Power System Dynamics and Control
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Lecture No. #31
Load Modeling

One of the interesting things which we were discussing at the end of the lecture, the previous lecture was that the rate of you know magnification or increase of the unstable oscillation predicted by Eigen analysis is somewhat different from what is obtained by our simulation. Now, simulation we see a larger rate of change .So that of course was not a very surprising, in fact the reason why that probably what is was true was, because we used Euler method for numerically integrating the equations which tends to show an unstable system to be even more unstable than it actually is.

So, that is one of the reasons why the rate of growth in the simulation seem to be much much higher than what we saw in the from the Eigen analysis. Just to you know show you the results again I will do that in a short while from now. So, today's lecture of course, we will continue with our discussion of what this behavior the simulation of the A V R automatic voltage regulator, regulated synchronize generator which is connected to an infinite bus, but we will probably have more time, and we can now shift in this particular lecture to another topic which is the the issue of load modules.

So, there is another component or you know class of components which need to be considered which are the loads themselves. So, what we will do now in today's lecture was the new topic of course, would be a load modeling which we should begin with in this particular lecture. We will of course, discuss some of the remnant issues in our discussion of the automatic voltage regulated synchronous generator.

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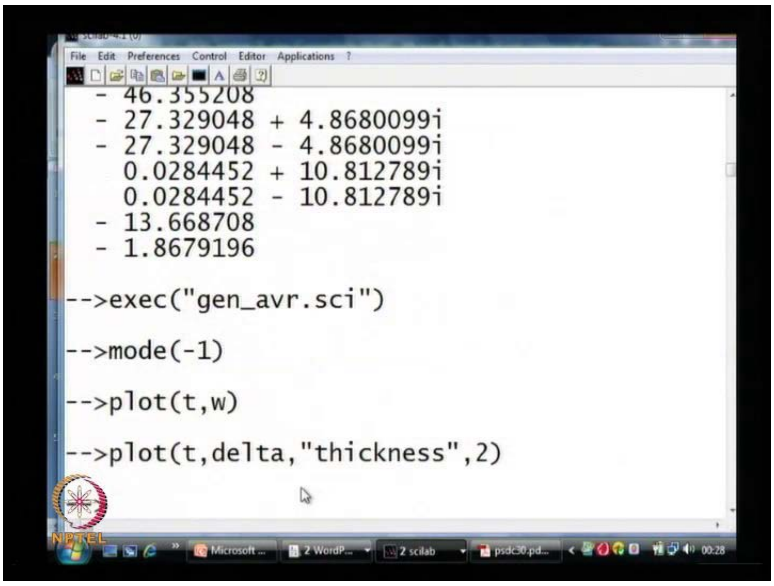

Now, to see the results as I spend some time back, again I will run a (( )) program which really display's the behavior which I was talking of.

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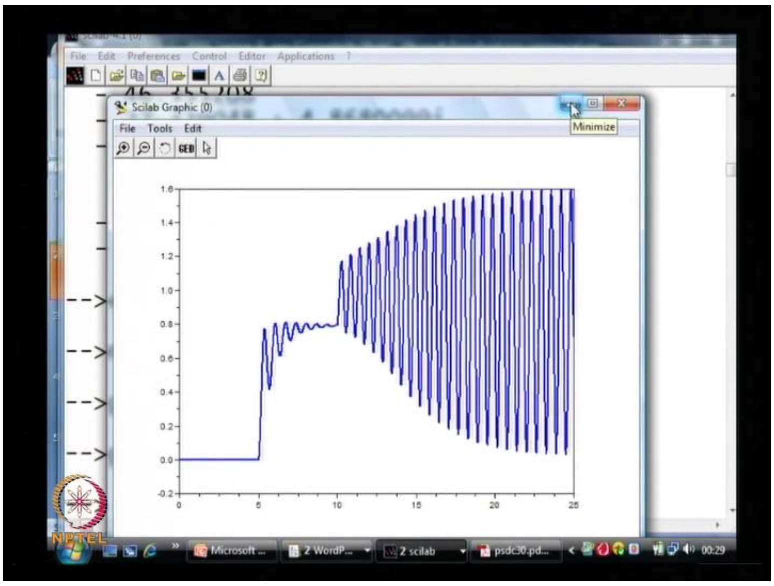

So, what I was telling you in the previous class was the operating point corresponding to the torque being equal to one per unit appears to be unstable, because the system when given a step change in mechanical torque does not seem to be going and settling to an operating point, there is a growing oscillation.

The rate of growth of the oscillation is much higher than that was that was predicted by Eigen analysis. Remember, here we are giving a step change is in mechanical torque and in some previous simulations you also saw step changes in the voltage reference of the automatic voltage regulator, remember that the final operating point to which it has to settle to must be small signal stable in order that the system go and settle to that operating point, this is not what is happening in the case of the operating point corresponding to mechanical torque being one per unit. In fact, the operating point corresponding to t m is equal to point 5 is. In fact, stable.

So, you will find that this first disturbance which in which we gave a step change of mechanical torque from 0 to 0.5 was indeed stable the system was kind of settling down to an operating point, but the second disturbance which takes the system to a new operating point, is does not settle down because the new operating point is not small signal stable. So, this is what really we were we were discussing in the previous lecture. So, just to make things even more clear.

We just look at the same disturbance with change in. So, our first disturbance of mechanical power resulted in the electrical power settling to point five that was the first step change, the second step change taking it to one does not seem to settle because the new operating point of electrical torque equal to the mechanical torque equal to one is not the stable one ok.

So, that is what we saw in the previous class now when we did the Eigen analysis, we will do the Eigen analysis around the operating point corresponding to this what we saw then was indeed the system is not small signal stable because the real Eigen value has got a positive real part, the issue we were talking of was of course, that the rate of growth of oscillation of the oscillation as observed in the state variables etcetera was not as there, was much higher in the simulation than was predicted by Eigen analysis.

So, that is one point which we discuss and we attributed that to the numerical method i (( )) to actually try out other methods like trapezoid rule etcetera to see how much, what is the rate of you know the magnification of the oscillation

Whether it correlates better with the Eigen values so, this is something I leave to you as an exercise there are a few more points which we need to examine if you look at the plot of power we will just do this again, we will have to simulate it because the variables have got cleared. In fact, it is taking a very long time because I have used Euler method with a very small time step. So, this is not the thing to do in real programs.

Now, one more thing you notice is it that is oscillation not just growing with time if it was a exponential growing oscillation as was predicted by Eigen analysis, we would eventually find that this just blows up in this fashion and goes off to infinity practically you know.

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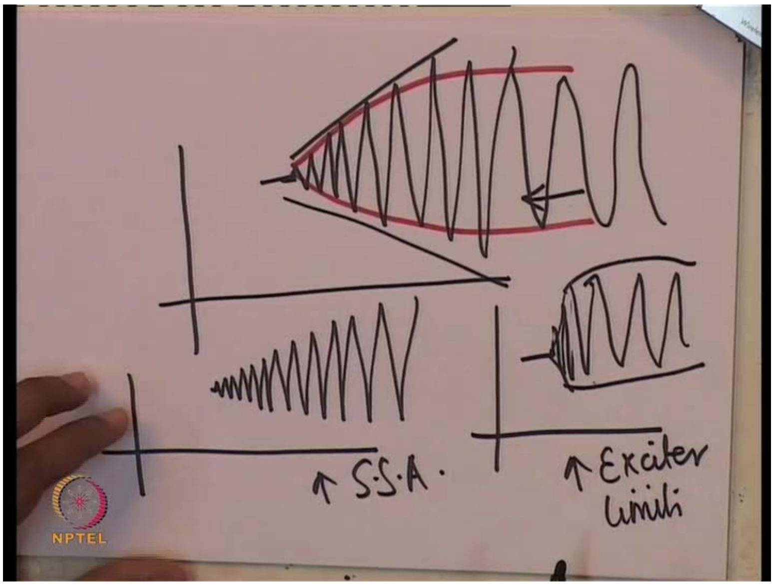

So, this is what our you know your Eigen analysis predicts, but of course, Eigen value analysis remember is of a linearized model it is not valid for large disturbances.

So, after a point you know our linearized analysis is not valid in the sense that as the oscillation grows the deviations from the equilibrium become large and it is no longer correct to assume that our oscillation should behave the way it is predicted by Eigen analysis. In fact, what we find actually is it is kind of the oscillation is kind of saturating to a steady oscillation.

Now this is an interesting behavior which cannot be explained by the linearized analysis, it is purely a non-linear phenomena and what you see is that this is something which is obtained only by simulation it something we cannot predict by Eigen analysis.

In fact, the origin of this itself is an interesting enough dynamical phenomena. In fact, if you look at the field voltage what we see if the field voltage seems to also oscillate and it is clipped to a certain value, why is it clipped? because the static excitation system has got limits. So, that is the reason why it is getting clipped, now in case I do not have this clipping action.

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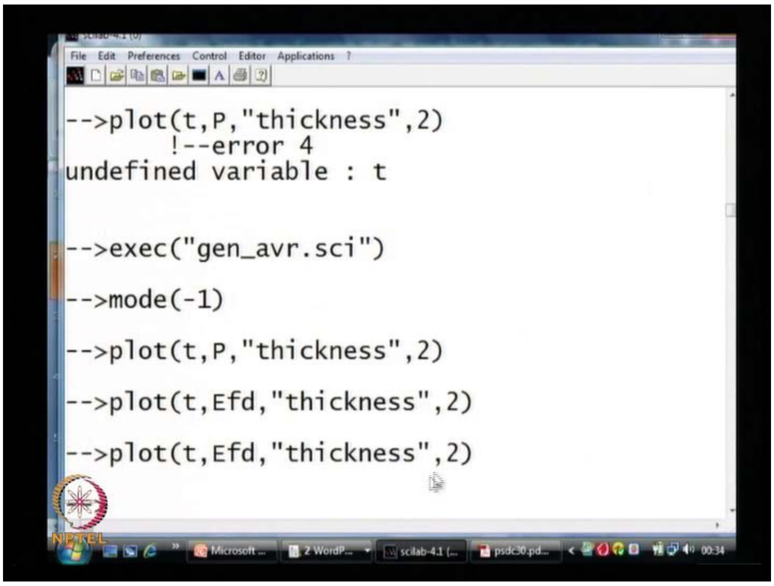

So, if I remove the limiters in the model in that case what happens? Now if I do that, so I will just do that for you what I will do is I will make the limits very large which.

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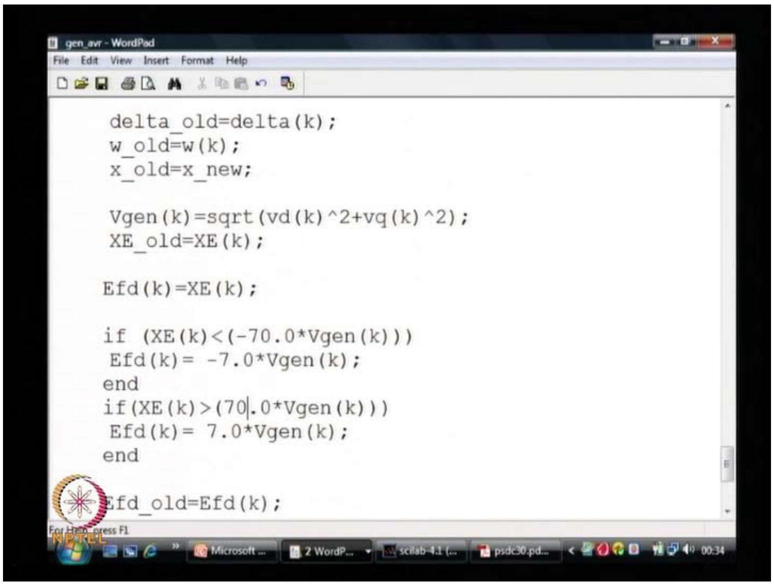

In fact, practically disables the limits may instead of seven times the terminal voltage e f d is limited to seventy times this is of course, a very large value. So, for all practical purposes this excitation system is no longer limited. So, I re run the simulation without, with the excitation system unlimited having unlimited voltage field voltage capability and in that case this is what I get, we will plot the phase angle.

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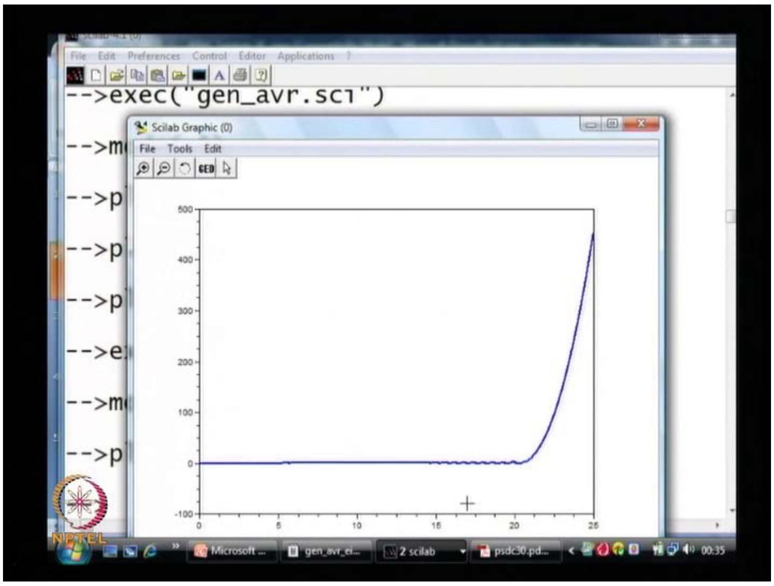

The angle delta the rotor angle and now you are getting an altogether different behavior.

So, if I remove the field voltage limits you are getting altogether different non-linear we have delta is going on increasing. So, instead of having. So, if you look at what is predicted by Eigen analysis around this equilibrium point is for any disturbance the deviation grow with time and go to infinity, this is what small signal analysis predicts what you got with a non-linear simulation was with a Euler method was high rate of growth initially which saturates, this is in case exciter limits our model exciter limits our model.

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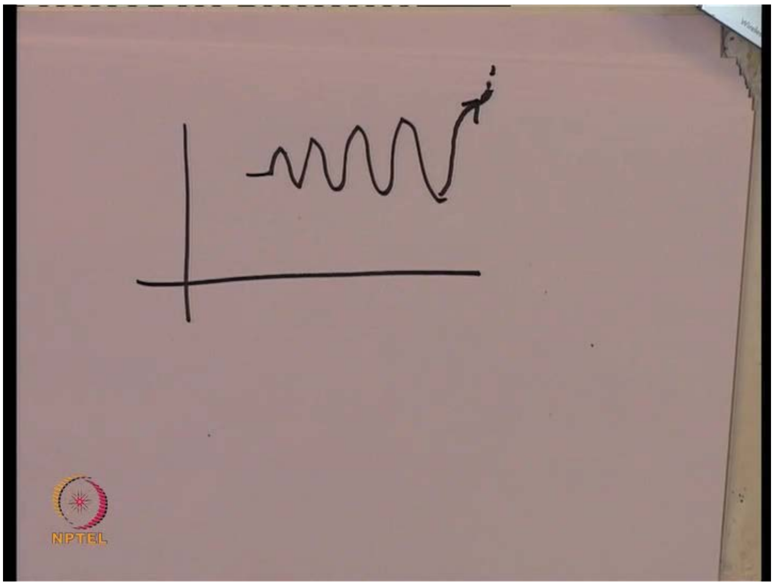

And in case you assume that excitation system does not have any limits, we find that this movement of delta eventually it becomes a monotonic movement as seen in this figure. In fact, if you expand this will become very clear, yeah do you see this.

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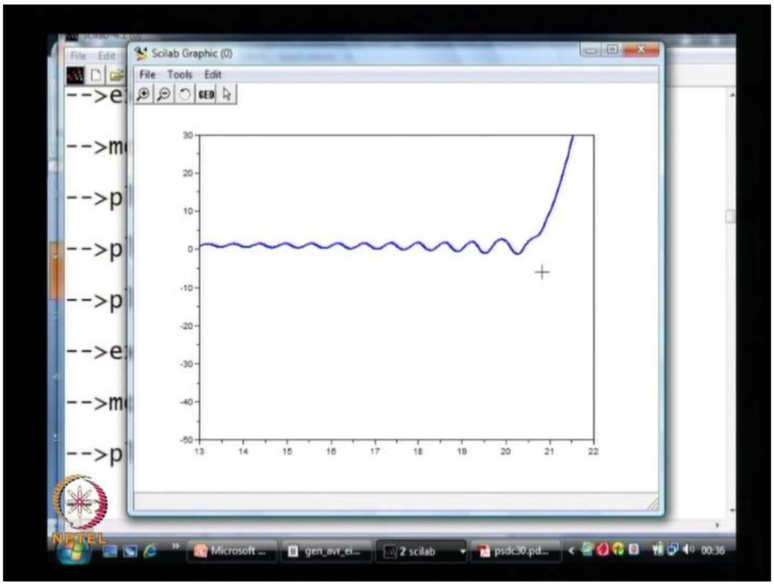

So, what you are seeing is the classical loss of synchronism phenomena. So, what happens is that you get different non-linear behavior depending on the kind of excitation system model you have used. In fact, excitation system model with limits seems to be giving us a sustained oscillation and not just a growth towards the loss of synchronism, this is a classical case of loss of synchronism remember loss of synchronism is also a non-linear phenomena it is something which cannot be predicted by Eigen analysis and because it is a kind of monotonic increase in the rotor angle after a point it just goes and loses synchronism.

So, this is these are interesting non-linear behaviors observed in the synchronous machine. In fact, if a machine is a small signal unstable there two things which will happen you will have a sustained kind of oscillation because it does not settle down to the equilibrium point or you have got this loss of synchronize phenomena.

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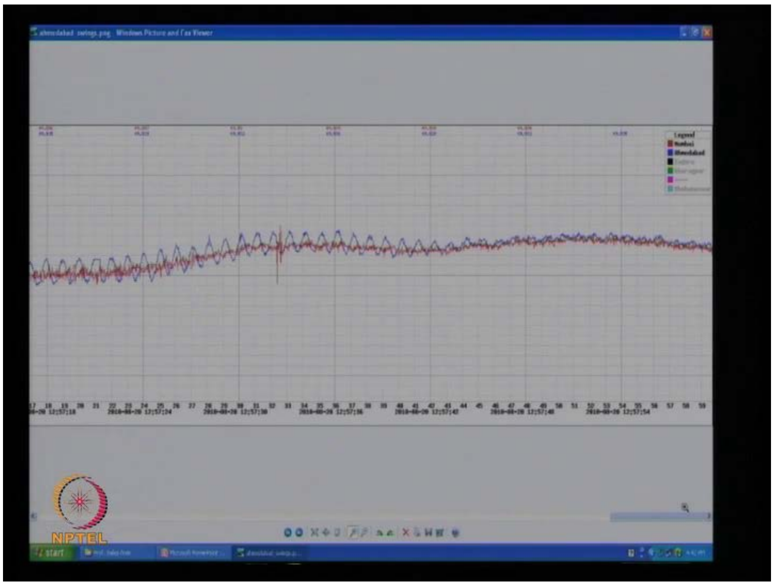

So, both this things are. In fact, possible and I will now show you a real life example a real life measurement of a small disturbance instability, this was observed on 20^{th} august 2010, what you will see in this figure is the frequency of two places, two locations which are quite far apart. In fact, one is in Mumbai and the other is Ahmadabad, both in the western region of our country, what we see is that the frequency which is a near about 49.9 hertz. Is in fact, not constant you know the out here they seems to be an operating point change.

And there after you see that the frequency at Ahmadabad seems to grow with time and then settles to a sustained oscillation. Which in fact, last for a more than a few minutes. So, you just see how it is just going on and on. So, this is an example of small disturbance stability which has been observed and if you look at the frequency of swings of this swings it is roughly you know corresponding to one hertz.

So, this is. In fact, a electromechanical swing which is observable in the frequency measured that Ahmadabad and you see that the frequency does not damp out. In fact, it does damp out, but only after the operating point appears to change. So, it just goes on and somewhere here the operating point changes which is seen by a slight change in the frequency and then this oscillation peters out

So, this is an example of small disturbance oscillations you know of poorly damped small low frequency oscillations of swings and this was actually observed in our Indian grid. So, we will just have a look at it again we will just run through it again. So, these are the frequencies measurement and there is the frequency and finally, the oscillation dies on after change in operating point. So, you have a sustained oscillation for almost five minutes.

So, shows that that particular operating point was in fact, small disturbance unstable of course, if the system tends to lose synchronism or in some cases when you have got sustained oscillation this is a good chance that some relay or protective relays which are present in the system may pickup, they will see that something abnormal is happening and if it fits in the logical conditions which are given for relay tripping operation they may actually trip out the machine. So, we should of course, take our results is not the full story. In fact, once a system is unstable it is possible that they may be a relay operation at some point of time when the response is playing out; the unstable response is playing out. So, this is something you should keeping in mind.

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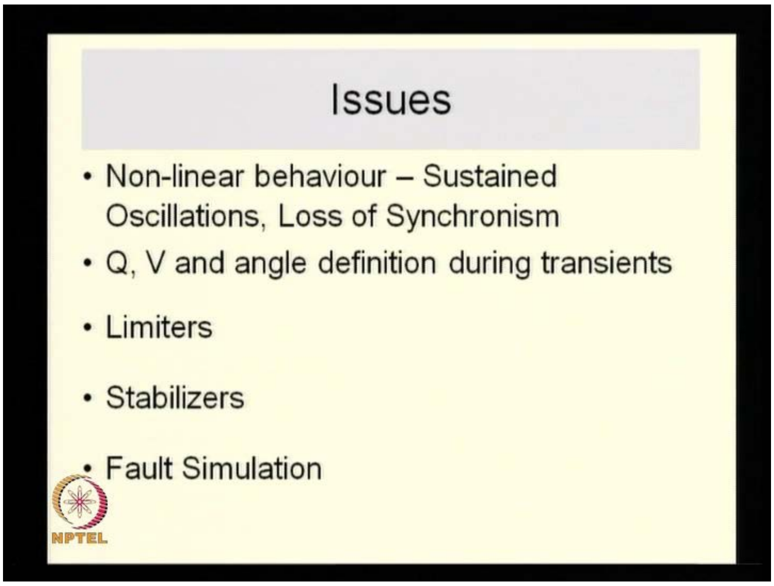

So, the things which you now should remember about our AVR modeling and simulation what are the issues, what is the special issues you have of course, done the modeling and behavior of the AVR and the special behavior when it become unstable under certain circumstances. So, these are the special issues these are not the issues of an automatic voltage regulation system. In fact, if the system is stable and designed well you may find that you will not come across instability that often. In fact, it may happen once in a while for situation which you have not envisaged when you are doing a design

But more often your voltage regulator will behave normally and you will have a stable response and you will have good voltage regulation and. So on. So, we should not take instability as the thing which always occurs it occurs under special circumstances.

Now, the thing of course, is that it does occur sometimes that is something which you keep in mind. Now, the issues which you have seen in this first part of our lecture today was that the two kinds of non-linear behavior which may manifest itself, themselves and those are will not be predicted by small signal analysis they are sustained oscillations and the loss of synchronism. Loss of synchronism incidentally can take place under other circumstances as well if there is a large enough disturbance you may also lose synchronism, we saw the situation in the later simulation which we did today in which the system loss synchronism because the rotor angle went on increasing with time and after a point it just split from the infinite bus to which it is connected to, split i mean the system is still be connected, but your router angle has became very large and keeps on becoming large and the machine kind of slips against the infinite bus there is a pole slipping taking place, and as I mention some time back as you have pole slipping and other unstable responses it is very likely some realize also would trips. So, in that sense our simulation is not really complete.

So, we saw loss of synchronism because of small signal instability this also can occur or you can have sustained oscillations this is also can occur. Now, one of the other issues which are special to our discussion of automatic voltage regulation systems was our definition of Q V and angle during transient, nothing to do with automatically automatic voltage regulation systems per sake, but as we analyze it we did come across definition of reactive power voltage magnitude an angle during transients.

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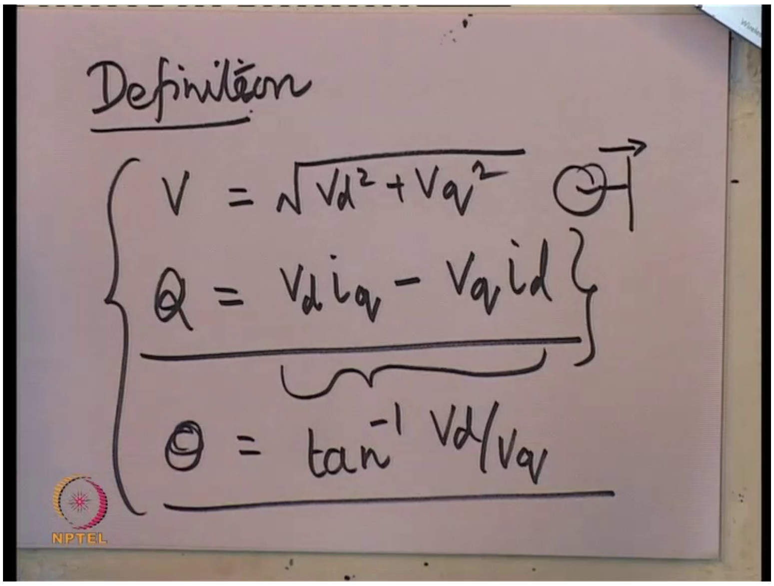

So, just to, these are important things which you should remember these are definitions it is difficult to assign a physical meaning to voltage magnitude reactive power and phase angle during transients that is difficult to do. So, these are definitions. So, the definitions which you should remember as voltage magnitude is root of v d square plus v q square this is a definition of voltage magnitude during transient conditions as well reactive power can be defined as.

This is the reactive power fed in to the generator terminals from the generator this is Q this is something is consistent with our definition of reactive power in steady state. So, it is up to you to prove that our definition of reactive power in steady state confirms to this definition in transients. So, this is an interesting thing which you should try to prove. Similarly phase angle theta during transient can be defined as v d by v Q, this are all interesting things which do not have the difficult to assign physical meaning to them during transients, but they confirm, they can be used and confirm to the steady state definition in steady state. So, in steady state you will indeed find that are inductive idea of what voltage magnitude of a sinusoid is what is been given by v d square plus v q square the square root of that, similarly the this definition confirms to the definition of reactive power in steady state. So, this is something you prove this is also something you should prove.

The other special issue which I did not, I am not, tackled here is that you have other kinds I remember, when we discussed our automatic voltage regulation system or the excitation system in general you had basically the excitation system power apparitions then you have got the control system which is essentially the regulator, but the automatic voltage regulation function is not sacra site you know, in case any limit of the synchronous generator is it.

Suppose the field current limit of the synchronous machine has been exceeded in the sense that the field current has became too large and it causes excessive heating of the field winding what we would like to do is once this limit is hit we can sacrifice what we need to do of course, is reduce the field voltage.

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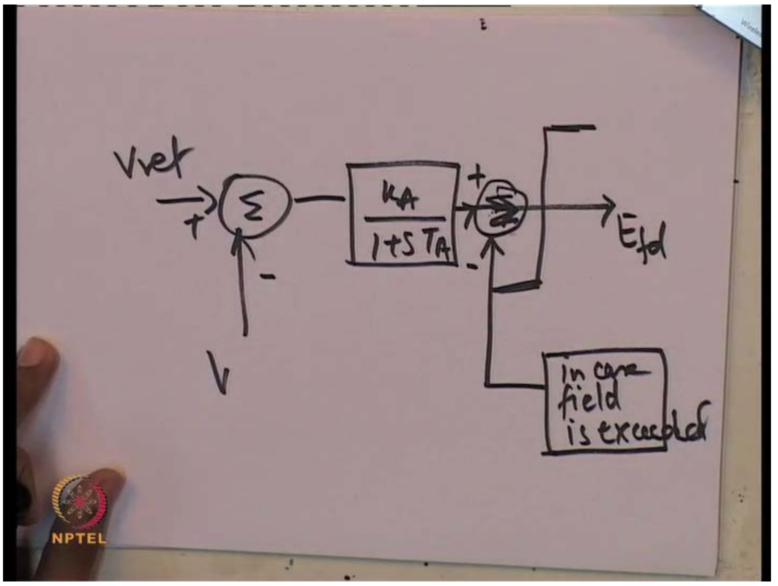

So, what one can do is, suppose this is your AVR, suppose and this is your static excitation system a simple model which is just a limit, this is the voltage limits at the output of the static excitation system, but on the other hand if a field current limit is exceeded what we need to do is reduce the field voltage, to reduce the field voltage you will have to reduce the field the signal given to the ac to dc convertor the thruster convertor by the AVR.

So, one thing you can do is have a summing block here, plus and minus in case. So, I will just write the logic here in case field current is exceeded, over write or modify the order given by the automatic voltage regulator and reduce the field voltage. So, that is the thing you have to do. So, I will not spend much time on what logic you can use. In fact, you can instead of reducing the field voltage, the control order given to the static excitation system you can also, instead modify the field voltage reference itself you can reduce the field voltage reference in case the field current limit is exceeded. Remember of course, this is point of practical concern when you are designing a logic is that when the field current is exceeded it exceeds its steady state limit, it is not necessarily to necessarily to do anything right away the thing is that the since a time constants for heating up of the rotor are much higher or larger, you can wait for a few seconds it is not going to machine is not going to get immediately it will not exceed its temperature limits.

So, for a short while you can, In fact, sustain a slightly larger value of field current than the continuous limit so. In fact, for a short while say few seconds you can, in fact, exceed the field current by say one point to a one point three times the steady state limit, there after you can actually start dropping down the current. So, what basically is important is that the temperature of the rotor should not rise; the rotor winding should not rise beyond the related. So, for that you can sustain for a very short while a larger field current than the continuous maximum limit, a maximum limit under continuous conditions. So, we can call it some kind of transient rating of a synchronous machine may be higher than the continuous rating of the synchronous generator.

So, here whatever logic which you use in your designing of the excitation control system should use the fact that the system has got higher transient ratings than the steady state ratings. So, for short while you can In fact, use the field forcing capability of a synchronous generator to improve the response of the synchronous generator.

The other thing which is used in automatic voltage regulation system or rather I should say the excitation control system which also includes the regulation system as one the major component, is the stabilizing function, the stabilizing function or stabilizer is something which does not act in steady state at all. So, those in steady state you should do voltage regulation if some limit is being hit modify the regulation function over write it slightly, but both these limiting functions and thus regulation function are to large extent steady state functions, but if you want to use improve a dynamic response for example, we saw that for a particular operating point your oscillations are unstable they were small signal unstable they were predicted by linearized analysis as well to be small signal unstable in such a case, you can modify your basic control system.

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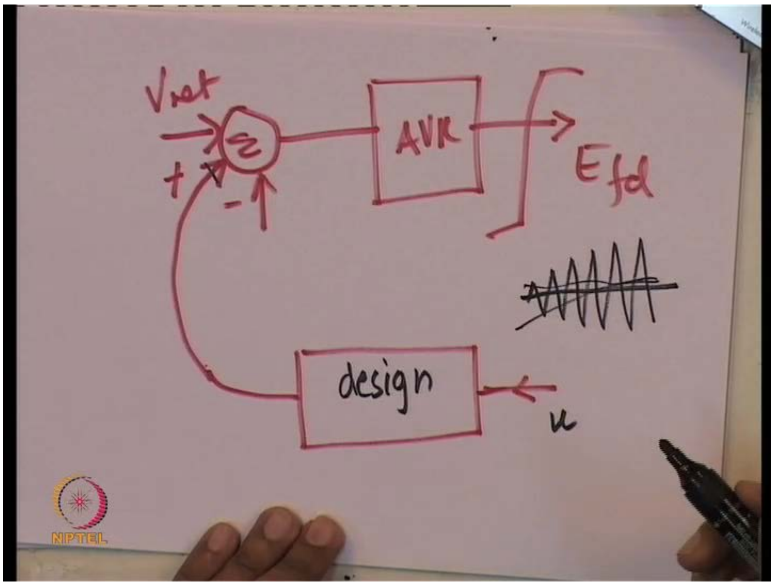

So, for example, you could this is the automatic voltage regulator, is giving E f d you could for example, put in a modulating signal or an additional signal to modulate the AVR reference in a certain way, so as to improve your stability. So, what you are doing is take a signal in which this oscillation is observable, take some signal for example, the speed power etcetera design a control system design a transfer function appropriate transfer function and modulate the voltage, this modulate v ref at this summing point. So, that the oscillation which would possibly grow with time for certain operating points is in fact, stable. So, this is in some sense are controller design problem.

You are designing an additional loop, additional stabilizing loop in your system which already exists so as to make your system stable. So, this is something you could do of course, the question which may be asked which is very natural you said instead of having this particular loop.

This particular loop here, why cannot we just modify the transfer function here? So, instead of just having K A upon one plus s t a, the thing is that the parameters of the AVR in fact, do affect the you know the response, you know the stability of the swing mode if I change this K A this is something I did not actually simulate and show you, but this is something you can try do it yourself you change the a AVR gains or instead of a simple proportional gain you have a proportional gain in addition to a lead lack block. So, if you have got all these things it is possible in fact, for you to modify the stability of various equilibrium points, but normally this is not what is done in fact, you will have this extra stabilizing loop which is provided here.

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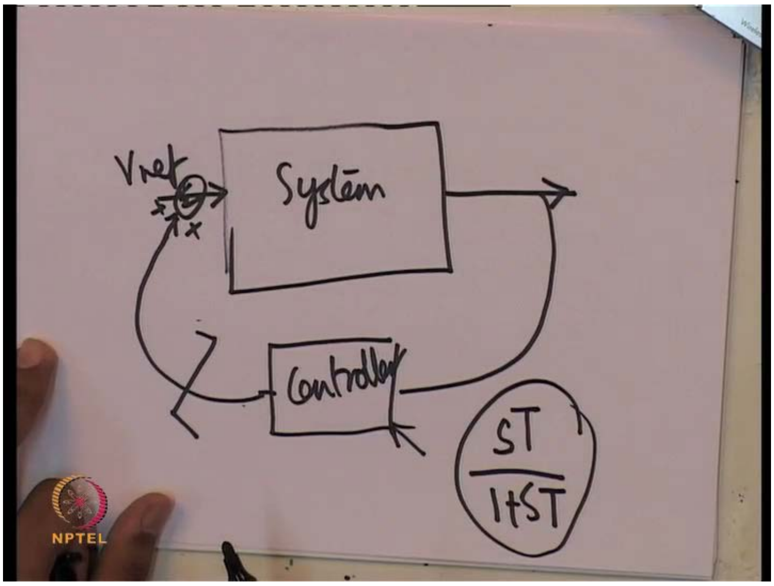

So, you have got something which modulates the v ref and by doing that you try to improve the response. So, let me just put it this way. So, what you are trying to do here just take minute yeah if this is your system, this is your v ref this is your synchronous machine excitation system etcetera you have got a variable like speed or delta or power in which this oscillation is visible, delta is a bit difficult to measure using just local measurements, but speed and power you will certainly see these oscillations along with delta. So, you can take speed as a feedback signal design a controller and modulate this voltage reference itself, this is what I really mean this controller is also called as stabilizer because it has no steady state function. So, it in fact, should not you know over write or interfere with the voltage regulation function too much.

So, you will have to limit. Another this thing is that during steady state it should not affect your voltage regulation function. So, a controller of this kind will always have some high pass filter component which will prevent any output from coming out in steady state conditions. So, this is a generic way how people try to stabilize oscillation, other option as I mentioned is do not have this loop, but you play around with the gains of the AVR also the structure of the AVR itself, this is also conceivable, but this is found to be a better way of doing things because you can actually choose variables in which the oscillatory mode is more observable and therefore, you can have much more effective stabilizer this way. So, this is something of course stabilizers is something when we will just too briefly, when we understand methods of enhancing system stability.

Now, let us just go on to another point will not really going in to stabilizer designed at this stage, that is the topic of doing other kinds of simulation now we have really done in this particular past couple of lectures, two simulations we have done simulations as well as Eigen value analysis of disturbance is like step change in v ref. In fact, step change in v ref is very much doable, you go to a power plant and you go to an excitation system there will be a provision for you to, which will allow you to give step changes to an automatic voltage regulator. So, doing this step change is very much possible it is a realistic disturbance which you could do give. In fact, system operator may wish to change the v ref why is this facility given not just to test, but v ref may be changed by a system operator or plant operator based on the reactive power output which he wants out of a synchronous generator.

So, v ref in fact, is decided by us, if we are operating the power system or a particular generator, but the other disturbance which we consider that step change in mechanical torque is not really very realistic we cannot really give step change in mechanical torque it is not an easy thing to do the prime mover systems are much less amenable to this kind of step change is. In fact, to give a step change in torque what conceivably would have to do is suddenly increase the, you know in some sense the steam force on the turbine which is not really feasible. But we nonetheless use that as a disturbance just to show certain phenomena.

So, just we will keep the realistic things in mind a more important disturbance which does occur which we could have tried to simulate using this simulator you know this simulation which we did was simulation of a fault, simulation of a disturbance in the form of a fault. So, fault is a short circuit due to a loss of insulation in the system. So, you could have a transmission line in which the insulator insulation has broken down on some insulator as a result is a flash over between a conductor and a tower and that is a short circuit effectively. So, that is a fault and fault is usually cleared by protective action by tripping of the faulted line. So, there is a there is a system which actually senses this and strips it out. So, you can in fact. So, what we did was we studied very disturbances.

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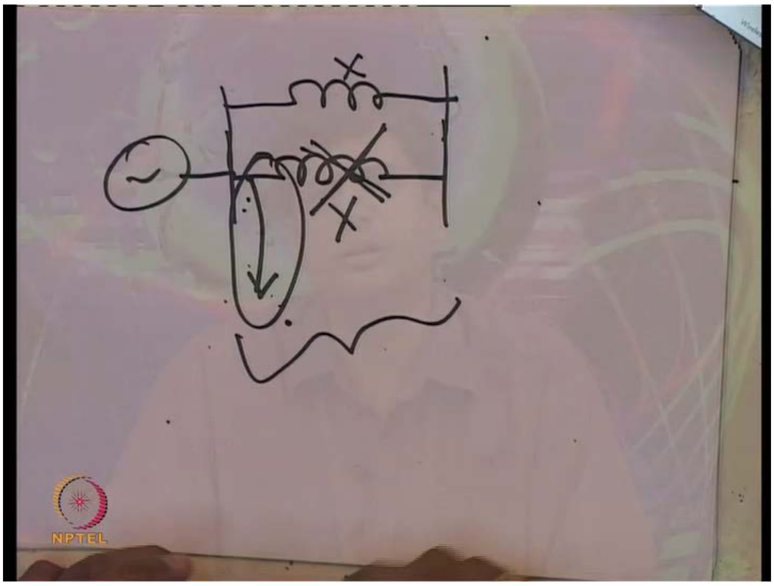

In fact, some of them unrealistic like a step change in torque we can in fact, give other disturbances for example, we could have modeled instead of one line two lines and assume that at some point of time they would be a fault here that is v d v q at the terminal of the generator would become 0 and as a result of which, some protective relay would act and this line would be out. So, you would need to change your equations.

So, whenever there is a sudden disturbance like a fault your, equations of the system change. So, your simulation in fact, would require you to not change the inputs like in the case of v ref and t m, but in case of a fault you would need to change your mathematical equations which describe the system itself.

So, if you have got a three phase fault for example, you would need to put v d v q equal to zero for the faulted duration, once the fault was cleared you would have to write your equations describing the interconnection only one line would be present after clearing of this line. So, you would need to modify the equations. So, this is something is not very difficult to do you can try to do it yourself we try to give a small disturbance rather a large disturbance in the form of a fault and then you trip the one of the transmission lines on which you have a fault.

So, this is something you can try to attempt to do of course, one point you know it is important to rise it at this juncture is that, in case you have got an unbalance fault there is one problem which you will come across, is that your model of the network or interconnection using d q variables may be of less value because when you do the d q transformation of an unbalance system, unfortunately you will not get time in variant differential equations.

You will have differential equations with vary with time. So, please chew on this just think over this and contemplate what would happen in case you did have an unbalance system you should apply it for example, d q transformation an unbalance star connected r load a resistive load, just a star connected resistive network will find at the equation which describe them would suddenly become time variant in the d q frame in new variables.

So, this is an important point which you should remember. So, you need to handle this in when you try to simulate practical disturbances because faults most of the times are in fact, single phase faults. Single phase faults which and the most common type of faults single line to ground fault and so on. So, when you use d q frame first thing you will of course, have to consider the zero sequence equations, the second thing is that the d q equation, equations in the d q variables will become time variant.

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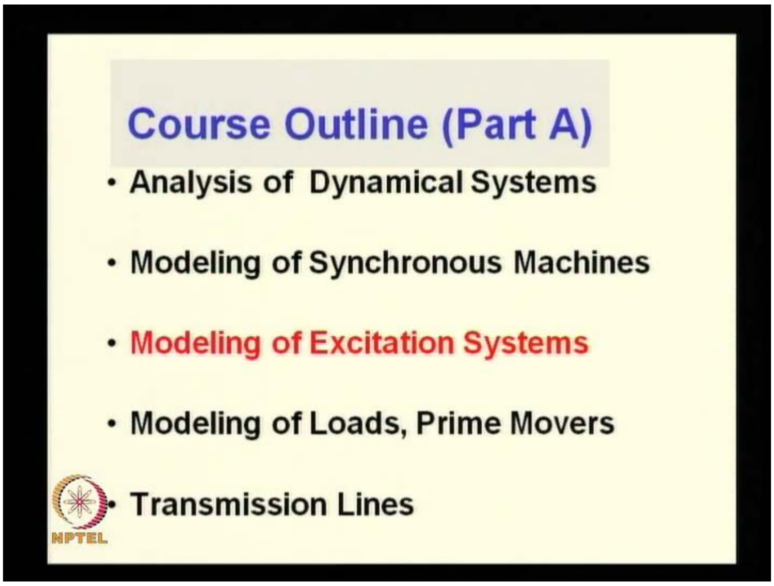

So, when you simulate you will have time variant components in your system. So, let us go now just we have kind of concluded our discussion of automatic voltage regulation systems and excitation systems, let us just look at where we stand a kind of a birds I view we have completed the modeling of excitation systems right now, we have also done modeling of synchronous machines and the general analysis, general principles for the analysis of dynamical systems.

What we need to do in the next couple of lectures or may be three lectures is the modeling of loads prime movers and transmission line these are important component which we should consider in our discussion.

Before we move on to a relatively shorter discussion of stability of interconnected system in fact, we have studied a bit of this in the simulations which I have shown I have shown you loss of synchronism, small signal, instability at certain operating points, these are phenomena which actually occur and I have tried to show them with a very simple system, when we talk of stability of interconnected power systems later on we will move on from studying just a single machine system to multi machine systems as well. I have already kind of introduced you to how you can make stability analysis tools you have to make basically, you have to numerically integrate the differential equations or do an Eigen value analysis of the linearized systems around equilibrium points.

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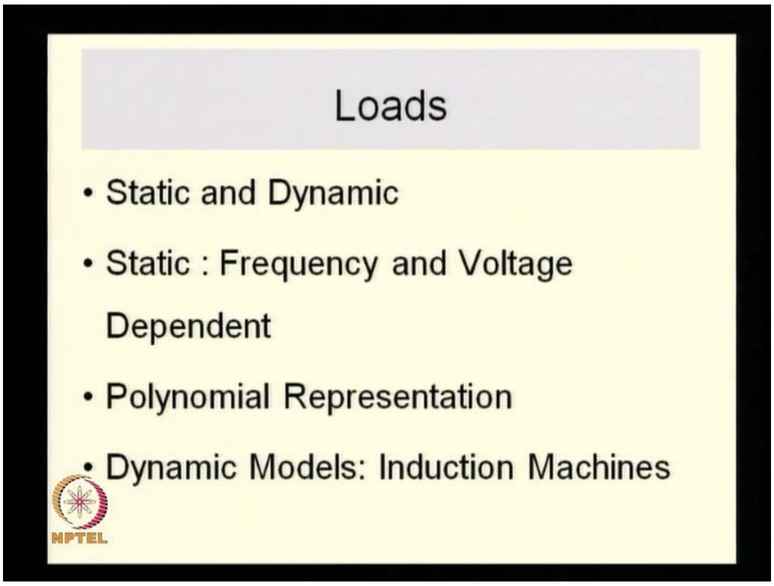

So, these are the basic tools in our armory, which we can use to attack this problem. Of course, we will I have already given you hint of how you could improve the stability, say the small signal stability of a system by making improvements are designing or constructing additional loops, controller loops in your power system. So, we will discuss this aspect as well later again. Now one of the things will move on to today is the modeling of loads.

Loads of course, are difficult to model you will you will appreciate that in a large power system, loads in fact, you cannot talk of a individual load I mean it if for example, if I am studying the Indian power grid.

The whole you know grid let's say that the southern grid of this system which is a system of this country, which is a synchronous grid. So, southern grid of our country is a synchronous grid. Now if I am going to talk of load on the grid we actually have a vast or huge diversity in the kind of loads which we have. In fact, even if you look at the loads in this studio there in fact, many and varied, in fact you have got incandescent lamps, you have got this computer load then you have got an air conditioner which is right now off because it thumbs a bit and many other loads which I have not mentioned here.

So, when you are talking of modeling loads in a system do I have to model everything in anything in detail for example, do I have to model the motor in an air conditioner or do I have to consider every each and every bulb, now you will realize that this is will get us nowhere of because when you are talking of the dynamics of the complete southern grid which has millions of loads, millions of individual loads it will become impossible to do a any kind of analysis of the kind I have been mentioning you cannot really find, you will not be able to come up with any useful inferences because the system will become too large to handle and even more worse you will not have the data of each and every load.

Loads keep on changing depending on the day, weather, season and you know and so on. So, it will become an impossible situation to model loads. So, what we really need to do is aggregate loads wherever we can, by aggregation I mean I will aggregation in not only clubbing together of similar loads, but even modeling them by some grows characteristics, we do not really go in to very much in detail unless we feel that indeed there is a reason to really model each and every, some particular component in detail for example, if you have got a few large motors in the system you know of say several mega watts like our power plant auxiliaries, in some cases you may require to model depending on what study you are doing model each and every individual load in the power plant itself.

So, that depends on nature of the study you are doing, but more often than not many loads can in fact, be clubbed and we have to flag of loads which need to be consider in much more details. So, most of the loads will be modeled by some general and aggregate method and special loads of course, you will have to flag of and modeled in detail

Special large loads so, that is what we need to do, load at a bus the simplest way you can try to model a load is simply by describing how its real and reactive power, the amount of real and reactive power it absorbs as a function of frequency and voltage. So, you know you can just make a algebraic relationship between p and q of the load and the frequency, prevalent frequency and voltage at the bus to which it is connected.

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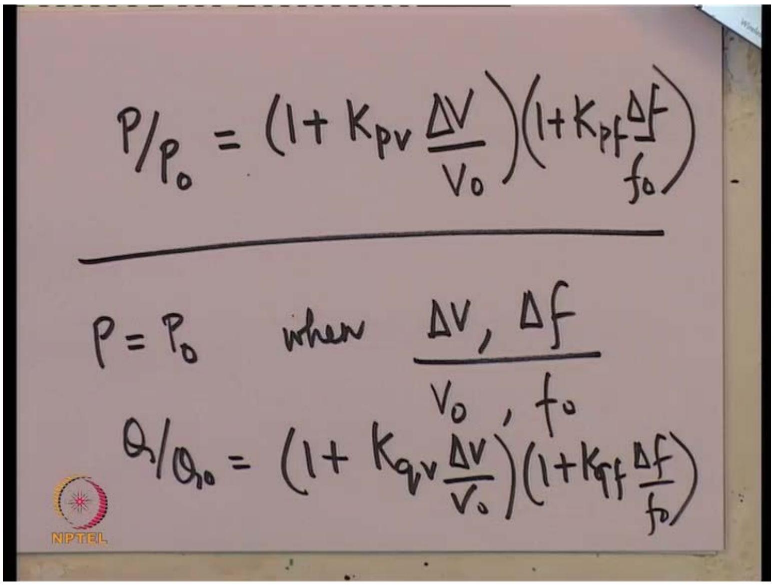

Now, the best, the simplest way you can do it is some kind of simple polynomial or simple first order polynomial representation for example, p by p zero is equal to one plus k p v into delta v, this is a simple representation.

First, it will be valid for practical for small changes in voltage and frequency this is a algebraic representation. So, K p v and K p f are some parameters which you have to take out kind of, for that aggregated load.

So, what is p 0? So, p by p zero is a normalized power, power at the normalize. So, p is equal to p 0 when delta v and delta f, which are the deviations from the normal nominal voltage and frequency take place.

So, sorry p is equal to p 0 when delta v and delta f are in fact zero. So, delta v delta f are the deviations from v naught and f naught. So, this is one representation of loads and similarly q by q naught is 1 plus K q v q f delta f by f 0. So, this is a neat way of writing down the aggregate characteristics of certain loads. So, when you do not have for example, any data it may be a good or rather you do not have very detail kind of data it may be a good idea to try to fit the characteristics roughly to these algebraic equation, so this is the, you know equations for the loads.

Now, of course, when you making aggregation it would be nice to know or whenever you are deciding your, this parameters K p v, K p f, K q f and K q v it be good to know you know for example, what are the various components of the load, I mean I am not saying to the last detail you know, but for example, if I know that at IIT Bombay our loads are mainly lighting and air conditioning loads, then I can get a proper roughly from you know, other studies which have been carried out by others you can get this, you can put in a value of K p f and K q f which fits in well with this kind of load.

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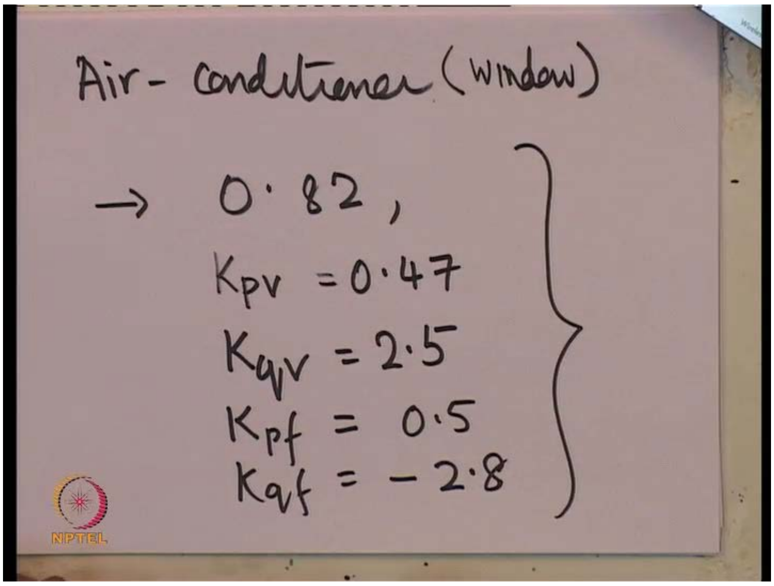

This kind of load mixture, so for example, it is a people have carried out studies and they found that for air conditioners for example, a window type air conditioners their power factor can be approximately point eight point eight two or so, these are obtained from certain studies; obviously, they will change depending on the rating of the air conditioners and so on, and this K p f K p v is for example, for window air conditioners it has been found in certain studies that 0.47 approximately, K q v is approximately 2.5, K p f is roughly 0.5 and K q f is minus 2.8 .

So, this is one particular load characteristic which you can use you know. So, if there is a lot of air conditioners load are certain proportional of the load is air conditioners then you can model one chunk of the load in this fashion, with the appropriate values of K p v and so on.

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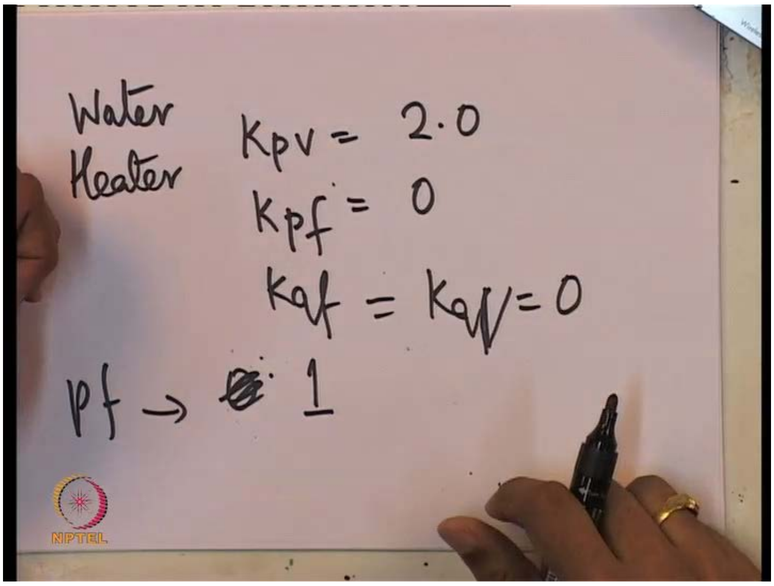

Similarly let us just talk about for example, water heater. So, water heater is basically a voltage dependent load it has practically no, you know it does not draw reactive power and it is not dependent on frequency you do not expect the heating of the element of any heating kind of load like water heaters to have a anything other than the real power dependence on voltage. So, what you will find is K p v is 2.0 in fact, if you just a moment. So, K p f and similarly K q f, k q f, K q v is equal to 0 power factor is of course, 1, this is the power factor. So, the water heater for example,

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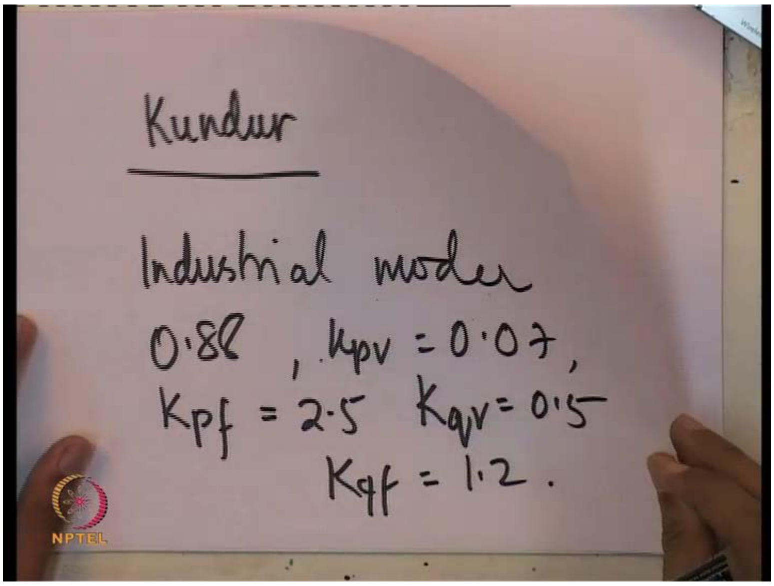

So, you will find at for this particular class of loads you are this is what you will get, similarly you have got florescent lighting and so on. So, you should in fact, you can for example, look into load modeling chapter of the book by kundur which I have mentioned sometime back and look at wide variety of loads and their characteristics which I had given there.

One of the things which probably could be of interest is industrial motor, in an industrial motor in fact, has got a certain class of a industrial motors has got power factors of 0.88 K p v of 0.07 which means it is not really voltage dependent, K p f which is 2.5, which is fairly go five frequency dependence and K q v which is 0.5 and K q f which 1.2. So, you see this fairly large variation in these constants.

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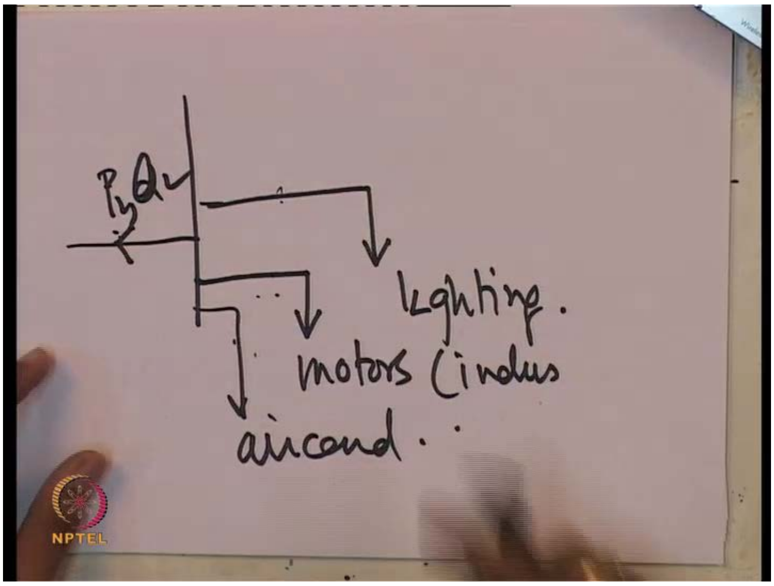

So, what we need to do is once you have got a load bus, it is better to first split it up into various components of load you know like lighting loads, lighting means whether you have to really distinguish whether it is primarily incandescent or is it florescent, then the motors, air conditioners, this could be industrial motors, air conditioners and therefore, get a kind of you know describe these individually by the appropriate K p f and K q f and so on, and then get a kind of characteristic of the final load and reactive power load which appears on the system actually drawn by the system.

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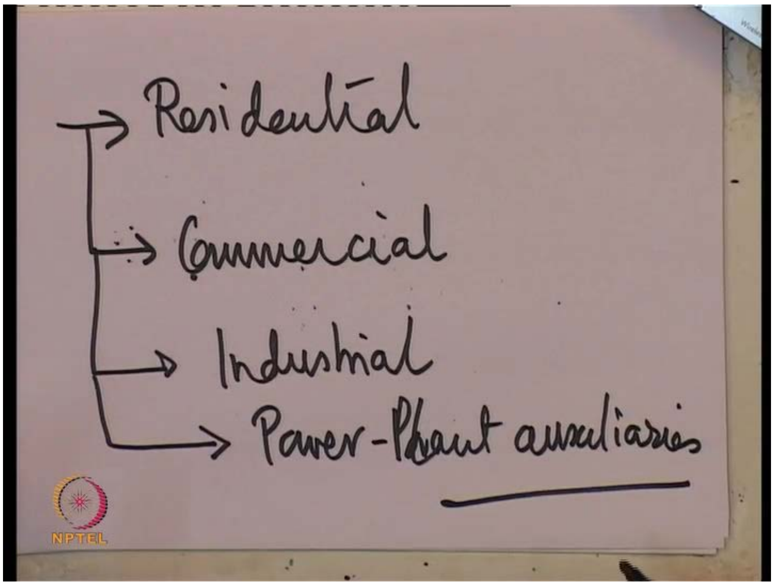

So, this is what you need to do sometimes of course, even this when you are doing large study even this may be very tedious to at this kind of data may be very tedious to get. So, you may find in fact, people kind of classifying loads as residential, commercial there is office spaces etcetera and industrial, usually manufacturing industries etcetera and power plant auxiliaries.

So, you can have this load classes and similarly for these load classes we can actually get this K p v and K q v and so on concern. So, if you know for example, Mumbai load is this much of it is residential or domestic this much is commercial. So, you can actually get an aggregate load model for Mumbai, as partly commercial, partly residential, partly industrial and in wherever there are power plants right at that bus you have got power plant auxiliaries, remember this theme power plants require substantial amount of auxiliary power you know for their pumps etcetera.

So, you will find that, that itself may be five to ten percent of the plant output itself, the rating of all the auxiliaries. So, that itself is quite a substantial load. That also has got certain characteristics. So, I refer you to the book by kundur which gives these characteristics in one place, you will find that given in one place. Now, what I mentioned to you the load model you can say which I have mentioned to here is in fact, a static load model is an algebraic relationship between p and v and p and f and so on.

A better way of representing load should be with a dynamic model, but as I mentioned it would be too difficult first of all to get the data for the dynamic model, but certain loads you know like very large motors you know which may be present in some places you know, for them you could flag out these loads in fact, and then model them in detail for example, induction machine loads very large induction machines are there you know several mega watt rating machines are there. So, those machines you may try to flag out and model separately as dynamical equations instead of static equations.

So, if you look at induction machines they also come out you know, the modeling of induction machine may be required in another context, not only have you to model large induction motor loads, individually using dynamical equations very large I am talking about mega watts whenever you are studying a grid those kind of motors, the other context in which induction motors really, a induction machines may manifest themselves is when you are trying to model induction generators, now many of the for example, wind farms or a wind generators are in fact, induction generators and it is a good idea and they are also many, very often connected to low voltage systems. So, they almost like negative loads negative induction motors.

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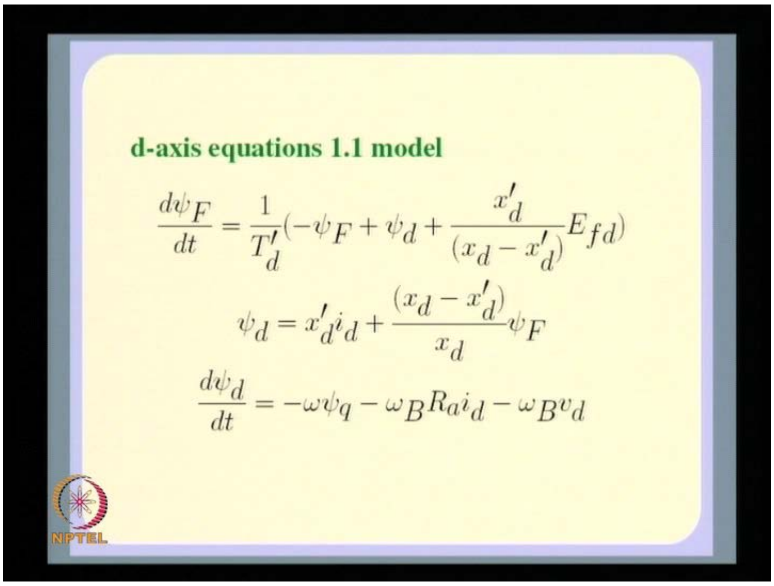

So, you may actually have to model certain large induction motors as well as large induction generators, in your grid individually using differential equations, now how do you do that? Remember we will just not go very much deep in to this I will just indicate how we can do it using the synchronous machine equations themselves, now just remember that I mentioned some time back that you can get a simplified model of a synchronous machine using 1.1 model, that is one winding on the d axis on the rotor and one winding of the q axis of the synchronous machine on the rotor.

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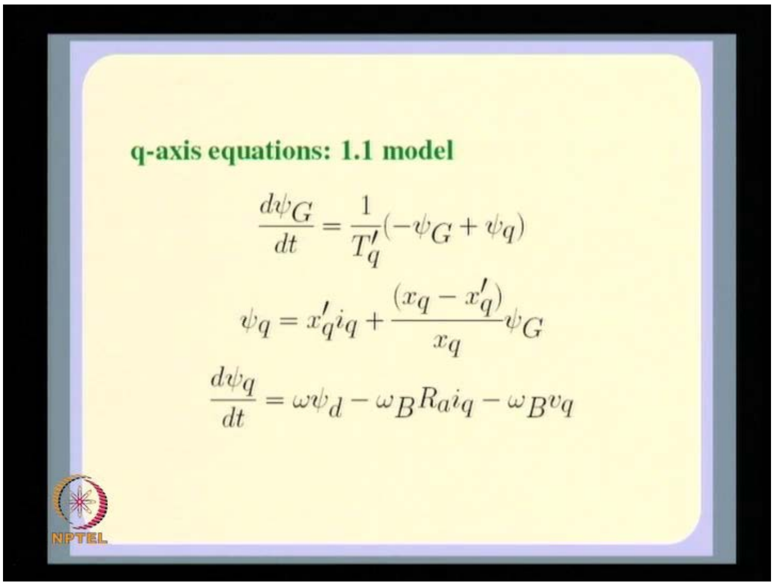

So, the equations which you get in fact, are given on the screen we have done this in the 22nd and the 23rd lecture, and the q axis equations are these so, these are of course, of a synchronous machine.

Now, an interesting question to you is, which I just kind of hinted in that lecture also was that using the 1.1 model in fact, you can get a model of an induction machine as well, how do you get that? Well you need to make, just remember what an induction machine looks like, usually it is a round rotor configuration there is no actual distinction between the d and q axis, especially of a squirrel cage machine it is very difficult to define what is the d axis and the q axis, if you have got a squirrel cage it looks exactly the same in both axis.

So, in such a situation what you see is that you cannot have a distinguish, distinction between the parameters of the d axis and the q axis, another important point which is there is that, there is no field voltage applied to a particular winding on the d axis,

The d axis and the q axis look exactly the same, even if you are modeling two windings the parameter of the winding will look exactly the same. The E f d is 0 because you are not applying any field to voltage of the field winding the there is no field winding so, the field winding in fact, has to be converted to a damper winding which is short circuited on to itself so, your E f d as to be made equal to 0.

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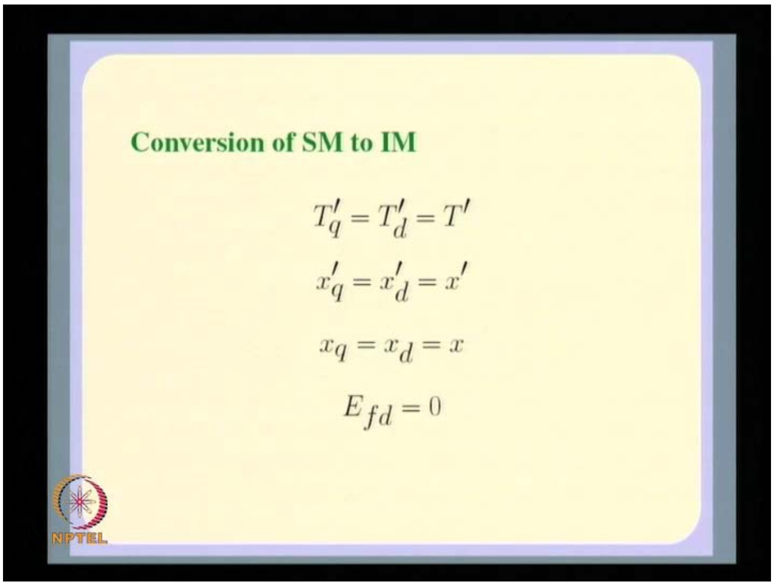

So, if you want to convert the synchronous machine model to an induction machine model, then what you need to do is, T q dash T d dash have to be made equal, x d dash x q dash in this 1.1 model have to be made equal, and x q and x d also have to be made equal and E f d has to be set to 0

So, what you will get is a model of an induction machine, it is effectively like two damper winding, one of the d axis and one of the q axis, otherwise the machine looks exactly the same, it is no saliency either in transient conditions are in steady state conditions.

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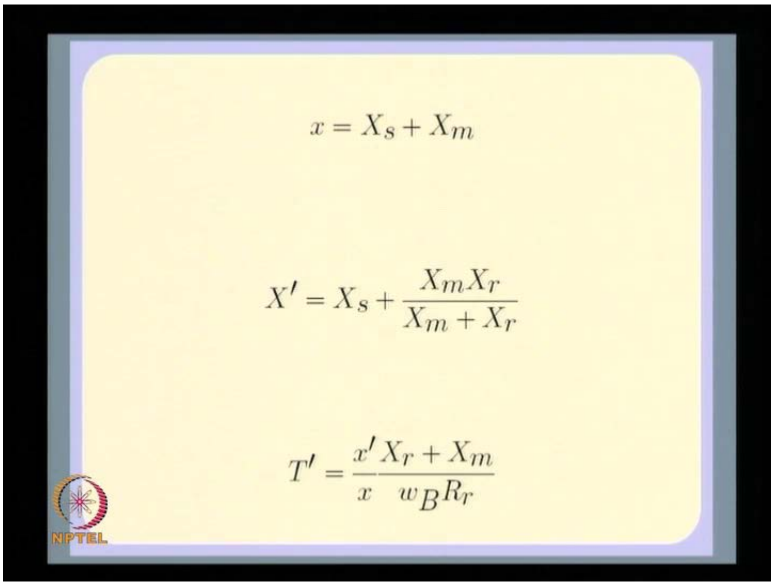

Of course it is all very well to say now we have got the model of the induction machine, but typically if you look at induction machine theory etcetera you will get your parameters in terms of the leakage reactance's stator leakage reactance's, the stator mutual reactance rather the mutual reactance x m, you will also get the rotor leakage reactance referred to the stator X r and from that in fact, you can get the parameters X dash X and t dash, which I have just mentioned using these formulae, now this is not difficult to prove in fact, you can take the 2.2 model of a synchronous machine set r k and h or h tending to infinity to open the two extra damper windings then you will get 1.1 model you can use the basic equations of the synchronous machine as described in the 11th , 12th and the 13th lecture of this course and actually derive these X s dash and t dash this is of course, as I do to many tedious things which are which we have to derive I leave it to you to derive this.

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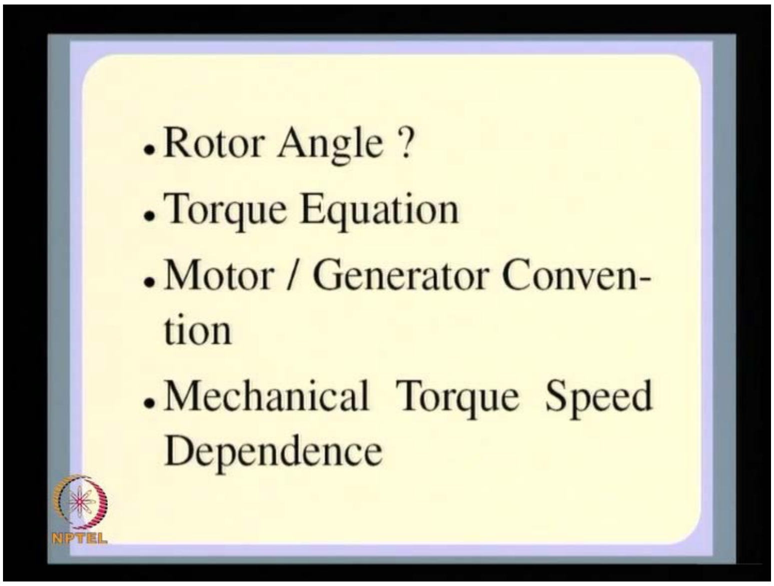

Now, there are some other issues for which we do not have adequate time in this particular lecture we will revisit this in the next lecture, when you say I have converted the synchronous machine model to an induction machine model well what do you mean by rotor angle first thing is a synchronous machine behaves differently from a induction machine in fact, in steady state the synchronous machine speed is equal to the voltage source to which it is connected.

So, rotor the speed is in fact, equal to the voltage source to which it is connected induction machine in fact, does not behave that way except, when it is under no load conditions. Rotor angle is manifest in the torque the question is it manifest in the equations of a induction machine torque? The answer is no, this is something we will discuss in the next lecture. In a synchronous machine yes you can show that your torque is in some way related to the angle delta, but in a induction machine it is hint

Another thing is we of course, will need to most often model induction motors so, there is some change in convention which we may have to do, because we have derived the synchronous machine equations in the generator convention, currents going out of the machine the mechanical, and electrical torques in certain direction with reference to the rotating direction, and so on.

So, we have to actually discuss this issue in the next lecture. Also we will also discuss the mechanical torque in speed dependence, this is something will also have to discuss in the next lecture. In next lecture will also hint at how using the dynamical tools which we have discussed so far, there is a Eigen analysis and simulation, we can actually prove the phenomena of self excitation of induction machines. I will just tell you, how you can actually try to prove it. So, that is of course, something we will do in the next class.