Power System Dynamic

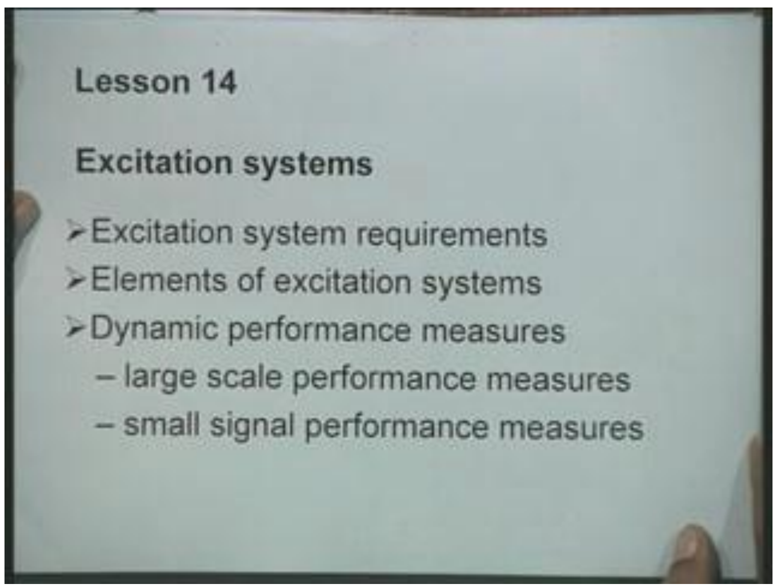
Prof. M. L. Kothari
Department of Electrical Engineering
Indian Institute of Technology, Delhi

Lecture - 14

Excitation Systems

Friends, today we will study excitation systems.

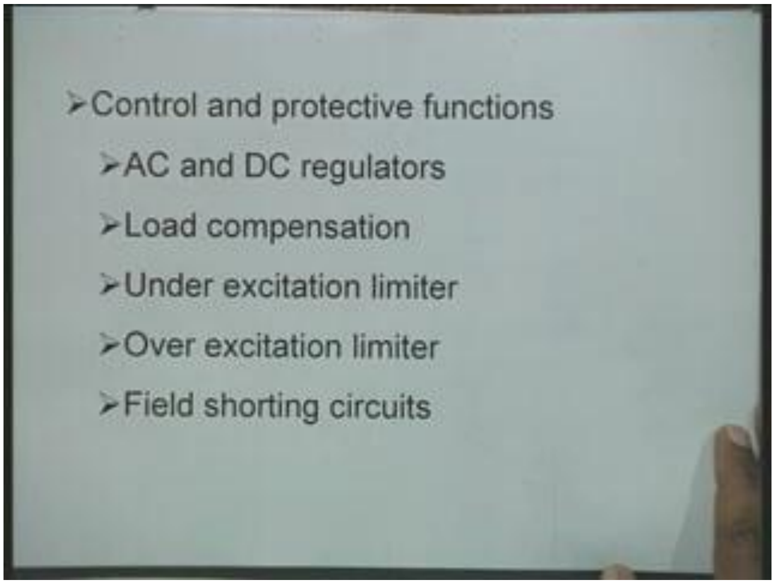
(Refer Slide Time: 01:18)



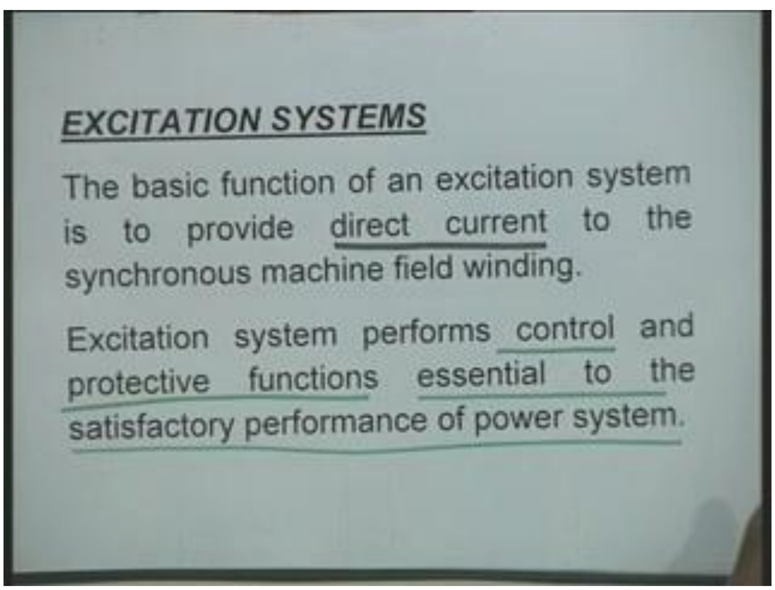
In this topic we will cover what are the excitation system requirements then what are the basic elements of excitation systems then the dynamic by performance measures dynamic performance measures are categorized into 2 categories large scale performance measures and small signal performance measures. Then we will discuss about the various control and protective functions which are provided in excitation systems the some of the control and protective functions which we will discuss are AC and DC regulators, load compensation, under excitation limiter, over excitation limiter and field shorting. Now we will briefly address to all these points.

So far the excitation system is concerned it plays a very significant role in the stability analysis of a power system and it is also very powerful control which can be used to improve the stability of the system. Here I would like to tell that ah over the years, over the years the different types of excitation systems for the synchronous generator have been developed. You know that we have in today our power plants, the DC excitation systems, AC excitation systems and static excitation systems and in AC you have brushless excitation systems and the static or stationary rectifier excitation system right. A variety of excitation system have been developed and these development has been have been possible with the development of the power electronic devices. Okay we will read into go into these details as we proceed across or proceed with, now first let us see the basic function of excitation system.

(Refer Slide Time: 01:45)

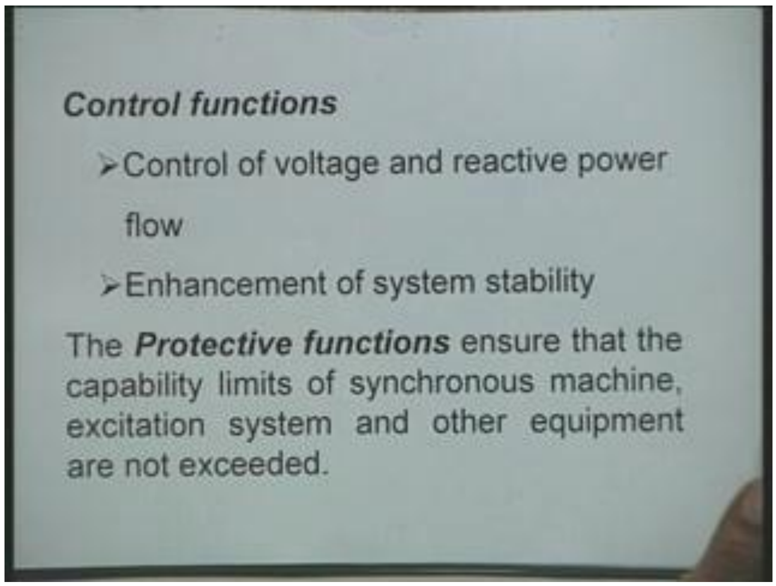


(Refer Slide Time: 03:42)



These are all it is known to all of you that the basic function of an excitation system is to provide direct current is to provide direct current to the synchronous machine field winding. This is a very simplest thing that in any synchronous machine right, we have to provide DC current or direct current right it operates. This is the main purpose of excitation system then the excitation system also performs various control and protective functions. We will see control and protective functions, these functions are essential for the satisfactory performance of the power system that is the modern excitation systems are provided with a variety of controls right and variety of protection functions, the very propose of providing these control and protection functions are, so that this excitation system can give you the satisfactory performance for the operation of the power system as a whole. The as I told you that there are two functions control functions and protection functions okay.

(Refer Slide Time: 05:13)



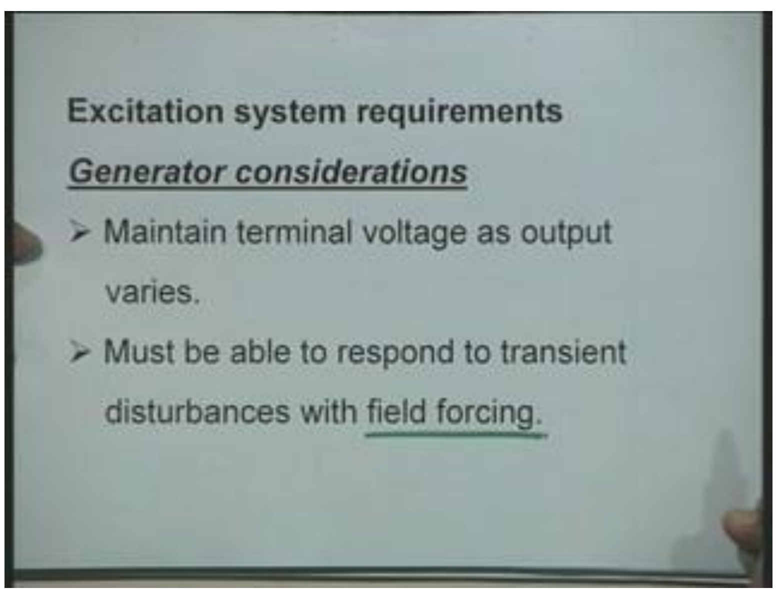
Now what are these control functions let us see, control functions are basically you can put at control of voltage and reactive power flow. In excitation system right we provide various controls so that we can maintain the terminal voltage constant under varying load conditions. I hope all of you aware of the capability chart of a synchronous generator where a synchronous generator operates operates in the given region in the pq plane, okay and this ah capability charge is decided from the consideration of over heating of the armature, over heating of the rotor circuits or field system.

Similarly, the small signal stability or stability considerations right therefore, any synchronous generator is required to operate within the capability chart. In addition to this the synchronous generator has ah certain short time capability also. So that under for a short time you can operate the synchronous generator to enhance the system stability right and we take advantage of short time capability of the synchronous generator, the short time capability is generally of the order of 30 to 60 seconds right and therefore, when I talk about the excitation system it has large number of controls right and these controls are provided primarily to the achieve these two goals, one is the control of voltage and reactive power flow, okay second is enhancement of system stability okay that is the excitation system can be appropriately controlled so that you can operate the system with larger transient stability limits. Okay that is called the enhancement of the stability of the system.

Then the protective functions, why do you require the protective functions? okay the protective functions ensure that capability limits of synchronous machine excitation system and other equipment are not exceeded that is you operate the system within the capability limit of the excitation, limit of the synchronous generator, limits of the excitation system right and any other associated equipment as I have just now mentioned that a synchronous generator has to operate within the capability limits and that limits are obtained in the form of a capability chart okay and this synchronous generator has a short time extra extra capability it can supply extra reactive power, extra real power but for a short time okay and therefore, our controls are so provided so that we can use the or we can take the advantage of this short time capability for improving the transient stability, long term stability, dynamic stability of the system.

Okay but we provide in addition to this control functions protective functions. So that in case any of the capability limit is violated right the protection functions will operate right and and keep this or operate in such a fashion. So that you operate within the capability limit we should not go outside the capability limit because any attempt of the system to go outside the capability limit means system is likely to be or generator is life is going to be affected. Okay therefore, these are 2 important functions which you have to look into all the time control functions and protective functions.

(Refer Slide Time: 09:17)



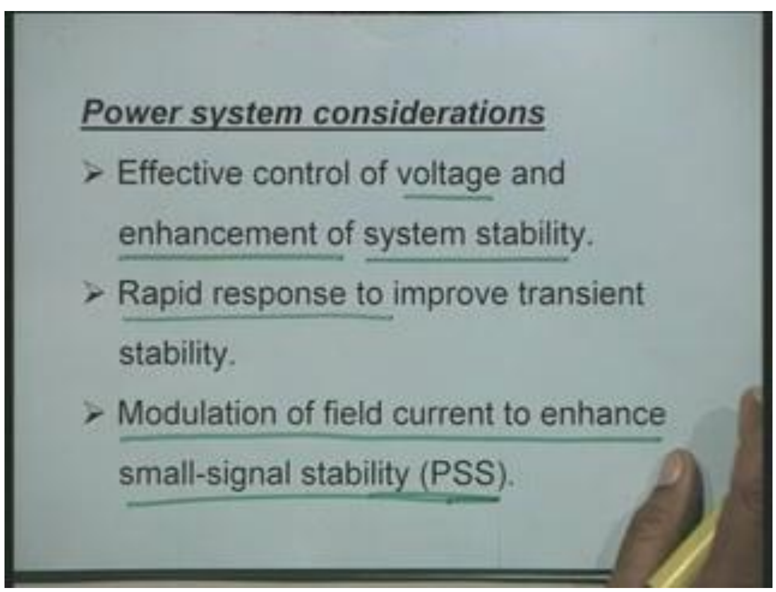
Now we we can look into the excitation system requirements from 2 considerations, one is the generator considerations from the consideration of synchronous generator and another is from the consideration of power system where synchronous generator is part of the large power system right and therefore, we will look into the excitation system requirements from the 2 considerations, one is generator considerations another power system considerations.

When you look into the generator considerations the main function of the excitation system is to maintain terminal voltage as output varies it has to automatically adjust the excitation current as the output varies and keeps the terminal voltage constant. This is one of the important requirements from the generator point of view second is that the excitation system must be able to respond to transient disturbances with field forcing.

Now this terminology is very important that is our excitation system should be such that such that whenever there is some transient disturbance okay and that particular following that disturbance if you want to reserve to field forcing field forcing means we apply a large voltage to the field winding of the synchronous generator so that more current can flow through field winding that is excitation current can be increased temporarily or for a short duration.

Now this field forcing capability is one of the important requirement of excitation system as you will see that that to have good field forcing capacity the ceiling voltage of the excitation system right the ceiling voltage when you design the excitation system it will have a high ceiling voltage.

(Refer Slide Time: 11:25)

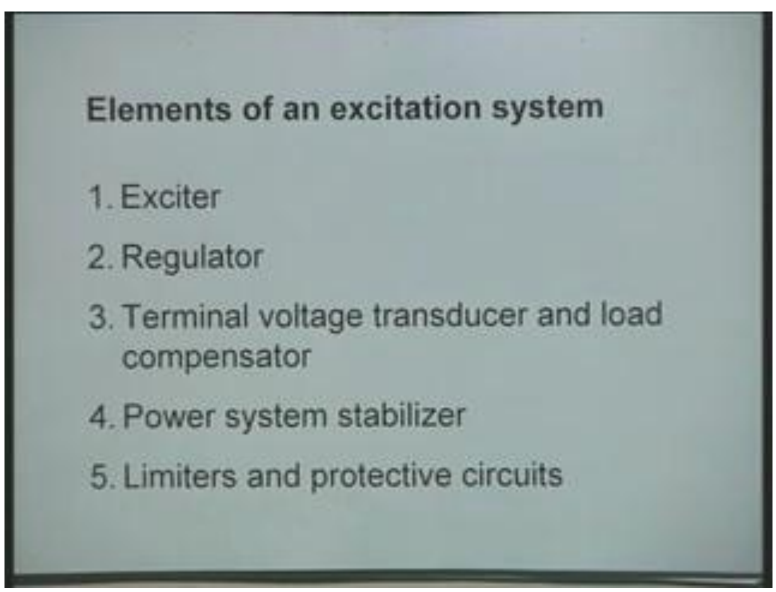


Now when you look from the power system power system considerations then the excitation systems which are provided on synchronous generator should be should have effective control of voltage and enhancement of system stability that is we should be in a position to control the system voltage by controlling the excitation system okay and we shall also be in a position to enhance the system stability. Okay, second is to achieve these goals its response should be high, rapid response, rapid response, so that you can improve the transient stability. Okay that we will talk subsequent in our subsequent discussion that how the rapid response or high response of the excitation system improves the stability of the system.

Okay but first we will understand what we mean by rapid response how we quantify the dynamic performance of the system okay. Then we should have a provision to modulate the field current to enhance small signal stability that is when the system is oscillating you know whenever there are some perturbations taking place right the oscillations are created in the system the system is never in steady state condition it is always in the quasi steady state condition because load changes are taking place continuously okay and whenever the load changes take place the generation changes the load change load changes and therefore in this process of generation changing the load right the system is in the dynamic condition okay and there are always small oscillations in the system when I say small oscillations magnitude of oscillations is small and the frequency is the low frequency oscillations right and to there is a necessity to improve the damping of these oscillations by providing power system stabilizers right.

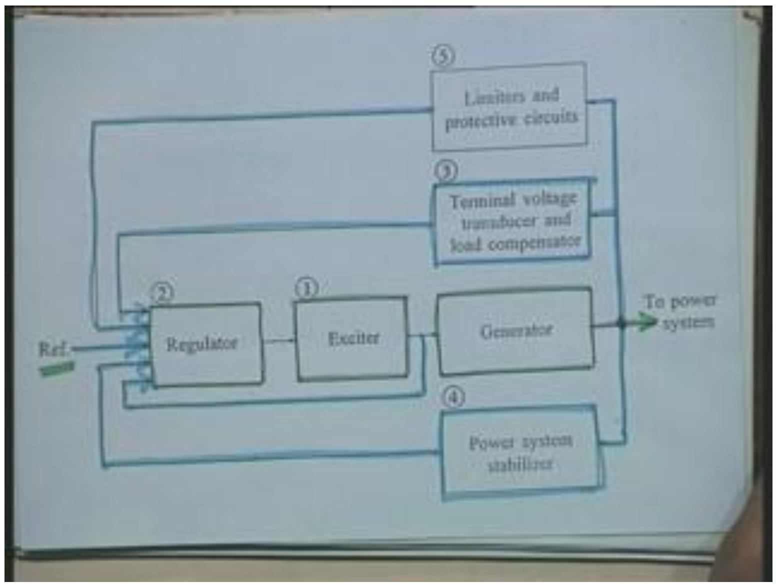
Therefore the power system stabilizers are provided in the excitation system to enhance the small signal stability therefore, the from power system consideration I can say it should have the capability to enhance transient stability for improving or for achieving this goal its response should be high right and then we should have the facility or capability to modulate the excitation system. So that we can improve the damping of the low frequency oscillations, okay now these are the requirements from the power system considerations. Now let us see what are the main elements of an excitation system?

(Refer Slide Time: 14:31)



The elements of an excitation system can be listed as exciter, regulator, terminal voltage transducer and load compensator, power system stabilizer, limiters and protective circuits that is if broadly if I look into the complete excitation system then the various building blocks of the excitation system can be put as the exciter there is a regulator there is a terminal voltage transducer and load compensator, a power system stabilizer and limiters and protective circuits okay.

(Refer Slide Time: 15:29)



Now this is the block diagram which shows how these elements are interconnected or form the complete excitation system. Now this is the main block where you can say this is our generator, a synchronous generator this synchronous generator is connected to the power system, okay the field winding of the synchronous generator gets its current from exciter that is the exciter supplies the field current this is your exciter then the field the the output of the exciter is controlled by providing a regulator this is the regulator.

You can see here that regulator has number of inputs here. I will explain but one of the biggest or very important important building block of the excitation system is a regulator because here we are not talking about the exciters only we are talking about excitation system okay. As I have told you that the primary function of the excitation system is to is to provide DC current to the field winding of synchronous generator, okay and we provide various controls and protection system so that we achieve the requirements of the system from generator considerations and from power system considerations.

Now first, let us look at actually at we maintain the terminal voltage How do we do it? we sense the terminal voltage from the synchronous generator terminals. Okay now this is the block which shows the terminal voltage transducer and load compensator I shall separately talk about load compensator but you can understand that when I want to regulate the terminal voltage of synchronous generator right we sense the terminal voltage okay.

Now since the synchronous generators terminal voltage is AC terminal AC voltage it may be 11 k_v may be 16 kv depending upon the design of the machine therefore, at this point the voltage is stepped down okay and then it is rectified and we get a DC signal which represents the terminal voltage of the synchronous generator. Okay that is why what I used is the terminal voltage transducer that is you step down the voltage you rectify and bring down to a level which can be used for the purpose of control okay and this signal which is the which represents the terminal voltage or a function of terminal voltage and load current because we will be showing about the load compensator also this is fed to the regulator, this is one of the input signals that goes to the regulator. Okay the second block which I have shown here is the limiters and protective circuits okay.

Now the limiters will also sense the terminal voltage load current okay and looking and it is going to process these signals current and voltage which are sensed from the terminal of the machine okay and then we will decide whether the synchronous generator the operating condition is within the limits or not in case it is going outside the limit it will take appropriate action, again the action is taken through regulator. Therefore, this this signal which is coming from the limiters and protective devices also is fed to the regulator.

Then you have one feedback loop around the exciter this this loop is generally we call this the excitation system stabilizer that is here you sense the output of the exciter okay and in case you do not have this feedback loop then the exciter itself may become unstable because once you have a close loop control system right the stability is a very important requirement and therefore, you will find that there is one feedback loop right that loop is called excitation system stabilization okay and that again operates through regulator and the last feedback loop is through power system stabilizer. You can see this power system stabilizer again this power system stabilizer takes its input signal from the generator terminal, the input signal to the power system stabilizer is generally the speed deviation.

When a synchronous generator speed deviates from synchronous speed this division is sensed another signals which have been tried are the deviation in the power output instead of sensing the speed deviation you can sense the deviation in the power output, the delta pe right or deviation in frequency also has been looked into it or a combination of these quantity, these signals okay.

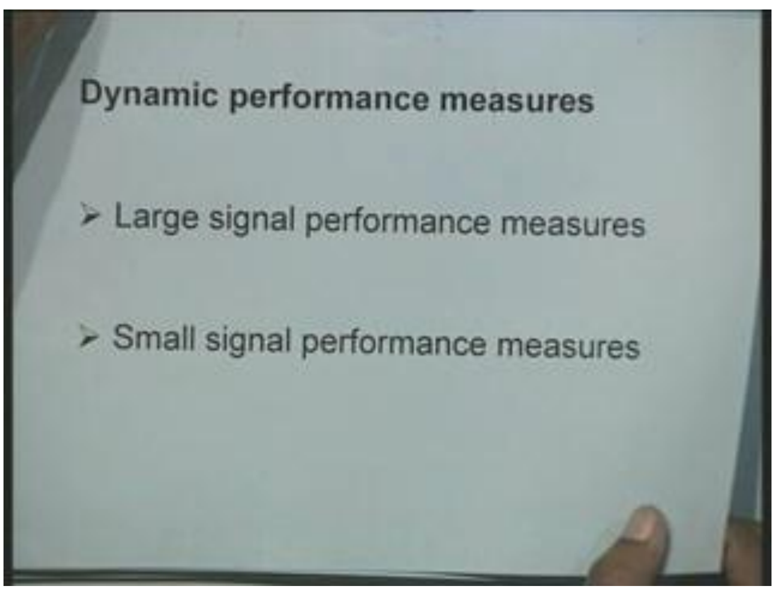
Now this power system stabilizer is basically an auxiliary controller it will operate only during the dynamic conditions not during the steady state conditions okay and this also operates through the regulator and any regulator basically basic function of the regulator is to is to perform all the required functions and maintain terminal voltage constant and therefore, we have a reference therefore input signals which come to the regulator okay they come through the terminal voltage transducer and load compensator, a voltage signal which is function of terminal voltage and also the load current, a properly processed we have to discuss in detail about this block then limiters I have told you that we , we have to see that synchronous generator always operates within the operating limits whether actually you want to use the short term capability then still the limits are decided.

Okay we have to operate within the short term and long term operating limits of the synchronous generator. Then this power system stabilizer is to damp the low frequency oscillations which are normally provided or which happens because or which exists low frequency oscillators exist because of because of the perturbations which are taking place continuously in the system and this oscillations need to be damped they should not increase they should not grow, otherwise system will become unstable. Okay now these are the basic building block of a complete excitation system okay is it okay or any doubt.

See see these these functions are provided in a complex manner, complex manner but limiters have they just they just monitor magnitude of the voltage okay terminal voltage magnitude of the current which is flowing through a synchronous generator, magnitude of the power which is output, real power, reactive power not only one quantity they will monitor so many parameters because when I talk about the capability limit of the synchronous generator then we look into the pq, pq plane okay for a given value of p there is certain value of q possible.

Okay therefore pq plane we have to we have to maintain this is there therefore this is not only sensing the terminal voltage but this limiter will sense all other parameters also and not this block diagram is just to give you basic features of the excitation system but it senses not only the the generator parameters but excitation parameters also exciters will also not go beyond its operating limits right.

(Refer Slide Time: 25:47)



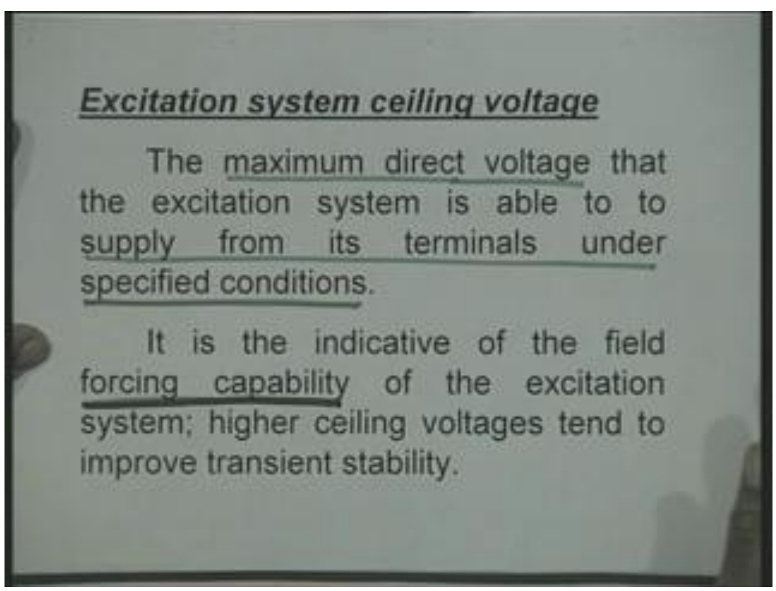
Therefore this is a it limiters means you just look at the movement limits are crossed it will take action the action may be that it may even trip the synchronous generator from the system suppose it feels that now the synchronous generator is going outside the capability limit then these limiters can even trip the synchronous generator. Okay they are very very I say actually that ah a very complex control protective functions are provided and our main consideration is that we take the best out of the synchronous generator right from the system point of view and at the same time its its safety is safe guard is ensured okay, is it okay. Now we will look into some basic performance measures.

Here as I have stated that the excitation system control should be such that we are in a position to improve the stability of the system. Okay and to improve the stability of the system, we have to look into what are the desired characteristics okay and and therefore we look into the dynamic performance measures, when the system is under dynamic condition what are the performance measures okay.

Now this performance measures are further classified into 2 categories, the large signal performance measures and small signal performance measure that is when the system is subjected to large disturbances okay we have to achieve certain performance measures related to large disturbances then whenever the system is subjected to small perturbations, okay then we have to basically look into the the stability of the system okay.

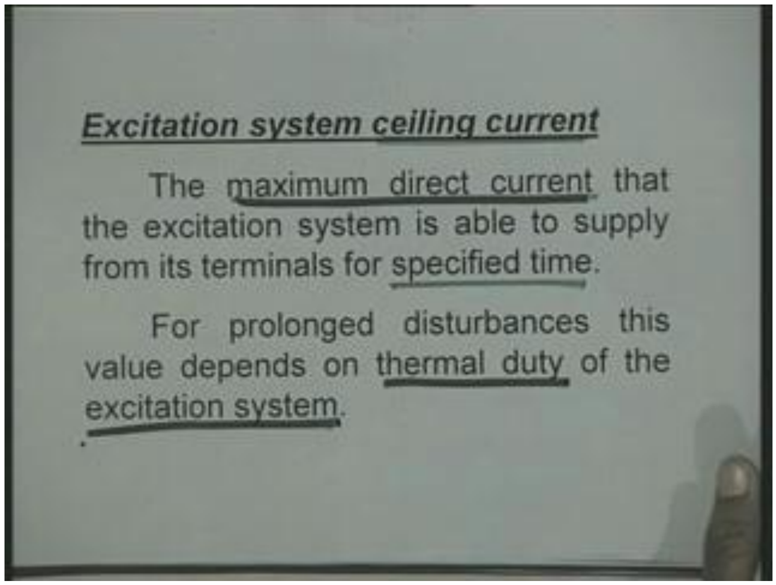
Now large signal performance measures in the sense that suppose a 3 phase fault occurs in the system or a important transmission line trips right then the system is subjected to large perturbations and at that time how the system should behave and how are our excitation system and excitation control should behave right therefore, we want to quantify that what should be the dynamic performance measures of such a system. Now related to the dynamic performance measures there are some basic definitions, we have to clearly understand.

(Refer Slide Time: 27:42)

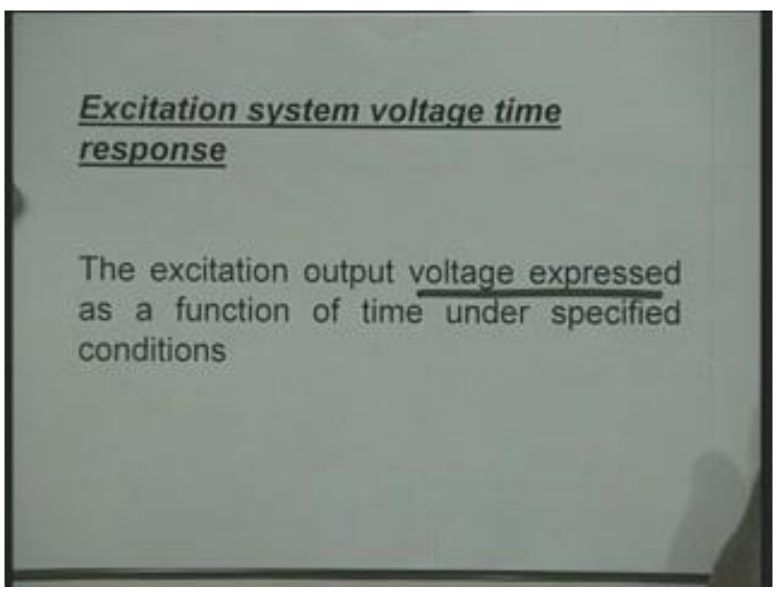


The excitation system ceiling voltage is the maximum direct voltage that the excitation system is able to supply from its terminals under specified conditions. It is the indicative of the field forcing capability of the excitation system; higher ceiling voltages tend to improve transient stability. This is a very important factor that the excitation systems which have higher ceiling voltages right will have a higher field forcing capability and resulting transient stability limit will be high, the next term in the excitation system ceiling current.

(Refer Slide Time: 28:27)



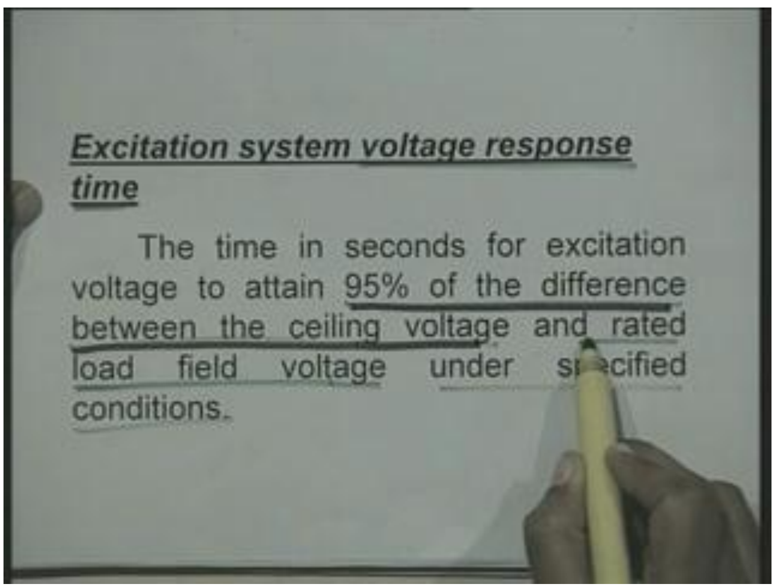
(Refer Slide Time: 29:15)



The maximum direct current the maximum direct current that the excitation system is able to supply from its terminals for specified time right therefore, time is a constant here for a short time it can supply current more than the rated value for prolonged disturbances this value depends on thermal duty of the excitation system. In typical excitation systems the ceiling current is of the order of 1.6 times the rated current. The next important term is the excitation system voltage time response.

The excitation system output voltage expressed as a function of time under specified conditions that is if I create certain control conditions so that the excitation system system causes increase in the terminal voltage and this increase is when it is plotted as a function of time right then that graph represents the voltage time response of the excitation system right. Suppose I give given example actually that suppose you make a step change in the reference voltage right, the terminal voltage of the synchronous generator is going to increase and if you plot voltage as the function of time right then that curve is the voltage response curve. Now to quantify the voltage response, we define a voltage response time.

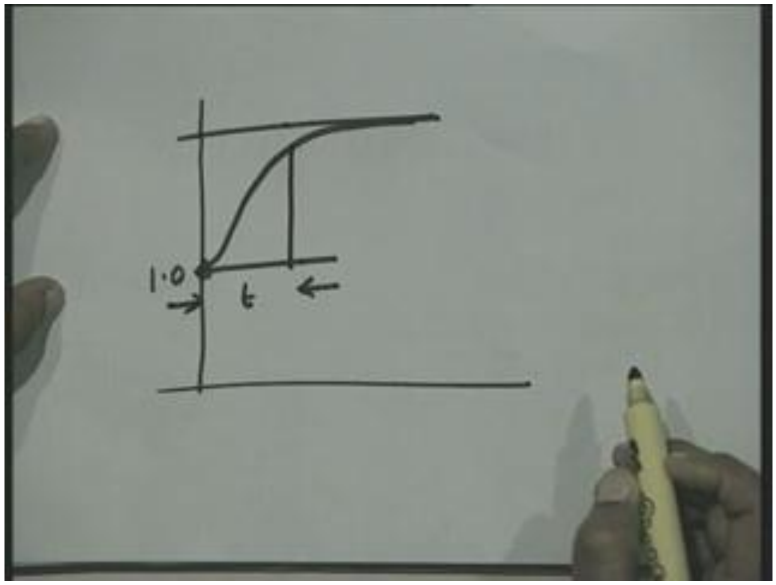
(Refer Slide Time: 30:30)



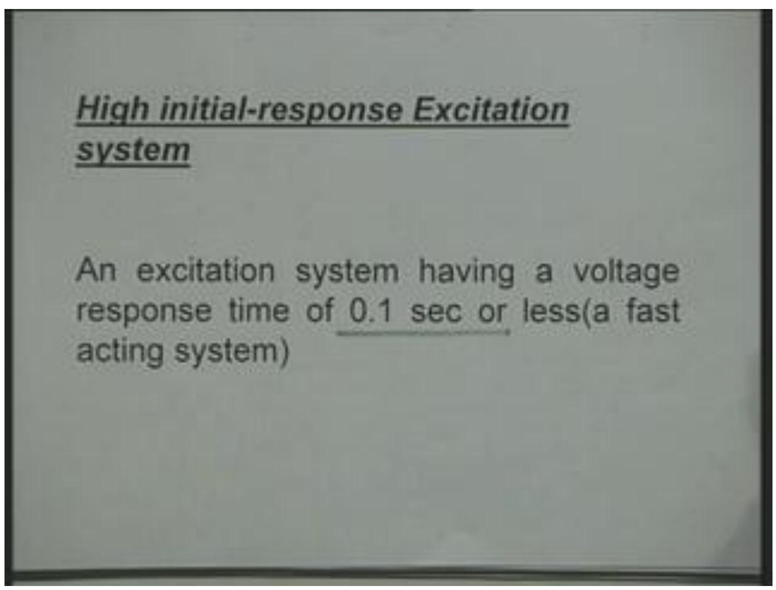
The time in seconds for excitation system voltage to attain 95 percent of the difference between the ceiling voltage and the rated load field voltage under specified conditions just to illustrate this suppose we this is the rated voltages let us say it is 1.0 if I create terminal conditions or the voltage regulator operate in such a fashion, so that voltage is made to increase in this fashion and let us say that this is the ceiling voltage right, this is the ceiling voltage.

Then you find out the difference between the ceiling voltage and the rated voltage and the time which is required to attain 95 percent of this value. Let us say this time that is this is the 95 percent of the difference between the ceiling voltage and the rated voltage and this time t right, the time t in which actually the the voltage will rise from no rated value and it will attain 95 percent of the difference between ceiling voltage and the rated voltage this is the voltage response time.

(Refer Slide Time: 30:57)

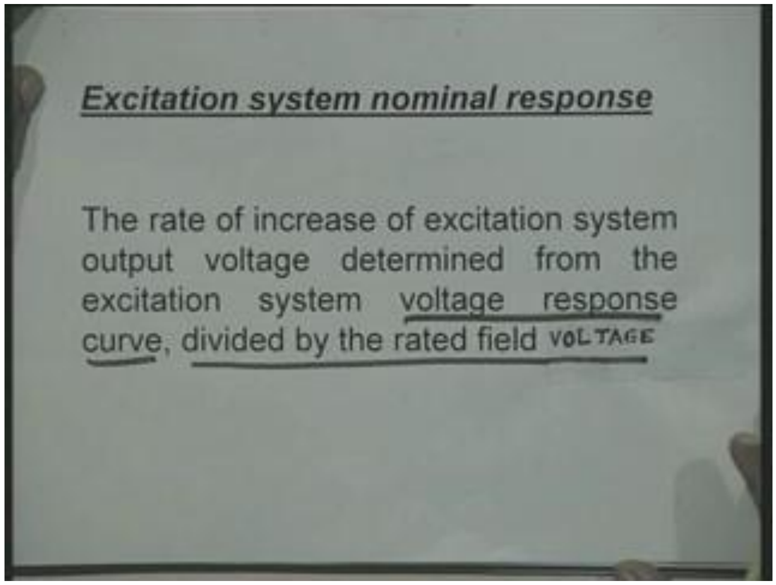


(Refer Slide Time: 32:32)

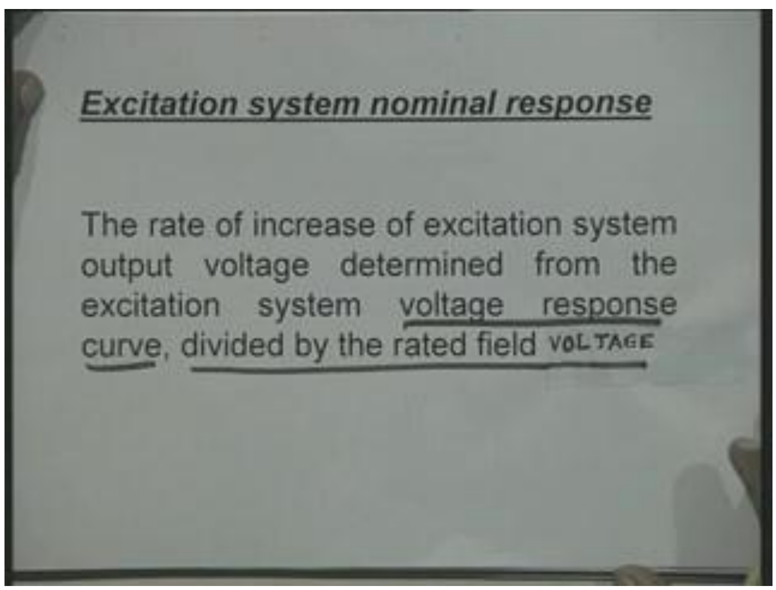


Now at the modern excitation systems have very high response and we do specifically specifically characterize the excitation system as high excitation systems whose response time is .1 second or less than .1 second right that is you have variety of excitation systems okay and those excitation systems whose response time is .1 second or less than .1 second are characterized as high response excitation systems.

(Refer Slide Time: 33:20)

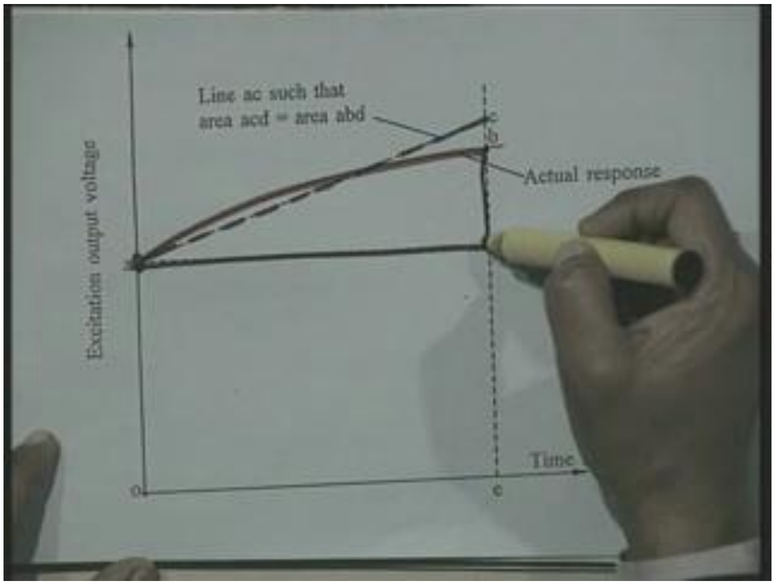


(Refer Slide Time: 33:10)



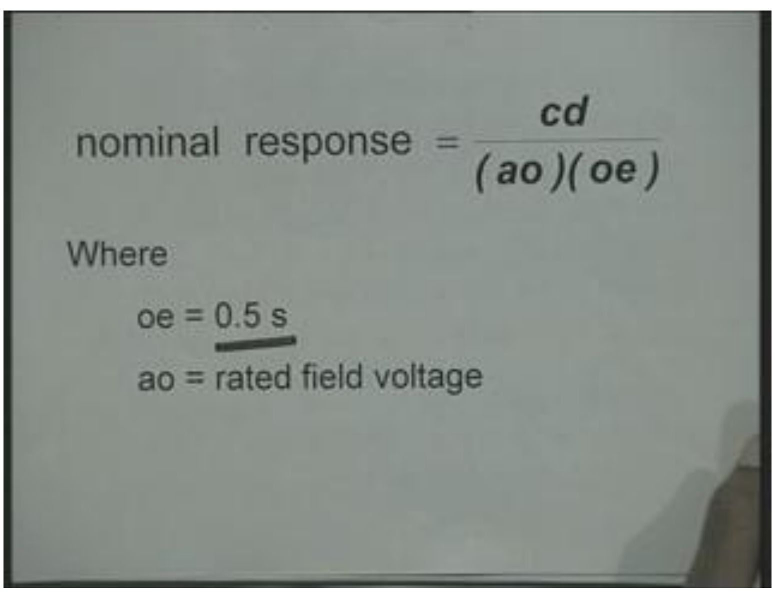
Then we also define a term which is called nominal response of the excitation system or excitation system nominal response. Now to understand this excitation system nominal response, let us look at the voltage response of an excitation system that is here in this graph we are operating so that the excitation system output voltage is represented by oa and the terminal conditions are so created so that the voltage increases and follows this graph of this curve right.

(Refer Slide Time: 33:28)



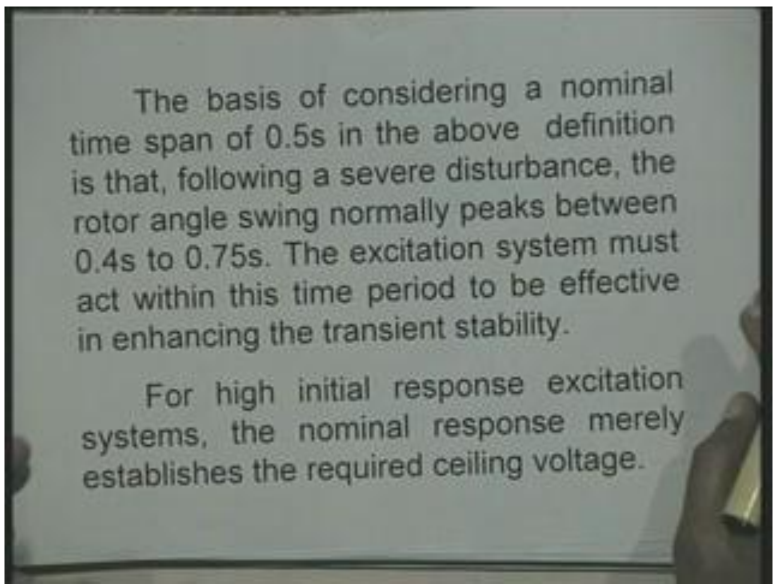
Then on this time axis we choose a time which is equal to .5 second or this is represented by the line ad okay then we draw a line a straight line passing through this point a in such a fashion. So that the area of this space that is this area the area abd is equal to the area of this triangle this acd that is you are this is the actual response curve.

(Refer Slide Time: 35:15)



Okay you draw a straight line such that such that this area abd is equal to the area acd that is the acd is the area of the triangle then the slope of this graph represents the nominal response and it is expressed as the slope here, the slope of the um curve is you can see the slope the slope is cd divided by ad. You get this slope and you divide this slope by the rated voltage okay. So that you get nominal response now there is a reason for choosing this time .5 second for defining the nominal response the whenever whenever actually the system is subjected to the large disturbances right and the the the swing curve which we plot the peak value of the swing curve normally occurs in the range in the time range of around .4 second to .75 seconds and of course this these figures are not very rigid but when we subject a system to a large perturbation or large disturbance like a 3 phase fault.

(Refer Slide Time: 36:06)

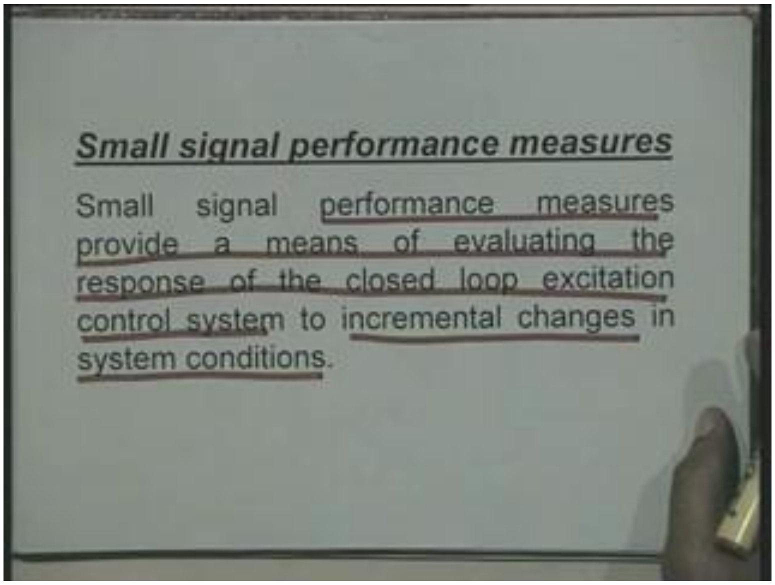


Okay then the swing curve when you examine right the for a stable system the swing curve will attain its peak value in a time something like .4 to .75 second and in case we the excitation system is to come to rescue the system and improve the transient stability then it must act within this time. In case suppose it is slow and it acts after this peak is out right then you cannot do anything right therefore, the the .5 second is the time which is being chosen and used.

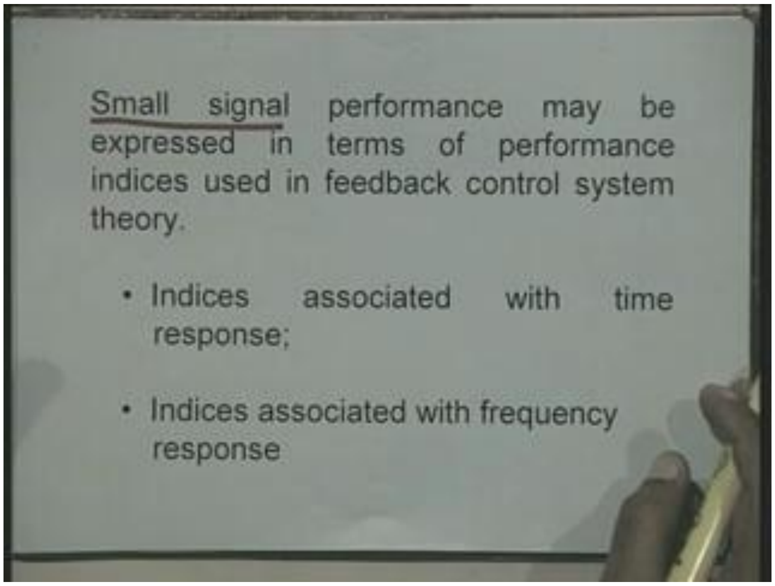
Now we will talk about the very important performance measure that is small signal performance measures till now what we discussed was the certain definitions which are related to large disturbance performance measures or large signal performance measures. The small signal performance measures provide a means of evaluating the response of the closed loop excitation system control to incremental changes in the system conditions that is here these measures which we will discuss right these measures help us in understanding the behavior of the excitation system when small perturbations take place right.

Now when we want to examine the performance of the excitation system when small perturbations take place there we use a linear model that is the system is linearized around the operating condition. Once we use a linear model we can use the linear control theory to examine the behavior of the closed loop control system or the excitation control systems okay.

(Refer Slide Time: 37:09)

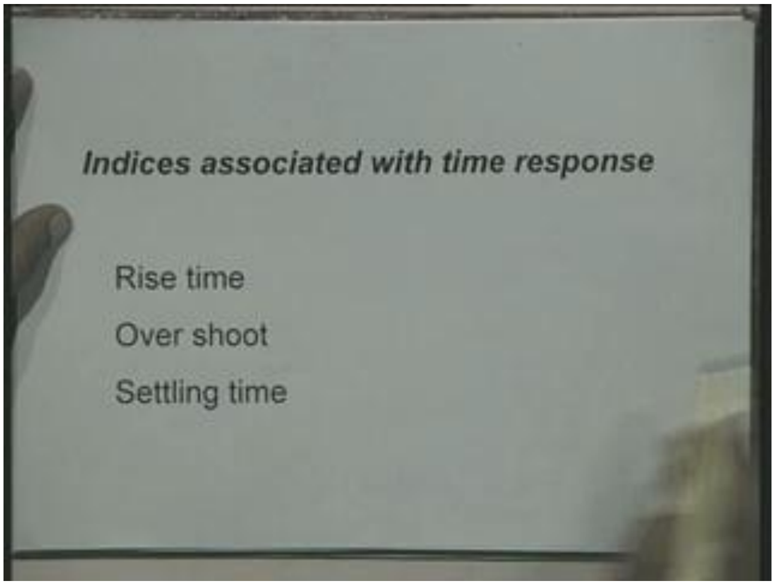


(Refer Slide Time: 38:32)



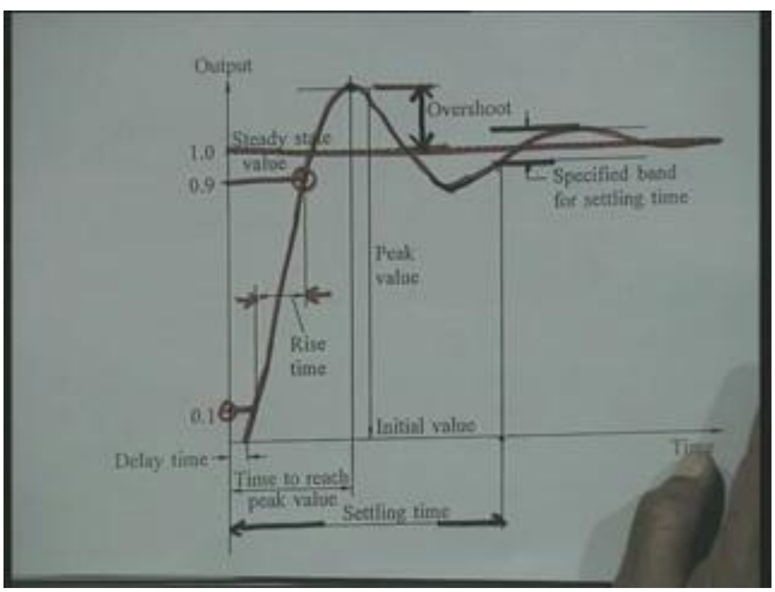
The performance measures for small signal behavior or the small signal performance measures can be categorized or can be put in two ways one is the making use of the time response right that is the indices associated with time response, another is the indices associated with the frequency response that is we talk about the performance of the excitation system following small perturbations either making use of the time response of the system or frequency response of the system okay.

(Refer Slide Time: 39:19)



The indices associated with the time response are rise time over shoot and settling time, rise time over shoot and settling time these are the indices indices with which we can we can quantify the performance of or small signal performance of the excitation system. Now to understand these terms, let us look at the at the step response of the excitation system.

(Refer Slide Time: 39:57)

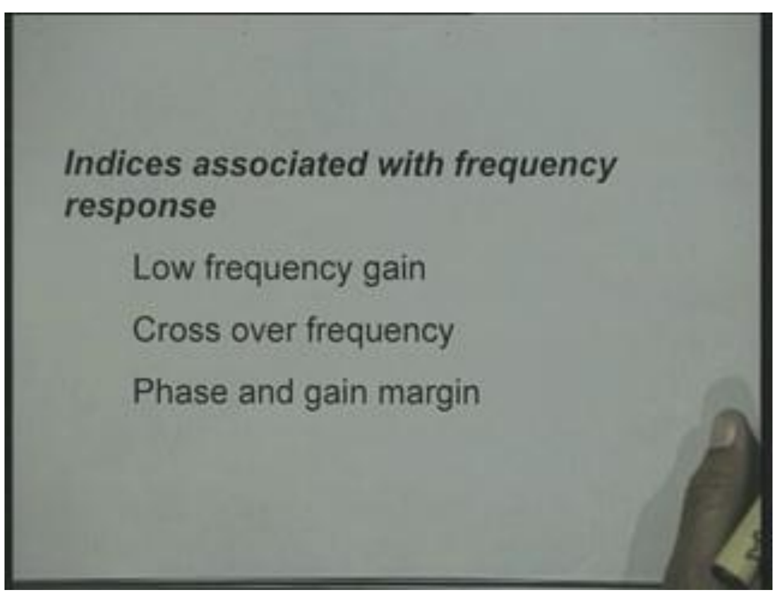


Now this step response is plotted under no load condition for a closed loop control system that is when the generator is not loaded under no load condition right. We obtain the step response, now this this graph or this curve represents the step response of any closed loop system right in the series this is step response okay now if you have given a step input equal to 1 per unit that is unit step input then this is the steady state value that is under steady state condition right the output of the systems will attain a value equal to 1 because we have given step input or unit step input okay.

Now the method of defining this rise time, rise time is that you look at this 10 percent value that is .1 per unit value look at this on the graph the time corresponding to the .9 per unit value. Okay and then the time required for the for the response to rise from .1 corresponding to .1 to .9 right, this time is called the rise time. The lower the lower the value of this rise time the response is fast. Okay the another measure is the overshoot, you can just see here this is the overshoot actually this is the steady state value the this is the positive peak and therefore overshoot is defined by this value. Okay therefore, this is another you know measure for for characterizing the dynamic response or small signal response and third is the settling time that is the time in which the time in which the response settled to the steady state value within certain specified limits because you will find that this response is going to have some oscillations.

Okay and the moment it comes within these limits right then this time is called the settling time that we are not to wait till it attains the value equal to one the moment it comes in this band which is the permissible band right that is the specified band for settling time right. Now this band is again ah different actually but normally we can have 5percent plus minus 5 percent band therefore once it reaches within plus minus 5 percent.

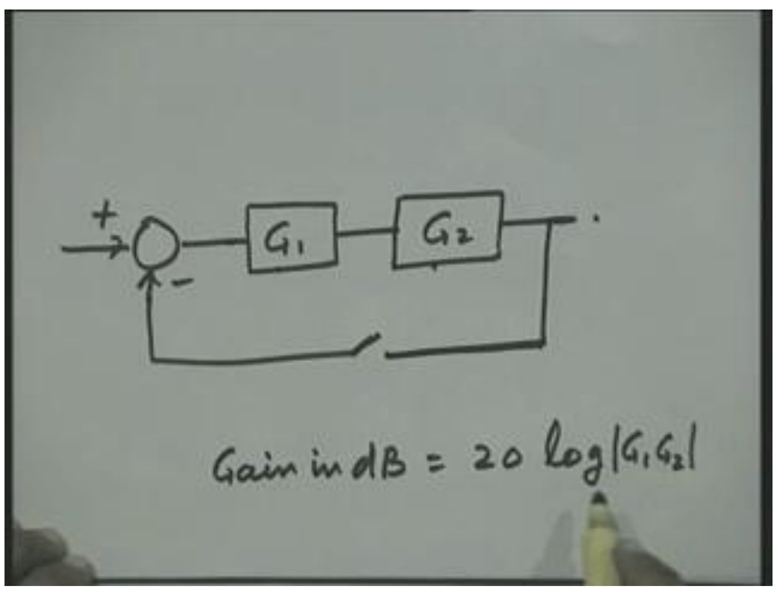
(Refer Slide Time: 43:36)



Okay then this is the therefore these are the three important parameters which characterize the small signal performance of the excitation system the another indices which are used making use of the frequency response of the excitation system. The indices associated with the frequency response are low frequency gain, low frequency gain cross over frequency and phase and gain margin. These are the three important parameters before I talk about these three parameters I will like to highlight here that since it is a closed loop control system. Therefore, stability and the degree of stability these are of importance okay and another thing which we need is actually in the closed loop control system we want the low steady state error steady, state error should also be low because suppose I want to regulate the terminal voltage right then I want to regulate the terminal voltage within a small band and that that the steady state error will depend upon again the characteristic of the excitation system and as you will also see actually that these requirements are conflicting.

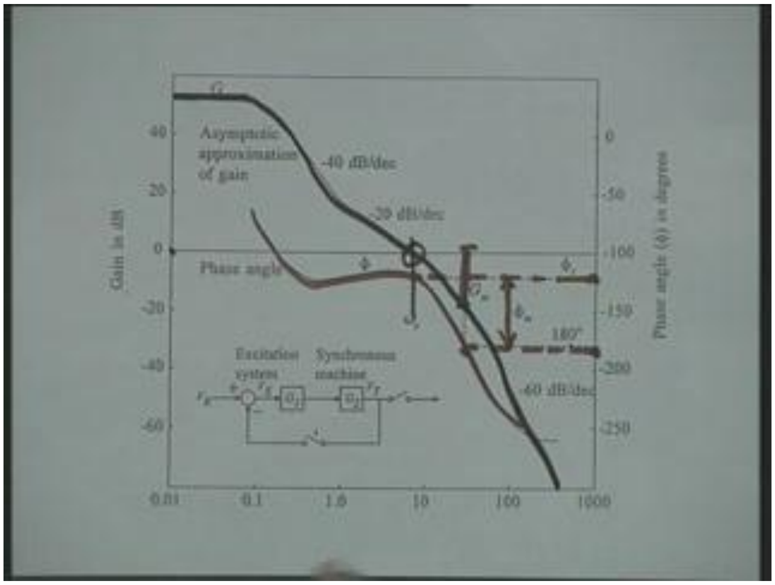
Suppose you want to achieve achieve a very low steady state error then the stability may have to be compromised right therefore these are the conflicting requirements and in the frequency response these are the 3 important indices the low frequency gain crossover frequency gain and phase and gain margin. Now here here that need to be listed this let me see.

(Refer Slide Time: 45:35)



See the any control system any control system can be put in this form. Okay that is the $G_1$and G_2 are the transfer functions right and now what happens is that when we are interested actually noting the frequency response of this system, we plot the frequency response of this 2 transfer function G_1into G_2 right G_1 into G_2 or you can call it actually the open loop transfer function open loop transfer function.

(Refer Slide Time: 46:43)



Now this graph shows shows the frequency response of open loop transfer function of a typical system. Okay now when we plot this graph, we plot 2 curves one is the gain another is the phase angle we plot phase angle and gain, the gain is plotted in decibel that is gain in dB. Now the gain in dB is defined that is gain in dB is equal to twenty times the log of G_1 G_2 that is this G_1, G_2, G_1 G_2 is the transfer functions of the open loop system okay and G_1 and G_2 both are function of Laplace transform s right and when we plot the plot the frequency response characteristic of the system then on x axis we mark frequency frequency and on y axis we mark the gain in dB okay this is the very standard terminology used and since G_1 and G_2 both are function of frequency right therefore magnitude and phase angle of this open loop transfer function vary as the frequency changes .

Now this graph you can just see this is a typical graph this is a typical graph I hope it is visible, a typical graph is shown like this that is this is the gain this is plotted in dB. Okay and this is the frequency and then you will see actually that these are plotted actually in the logarithmic scales the frequency is also marked in log of omega n. Okay now the low frequency gain is shown here actually when the frequency is low this is the gain right. The higher the value of this low frequency gain right the steady state error is going to be low right because when the system is under steady state condition right then at that time the system is not the omega becomes 0, we can say right therefore, at very low frequencies are actually when omega is 0 steady state condition this gain will represent the steady state error higher this value, lower will be the steady state error. Then this is the there is a frequency here at which this gain becomes 0, this is called crossover frequency, this is the crossover frequency.

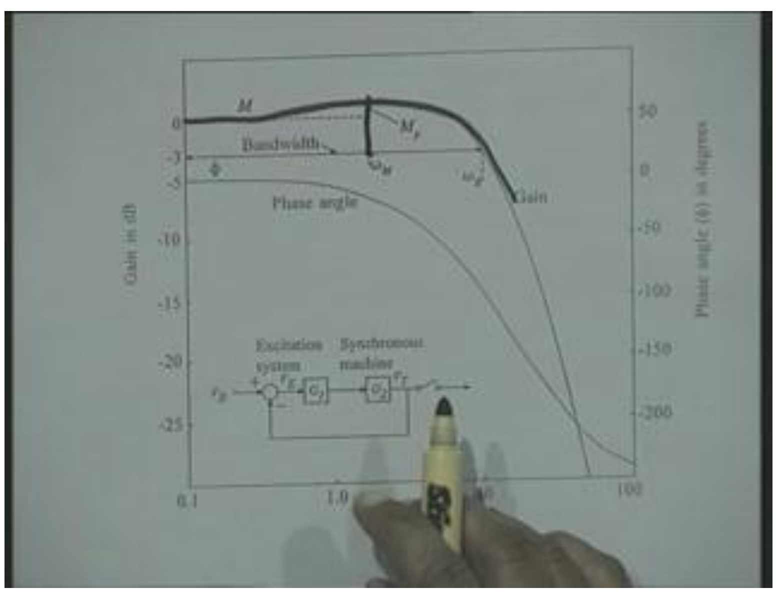
Now similar to similar to this graph on the same diagram, we plot the phase angle characteristic now typical phase angle characteristic is shown here like this. Now on this axis we have marked the phase angle in degrees okay. The frequency at which the gain becomes 0 is called crossover frequency and higher is the crossover frequency better will be the response. Okay now when we talk about the gain margin and phase margin now to understand what the meaning of this gain margin is, you look at the phase characteristic or phase angle characteristic.

Now you can see here actually that when this phase angle for this particular frequency the phase angle has become minus 180 degrees. Okay now corresponding to this phase angle that is at this frequency I find out what is the gain, for example for this phase angle is minus 180 degrees the corresponding gain is this and this gain is called gain margin, gain margin this this quantity is called gain margin.

Now then we also specify what is the phase margin to specify the phase margin what we do is that we look at the crossover frequency what is the phase angle of the system at the crossover frequency, what is the phase angle of the system and let us say phi c is the phase angle at the crossover frequency and this difference this 180 minus phi c this represents the phase margin, this quantity that is the phase angle corresponding to crossover frequency and the phase and this one eighty degrees phase angle right, this difference is called phase margin.

Now for any control system higher the value of gain margin and higher the value of phase margin higher is the stability of the system okay now we can see one very interesting thing here that suppose suppose we want to increase the low frequency gain. Now for increasing low frequency gain means the I increase the gain setting of the this block G_1 or G_2, okay now when you increase this gain setting means this graph will go as a whole up that this graph to make this quantity more this graph has to be shifted up.

(Refer Slide Time: 54:30

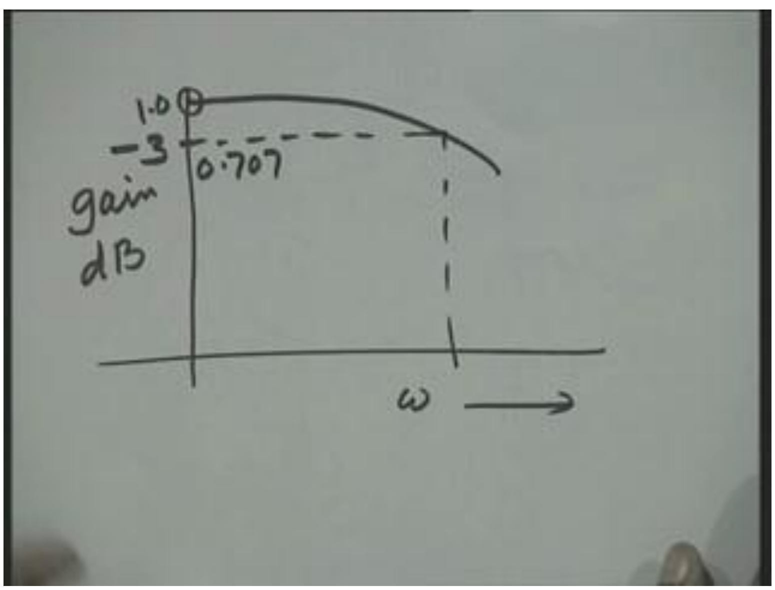


Now when you are doing this shifting in this graph up both this term this G_m will reduce that is the gain margin will reduce and phase margin will also reduce and this very clearly shows actually that when you are trying to tune one parameter right the other it has a detrimental effect of other parameter, other aspects. Okay and in field actually the AVR tuning is important ah exercise to be performed where the gain setting and other parameters are to be set so that we obtain a certain amount of phase margin, gain margin and actually the desired steady state error.

One more important parameter they are not one but they are two more parameters which are also important which are obtained obtained from the frequency response characteristic and here we plot we plot the frequency response of the closed loop system that is G_1, G_2 right this loop is closed that is the feedback loop is closed and the the the generator is disconnected from the system that is generator is not loaded under unloaded condition. Okay now the graph which is plotted here is one is this graph that is the gain gain, you can see this is graph for gain like this another is the phase angle. Okay now the peak value of this graph that is generated by M_p, let us say Mp is the peak value which occurs at a frequency omega M.

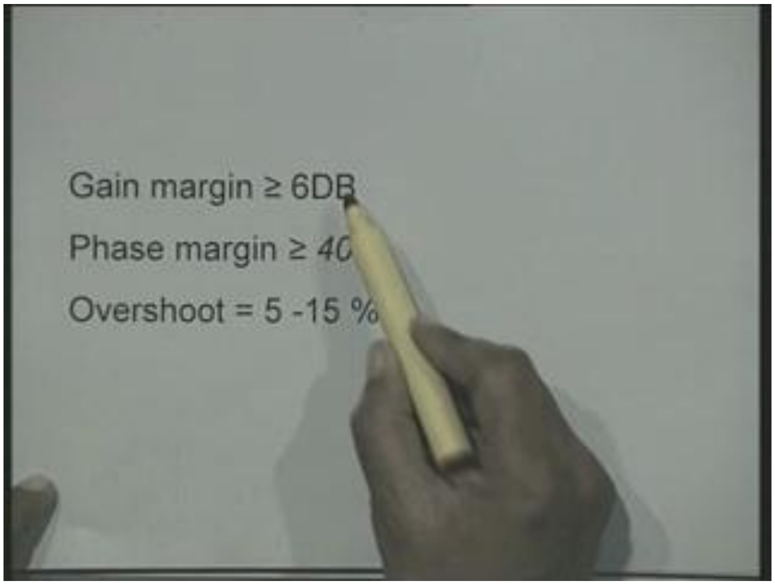
Now this peak value also represents the overshoot in the time response it has a relationship between the it is a relationship respect to the time response if this peak value is high then the overshoot is also going to be high, the another term which is used is the bandwidth bandwidth.

(Refer Slide Time: 55:54)



Now to understand this bandwidth if we plot a graph that is omega versus the gain in dB right. Let us say for a typical I am not showing this overshoot anyway that is like this then in case suppose I instead of plotting gain in dB let us say the actual gain, let us say this is 1.0 and the frequency at which this drops to 0.707 right then this frequency is called bandwidth and if I plot the graph in terms of gain in dB, gain in dB then this point will become 0 because if I if I take the log of 1 to the base 10 it becomes 0 right and this will become minus 3that is on this in the same graph if I plot gain in dB then this is 0 this is minus 3 and therefore this the bandwidth is determined by plotting the okay by plotting the frequency response of the closed loop system okay.

(Refer Slide Time: 57:22)



For any particular system to have good characteristic, the features are the gain margin should be 6 dB, phase margin should be about greater than 40 degrees, greater than equal to 40 degrees and overshoot should not be more than 5 to 15 percent that is overshoot is around 5 to 156. Now let me conclude here that we have discussed the excitation system requirements performance characteristics, the performance characteristic related to large disturbances and small disturbances. For small disturbances, we have discussed the time response as well as the frequency response. Thank you!