High Voltage DC Transmission
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Module No. # 06
Lecture No. # 05

Welcome to lecture number 5 of module 6 and this is … Last lecture also we were discussing about the transient stability analysis and we saw the various approaches and various, the models levels for which the AC DC stability analysis are done.

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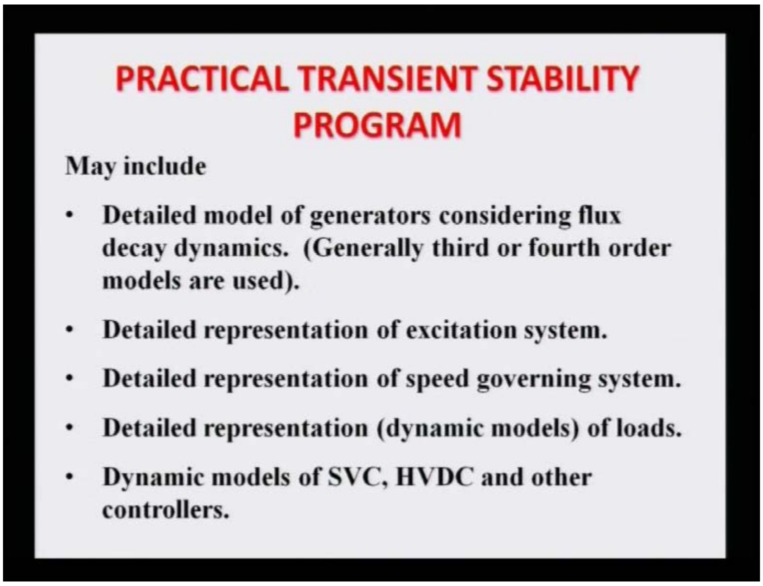

In this will see, in this lecture mostly I will go for the various component modellings and then we will see what are the methods to analyze what are the various methods to solve this transient stability analysis. To see this, any practical transient stability program whether it is for ac or it is a dc or it is a ac dc both we have to include the various components are that those are involved for the transient stability and that may include the detailed model of generator considering the flux decay dynamics; generally third or fourth order models are used.

However, in the previous lecture we saw the classical models, only the second order which is the second order differential Equation that was the single equation just I derived, I show it. And that is, you can say just that is called the second order but, if you are going for the field decay model and taking care of some other components then we can increase the order of modelling. But, as you know the number of differential equations are increasing at the same time, what we are just, number of computational burdens for, because, it is, we are going to increase for each and every machine. So, if you are in power system or whole ac dc system, you are having n number of buses. So, you are keep on increasing the differential equations and the solution techniques requiring more and more computational time. So, the detailed modelling again up to what level you are going to analyse it so that modelling is required.

Second, then we have to represent the excitation system because, each generator is equipped with the excitation system so that modelling is also to be done. Then, since speed governing system whether it is a hydro or it is your thermal power stations or even though, the whatever the gas power station, we are having the speed governing system and that modelling is to be also included. Then we have to, another side on the power system side especially, for the load side we should also model the dynamic models because we are having some of the huge induction motors. Also, some, even though some of the loads, they are dependent on the voltage frequency those should be also modelled in this transient stability program. Last but not least, if you are having any facts devices including your TCSC, static Var compensator that is, SVC or you are having the HVDC systems, those controllers should be also modelled in the transient stability program. Because, they are also going to affect the stability of the system by the, its control action.

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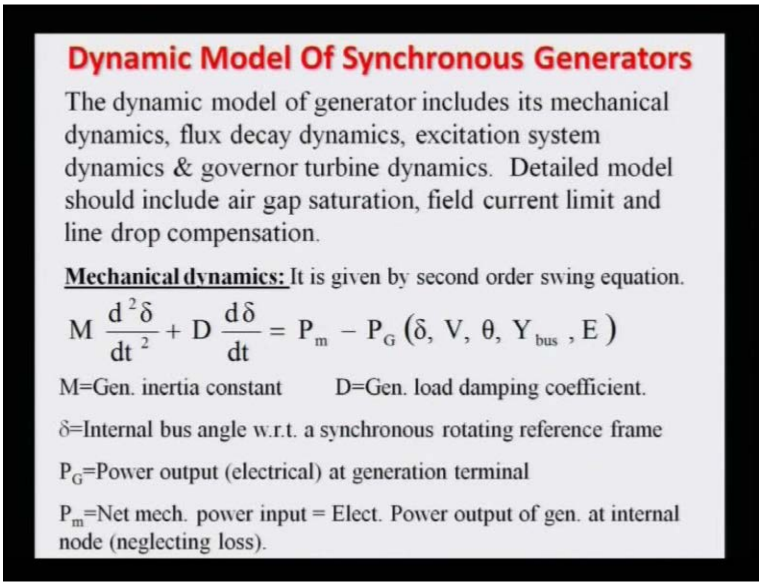

So, whatever other controllers including your SVC, HVDC and others are there, they should be the modelled in the detailed. So, we will see all these modellings one by one and then finally, we will just combine together. So first, I will discuss about dynamic model of synchronous generators, as we know most of the conventional power stations are running by this synchronous generators sometimes, we also call alternators and they are rotating at synchronous speed and the synchronous speed as you know this is, what is the rotating speeds the maximum speed for 50 hertz cycle or 50 hertz frequency, it is 3000 rpm especially, those are used for the thermal power stations but, for hydro it may be the less because, you know the efficiency of hydro power stations are less at the lesser speed; however, it is the reverse is true for the table alternators.

So, we have to, the dynamic model generator include its mechanical dynamics, we have to also include its flux decay dynamics, excitation system dynamics, governor turbine systems and the detail modelling should include air gap saturation also because, always we work on the knee curb; whenever the loading is increasing the saturation is taking place and the field current limits should be also included and sometimes we are having some sort of the line drop compensation techniques in the your excitation system that should be also taken care.

So, in the previous swing equations if you remember, what are this Equation if you will see, this is the differential Equation, this second order differential Equation. This is a model, this mechanical dynamics I can say this is a second order swing equation. Here this one term extra, the size added that is, D del delta upon dt, there is a dynamic terms were ignored in the same equation. But since power system is having, it having some dynamic, some damping factor and that factor should be also include. This factor basically related with, if suppose you are changing frequency of the system changes the load released by the power system is also going to affect the factor. So, this should be also taken into count and the, your right hand side you can see this is the mechanical power minus your electrical power that is, PG and this is nothing but, is a factor of your delta that is, a machine internal angle, this is a voltage of the bus and this is a theta, is basically angle of this Y bus matrix, that is your real component, this is your angle and E is the internal voltage of the machine. So, already here M is called the generation inertia constant, D is the generation load damping coefficient and delta as already mentioned this internal bus angle with the respect to a synchronous rotating frame reference and PG is the output, that is electrical at the generation terminal, the Pm is net mechanical output and this is normally is equal to this PG when this losses are neglected.

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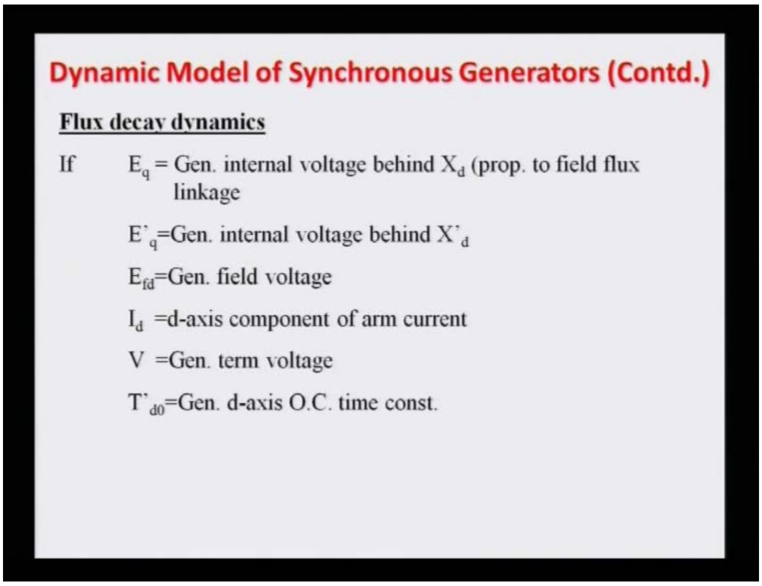

So, this is a general, I can say the swing equation. If you are ignoring this, this is a normally the swing equation is used for your the classical analysis of the transient stability of machine. Now, if we are going to include, as I said we have to go for the, considering, when we have to consider the flux Pk dynamics as well because once machine is loaded there is some disturbance outside the machine and then the flux is also going to change so that and due to this flux change the induced voltage etcetera also going to change. So, that dynamic should be also accounted for and if E q, that is generation internal voltage behind the X d and that is proportional to the field flux linkage. E q prime is the generation internal voltage behind the X d prime and E f d, if it is a generation field voltage, Id is the D axis component of armature current, V is the generator terminal voltage and T d o prime is the generation D axis open circuit time constant, if these are the terms then we can write the flux decay dynamics, can be describe by this equation. And this equation you can say this a T d o prime, that is a prime constant d Eq prime upon dt is equal to E f d minus Eq. This Eq etcetera, that can be computed and we can fit this value, can be written, this Eq will be from the phaser diagram if you know the machine characteristic, machine self-phaser diagram, based on that we can compute this, Eq is nothing but your Eq prime plus Id, the d axis current and this is multiplied by Xd minus Xd prime. Normally this is, sometimes we assume because, this is a simplification way where it is assumed this Xd prime is equivalent to this Xq. Again depends upon whether your machine is your salient synchronous machine or it is a cylindrical based on that is Xd and Xq should be determined. So, the Tdo prime this Eq double prime here we can write, here this is basically dark here it is missing you can see this Eq prime this again we can simplify in this manner where these are basically derived from this Equation and finally, we can write this is a differential equation that is two.

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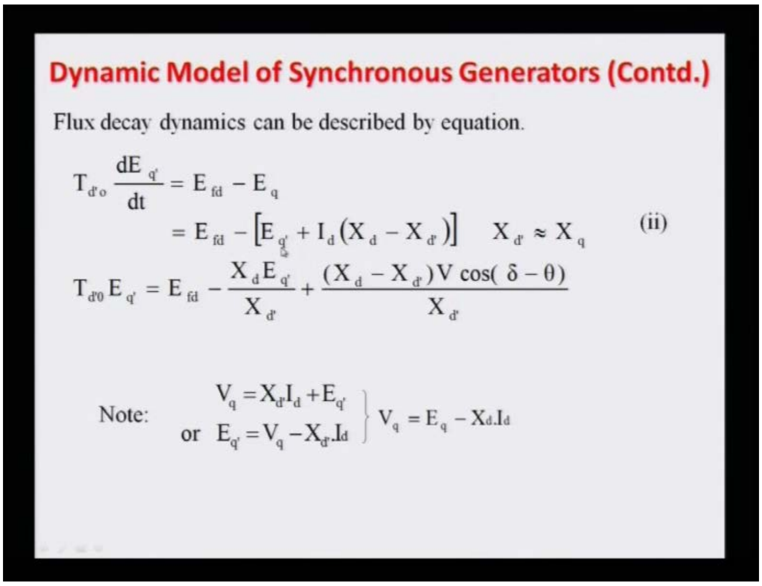

So, now you can see the equation number first that is here, I wrote here this equation number first, then we are having this equation two. From this two, we can see now we are having the third order model of generator because the equation first is having the second order and then we are adding another differential equations so it is a three order and that is why it is called third order model of the generator. Sometimes we also go for the, again more precise representation of synchronous generators and that basically nothing but, the fourth order model includes the additional equation that is third and here you can say that we are using the dynamics of the voltage generator of the d axis.

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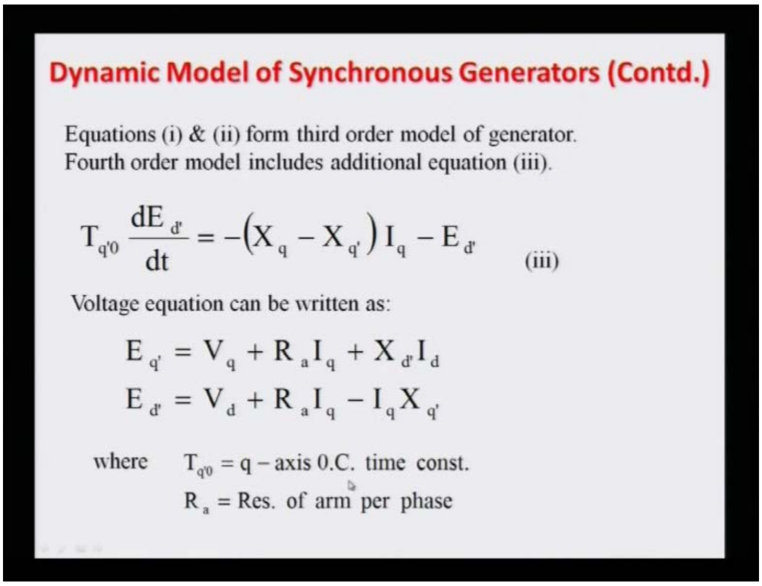

So, this is, del Ed prime upon dt, that term is going to be added and this is define as, again this can be derived by the phasor diagram and the detail modelling of the synchronous machine. This is nothing but, your is equal to minus of this Xq minus Xq prime multiplied by Iq minus Ed prime. So, the voltage equations can be written here because all these variable here Ed prime can be written in this fashion because we know the Vd voltage, we know the Xq prime all the currents and then we can write. Only here this T, Tq prime o, it is nothing but, the q axis open circuit time constant and Ra is the resistance of armature per phase. So, this if you are adding this, now we are having the fourth order model.

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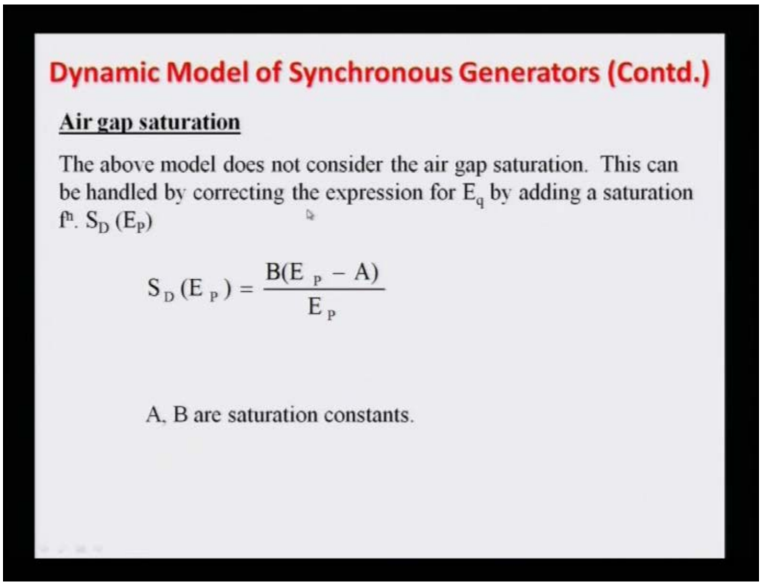

Now, even though we can also include some of the double primes like Ed double prime and Eq double prime equations then we are going for the six order model as well so again it depends upon need you can go for the more more and detailed modelling of the synchronous machine. But, normally third and the fourth order machines as I said in the very beginning for the practical analysis they are used for the third or fourth model of the synchronous machine. To include the air gap saturation, all those equations does not consider as I saw that is, we have, did not consider the air gap saturation and this can be handled by this correcting the expression the Eq prime because the Eq prime which is q axis voltage, induce voltage when there is knee curve you know it and that knee curve can be saturation, can be included by a saturation function. This function and this SD this function which is function of potier voltage and that it can be written SD here EP is equal to B, EP minus A is equal to here AB, A and B are the saturation constant. That can be seen here this EP is the voltage behind the potier reactance as I said and the flux decay equation gets modified here because the Tdo prime here, we are writing this q prime here, this is a dot I think is missing and this we are having here, you can say this Eq is multiplied by 1 plus some saturation factor here.

So, this factor basically, this is other things are same compare to your, this is equation number 2. Here this SD, this is function of Ep is going to added 1 plus this and this that is why it is getting modified. So, the Ep basically is defined, that support your voltage behind the potier reactance, it is E D prime square plus Vq prime square, square of these

2 additive and the root of this. So, the Xp here can be again, this the voltages can be calculated by the Vd, this the d axis voltage, here is q axis voltage, here minus Iq into xp and xp is nothing but, it is a potier reactance.

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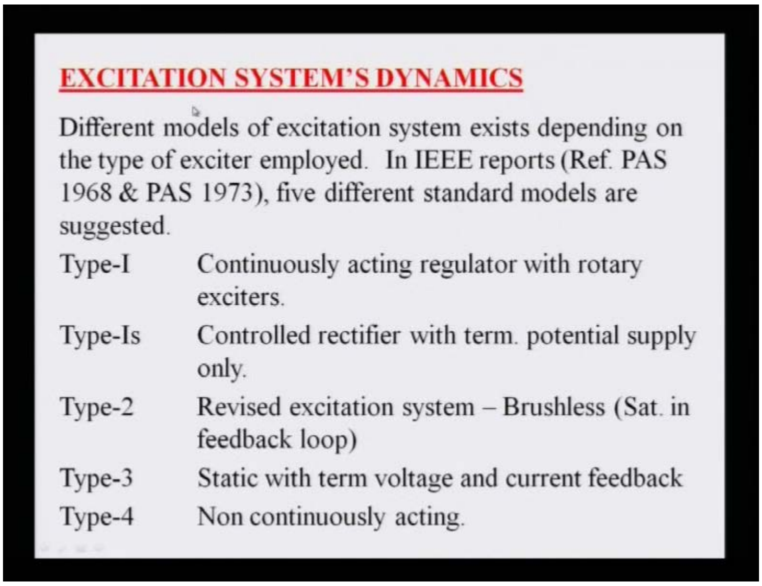

Now, coming back to another modelling that is, as I said we have to model the your synchronous machine now, another modelling required for the transient stability is your excitation system. So, the dynamic of the excitation system again people have gone for the various we know the we are using the various type of excitation system depending on the various type of generators, whether is a small generator, large generators, hydro generators, so we are having again some of the old and some we are having the brushless excitation, we are having the classical excitation and we are having various type of excitation systems are used. So, the different models of excitation system consist depending upon the type of excitation basically used in the alternator. In IEEE report, reference power system, this is PAS operation systems, in 1968 and PAS 1973, 5 different standard models were suggested. Tuhese models include type 1, type 1 s, type 2 and type 3 and type 4. So, these 5 models are normally recommended and that those are normally used for the transient stability analysis.

So, type 1 is continuously acting regulator with rotatory excitation system. In the type 1 s the controlled rectifier with the terminal potential supply only and type 2 is your revised excitation system this is nothing but, is a brushless excitation system where saturation is including the feedback loop. Type 3 is static with the terminal voltage and the current feedback and the type 4 is the non-continuously acting excitation system.

So, normally most of the people go for the type 1 type excitation system and that gives even the better representation even though, suppose your machine is used with some of the other excitation system but, if you are handling, if you are using one of the excitation system like type 1 or type 1 s, this is giving a better picture of about your stability but, if you want to very exact then, you have to use, the what excitation system is used in that machine.

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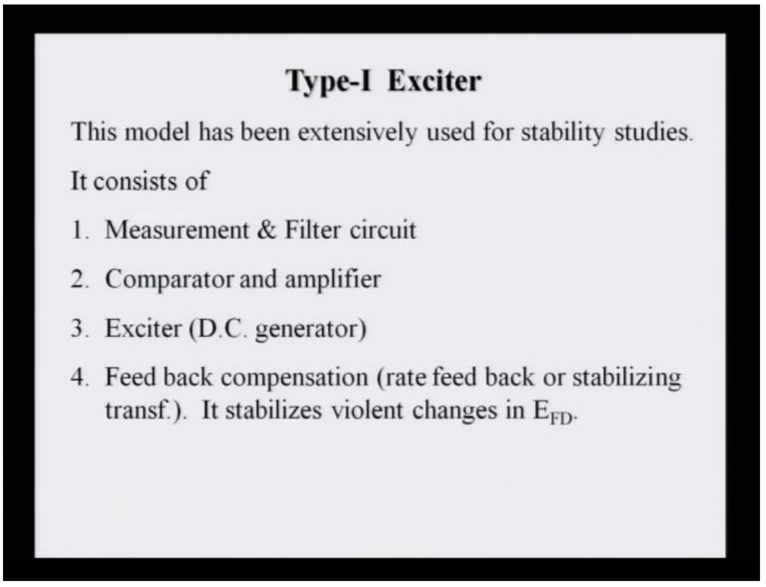

So, here in this lecture only I will consider on discuss this type 1 excitation system. If you want to go for the all various excitation system you can use any power system stability and control book, like you can use the Prabha Shankar Kundur book or you can use the Anderson and Fraud book, all they have discuss various type of excitation system, detailed modelling and their detailed differential equations and those can be included in your transient stability program.

So, in this lecture only I will be considering the type 1 excitation system and this model has been extensively, as I said it is used for the stability studies. Most of the people use this type 1 excitation system and this excitation system is consist of, is of the measurement and the filter circuit, comparator and the amplifier and we use the exciter that is a dc generator here used and the feedback compensation is used, which is the rate feedback or stabilizing transfer function and it stabilizes those huge changes, whatever the changes in this EFD. So, apart from above it may also have following other basic elements that is, we should include the limiters, we should use the line drop compensation and also we have to include the, here you can say the saturation of excitation system. In the voltage limiter, the exciter voltage ceiling or you can say regular voltage ceiling should be done. It should have maximum, minimum value because we do not want to allow this high voltage, should go and that may create the problem in the your excitation circuits. Another is use a line drop compensation, we give another out filter signal in the your excitation, we will see where this signal is going in this other slides. So, before the measurement circuit to account for the line drop compensation, it is use before the measurement circuit at that is, this is whatever the, what is drop in the line that is Xc, that signal is going there. So, you can see this is signal to the measurement circuit, before that, here it is not a voltage, it is the voltage plus Xc and whatever the current flowing there. So, this voltage and this quadrature of this is modulation of this, the VC signal is used instead of the V signal.

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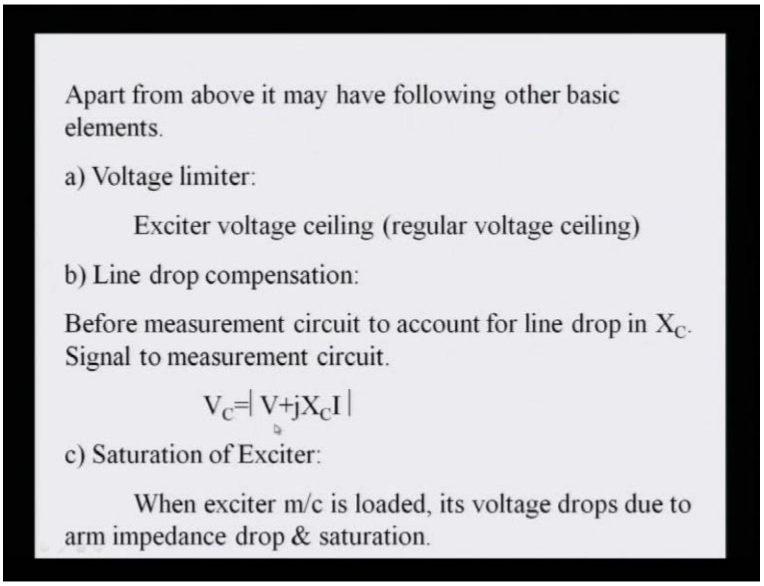

Another, as I said we have to include this saturation effect as well because, you know once your, the disturbance is there, normally in the steady state, the saturation is not require because, is a steady state and it is working on the knee point. But, whenever there is a disturbance your excitation will increase or it will decrease, once it is increasing so saturation effect must also be taken care. So when exciter machine is loaded, I just said and then it voltage drop due to the, an armature impedance drop and the saturation so its voltage is decreasing. So, we have to take care of the saturation effect as well, in our, the modelling.

So, these 3 are also used apart from the all this, here I said the 4 components. Now to include the saturation effect; already I said this is a, this is a function that is a saturation effect, this is B minus A upon A and if A is no load current to produce the rated voltage. Because A is no load current, this if A is current which is producing the no load voltage, rated voltage, B is the full load voltage to produce the same voltage, the function, this is define as this so B minus A is equal to this.

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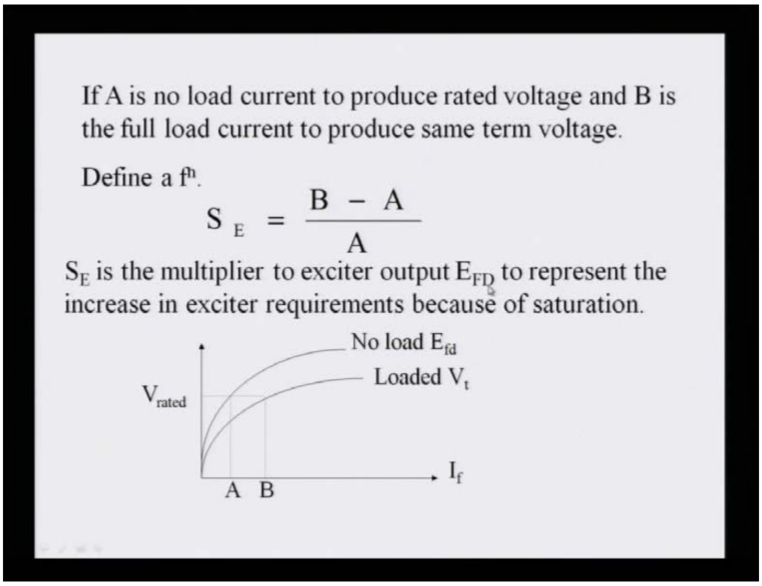

So, the function S E is the multiplier to the excitation output EFD, to represent this increase in the excitation requirement because of the saturation. You can see this is no load EFD, here this rated voltage and this is a field current, A is value here, your rated voltage is A but, due to the loading the terminal voltage is going to decrease and this is your B. So, this saturation factor is defined as B minus A is equal to A. So, this factor is to be incorporated in the EFD, this is basically the multiplier to the excitation EFD taking care of the saturation.

Now, see this is the block diagram complete to, for this excitation type 1 excitation system where you can see here, already as I said that we are having the amplifier, you can start here this generator terminal voltage, this hand side. This signal is coming here

V and then we are using the line drop compensator. If you do not use the line drop compensation this term is 0, means directly you are measuring the terminal voltage and coming here that is a measured in the your measurement and the filter circuit. So, if you are using the line drop compensation because some of the generators use the line drop compensator. So, this voltage, terminal voltage is getting modified due to the line drop and then it is used for the measurement circuit. This measurement circuit and the filter circuit as I says, there is a measurement, there is so many harmonics, so many noises here and there that should be the filter out and we require the voltage here that is coming here.

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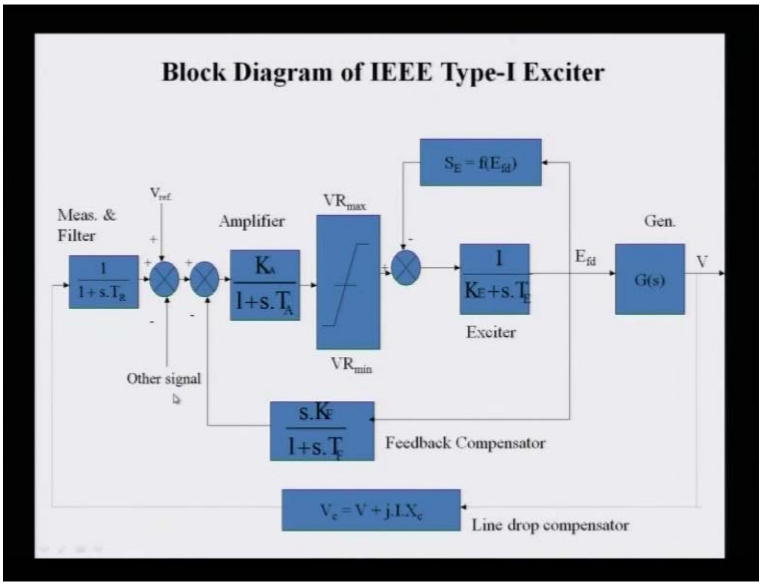

This voltage is compared with your, the reference voltage and then finally, it is going to for this, your in whole excitation system. Here you can see it is written other signal, other signal means sometimes we can have your generator may be having the power system stabilizer that we call PSS. Then that signal also, it also give the voltage signal and that is also used to avoid the dynamic stability of the system and we will see the PSS, we will not see the PSS but, we will see this dynamic stability. So, to stabilize the (), provide the better dynamic stability of the system, we use the PSS and then PSS signal is also included here to take care. So, if the PSS is not there then this signal is 0 and only we are comparing the V with the reference, your V reference and the finally, this signal is there. If this is used, that is also going to be taking care.

Once this signal is coming then, this signal is having the very small magnitude for, we use the amplifier. And amplifier, here you can see this is a K, that is the gain of the amplifier and plus it is a time constant s into T, that is the time constant of this. So, this after amplifying this, we should have the some regulation maximum or minimum value, we are having the limiter and this voltage now is coming here and this voltage is given to your excitation system, as I said the type 1 excitation system is a dc excitation system. So (), its transfer function can be modelled and the, already you can see some of the books for the detailed modelling of this. We can write 1 upon Ke plus s plus Te. So, this Te is the time constant excitation system. This Ke with this parameters can be calculated and then this output which is coming here, it is your the field voltage for your generator. So, this EFD is the field voltage which is given to the field winding of your generator and this generators are means terminal voltage, we use coming here. So, this is a transfer function of the generator issue. You can see this EFD here, is going back here because, due to the saturation effect this s E is also going to be taken care. So some function this, the EFD, as I said the multiplier here is used and that is getting back here. So, this will be taking care of the saturation effect. Also to stabilize this, your excitation, we should not be open loop, we are having the feedback compensation to give the better accuracy and the stability of the system. So, the EFD is coming here to the feedback compensator and this is again going back here and this is a compare. So, that we can maintain the terminal voltage whenever require and this is the feedback type of system.

So, this is a complete block diagram of excitation system, wherever you can see this there is a s, you are having s is a laplace transform. Function s and you can say wherever you are using you are having one differential equation.One order, this you are increasing in the modelling. So, here you can see 1, here you can see 1, here you are having 1, here you are having 1 and if you are modelling even including here. So, then you are having. so many differential Equations as well in your, for taking care of the excitation system and this VT is coupled with your dynamics of the first swing equation.

Now, second, third component I said that is we have to also model the speed governing system and the turbine. So, this basically I have taken from power system stability book, this Anderson fraud, as I said and from there this, we can have this model, can be described as the T 1 dX general expression here, we can write in this fraction, here we can write and the various other components, other state variables x 4, x 5, x and the Pm, we can write the various differential equations that governing for your governing system as well as your turbine system.

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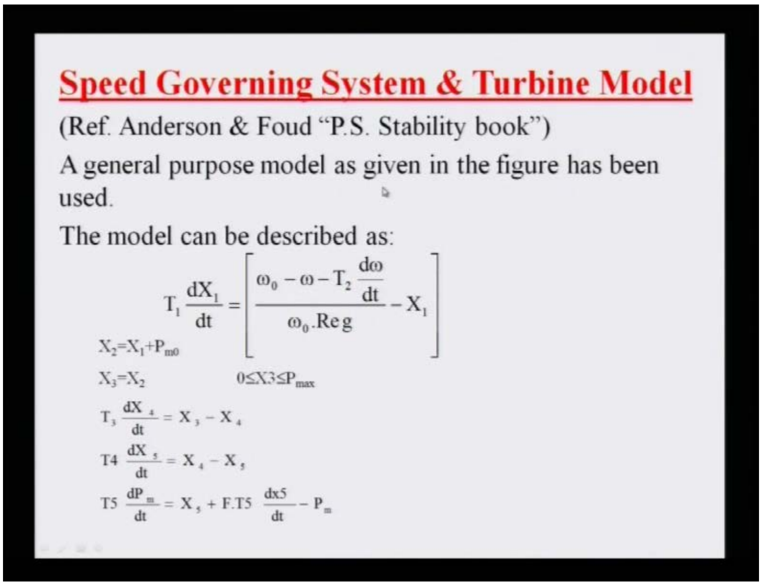

So, a general purpose model is given in the figure, you can see this is a figure, these are the time constant just I want to say this is your general purpose speed governing system where this is your governor or pilot valve.

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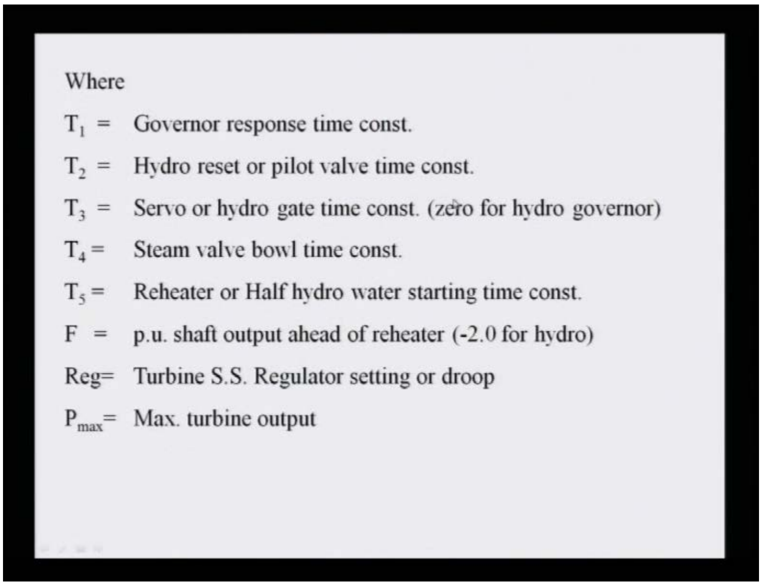

If it is having governor system that is, thermal power station governing system, then you are having a pilot valve, if it is for the, your hydro. Then you are, this is your speed is here, the change in speed is coming here then we are having the Pm also, this mechanical, this desired power output then we are having the ceiling here, the limiter then we are having gate or steam valve. So, gate opening in case of your hydro and the steam valve opening shutter in terms of thermal and then finally, we are going for the steam bowl, we are the steam here there, then we are having the reheat basically, this is nothing but your turbine modelling. Then here, the reheater or the penstock for this penstock for hydro and reheater for your thermal and finally, this Pm is coming and this P electrical and this is going for the Pa.

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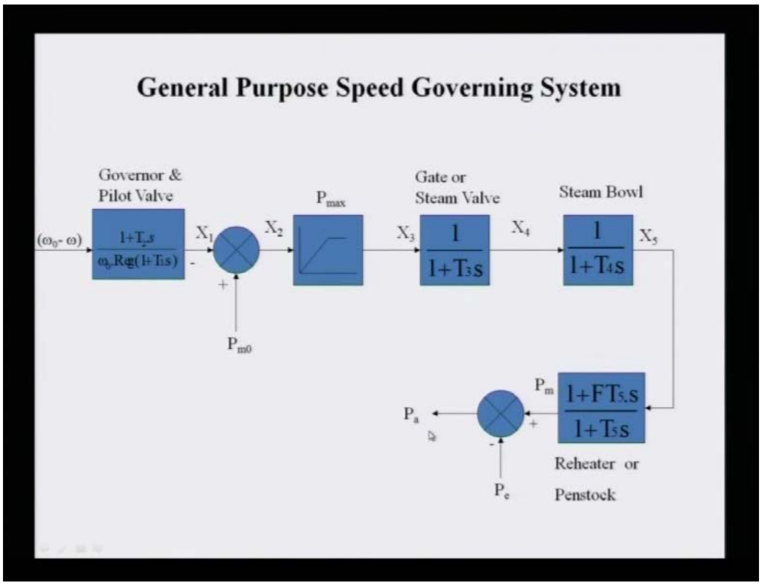

So, this is a general purpose speed governing system and you can say all the time constants here it is written that, the T 1 is the governor response time constant, T 2 is the hydro reset or pilot valve time constant, T 3 is servo or hydro gate time constant, 0 for hydro governors basically and T 4 is a steam ball bowl time constant and T 5 is a reheater or half hydro water starting time constant, F is the shaft output ahead of the re heater and it is minus 2 for hydro and Reg for your the turbine and SS regulator setting on the droop and the Pmax is a maximum turbine output.

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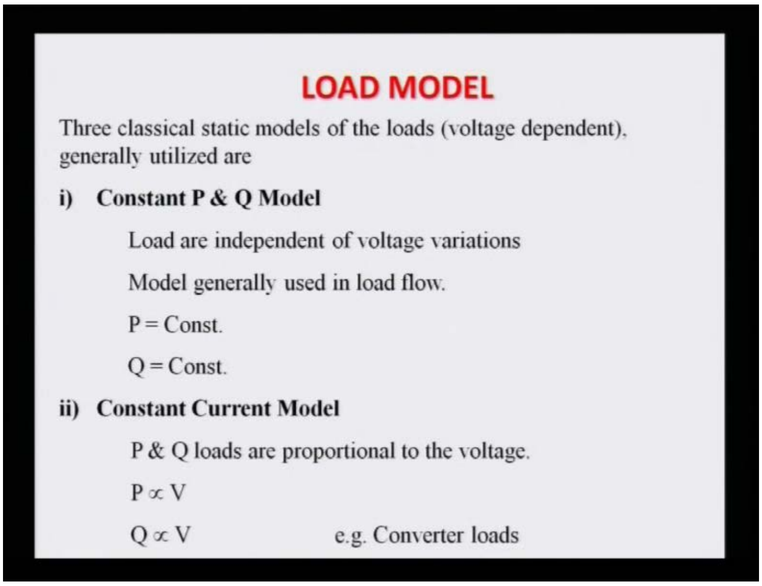

So, with this, we have this governing model and and now we have to go for, this is a load modelling. So, let us start the load modelling as I said is a fourth component that is a load should be also model accordingly, depending upon the need. In the classical normally, the loads are classical analysis of the transient stability, the loads are fixed but, if you are going for the detailed analysis of the transient stability then you can model the load accordingly.

So, loads can be classified in the 3 static load models and can be 3 types. One can be your constant P and Q model where the loads are independent of voltage variation and the mode generally I can say, normally they are use in the load flow analysis where the P and Q are treated as a constant. So, this is a some sort of the constant P and Q model, another is your constant current model. The constant current model where the voltage, this is proportional, the P and Q is proportional to your voltage and that is why it is a real and reactive power of the loads or proportional to the voltage and the example of this is converter loads. So, the we can model this real and reactive power in terms of that is proportional to the voltage.

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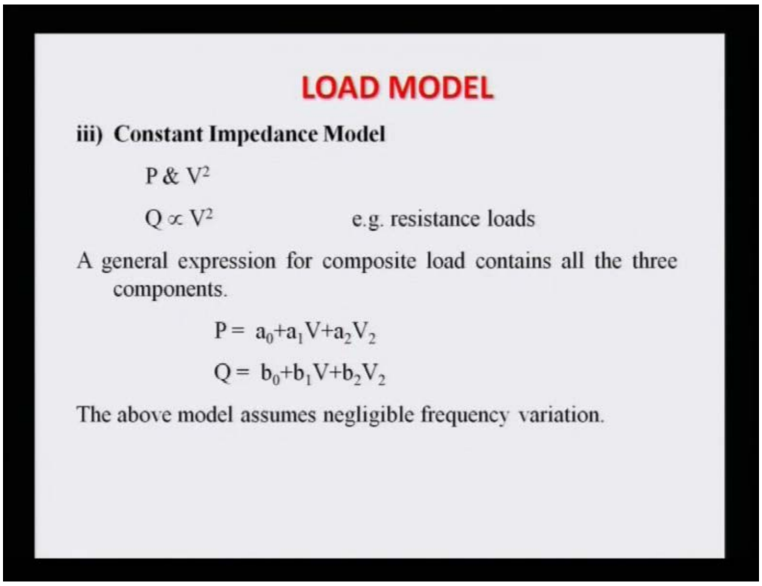

Third type is your constant impedance type, specially you can see the resistance load, it is a simple resistance and you see the power consumed by the resister is proportional to the voltage square. So, the real and reactive power is proportional to, here you can say this is not end, it is proportional so the P and P, that is real power and Q is your reactive power, it is proportional to the voltage square. So, taking care of all the 3 types of load, we can basically consider combination of all these 3 varieties of load into 1. So, I can write this, the real power is equal to the a naught, a naught is nothing but your, the constant, your P type load and plus a 1 V which is a constant current load, that is multiplied by a 1 and that is another one is your, a 2 and here is V 2. Here it is, I think that is a mistake here is not V 2 is V square basically so the another factor. So, it is not V 2 it is should be square. So, P is equal to a naught plus a 1 V plus a 2 V square and similarly, the reactive power we can write say b naught plus b 1 V plus b 2 V square.

So, above model assumes frequency variation is negligible. So, we are not considering this, what will impact on the load with the respect to the frequency variation. So, ignoring this we can write this your real and reactive power can be treated as the voltage dependent and that is, you can say the constant impedance type load model. Here is a constant current, is a constant P and then we can combine together with the various factor a naught, a 1, a 2 and here similarly, for the reactive power is b naught, b1 and b2.

Epri has suggested the use of following general model of load, you can see they have used here the frequency variation as well. So, you can see this P is P naught V upon V, V naught and that is, they are just putting some exponent that is the Pv, that is real power voltage exponent. Similarly, they are putting this f here, that is, this is r, it is exponent of the frequency. If your both voltage and frequencies are varying then you can use this model for the real power and for your reactive power you can write the Q is equal to Q naught and again here the V upon V naught exponent Qv and again the frequency variation. This V naught and the f naught are your nominal voltage and the frequency and this V is actual voltage and the frequency and then exponent basically depends upon the system characteristic because depend among system to system.

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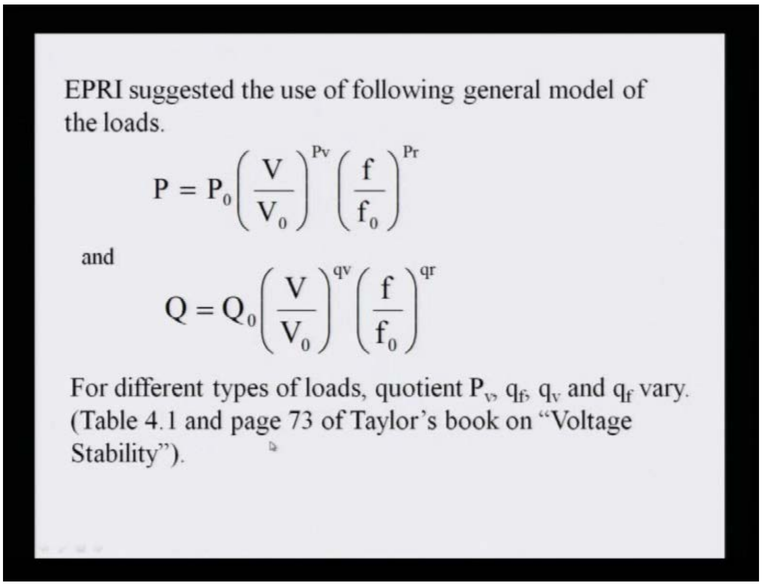

So, the different type of loads and the as I said the quotient here Pv, Qf, Qv and Qf are varying and these are basically, you can find in the Taylor's book of the voltage stability at the page number thirty-three. You can find the various types of load, He is given the various components that is used. For example, already you can say for the, if you are having the space heater or the resistive load, these values you can say this PV is is 2 and other components are 0. For the small motor load, you can find these all the terms are appearing, for the large motors or you can say all the motor without negative part here but, you can say frequency here it is minus 1. So, for fluorescent lamp you can have this components and for the room air conditioners have the following component.

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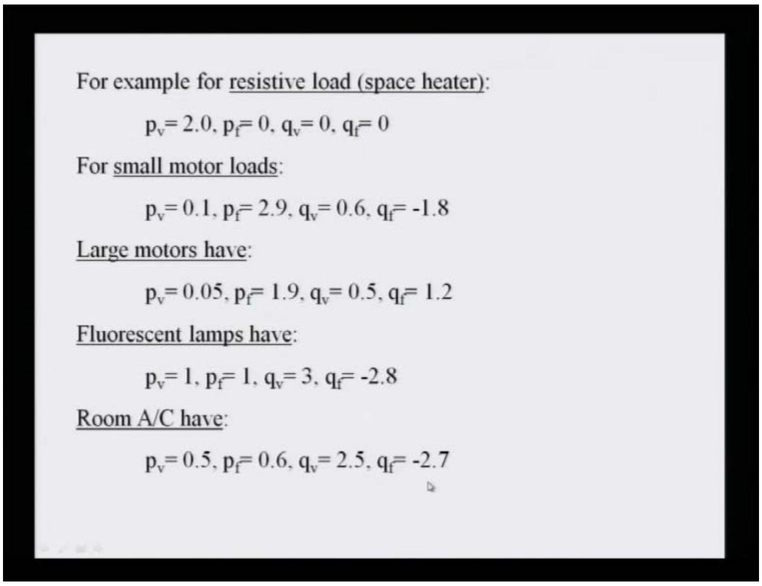

So, you can find the for various, he has computed and found the various components can be used but, in the actual practical system it is not a single house because, it is whole power system, you are having the varieties of loads so that is again, you have to see what is the value of P and V and that should be some, normally lot of people have done for the load modelling itself and that concept can be taken for the modelling of the load.

Even though, so far I discuss about the static, when we were not talking about the motor loads but, you know in the power system approximately this 50 to 80 percent loads are your motor loads or mechanical loads and this motor loads should have some dynamics because some of the machines normally, the loads are the induction type motor loads and they are having, some motors are very high capacity. So, the static model have been reported to be the insufficient to capture the voltage dynamics, the major portion of this dynamic loads are the induction motor, as I said which has the significant effect on the voltage stability and also on the transient stability. The following models of induction motors have been used by Zaid and Taleb in 1991 on, to be transaction energy conversion, volume 6 and they have used, you can see here they are using this voltage with respect to time and that is dynamics that is they have used.

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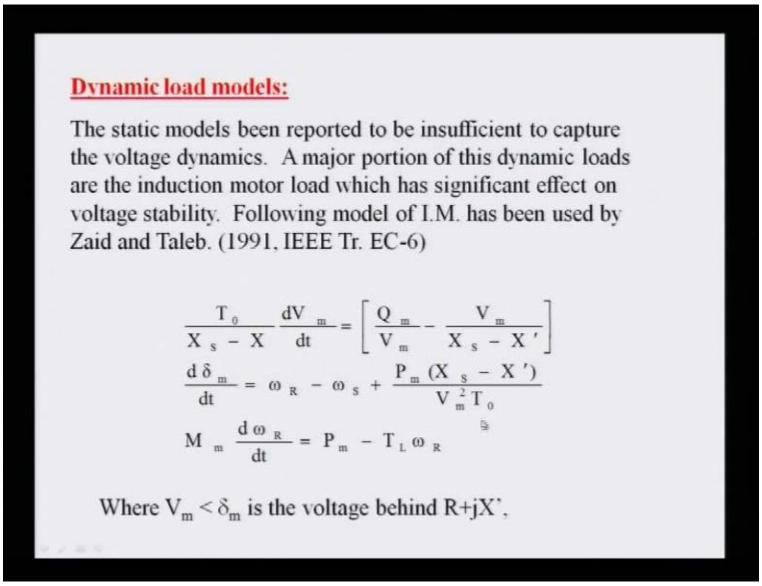

Here Vm is, this is a voltage, is the voltage behind R plus jx is not less than it is the angle Vm magnitude and this motor angle terminal voltage. So this dynamics can be used for the modelling of your machine as well as and this delta M is not a synchronous generator delta, is a machine a motor angle and this is rotating speed of your, omega r is the speed of the induction motor. So three, here the differential equations can be used for the motor loads and some people have seen it is also affecting your especially, the voltage stability; however, the in transient stability, their impact may be less but, that can be also included and that can be solved.

So, all this you can see this terminalogies those were used here Mm, here just which we used this is nothing but, here this Mm is your, this M of basically the inertia of the induction machine and induction motor basically. To is open circuit transient time constant Xs and X primes are the steady state and the transient reactance of the induction motor. This Pm and Qm are the real and reactive power drawn at the internal node of the motor.

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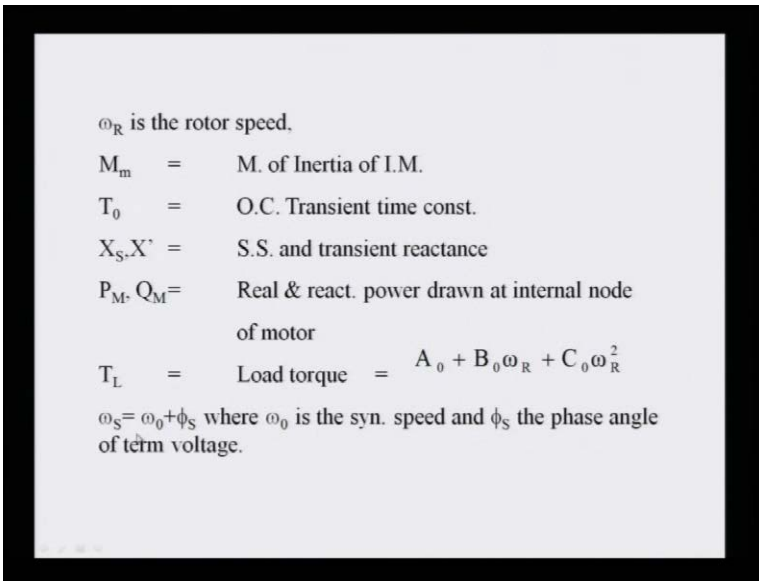

And TL is the load torque and that can be written as A naught plus that is a function of the your speed and the rotor speed that is omega r is basically the rotor speed. Omega s is a synchronous speed that is omega naught plus 5 s where omega naught synchronous speed and 5 s is the phase angle in terms of voltage which is changing. So, that can be included. Some people also gone for the different one because they are saying and for different models are suggested for the stability studies, the load model suggested by the Walve in the CEGRE report 1986 that is, if the Ps plus jQs, the real and reactive powers are the static components and Pd and Qd are the dynamic components, then we can take this Ps and Qs as a constant but, the Pd and Qd who are the dynamic components, that is basically, it should be added here, this some gains that is, a real power with respect to the theta dynamics and kv here the voltage dynamics, all these things are basically now added and then people have analysed for the transient stability.

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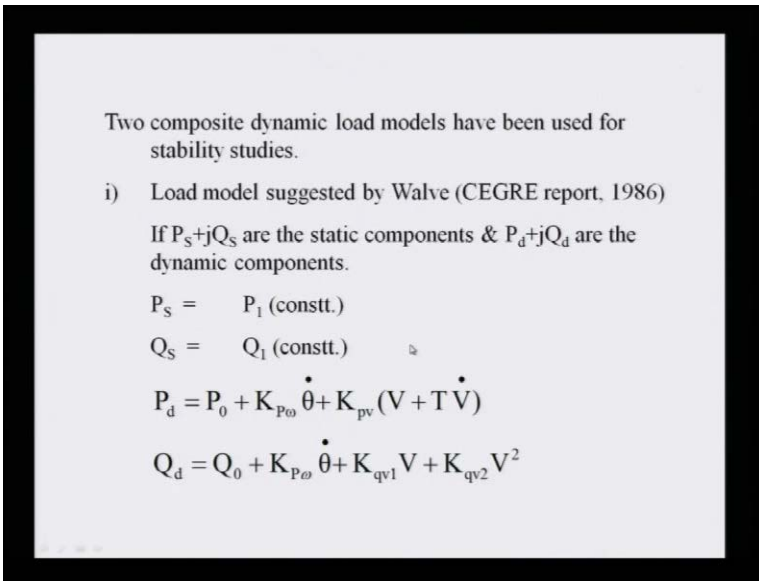

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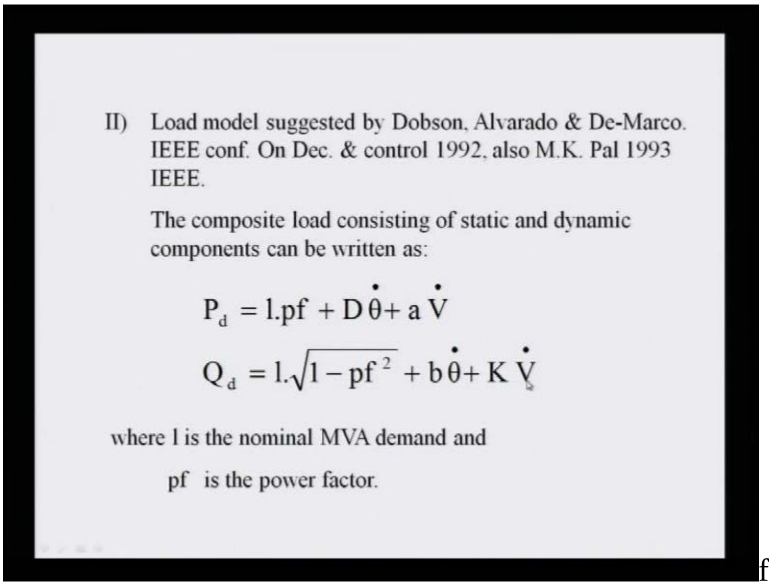

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So, just said the people having modelling of the load is very difficult because in complete power system knowing at any particular instant, what is the components in that load is very very difficult. So, that is why people have taken some approximation and from the system to system this constant should be find out, on then based on that, then can be analysed. In the load model suggested by Dobson and Alvarado for basically in their paper the IEEE conference, on the decision and control in 1992 and also by MK Pal in 1993 in the IEEE transaction paper, they have used another type of composite load consisting of the static as well as the dynamic components and they have used in here this is, L is the nominal MVA demand and pf is the power factor and then this is D is a damping, theta dot plus a is a constant ab of the constant. So, they have used this type of relation for the Q they are using here the k plus V also and that, this whole the dynamics they have included for their studies.

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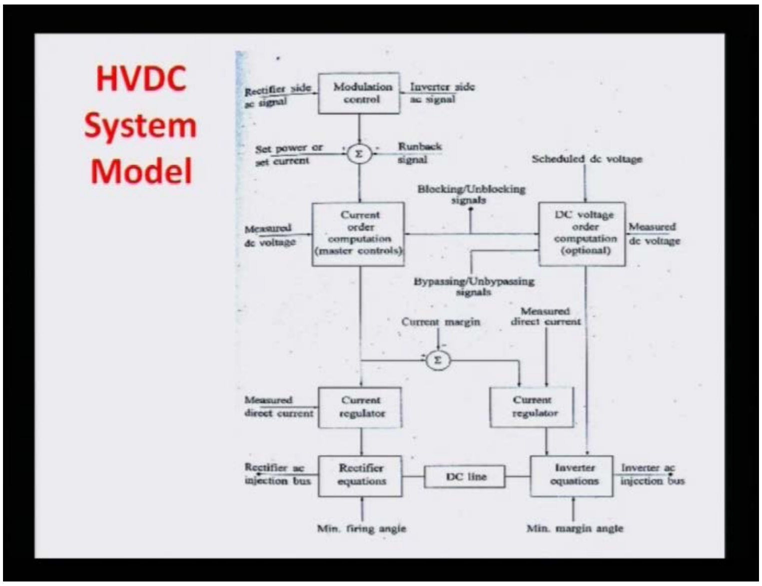

Now, coming at the last one, a model in the transient stability is your model of HVDC system model and this model is taken from the PS Kundur book on the power system stability and control. You see this, what happens any converter HVDC link will have your rectifier at one end, inverter on one end. You can see here we are having rectifier and then we are having inverter. So we should go for the rectifier equations and also we should have the inverter equations and these two are basically connected by a dc line. So, we should also model the dc line as well. In the rectifier, we know the control characteristic that is, we have the minimum firing angle control that is, minimum alpha and also we are having the minimum margin angle that is, should be set to avoid the commutation failure in the inverter side. But, some other argyle are required because here this you require this, we have to have the modulation control and this, all the signal here is you can say this side the rectifier is controlling current; however, this inverter is controlling your voltage and this should, coming here sometimes also this is a reverse back because, if a power is flowing from the rectifier this end to this end, this the rectifier, now it is rectifier, this will work as a current and this will be working as the voltage and if it is a reverse then this will work as a current controller and this will working as the voltage controller. So, you can see here the current controller both are there and here we have the current margin. Whenever you want to change the power direction this margin will be added here and this this current minus this will be going here and that will see the characteristic of the controller, already we discuss in the model, model second when the, what will be the control characteristic of the HVDC link and already again I will show it here in the other slides later on. So, what we require, we have to calculate basically the current order, we have to calculate what should be the current and that is basically decided by the set power. How much power you want to flow and that power basically this is, that is why it is written set power or you can say the current. You have to either set the current or you can set the power because, the voltage you know and then you can calculate the current. So, either P reference or the current reference are here basically there and based on that we have to calculate the current order. To again, to have this we are getting the signal from the rectifier side, the ac signal and also from the inverter side ac signal and these signals are used to have the modulation control and that signal is coming here and based on that difference we are calculating this current order computation, this is a master control. And, here you can say we are measuring the dc voltage because, here the power is coming then you have to measure the voltage and then you can calculate the current.

Now, this side you can see, here the blocking and unblocking signals are also use because, sometimes you have to block the rectifier, sometimes even you can say bypass the signals also, we use sometimes some of the bypassing signals are use especially, when the starting and stopping or there is some fault in some of the valves then it should be also bypassed. So, these are the argyle signals are also, they are sometimes given and then after that if the dc schedule voltage, what is require what you are measuring based on that we are calculating the dc voltage. So, these signals are basically during the starting, stopping or you can say some, there is a some fault or another things we can go for the bypass in this. So, this you can see this voltage is coming to the inverter side.

So, the in the normal fashion if the power is flowing from this rectifier to the inverter side, this rectifier, we require the current signal here, we require the voltage signal but, as I said whenever we may also require that is, this inverter should operate in the constant current mode and then we have to bypass change it and with along with the some change in the current margin, already I discuss these things how this changing and in our module number 2, when the controllers of HVDC link were defined.

So, then this inverter Equation and after that we are having the ac injection buses where they are connected to the ac side, here they are connecting again the rectifier ac side where the ac system is there. So, already we saw the various modelling of the ac side components and now we have to model all this controllers here for your, the dc and this should be included.

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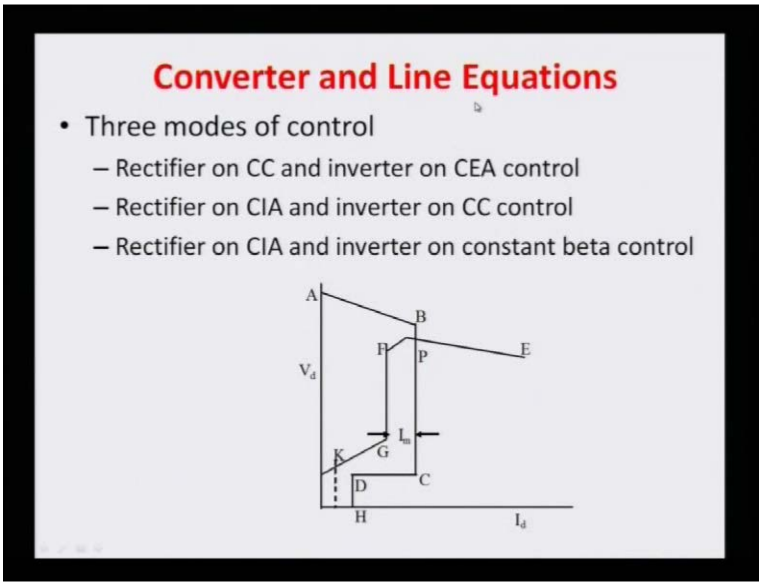

So, to see this converter and the line equations, we have to go for the modelling of the line, sometime we take only the resistance we ignore the capacitance etcetera but, if you are going for the detailed modelling you have to also include the capacitance between the 2 poles. So, in the control we know there is three type of control, this is control characteristic which was discussed in the previous module. Here you can say this is A B is alpha minimum control and that is called here this is C I A control that is, a constant ignition angle control of the rectifier side. This B C part is a constant current, you can see this is a current axis, this is a voltage axis so this is a constant. So, the constant. So, in the normal operation you can see here, the constant rectifier is working on the constant current CC, that is a constant current control mode and the inverter is working in the constant extension angle control, CEA control and this is your basically, this curve is basically your CEA control and the intersection of these 2 characteristic CC and CA is your actual operating point. But, due to the change in the voltage or the limiting or the problems in the ac and dc sides because, suppose there is a voltage, huge voltage drop and the your OLTC etcetera is exhausted then your characteristic can shift. So, then we have given another characteristic you can see, this your rectifier is working here because, this here and your inverter is working your constant current controller because, this voltage can be falling here and you can say various characteristic you can get and this normally here and there is intersections somewhere in this axis FG. There is also possibility that we are operating here and then this zone F here, this characteristic is given that is called constant beta control and already I explained why we are going for the all these control. So, this characteristic was completely defined and I have taken again back from the module 2 when the control characteristics were defined basically. So, this characteristic is again we are having the various modes of control and this we have to incorporate on this

So, here as I already explained the various modes of a converter control and it should be represented by appropriate dynamic models and we will see later on in the section. Another is a line equations and the line equations basically, it is nothing but, the dc lines where this dynamic model which represent the resistance, inductance and the capacitance effect of the dc line can be included. The capacitive effect may be very important especially if we are having the cables and then it should be properly modelled.

So, in this converter control characteristic, first characteristic as I said it is the CC control and you can see the constant current controller here is represented in this block diagram where this Id here the modulation current is compared and then we are having a switch which is either close at this point or close at o and then we are having this transfer function and finally, the T 3 is the response time of the current loop and we are having some limiter here because current should not exceed certain value so the limiters are used and this is your integrator 1 upon s and finally, you are having either D desired restart or is s 2 and then we are finally, getting the Id current.

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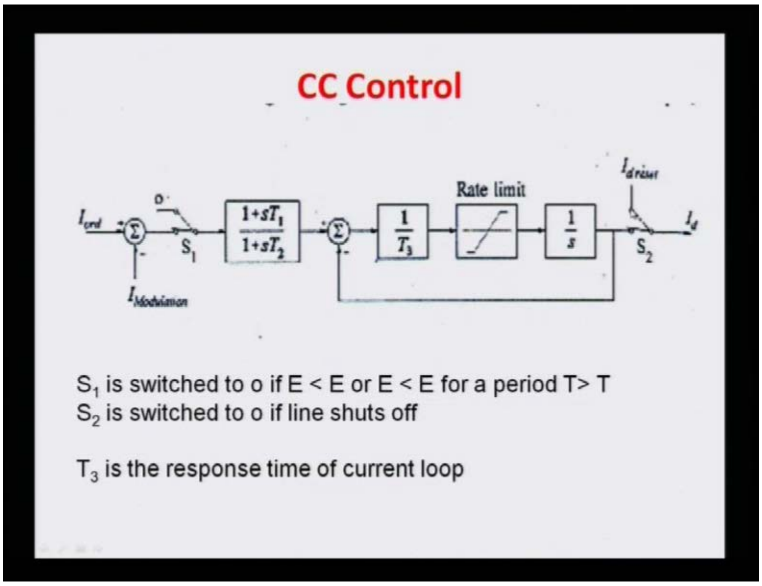

So, s 1 is switched to o, here this s 1, if your E is less than desired value and then it can be calculated. This s 2 here is the switched to o if line has to shut off then we have to, no dc current here, this should go somewhere here and the dc should be restarted. So, this is that one. Another, we are going for this complete, you can say this converter control and this converter control basically, this detail, this is HVDC converter model that is you can see here. This block diagram is taken from the book Power System Stability and Control by the Prabha Shankar Kundur. Here you can see the Vd which is measure and this is a transducer value where we are measuring the dc voltage. This dc voltage is coming here and then here this is, this for the inverter we will see the later on what is the 4. 4 is P desired thus, we are value are getting and then we are coming here. We are also measuring the current here, this current is the dc current and then we are using the dc transducer and it has sometimes constant. So, the current is coming here and after this current here you are measuring, in the voltage you are measuring then this plus line resistance, RL if you are adding here then you are getting the actual voltage of your, you can say another side that is your going for the your inverter side, of your measuring the voltage of your inverter side here because, we are measuring the inverter side and then the current is there, then we can calculate what will the voltage on your rectifier side So this voltage is this, you can say this voltage multiplied by this circuit we are having this V. So, after this V we can calculate, if you are having some P desired value and this P desired value divided by voltage you are going to get the I desired and this is a constant power mode in this way. So, you can have the 2 types of controller here are, you can see

I desired either you are having the constant power mode or you are having the constant current mode. If you are having the constant power mode here, P desired then I desired is calculated accordingly or this which is here then you are having the constant current desired mode and this is coming value here

From here basically we have to see this voltage, this current should not exceed so, we have to determine the maximum current that if its having some limiter and this max is basically used here I ordinary is equal to I des and if I minimum is between this I ordinary we have to say this ordinary should not goes in that limiter. So, I ordinary here that is, determine that is, current order basically its order I order is calculated here and that coming here after the measurement we are dividing this value and then we are having this current regulator.

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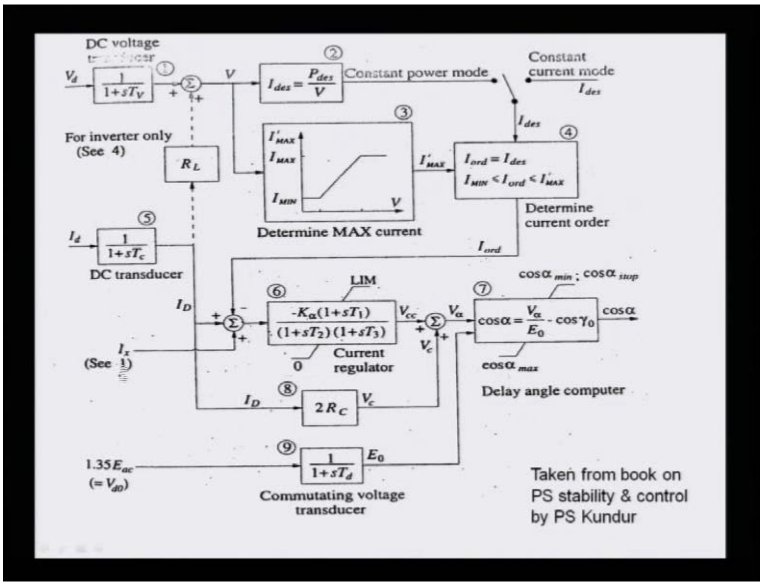

You can see here the Ix, Ix is nothing but the, which it is returns E 1. E 1 is nothing but, Ix is I reference minus I modulation for the rectifier and the Ix is equal to I margin for the inverter.

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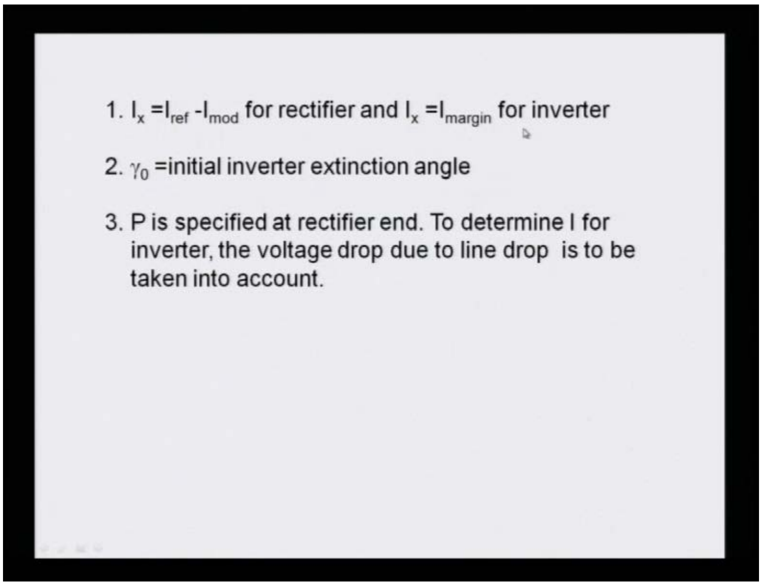

So, here we are using some, is addition if it is inverter then some modelling is added, if is a inverter then the reference minus your, the modulation is going to be added here and then based on that we are calculating the current regulator and we have the limiters means, this current should not exceed very high value. Then based on that what we are getting here, we are using the compensative current control voltage and that voltage is basically added with this, whatever the Id you are measuring here, this is multiplied by 2 Rc and this is the voltage, the commutation voltage you are getting.

So, this voltage and this voltage, both are added and then this is known as IV alpha, which will decide your, the what will be the value of alpha. Here also while calculating this alpha, the delay angle computer, here we will see this value should not exceed maximum or minimum value due to the various reasons and then based on that we are getting the cosine alpha and this alpha basically coming here. You can say the commutation voltage is also here from calculated, the commutation voltage transducer, it is measuring and this is going to be added which is used to calculate cosine alpha. If you will see the basic equations of a rectifier circuit or inverter circuit, we are the voltage cosine alpha Vd, some voltage multiplied by the cosine alpha and then another component is coming into the commutation reactance multiplied by the current or you can say commutation voltage. So, that is used to calculate this cosine alpha. So, this alpha is to be calculated.

So, in this complete, you can say whether you are having your converter, is your working as a inverter mode or it is working your rectifier mode, this complete block diagram is used for both. Only we have to see where it is inverter or rectifier, based on that the modes as I said the, either it is a CC modes, already these modes which I explained which 1 is working on which mode whether, inverter is working as the CC or beta or CEA, it can work on the 3 modes, this can work in the 2 modes that is, a CC or CIA mode, based on that we have to, already we have to write the here the switches and etcetera, will be formed and then we have to write the differential equation accordingly So, along with the other equations here, you can say some of the value which are defined here is 2, is gamma that is we are using gamma naught, that will be used in the differential equations here and also P desired is specified at the rectifier end, to determine this current for the inverter and the voltage drop due to the line drop is to be taken into the account, this I here, this order is to be calculated.

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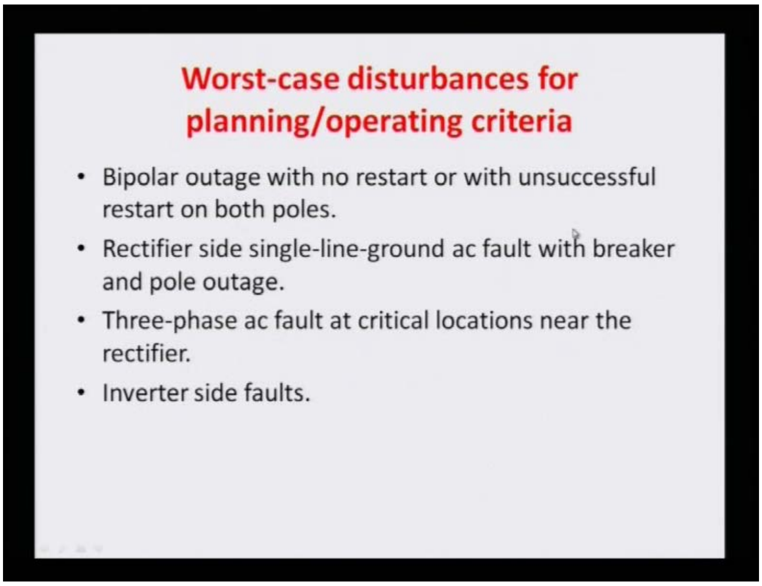

Now, we saw all the modellings and modelling include your each and every component, I said including your ac system that including the synchronous machine, excitation system, governor system, then we have to go for the load modelling and the final just we have to include your HVDC system. If you are having some other controllers like your static wire compensators or TCSC or EPFC, I can say, if you are having the flexible ac transmission system devices, controllers that controllers should also be modelled and then it should be added. So, as all the controllers along with the machine should be included and then you have to write the governing equations and those governing equation or your, the differential equations along with the network equations and this should be solved.

So, to some of the conditions basically, what are the worst case what are the faults normally are considered, already we have seen the for faults in the ac systems, we very well know the various type of fault, it may be your 3 phase fault, it may be your line to line fault, may be single line to ground fault, all the faults are basically analysed and we see what are the critical faults, those where the system can be unstable. So, similarly, there is various faults near to the HVDC system or inside the dc system that should be taken care. Already the mal-operation another things already I have discussed in the our previous modules, here we can consider the various, the worst case disturbances for the planning and operating criteria and those are basically, if we will see the dc side, we have to include the bipolar outages with no restart or with unsuccessful restart of the both poles. If the both poles are out or we are trying to close and still it is not working so that event is the Dc side we are taking care. We can also take if the fault is occurring in the dc line along with the resistance and because we are having some capacitances, what will be the dynamics, what will be the current level, etcetera, that can be also seen.

On the rectifier side, we can go for the single line to ground fault and the ac that is, ac fault with the breaker and the pole outage. If the fault has occurred at the converter station itself and then the breaker, your is and pole is going to out then what will be the repercussion whole system. We can similarly, this is as I said, the single line to ground fault is not very sever fault compare to the 3 phase fault but, 3 phase ac fault at the critical locations near the rectifier should also be seen and it should, the impact should be the analyse properly. Similarly, we can also analyse for the faults related to the inverter side and inverter side you know, the faults are very very sever compare to the rectifier side because there is possibility of the commutation failure and other things in the inverter station. So, we have to same, we have to go for the various faults here instead of inverter side, I have to write the, instead of rectifier side I have to write here the inverter side and similarly, here also here rectifier, we can write the inverter. So some other faults like even though there is no fault and there is some delay in the signal, in the you can say the firing circuit that may be leading to the commutation failure that should be also taken care.

So, all these things are basically analysed in this whole analysis and then complete ac dc system should be modelled and then we have to solve these all the differential equations. And then we require some tool to solve and that we will discuss in this next lecture. But, to summarize here, in this lecture I can say that is, in this lecture we model and we saw the various level of modelling of synchronous machine, we are the third, for already in the previous lectures we have seen this the swing equation that is a second order, then we say the flux decay model we use the third order and we also saw some other models like the fourth order models, also taking care of saturation. Then we saw the type 1 excitation system having complete block diagram, complete modules, complete blocks of that including your amplifier, line drop compensation, excitation system models, measurement circuit and saturation effect, etcetera, is taking care. Then we have to go for the governor and the turbine models are to be done for all your hydro as well as the thermal power stations and your load model is also equally important for complete transient stability.

So, people can go up to certain approximation of the load model as I said it is a very difficult task to model the load because, complete power system having the varieties of loads and it is keep on change. So, it is not a fix. So, that is we have to go up to certain level of the modelling of the load as well may be, it is the voltage varied load or also your frequency dependent and moreover, we have to also take some dynamics load. And in this ac dc transient stability program, the modelling of the dc that is, HVDC converters, its control aspects and the dc lines are also very important. So, already in the previous lecture I discussed that, we can go for the 3 level of model, simple model that is very simple where almost HVDC line is excluded, we simple say injections or real and reactive power then we can go for the response model and then finally, it is a detailed model.

So, if you are going for the detailed model I can say that is you have to model all these aspects of the converter as well as the dc lines and their control modes along with the, some various other mal-operations should be included and that is, we have to model and then finally, we have to write the governing equations along with the some algebraic network equations and that should be solved. Thank you.