Power System Dynamics and Control

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Lecture No. #40
Voltage Stability Example (Contd.)
Fast Transients: Tools and Phenomena.

Today, I will show you a simulation example to illustrate slow voltage collapse which can occur, if you have got a load which is controlled, in the sense that it is the amount of power drawn is kind of made kind of maintained constant by the load irrespective of the voltage which appears at the terminals.

How is that done? In the previous class, we saw that you know if we use for example, tap changing transformers one can kind of overcome the effect of falling voltage, is in still draw the same amount of power by increasing the tap ratios. So, what in effect we have is a kind of a selfish load which tries to keep its power constant even if the voltage drops. So, the load effect for example, if you got a resistive kind of load you connected via a tap changing transformer, and the tap ratio is changed. So, that irrespective of what happened in the primary of the transformer is connected to the distribution supply.

The secondary voltage that appears across say a resistive load remains constant. So, how do you do that is by changing the tap ratio of the transformer. So, this is an example of a selfish load. Now, we know that a selfish load may cause problems in the sense that in case though system impedance is large - it becomes quite large, then you may have a situation where in attempting to maintain the power output consent of the power drawn constant by the load, by the mechanism say of tap changers. We may end up doing exactly the opposite thing, that is the voltage may decline to such an extent that at decrease in hour, effective decrease in hour causes the voltage to decline further to such an extent that the power actually reduces with decreasing hour.

So, this kind of you know phenomena is something I qualitatively discussed in the previous lecture, let us do simulation example in which what I am trying to say becomes more clear. So, today’s lecture we will divide between having a simulation example of voltage stability, and also begin our discussion on some of the tools and phenomena associated with fast transients and power system something which you have kind of not considered much in this course, so far.

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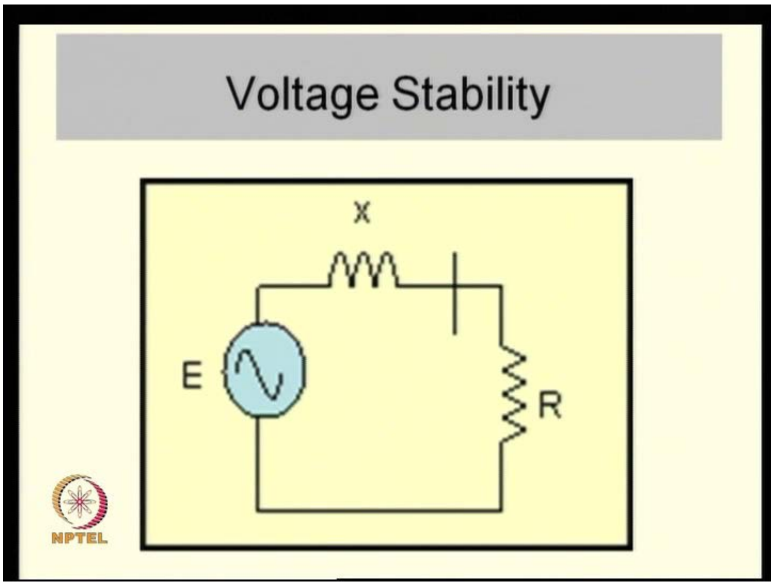

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Now, if you recall the quickly going back to what we did in the previous class. If you have a system of this kind a voltage source feeding, say a resistive load in that case.

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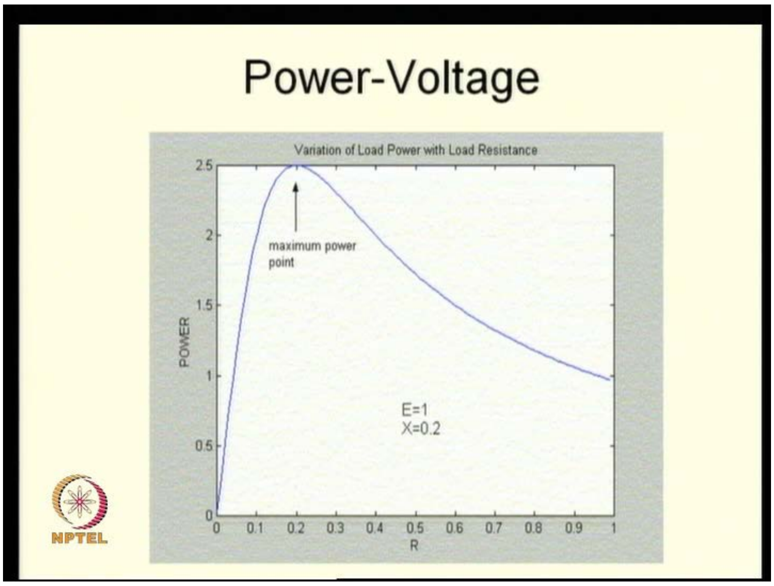

There is a maximum power point when R becomes equal to x, we see that a decrease in resistance. In fact, causes a decrease in the power dissipated at the load. So, this is called a maximum power point and if you see the load power as a function of the resistance R, you will find that it actually reaches a maximum when x is equal to R .

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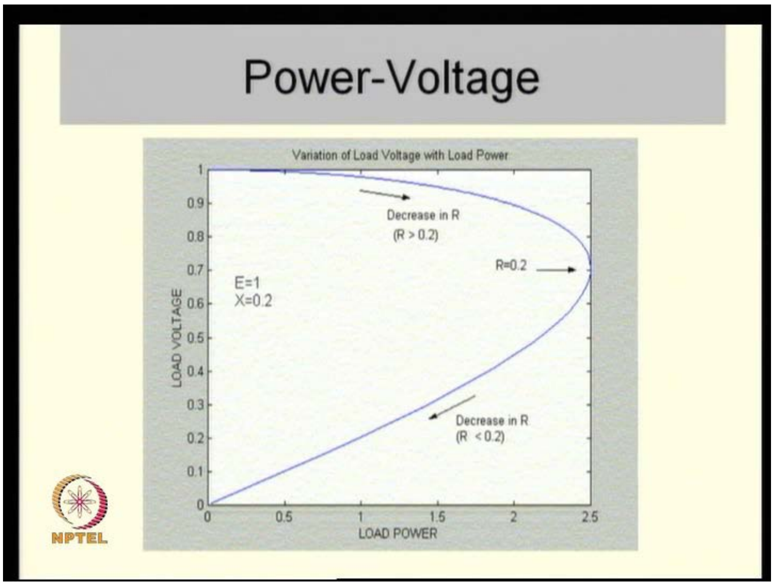

So, this is something we saw last time and the same thing the reason why that happens is that the load voltage dramatically starts falling with decrease in R and eventually v square by r actually drops reduces with decrease in R at after R is equal to after r is decreased beyond point two which is equal to x.

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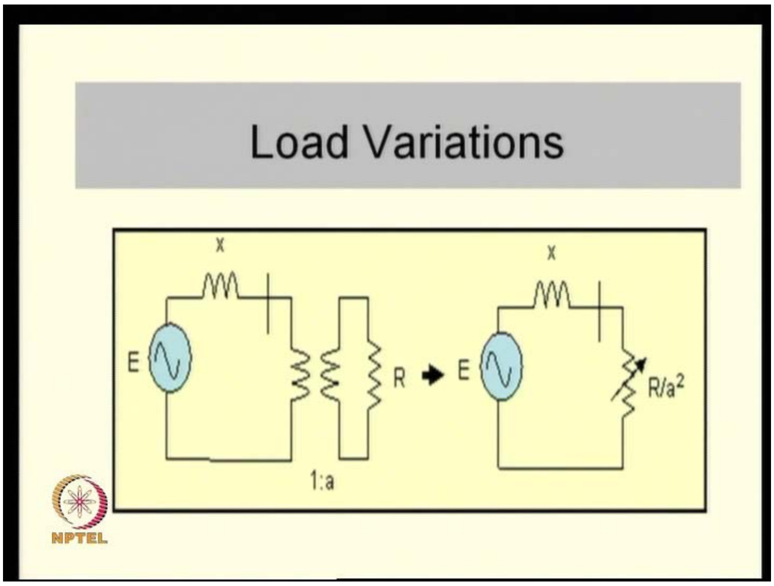

So, this is something we saw in the previous class. Now normally we don't have we know a variable R kind of load is not is quite rare, but effectively we can have a load which is a variable R in this fashion. The R is fed via a tap changing transformer, the load is fed via a tap changing transformer and the tap is changed. So, that the voltage at the resistance is practically constant, so this is the selfish load which draws the same amount of power irrespective of the voltage which is there on the primary of the transformer .

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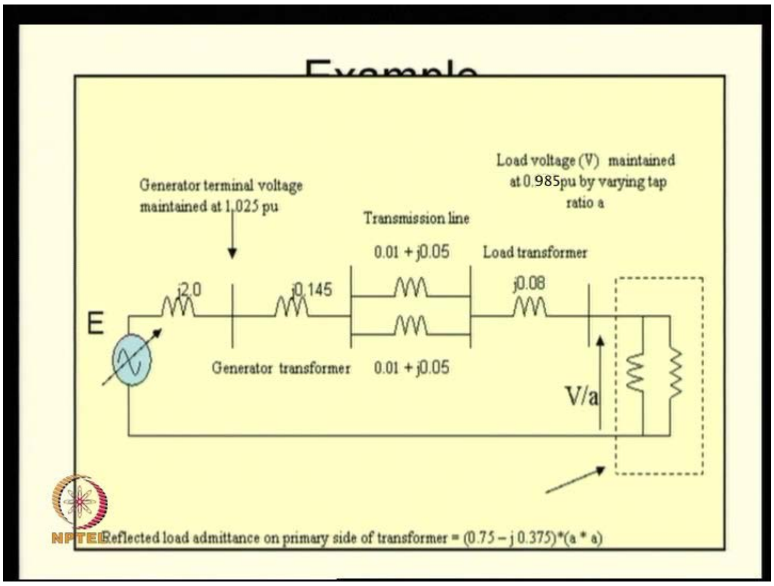

So, at the secondary you try to keep the voltage consent, so effectively we have our you know resistance which is a function of A. The resistance presents itself to the system as a function of A and this A is changed. So, that the power dissipated by the load is constant. So, this is a selfish load which irrespective of the voltage at the terminals tries to dissipate the same amount of power. So, the A is changed to keep the voltage at this secondary almost constant. So, in this fashion you have got a variable resistance, so what we are going to do today is a kind of an example of a voltage collapse scenario in which I will have a synchronized generator. A synchronized generator in steady state and if saliency is neglected can be represented as a voltage source behind the synchronous reactants.

So, we assume here that x d is equal to x cube then it is steady state the generator can be represented in this fashion of course, this voltage behind this synchronous reactance can be controlled by the field voltage applied to the field winding. The field voltage is continuously controlled so as to keep the terminal voltage in this example, at 1.025 per unit. So, the terminal voltage is maintained constant, so for all practical purposes this generated terminal voltage is actually constant. So, E is changed so as to keep this a constant. Remember that this can be done up to a point if the field voltage hits it is limit. In fact, the field current hits it is limit, field current and field voltage are directly proportional to each other because of heating; we may not be able to increase this E beyond the certain point. Of course, one thing which I missed telling you last time was this field heating limits may actually be time dependent.

So, when I say that the field hits it is limit, what I mean is that you cannot continually operate the machine with the field exceeding its limit. So, actually there are short term and long term limits of the field current remember that, even though field winding may exceed its continuous limits, continuous time limit it can for a short while have a transient over heating because the wheel winding takes a little bit of time to heat up. So, this is one aspect we will not consider in this particular example.

We will assume that we do not make a distinction between continuous or continuous limits and short term limits. So, short term limits of a synchronous generator field winding can be quite high you can in fact, increase the field current to more than 1.5 times its rated value for a short while. But in the long term you will have to get back the field winding to its rated value you cannot exceed the winding otherwise the field winding will get hot. So, we will not in this example let me reiterate consider the distinction between short term and long term limits, we will assume that there is one limit and the field winding cannot exceed that limit .

So, as I was saying this synchronous generator for all practical purposes as long as you can vary the field voltage and the field current you can maintain the terminal voltage a constant, but if in case this hits its limit then we should not read this as if it’s a constant voltage bus, but treat take the synchronous machine as an equivalent E behind the synchronous reactants. In fact, it is a equivalent E behind the synchronous reactants, but E is variable, but when it hits the limit E becomes a constant. So, as long as you know your field winding is within the field winding current is within the limit this is practically the stiff voltage source otherwise this becomes a constant voltage source once it hits its limit this becomes a constant voltage source, but it is behind the large reactants.

So, remember we have for all practical purposes, this is the voltage constant magnitude voltage source provided is within limits you have got a generator transformer whose reactance is quite small compared to the synchronous reactants and transmission line reactants is also quite small they are not very large. This is the equivalent kind of system, we assume we have got two transmission lines then you have got a load transformer and then you have got this load, this load of course, is the voltage V is the voltage at the secondary of a tap changing transformer.

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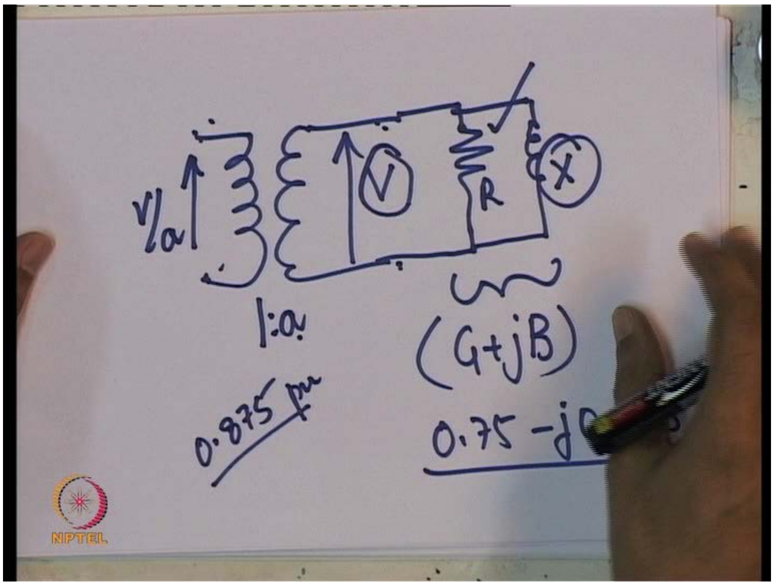

So, when I say this load is this is V and. In fact, load admittance, the load admittance that is G plus j B is 0.75 minus j 0.375, this is one upon this is suppose this is R and this is X.

So, B is equal to minus one by X, so basically this is a inductive load. So, that is why you get 0.75 minus j 0.375. So, this is the resistance of the load remember that the tap is changed so as to keep this V constant. So, if the voltage here is V the voltage here becomes v by a. So, we will try to keep this voltage V by changing the tap at 0.875 per unit irrespective of what voltage appears here. So, we now if the voltage here goes below 0.875 we will try to increase the tap.

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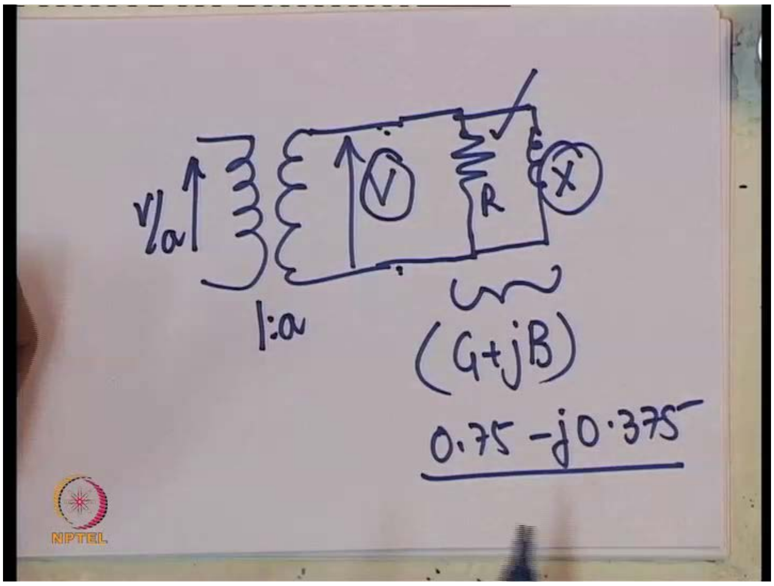

There is a minor correction here instead of 0.875 what I meant was 0.985. If you look at the system you will find that the equivalent R dash and X dash are such that you will get the admittance that is G dash plus jB dash is nothing, but 0.75 minus j0.375 into a square. So, this is the reflected load admittance as seen by the system, so when I am doing the analysis remember that the as far as the system is concerned the voltage here is V by a, V is the load side voltage remember that there are load admittance 0.75 is actually much smaller than the system impedance under these conditions the system impedance is 0.145 plus, 0.j08 plus, the equivalent impedance of this line.

Now, if you look at the admittance rather the equivalent admittance it is much greater that one upon the system impedance, so we are nowhere near the condition of voltage you know you can just check this out you can do a power versus admittance study and you can really see that with this much source relatively low source admittance impedance you are not near the maximum power points. So, if you add up the load admittance from this point onwards, why this point onwards? This voltage is practically maintained at 1.023. So, you can at this point assume it is a voltage source and this is the system admittance the system impedance effective impedance which is not very large it is nowhere near the maximum power point of this load.

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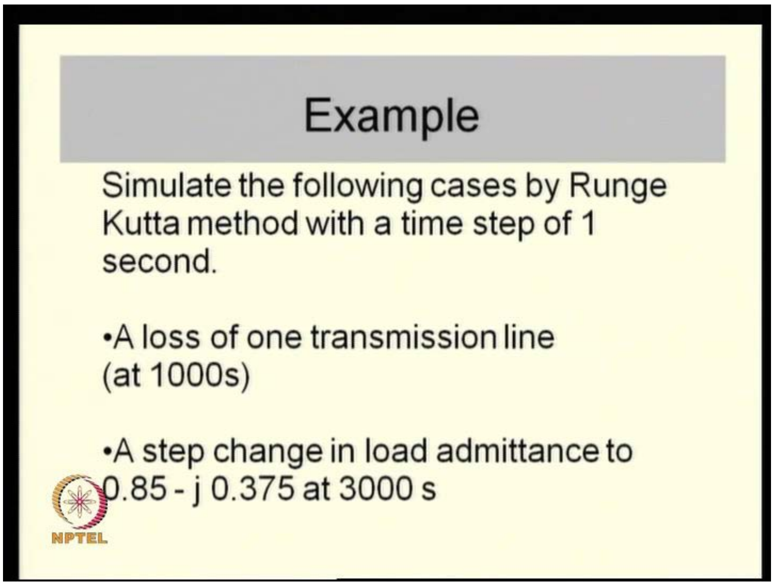

So, this is the initial operating condition of course, now what I will do is, I will simulate this system using R K method with a time step of one second. Now one of the important things regarding the modeling, what we are going to study is relatively a slow phenomenon, we are not going to study fast transients here. In fact, the tap changing action is over several seconds if not minutes. So, what we really are going to do here is, we can actually assume that the system is sinusoidal the network especially we do not have to model by you know we do not have to model the network transients network d i by dt etcetera d i d by dt, d i q by dt etcetera is not model.

You can treat the network as if it is in sinusoidal study state the synchronous machine also, we represent by its steady state model that is the voltage source behind the reactance. Why do we model it that way? Because these transients are very slow so the synchronous need not be modeled by any you know dynamical equation except the dynamical equation corresponding to the variation of E. So, that is something I will discuss shortly. In this particular example, we do not have one synchronous machine connected to another voltage source, on another synchronous machine it is simply a synchronous machine connected via a transmission system or a distribution system to impedance.

So, relative angles or relative angles stability is not an issue here all the loss of synchronism swings etcetera is not at all an issue here. So, we are looking at distinct phenomena in which these things are not coming into the picture, because it simply have one synchronous machine connected to a load. So, the disturbances we will consider are the loss of one transmission line, we will assume of course, the system is initially at steady state then we will consider the loss of one transmission line at thousand seconds and the step change in the load admittance a small step in the load admittance at 3000 seconds.

So, there are two disturbances, so I will first show you what happens when you have the first disturbance. Now remember what we are going to do here is, trip one of these lines tripping one of the lines will reduce the source impedance rather you will increase the source impedance. So, because of that the voltage here of course, will change. In fact, will drop down a bit because the impedance has increased the tap will be changed the tap or the of the tap changing transformer being changed, will change the reflected load.

Now, So, the amount of current obviously, when you trip a transmission line eventually the current flowing through this system will change once the system current changes the stator current changes you will find that the terminal changes tends to vary, but luckily since I have got a field voltage which can vary I adjusted. So, that this terminal voltage is back to its original value.

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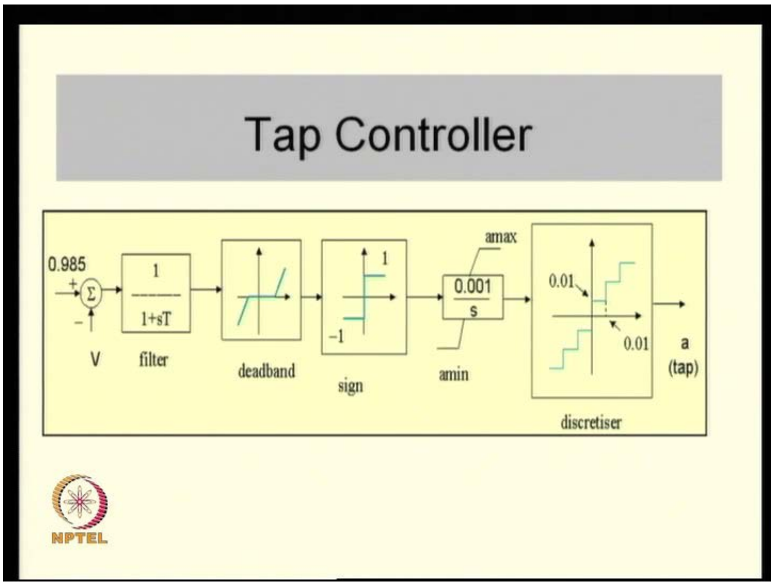

So, this is what we will try to simulate and see remember that we need to simulate a tap changing transformer action we will assume that it is a dynamical system. This is one possible logic for tap changing this is of course, not a standard logic or anything of that kind just a reasonable logic which you know a person in the first cut could think of. So, what you we want to regulate the load voltage to 0.985 per unit, so what I do is give the set point compare it to the actual prevailing voltage at the load then I filter it so that I do not respond to fast changes and noise, so I filter it then I pass it through a dead band so that if there are very small changes in voltage I mean for example, if the voltage V is 0.986. I may not think of actually adjusting the tap its very small. So, I this error is very small so for very small errors nothing is done, but if the error is reasonable beyond this dead band. What I take it as an indication that I should either increase the tap or reduce the tap, but I do not do it right away what I will do is I pass this signal say one, one says that you increase the tap.

Now, what is done is that one is passed through an integrator or a counter so once this thing is integrated says if this is one then you can notice that it will take about a thousand seconds for this to increment, to the output of this to become one, because this gain here is 0.01. Similarly, if this is one for hundred seconds, if this is one for hundred seconds this will increment eventually by this will eventually increment by 0.1 after thousand seconds. So, this is kind of did I say the right thing? If this is one for a thousand seconds the output here will become increment by one since this is the plain integrator.

So, of course the output of the integrator is a continuous value a kind of a venire value, it is a continuous value. We the tap settings are discreet, so we need a quantizer or a discreatizer to actually tell you what the tap is. So, the tap of course, normally is one so you start off with the tap of one, one is to A. Let us assume A is initially one so any time this exceeds the limit exceeds V rather there is a error between this which is greater than the dead band. This will start incrementing or decrementing depending upon whether the error is positive or negative and reduce or increase the tap, but the tap is a discreet value.

So, this is one possible way you can have a tap controller of course, this is not the way which is you know implemented may be in a real set up, but this seems to be a reasonable starting point of how a tap changing controller should look like.

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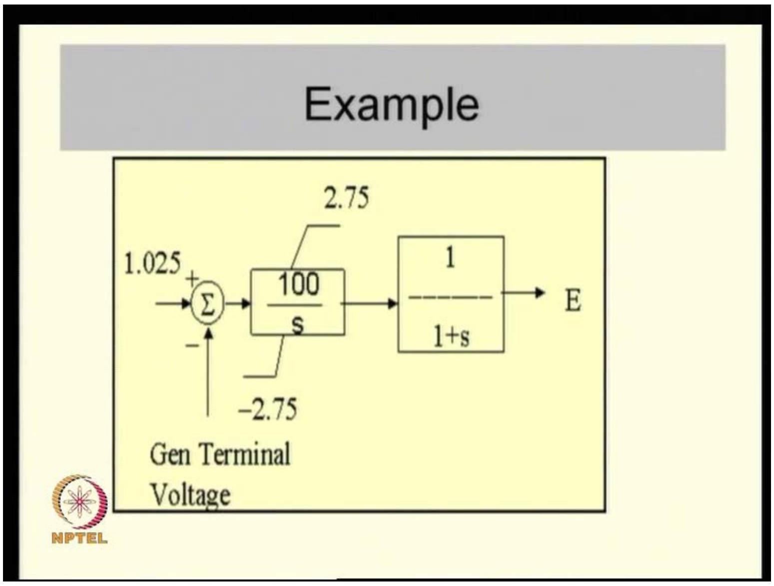

We now look at the field, field controller of a synchronous machine. So, synchronous machine is trying to keep its terminal voltage as 1.025 per unit you measure the terminal voltage the error is passed through a integral controller you can have a p i controller p controller with large gain any of these possibilities exist. And of course, the important point is that the field voltage is not allowed to increase beyond 2.75 and minus 2.75. So, this is the absolute limit of the field voltage, actually in study state one does not expect the voltage to be negative anywhere so actually this could have been need not have been given as minus it could have been just a zero or slightly more than zero positive direction.

So, the thing which I was trying to tell you again lets come back to that, this terminal voltage is being regulated by an a v r. In this case the a v r is assumed to be an integral control and the field voltage limits are 2.75 per unit, so you cannot increase e beyond 2.75 per unit. Now of course, if you recall in our a v r discussion of a v r, I had once told you with the field voltage ceiling limits are sometimes even high as 6 or 7 per unit. But remember that is the transient variation which you can have normally you cannot increase the field winding beyond roughly these kind of values; this is practically the limit of the field current, so continuous rating cannot be more than 2.5 or 2.6 or in this case 2.75 per unit.

So, this is one important thing which you should keep in mind, let me repeat it that a transient field voltage limits can be quite high you can have transient field voltage to be quite high and for a short while, but in steady state your field voltage limits are likely to be around this range. In fact, in study state there is no almost no chance that you will apply negative field voltage, so in fact this is a kind of an error I should keep the in steady state, if these are the steady state limits the lower limit should be actually a positive value not a negative, small positive value not a negative value.

So, just remember these important points we can actually kind of make a distinction between, we need not make a distinction between fast and slow limits, because the phenomena we are going to study here is very slow. So, we can talk in terms of just the continuous time limit of the a v r not worry about transient limit of the a v r which can be actually quite high for a short while you can have a large field voltage and. In fact, exceed the even the current rating of the field winding for a short while.

Now, of course important thing is that this is the field voltage is applied to a synchronous machine it will manifest as the a f d after the field voltage the voltage at the stator will kind of manifest after sometime. So, how it manifest in transient is dependent on the dynamical equations of a synchronous machine, what we will assume here is that you know if i give a change in the field voltage it take about a second before it manifest, as the you know voltage or rather the effect is seen only after sometime. So, this is some kind of very rough modeling of a synchronous machine.

So, this is something which is if you want to study slow transients, but it is a certainly not if you want to study transient stability or angular stability and so on. So, this is just a very rough model of a synchronous machine; so this delay of one second this time constant of one second in this transom function is kind of representing all the cumulative effects faster effects which are there, which we are neglected.

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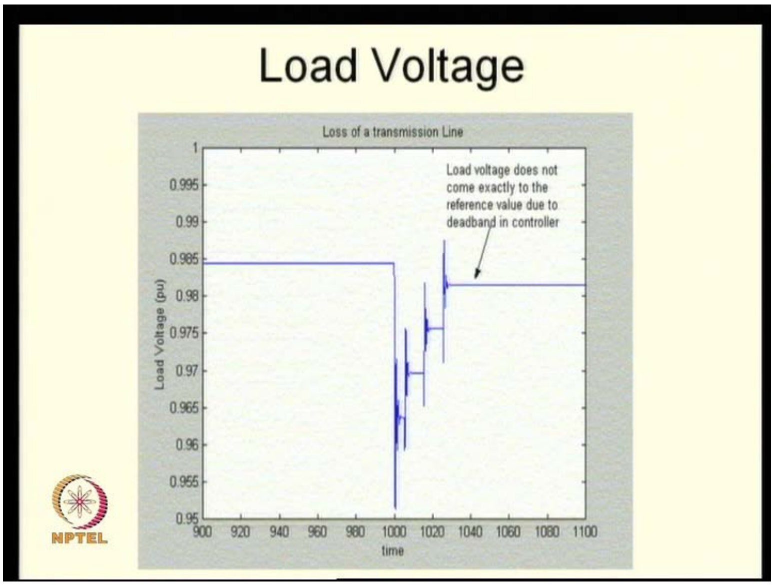

So, this is the very rough kind of model, but if you are going to study slow transients like the one we are doing here. So, what happens if we lose a transmission line? So, if we look at what is seem here in this response you see that the voltage of course, of course,, initially is 0.985 a thousand seconds one of the transmission line trips, so one of the transmission line trips and the voltage dips suddenly at the load because the load directly you know there is a larger source impedance and the voltage drops. Now the voltage drops to a value of 0.965, but what you are seeing is practically like steps which are occurring are because of the fact that the tap is incrementing. So, the voltage is dropped beyond 0.965 below 0.965, so a tap changer will try to change the tap remember the tap changing controller we discussed some time ago it will try to increment the tap.

So, of course the tap is incremented you know there is a definite time period which is required before the taps increment and the another thing is of course, that is also a discrete value of the tap. So, there is a there is a fixed time delay before any tap is increase and also the tap values are discreet in nature, it is not a venire smooth control, so you find that the tap increases; but shifting the tap by 0.01 does not really bring the voltage back to 0.985. So, after sometime again another tap is changed the rather the tap is incremented again then again.

But beyond this point you see tap is not incrementing though we have not reached the value 0.985, the reason is of course, we have got a dead band which allows you to settle down at a voltage, which is slightly less than the reference value. So, beyond this point in fact, you see that there is no increment in the tap and the voltage settles to the value which is almost the same this 0.98 may be 0.982 or so, which is almost the same as the reference value so this is the acceptable behavior there is nothing wrong in this.

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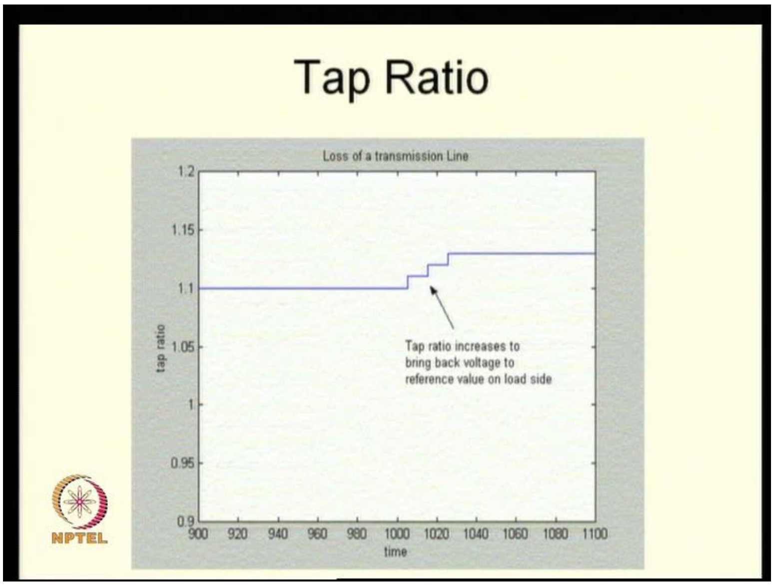

If you look at the tap ratio of course, as I mentioned some time from the initial tap. I think the initial tap was 1.1 which I have mistakenly said was one initially its 1.1 initially, it goes on increasing in steps rather it increases gradually in steps to this value in a discreet fashion, so the word gradual may not be appropriate here. I would say in a discrete fashion it increases to a new value.

This basically action of the load is ensuring that the voltage which appears at the load itself is almost 0.985, 0.985. So, this voltage which you see here on the sheet of paper is actually 0.985, so if you look at this here it is 0.98 it is brought almost back to 0.985 by adjusting this tap a, so this is what is done.

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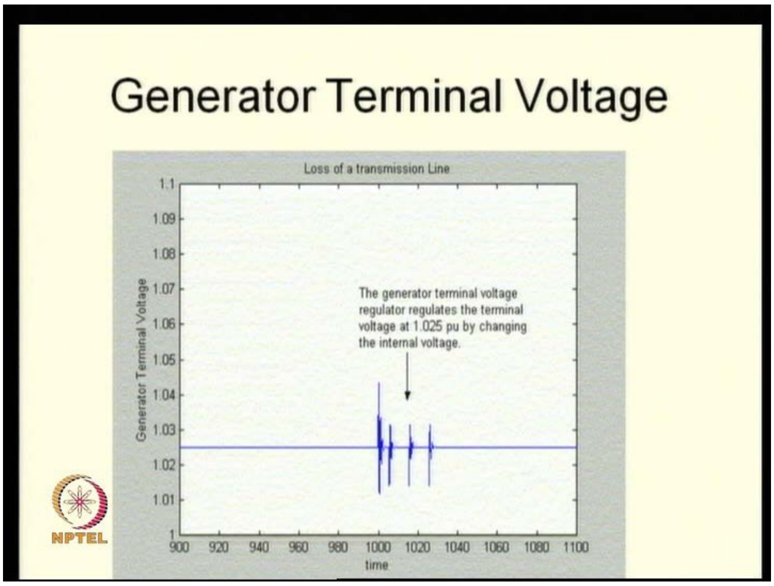

If you look at the generator terminal voltage. In fact, the voltage is maintained at point 1.025 almost strictly there is a terminal voltage of the generator, it is not E. It is the voltage which appears at the terminal of the generator, the generator terminal voltage is regulated quite well the reason of course, is that none of the limits are hit. So, that is one of the reasons why this happens.

In fact, if you look at the internal voltage E of the generator, what I call is Efd. You see that with every tap change, see what happens initially is that when the transmission line is tripped the voltage at the load decreases and eventually it turns out that the generator the voltage which is required the generator internal voltage which is required to maintain the voltage at 1.025 per unit, actually becomes smaller that is because the load probably drops, because of the trip of the transmission line, but as the load recovers it tries to draw the same amount of power by increasing the tap, you find that the reactive power loading or the current loading of the synchronous machine increases and probably the voltage at the terminal is tending to drop.

So, what happens is that the as every tap is increased the requirement of the synchronous machine increases the E requirement in order to maintain the terminal voltage of a machine constant increases. So, you see with every tap change the internal voltage increases but of course, it is much lower, it is still lower than the limiting value 2.75.

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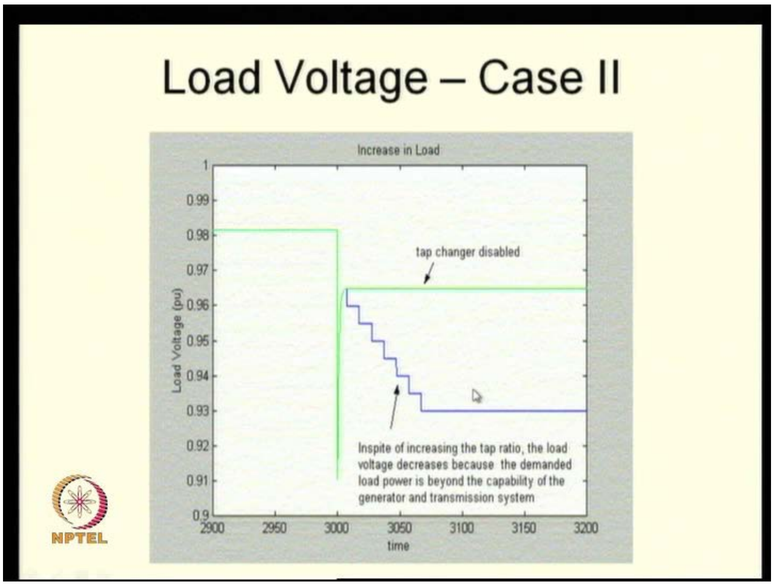

Now, what we will do is very interesting example is where we increase the load voltage increase the load admittance or rather you change the load admittance, you increase the load if you look at this load here this R is suddenly decreased or G is increased from 0.75 to 0.85. So, what you have done is increased the load on this system by changing R. If I decrease R suddenly your voltage here will change the load voltage will dip, because you have increased the load resistance. Now, if you decrease the load resistance, decrease your resistance the voltage here tends to drip and what happens is your tap changing action starts increasing A in order to keep this voltage constant.

Now, this would be a normal and natural thing to happen and well there is no problem in a way this is what one would expect a tap changer to do and probably, we think it would be doing the thing quite right, but actually the opposite thing happens. When you look at the step change in the admittance the surprising thing is that the voltage dips and the tap tends to as the tap is increased, you look at is blue graph as a tap actually increases, the tap ratio is actually increasing as I will show you in the next slide I will just show you that first perhaps.

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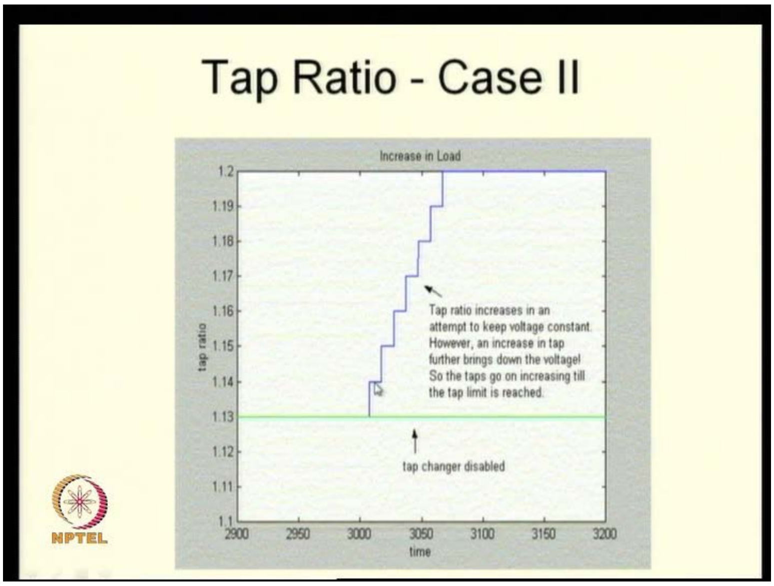

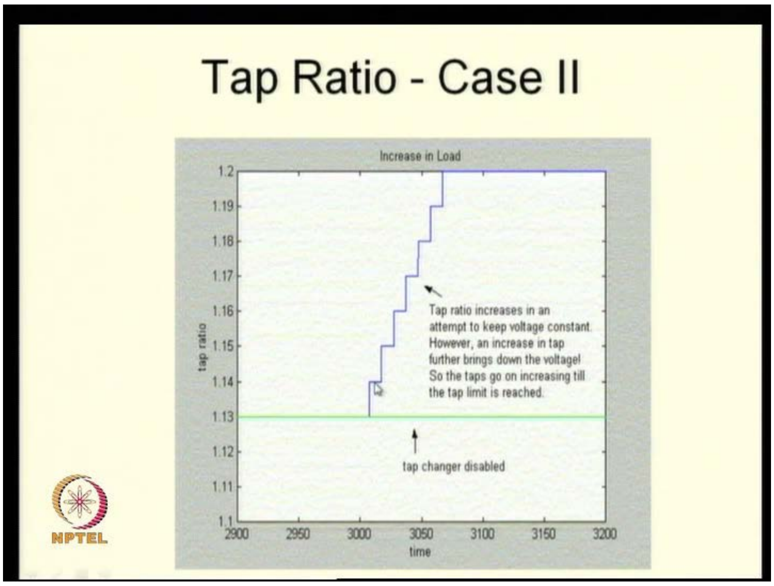

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The tap ration is increased to try to maintain the voltage V a constant, but the surprising thing is the surprising thing is as the tap a is increased the voltage actually starts dipping, every time I increase the tap instead of expecting, instead of having the voltage increase as I would have normally expected, the voltage actually dips increasing a voltage dips that is a very surprising thing the reason why that happens is that will be apparent in some in the next slide.

So, if you just right now we will concentrate on the blue graphs. We will come back to the green graphs a bit later. So, the blue graph show that a tap ration increases in an attempt to keep the load voltage constant; however, an increase in tap further brings down the voltage so the taps go on increasing so it is a kind of an unstable situation till the tap limits are reached, so you go on increasing the tap still tap ratio becomes 1.2 which is the limit.

Now, why is that happening? Now, what you notice here is the generator terminal voltage, when you increase this load admittance just concentrate on the blue graph right now, we will discuss the green graph a bit later. If you look at this blue plot as because of the load increase, the load admittance has been increase or the load resistance has been decreased the load on the synchronous machine has actually increased and because of that the voltage drops and every time the tap increases the generator terminal goes on voltage goes on decreasing.

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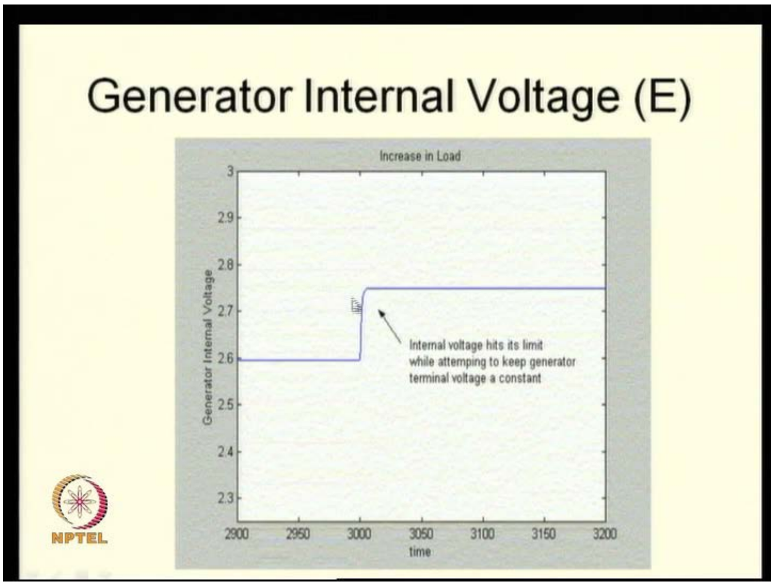

Now, why is it actually decreasing the generator terminal voltage after all is regulated right? The reason why it is going on decreasing, the terminal voltage is going on decreasing is because the generator the internal voltage of the generator or the field voltage which is proportional to the field voltage E has gone and 2.75 the upper limit.

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The continuous time upper limit has got has been hit. So, because of this reason the generator is not able to regulate the terminals, terminal voltage magnitude a constant because the internal voltage has hit its limit. So, the correct equivalent circuit now is the E rather the correct equivalent of a synchronous machine, which is unable to maintain its terminal voltage constant would be a large reactance as a synchronous reactants almost two per unit on its own base behind E which is around 2.75. Although E is 2.75 remember now it is a constant E, so when you are analyzing the system you will have to take the system as E which is constant and the system impedance now has to include that two per unit reactance of the synchronous generator, in some sense when the field voltage had not hit its limit and you heard this close loop voltage regulation this synchronous machine was effectively a stiff voltage source.

Because we could adjust the field in order to keep the terminal voltage constant, but this cannot be done anymore and now the machine is like a constant voltage source S but behind a large reactance. So, it is a constant voltage source of 2.75 per unit behind a large impedance and because now the impedance of the synchronous the of the generator is in series with a large impedance that is, in series with the transmission system and the distribution system impedances you have actually gone beyond the maximum power point of this system. So, if in fact, the R value or the load value has gone beyond the maximum power point, so any now attempt of the load to effectively draw the same amount of power, by effectively presenting to the system as a decreased reactance because of the action of the tap is bound to fail because a increase in the tap, increase in the tap, decreases the effective R seen by the system which in fact, results in lower power output or in effect the load voltage is not able to we cannot maintain the load voltage a constant.

So, that is a very interesting point that under certain circumstance the load taps changer in fact, does some kind of harm because every time the load tap changes the voltage actually decreases and this happens because the system impedance is become really very large. Now, let us focus on the green plot the green plot is a plot of if there was no tap changing action that is the tap changer has been disabled and kept at whatever value it was before this disturbance. The interesting thing is that if tap had not operated one would have settled down to value of 0.965 or so. So, per unit at the load, so interesting let if he had just disabled the tap things wouldn’t be so bad, but because the tap changing action is there we are ending up causing a voltage drop or a voltage collapse scenario because the tap changing action after the maximum power point is exactly the opposite of what is actually should be done.

So, decreasing the tap or rather increasing the tap actually results in lower load voltage the voltage V reduces. So, the same thing you can see with the terminal voltage of a synchronous, if the tap was not operated at all then we would actually have we would still be in an acceptable kind of scenario the voltage would have been lower, but you wouldn't have allowed voltage to collapse to an unacceptable value. So, this is what really this example tells you that sometimes the effect of load controllers like load online tap changers can sometime cause, some detriment to the system because under stress condition they may effectively present the load to the system as a very selfish load is drawing or trying to maintain its power no matter what kind of voltage is there at the terminal and if you try to do that you end up achieving exactly the opposite of what you intend to do. So, voltage actually decreases instead of increasing as you change the tap.

Of course, this happens only when the effective system impedance becomes large and in this case it becomes large because the field winding of a synchronous machine has set its limit and you can no longer regulate the terminal voltage thereby, the effect of synchronous reaction or the armature reaction of the synchronous machine really comes into full force. So, this is a example of a slow voltage collapse caused by tap changing action resulting in a selfish load. Now I told you sometime back I discussed in the previous class, that you can have under other situation where there is faster voltage collapse as well. Especially, when you have induction machines you know kind of stalling in case the voltage goes down voltage for example, if you have got a bus in which there are several induction machines and the voltage drops the slips off in the machine change, they draw more current cause a further drop in voltage and eventually you can land up in a fast voltage collapse even when you have got these kind of situations of course, if the system is strong that is the system impedance is large or rather system impedance is small the source impedance is small less likely you are going to have voltage collapse.

Now, so remember now in your mind try to this phenomenon actually looks quite different from the kind of phenomena we have seen you know when we are studying angular instability and so on.

Angular instability was different it pertained to the kind of phenomena which occurred when you connected two synchronous machine or many synchronous machines to each other and they do not stay in synchronism. Of course, one interesting point which you can just experiment taking the two machine example which you know we had discussed before coming to voltage stability is that in case a two machine or a multi machine system loses synchronism the voltage does vary very wildly, when you have got a loss of synchronism scenario.

We have discussed this sometime back when you have two sources of two different frequencies connected together by an a c transmission system, somewhere near the midpoint of this the transmission system the electrical center you can say the voltage undergoes very very large variations in case you lose synchronism. So, voltage variation or voltage dip after loss of synchronism can occur, but it is a distinct phenomena than this kind of system, this kind of phenomena, this voltage stability phenomena as you see is not really associated with relative angles of synchronous machine its completely a associated with the dynamics of the load operating in a low or larger or a weakened transmission or generation system.

So, this is what you should keep in mind as far as this phenomena is concerned now if you are studying slow voltage collapse like this one unload tap changing you can consider very simplified models, remember we have considered synchronous machine model which is very very simplified. It is more of a reasonable model rather than the derived model in the sense that the field the synchronous machine is represented by its steady state Efd behind a synchronous reactance. So, it is a kind of a steady state model E is practically proportional to the field voltage, but all the dynamics kind of has been gathered together and represented as a simple transom function one upon one plus S this is very kind of rough model but this you can actually show that this kind of phenomena can occur.

If you are going to if you are studying for example, fast voltage collapse for example, especially associated with induction machines in that case of course, you may have to model you know things in much more detail for example, if you have got one synchronous machine feeding several induction machines and under that circumstances you are studying actually fast voltage collapse. In that case you may have to model the synchronous machine and its excitation system in more detail this is something you should keep in mind but when you are studying o l t c kind of dynamics it is not necessary.

Now, we move on to another aspect which some in some sense in our last part of our course we have been kind of neglecting this aspect because some of them are very exciting and common phenomena in commonly seen phenomena in a synchronous grade relate to angular stability and you know stability of the frequency, or focus has been to a large extent in this course on slower transients you know this what we saw is an o this o l t c kind of transients, tap changer transients are ultra slow loss of synchronism and angular stability, relative angular motion were relatively faster but we have of course, faster transients compared to that we have other transients which are faster than that which we are not really analyzed or I have not actually told you of any phenomena which involves say transients which are faster or rates of change which are faster than say five ten hertz or so.

We are talking about swings, power swings etcetera. We have talked of that so far relative angular swings etcetera, they are much slower they are around one hertz and so on.

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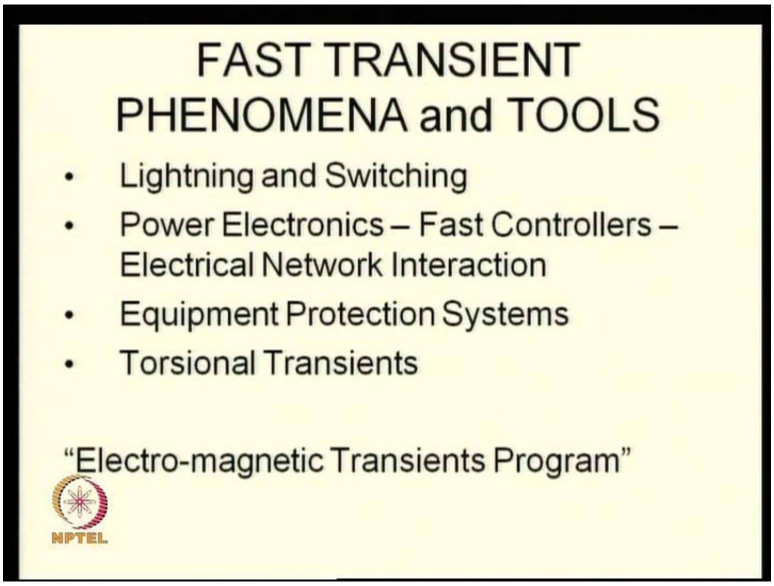

Now, if you are going to study faster transients, let us just have a look at what are the transients, fast transients phenomena which we have not really studied very much in detain in this course but of course, they are important this is a dynamics course. So, any transient is important for example, the phenomena associated with lightening and switching these are fast, very fast transients in which you may have to model a transmission line by distributed parameter model travelling wave phenomena really important here.

You may have you may want to study the dynamics of power electronic controllers for example, an h v d c system you want to actually see how the firing angle angular, firing angle controllers, the face lock loops synchronization system that is the synchronization system, current regulators etcetera work. They how they interact with the electrical a c network these kinds of transients also are fast and require you to model relatively faster phenomena you cannot use the approximation of you know for example, neglecting stator and network transients, so the network transients become important.

Another reason why you would be interested in studying fast phenomena was for example, how do equipment protection systems behave how do differential protection schemes are you know distance protection schemes behave for example, if there is a sudden fault in that case you will have to model the network in relatively more detail. In fact, many of these unbalanced disturbances something we have not really dealt too deeply into in this course. So, you can have unbalanced disturbances nothing in our course of course, prevents you from applying the modeling principle to fast phenomena as well but remember that this is one aspect we have not spent too much time in this course probably it will require another course to study the fast transients as well you know specific transients relating to fast phenomena.

Now, equipment protection schemes need to be checked out. So, you may actually need to see whether your protection logic or relay logic, protective relay logic is working fine or not, so that kind of a study, those kinds of studies may require you to model fast transients. You also have another kind of transient’s torsional transients which may be relatively higher frequency phenomena more than ten hertz kind of phenomena. Now if you look at that the basic tools which are required for studying fast phenomena they are kind of classified the generic name for a simulation tool which studies faster transients like the ones I have mentioned right now, is called the electromagnetic transients program this is generic name EMTP. These are a class of programs which study faster transients they model the network in detail in the sense that d by dt is you know which are not you know in when we are studying relative angular stability or slower phenomena we often neglect the in the d q reference frame the d by dt is associated the voltages and currents in the network.

Remember, we had in our study of the two machines system you know the neglected the transients associated with the stator and network. So, what we got effectively was algebraic relationship between the voltages and the currents of the network in fact, we use the well known admittance matrix to describe the behavior of a network by purely algebraic equations.

This cannot be done if you are going to study fast transient. So, the electromagnetic transients program in fact, does not model, in fact, does not make the kind of approximations we make often when we study slower dynamics like angular swings and so on.

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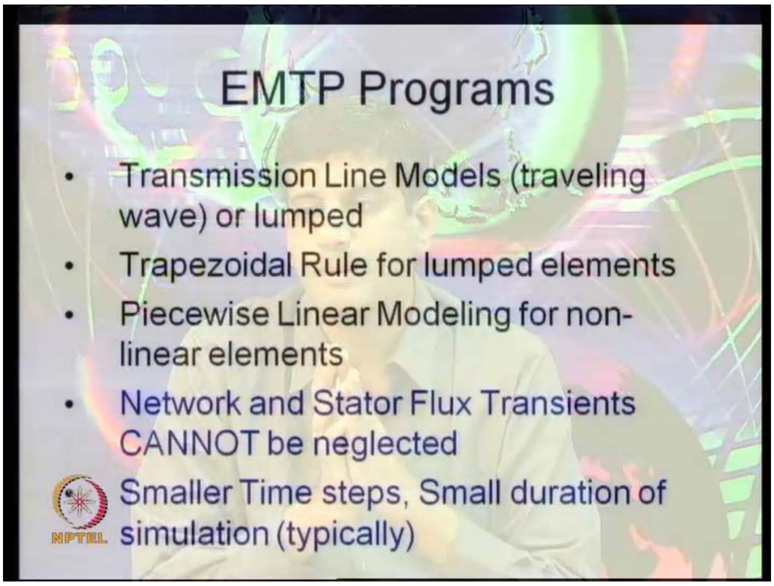

If you look at EMTP programs, if you look at the features of EMTP programs first thing is that because if EMTP can be used to study lightning and other and switching transients which are quite fast, very fast you may actually represent transmission lines by travelling wave phenomena that is the you know. What I would say is the partial differential equation kind of model you could also model it by lumped element, you can always model a transmission line by lumped l and c's. If you recall when we are talking of a transmission line models, we saw that for slower phenomena for on a slightly longer time scale a lumped pi equivalent of a transmission line will work just as well as a distributed parameter travelling wave kind of model, but for just the few you know may be tens of mille seconds after a disturbance you may see a significant difference between a lumped model which is an approximation of course, and a more appropriate the more exact travelling wave or distributed parameter model.

What is usually done whenever we have an if you look at an EMTP program is you know that if you are, when you are working with partial differential equations you have to solve partial differential equations but if you look at EMPT programs they do not really they do not look actually so complicated they do not really solve partial differential equations in the classical sense the transmission, we know that a lossless transmission line is a kind of has a travelling wave behavior.

So, if you recall what I discussed when we were discussing transmission lines the voltages at one end of a transmission line are related to the voltages and current at the other end of the transmission line some sometime ago. So, the voltages at the other end of a transmission line sometime ago are you know in some way you know manifest or someway manifest on one end of the transmission line. So, there is a kind of a transmission delay associated with purely lossless elements if you have got loss elements there is an approximate way to handle that.

So, EMTP program actually take help of this lossless model and kind of make an incremental change to include losses for lumped elements trapezoidal rule is used, so you can actually get a relationship between the value of a variable at the k th instant and the k plus one the instant discreet time instant. So, usually trapezoidal rule is used for the lumped transmission line, network transmission line elements if they are non-linear on-linear elements in the network you use piecewise linear model you assume that the model is linear piecewise, so if you have trying to model saturation for instance you do not assume it is a continuous kind of curve but the piecewise linear kind of curve this kind of approximations are made in order to make the program more efficient.

Network and stator transient cannot be neglected in any m t p kind of study. So, you have to model all the d by dt’s associated with the stator flux in a synchronous machine and of course, EMTP programs typically are for small duration you try to see what happen just after a fault for a short duration. So, you can in fact, model things like synchronous machines and our speed dynamics you can in fact, freeze them you know you can assume that the speed of a synchronous machine or the rotor angle is almost a constant if you are if your simulation is for a short duration but you will usually use smaller time steps the time steps in a EMTP kind of program can be quite small, say for if you are doing a study to often HVDC system in which there switching's occurring every say 12th of a cycle .

You may for getting adequate accuracy huge time steps of a say around fifty micro second or so, these kind of time steps are used in EMTP kind of programs.

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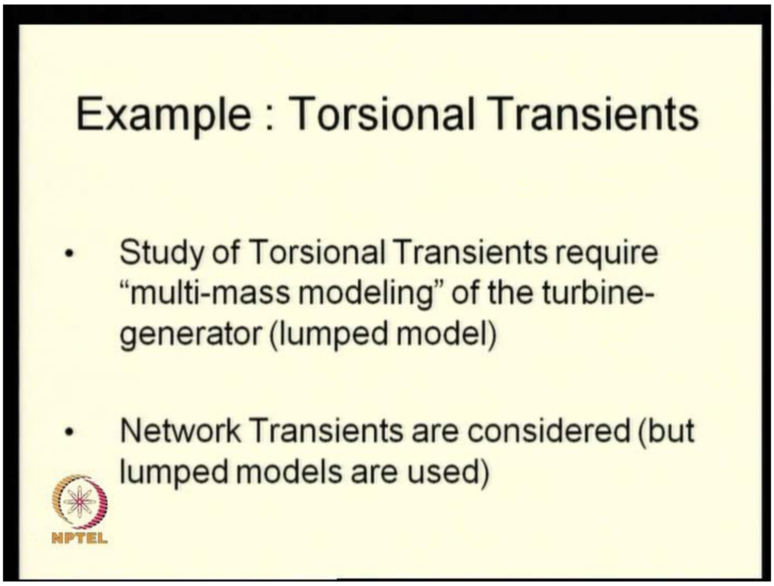

We will now study one particular kind of example of fast transients it is not as fast as lightning transients, but this transient has typically a band width or rates of change which are approximately greater than ten hertz. So, its they are faster than relative angular motion but not as fast as lightning or switching transients, so this particular example is something we will discuss in the next lecture its relating to torsional shaft torsional transients, which do require you to model the network in detail, I mean detail in the sense that you cannot assume that network and stator flux transient are neglected.

So, this is something we will do in the next class; it is a example of an interesting phenomena which is relatively fast. So, we will get this balance back into the course of considering at least some one phenomenon pertaining to faster transients, so this is something we will discuss it is a very very very very interesting thing which occurs. So, we will use the twin tools of Eigen analysis, and simulation to understand this phenomenon. So, that we will do of course, in the next class.