Power System Dynamics and Control
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Lecture No. # 34
Transmission Lines (contd.)
Prime Mover Systems

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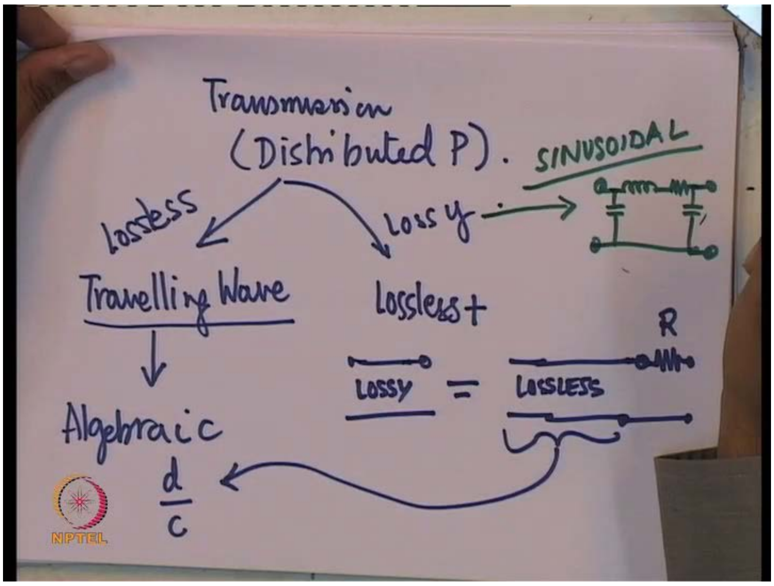

The situation so far, as far as transmission line modeling is concerned is as follows. So, transmission lines of course, distributed parameter devices, and in case it is a lossless system that is the series resistance and shunt conductance are neglected; in that case, the solution of these the system is in the form for travelling wave. And in case you have this lossless system and the travelling wave solution it can be shown that you get, you can get a kind of algebraic relationship between the voltages and current set one end of the line and the voltages and the current set at the other end of the line, but of course, the effects on one side of the line are apparent only after a delay of d by c where c is the velocity of propagation and d is of course, the distance or the length of the line .

In case you have got a lossy transmission line, in such a case you do not get travelling, the beat traveling wave solution. What you instead can do in case you want to kind of, you know solve these equations easily, is to assume that a lossy line is. In fact, a lossless line plus the series resistance can be lumped together and put outside the lossless line.

So, you got lossy lines is equal to a lossless line plus the total series lumped resistance can be taken out. So, this is kind of an approximation. So, for the lossless model of course, the solution is a travelling wave equation of course, this we are handling only the series resistance this way. In fact, the shunt conductance is quite small and they can be neglected quite safely.

So, the series resistance on the other hand may have to be accounted for and you can do it by modeling the lossy line is a lossless line for which the solution is very well known, plus account for the resistance using separate element connected in series. Interestingly enough the model of the travelling wave solution for a lossless line makes a transmission line model easy to interface with the discretized equations of the lumped dynamical elements connected to the transmission line. For example, like capacitors and inductors etcetera, you got a lumped differential equation continuous time differential equation when you discretize it using trapezoidal rule or any numerical integration technique, you get algebraic equation. So, algebraic equations obtain in that contexts slightly different from what you get here. In fact, there is no approximation once you get the travelling wave solution the algebraic relationship which you know a kind of relate the sending end and the receiving end are. In fact, exact you know representations of the solution.

So, that is one important and interesting point. Another interesting point was that the steady state solution for a lossy lines and of course, also for a lossless line the sinusoidal steady state solution, the sinusoidal steady state solution of a transmission line effectively allows one to represent, transmission line is a two port network with lumped impedances and admittances. So, this kind of model can be obtain which is valid under sinusoidal steady state conditions, this is a lumped model of a transmission line.

Now, what we showed in the previous lecture was. In fact, the travelling wave solution of a transmission line and the solution numerical solution or even analytically obtained solution for this L c circuit, lumped L c circuit are close to each other, but not same. In fact, there are some notable differences, but if your interest is only in low frequency behavior you can model a transmission line by lumped parameters of this kind like, like this circuit, but remember that the lumped circuit in infect came from the sinusoidal steady state solution.

So, it is a nice thing that at least for low frequency behavior one can use this two port net equivalent, sinusoidal steady state equivalent to actually derived lumped parameter dynamical model of this system. So, it is a nice thing because it simplifies at least in certain circumstances our analysis. The other thing which we discussed in the previous class was when you have a three phase a coupled line.

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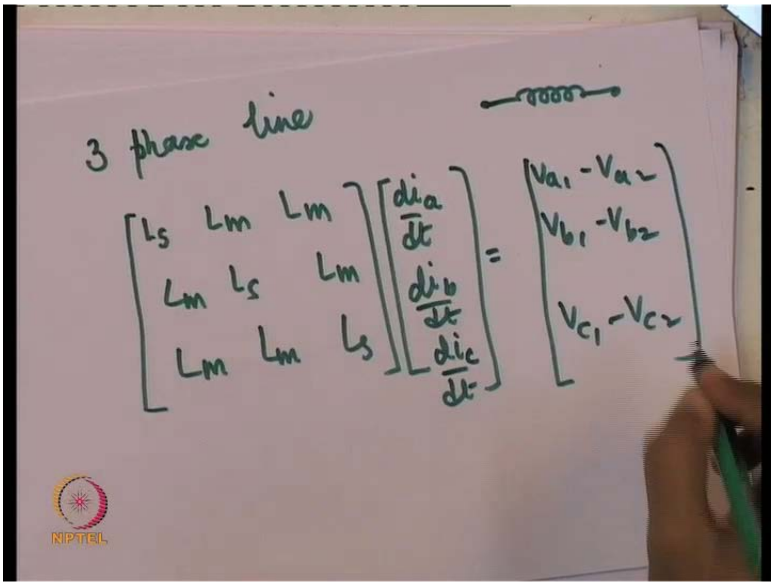

Three phase, phase lines your inductance matrixes and capacitors matrices are in fact coupled, but if it is a symmetrical three phase system what we saw was one can use transformations. In fact, you can use the d q transformation and actually get a decoupled representation of a transmission line, that is, if you recall what we did last time for example, if you take a simple inductive element which is coupled, you know in this fashion, recall what we did last time.

So, suppose it is, for the time being, let us assume it is a lumped element, but it holds to this decoupling which I will be talking of force to even for the, you know for the distributed parameter model. So, this is V a 1 minus V a 2, V b 1 minus V b 2, V c 1 minus V c 2, and if i use the transformation from a b c to the d q frame you get.

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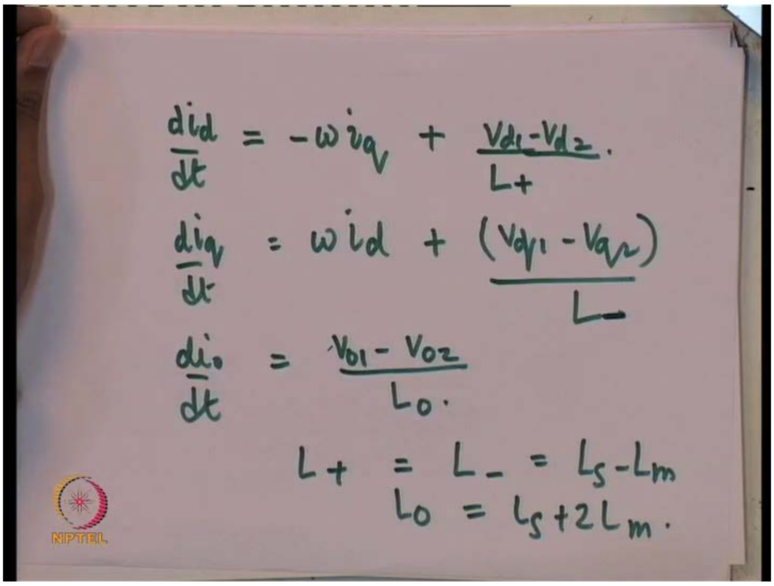

In fact, some interesting and what we get effectively is did by dt is equal to minus omega multiply iq plus V divided by L that is Vd1 minus Vd2 divided by L. Similarly, you will get diq by dt is equal to omega multiply id plus Vq1 minus Vq2 divided by L. So, and of course, this is 0 sequence equation.

So, I will call this. In fact, L plus L minus and this is, you will get V01 minus V02 divided by L0. In fact, L plus equals to L minus is equal to Ls minus Lm and L0 is equal to Ls plus 2 Lm. So, what we see essentially if we have got equation coupled equation in case of three phase lines

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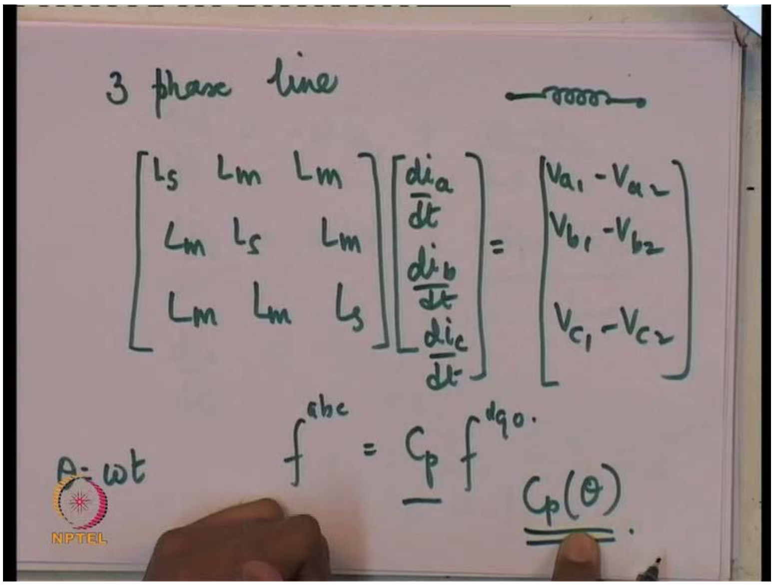

You are going to if you apply the d q transformation the d q transformation, if you recall relates the a b c variables to the d q 0 variables and C p is in fact, a function of theta and theta itself is omega t. So, this of course, transformation is defined based on the theta, there is a position of a synchronous machine. Now, if you have got just one synchronous machine connected via a transmission line or a lumped L element like this to an infinite bus, this is what we did in fact, in the examples previous to this topic when we were considering the behavior of an AVR in that case you can use in fact, the theta of the synchronous machine, the single synchronous machine which is there.

So, but if you got many machines what do you do, is something we will discuss when we come to few multi machine examples, but in case you have just one machine you could use the transformation defined by the position of the machine. So, this parks transformation which uses theta, which is the position of a synchronous machine. So, if we use this transformation on the transmission line equations, this is what you get and a interestingly L plus and L minus are lets, you know what whatever appears here are in fact, equal. So, L plus and L minus are on fact equal to Ls minus Lm which incidentally is also a positive sequence inductance similar things can be done for capacitance also capacitive elements.

So, this of course, is nothing to do with necessarily a transmission line because I have just shown you what happens if you got a couple three phase inductive element. So, you can use this even for lumped elements capacitors which are there in a transmission line, but this is also going to hold true for the distributed parameter model of a transmission line. So, if I in spite instead write the three phases coupled partial differential equation you should be able to apply this transformation and get it decoupling in a similar fashion.

Now, more than the decoupling you know you get a kind of decoupling between the 0 and the d q again here. What I want to really say is that applying the transformation to the set of equations like this using synchronously rotating transformation or parks transformation C p.

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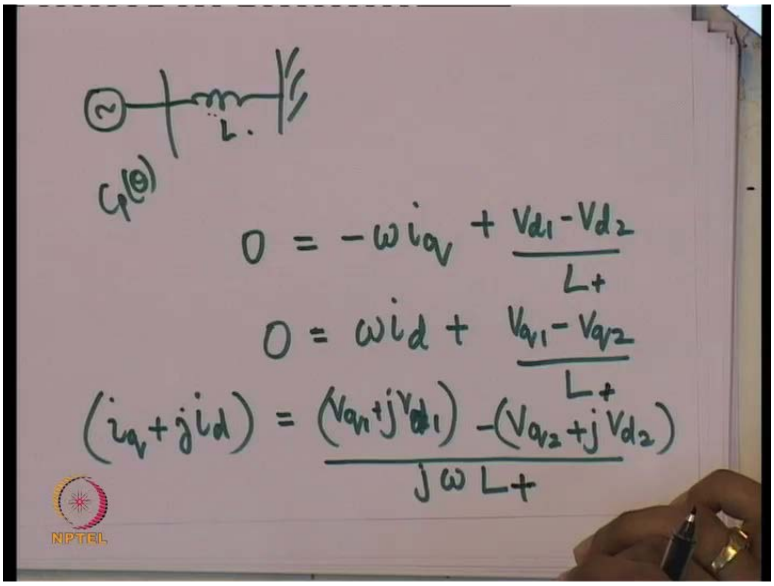

In fact, does not create any problem. What do I mean by that, see whenever you are interfacing a synchronous machine via say a transmission line or a lumped inductive element, to say an infinite bus, remember that whenever you are your formulated this synchronous machine equations in the parks reference frame. If you want to interface the d q variable obtained of the synchronous machine with the transmission line, what you really need to do is, really also get the currents of the transmission line in the d q frame. So, this is exactly what we have done here. This is exactly what we have done here, we have got the currents of the transmission elements in the d q frame and this may be easy to interface or it is easy to interface with the synchronous machine model eventually. So, this is one thing which you should keep in mind. An interesting thing is that if I set did by dt and diq by dt equal to 0 what we have essentially 0 is equal to minus omega iq plus

Vd1 minus Vd2 by L. In fact, we will get this. So, what we have essentially is, if you look at these equations what they are really telling you is iq plus jid this is just a compact way of writing these equations. I will just combine these two equations, you can just verify that this is true, is equal to Vq1 plus jVd1 minus Vq2 plus jVd2 divided by j omega L.

So, what we an interesting thing about this formulating a lumped inductor equation in the dq frame is, that in steady state the current through an inductor can be obtained from what looks like a phaser equation with the d and q components is a real and imaginary parts of the phaser. So, this is a compact algebraic relationship, which exists in steady state for a lumped inductive element. So, in fact this L plus and L minus are equal. So, actual this will be is how it is. So, this is a compact notation. So, that is what one has to note here and it is valid only in steady state. In fact, in dynamic conditions for a lumped inductive element coupled, three phase inductive element the equations are like this. For a distributed parameter network of course, you will have partial differential equations, but you would even formulate the partial differential equation in the dq frame.

So, what I really want to show you here is what will be using later on in our analysis, that is, formulating all the electrical components in the dq frame while interfacing them you could do the opposite. For example, a synchronous machine equations are formulated in dq frame, the easy to solve in the dq frame because the equation at time invariant. You could for example, convert the dq back to ia ib ic formulate the transmission line equations in ia ib ic and interface its synchronous machine in currents ia ib ic with the transmission line.

So, this is something you can do, but in whenever you are studying slow transients it is usual to formulate everything in the dq frame, rather than getting back the synchronous machine currents or voltages in the a b c frame and then interfacing with a b c model of a transmission line. So, it is good what we will see in fact, in one of the examples which will be talking up shortly in the next few lectures is that, we will formulate all the electrical elements in the dq frame of reference. We now move on in fact, to another important element of a power system, important component of power systems. In fact, it is not really an electrical engineering kind of element, it is not an electrical component. What we are going to just do relatively faster study is about the behavior of the prime movers systems.

In fact one of the things you would have noticed is that one thing we did not do in the previous simulation and analysis which are shown you in this course is trying to model how the prime movers itself behave. In fact, we have taken a constant torque input Tm the mechanical torque is in fact, taken to be constant in most of the simulations and analysis which I have done before. Now, what I will do is a just look behind and see what really are the models of the dynamical systems which are there relating to the prime movers systems. So, of course, my approach will be more like an electrical engineer my; obviously, a very detailed treatment of the you know equations mechanical equations is beyond the scope of this work. What I will try to do is give a somewhat compact representation of some of these prime movers systems. The prime movers systems in fact, the two most important ones are those corresponding to hydro turbines and steam turbines.

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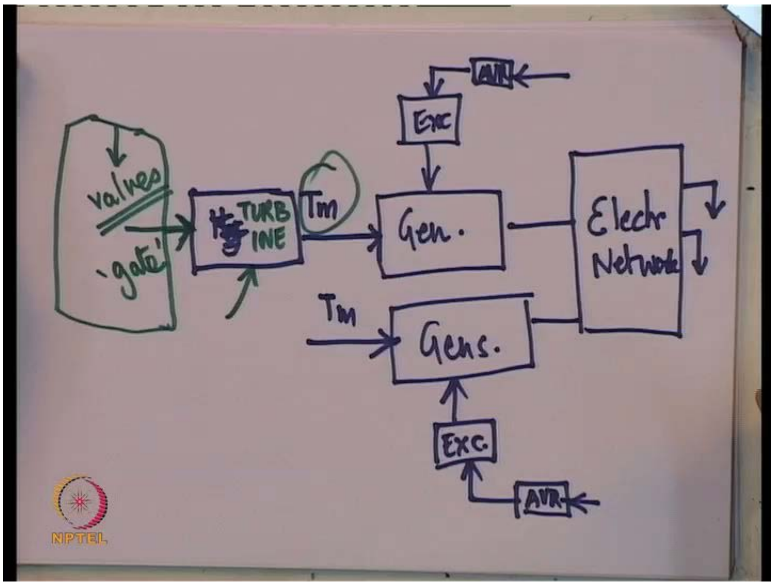

In fact, if you look at, how look at the block diagrams so, to speak of these systems your generator is an electrical element and you have got of course, an excitation system and excitation system has got a controller. So, this is something which we have done before; generator connected to an electrical network and possibly through the electrical network to loads and other generators. So, you have got other generator as well. The important thing about this the AVR, the AVR and associated excitation control systems, limiters, stabilizers which are present as a part of the complete excitation system package. The generator itself one of the most important things, inputs to the generator is a shaft torque, the shaft torque of the generators. No, the shaft torque of the generator is actually got by from a turbine. So, turbine is essentially a steam turbine or a hydro turbine is also a dynamical element.

So, this is the turbine is a dynamical element. It is not, what do I mean by dynamical element the turbine power itself is determined by the flow of steam and pressure of steam and that is in fact, affected by the control systems which control in a steam turbine. For example, the valves control valves to the turbine as well the boiler. Now, so in fact, the control valves are in some sense controlling the turbine output power or the output torque. So, of course, in the hydro turbine you call it a gate, the gate in effect determines, the gate position determines the mechanical power output at the shaft.

So, the valves or the gate in a hydro turbine actually determine the mechanical power output which goes to a generator. Now, remember that in a steam turbine or a steam power generating station, just the valve position of course, does not determine the mechanical power. In fact, if I want to increase the mechanical power I would also have to, you know, increase the fuel in the boiler. So, this is in fact, simplistic way of saying that only the valve control affects the mechanical power, but for short while years just by controlling the steam input to the turbine through a control valve one can actually change the mechanical power eventually of course, you will have to adjust the fuel input also otherwise the pressure will change.

So, the turbine is a dynamical element in the sense that if I change the valve position here, the effect on the mechanical torque is actually felt after some time. In fact, it is determined, the behavior is determined by a set of differential equations. So, in that sense a turbine is a dynamical element. If you look at in fact, what other things we have to consider you will also have to consider for example, the control systems or the actuators actually change the position of the gate or valve. So, valve and gate position changing also is a dynamical kind, of you know phenomenon you can say dynamical it involves dynamical response. So, you know if you want to change the valve position. In fact, you have to use hydraulic systems and the hydraulic systems are in fact, triggered or you known made to change by controls systems.

So, again here as in a excitation system we should differentiate between the main power apparatus in this mechanical systems it is a turbine, the control is done by the valves the valves are themselves you know the position is change using actual hydraulic actuators. The hydraulic actuators again is you know control by low power, you know it is you can say control system. So, this is a control apparatus which is essentially a very low power apparatus which actual tells you how what to change and how to change. So, this is what you have to appreciate here. The control system of course, of a turbine or the prime movers system is in fact, responsive to various requirements and feed back for example, one of the major or most important control system of a turbine, eventually the mechanical power output is the speed the of the turbine, you know. For example, you want to wish to keep the speed of turbine generator system almost constant.

So, that could be in certain situations one of the control objectives. So in fact, if you look at the example which I have done so far in fact, all the examples so far, you had a synchronous machine connected to another voltage source or an what we call it an infinite bus a constant frequency voltage source. So, this voltage source was capable of absorbing what all whatever you could deliver to it. So, there is no issue of speed control because we know, we knew that eventually the system would or the synchronous machine has to, if it reaches steady state be at the same speed as the voltage source, same frequency as the voltage source. So, otherwise it will be have would have loss synchronism. So, in steady state speed of a synchronous machine is also is always equal to the speed of the voltage source.

So, we did not have to do speed control, whatever mechanical power the generator if I increase the mechanical power it would lead to increase in the electrical power and voltage source would happily absorb it without any problem because we idealize the rest of the system as the voltage source whose would be unaffected by what current is flowing into it or how much power it is absorbing. However, suppose you have a situation where you have got a single generator connected to a load and a load changes. We are not talking of how much synchronous machine connected to a voltage source, we are talking of a synchronous machine say connected to a passive load, say the lighting load in commercial establishment.

So, you have got a local generator which is supplying this lighting and if I switch off one light the electrical load changes. If the electrical load changes in that case the speed of the turbine will be affected, speed of the turbine and the generator will be affected, and under such circumstances we are gone isolated generators connected to passive load you have to do some kind of speed control. So, one of the control objective of a turbine generator system or a prime movers system is to control a valve position so, as to control the speed of the machine. So, in fact if you got many generators spooling in their power into a grid and supplying many loads you have to in a co-ordinate fashion, in a co-ordinate fashion control the speed of the generator. Of course, all the generators eventually settle down to the same speed.

And your control system, the prime mover control system should be such at any change in load which will result of course, change in the speed of generator would be compensated or controlled by changing the valve position or the gate position and enhancing or reducing the torque. So, that eventually there is a load generation balance. So, the main idea behind turbine a prime mover control system is of course, to ensure this load generation balance and therefore, in fact a maintain speed and of course, this the job has to be done in a coordinated fashion in fact, to be share this job among various generators. This something we will do a bit later how this sharing is done and so on. What will right now do is just look at, you know, the basic models of these dynamical models of the turbine etcetera. We will talk about the control of the valve position or the gate position a bit later.

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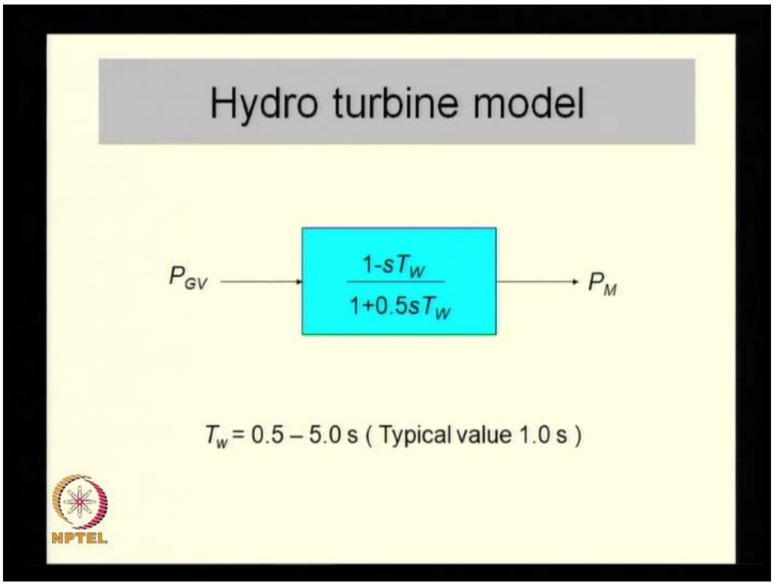

So, one thing you should appreciate here is looking at, we have to model a turbine by a dynamical model and of course, that involves differential equations or in case the system is linear you can actually represented compactly using transfer function. So, when I show you a transfer function of course, it is indicative of the underlying dynamical system or differential equations. Now, the point here of course, which you should note is this model which is shown here of a hydro turbine is extremely simplified, an extremely in the sense that, first of all this is a kind of a linearized model of the hydro turbine, no non-linearized effects are considered.

A second thing is, the second thing is that you are assuming the, you know, water falling through the pen stalk to be a kind of rigid motion. We are not considering any of the elastic effects or travelling wave effects. So, this is the very simplified model, we will not derive the model itself from first principles. What we will do is take this transfer function as our model of a hydro turbine, but remember that this model is valid only for small changes in the gate position. Now, one of the striking things about a hydro turbine model is that, it is non-minimum phase. In fact, it has got a 0 in the right half plane.

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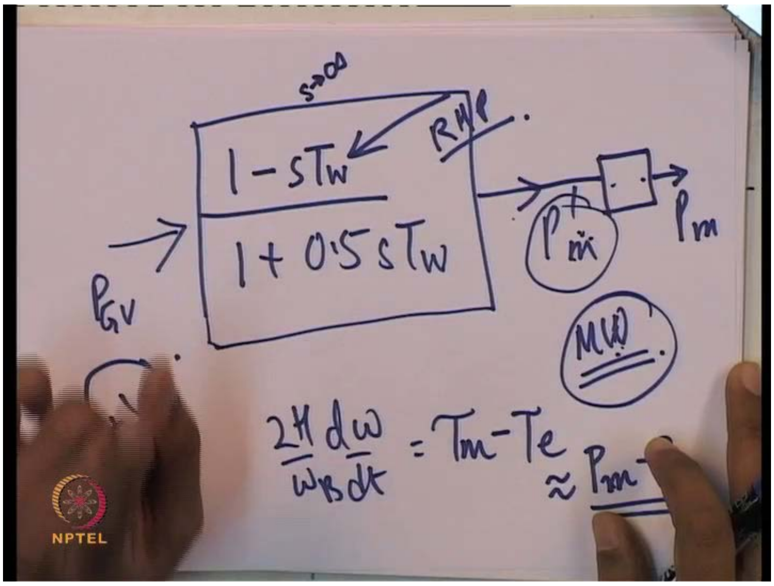

If you look at the transfer function is 1 minus S T w upon 1 plus 0.5 S T w this is the transfer function of a hydro turbine. Now, of course, you may say well it does not seem to have any gain at all, you know. If you look at a steady state gain it is one the reason why it is. So, is of course, that we have normalized the equations. So, when I say you know the gate position, that the gate position itself is normalized, that is, if the gate position is one you will get a rated power of the machine in mega watt. So, this is normalized in that way. So, gate position 1 means p m is equal to 1. So, we have normalized and therefore, we have unity gain to this. So, gate position is not really given in terms of the position actually, but the normalized position. Fully open would be 1 and close would be 0. So, that is how we are normalized it similarly p m is also normalized to the mega watt. So, full rating means p m is 1, full rated power would mean p m is equal to 1.

Now, the important thing of course, here is that when you use this mechanical power in your torque equation, you know if you recall or rather the swing equation remember that the mechanical power is normalized to the m V a. So, you may have to do a conversion here before you apply this p m, in your swing equation. If you call the swing equation and if your speed is near the synchronous speed this is nothing, but p m minus p e in per unit. So, T m and p m are almost the same of your speed is near about the synchronous speed.

Now, the rated speed I should not say synchronous speed, the rated speed of the machine or the base speed of the machine. Now, remember that this p m and p e here are in m V a base. So, if you are p m here is on m w base if you use this. So, you have to use an additional conversion to actually convert this p m dash to p m, p m dash is on normalized to the mega watt of the machine. So, this is the small point, but an important point. Now, if you look at this transfer function as I mentioned sometimes its non minimum phase it is a 0 on the R H P, that is, the one of the 0 is it is on the right hand side of the complex plane, which also means that if I give a step change. Suppose it was possible to give a sudden change to the gate position I increase open the gate. In such a case the behavior is very interesting and hard. If you look at the steady state gain of this how do you get the steady state gain just put S is equal to 0 here.

So, if you give a step change the steady state gain to the step change is one because if I put S is equal to 0 here you have 1 by 1 which is 1. Now, but what is the transient gain, the transient gain is obtained by trying put S tending to infinity here in this transfer function what you will find is the transfer function gain is negative. In fact, negative it is minus 2, the high frequency behavior or the transient gain is minus 2 whereas, steady state gain is plus 1.

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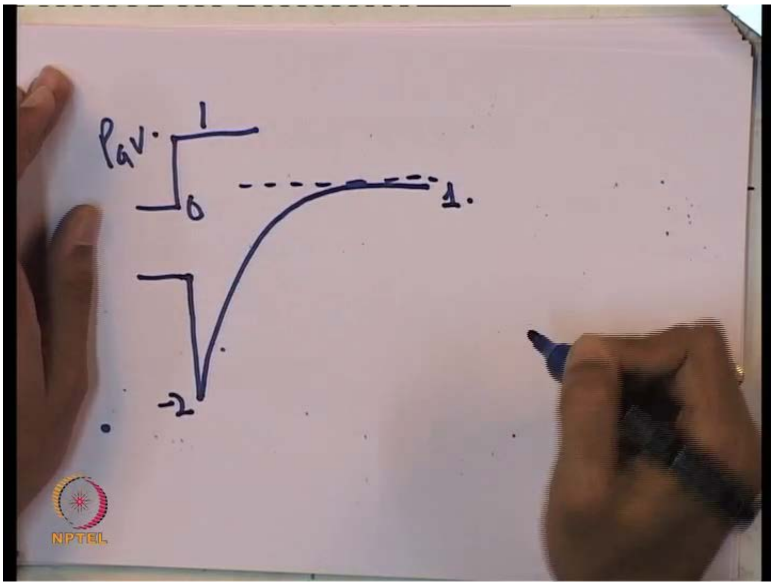

So, what you can expect is that if I give a step change in P G V the mechanical power. In fact, goes down suppose this is 0 and 1 in that case this will go down to minus 2 and then raise with the time constant of T w to 1. So, in fact I am not drawn it very well to scale.

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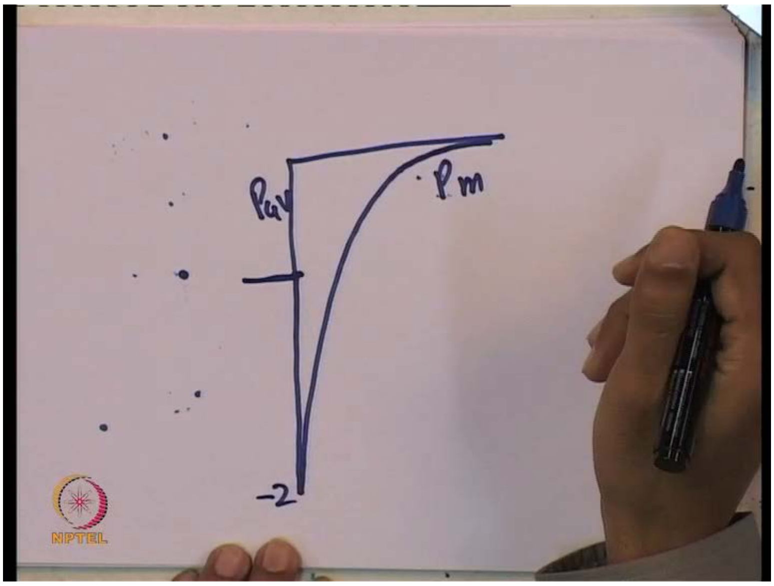

So, I will just do it again, this is how P m will look like, this is how P G V will look like you know this is, this is double of this. So, what you really seeing here is very funny kind of response, that is, it looks a bit odd you know, you are opening the gate initially the power dips very substantially and then it raises on, to what is what corresponds to the steady state power under these gate conditions. So, this is very it almost appears strange, but this is how it is. In fact, in Kundur there he has given an example of a system which electrical system which also satisfies this behavior.

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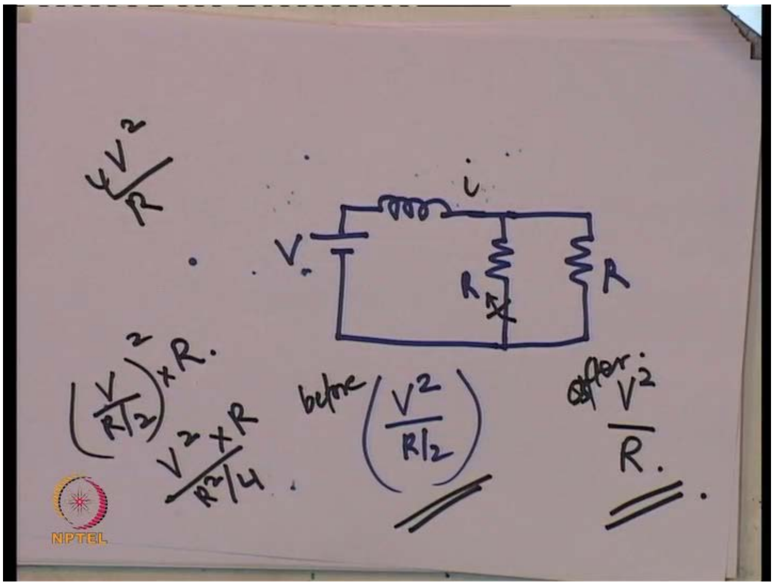

What he has given is, suppose you are analyzing this system. Suppose, this system is in steady state initially. So, if this is V this is R and R the amount of power flow is of course, V square divided by R by 2 this is the power dissipated. Now, in this system also if I suddenly disconnect one of the resistances, what is going to be the steady state power, it is going to V square by R. So, this is the steady state power before after, but as soon as I disconnect this as soon as I disconnect this, note that since you have got an inductor here the current here is going to be constant for some is not going to change instantaneously.

So, what is your current if just before the switch opens V divided by R by 2. So, as soon as you open the switch the current instantaneously does not change and flows through this resistance. So, the amount of power flow is in fact this. So, just as you open this switch your power flow in fact, becomes is in fact, what is it V square, V square divided by R square by 4 multiply by R. So, that becomes V square divided by R multiply by 4. So, what happens is initially your power. In fact, what happens to the power, well initially what happens is as soon as you open the switch the power in fact, increases and then decreases. So, this is before which is a high value this is a low value.

So, what you see is that although the final power is lesser if you open the switch as soon as you open the switch the power is in fact, increased. So, the direction to which it finally, settles down to, in this case by opening the switch you reducing the power, but as soon as you opening the switch the power in fact, increases. So, this you know behavior or opposite behavior is actually similar to what you are observing this hydro turbine model. So, this is one thing which is interesting. If you look at steam turbines on the other hand

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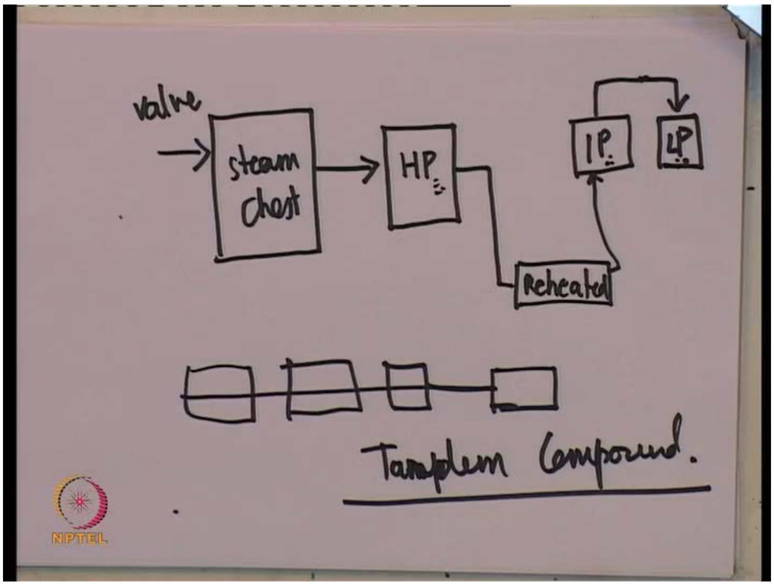

Let us talk let us discuss a common configuration in steam turbines, in common configuration is the valve determines the steam flow and the valve position in fact, and you have basically steam chest, a high pressure turbine, this is the typical configuration. The steam from the high pressure turbine is reheated pass through an intermediate pressure stage this is another turbine then there is some crossover piping and it feeds a low pressure turbine.

So, this is one of the possible configurations which you can have. All these turbines the high pressure, intermediate pressure, and low pressure turbines are in fact, mounted on the same shaft. So, you have got these three you know, stages of three turbines mounted on the same shaft as a generator. This is called a tandem compound, this is a tandem compound configuration for a steam turbine, you have other configurations you will not consider them in this course, but you can just have a look of, look by reading up some of the books reference books which have given at the beginning the course. We will just restrict our self to 1 of the possible configurations of a steam turbine.

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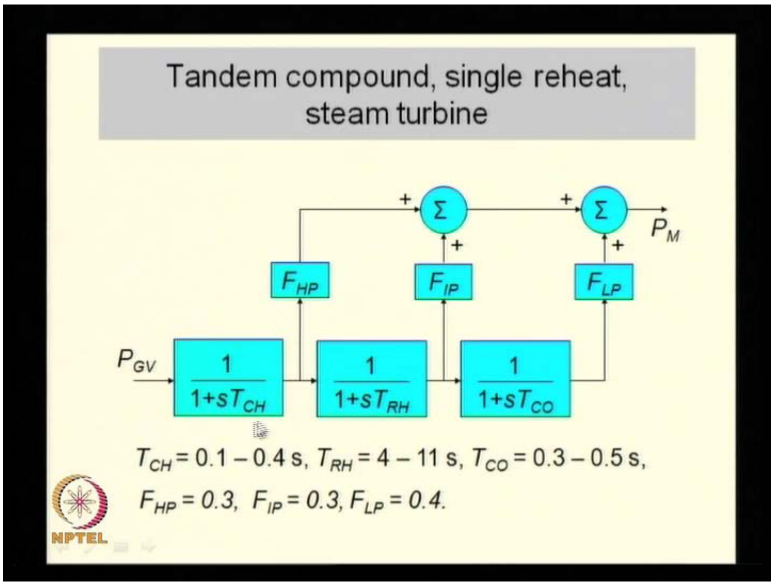

Now so, in a steam turbine here this is the normalized valve position. This is the dynamical model of the steam chest. The steam then goes to the hydro high pressure turbine because of which you get certain the hydro turbine has a certain power output, the high pressure turbine I am sorry the high pressure turbine has got a certain power output the intermediate pressure turbine also contributes to some power and low pressure turbine also contributes to some power, but the steam which is emanating out of the high pressure turbine in fact, is reheated and has the time constant or a dynamical process involved in this, which is represented by this transfer function again the steam which is coming out of the intermediate pressure turbine has to go through the crossover piping, which also has got dynamical behavior. It is not have got a certain time constant T CO the reheat time constant is relatively large. F HP F IP and F LP are giving you the fractional component of the total power which is seen at the shaft. So, each of these turbines contributes to the total power in this ratio, point three point three and point four of course, you see that it adds up to 1.

So, it is basically telling the ratio in which each of these turbines contribute to the total shaft power, which is p m, again remember p m is normalized to the mega watt rating of the machine you may have to convert it to the m V a base big, when you are using it in your swing equations, The gate position in fact, or the valve position here is determined by the control system. Now, of course if you look at, you know representation given here it appears that the valve position is the soul detrimental determining factor in the mechanical power. In fact, it is not so the pressure also of the steam also determines this mechanical power. In fact, if you look at real turbine you will find that the power output is dependent on the steam pressure. In fact, if you change the valve position for sometime the mechanical power changes, but if you want to change the mechanical power, you know in some way some sense permanently, you will have to actually change the fuel input to the boiler which will eventually insure that the pressured does not drop. So, you open the valve the pressure if you keep it open for some time you will find the pressure eventual will drop.

So, any change in mechanical power actually requires you to change the boiler fuel and other inputs. So, that is what is important, but for most studies which you are going to do especially related to short term behavior in the sense of few seconds you can assume that the mechanical power is only determined by the valve position,but if you have seen if you have seeking long term behavior of a system of course, you should consider the effects of the boiler or the dynamical response of the boiler in maintaining the steam pressure as well.

Before I, you know, go ahead let we just discuss again now the control systems and actuators remember that as I mentioned sometime back, although the valve position is change of valve position results in mechanical power change or in fact, change of gate position in an hydro turbine results in mechanical power change, how the valve itself is to be changed depends on a control system or a manual change in set point.

Now, when should make an manual change in set point of course, you have to change the control valve position and you have got actuators for doing that you cannot do it requires some amount of force amplification to change the valve position. So, you have got hydraulic systems which themselves have some, you know dynamical behavior also as I mentioned sometime back you may have be having a close loop control system to control speed, that is called a governing system. So, what comes before or what is the dynamical representation of what comes before this point I mean how is p G V itself determined.

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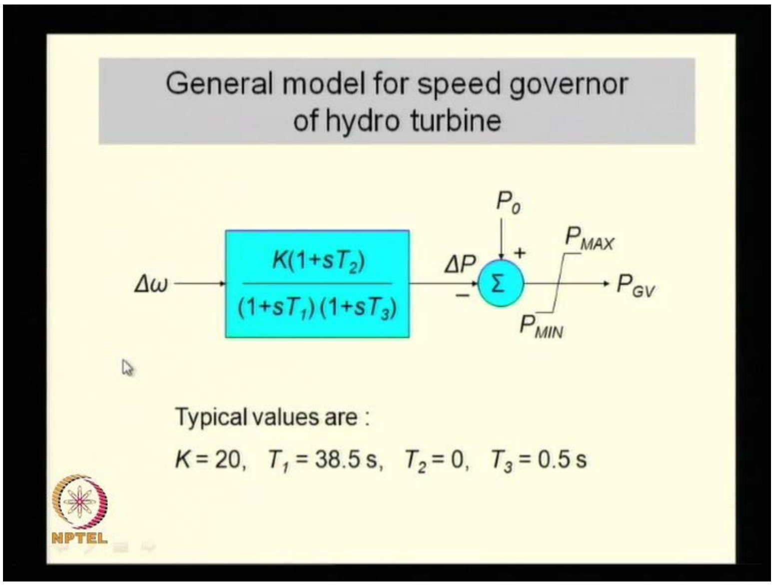

So, a generic model of a steam turbine of a hydro speed governor you know in fact, the one of the control systems or one of the control objectives could be to maintain or to control the speed. This is the delta omega is the deviation from the reference speed. So, if there is a deviation from the reference speed you change the gate position. So, the crescent gate position is determined by the load reference or manually, you know setting how much power you want out of the machine, but if there are any changes in frequency the gate position is changed by this particular control system. In fact, when you look at this control system it also includes the hydraulic actuation system which actually changes the valve position.

There is some issues here remember some of the issues which you have not really spent much time on is the gate position, you know the power output is not a linear function of the gate position. So, you when you are making a control system block diagram or you know transfer function block diagram you have to add a non-linear block here, which really is a linearizer, I mean you know what happens that if you change the gate position, it does not linearly change or proportionally it will change the mechanical power output. So, you may have to actually represent that also.

It is not shown here, but you may have to representative represented. Remember that the actuation system as I mentioned sometime back also as a dynamical response and that also needs to be represented by transfer function. In this particular block diagram, which

I have shown you sometime back all these effects are absorbed in this transfer function here. So, this transfer function in fact, contains you know a model of the actuation system as well as the speed control system. So, I mixed up the actuation system as well as the control system the speed governing control system.

Now, remember one interesting thing which I had mention sometime back was the mechanical power output in a hydro turbine has got a kind of non minimum phase dynamical behavior, that is, it is got a 0 on the right hand plane it is got a real positive real 0. So, one of the important consequences of that which is important from the point of view of designing good governing systems or designing good control system is that a hydro turbine whenever you design your control system has to be a bit carefully designed because just lo at intuitively we will not actually go and do any numerical analysis to prove this. If I want to control a system behavior which is given here

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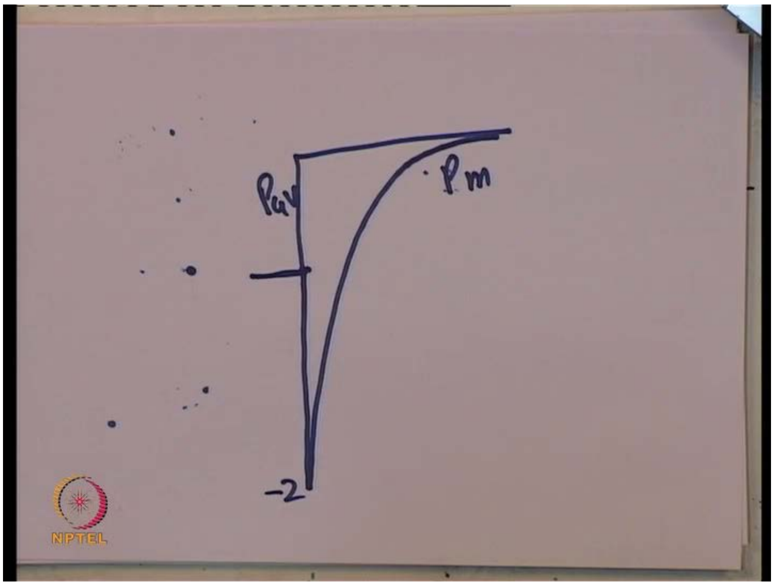

Suppose your basic turbine behaves as shown in this, you give a step change in the gate position, your power changes like this. Suppose, I want to control do feedback control of this gate position, one has to be a bit careful, why? What would a normally a control system do it would take feedback of power or speed, speed is of course, directly affected by the mechanical power and then change the gate position by feedback control, that is, what a speed governor does the thing is that, what is the control system do it senses something and appropriately adjust.

So, eventually if I want to increase the power the gate has to be open further, but if you take a close loop feedback system and you have got a response of the turbine in this fashion I have to be careful because if I am using feedback control and I change the valve position initially power drops. So, it make sense to actually whenever you are doing any control of this do not response to the initial fast changes, you know, that later on it is going to follow, you know whatever reference it is going to follow, do not get misled by what you going to see right in the beginning or in other wards when you are designing your control system do not design it to be very fast acting.

So, non minimum phase system. In fact, if you do not want them to be, if you want to get good behavior, non oscillatory behavior, non rather stable behavior you it is a good idea to weight or design your control system it is slightly limited bandwidth, do not make it a very fast acting control system, that is, an interesting and important point in the design of controllers for systems which have got this kind of non minimum phase behavior. This block diagram here K 1 plus S T 2 divided by 1 plus S T 1 plus 1 plus S T 3 is. In fact, the composite block diagram which includes the effect of the hydraulic actuators which actually changes the gate position.

It also includes of course, the governor control system and one of the important things in hydraulic turbine governing systems is that because the non minimum phase behavior of the turbine, you have to deliberately design your governing system to have a low gain during transients and later of course, it can have a high gain.

So, initially you insure that it is not so fast acting. So, this is an important thing which you should keep in mind. Of course, this is if you look at this control system the overall block diagram of the control system and the hydraulic, we know servomotors or actuators, you will find that it is a kind of proportional kind of this, you know there is a finest steady state gain. So, it is a kind of a proportional control of mechanical speed. This controller will not regulate the frequency exactly. So, this is something which you have to keep in mind.

We will go on to a general model of a steam turbine, a steam turbine luckily does not have the non mini ways minimum phase problem which is faced with hydro turbines. So, typically the speed governing system model is very very simple and actuator is of course, model separately here the valve actuators. So, normally this is simply a proportional control system with T 1 equal to T 2. This proportional system gain in fact, determines the extent to which you can achieve regulation it is also, it is also the reciprocal of what one calls as a drop in the power and frequency characteristic of the turbine. These some of these things will become clear when we consider an example later on.

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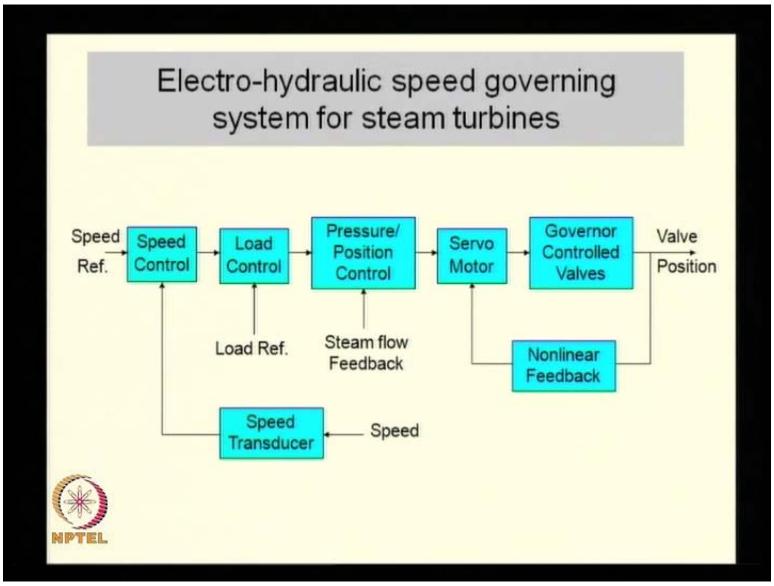

We will stop at this point and consider a few more points relating to the prime mover systems in the next class and then we will go on to a example which will require as to model a prime mover systems. What we will do is actually in the next class handle or introduce you initially of course, we will take more than one lecture to analyze the whole thing completely. Introduce you to the transients in a two machine system where we will be actually modeling even the turbine and governing system.

So, far we have actually in our discussion of automatic voltage regulators, part of only or really discussed only single machines connected to infinite bus where frequency eventually reached and equilibrium which is determined effectively by the frequency of the voltage source which we of course, assume it does not change, when you have got do not have this infinite bus or a voltage source in that case frequencies in some sense determined by the speed control systems that we have. So, we will graduate from a single machine infinite bus or single machine connected to voltage source to a two machine system and hopefully lot of these things will become clear when we do that example. So, we will stop here.