Power System Dynamics and Control
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Model No. #01
Lecture No. #24
Excitation System

We now move on to discussing another important element in a power system. Our lecture, so far have been concentrated on modeling a synchronous machine, which itself was a fairly long, and tedious process. In the last class, we describe some simplified models of a synchronous machine. Of course, the there is practically no end to the amount of detail one can go in our discussion of synchronous machine modeling. There are in fact a few topics, which we have not covered, one of them being the saturation performance of a synchronous machine. How would you change the modeling, in case saturation exists? We will not discuss this much in detail in this course. In fact, we will just carry on. I can refer you to the books, which which I had mentioned right at the beginning of the course. You can refer to them, and there is some interesting reference is relating to saturation modeling.

Now remember, what is the main issue there? When you try to model the synchronous machine with saturation considered; remember, it is no longer what is known as a linear machine. In that sense, you cannot you know get a flux current relationship, which is linear and as a result of which it becomes difficult to apply the full machinery of d q transformation. Remember that when we did the modeling of a machine, when we derive the inductance inductance matrixes, which relate the fluxes in the A winding, and currents in the A, B, C, D winding and so A, B, C, F, G, H, K windings. You will notice that what we did was of course, you know try to do some kind of super position of fluxes mmf, etcetera.

You know, we effectively used super position, in order to determine the nature of the inductance matrixes. You can no longer do so in case saturation exists, and that really quires the pitch, and as a result of which there there is not a nice or a neat or a mathematically rigorous way to approach, you know saturation in synchronous machine. Of course, one may argue that again, you know whenever you have modeling, there is the physical laws are known. And one should be able to model even saturation by actually computing the electromagnetic fields at the you know the flux configuration, which exists during saturation of a synchronous machine.

But, that would be really very tough and it is not justified, when doing the stability kind of studies, when we are studying slow electromechanical transients but under certain circumstance, it can actually affect the result. For example, the even the steady state behavior of a machine if one does not consider a saturation, one can end up with you know a fair degree of error and that is a reason, why people are worried about it the and although, a very rigorous way of tackling saturation is not really been discussed in the literature but some ad hoc techniques have been discussed and I prefer you to the books by the Padiyar, Kundur and good discussion exists also in Sauer and Pai, which discusses some of the theoretical implications of various saturation models.

So, I the basic model, which we have derived in the d q reference frame, we tweak it a big, we tweak it, we do not really go ahead and try to start from scratch ad try to derive a saturation model, which is a absolutely rigorous but we just simply tweak the d q model to account for saturation and its quite ad hoc and you can say a pragmatically approach is usually followed. We do not discuss this any further. I refer you to the books, which I have just mentioned. We move on to today’s lecture, which is on excitation systems.

Now, to look at the role of excitation systems, let us just look look back what at what we have been doing. We have studied a synchronous machine connected to a voltage source or an infinite bus. Sooner or later, we will have to consider synchronous machines connected to other synchronous machines to loads to a network and try to infer. you know infer How a power system behaves? A integrated power system behaves.

But, even before we interconnect the synchronous machine to a network and try to study that kind of system. We can look at the two important inputs, which are there in a synchronous machine, that is one of them is of course, the mechanical power or the mechanical torque and the second thing is the field voltage. We have been using the symbols T m and E f din our synchronous machine model. In fact, all the simulation so far we took E f d to be some kind of constant. In fact, we did simulate step changes in a the field voltage or E f d but we did not really have any kind of continuous control over either the mechanical power or the field voltage but these two are essentially the inputs to our synchronous machine.

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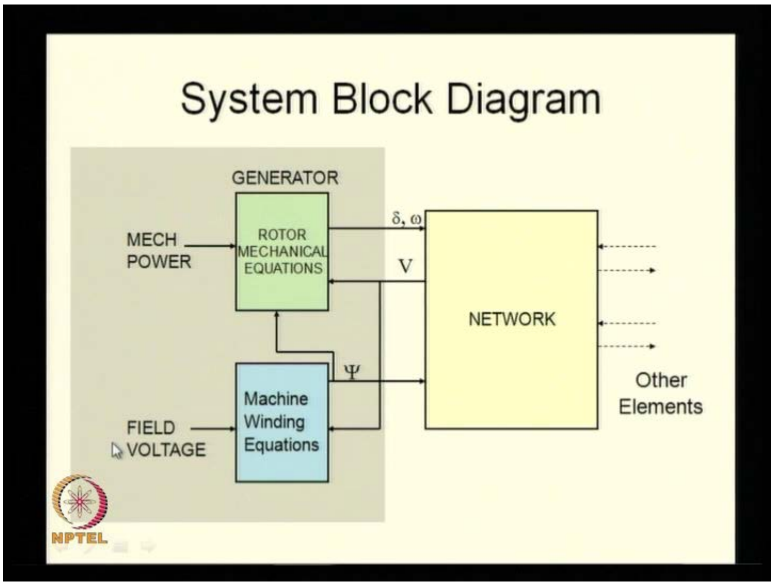

System Block Diagram

Now, if you look at where we are right now, we have done the synchronous generator modeling, in which we have the rotor mechanical equations and you also have the machine flux equations. The differential equations in the fluxes of the machine and a rotor mechanical equations are generally formulated in terms of delta and omega and given the mechanical, the rotor angle, the mechanical speed and the flux is, one interacts with the network, you can connect the generator to a network, which you may consist of a voltage source, it may be just a load or it may be other elements. So, you have typicallya generator connected to a network and connected to other elements, which could be other synchronous generator, it could be other loads and so on. Now, the generator itself has two inputs. You have got your mechanical power or the mechanical torque and you have got the field voltage. These two things are in fact, things we need to be controlled.

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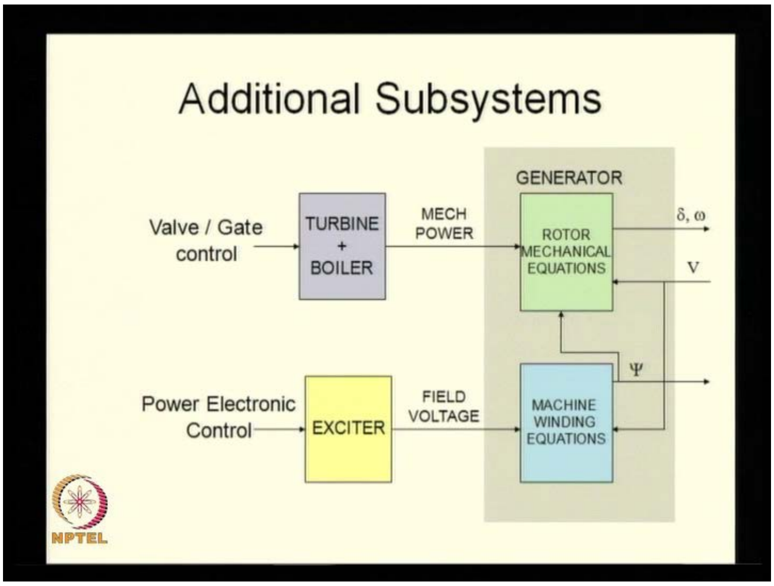

Additional Subsystems

Now, if you look at another figure. The power apparatus, which controls the mechanical power, is essentially that turbine and a boiler. Boiler, of course in case of steam turbine driven machine. So, you have got a boiler and a turbine in the steam turbine driven machine, which really gets the mechanical power at the shaft of at the shaft of a generator. The power apparatus, which generates the field voltage for a synchronous machine is called as an exciter and it is usually consisting of at least one control power electronic equipment. So, in fact you will find that the exciter is a control element, by which you can control the field voltage and it the control is via power electronic convertors.

Now, the valves or the gate control of a synchronous machine really controls the mechanical power input to the machine. So, you can control both the mechanical power and excitation to a synchronous machine. Now, there are various ways you can generate this field voltage. We will consider two of the most common ways. One can generate field voltage for a synchronous machine.

So, we have to actually, when we talk about excitation system, one one of the thing we have to discuss is a power apparatus, that is the excitation system and of course, the control of the field voltage itself. We kind of hinted, when we consider the the simulations in the past two lectures, that if we we need to change the field voltage we need to change the field voltage as the generator is loaded, otherwise you may not be able to operate the generator acceptable acceptable. In the the case which you simulated, we saw that trying to load a synchronous machine without simultaneous control of the field voltage resulted in a loss of synchronous and the machine was loaded up to its rated value. So, we do require some kind of control over the felid voltage that is a very important idea.

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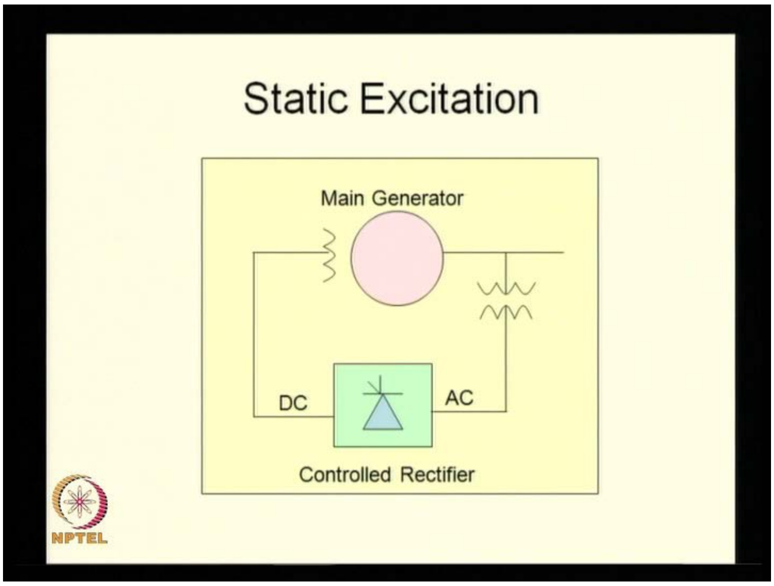
Static Excitation

Now, the various ways of course, one can obtain the power apparatus or the the configuration of the power apparatus in order to excite the synchronous machine. Now, the major controllable element in any of this excitation system is as I mentioned some time a power electronic convertor. In fact, it is usually a Thyristor based control rectifies. So, most of the generator you will find I have got controllable element in the excitation system, which is the control thyristor bridge.

So, that is what is essentially there in a synchronous machine. Now, one of the important thing you should remember at this point is, that is synchronous machine has got an extremely large synchronous reactants. What would mean by large? In relative terms, if one wants to understand this.

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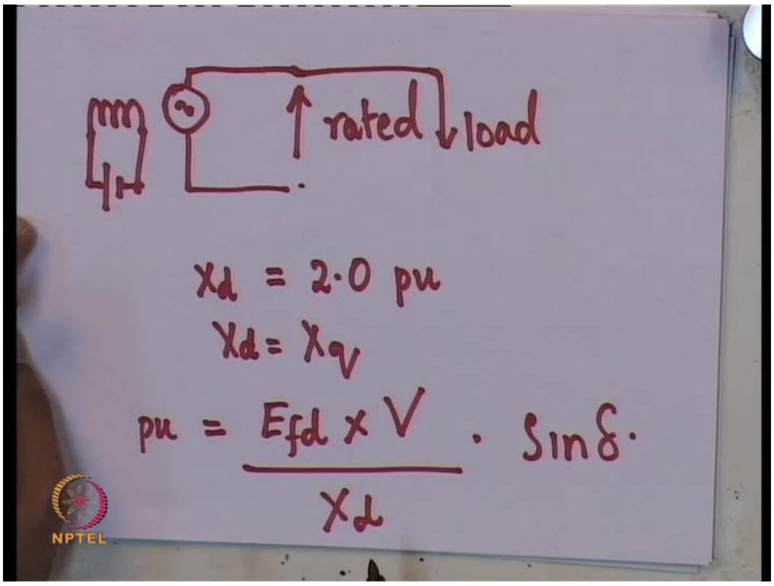

If you have a synchronous machine, suppose you have got a synchronous machine, which is unloaded. It is operating at no load. So, the felid voltage, which you would you would require certain field voltage in order to get rated the rated voltage at the generator terminals.

So, you will have to actually give a field voltage. It just represented temporarily as a battery. The field excitation you would have to give, so that you got the rated voltage. Now, the important point here is, if I start loading synchronous machine if I start loading a synchronous machine, you will find that, if I load the synchronous machine, you load it and you will find it the voltage keeps on dropping and this drop can be very very very significant. In the sense, that if you take a typical synchronous machine, you will find that you will not even be able to load it to its full value, full rated value.

Unless you increase the field voltage, for example synchronous machine, say with an X d of 2 per unit and let say, it is X d and X q are equal, then the per unit power per unit power will be equal to if your E f, you got E f d into the voltage at the load divided by X d into sin delta. So, if I connect the synchronous machine to a voltage source line to line r m is V, then the per unit power is this. Now, if I keep my E f d at 1 per unit, V is also 1 per unit, then the amount of power you can actually push is half, maximum power you can push is half per unit.

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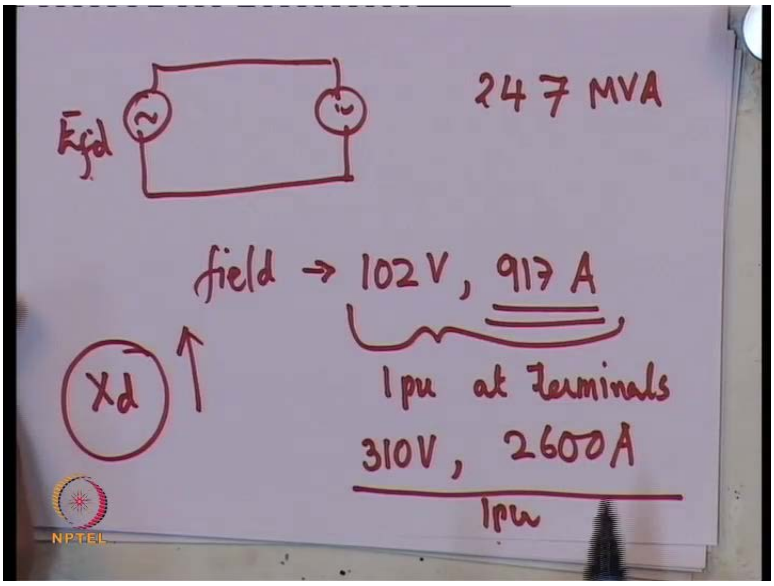

So, if you have got a synchronous machine a synchronous machine connected to another voltage source. Then In that case, the amount of power we can transfer is limited, unless unless you change E f d. So, this is what is done. When you load a synchronous machine from no load to full load, you would need to change this E f d and very very significantly. In fact, you may have to even double the amount of field voltage in order to load, whenever you load a machine from no load to full load conditions. In fact, if you look at a typical generator, which is used in the Indian systems, is it 247MVA generator.

This is a typical unit sizing, which is found in a most Indian power systems. You will find at the no load voltage, field voltage. This is the voltage applied at the field at no load is 102 volts roughly and current under open circuit conditions is this, the field current. So, this is under open circuit condition. This gives you 1 per unit at terminals. However, if you load this machine to its full rating, you will have to apply which is value, which is more than double, a field voltage; so that, you will get 1 per unit at the terminals again.

So, you see that you need to really change the field very substantially. The reason of course is, that the X d of a synchronous machine is very very large or in other words, the armature reaction is very large.

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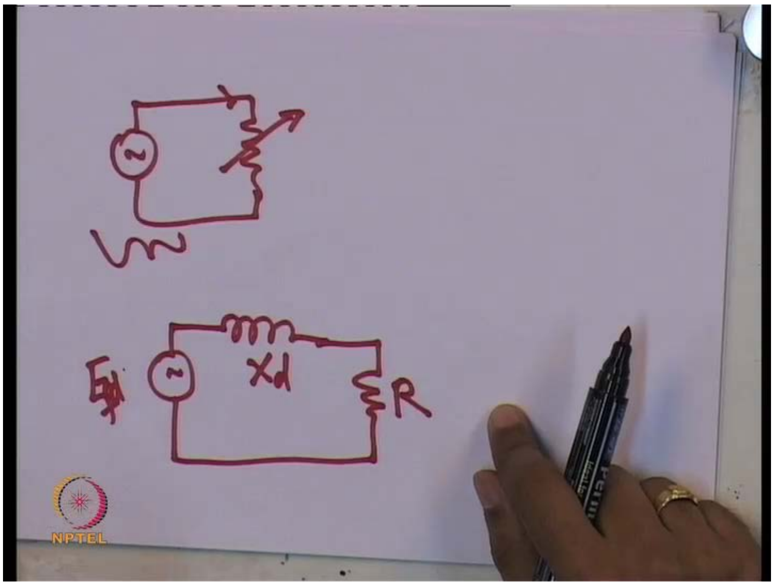

If you just connect a synchronous machine, you connect synchronous machine to a resistive load. This a just a schematic representation of that and you go on increasing the load by decreasing the resistance, you will find that the amount of power you can actually deliver has a maximum and that maximum is very low value. In fact, the equivalent of a synchronous machine, electrical equivalent of synchronous machine in steady state if it does not have any saliency is, simply voltage source of magnitude E f d, X d and the resistance R.

And you know that if X d is large, the maximum power transfer is going to be limited. You are not going to; rather I should say the power transfer in this situation is limited, unless I change E f d. So, I hope I made a good case, that you would really need to have a system, in which typically if a large generators you need to have when excitation system, which is very well controlled and as got very large range as well. So, from no load to full load you really need to change the felid substantially.

So, one example of exciter, the power apparatus if you look at, is a the static excitation system and what you really have here is the voltage, which appears at the terminal of the main generator, that is our generator which we which we are studying in fact, is rectify after stepping it down by a control thyristor base rectifier and then, the DC value is fed to the field of the generator. Remember of course, this is the control rectifier. So, I can control the DC value. The DC value of it is fed back into the generator and this is one way you can excite a generator. In fact, it may somewhat you know worry you worry you initially because the the voltage, which is required to be rectified in order to feed a DC voltage to the field winding is in fact being obtain form the terminals of the main generator itself and of course, if the main generator is an under open circuit condition, one may argue that there is no voltage in the terminals of a synchronous machine, if no felid voltage is provided.

So, as a result you will get no AC voltage at the terminals of control rectifier and the DC voltage is also not going to will not really have any value, will be 0.So, this whole system may not work but actually if you look at it, it is a some kind of positive feedback system. If there is some residual magnetism available in the generator, it can generate a small AC voltage. If that AC voltage is enough to forward by is the device is used in the control rectifier usually thyristor, then that would cause small DC voltage. The DC voltage would cause some field current, which will enhance the existing. If it enhances the existing residual voltage, residual flux, which is there in machine. You will find it the voltage increase and some kind of a you know positive feedback mechanism will ensure that the machine self excites.

So, this actually can happen in a practical situation of course, because you know you require adequate residual fluxes to generate. Initially, an AC voltage you will forward by thyristors. We do not actually connect the synchronous machine from scratch in this fashion. What we usually do is, start it up with battery. So, your field voltage, felid is initially fed wire or battery and then, after that this particular configuration the system switches over to this configuration, in which the voltage generated at the terminals of a generator itself, is used to power the field, in this fashion.

Now, this in fact can be actually shown in a laboratory using simple diode rectifier. So, if you actually replace the control rectifier by a diode rectifier in just, you know feed the output of a generator back on to its felid winding through a diode rectifier. You find that the voltage builds upon its own. You know it is a it is a kind of spontaneous increase. In fact, it is an interesting exercise for you to show that in fact, this if you write down the differential equations or the dynamical equations corresponding to this scenario, you should be able to show that in fact this is a unstable system and therefore, itself excites. So, if you give any non-zero initial condition, it builds up the voltage, builds up on itself.

One small caution again. In a real system, the residual voltage is may not be residual fluxes in the synchronous machine, may not be adequate to generate, just that initial kick to start this self excited system and as a result of which, you may actually have you may actually have to use the battery is in a power station to initially excite the machine and then, switch over to this configuration. So, whatever you do now, we just show you a small video clip of how one can simply excite a synchronous machine by simply connecting its output back on to the field, wire a diode rectifier. The diode rectifier in fact they nota control rectifier.

So, we will not be able to achieve much control over the voltage, which we are getting. I will just show you that the voltage suddenly kicks and the machine self excites. So, what I will do is, connect the diode rectifier or the input the of the diode rectifier to the output the terminals of a synchronous machine in the laboratory. Then, the DC terminals after rectifier, I will feed it back to the field field of synchronous machine, then I will rote start rotating the machine slowly and at a particular point, you will find that this whole system excites on its own.

So, let see that video clip. So, this is a our set up set up in the laboratory. What I have done is, I have connected initially the static control rectifier is connected to the field winding but I also have a diode rectifier, which right now is open. So, that is what was shown to you. The input of the diode rectifier is of course, the terminals of the A, B, C terminals of the generator itself.

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What I will do is the, I will disconnect the existing control rectifier and instead of that, I will connect the output the DC terminals of the diode rectifier to the synchronous synchronous machine field. So, that is what you have seeing here. So, the diode bridge is connected to the generator terminals on the AC side and the DC terminals are connected to the synchronous machine field winding.

So, this is what I have done. Of course, if I do not rotate the machine, there will be no voltage induce and nothing will happen actually by doing this but what I will do now is slowly start rotating the machine. Remember that I am not separately exciting it. The output of the output voltage at the terminals of the DC machine itself of the synchronous machine itself is being used to excite the machine. What I am doing now is starting the prime mover, which is the DC machine. What you have seen here is, I am applying the field voltage to the DC machine. Now, I am applying the armature voltage to the DC to the DC machine is the prime mover to the AC machine. As soon as I start the started this way you will find at the machines starts rotating. You will shortly see the machine rotating. What really we wish to show you is that after the certain speed, the voltage kicks and the machine the synchronous machine self excites.

So, what you see is that there is some voltage at the terminals of the machine. Also, you see there is a field synchronous machine felid current and a synchronous machine field voltage. So, the machine of course is rotating at a low speed. In fact, at a very low speed itself you find that there is enough voltage to trigger self excitation. So, just by connecting the output of a machine to a diode bridge rectifier and feeding it back to the synchronous machine felid, we are able to in fact demonstrate that self excitation can occur.

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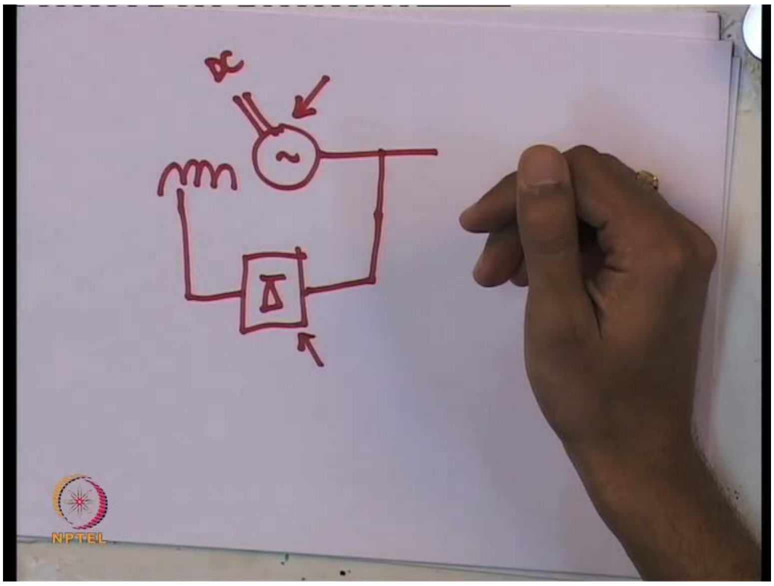

So, let me just repeat what I said, just draw schematic of what I showed you. So, what I had is a synchronous machine. Its output was simply rectified using diode rectifier and would have said to the field winding and you saw that after the certain speed is acquired by synchronous machine of course, synchronous machine is driven by DC machine, you find that there is a adequate voltage to trigger a kind of positive feedback or you know this self excitation phenomena. Right now, remember that in order for this to work well, the voltage here the residual flux in the machine should be enough to forward bias the diode diodes in the bridge at least at some speed.

So, there at some speed the voltage magnitude here should be adequate to trigger self excitation. Otherwise of course, one will have to use the station battery is for what is known as felid plashing initially and after that one can switch over to this configuration. So, what you have here is of course, a static excitation system. A static excitation system requires brushes and slip ring to in fact, two slip rings and brushes to convey the felid voltage to the field winding, which is usually rotating in a typical synchronous machine.

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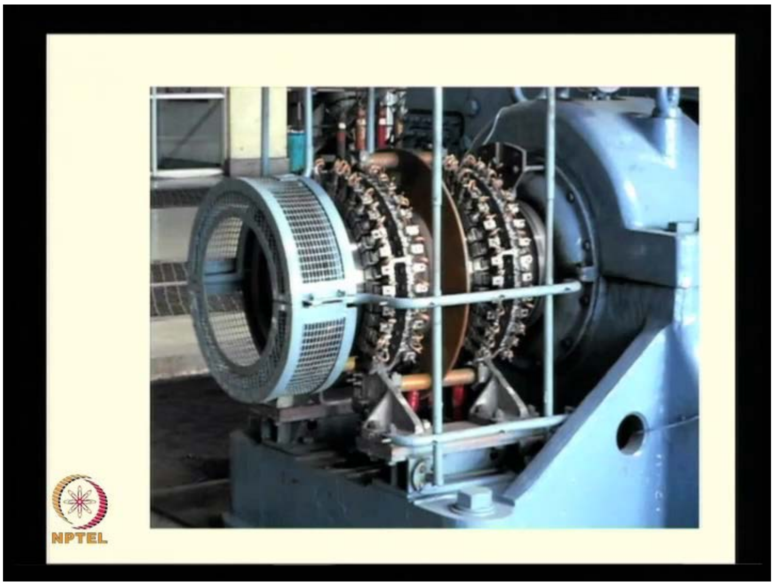

So, if you look at some interesting pictures, which I have got here, which is courtesy, the western regional power committee, Mumbai. You will find it, this is a snap short of a synchronous machine. What you see here, right at the end are inflect the slip ring, brush arrangement.

You see, this is actually luckily it is exposed for us here. So, you can see that the brushes and slip rings. So, this is a snap short of that, you get close up also. So, you see those brushes rubbing against the slip ring. So, this is the end region of a end, this is on one side of this synchronous machine.

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In fact, if you look at this another snap short, what you see here is on one side is the place, where the slip rings are. On one side, you have got the slip rings through which the field voltage is conveyed. In fact the exciter itself is in another room.

And the voltage is a conveyed to the slip rings wire, the brushes. On one at one end you see these green structures here. The blue structure here is of course, the synchronous generator itself. The green structure here are in fact the turbine, which really control the mechanical power input to this synchronous machine. Another kind of excitation system is what is known is the brushless excitation system. This slightly looks a bit more complicated than our static excitation system, in which the exciter itself is static. It does not move and the voltage, which the exciter gives this conveyed wires, slip rings and brushless arrangement.

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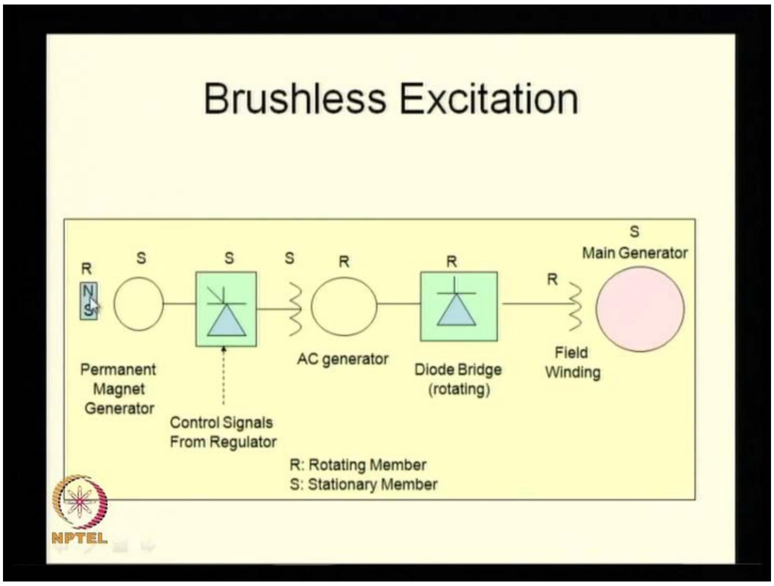

Brushless Excitation

Now, a brushless excitation system on the other hand has got a slightly different structure. What you have essentially, I will just try to you know describe it here. A rotating permanent magnet, a rotating permanent magnet is there in a permanent magnet generator. So, rotating permanent magnet causes voltage to be induced in the stator, the stationary part of a permanent magnet generator. The voltage output of the permanent magnet generator itself is fed. This is a this is fed to a control rectifier, this is again a thyristor based rectification system. This is a control rectifier, in the sense that the DC voltage is a function of the AC voltage as well as the control signals, which is essentially the firing angle delays, which is obtained from a control system. We shall discuss this control system, it is also called a voltage regulation system.

So, this is the control rectifier by which we can actually control the output, which eventually goes through the main generator but of course, there are unlike a static excitation system, there are several steps before this is actually done. What you have here is of course, the control rectifier, which controls the output of, this is now DC. The output of the control rectifier is DC. The permanent magnet stator, the control rectifier are both stationary whereas, the magnet of the permanent magnet generator of course, is rotating. The DC output of the control rectifier is fed to the to the field winding of an of an AC generator. Now, this is not the main generator, which we are talking of. This is a generator of the excitation system.

Now, the field winding of this particular AC generator, remember is stationary. So, on the rotor of the synchronous of this particular synchronous generator, the rotor has got the armature windings. The stator has got the field winding. So, the three phase armature windings are in fact on the rotor of this machine. This is called an excitation system generator. Now, the output of this synchronous generator is three phase AC. So, you have got rotating armature windings. So you have getting rotating winding, which are in which three phase AC is induced AC voltages are induced. Now, these three phase AC voltages are fed to a rotating, this also rotating; uncontrolled rectifier, which is nothing but a diode bridge, a three phase diode bridge, which is also rotating. So, this R on top here indicates rotating structure.

So, you have got rotating structure, a diode bridge is rotating. The output of this diode is fed to the field winding, which is also rotating. So, the final field voltage is conveyed to the field winding of the main generator. The generator which we really interested in. Directly, you do not have to have a slip ring brush arrangement because the rotating, the diode bridge is also rotating along with a field winding. So, it is a direct connection. You do not really have to have a slip ring brush arrangement. So, I will just repeat this again. You have got a permanent magnet generator, in which you get three phase voltage is induced on the stator. The three phase voltage output of the permanent magnet generator itself is rectified using a controlled rectifier. The output of the controlled rectifier is fed to the stationary field winding of a excitation alternator or excitation synchronous generator.

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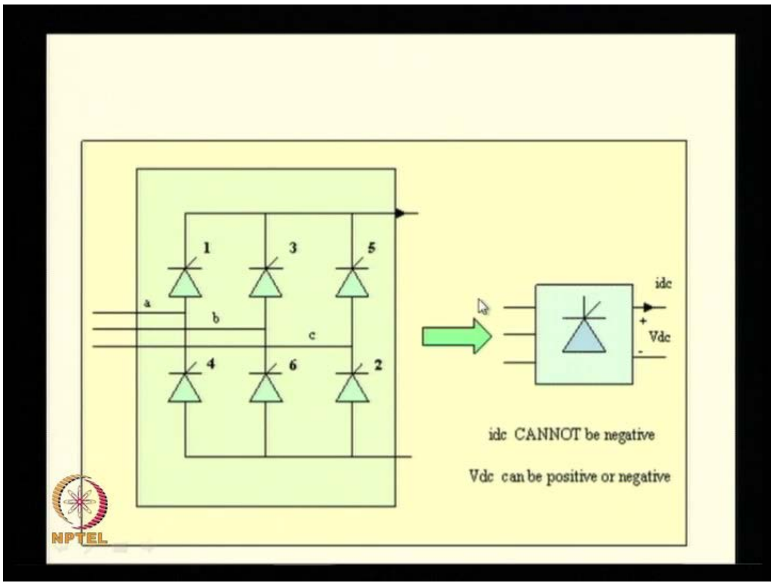

idc CANNOT be negative

Vdc can be positive or negative

The three phase voltage is of this generator are excited on the rotor of the machine. They are on the rotor of the machine. The output of that is fact to Diode Bridge, which is rectifier and fed to the main field and does not require slip rings. So, some large generators in fact have this kind of arrangement. Now, of course I have been talking of control rectifier and so on. What exactly is a control rectifier? It is in fact, an arrangement of thyristors typically, it is the kind of rectifiers, which are used in most excitation system or using thyristor.

So, controlled rectifiers are made out of thyristors. If you look at a thyristor three phase Thyristor Bridge, it is made out of 6 thyristors. The input of course, is a the three phase AC wind AC input and the output is DC and that is what I have been representing as this box here. So, this is equivalent to a box with three phase inputs and the DC input in this fashion or DC output in this fashion. One important point which you should note at this point. I do not know whether it is visible on this screen. So, I will just redraw here.

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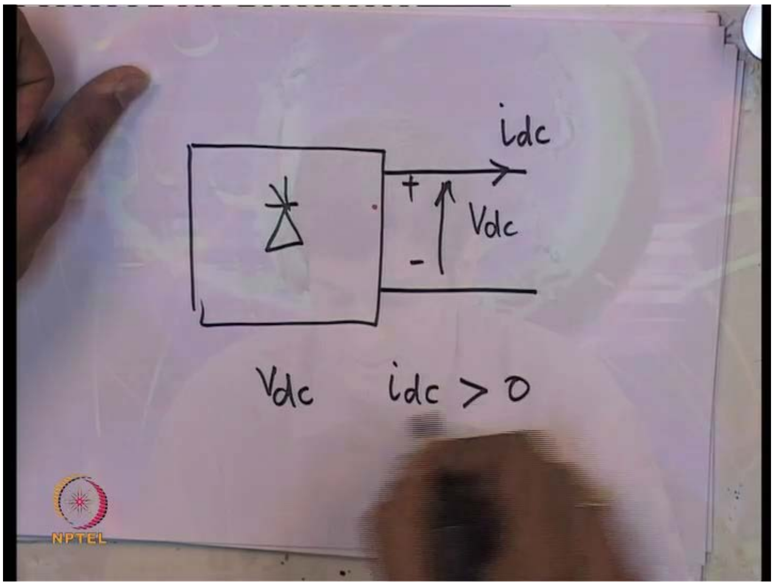

So, if you take a thyristor bridge, which is schematically denoted as I showed you sometime back. Remember that a thyristor bridge as if you denote the voltages and currents in this fashion, the V d c can be positive or negative but i d c is always positive.

So, that is one important thing, which you should remember that this particular rectifier does not allow current to flow in the negative direction. Now, we have a small video clip, which shows you controlled rectifier operation. In fact, you can by manual you can manually in the in the video clip, we are showing we are showing the voltages, which are developed in a synchronous machine. Due to application of this excitation voltage, the excitation voltage itself is the output of the control rectifier and the control rectifier is controlled by controlling the delay angle of the thyristor bridge. So, you can actually by doing that you can control the DC component of the voltage, which appears across the Thyristor Bridge.

Now, remember one small point, which you should you know this thyristor bridge if it is uses 6; what you call thyristor bridge consisting of 6 thyristors as I shown some time back, you can look at it again. In that case, the DC voltage is V d c will have this 6 thermionic. It is a DC voltage with 6 thermionic and DC a component itself. So, you have got a DC 6 thermionic, 12 thermionic and so on. No lower order harmonics are present other than of course, the DC component itself. So, you have got the DC components 6th, 12th and so on. So, this is known as often called a 6 pulse thyristor bridge.

So, what we will do is now, see a simple situation here. A simple video clip, which we will demonstrate to you, how thyristor thyristor bridge voltage, the output DC voltage can be changed by controlling the delay angles.

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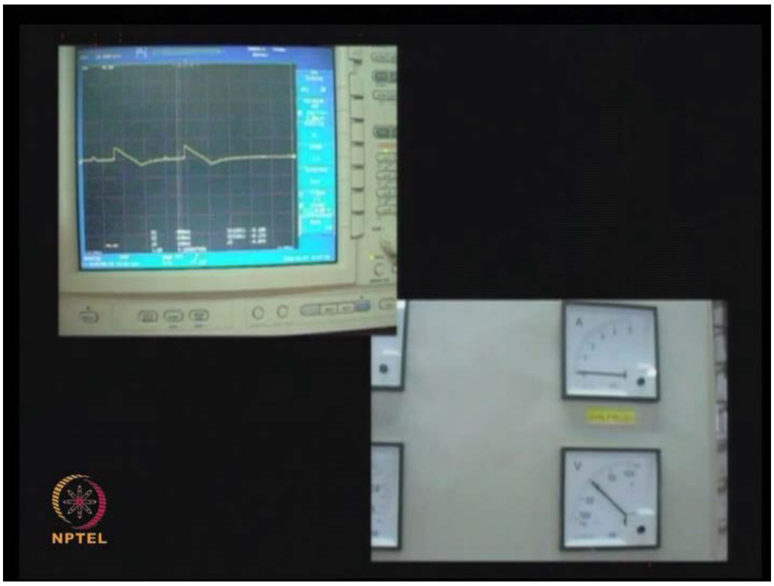

So, that will be done manually in the video clip, which will be shown to you. We do not start the machine for this purpose, we just switch on the excitation system and applied DC voltage to the field winding. The aim of course, is to show you 6 pulse operation. This is the static excitation box, in which we have got 6 pulse bridge. You will have to pay attention to the ammeter and voltmeter on your right. What we will do now, is to reduce the firing angle from greater than 90 to less than 90 after the point than average DC voltage, which is greater than 0 appears and continuous current is established.

And what you see here is the output of 6 Pulse Bridge near about 70 or 80 degrees. Now, we are increasing the DC voltage by decreasing the delay angle and you see of course, the repel comes down and it average value seems to going up. You can see the ammeter, voltmeter as well as the CRO on our left. Now, what we will do is, well of course increase the voltage and make firing angle near about 30 or 40 degrees. We will do now by increasing the firing angle again, we can decrease the DC voltage and now you see again the voltage is coming down the DC voltage and the repel of course increases. You would have notice of course, if the repel is a of course, it is not very clear on the CRO it is a 6th thermionic repel.

Now, before I go ahead and you know you know discuss something more about the excitation system itself I mentioned to you that there is a need to have some kind of continuous control over the excitation system because the excitation voltage, which is given to the synchronous machine because the synchronous machine as got very poor regulation because of having large value of X d. So, this something which I discussed just some time back. So, what I will do now, we show you a small second third video clip of the drop to a very precipitous drop in voltage, once you start loading synchronous machine by resistive loads.

So, what I will do is, start the synchronous machine, set the field voltage at a certain field voltage. So, that you get roughly the rated voltage at the generator terminals. Then, what I will do is, load the synchronous machine by a resistive load, as simply a passive resistive load. As I try to decrease the résistance from if it is open of course, the resistance the infinity but as I start loading it, that is I reduce the resistance from a certain value I go on decreasing the resistance and load the synchronous machine, you will find what happens is, that this terminal voltage of synchronous machine drops and as a result of that, you will find that in fact the synchronous machine is not able to take on much power because the voltage drop so much, that it goes beyond the maximum power point of you know of this particular situation of this particular source.

So, as I go on decreasing the resistance, I have try to load the machine but unfortunately the terminal voltage goes on dropping. So, eventually the machine does not get loaded at all. So, this is what you will see in the next video clip.

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So, the machine has been started, wire the prime mover. Now, what I do is, that adjust the tool winding. Right now, there is no voltage, which there across the field. I change the delay angle of this thyristor bridge and gradually try to develop some voltage across the felid and therefore, the terminal voltage will appear. yeah So, I have a kind of try to change the delay angle.

So that, I get the rated voltage at the terminals of the synchronous machine. Now, what I will do is, I load the machine by connecting resistive load to it. So, this is been done gradually. So, you can keep an eye on the power meter. yeah Now, the we can see that load is slightly increasing as I introduce the resistance but what is very striking is the voltage initially, which was 230 volts, decreases as a go on loading the machine. In fact, if I go on loading the machine, the voltage in fact drops almost to half of what the rated value was. So, if do not touch the field winding voltage, what I am showing you now is, I am readjusting the field voltage so I as to and readjusting the field voltage so I as to get back to the rated value.

So, unless I do that, the voltage will drop to very low value and we will not be able to load the machine adequately. So, what I will just repeat what I did. I loaded the machine and you saw that if I kept the felid voltage constant, you find that the terminals voltage of the machine drops and in fact you not able to take on the complete power. The actual power, which deliver to the load is not we cannot increase it beyond the point because is the large source impedance in the form of X d but if I increase E f d, that is the field voltage, I can get back the voltage back to the rated value.

So, that is what is really need to do. If you look at what needs to be done in a typical excitation system, is to have some kind of continuous control. We did not have it in our the demonstration, which I showed to you so far. In fact, you can see that the there is no continuous control; I had to manually adjust the field voltage of the excitation system. This is not desirable because the load could change suddenly and then, you may have sudden dip in the voltage. So, you always need to have the excitation system in continuous control mode. So, what you need to do? For example, the most simplest thing would you need to do is monitor the terminal voltage of a synchronous machine. In case, it drops to keep adjusting the field voltage.

So that, the you know the voltage is maintained. So, you adjust the field voltage in such way. Now, this really brings us to a new dimension so to speak in our course. We will be we have been so far talking about modeling of power apparatus. We can of course, talk in terms of now, how you really introduce control system, which themselves may be dynamical systems mind you. So, how do you have control continuous feedback systems introduced into our models, so that we can accurately describe their effects. So, for example, right now one of the various one of the things you would probably do is, measure the terminal voltage of the generator.

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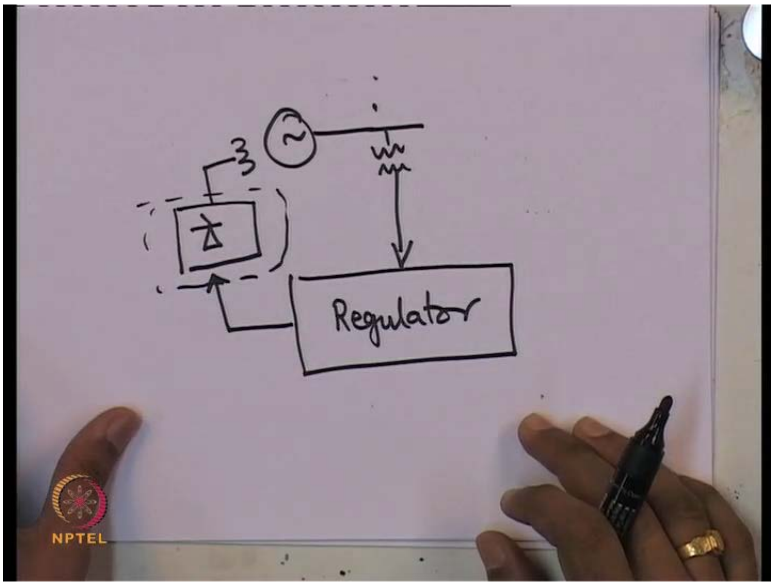

So, you measure the terminal voltages of a generator. So, what you do is of course, have a p t and feed it to a regulator. The regulator in fact, gives the appropriate signals to the control rectifier of your excitation system. It could be a brushless excitation system or static excitation system.

And that feeds voltage to the generator field. So, this excitation system could be a brushless excitation or static excitation system but in both cases you do have a control rectifier. The signals to the control rectifier to enhance the voltage or reduce it or in fact obtain from the voltage regulator.

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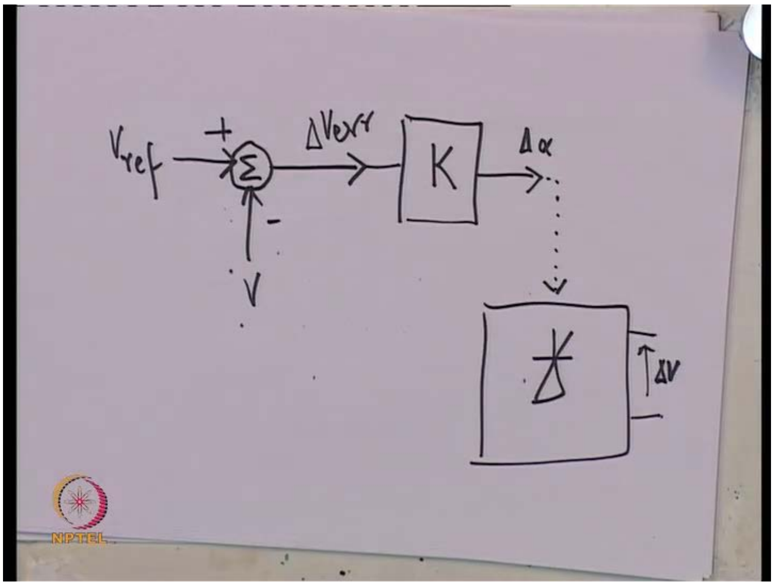

Now, what is the voltage regulator? The voltage regulator itself is some kind of control system. It is a dynamical system but it is not power apparatus. It is basically consisting of some hardware, which tries to implement certain mathematical functions. Remember, that the control signal to a thyristor bridge is not what is known as high power signal. It is just a it is has enough strength to convey to a thyristor or to the gate of the thyristors to delay there firings.

So, the power levels, which which are here which are used by control system are much much lower than the actual power rating of the apparatus it is trying to control. So, in that sense although we will be modeling these regulators etcetera there are also going to be differential equations and dynamical systems in most cases but they are not power apparatus. They are in fact low power apparatus. It is essentially signals. So, for example, you could give some set point to rather set point is the value would like the terminal voltage of your synchronous generator to be, if the value at which it should run. You measure the actual voltage, which is generator; step it down and get it measureable or signal levels; a low power signal you can say. You have comparator. This is some hardware. It is some kind of built in hardware, comparator or that is using analog electronics, you make comparator or using even digital systems, you can implement is using some software.

So, we will of course, discuss these things a bit later, may be in the next class. So, by comparing this, you will know the error and then, by some control law. The control law could be just a simple gain or an amplifier. You could determine the control signal, which is to be given to the control rectifier, which is the power apparatus. So, the this is the power apparatus.

So, the output of this is a control system is a signal, which is given to this power apparatus. Now, this power apparatus interprets this signal appropriately and appropriately changes the output of the voltage of this rectifier. Now, there is some mapping of course, between the value, which is obtained here and how much change it causes here. So, I one way of doing that is, if I the output of this change is by delta alpha, how much is the voltage change here.

So, that is something you should know before and before you design this control system. So, what this is one way of controlling the voltage. If there is a larger the error, the larger this correction, which you make here. So, of course, of course if the voltage is low, if V is less than V ref, this error will be present and you should of course, control design your control system. So, that it drives the power apparatus to rectify the situation, correct the situation. So, it changes the signal given to the control rectifier.

So that, the voltage increases. So, this is what it will do under circumstance where voltages are low. So, it is a continuously acting of course, is very important the continuously acting control system. So, this is one thing, which you should remember, you need to do this in addition to just having the power apparatus. You have continuously control control system. Now, remember that once one of the things, which I hinted to talk you about is, you need to know how much you need to change the output of a control system.

And map it to what the power apparatus or what the power the excitation system the way it behaves. So, for example, in a brushless excitation system, which I had shown you some time back. You should have in your hand or mapping of how this control signal change in this control signal changes the DC output of this. How that change in DC output of this changes the AC voltage output of this synchronous generator and correspondingly, how this change reflex here in the final change in the field voltage and of course, once you change the field voltage, we know how it affects this main generator by just the synchronous machine equation, which we have been discussing all this while, in the previous lectures.

So, you know how a synchronous machine behaves but you need to model all these components here. That is the rectifier itself, then the AC generator. It is also a generator. So, you may wish to model this in detail. I mean the amount of the detail something, which is based on our engineering judgment. You also need to model a behavior of a diode bridge rectifier. So, you need to model not only you know these are not just algebraic relationship you put in the input and the output. You may actually have to model some of these components at least as dynamical system rather differential equations.

So, what you have it this power apparatus, which is the synchronous machine itself. Now, you have got another power apparatus, which is the excitation system, which you need to model in some detail. Now, the amount of detail depends on the kind of studies you are doing. So, as I mentioned some time back, in a brushless excitation system, you have a generator, the excitation system itself has a small generator there. It cannot have large of course, as the main generator. That itself may have to be model in some detail, but their of course, on the other hand there are some studies, which really do not require you to model this things in great amount of detail. You will get more or less the same results even if you use simplified model. So, these ends some other issues will be discussed in our next lecture.