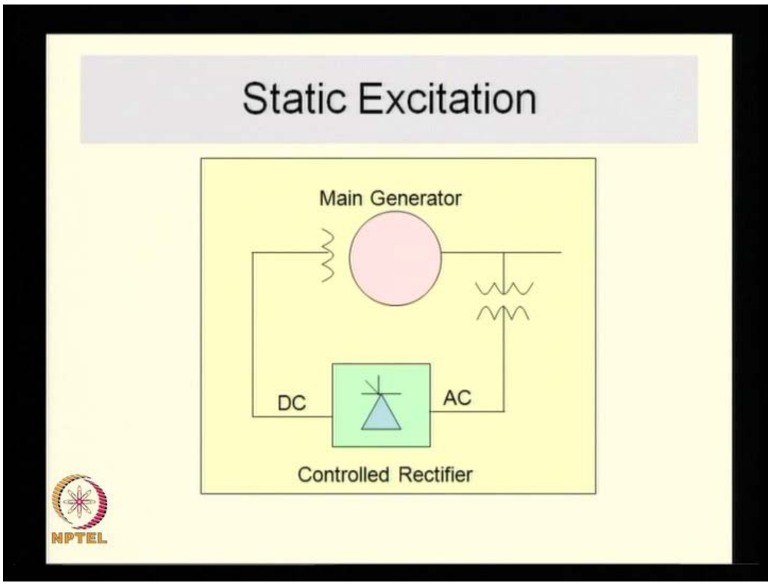
Power System Dynamics and Control
Prof. A. M. Kulkarni
Department of Electrical Engineering
Indian institute of Technology, Bombay

Lecture No. # 25

Excitation System Modeling

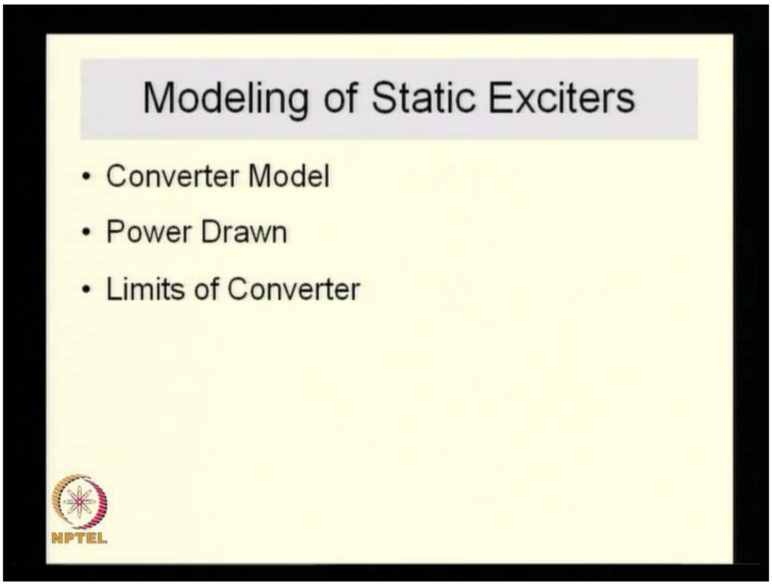
We discussed, the basic operating principles of two kinds of excitation systems, one was the static excitation system, and the other one was a brushless excitation system. In order to really go ahead and use these exciters or rather the study the effect of these exciters, we need to really model them mathematically. And that will be the focus of today is lecture, so today is lecture is focused upon Excitation System Modeling.

(Refer Slide Time: 00:48)



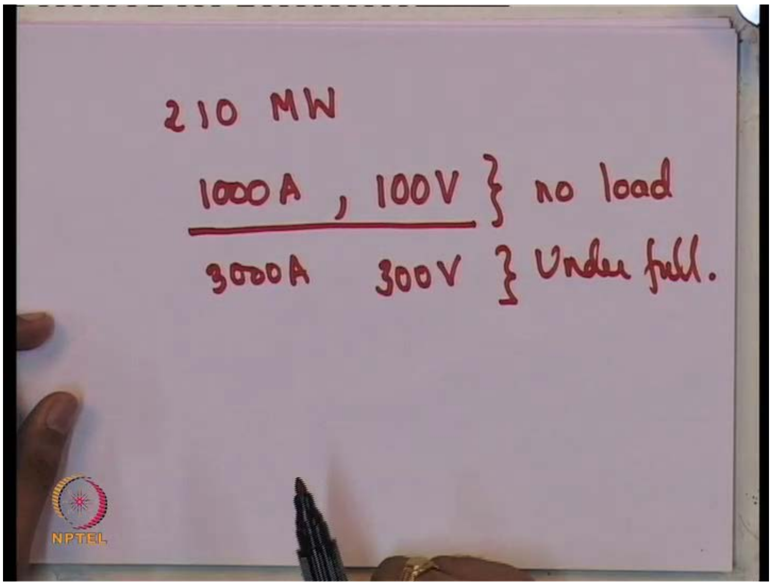
The basic static excitation system which was studied in the previous class will just recap what we did? The static excitation system consists of a controlled rectifier it is a thyristor based rectifier. The AC input of it is derived directly from the output of the or rather the stator voltage is of the main generator; and the rectified output is fed to the field winding. So, this kind of system is amenable to self excitation as I mentioned sometime back, but in a realistic situation, you need to initially develop some voltage across the stator windings in order to start up the system. So, this is done usually with the station battery and is known as field flashing. Now, if you are going to moderate to model this particular static excitation system for our stability program or stability studies.

(Refer Slide Time: 01:42)



We need to see, how we can actually represent the various components in this system. Now, one of the important things, which you should remember here is that, a static excitation system draws a bit of power. In fact, it slightly loads the main generator if you look at the block diagram here (Refer Slide Time: 02:04), you will find that it is loading the main generator. But, remember that the amount of excitation power which is required is very small compared to the overall rating of the synchronous machine. So, we need not even considered the loading of a excitation system on the main generator.

(Refer Slide Time: 02:27)



So, for example, a typical set of 210 megawatts under no load condition, you have got excitation currents of approximately 1000 Amperes and voltage is of around 100 volts applied to the field winding. So, this is the under no load conditions or open circuited conditions. And of course, under loaded conditions this may be three times as much. So, approximately 3000 volts in rough 300 volts and roughly 3000 Amperes, this is the roughly under full load conditions.

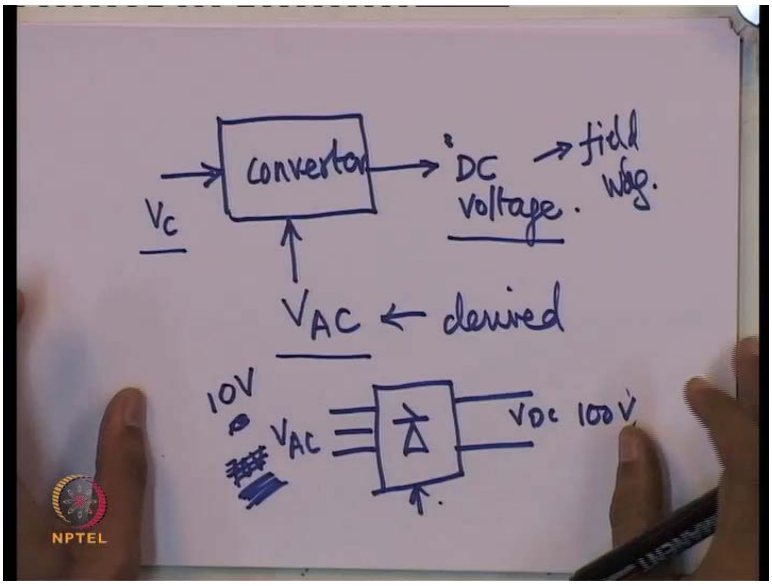
So, the excitation power required is not very very high, so you look at this, it is less than a megawatt. So, if you look at the no load excitation power requirement it is quite small. So, we really need not represent the load the loading of the synchronous generator on the excitation system on the generator itself. So, what we need to do of course, is however, try to model the control rectifier itself.

As you may have guessed, a controlled rectifier is a very fast acting system. And in fact, if I give an order to the control rectifier to change the voltage or the DC voltage it is practically implemented instantaneously. So, if you look at what basically it involves is changing the firing angle delay of the thyristors of the bridge. And a there is a switching, if you use a 6 pulse thyristor bridge, a 3 phase bridge as is commonly known; then every 6 th of a cycle you can effectively change the firing angle delay.

So, if you just have to have wait for our 6 th of a cycle to change the firing angle delay. And if such is the case, then for most of the studies of our interest, we need not model convertor operation in detail. We can just treat the convertor as some kind of instantaneous, amplifier of the control signal. So, your control signal is something, which you use to control the output, which is fed to the field winding. So, the convertor itself is almost instantaneously acting, so we do not really have to model it in detailed. Now this of course, presumes that the kinds of studies we are doing are essentially power system studies; we do not require as to do such a detailed modeling. Of course, if you are involve in a excitation system design itself then of course, you need to model a convertor much in detail.

But, we will just at least see what are the limitations or what are the you know modeling intercedes which, we need to consider whenever, you make a mathematical model of an excitation system (Refer Slide Time: 05:17). Now, a static excitation system luckily, the convertor itself can be model as something as a kind of a static block static in the sense that as I mentioned sometimes back.

(Refer Slide Time: 05:27)



If I give a control signal, this is the control signal let us call it V c then, the DC output of the system immediately changes, so this is one model of a convertor. So, this convertor model can be very very straight forward. So, you have you give a controlled signal and it immediately results in the change in DC voltage, which is applied to the field.

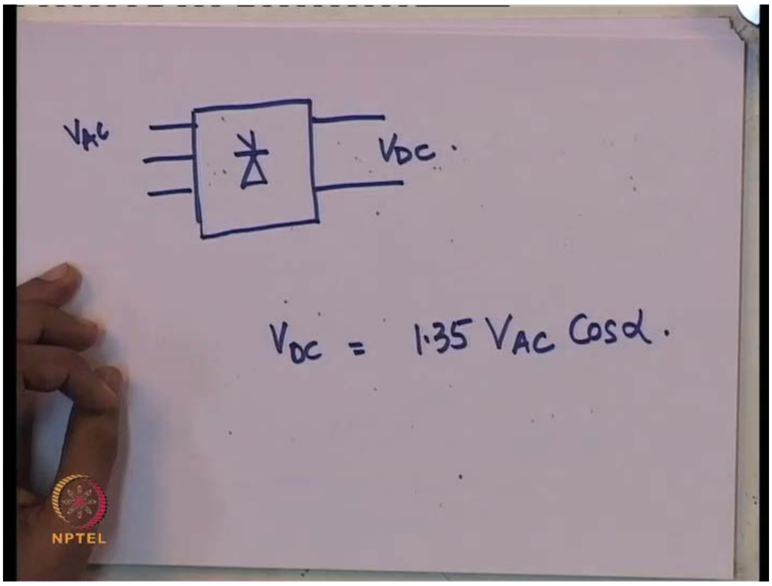
Now of course, the DC voltage is applied to the field is related to the voltage, which is applied at the AC terminals of the convertor. So, if I decide to have a certain output voltage here, I will appropriately change the control signal. Of course, there should be a certain mapping between the control signal and the DC voltage, which is which appears here. In fact, this control signal essentially is the order to the convertor to change its firing delay.

So, if you look at if you look at the convertor itself, this is fed to the field winding, this is actually derived from the terminal voltage of the synchronous machine. So, the main generator it is output voltage, theater voltage itself determines V AC. So, if I give certain control signal say I say, I want say 115 volts to appear here, I can give an appropriate control signal and we will get this voltage here almost instantaneously.

So, one thing is that you should map this V c to the DC voltage which appears here. So, this is one thing. The other important thing which we should consider, if you look at the slide the third point in this slide the limits of the convertor (Refer Slide Time: 07:17). Normally, whatever we desire to have at the output of the convertor can be got it can be got provided V AC has got an adequate magnitude. In fact, suppose I want to get you know say 150 volts here or 110 volts here, your V AC should have adequately high magnitude. Remember that (Refer Slide Time: 07:44) you are feeding this voltage to the convertor and this V DC here, is dependent on V AC as well as the control signal or the firing delay angle effectively.

So, if V AC of course, is too small if V AC is very small suppose, I desire 100 volts here and I the V AC is only you know, what appears across the convertor AC side is only 70 volts. You may not be able to achieve these 100 volts, it depends on the conversion factor between the AC and DC voltages and the firing angles. So, you for you know you if for example, you had perhaps of 7, I can perhaps put a lower value here to illustrate, this if I have put 10 volts V AC here whatever, be the value of the firing angle you are not going to get 100 volts.

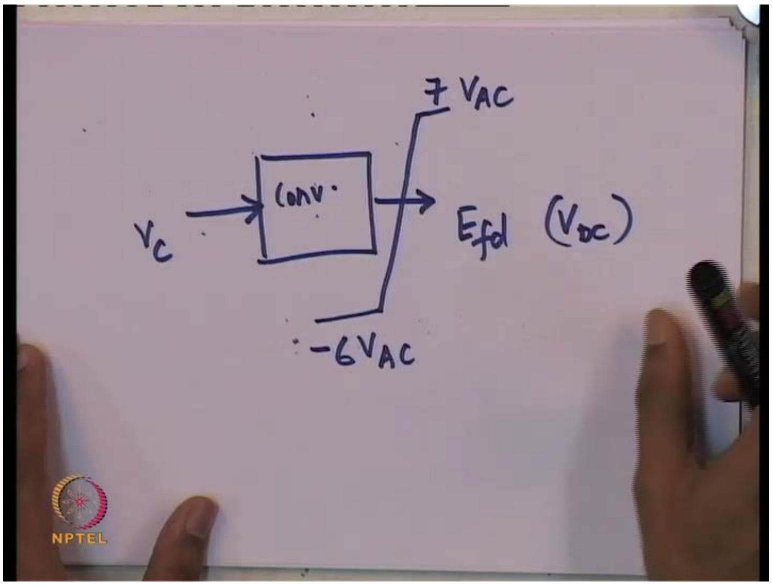
(Refer Slide Time: 08:48)



So, in fact those who are familiar with some basics of power electronics will recall that, if you have got 6 pulse thyristor bridges. A thyristor bridge consisting of 6 thyristor then, and this is V AC is a line to line rms voltage then, V DC is roughly 1.35 V AC. V AC is a line to line rms value at the terminals of this into cos of alpha. So, the maximum value V DC you can get out of this is 1.35 into V AC.

So, there is a limitation now normally of course, one would design a excitation systems such that, the normal voltages which you require which we desire at the field winding are achievable with the kind of V AC we will have; remember V AC is derived from the terminal of the generator which is step down. So, the step down ratio of the transformer is adjusted in such a way. So, that for all conceivable situations which are acceptable of course we can get the value of V DC by appropriately choosing alpha. But, there are certain situations like for example, if you have got a fault on the synchronous machine or there is a short circuit at the terminals near the terminals of a synchronous machine, so through terminal voltage of the generator it self will dip. If the terminal voltage of the generator dips, you will find that V AC small and in some cases you may not be able to achieve the V DC which is desired.

(Refer Slide Time: 10:30)



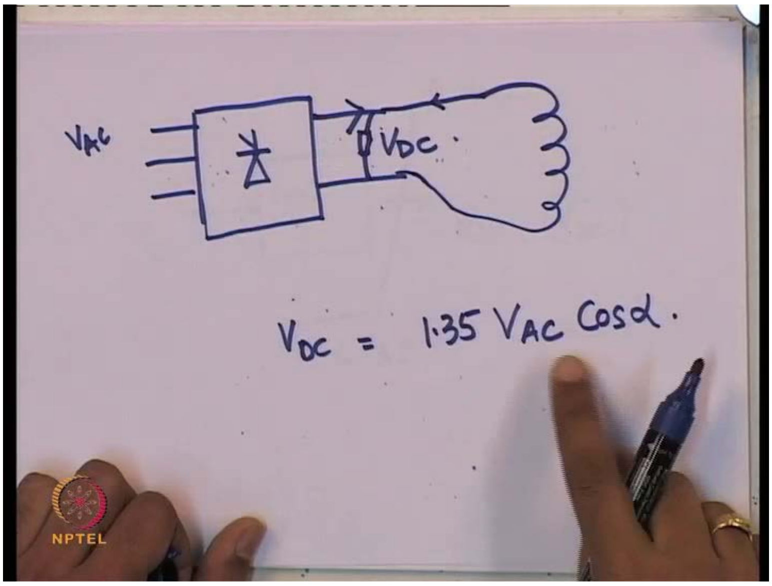
So, one of the ways you can model convertor is, so this is your convertor models this is your control signal, this is the voltage applied to the field winding, you need to appropriately put limits on the convertor. The limits really tell you that the voltage is at the output of the convertor cannot be changed beyond certain values. So, for example you could this could be roughly so these are the maximum values you can have for E f d. So, this is one E f d is nothing, but V DC or just normalize E f d is a normalized value of

V DC. The basic idea is that if you want to get a certain V DC when V AC is very small say, due to a fault you may not be able to achieve it because of these limits.

Another interesting point we you should remember is of course, something I mentioned previously, a convertor can have negative voltages. So you that is why you see this minus sign here. So a thyristor based convertor (Refer Slide Time: 11:54) can have negative voltages V DC, but the important point is that current is always in this direction you cannot have current flowing in the opposite direction and (Refer Slide Time: 12:09) in case you wish to allow current to flow in the opposite direction in the field winding you need to have separate shunting elements which has switched on as necessary.

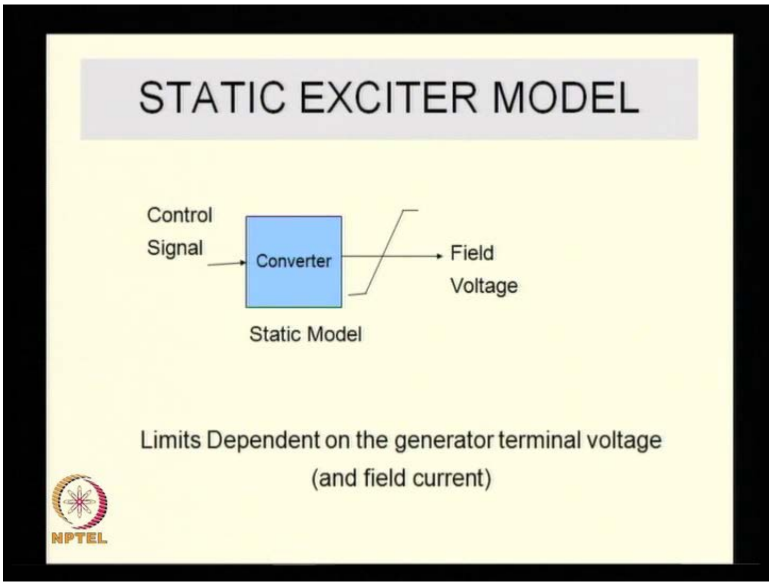
So, either these could be a switched kind of shunting element which will allow current to flow in this direction from the field winding this is the field winding of the generator. So, are you can have a non-linear varistor which allows current only in this direction in case the voltage across the field winding becomes very large? So, this kind of arrangement can allow reverse current flow in the field winding, but this convertor itself does not allow any current to flow in this direction.

(Refer Slide Time: 12:46)



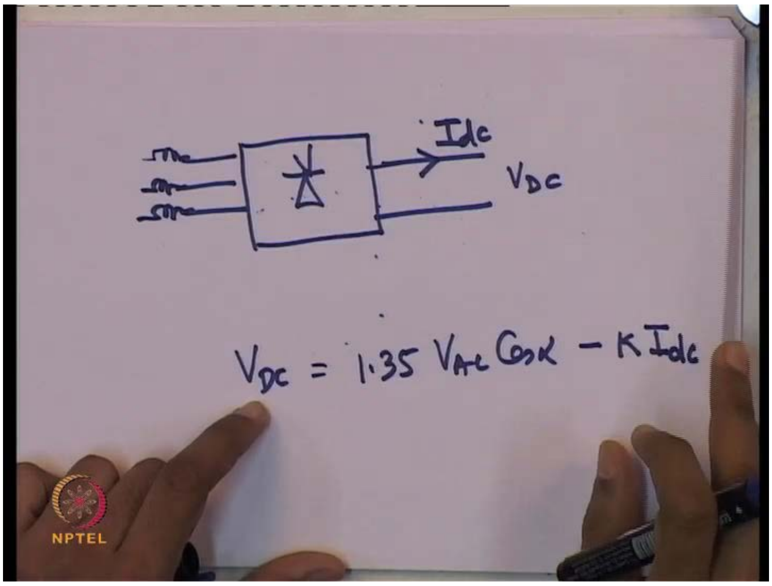
But V DC of course, can be negative. So, that is an important and interest thing capability of the thyristor bridge itself.

(Refer Slide Time: 12:59)



So, this if you look at what I have just told you to summarize a control signal is there you have got a convertor. The convertor is a can be actually just a static model, what I mean is that the field voltage is algebraically related to the control signal, we do not have any differential equations or delay elements or anything of that kind the simplest model is a simple static or simple algebraic relationship between the control signal and the field voltage. The important things of course, are the limits of the static exciter; the limits are dependent on the generator terminal voltage. One interesting point which of course, I did not mention in my discussion, so far is that the voltage also get us limited in some sense because of the field current.

(Refer Slide Time: 13:50)



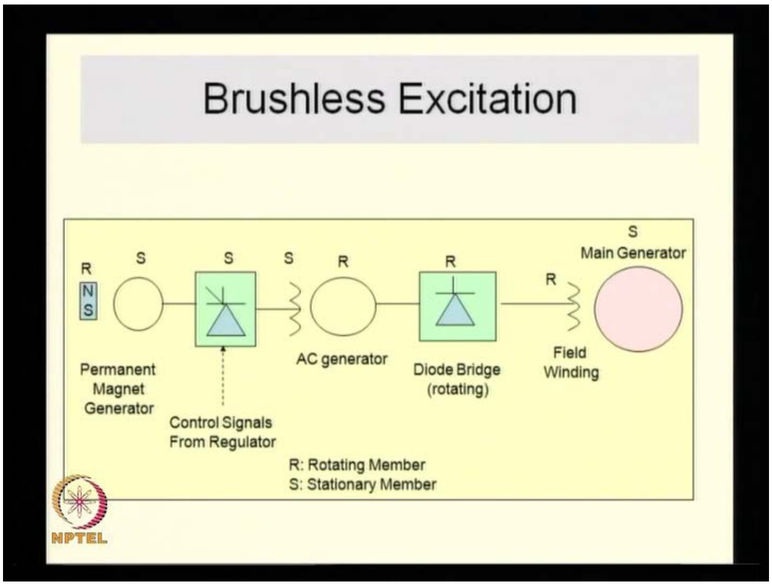
Now, what do I mean by that if you look at a typical convertor and we just fed a form of source the V DC although I mention sometime back it is roughly 1.35 V AC cos alpha for a 6 pulse bridge, thyristor bridge where, alpha is the controlled quantity. So, we can get the V DC we require if V AC is large enough and for the certain control delay angle. But one small thing one small issue which I did not consider in this is that V DC is also dependent on they I dc of the convertor the current which is flowing out, so it is slightly draw droops.

So, V DC slightly falls if I dc becomes larger this is because of, what is known as commutation overlap effect due to source inductances is, so you may have actually some kind of regulation in some sense. The V DC is not just a function of V AC, but it is also a function of I dc. Now, so this the normally does not matter because you could always adjust alpha, so that we get we whatever, V DC we require however at the limits for example, if V AC is very low, in that case you will find that the limits are also determined by I dc. Let we just retreat what I say?

Normally by changing alpha you can get whatever, V DC we require irrespective of AC and I dc; however, the minimum value of alpha is actually theoretically speaking 0, but typically 5 degrees also, in such a case V DC also get us limited because of V AC and I dc. So, if I hit the minimum value of alpha you cannot control V DC any longer you cannot increase it beyond that point. So, one important point which you should keep in mind is of course, that V DC is limited not only by V AC by, but by I dc also. So, V AC becomes very small it slightly that you will hit the limit and you will not be able to achieve what V DC you want. So, field current also comes into the picture because V DC is dependent on the field current as well though strictly speaking it is or rather practically speaking it is a weak relationship. Normally if static excitation is fed the AC voltage is obtained simply by stepping down the voltages of the main generator the stator voltage is of the main generator, so called commutative reactants of the source impedance is quite small, it is says the leakage impedance of the transform. So, in such a case we can almost neglect the limits the dependency of the limits on the field current.

If you are not in the limits, within the limits we can assume that the field voltage is simply as I said algebraically related to the control voltage. So, if I if I say I want to want a certain voltage and I give an appropriate control signal you will instantaneously obtain that particular field voltage, if you know the mapping between the control signal and the field voltage. So, static excitation model is very simple (Refer Slide Time: 17:17).

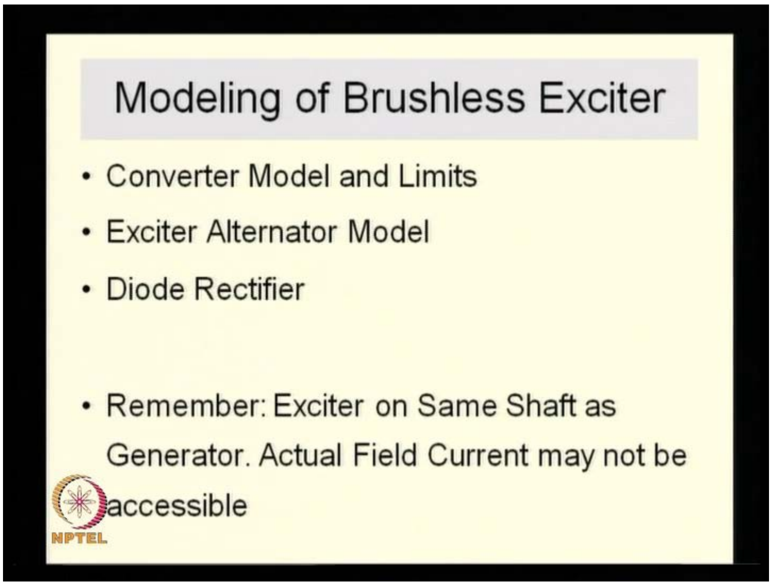
(Refer Slide Time: 17:23)



And what we really need to spend more time on is the other kind of excitation system we will not really go in to the gory details of this model. But let us at least try to co-relate the various modeling, you the mathematical blocks which need to be present in the bro brushless excitation how is the brushless excitation different, first thing is that the controlled rectifier is here, thyristor based rectifier is here, the control signals are given here, the power is derived from a permanent magnet generator which rotates on the same shaft as the turbine and the generator. So, actually power is coming from the turbine some sense for the excitation system.

But one, this is the point at which we control the voltage. Hereafter on the right hand side we have an AC generator this is called an excitation generator. This is not the main generator this is an excitation generator a diode bridge and the field winding. Now, what you need to model really here are the convertor model and the limits in fact, the control rectifier which you see here, is as similar characteristic has the static excitation system convertor, so there is nothing really difficult or you known different from the convertor the static excitation system model here, but there an additional elements which have dynamical characteristics which need to be represented in a excitation system model. Now, if you look at what are those we need to model the exciter alternator.

(Refer Slide Time: 19:11)



The exciter alternator is not the main alternator remembers then we also need to model a characteristic of a diode rectifier and us when we do this modeling we need to remember that a exciter runs on the same shaft of the generator. The generator runs almost for most operating conditions for most of the studies we have going to do the generator will be near about the nominal speed. So, we can almost take assume that the permanent magnet generator which effectively generates voltages for the elements of this excitation system is actually running more or less at the nominal speed.

So, we need not you know bring in this at additional complication of making everything speed dependent here. (Refer Slide Time: 19:58) Moreover, you will notice that since, the control control rectifier is here whatever, voltage we desire can be achieved by giving an appropriate control signal subject to the limits, the limits again are dependent on V AC here the V AC is derived from a permanent magnet generator. So, you can model this much this in much the same way as you have done for the static excitation system. The voltage here is speed dependent, but as I mentioned sometime back you will almost be at normal speed. So, the limits of this convertor the limits of this convertor is dependent on V AC here, which we can for most for most purposes assume that that V AC is a constant. But not dependant on speed because speed variations considered for more studies we will be doing in this course I am not going to be much away from the nominal. (Refer Slide Time: 20:57) Another interesting point here is that the actual field current may not be directly measureable, so unless (Refer Slide Time: 21:04) you have made some specific provisions you may not be having a actual measurements of this field current you may know, what the excitation system generator this generator here, what it is field current is?

But we will not be able to find out a well in many cases we are not having the exact measurement or actual measurement of the field the winding current of the main generator. So, this could be a possibility which you should consider that the measurement is not available, but this is accessible this current here this is the excitation generator current this is accessible. (Refer Slide Time: 21:40) Another interesting point which you should note is the diode rectifier itself is slightly different from a thyristor based rectifier. In a diode rectifier we do have similar effects as in a control rectifier thyristor based rectifier. But a diode rectifier itself gives us snow control it is an uncontrolled rectifier.

Another interesting point which you should note is diode rectifier voltage also cannot be negatives. The diode rectifier voltage is a function of the AC voltage which is applied you know to it is a c thermals as well as the actual d c current which is flowing. So, both these things determine what the DC voltage of a diode bridges is in fact, if you look at a thyristor bridge, (Refer Slide Time: 22:29) it is dependent on alpha V AC and I dc. But for a diode bridge a diode rectifier if it is a diode rectifier this cos alpha is practically 0 and you cannot change it. So, this is one thing, as a result V DC cannot be negative in a diode rectifier, you cannot have V DC negative that is one important and interesting point you should note.

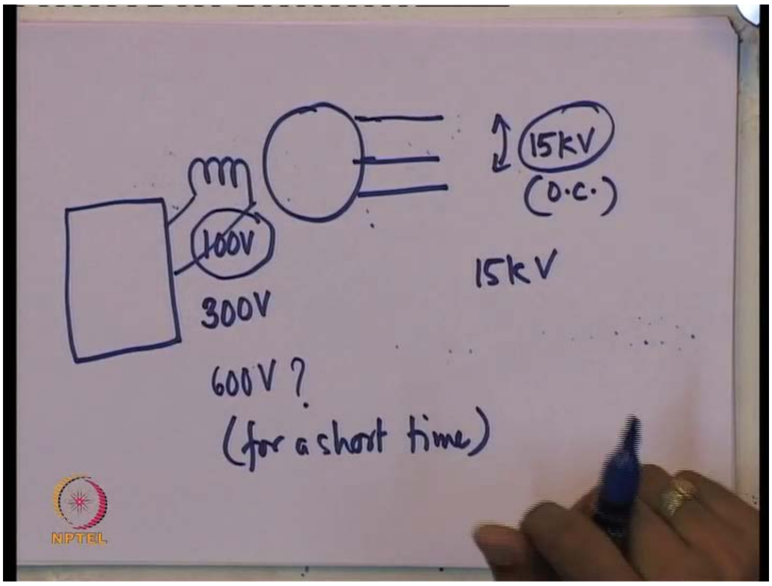
Now unlike in a static excitation system, which is fed from a transformer at the source impedances of which are not very large, but diode rectifier here is fed from an AC generator and AC alternator the excitation system alternator whose impedance can be significant.

So, what I mentioned here is this effect of the loading on the DC voltage may be significant. So, this loading (Refer Slide Time: 23:27) effect may be significant incidentally, this K is not a constant, it is dependent on an, I dc itself so, in an especially when you have got large amounts of I dc, this cable change.

So, that is another complication which we have to consider, again to summarize of a static excitation systems fed from transformers, this effect is very small. But the for the brushless excitation system the source impedance (Refer Slide Time: 24:04) that is the source impedance of the AC generator feeding, the diode bridge may be large and then you have to consider this effect.

Now, one of the important issues which you should keep in mind is that, what is the range of a static exciter. So, whenever I am designing an excitation system, I would need to know how much field voltage I need to apply to the synchronous generator in volts based on that I would have to decide the voltage rating of various elements. Now one of the important things you should note which you will see in brushless excitation systems as well as in static excitation system is that they given a voltage range or voltage capability, the final voltage which you actually get at the output of the exciter that is what is fed into the field winding of the main generator can be quiet large. In fact, it it may be 5 or 6 times the voltage which is required to get rated voltage at the output of the stator of the main generator under an open circuited condition as one per unit. So, to get let me just this was quiet a mouthful.

(Refer Slide Time: 25:23)

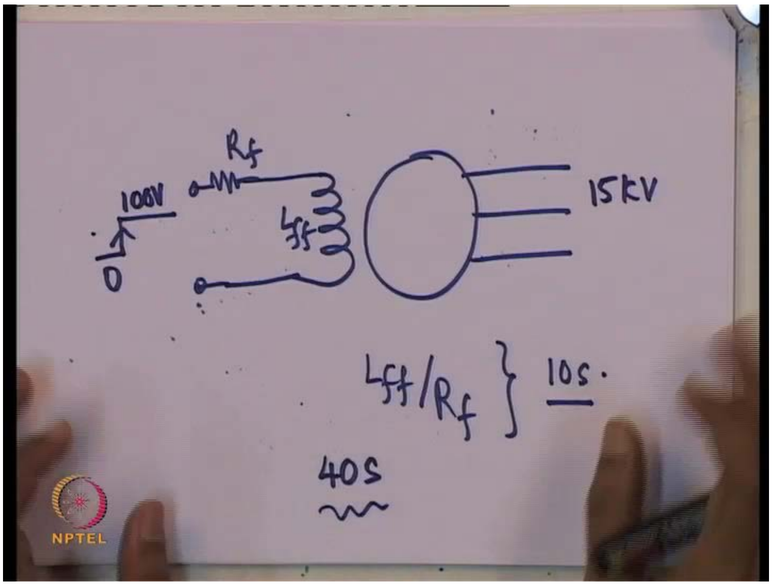


So, I will just retreat what I sent. So, if you got the field winding and it say takes 100 volts here, to get the rated voltage here. So, if I want to get the rated voltage here, say 15 kilovolts line to line rms suppose I need to apply 100 volts. Now, an excitation system normally under open circuit conditions so, under open circuited condition suppose to get 15 kilo volts and I needs to put 100 volts I have already mentioned to you if I load the machine I may have to put especially in stream turbine driven generator, you may have to put almost three times 2 to 3 times the field voltage in order to get 15 KV under full load rated load conditions. So, there is a big range of voltages which you should you know budget for whenever, you are designing the excitation system. In fact, another complication or another interesting point is that most of the excitation system as I said may be rated for 6 to 7 times what is required to get 15 KV under open circuited conditions now why is that? Why do I need to rate static excitation system at 6 to 7 times?

It is capable under for a short time for a short while of giving 600 volts if 100 volts is what is required to get 15 KV under normal conditions. Now why is that,(Refer Slide Time: 27:08) let me just amplify what I said, what I mean to say here is of course, that these limits here, are such such that if it requires 100 volts to get the rated voltage under open circuited condition that the terminal of the generator. The limits here may be 6 or 7 times plus or minus 6 or 7 times of what is required?

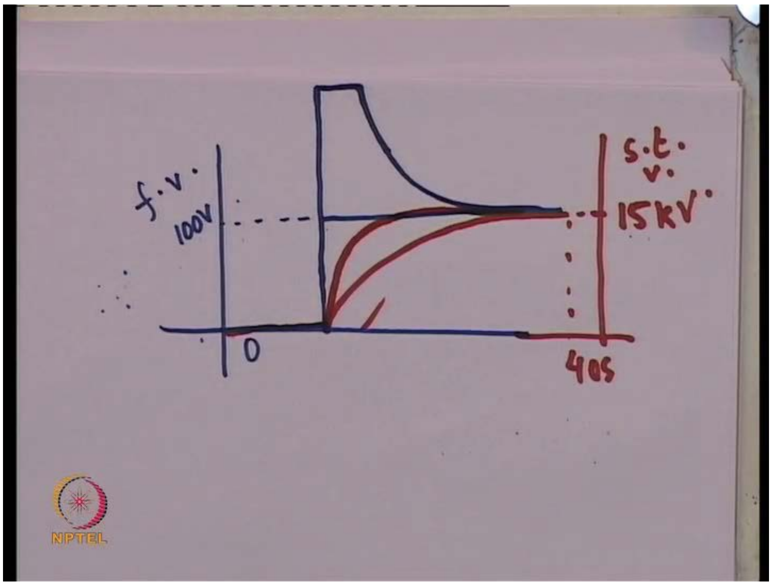
So, what you should need to do is of course (Refer Slide Time: 27:38), that you should appropriately rate your transformer. So, that it gives you an AC voltage which is sufficient to give you these 600 volts. So, this is what is normally done this is how it is done? Now I am not told you why it is required to have such a large range of course, as I mentioned sometime back you need to at least double the voltage of the field the field (Refer Slide Time: 28:08) voltage if you start loading the generator and you expect a rated voltage is to appear. So, you should almost have double or triple the no load field voltage, but why its 6 to 7 times the reason is such if it look at the field winding it is the slow acting winding what I mean by slow acting winding?

(Refer Slide Time: 28:28)



If you just look at the synchronization rate or under open circuited conditions the L ff by R f the time constant L ff by R f is extremely large, for stream turbine driven it can be as a near about 10 second it could be as large as this. Now if for example, if I just as a academic kind of example if I give E fd if I give a step change of the field voltage from 0 to the voltage required to get rated voltage here, suppose I just give from 0 to 100 volts I will get 15 KV in steady state using the example, which have given you previously, I will get 15 KV in steady state, but the time required will be roughly if the settling time for this voltage to appear here will be almost 40 seconds, because of the large time constant of the field. So, under open circuit condition you will require almost 40 seconds to achieve 15 KV even though I have given a step change here. So, this is this basically is not a very this becomes a very slow kind of system.

(Refer Slide Time: 29:56)

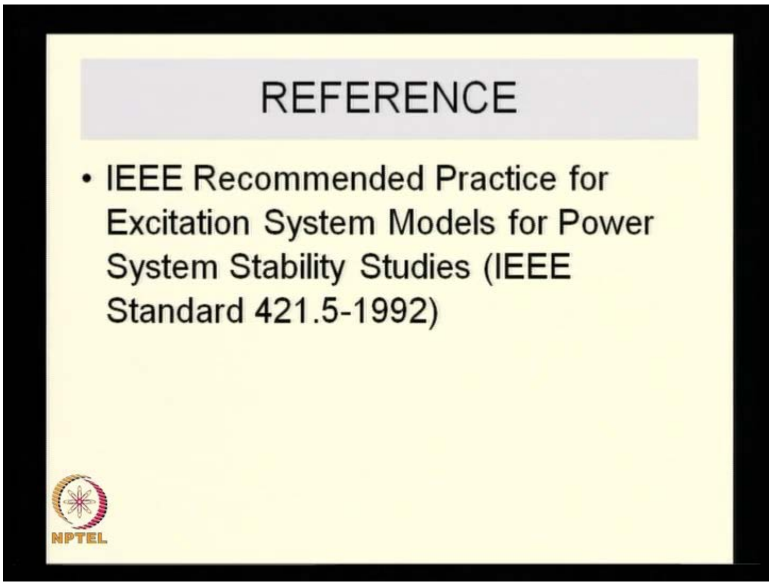


So, what I will just illustrate, what you need to do? Suppose I want 50 KV at the output the rated voltage at the output. So, what I do is I increase the field voltage from its 0 value to its rated value you will find that the field voltage increases from this with another rather the field voltage is step. Then the terminal voltage will increase like this I will take almost 40 seconds for it to settle down this scale for this is of course, 15 KV. Now, instead of doing this this is the very slow acting subsystem, so what I do instead is, what is known as field forcing, what I do is?

I in order to make this raise very fast I give a step change thought of 100 though I know that 100 yields 15 kilo volts I give a step change field voltage this is the field voltage this is the stator terminal voltage stator terminal voltage the field voltage I do not give a step of 100 what is required I give it give a much larger value you say 5 or 6 times its value.

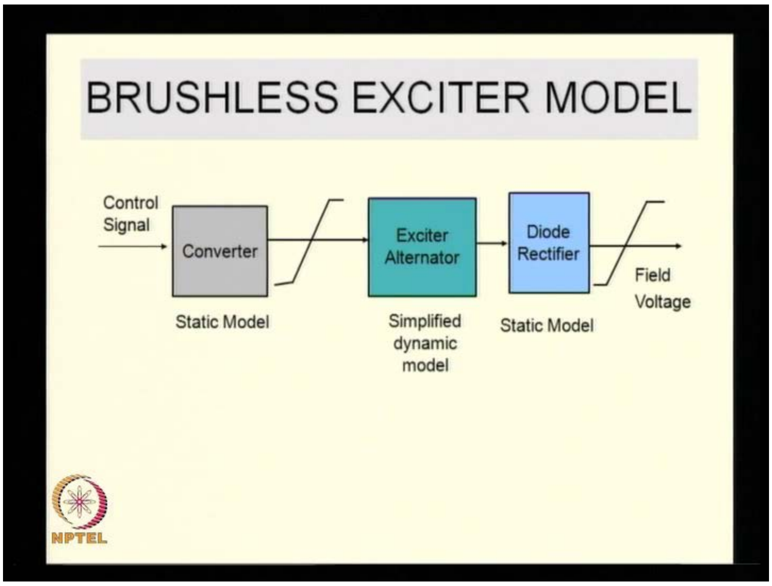
And then I reduce it to this. So, in such a case the synchronous generator terminal voltage will tend to rise like this and you can get a much faster response. So, by forcing the field by putting much more voltage than what is actually required you can overcome the effect of having the relatively slow acting field winding. So, you give a much larger push. So, in order to give that large push that range of the excitation system is often the ceiling voltage as it is called is quiet large. So, may have given it as 6 to 7 times. What is required to get the rated voltage under steady state conditions?

(Refer Slide Time: 32:12)



So, this is one of the interesting points now, if I have really discussed the various models of rather the issues which need to be taken into an account while modeling one of them the limits then us talks about the diode rectifier, the static excitation system. The static excitation system are the convertor model and the diode rectifier model are static in the sense that we assume that these are instantaneous acting devices and there is no no real dynamic associated with them the input and the output follow well defined relationships algebraic relationships. A control rectifier you can get the output which you want simply by giving appropriate control signals subject to the ceiling voltages. Ceiling voltage are dependent on the AC voltages which are applied to the convertors, so as far as the controlled rectifier, thyristor based rectifier component in any excitation system is concerned in it in just a static element with limits you get what you get what you want except subject to the limits. A diode rectifier the output voltage of a diode rectifier is simply algebraically related to the AC voltage which is applied and the current the DC side current because of the effect of commutation overlap now one of the components. Unfortunately, or well which you need to pay much much more attention on is the excitation system generator itself that is in an otherwise, static excitation system model that is one element which we requires you to model you know that the dynamics of the exciter. Now if you look at the kind of models (Refer Slide Time: 34:00) which are recommended by the IEEE I refer you to this IEEE reference in which these system models are actually derived and I also refer you to the three books in which we have got a (Refer Slide Time: 34:20) fairly good discussion of excitation systems are very good discussion of the excitation systems existing in all these books may with the first two books have a larger treatment (Refer Slide Time: 34:32) now, coming back to our excitation system models.

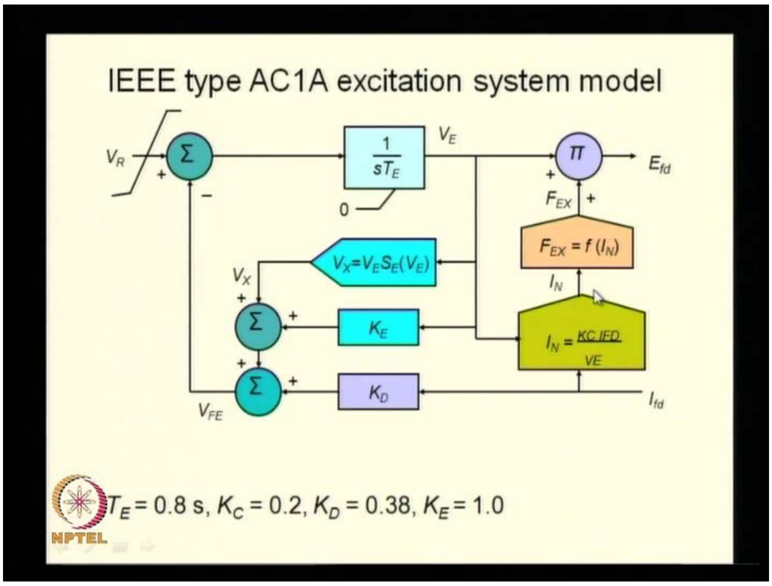
(Refer Slide Time: 34:35)



If you like at a brushless exciter model as I mentioned some time that control rectifier is a simple model your output is a function of the control signal. The diode rectifier the output field voltage is dependent on the current the output current as well as the exciter voltages this exciter alternator voltage. There is a limit here; the convertor limits are really determined by the AC inputs the maximum AC input you have I of the convertor. The diode rectifier limit on the other hand the field voltage the final output cannot go negative, that is the basic limit of the diode rectifier.

In fact, there is no upper limit in the sense that a diode rectifier is just dependent on the AC voltage and the field current that is no upper limit separately defined there is no no upper limit it is simply a relationship between the AC the DC voltage simple related to the AC voltage and a field current by an algebraic relationship, but it cannot go negative. So, actually that there is no top limit here there is no need to specify any top limit that the bottom here we cannot go below 0 volts.

(Refer Slide Time: 36:00)

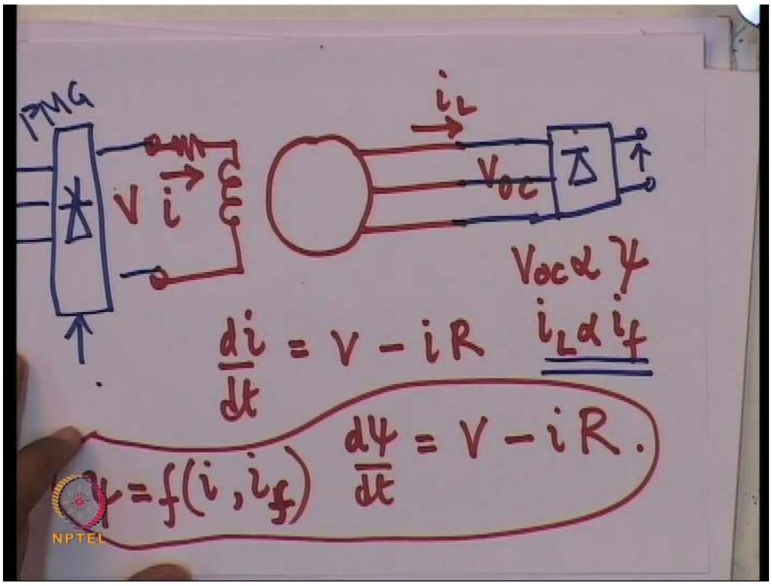


Now, if you look at the excitation system models which are given in the reference which I have mentioned you will come across something like this. Now, before we really I would not really derive this complete model this is the standard brushless excitation system model what I will tell you is, how you can come to it? Now a convertor model as I mentioned is straight forward the exciter alternator model is what is a bit tricky and as I mentioned sometime back the diode rectifier itself you know is algebraically related to V AC as well as the AC voltage which appears here as well as the current which flows.

So, the diode rectifier model has to be slightly we have to pay some attention to it the excitation exciter alternator now some body may argue that well this is an exciter alternator now, we need to model an alternator as we have done before in the sense when we have done synchronous machine modeling that is also an alternator. We have already come across you know a model which is fairly detailed I mean in the largest amount of detailed we have considered is what is known as 2.2 model which you have field winding and three damper windings in addition to the stator windings.

Well this excitation system alternator we do not take that approach we do not need to model it in. So, much detail one of the reason is of course, that the excitation system alternative is of much smaller rating it is characteristics are such we do not need to we can represent the gross effects of the exciter rather than modeling it as in as much detailed as the synchronous machine; this synchronous main synchronous generator itself what we will do is we will get a kind of rough exciter model. So, what are the issues which we need to worry about.

(Refer Slide Time: 38:03)



So, how is and the excitation system is like a normal alternator. So, the field winding is here, the convertor output is fed to the field winding of this alternator exciter. An exciter alternator it causes a current in the field winding and that changes is the output voltage. Now, if you look at the various relationships you have one of the things you will notice is the current flow through this is obtained from a differential equation.

So, first thing you will notice is that the current here the current here, so this is in fact, if you look at this if this is the voltage and this is the current this is what you get of course, this is a linear exciter this is not a linear device you may have to consider saturation. So, better you have putting it is b psi by dt if the field flux link with these winding is equal to V the voltage applied here, minus i into R. And the flux psi which is the flux link with this field winding here, is a function of it is a it could be an non if the machine is saturated it becomes non-linear that the in general I can write this is i the depends on i as well as the current, the load current of this exciter alternator. So, I will call this the load current of this exciter alternator. So, if you look at there the relationship it is like this now of course, this is the flux link with this winding we can say consider the open circuit voltage which appears or rather the voltage which would have appeared under open circuit conditions is roughly proportional to so, V oc here is roughly proportional to the flux psi.

So, if you look at the various relationships which are there you have got the open circuit voltage the open circuit is proportional to 5 or this psi, this d psi by dt is given by this differential equation psi itself is the function of this current as well as the load current which flows here. The load current in fact, is fed to the diode bridge which feeds the field winding so in fact, i L is proportional to the actual field current, the field current on the main synchronous generator. So, what you have essential is you can write this is i f here, so this the relationship you have got. Now if you try to model this then you would need to in have an integrator in the model you need to have an integrator in the model you have to provision for this non-linear relationship because, you may get have saturation effects this is the open circuit voltage in fact, due to armature reaction of this synchronous generator what actually appears here will be slightly different under loaded conditions. So, actual voltage which appears here is not V oc in fact, this feeds a diode bridge (No audio from 42:01 to 42:10).

You will have commutations overlaps in on which some senses like armature reaction in fact, it is due to source impedance. So, what you get here is not V oc is not proportional to V oc, but is proportional to well it is dependent on the generator reactant is the load currents. The load currents i L is approximately you can say is proportional then you can say the rms value of i L is proportional to i f for a diode bridge in steady state. Now, so a kind of a rough model of this kind can be used so, if I give the output of the convertor the what comes here is actually the output of the convertor control rectifier this is the controlled signal this is the AC voltage coming out of the permanent permanent magnet generator.

So, this of course, is a completely controlled element, but here onwards these relationships actually determine what appears here eventually. In fact, so appears eventually here which is fed to the field winding is a function of V oc as well as i l which is proportional to i f. So, this is what really you have you have got one integration which has to be performed of this differential equation. So, if you look at the IEEE model of this kind of excitation system we will derive it. (Refer Slide Time: 43:45) But we should be able to identify the components corresponding to this.

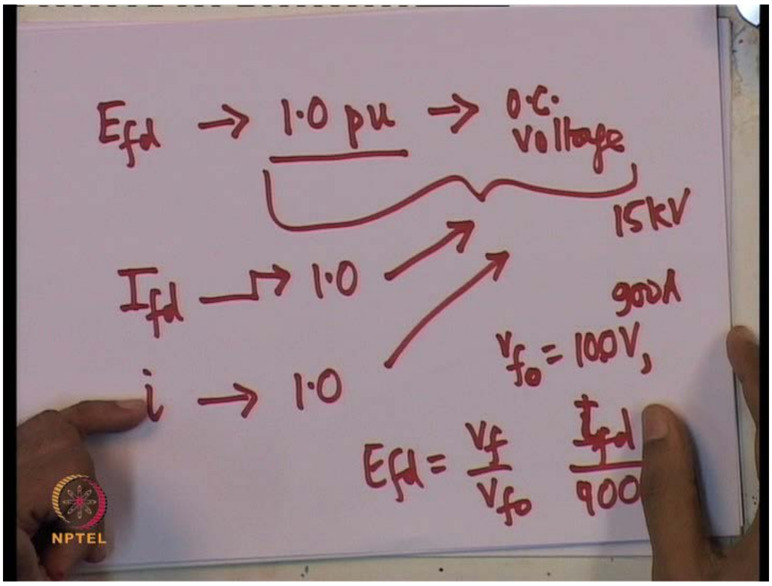
So, if you look at this figure here, this integrator here is actually this is the one integrator which is required for obtaining the open circuit voltage of this exciter alternator. The open circuit voltage of this exciter alternator does not directly manifest as the field voltage. There is an excitation, the diode rectifier itself has got due to commutation overlap phenomena has got some regulation.

In the sense that what open circuit voltage is there across the excitation alternator does not the directly appear is not directly related to E fd there you have to put a kind of a a correction function here, you would have multiplying F EX to E VE in order to get E fd. So, this is this what you see here is a component which takes you to account the diode rectifier regulation remember that this correction factor which is multiplied with V E in order to take in to account this rectifier commutation overlap is dependent on the field current I fd here as well as V E then you know the output voltage of the excitation armature.

Now, the non-linear effects are taken into account using this function here and the effect of an armature reaction is also taken into account here. So, although I am not derived this I am just directing you towards the various components as they have modeled in this standard excitation system model. Now the typical values of these the time constant T E here which dependent on of course, the parameters of the excitation system alternator like the field winding resistance itself K C which is the factor which takes into account; the commutation overlap phenomena which makes the field voltage dependent on the field current K D is a factor which corrects the output voltage of the excitation alternator it is it is basically trying to represent armature reaction and K E which is typically one.

So, this is effective and S E is a saturation function here. So, this is basically the excitation system model one clarification I need to give here these typical values which are given here are obtained in this block diagram assuming that, E fd and I fd are normalized.

(Refer Slide Time: 46:56)



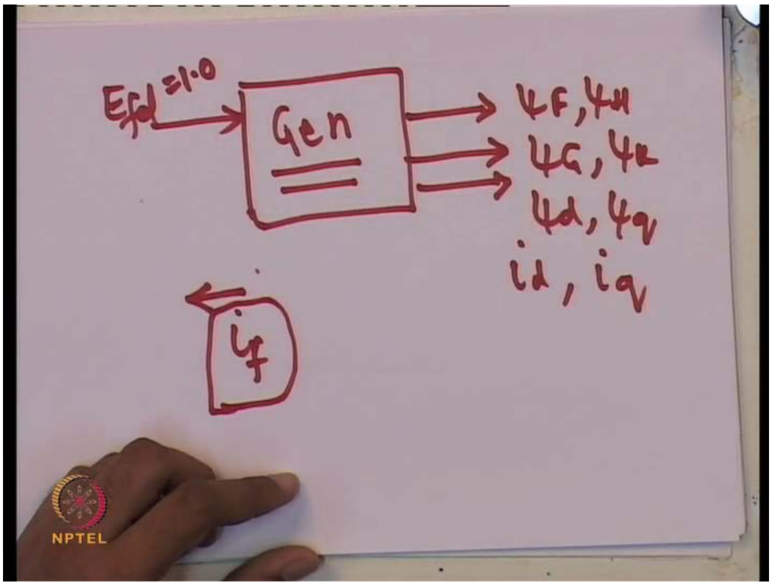
So, E f d and I f d and the exciter alternator field current are normalized. What you mean by normalized? E f d is assumed to be 1 which is actually consistent with the notation we are been following, so far E f d is 1 if the open circuit voltage of the main synchronous generator line to line voltage is the rated value or the base value.

So, instead of talking of E f d in volts or field voltage in volts should be using E fd which satisfies this, so the mapping is known. So, this E f d is in one per unit I fd is also one per unit if in steady state it results in the open circuit voltage which is equal to the rated voltage. And also in addition the exciter current this exciter alternator current I also is taken to be 0.1 in case this is satisfied. So, the gains which I have shown here in this slide here K C K D K E are assuming that such normalization has been done. So, we have normalized what you mean by normalized divided the values by divided for example, the actual field voltage by by a value (Refer Slide Time: 48:30) such that E f d is one per unit when you get when you get the rated voltage under open circuit conditions at rated speed. Similarly, I f d is defined and similarly, I also which is the excitation system alternator current field current.

So, what I mean to say is that if your (Refer Slide Time: 48:53) field voltage is 100 volts 100 volts is required to get the rated value 15 KV at the terminals under open circuited conditions. Then whatever, so I will call this V f 0 so whatever, field voltage is you are going to get under other conditions is normalized by this, so we will be using E fd which is V f by V f 0. So, that is what I mean?

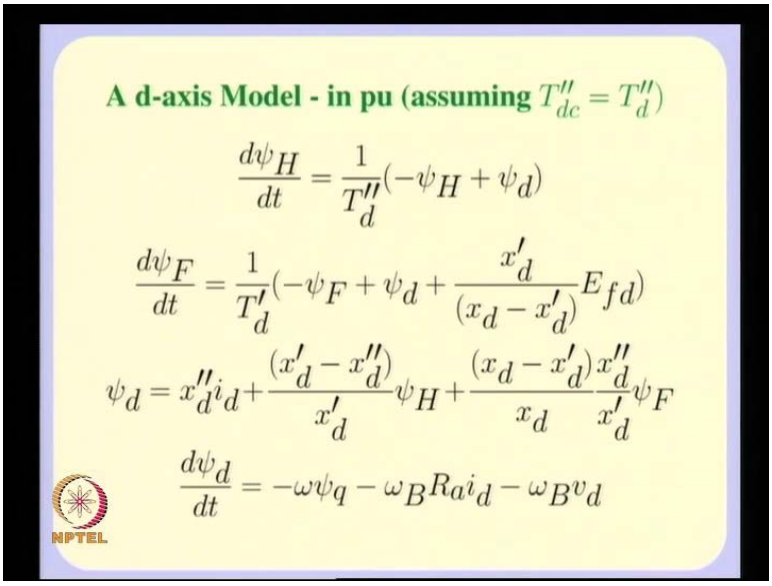
Similarly, water value of I fd you get it is divided by the value which flows under these conditions. So, if suppose it is 900 Amperes in that case I will have to normalize this by 900. So, if you do all these (Refer Slide Time: 49:46) then what you get in this block diagram these K C K D t the typical values will be this, so it is imported to know what this normalization is, so that is what I have just shown you here the field voltage the field current and an excitation system field current is normalized. So, that it becomes 1when we get 15 kilo volts under open circuited conditions at the stator terminal voltage. I hope that is clear now, one of the interesting points which I am not dealt with because this is something which you need to you know when you are doing a actual power system study what you will be doing is you will be giving E fd to the genera synchronous generator equations.

(Refer Slide Time: 50:36)



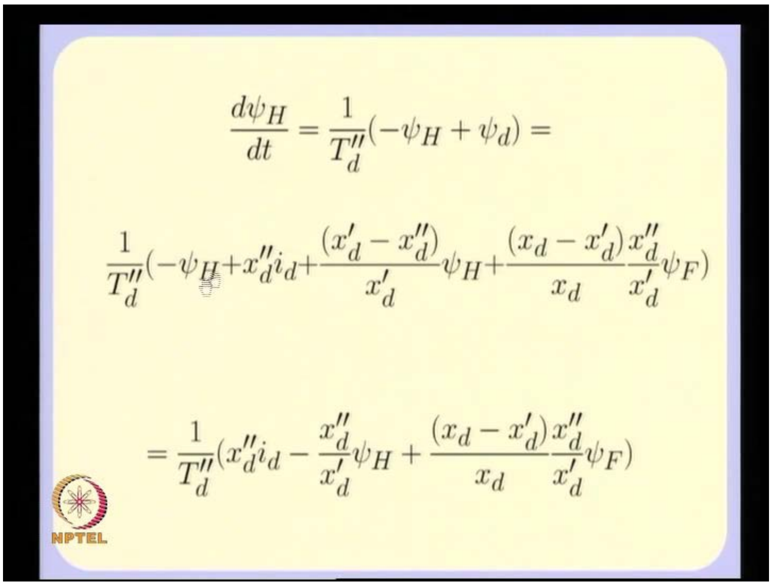
This main synchronous generator you will be giving E fd in per unit the per unit is what have I just defined 1 in case you get open circuited voltage equal to the rated value under rated speed conditions. Now, the synchronous generator equations once you solve that is you numerically integrate the differential equations you will get all the fluxes psi F, psi H, psi G, psi K, psi d, psi q and from this you can also get i d, i q and so on. Now the exciter excitation system model requires you to tell what i f is the field current is now, the field current is then we will normalize and then use this model this IEEE model which we have got now what is the value of i f (Refer Slide Time: 551:39) the field current. Now, if you use the synchronous generator model which I have defined sometime back. So, I will just show it you (Refer Slide Time: 51:50).

(Refer Slide Time: 51:54)



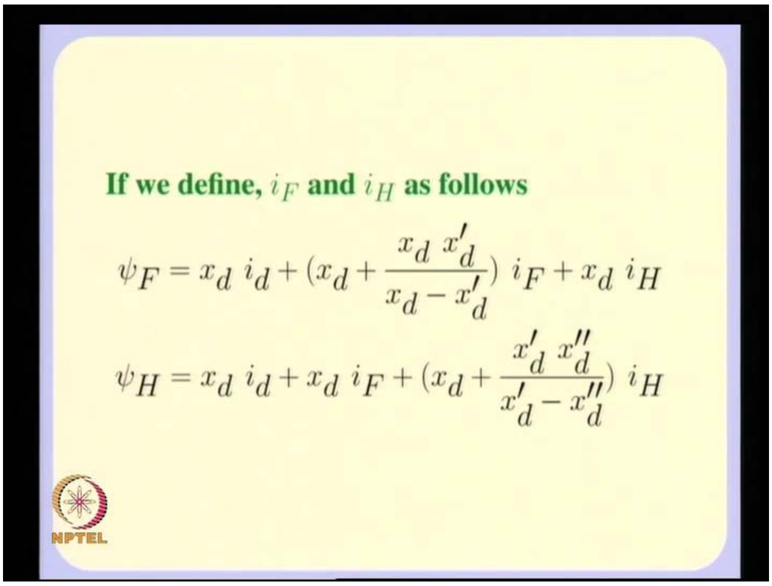
This is the d axis model in per unit which we have learnt in the previous class.

(Refer Slide Time: 51:58)



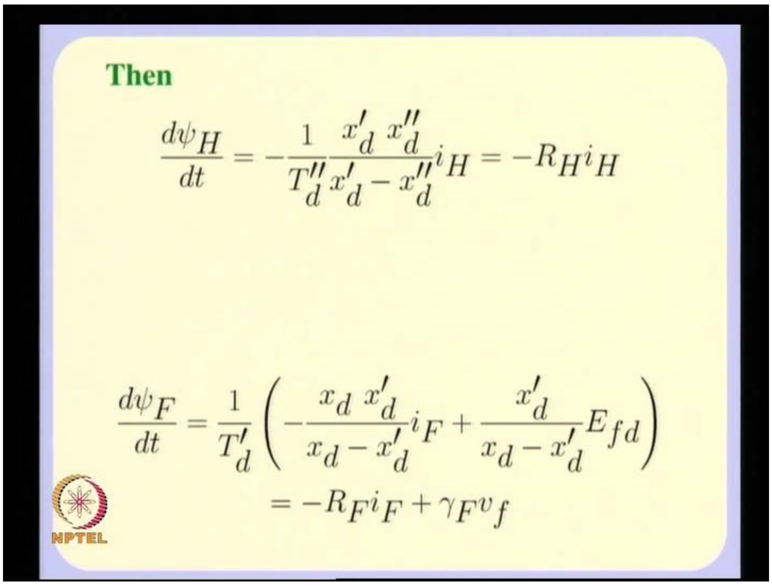
With this is something which we can rewrite by replacing psi d by the relationship the 3 rd relationship here, which is an algebraic relationship. So, if I substitute this relationship in this and this equation what I get is this. So, I am writing this d psi H by dt purely in terms of psi H i d psi H and psi F. Now, this yields this particular equation similarly, the d psi F by dt equation can be obtained in or rewritten in terms of i d and the state psi F and psi H in this particular manner.

(Refer Slide Time: 52:49)



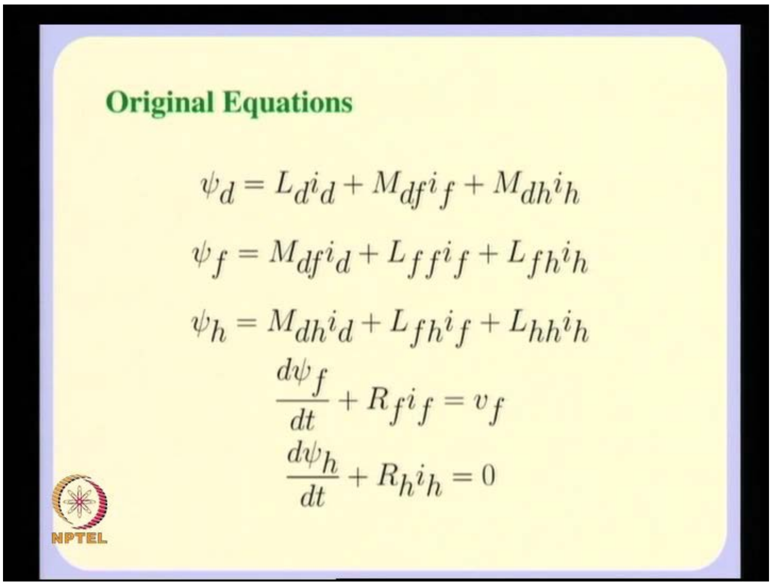
Now, if I define two currents i upper case F and i upper case H as follows. So, it is in fact, suppose I define it in this fashion.

(Refer Slide Time: 53:04)



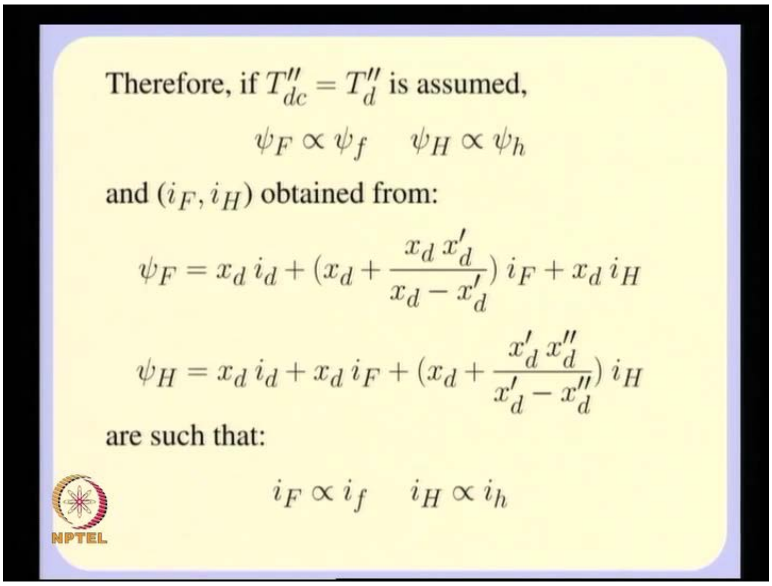
It is easy to see that you get equations which look like this now, what is the significance of this particular set of equations?

(Refer Slide Time: 53:18)



The point is that if you recall the original equations for the fluxes and damper winding fluxes, and the field winding fluxes were these I mentioned sometime back that psi upper case F and psi upper case H are related to the actual field fluxes and field the damper winding h damper winding fluxes by some transformation but, that relationship was never actually defined.(Refer Slide Time: 53:48) But if you look at these equations along with this it looks very very familiar to these original equations. So, what it follows we do not do very rigorous proof of this, but if you assume T dc double dash is equal to T d double dash.

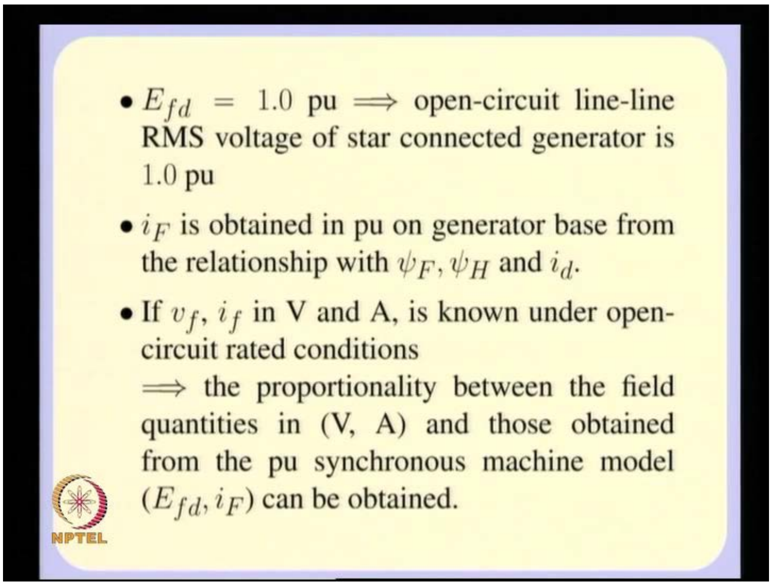
(Refer Slide Time: 54:04)



In that case, it is clear that what we have called is psi capital F or psi psi upper case F is actually proportional to the field flux and psi capital H is proportional to the damper win yes damper winding flux. And the i f and i h obtained from the following equations are such that i f and i upper case F is proportional to the field current and i upper case H is proportional to the damper winding current.

So, although in the earlier lectures I did not actually give you any physical significance of the psi capital F and psi capital H fluxes it can be seen that in fact, with this assumption that T dc double dash is equal to T dc T d double dash. In fact, these states are actually proportional to the original flux and h damper winding states you have not really done a rigorous proof, but by just looking at the nature of the equations we can infer that.

(Refer Slide Time: 55:16)



E fd is equal to one per unit implies the open circuit line to line RMS voltage of a star connected generator is one per unit i F is obtained in per unit on generator based from the relationship with psi F psi H and i d this something we have discussed just sometime back i f and i h obtained from psi F and psi H.

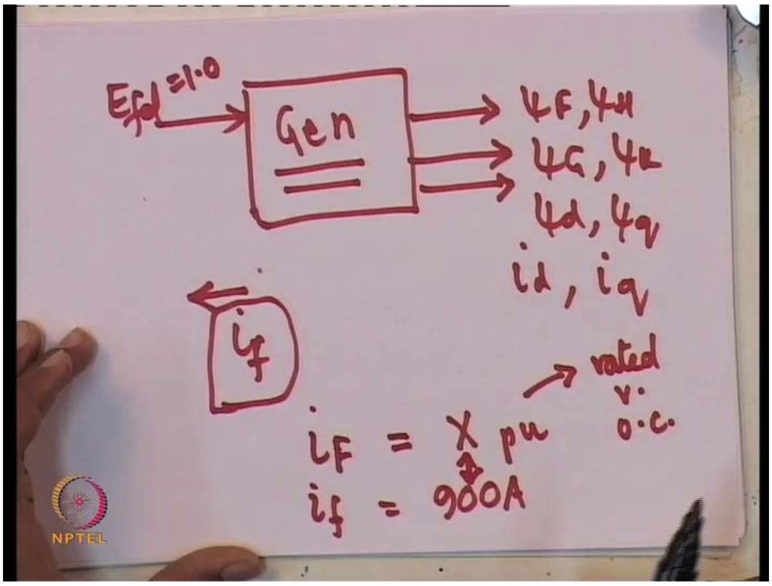
Now, you will of course, I a you obtain i a F in per unit on current on the generator current base. Now, when I mean generator current base its nothing, but a m V A base of the generator divided by the voltage base of the generators. So, you will get i F in per unit now, the question is that whenever, you want to use it for your static excitation model or for any other excitation system model if you want the field current in Amperes, you need to know the mapping between or the proportionality constant between i upper case F and field current in Amperes that is i lower case f.

So, one other ways you can get this mapping very easily is to see, you know if you know v f and i f in voltage volts and Amperes under open circuit rated conditions that is if I am running the machine at rated speed and I have got the voltage equal to the rated voltage that is one per unit at the generator terminals. And I know the v f and i f under that situation in that case effectively, I have got the proportional proportionality constant which I am looking for because, you can using the per unit model compute i f in per unit i upper case F in per unit you can compute E fd in per unit. Now you know what v f and i f is such that leads to this.

So, the proportionality between the field quantity is in volts and Amperes the actual field currents and voltage is in volts and Amperes; and those obtained from the per unit synchronous machine model can be obtained. So, you know the relationship this proportionality between i upper case F in per unit and the field current in Amperes. So, this can be easily got if this additional information is given that is the voltage the voltage field voltage and the field current under rated open circuit conditions if it is given to you you can get this mapping.

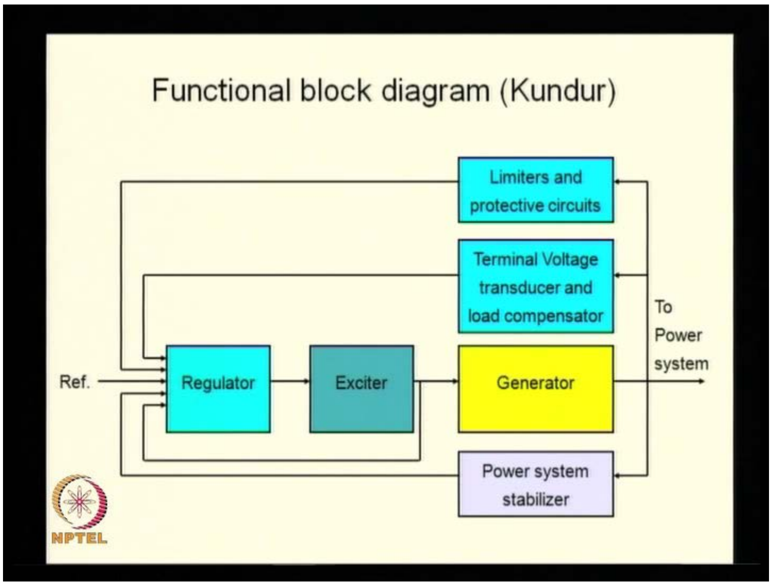
So, it is not a very tough task to actually get the field current in Amperes under rather situations as well because i f can be obtained in per unit from the basic synchronous machine model and then you know the proportionality constant. So, you can actually get the Ampere value of the field current as well.

(Refer Slide Time: 58:11)



So, if I know that i a f if you look at what I am writing here i F suppose, comes out to be X per unit when we get rated voltage under open circuit conditions X per unit and if I know that the actual field current in i f is 900 Amperes, then I have actually got a mapping between i f and i f this i capital F in per unit and i f in Amperes. So, I know what you know effectively I know the i f in Amperes, and then I can normalize it as I mentioned sometime back and then (Refer Slide Time: 58:57) use this model this IEEE model with this either typical or actual values these are the typical values assuming that E fd and i f are in fact, normalized.

(Refer Slide Time: 59:12)



So, this is one thing you have to keep in mind, we now move on to the control system associated with the exciter. The exciter and generator are in fact, what is known as power apparatus they are power apparatus the excitation system as I mentioned sometime back needs to be controlled you know there is a usually a closer look control system.

Exciter the exciter is convenient to control also because it contains basically a control rectifier which can be controlled by a low voltage signal so, the the block which does this known as a regulator. The primary function of an excitation system is to regulate the voltage at the terminals of the generator which otherwise would very very substantially with loading or during transient conditions.

So, that is the main reason why you need to have an excitation a excitation system regulator. Now a regulator has opposed to a exciter and generator is not a power apparatus is a low kind of a signal apparatus, it is a low low power apparatus you can say it is it is some kind of control system. Now we will basically try to I will try to tell you the block diagram are associated with this control system remove a control system is designed by us it is not a high power apparatus it is something which is designed by us to get appropriate control performance or transient performances.(Refer Slide Time: 1:00:45) Now, although I have said that regulations is the main function a exciter needs to be controlled. So, that it is stays within limits, so the limiters and protective circuits.

And you may also wish to use the leverage afforded by an easily controllable excitation system by modulating it in a certain way, so as to improve the transient performance. So, this is known as the stabilizing function. So, you notice that this power system stabilizer at the bottom of this figure, which is also used to improve the transient performance of a power system itself. So, to summarize we have discussed the the models associated we do not derived it, but discussed the model of the excitation power apparatus.

In the next lecture, what we will do is consider the dynamic models or the modeling of the other control systems associated with the exciter, which are essentially required to improve the dynamic performance of not only the exciter itself or the regulator itself. But of the power system as a whole of course, the interface of a generator to a power system etcetera we will have to wait for sometime what we will just discuss is the basic block diagram block diagrammatic representation of the typical excitation system controllers which are used in the next lecture.