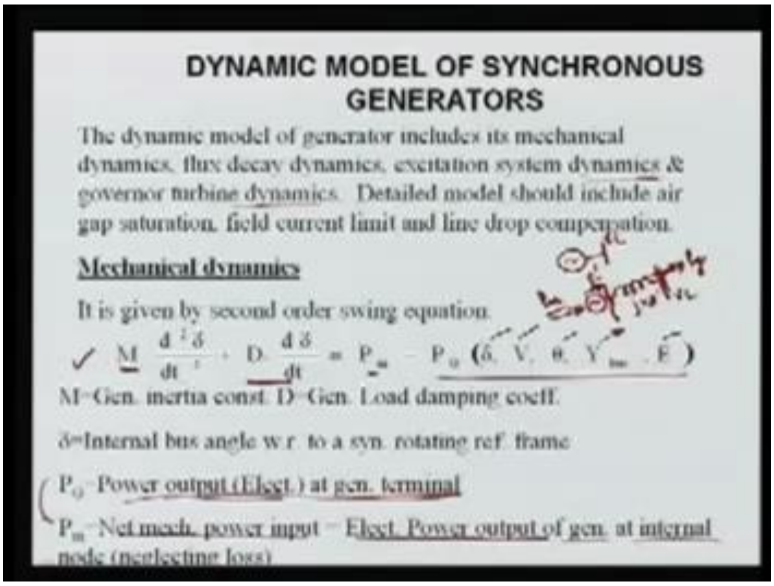

The dynamic model of generator includes its mechanical dynamics mechanical dynamic means again swing equation flux decay dynamics, again the representation detail, representation of the machine itself.

Then, excitation system dynamics that is the machine is equipped with the fast acting voltage regulators AVR. Then, we have to model this EXCIS excitation system dynamics and also we have to model the governor turbine dynamics because the governor of the turbine that gives the input to your synchronous machine. That may also work and it may change your in mechanical input power. So, if your study is for the particular long time, then this dynamics is also very important. So, we have to include all these dynamics including your mechanical dynamics machines flux decays dynamic excitation system dynamics and your governing system dynamics.

Detailed model should include air gap saturation, again in this you know your binding of machine may get saturated. So, the saturation effect should also be taken into account field current limits because there is several limits because field current cannot exceed certain values as you know there will be field hitting limits. So, that limits and also the line drop compensation, this is also used that thus this compensation should not exceed that value. So, all these models should also be included in this synchronous generator model. To see this mechanical dynamics, now we have to so far in the classical model, we ignore the term, this is your swing equation.

Here, this term this term is nothing but this damping of the system this is the generator load damping coefficient that is a d that is coming to the picture. In the previous case, we ignore this and then we solve the dynamic equation that is the swing equation of the machine, which is basically mechanical dynamics because here the angle and here machines inertia constant etcetera are included. So, now in the practical transient stability program, this is also taken into account and that impact a lot in the transient stability and other stability considerations.

So, we can write the second order swing equation including your m is angular momentum that is a double differentiation of delta with respect to time. Then, plus your damping coefficient that is k multi d multiplied by speed. That will be equal to your mechanical power input to the alternator and your electrical power output, that is a function of your voltages angles theta, theta is the basically admittance between your 2 i and j bus here y bus element as well as you internal magnitude of the internal busses. So, all these are included this P gi, so this pg is the power output that is electrical at the generator terminal.

This pm is the net mechanical power input and that is nothing but that is equal to your electrical power output of the generator at the internal node what it means? This is your generator and it is connected with this terminal bus, here it is your vt, this machine can be represented by here E f it is a impedance and this is your V t. Now, here we have E prime that is u that is a sometimes your E f that is the field excitation this is nothing but you r j x d prime. So, your P g is here that is coming out this P g is here and your pm which is coming here that is input to this it is equal to that is coming at this here internal node output.

If your losses are less or neglected in the machine losses here, so this can be equal to your power output of the internal bus, so that is why here written the electrical power output of generators at internal node that is here rather than here. It is your terminal voltage and that is your electrical output at generator terminal, so this is the difference between P g and P m.

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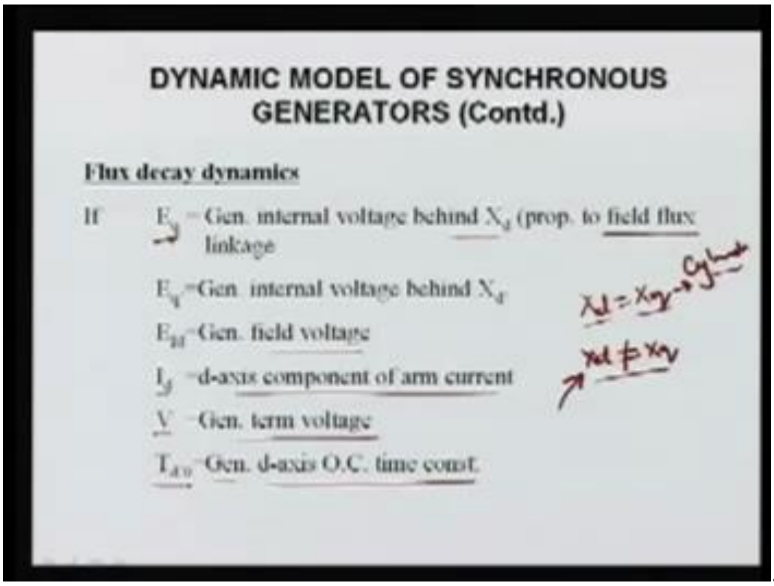

Now, coming to this flux decay dynamics, means detailed representation of machine itself, you know that two fluxes are there. One is rotate rotor flux, another is your armature flux both are rotating in air gap at the synchronous speed and the torque that is electrical power is produced due to the interaction of these two flux. So, the flux decay dynamic is used in most of the cases as I said it may be your salient type of your machine.

It maybe your cylindrical rotor, wherein the cylindrical rotor your x d will be equal to your x q, this is the case when your machine is cylindrical rotor machine cylindrical. This x d will be not equal to your x Q for your salient rotor type of machine salient poles.

So, in that case your x d and x Q will be different, so what we can do is a very general, we can write the flux decay model for this type of machine and wherever you what to use, your cylindrical machine. If your machine is cylindrical, simply you put this value x Q is equal to x d and then finally it is very easy that you can get the simplified equation from this general expression of the cylindrical pole machine.

So, to see this, we have to use the various notations and nomenclatures, so that is a E Q prime, E Q is your generator internal voltage behind x d and this is basically to the field proportional to the proportional to the field flux linkage. Your E Q prime is the generator internal voltage behind x d prime, so this E Q prime is the internal generator voltage behind X d prime. Your EFD is generator field voltage EFD, your ID is the D axis component of armature current, v is your generator terminal voltage and TDU prime here TD, TDU prime that is generator D axis open circuit time constant. Using these three, we can write the flux decay dynamics as follows.

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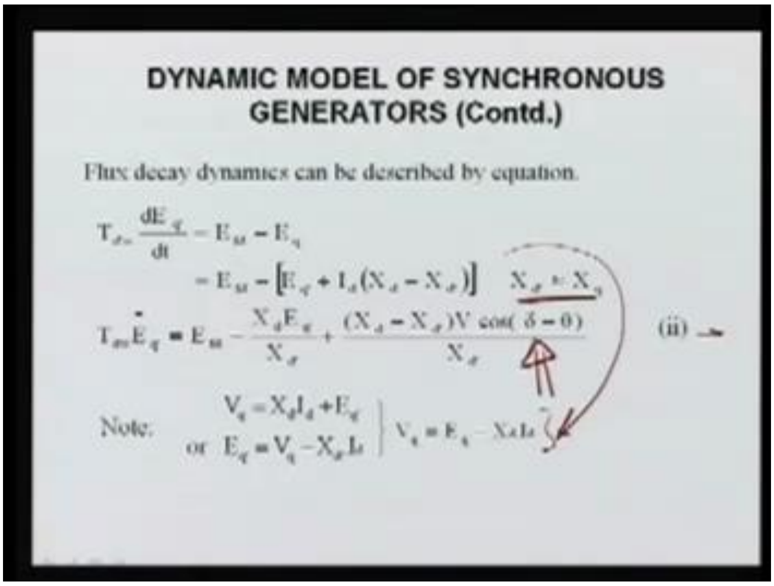

So, here if we are using this is your TDU here, T TD prime or we can write the differential equation in this relation, so this is your EFD minus your E q.

Now, this E Q here this is E Q prime ID, so we can write here and that x d prime is normally very equal to your x q. So, this again you can see the several books, they have a detailed flux decayed model normally we are going to use. So, this equation can be again simplified using all this and we can write here the TDU prime E Q prime, here we can get this equation 2, where this V Q will be your x d prime ID plus E Q prime. Here, this is your E Q prime here, means using these we can from here we can get this equation. So, we can simplify using this and we can get this one differential equation here that is equation number 2.

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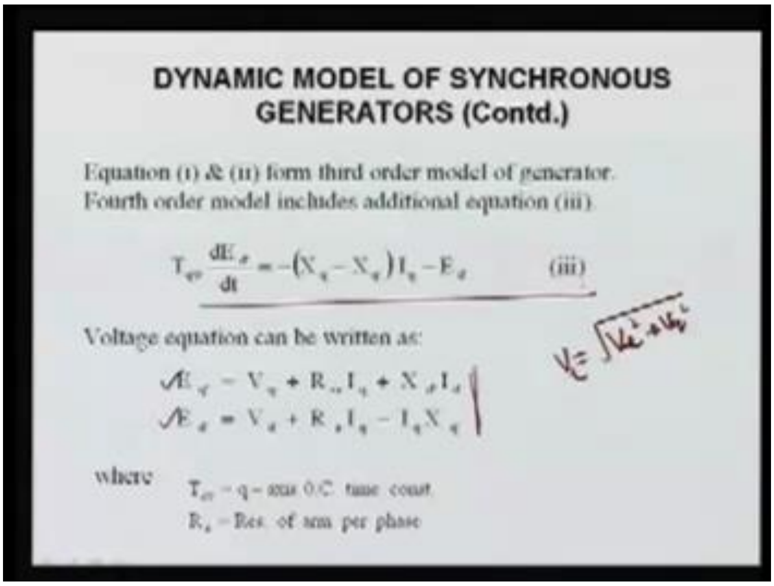

Now, from equation 1 and 2 forms the third order model of generator for the fourth order this model include the additional equation of you TDU prime. This one we are including this one, then it will be here another differential equation we are going to include. So, if we are going to include this, your third equation and that additional equation, if you are writing, they are differential equation for your here that is a ED prime. Then, you can get the third order; here it is a fourth order, means we are including this equation, so it will form a fourth order model of the machine.

Now, to get all these values here this eq prime ed prime thus they are related with the V terminal voltage as well and this is nothing but we know this terminal voltage V is your V d square plus V Q square and the root. So, we can get these values, this terminal voltage we know it and then again here we can using these equations we can again solve the various equation. So, all these equations are interrelated and then we have to use them in your transient stability program.

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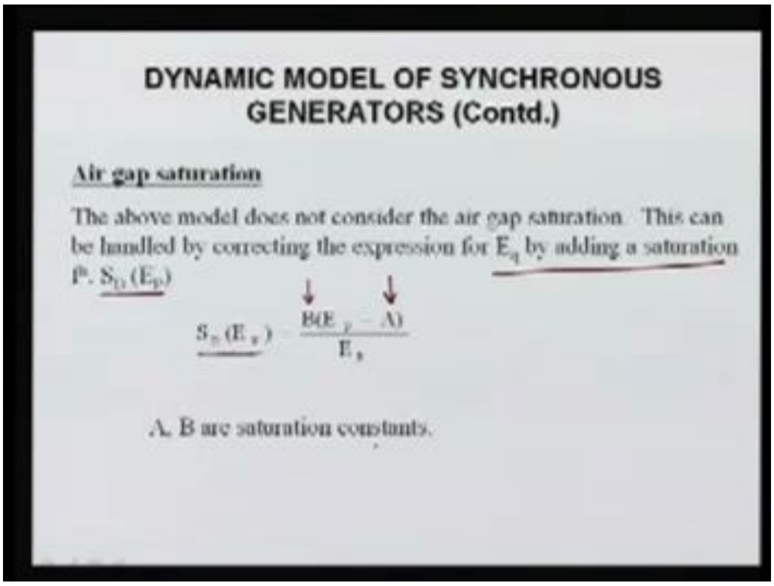

To include the air gap saturation, as we saw there is a previous equations there was no saturation was included. So, this can be handled by correcting the expression of E Q by adding a saturation function that is your SD E p. This SD E P is defined as some factor b and another factor is a it is just related with B E P minus A upon E P where A and B are the saturation constants.

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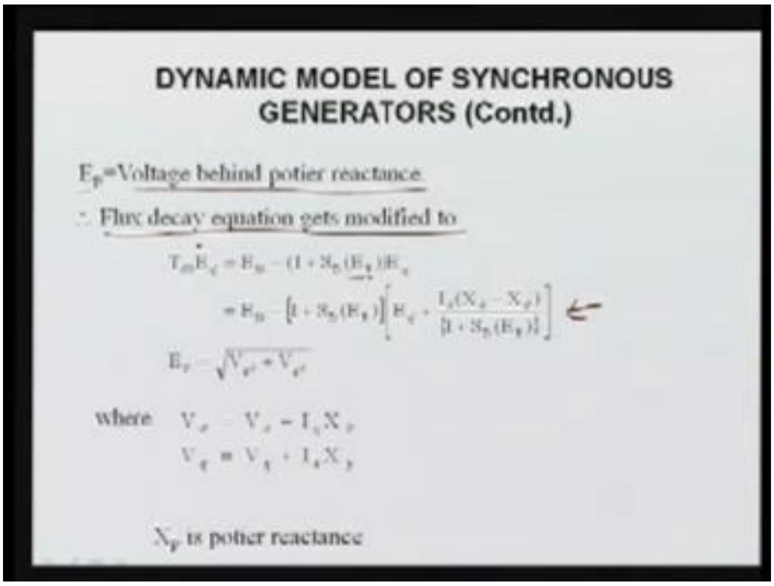

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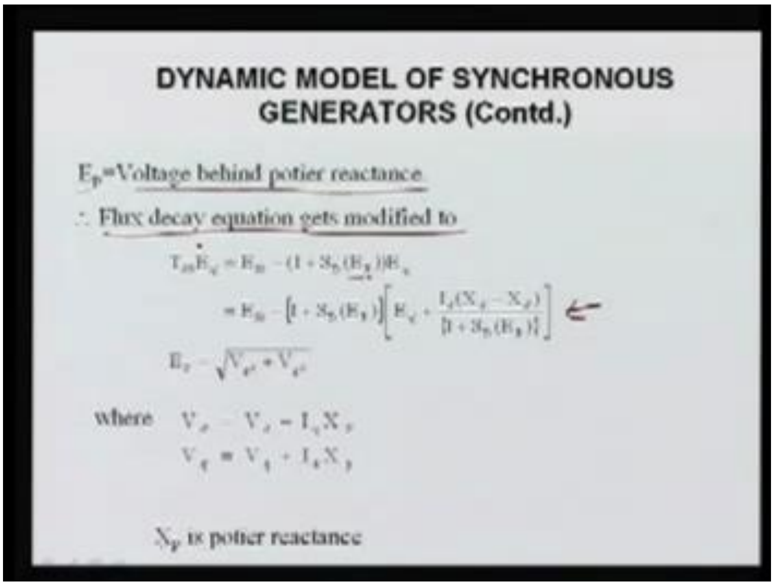

This E P is the voltage behind the potier triangles, again when we study the synchronous machine in detail, you will find this E P is your voltage behind the potier triangle. Then, this flux decay equation gets modified to here TDU E q, this one, this is your one differential equation. Then, here we have to put that value and then we can simplify and finally we are getting this expression, so where this is your x P is nothing but your potier reactance.

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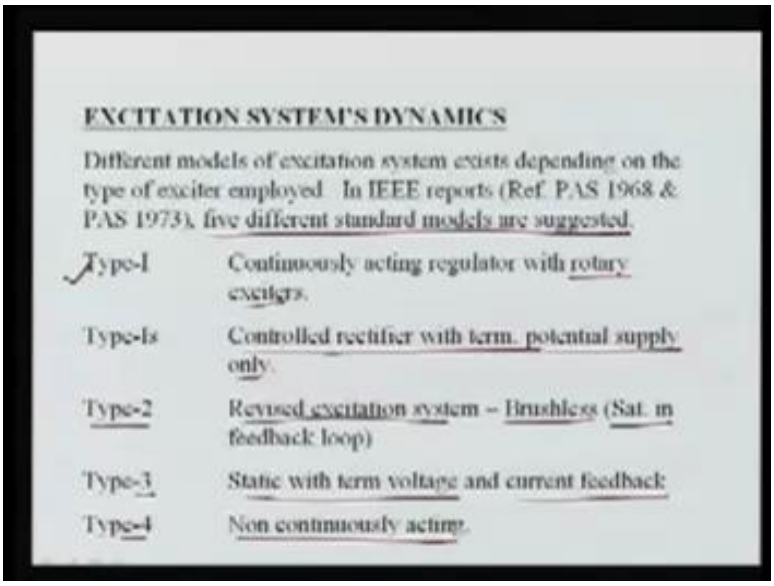

To include the dynamics of excitation system different model of excitation systems are existing and again it depends upon what is the size of your machine. So, there is a various type of excitation systems are used and again ieee reports they have standardized that so the five different standards model of excitation system is suggested that is first your type 1. Normally, we can say the type one is a continuously acting regulator with a rotary exciters, means here we use the rotary exciters.

Your type 1, which is your controlled rectifier with the terminal potential supply only your type 2 model that is a revised excitation system. It is a brushless and saturation is taken into the feedback loop. Type 3 excitation system is your static with the terminal voltage and current feedback and your type four is non continuously acting excitation system.

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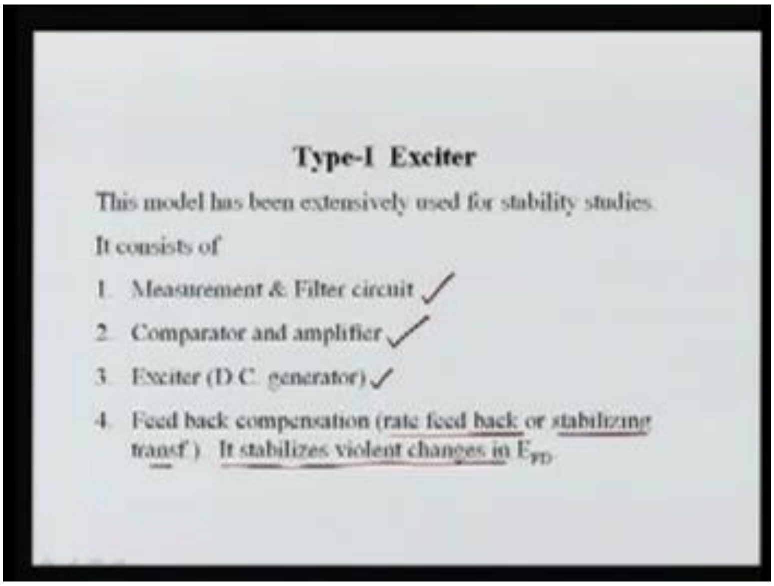

So, type one exciter this model has been extensively used for stability studies. It consists of measurement and the filter circuit comparator and amplifier excitation that is a DC generator and a feedback compensation that is a rate feedback or stabilizing transfer function. It stabilizes the violent change in EFD, to see this here; I just want to show this is your block diagram of IEEE type one excitation system.

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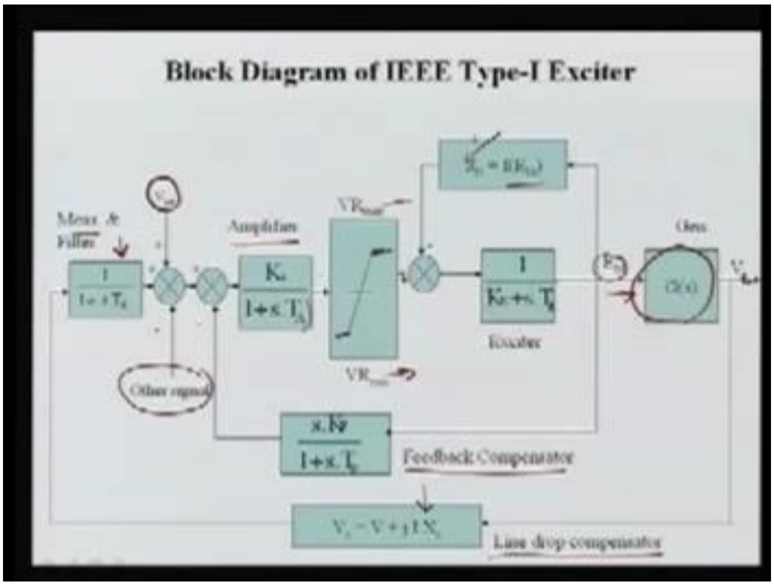

Here, you can say this as I said, it has the several modules, several blocks, one is your measurement and the filter module and the transfer function for this just can be retained. This is 1 over 1 plus s that is a Laplace transform s multiplied by the TR that is the time constant of the measuring system that is coming here. Then, we are using here v reference, means we are setting the terminal voltage that is the reference voltage certain value and this is added with this reference and then we are using another signal. This signal is nothing but other signals, like we can give some auxiliary signals from other sources, like we can use the power system stabilizers those are used to stabilized the power system, those are used to improve the time stability of the system.

So, that signal may come here if that signal is not there then it is 0, so that value is coming here and then it is your feedback compensator is there and that is here your EFD is coming back here. Then, it is compared and that error signal is getting amplified with the help of amplifier and the gain of the amplifier is k a normally represented and it is 1 plus S t a, t a is the time constant of this amplifier. So, it is a first order differential equation, thus it has been assumed for the amplifier this amplifier will have some limiting value. So, if this value cannot be more than V r max, it cannot be V r min if it is violating its limit, then we have to take its limiting value.

It means here output is more than this so that we have to set at this value. If this value is less than this value, then we have to set this and then finally it will be given here to the exciter. This exciter time constant here 1 over K e plus s into t e and this will be nothing but EFD, to include the saturation effect, this EFD here that is going to be subtracted because here we are taking the proportionate. Here, proportional value whatever we are getting here signal, directly we are getting the EFD, but this EFD, we will have some saturation effect. Then, we can take this se here this function S e is a function of EFD that is going to be subtracted and then this is a closed loop.

This EFD again is sent here and that is through the feedback compensator and now that is coming to your generator and this is the G s is your generator gain that is gs transfer function. Then, generator is giving your terminal voltage V t and this V t is coming through your line drop compensator that is V c v plus j i into X C, X C is your sum of reactance and then it is coming here again to your measurement and the filter circuit, so this is your block diagram.

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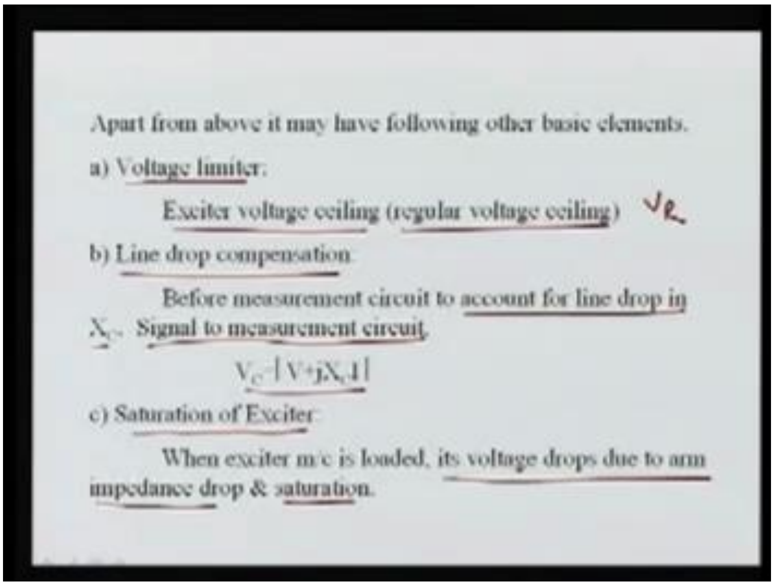

So, apart from other, it may have the following basic element that is the voltage regulator that is the voltage should not valid. So, the excited voltage ceiling limit that is voltage regulator voltage ceiling is a V r is also used. Line drop compensator is used before the measurements circuit to account for the line drop in X C, the signal to measure the circuit is different and of course, the saturation of excitation. When exciter machine is loaded, its voltage drops due to the armature impedance drop and the saturation.

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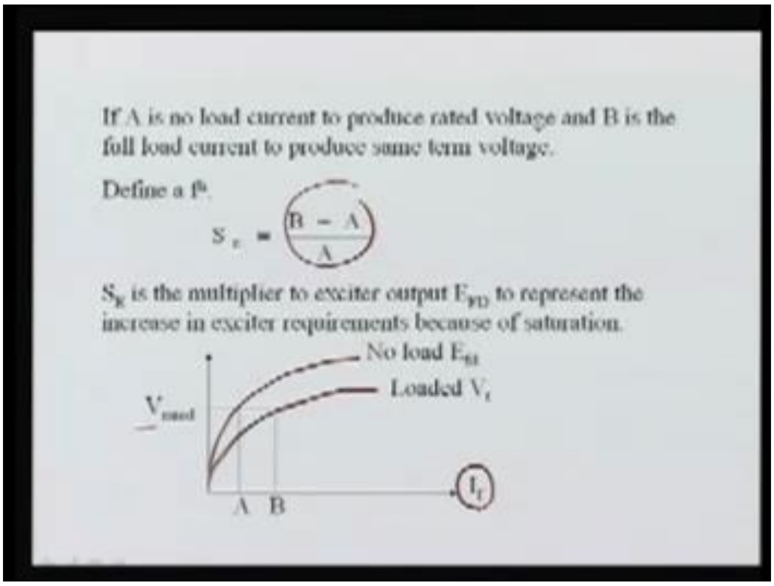

So, the saturation effect that I said we can take into that account here you can see this is loaded and without loaded. So, without loaded here, if your field current is increasing the terminal voltage is this one, but once it is loaded, your terminal voltage variation is this much. So, this is basically due to this saturation effect and that should be taken into account for the detailed modeling of the machine.

This is already explained the block diagram of IEEE type one excitation system, let us come to the speed governing system and the turbine model. Here, I am using the reference that is a book Anderson and Foud that is a power system stability book. The General purpose model as given in the figure this is the figure; I will tell you this is the figure that is general purpose speed governing system.

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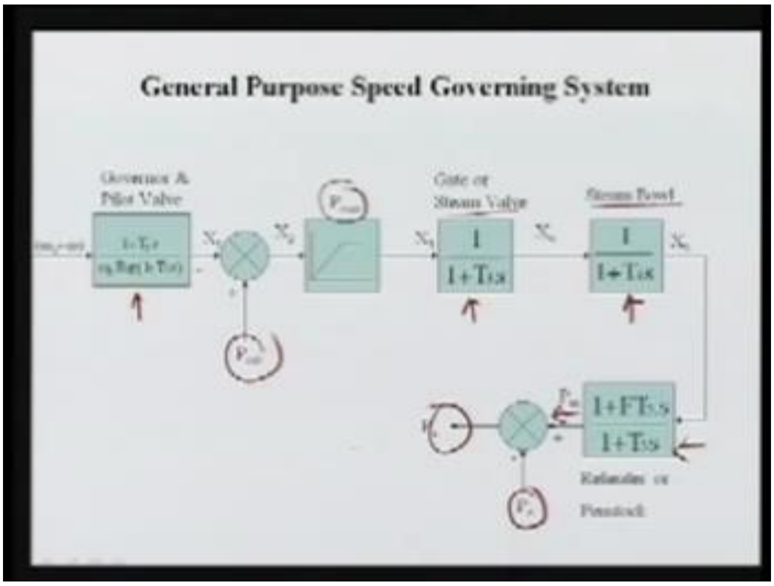

Here, you can say this is a governor and the pilot valve transfer function, and here the pm not is going to be compared with this, and then we have some limiter P max that we cannot increase the P max so much. So, there is a gate and stream valve dynamics is noted here and then here stream valve, and then it is having transfer function, and then it is coming here, through it is reheated. Finally, it is pm is coming here that is compared with your electrical and this is your accelerating power, whether it is positive or negative depending upon if power is increase or decrease here compared with this one

So, this is a general purpose and again this model, I will explain when I will be discussing the load frequency control because in the load frequency control, we have to see that how this governing system is acting to take care of any change in the load. If there is any disturbance, suppose there is severe increase or decrease in the load W h, how it is going to take care of those things? So, in the next module, we will discuss completely about all these blocks.

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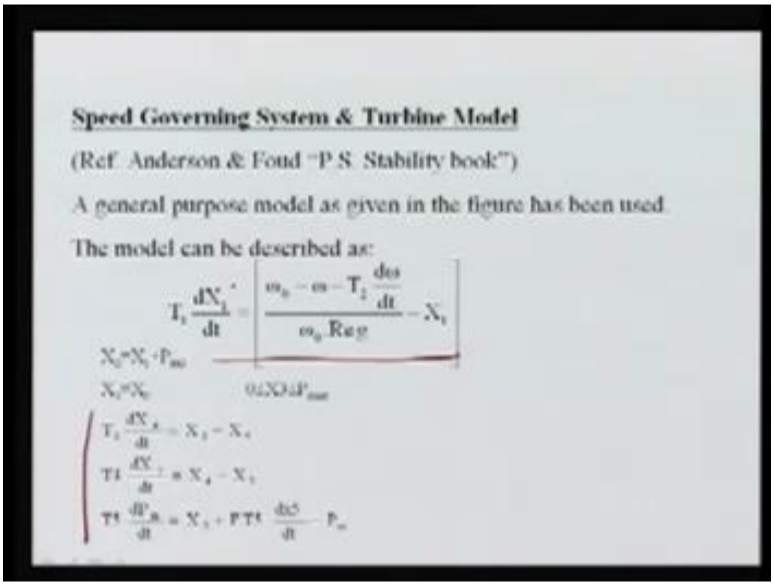

As I said here we can have the dynamics here this whole dynamics now you can have the different orders, means for this you can see how many transfer functions we are going to take. You can see the dynamics means here, this one is a 1 order 1 variable x 1 you are having another variable here x 4 you are having x 5 and you are having here x 6. So, here you are going to have 1, 2, 3 and 4, 4 again differential first order differential equation for the governing system itself, so again that will be included for each machine.

So, if you are using one machine, so the number of differential equation for excitation system plus the model of machine. If you are using third model, third order model or fourth order model that differential equation and then the governing system models of four equations here. So, the total for one machine the whole total it may go up more than 12 to 15 differential equations, so you have to include in your transient stability program for accurate analysis.

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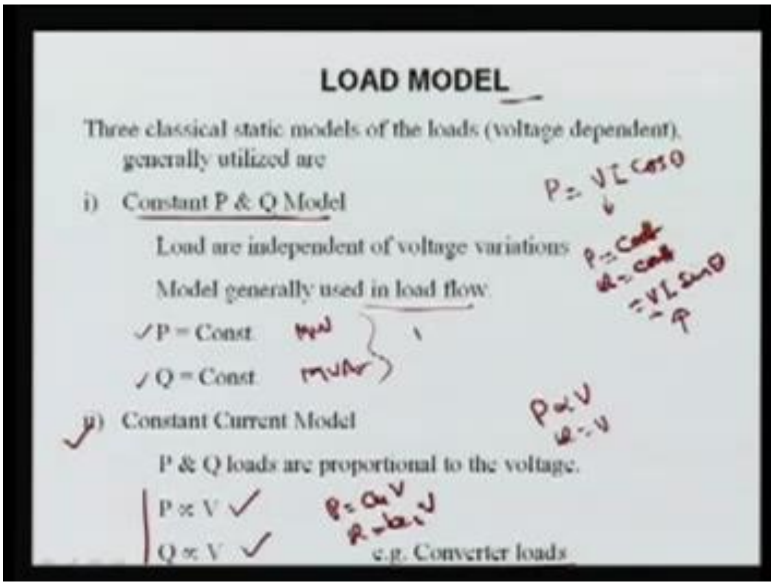

So, let us see the load model and that load model is also included in the transient stability program, as I said the loads are represented by the impedance or the voltage dependence or the dynamics of the load must be included in the transient stability program. So, three classical static models of load that is the voltage dependent generally utilized are first one is your constant P Q model. We know this P is nothing but your V I cos theta, theta is your power factor angle, this theta is your power factor angle and cos theta is the power factor as we know.

Now, if here your load is independent of voltage variation as well as the current, then we can say your P is your constant, and similarly your Q will be also constant because this Q is nothing but your V I sin theta. So, your V is constant, I is constant means your load is independent of voltage and current. So, that we can say your P is your P is constant and that P and Q is normally it is taken in the load flow. Load flow, we take P and Q constant we never take the dynamic of this even though in few load flow analysis. People are going to consider the voltage dependent load as well, but normally it is the constant P and Q loads are considered for the load flow analysis.

So, this is your constant P and Q and it is represented is how much megawatt and here it is determined how much m var and we have to include in your load flow analysis or you want to include in your stability program.

Another is your constant current model, in this constant current, here the voltage is varying, but your current is constant, so this P is called the proportional to voltage, similarly your Q is also proportional to voltage. So, the P and Q loads are proportional to voltage and these types of loads are normally the converter loads where the current normally again different type of converters are used for. Let us suppose you are using converter in HVDC system, then the current in this line is always constant and we keep on changing the voltage.

So, it is possible that we can change the voltage, your load if it given for a given load if we want to feed the power, varying power, there the current can be constant and the voltage can be changed so that you can give the variable power to that one. So, here in this one the P and Q that is real and reactive P is your real power Q is reactive power that will be proportional to the voltages here, this equation, as well as this equation.

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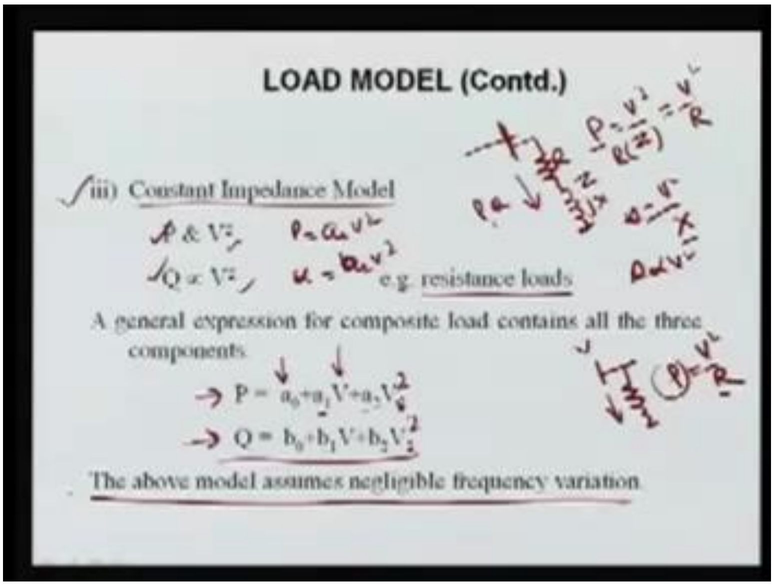

Third type of load model is called the constant impedance model and in this the impedance of the load is constant, means for example, let us suppose you have here a bus and there you have a resistance. Here, this is your impedance this is your Z and Z is constant, so what will happen? What will be your P and Q? Here, that will be nothing but if you write this P here, it is your V square upon your Z, basically here the real power of this and here it is a real of Z, so what is this? This r and here j x, they are constant, so the impedance is constant, so I can write here V square upon R.

So, if the terminal voltage here of this bus is changing, the power drawn by this load will be are fully changed. So, the real power will be now proportional to the v square, similarly your Q will be your V square upon X. So, x is constant, so I can say Q is proportional to your V square, so whenever the voltage is changed, reactive power as well as the real power drawn by that load will be changed. So, we have to take it if we have a load like this, for example a simple bulb that is a simple resistance. So, you can see when the voltage is less, it gives less life, what does it mean? It means the energy dissipated in that bulb that is a current this r is constant, so the power by that simple what is the bulb? Bulb is your resistor here simply.

So, if the voltage of this bus is changed, so your power that is taken here and that power is converted into the light. So, the light power is reduced, means here V square upon R. So, R is a constant here, V is changing, so here the power will be le less if V is reduced, if it is more, so it will glow more. So, this type of load is basically called the constant impedance load and the resistance load is one of the very popular load that is for lightning purpose. So, we can say your real and reactive powers, they are proportional to v square here and that can be included.

A general expression again for all these three type of loads as we know that is in any area any distribution system any transmission system loads are the combination of all these three varieties, means it is a constant, it is proportional to voltage. Also, it is proportional to the voltage square, so the general purpose expression for the composite loads, we can write this real power will be summation of your a naught that is the factor contributes your here that is independent of voltages. So, it is your constant load, then we have a another that is a proportional to voltage, so the basic a 1 is a proportionality constant and your a 2 is your voltage square, here this is not here, this is a square.

So, similarly we can write for the reactive power, so we can include all these three proportionality constant here, means I can write here that is a P is equal to your a 2, V square, here I can write the Q is equal to your a 2 V square. Similarly, we can write for this case P is equal to your a 1, V Q is equal to your a 1, here we can have a different. Basically, they are not constant, so a 1, b 1 here, I can write and here I can say P is equal to your a naught and Q is equal to your b naught. So, here we can write this is your b 2 V square, so we can write another because here b 1, b 1, b 2, b naught are the different, then because the reactive power is the different, so we can write different coefficients.

So, the above model assumes the negligible frequency variation, so in this load model we have not taken into the account of the frequency change of the system, it is only the voltage. So, it is not taking the dynamics of the variation of even the voltages, it is only again the static equations, that is we have taken and depending among the various loads we have formulated this.

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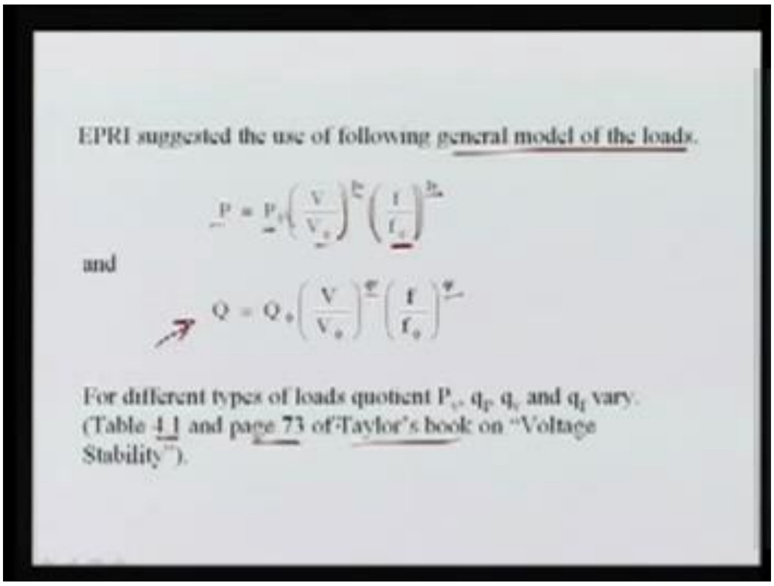

Now, again that there are several methods and several books references, they have suggested like EPRI, EPRI of USA suggested the use of following general model of the load and they have used this P is nothing but your P naught. This is now multiplied by V, divided by V naught, here v not is your nominal voltage, here it is a frequency, nominal frequency and what is your system frequency? So, if your system frequency is changing, this P will be also changing. So, this is now a general purpose, so here there are P V, here is the P r, similarly, we have the Q v and the Q r. So, this is the P r is the exponent of this term and here P V is the exponent of V, actual voltage divided by the rated voltage.

Now, these coefficients are exponents here P V and P R, similarly, here Q V and Q R for the reactive power can vary and the different values are given for the different type of load. So, this means these coefficients are basically taken from the Taylor's book on the voltage stability that is a table 4.1, page 73, you can see.

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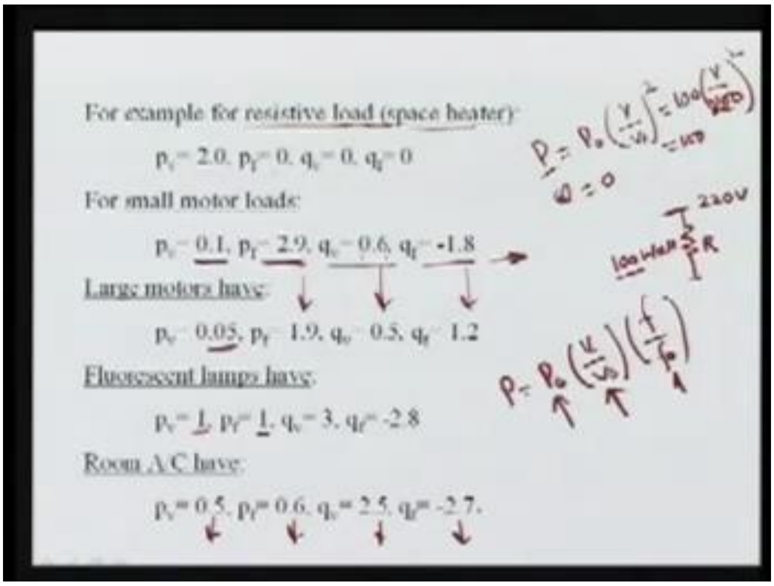

So, for the various here, for example, just I will tell you if P B is equal to 2 P F is 0, Q V is equal to 0 and Q F zero it is nothing but, a simple resistor means what does it show. It shows that your P is nothing but your P naught here v divided by your v naught here your square and your Q will be now 0. So, it is a simple real load that is a resistive its voltage is changing, and then we are getting the different power output. Suppose, you are having a voltage a bulb, let us suppose simple resistor here r and this is giving your 100 mega watt bulb, this is your bus, this is your resistance. So, it will have some value and this 100 watt, it is giving at, let us suppose 220 volt.

Now, if the voltage is changed, then what will happen it will be hundred v divided by your 220 volt, sorry and then it is a square. So, if your terminal voltage is 20, then it will be unity and it will be again 100 watt, but if voltage is reduced, then it is let us suppose 200, then it is 200 divided by 220 of A square, then your output will be reduced. So, it is a simple resistive load and it is used just like a in conditional lamps simple bulbs or it can be used in the heaters, heater is also resistive filaments. For smaller loads, they suggested that the P V value should be 0.1 P F, here is a 2.9 Q V, it is a 0.6 and Q F is again negative here 1.8, what does it mean?

It shows that for motor loads all, no doubt, it varies on the voltage, but it is more variation is more on your frequency that is 2.9, huge contribution in this, means you can see here I used this curve here in the P this value is very small. This is very high, so this ratio is very dominant and thus for a small loads here, they are suggested this value can be taken. For large motor, again you can see these values are very small because small the motors are very much causes very much fluctuating with the change in the voltage and frequency, but large motors here you can say this factor is very small. This is also reduced here, they are also reduced and this is also reduced.

For the fluorescent lamps, here you can see this it is one PF is also 1 means it depends upon frequency as well as your means, here this P. It is your P naught that is your V upon V naught, again unity multiplied by your f upon f naught, f naught is your rated value at which this P naught is given. So, you can see now, it is it is changing with the voltage as well as the frequency, so the fluorescent lamp is very sensitive to the frequency of the system as well. Room air conditioners have now P V is this P F is this and this, basically all this they are proposed with the different tasks, different simulation, different measurements. They are suggested for the various load, you can take these factors for your various studies.

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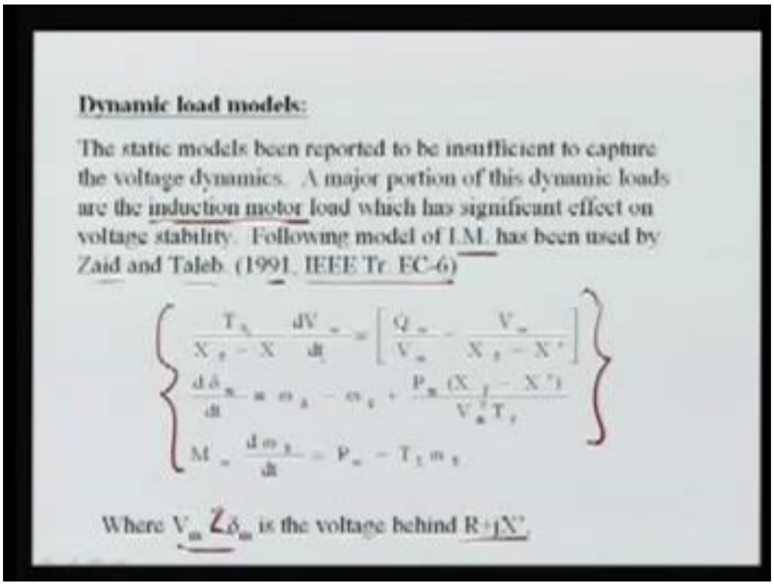

To model the dynamic loads as we saw that static models, which we discussed earlier they are insufficient to capture the voltage dynamics. They are the simply the variation of voltage, but there if the voltage is changing with the time, how they are going to affect your stability of the system and how we can analyze what will be the actual behavior of the system. Main purpose of the transient stability are any program that we can reproduce, we can know the exact behavior of system by simulating. So, the simulation we have to ignore as much as possible the assumptions, so to include this voltage dynamics we should include this dynamics of the voltage load as well.

So, a major portion of this dynamic loads are the induction motor load, as I said it is almost 70 to 80 percent loads are the motor loads and mostly they are the induction motors, which has a significant effect on the voltage stability. So, following model of the induction machine has been used by the Zaid and Taleb, they use in the IEEE transaction of energy conversion volume 6 in 1991. They just suggested that we can take this V m upon dt they have taken the time constant, so where this V m angle is the voltage, this is angle, V m is the voltage behind r plus j x. So, they use here you can see they use another two dynamics of the voltage as well as the delta that is interrelated, so we can have this basically solve using these dynamics as well.

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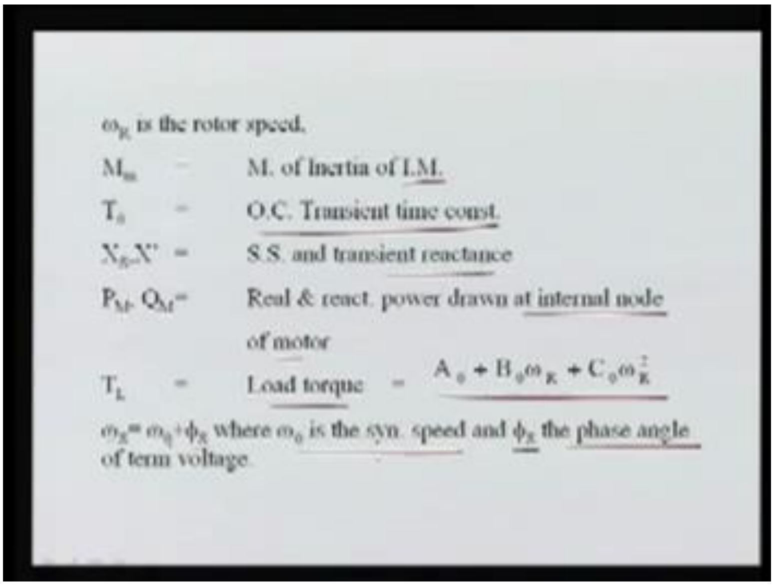

Here, this omega is your rotor speed, MM is the moment of inertia of induction machine T o is the open circuit transient time constant xx and x prime are the steady state and the transient reactances. Pm and Qm are real and reactive power drawn at internal node of the motor and T l was the load torque and that was given as the A naught plus B naught omega R plus C naught multiplied by omega R square. Here, the omega s is omega naught plus phi s, where omega not is synchronous speed and phi s is the phase angle term of voltages.

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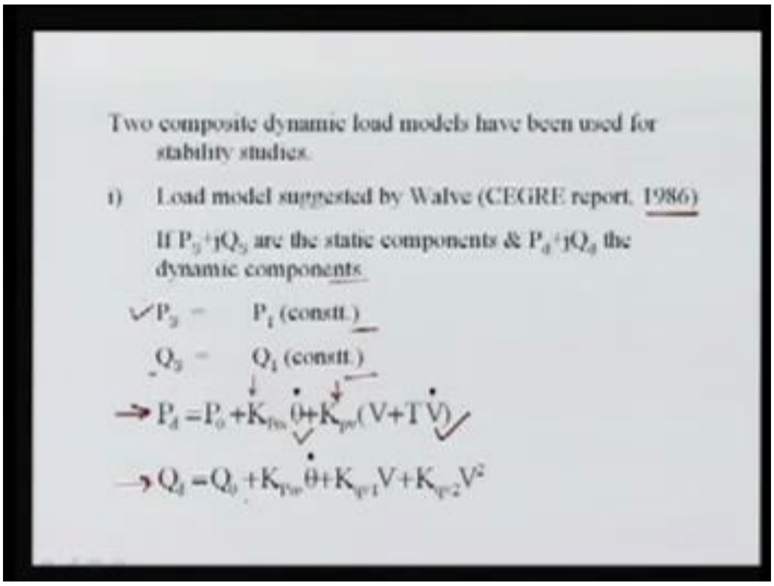

Two composite dynamic load models have been used for the stability studies, the load model suggested by Walve CEGRE report 1986. If there is a P s and Q s are the static components and the P d plus j Q d are the dynamic components component, then we can write this P s is equal to P 1 that is a constant Q s, we can also take as a constant, but the dynamic component here. if we are having this component, then we can write the dynamic equation in terms of voltage and in terms of theta. So, he has suggested we can take some constants here and then we can include those in your stability programs.

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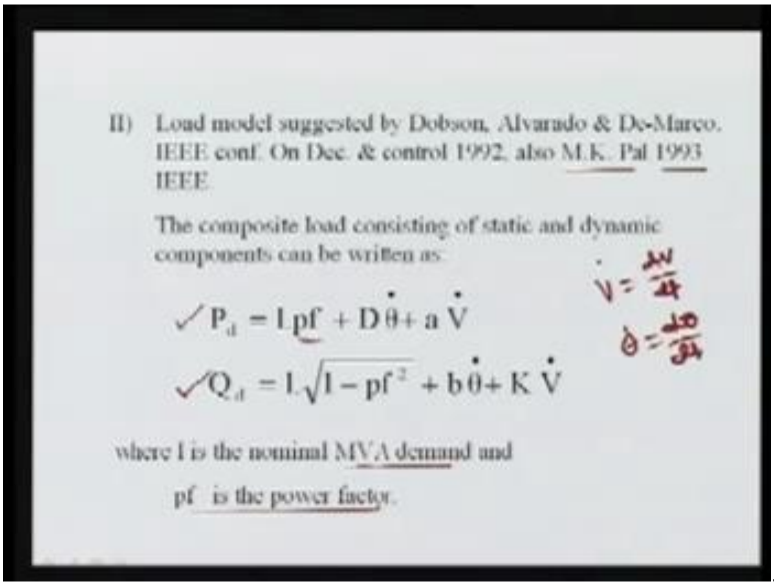

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Another model that was suggested is again by Dobson Alvarado and De-Marco. They suggested in and also in the M K Pal 1993 IEEE transaction. He has suggested the composite load consisting of static and dynamic components can be written as here the dynamic pd and here the react dynamic reactive power that can have even though this has a effect of your power factor and this one is here is the nominal MVA demand. This is a and P F is the power factor that is included plus d theta dot plus a v dot v dot here is the dv by dt. So, here v dot is nothing but dv by dt, similarly your theta dot is your d theta upon dt, so we can again they will be used this model.

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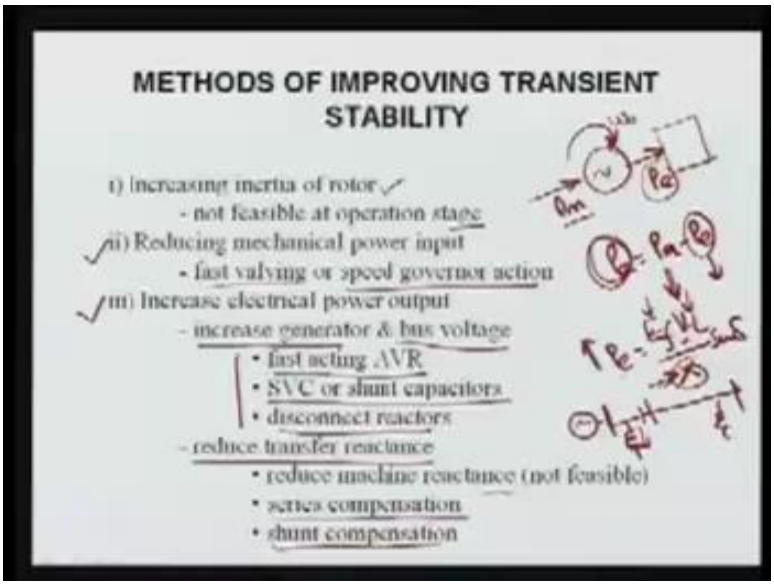

So, let us see again the various methods for improving the transient stability, already I have discussed with you, but here we have to recap it. First, we can increase if anyhow the inertia of the rotor means rotating mass of whole system, not only generator, it can be generating mass of your turbine as well as because all are on the same shaft. So, if that can be increased, then we can improve the transient stability, this is not possible during the operation stage, because once machine is installed, constructed and it is going to deliver power, it is not possible to increase the inertia constant.

It is only possible during the planning stage, so which size of machine you are going to install? That will at that time you can basically change the inertia that you can go for the larger and again you have to see the efficiency and performance. That again depends upon the economy and the performance of the system, so this factor basically is not possible during the operational stage. Another is second option is the reducing the mechanical power input during the transient disturbances. As I said here, this is your generator that is rotating here, it is your P e that is electrical power is coming out, here it is your P m and this difference here is your rotating. So, if here this is equal to this, this machine will be rotating at the synchronous speed.

So, if there will be any disturbance as I said if there will be some disturbance transient, disturbance beside that is it is your electrical side, what will happen? This P e will be reduced due to the fall due to the tripping of the system etcetera. So, this P e will be reduced, then what will happen? This difference that is your P a, accelerating power, it is your P m minus your P e. So, this value will be positive and this will cause acceleration of this machine and thereby it will increase the internal angle of the machine and once it is increasing, then it may even loose the synchronous if it is keep on increasing. So, what we can do to reduce this?

If anyhow we can reduce this as in the previous case, we saw that the P m is constant, but it is not so. If we can use some fast valuing or speed governing action, then we can during the disturbance, we can reduce this. So, this accelerating power can be reduced, so that the severity of the transient of the system will be minimized, thereby we can improve the transient stability of the system. Third option if we increase the electrical power output means as I said during the disturbance, this will be reduced, so what we can do? If anyhow we can increase this P e, so again the accelerating power will be minimized and therefore, here the we can reduce the delta angle of internal machine that it will be again minimized and then we can improve.

Now, to here to change to increase, this it depends upon the several factors, we already wrote this P e. It is your nothing but your E F terminal voltage divided by here x that is x is composite reactance including transformer lines and between the two buses here and here it is your sine delta. So, first when is that to increase this, after that we can increase EF as well as the V t or anyone of that, so increase in the generator and or the terminal bus voltage, so we can increase the P e. For that, we have to have the fast acting voltage regulator for increasing this EF that is excitation voltage, when we have to fast acting voltage regulator, excitation system will increase.

Another is to increase this V t, it is not in your hand, V t is very difficult to control unless until you are having some extra device and that device is nothing but your FACTS controller. Any shunt elements you can say shunt capacitor or static variance compensator or static compensator that is a stat com. That can be used to improve the voltage of this machine terminal voltage and then we can increase this.

Another is disconnecting the reactor because you know most of this transmission lines the big transmission lines here is the big transmission line, they normally use the line reactors. So, they absorb the reactive power so anyhow during that fault, if we are going to trip this so what will happen? The voltage here will be increased, so disconnect the reactors to increase the P e, so these are the three options for again increasing the P e and that is related with the EF and the V t increase. Another approach to reduce the transfer reactance that is x that can be done again reduce the reactance of machine, which is not feasible.

Again, I said there is a, again it is only in the design process and there is lot of pros and cons for the higher and the lower value. So, it is a compromise between what value you are going to take, so once it is designed, it cannot be changed. Another is that we can use the series compensation, we can use some capacitor here series, then the effective x will be reduced and then we can reduce the transfer reactance, if reduction of this means it has a more P e. Another we can also use the shunt compensation, some of the shunt compensation, they can also regulate in such a fashion that that re effective x can be changed and then we can use that.

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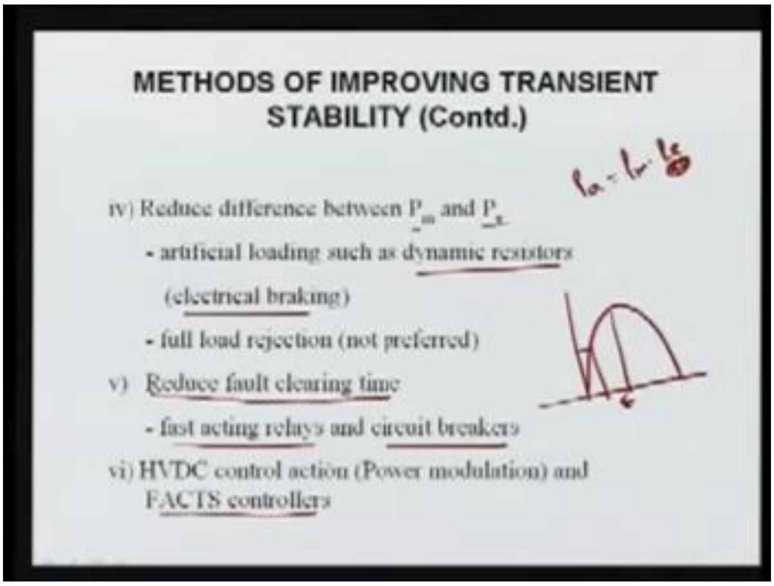

Now, another is that reduce the difference between P m and P e by using again the artificial loads, means here we want to reduce this P a means we can use some dynamic resistors and again here that is a P m minus P e. so, we can increase this P e during the disturbance by using some resistors. So, that is called electrical breaking and dynamic resistors are used for that or full load rejection that is not preferred, means we can reject completely load and then we can use. Another is the reduce the fault clearing time as I said in this angle here, if this machine is operating here, then this fault clearing point if you are always try to reduce by acting fast protecting system, then again your system stability will be improved.

It means that can be achieved by fast acting relays and circuit breakers, if you are having HVDC system connected with the system lines, and then HVDC control actions can be taken. Then, also at the same time, FACTS controller can improve the transient stability equal value. So, if these devices are present in the system, then along with those devices, if you are going to use, then it will be improved. So, these are the basically the various transient stability methods and that basically those are used for improving the transient stability of the system.

Thank you.