

Power System and Dynamic Control
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Module No. #01
Lecture No. #01
Introduction

Welcome to the course on power system dynamics and control. Power system dynamics and control is a subject which is concerned with the transient processes which occur in the power system. A power system is continually subjected to some disturbance or the other the disturbance could be severe like lightning, which may result in the tripping of some of the power system components or it could be very benign in the sense that a load change also is a kind of a disturbance on a power system. So, if you for example, switch on a bulb you are actually subjecting the power system to a kind of a disturbance.

And we would expect that whenever the power system is subjected to any disturbance you would expect that it would settle down to some kind of equilibrium. So, even without going through the whole you know detail of what is stability and what is equilibrium what is instability? We have a kind of intuitive notion about stability in the sense that we expect that voltage magnitudes which are available to us are going to be steady, the frequency also is steady. So, the fact that for example, in this class room the bulbs and lights are absolutely steady in a sense shows that the power system at present is stable.

However there are situations in which a power system may lose stability, and it can happen quite dramatically. In fact if you look at the past few years, past 10 years you will find that some larger small grid disturbances have taken place in which some kind of instability is occurred and there has been consequent loss of load to a customer. So, you will see that this it is important to learn the subject you will notice that a power system is in fact a very very very large system. It consists of many components, diverse components and is spread over a huge geographical area. So, typically you know power system could span entire nation. For example, 10000's of kilometers.

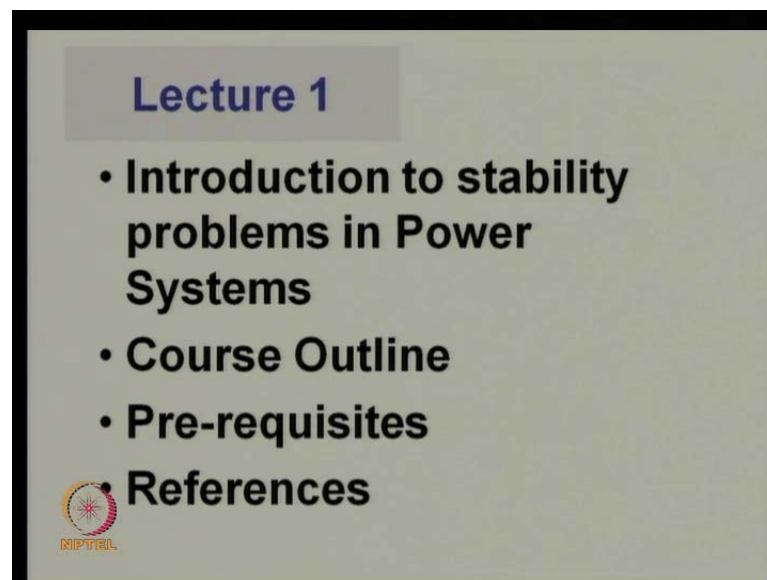
So, it is important to learn the subject of power system stability so, that we can design, operate a power system in a reliable fashion. The word plug and play has been invoke for

almost two decades, but in a way a power system has been a plug and play system for more than a century. To make a power system work normally one has to control it as we shall see there is some inherent phenomenon, which occur in a power system, which led to instability? So, we should operate or control the system so, that it is stable.

Before we go ahead with what is stability and what are the basic phenomenon which occur in a power system? Let us first understand what is the structure of today is power system? As I motioned it is a large system, having a large number of diverse components. The first lecture is usually an overview of what we are going to study in this whole course about forty lectures. So, I would not deviate from the tradition we will have a overview of the course in this lecture as well as the next.

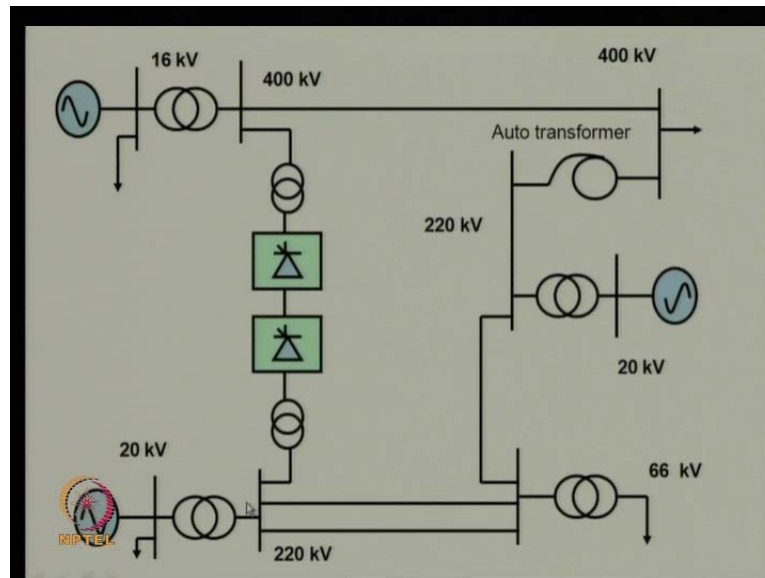
Today I will concentrate on showing to you a nice phenomenon we will even have a small video clip to display to you a certain kind of phenomenon which occurs in power system it is very interesting, but, first let us have a look at what we are going to study in this particular lecture?

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We will have an introduction to power system problems, stability problems in power system in particular we will concentrate on one particular phenomenon today. Then around the end of this lecture I will give you a course outline some prerequisites and the reference books.

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So, as I mentioned some time back let us first try to understand the structure of a bulk power system. So, the next point which we are going to study is the structure of bulk power systems. If you look at power systems of today they are spread over a huge geographical area and consist of generators, interconnected to each other, they all interconnected to each other through a bulk transmission network. For example, here there is a generator which generates power electrical power at a voltage of around 16 kilovolts.

A single unit could be generating as high as 1000 megawatts, I mean there are generators the unit size is 500 megawatts, 1000 megawatts, 200 and 10 megawatts. So, each unit could be itself generating 100s or even a 1000 megawatt and there could be several such units within a power plant though here I have just shown you one. The voltage 16 kilovolts is inadequate for power system transmission otherwise it will cause a large amount of losses if you try to transmit this electricity over large distances. So, what we have is a step up we step up the voltages to around 400 kilovolts or 220 kilovolts so, that we can transmit it over large distances. Load centers could be some times several 100s of kilometers away from where the generation is.

So, you cannot avoid transmission so, you what you see is that you have high voltage transmission lines. So, that you can transmit bulk power over large distances with lesser losses. They can be actually several e h p voltage level extra high voltage levels for

example, 200 and twenty and 400 k V system. In fact the 200 k V system may be embedded in a 400 k V system but, to interconnect the 400 k V and 220 kilo kilovolt system you do require a transformer, in this case it is a autotransformer.

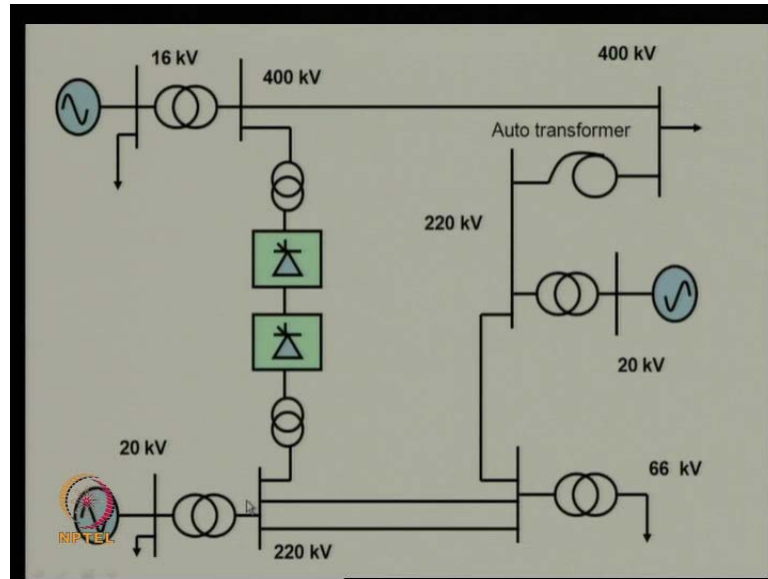
Do you know why we use an autotransformer in case you want to transform voltages say from 400 k V to 220 k V, Whereas, we use a 2 winding transformer when we want to step up voltages from 16 to 400 to k V? The answer lies in the fact that whenever the voltage step up ratio or step down ration is relatively small in this case around two and autotransformer gives you a cost advantage, a substantial cost advantage. Moving on we see that a power system may be meshed in the sense that there may be two parallel paths, two transmission paths from point say a to b, you can go ahead go from here or you can go here.

So, in some sense a power system being meshed is also quite reliable in the sense that if one of the transmission path say this transmission line is tripped you do have alternative power transmission paths. Now, you in addition to a c lines you could have in special circumstances d c lines, d c lines essentially are transmission lines which are operated at d c voltages obtained by rectifying the high voltage a c and inverting it at the other end. So, you have got a kind of an h V d ceiling here.

So, large power systems typically will have 1 or 2 h V d ceilings embedded in them. We shall see later then at that h d V ceilings may also be used for special interconnections called Asynchronous Interconnections. Now, one of the most important thing of course, is that loads are supplied at relatively lower voltages, they are 66 k V which is stepped down further right down to 230 volts phase to neutral which appears in your electricity outlet in your home.

So, this is the structure of the bulk power system from here onwards the load is at lower voltage and from here onwards power system is more or less radial. But, at the bulk level there is some level of meshing that is the parallel paths from any point any note from say a to b.

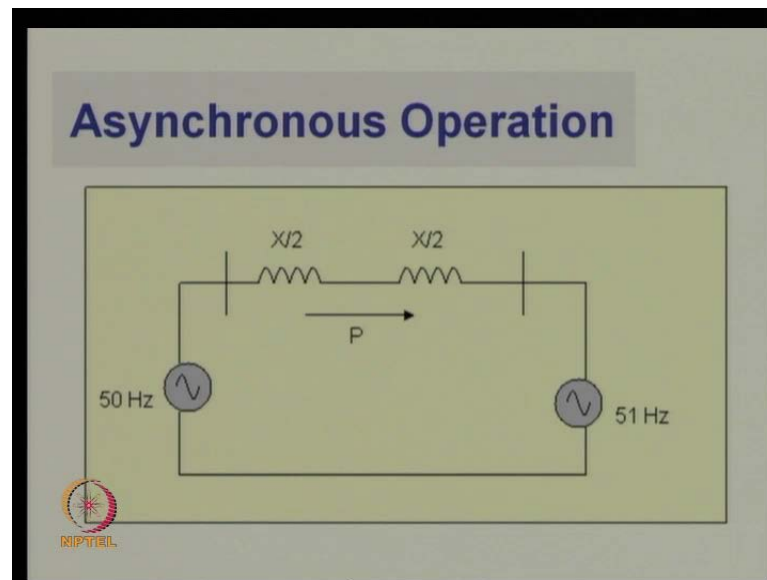
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So, some of the characteristics of synchronous grids today are that they are 3 phase a.c. They are essentially synchronous systems, which I shall elaborate on this point and that are usually connected by a.c. lines. Except for special situations like very long distance transmission or a synchronous connections d.c. links are used.

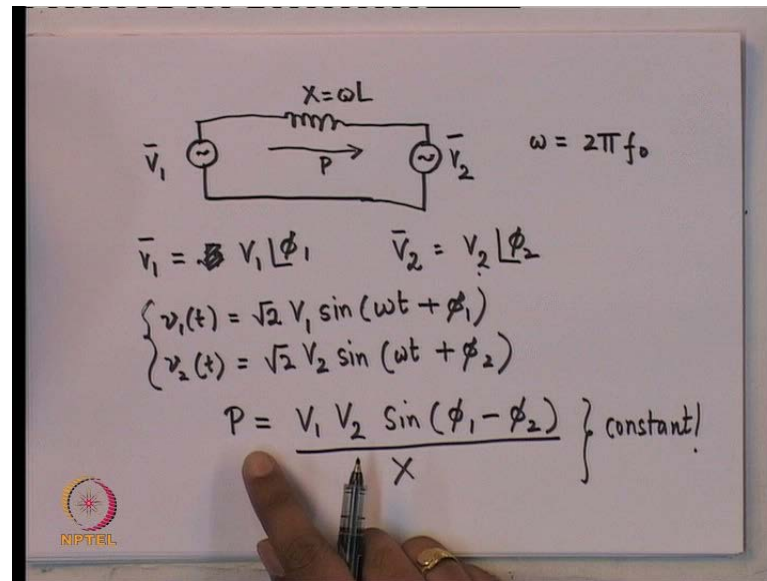
So, you will find that mainly the a.c. power system of today is consisting of synchronous machines interconnected by a.c. lines. Now one of the most important implications of this is that all the synchronous machines in steady state operate at the same frequency, this appears almost surprising but, if you kind of take a special situation or you take a typical situation you will find that if two synchronous machines are connected to each other and they are running at different frequencies we will not have steady magnitudes of voltages or power flows. To see this let us consider a simple example.

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Consider two synchronous machines one operating at 50 hertz and the other operating at 51 hertz. The question is what is the nature of power flow between the two generators? In fact in this particular diagram you have got a synchronous motor and a synchronous generator. So, if one of the synchronous machines is operating at 50 hertz and the other at 51 hertz what is going to be the nature of power flow and the voltage is at certain points in the network. You will notice here that the synchronous machine has been represented by a voltage source. In fact most of my all other a large part of my course is going to tell you how a synchronous machine is not actually a voltage source but, something much more complicated.

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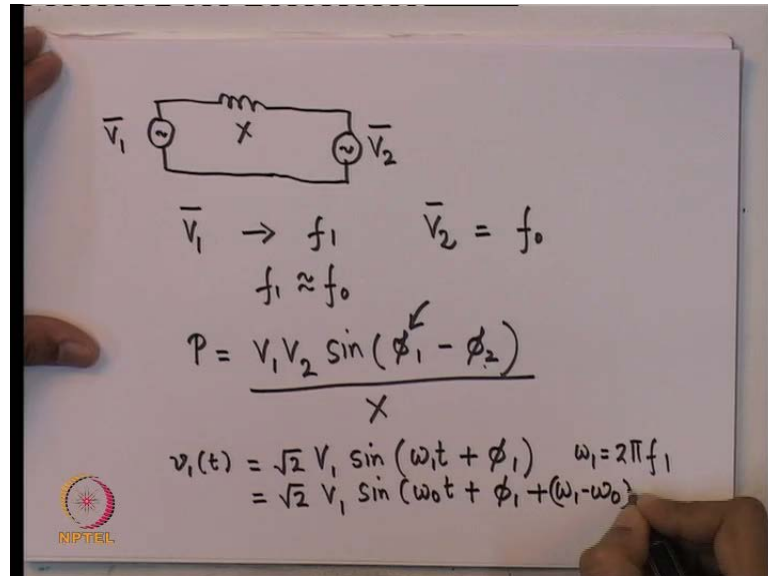
So, let us actually analyze this situation where you have got one synchronous machine which is operating at 50 hertz and the other at 51 hertz. If we have got two sources connected to each other, by a transmission line which is represented by its reactance x , in fact there is a big story of how we come to this representation of a transmission line by lumped inductor but, we will keep that for some other time. In fact x is nothing but, the frequency ω into the inductance of the line. So, the inductance in fact is the inductance per unit length into the length of the line.

Suppose you have got two sources, V_1 bar and V_2 bar. So, this is the phasor representation. Suppose V_1 bar is equal to $V_1 \angle \phi_1$ and V_2 bar is equal to $V_2 \angle \phi_2$. V_1 is the magnitude of the phasor V_1 bar. What does this actually mean the phasor representation? Let us assume of course, that the frequency of both the sources is equal that is say f_0 could be say 50 hertz. So, the instantaneous value of the voltage waveform here is $\sqrt{2} V_1 \sin(\omega t + \phi_1)$ and V_2 is equal to $\sqrt{2} V_2 \sin(\omega t + \phi_2)$.

So, V_1 bar and V_2 bar essentially mean this. What is the expression for power flow from source first source to the second source, in case your phasors are defined in this way and both the sources are at the same frequency. You know the well known formula power flow p is equal to $V_1 V_2 \sin(\phi_1 - \phi_2)$ upon x . If V_1 and V_2 bar are phasors V_1 bar and V_2 bar are phasors and essentially $V_1 V_2 \sin(\phi_1 - \phi_2)$ are constants

then what you have is that this is a constant. Remember that in a 3 phase system cumulative 3 phase power flow is a constant, remember in a 3 phase formula of power V_1 and V_2 represent the line to line r m s voltage magnitude at ends 1 and 2 respectively.

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Now if you have got a source, V_1 has a frequency f_1 and V_2 has a frequency f_0 . There is a difference of frequencies here, in that case the question arises how do you get the power flow expression. Now to a very good approximation if f_1 and f_2 are mere equal in that case I can directly use this formula $V_1 V_2 \sin(\phi_1 - \phi_2) / X$ but, remember now this ϕ_1 is changing with respect to ϕ_2 , how is that so, see you can write V_1 of t is nothing but, $\sqrt{2} V_1 \sin(\omega_1 t + \phi_1)$ where ω_1 is equal to $2\pi f_1$. So, we can write this is nothing but, $V_1 \sin(\omega_0 t + \phi_1 + (\omega_1 - \omega_0)t)$.

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$$v_1(t) = \sqrt{2} V_1 \sin(\omega_0 t + \phi_1')$$
$$\phi_1' = \phi_1 + (\omega_1 - \omega_0)t$$
$$v_2(t) = \sqrt{2} V_2 \sin(\omega_0 t + \phi_2)$$
$$\text{exact} \rightarrow P = \frac{V_1 V_2 \sin(\phi_1' - \phi_2)}{\omega_1 L \text{ or } \omega_0 L}$$

$\omega_1 \approx \omega_0$

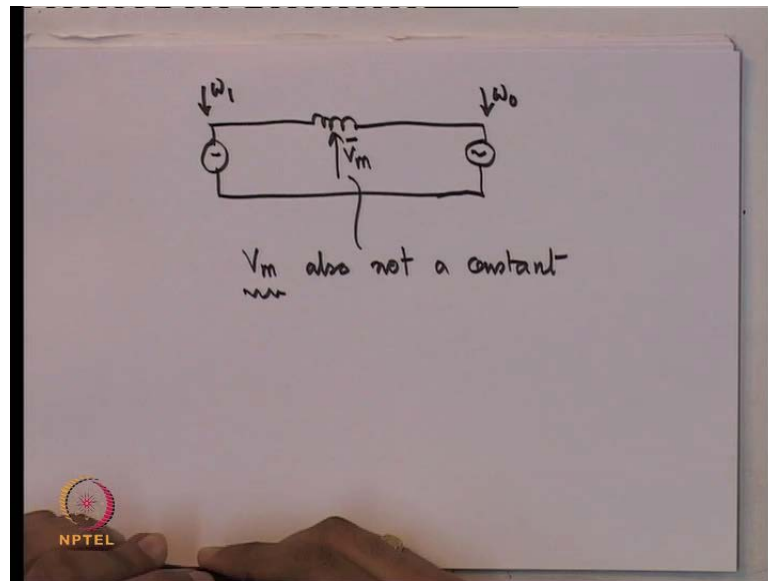
P will NOT BE A CONSTANT.

So, what we have is V_1 of t is nothing but, $\sqrt{2} V_1 \sin(\omega_0 t + \phi_1')$ where ϕ_1' is equal to $\phi_1 + \omega_1 - \omega_0$, it is changing with time. V_2 of course, is nothing but, $\sqrt{2} V_2 \sin(\omega_0 t + \phi_2)$.

So, you have when I apply this formula, I should use $\phi_1 - \phi_2$ by x . This is the way you will apply this formula even here you will notice that this is an approximation you cannot have power, equal to, this expression exactly one of the objections which you will immediately see is that when I use this value of x should I use ω_1 or should I use ω_0 .

So, there is a this formula cannot be exact but, I leave it to you to show that this formula is approximately true you can directly use this formula for power flow if ω_1 is approximately equal to ω_0 they are not equal but, they are mere equal. Now what do you see in this formula the power flow is not a constant remember ϕ_1 is changing with time.

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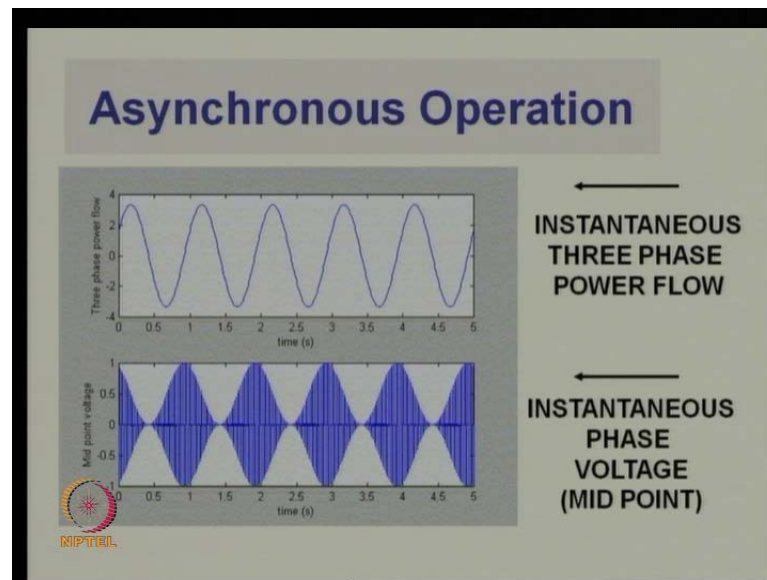


So, what you have is in case the frequency of the two sources is not equal power flow, 3 phase power flow will not be a constant. It keeps jumping around, can you also show that if you have got a source rather two sources with two different frequencies the midpoint voltage, the magnitude of the midpoint voltage, also will not be a constant.

So, magnitude of the midpoint voltage is also not a constant if the frequency ω_1 of this source and ω_0 of this source is not equal. So, the basic thing which I wish to tell you here is that if I do connect two synchronous machines together and your operating at different frequencies they may very close to the frequencies may be very close to each other but, they are slightly different then you will find that both the power flow as well as the voltages along the transmission line this something you can generalize. I am not going to be constant, they are going to keep jumping around so, your voltage will not be a constant at a particular location.

So, you cannot have a situation, you cannot have a steady situation if your voltage is rather the synchronous machines are not operating at a same frequency this is bit (()) because it means that if I have got synchronous machines which may be thousands of kilometers away but, if they are interconnected by a c lines then in steady state they have to be at the same electrical speed.

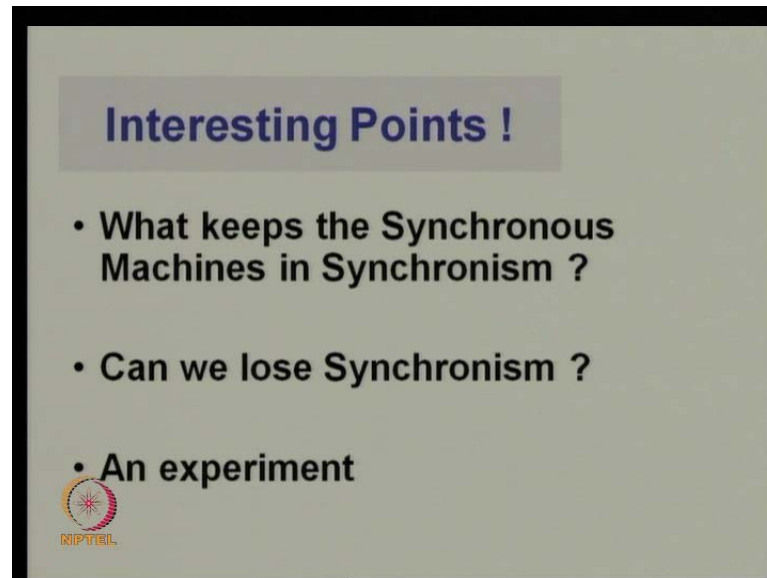
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See I just plugged in these values with two sources at 50 hertz and the other at 51 hertz and the way forms which you get are these. So, this something which are explained to you analytically that your power flow is not going to be a constant and the midpoint voltage for example, also keeps jumping around it actually jumps around at a difference frequency.


So, if you have got two sources one at 50 hertz and one at 51 hertz and you connect them together then you will find that the voltage is jumped around at a different difference frequency. So, the point of course, here is that we cannot operate steadily in case if you got synchronous machines connected by a c line, if they are operating at different frequencies.

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Interesting Points !

- **What keeps the Synchronous Machines in Synchronism ?**
- **Can we lose Synchronism ?**
- **An experiment**

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So, something which obviously comes to your mind is what keeps the machines in synchronism? Can we lose synchronism? The answer to the first question is something which you will learn in this course. The physical equations, we described the motion of synchronous machines as well as the behavior of the electrical network really determine the fact that synchronous machine tend to stay in synchronism if they are interconnected.

So, if you take two synchronous machines and interconnect them properly then they tend to stay in synchronism unless they are subjected to a large some large disturbance is certain large disturbance, if the disturbance is very large it may. So, happen that synchronous machines may lose synchronism.

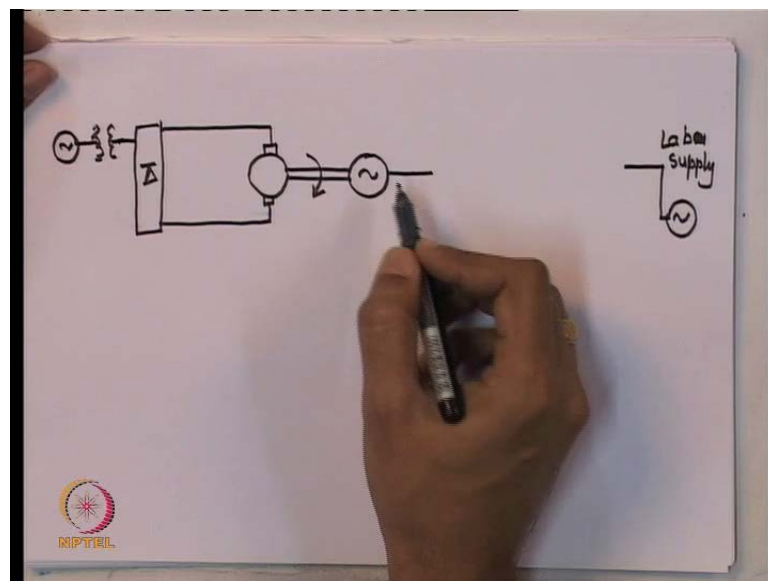
So, what you have is once the machines lock on to synchronism. They move together if there is a disturbance they could be a transient but, eventually the systems stays in synchronisms. So, a system operator does not have to do any manual intervention to ensure that the synchronous machines in our system are remaining in synchronism.

However, a system operator has to know and understand that a system can the synchronous machines can lose synchronism under certain circumstances. In fact I will show you a situation in which synchronous machines are going to lose synchronism in fact the highlight of this lecture in fact is a small video clip which I am going to show of synchronous machine losing synchronism in a laboratory.

So, this is the first and one of the most interesting stability phenomenon which you have you are going to learn in this course. Of course by the time you are able to analyze this particular phenomenon in a more rigorous fashion remember I took recourse to somewhat you know approximate expressions for power flow in case of synchronous machine operating at different frequencies and try to prove to you that the synchronous the system will be very unsteady in case your frequencies are different.

But, later on in this course we shall take a more rigorous modeling approach and we will try to rigorously show that this in fact is true. But, today I will show you a video clip in which you can actually see this loss of synchronism and once you lose synchronism of course, things are not steady and when you have synchronous machines not in synchronism you have to disconnect them. So, before we show you that video clip of the experiment, let me just tell you a bit about the experiment so, that you can appreciate what is really going to be shown to you.

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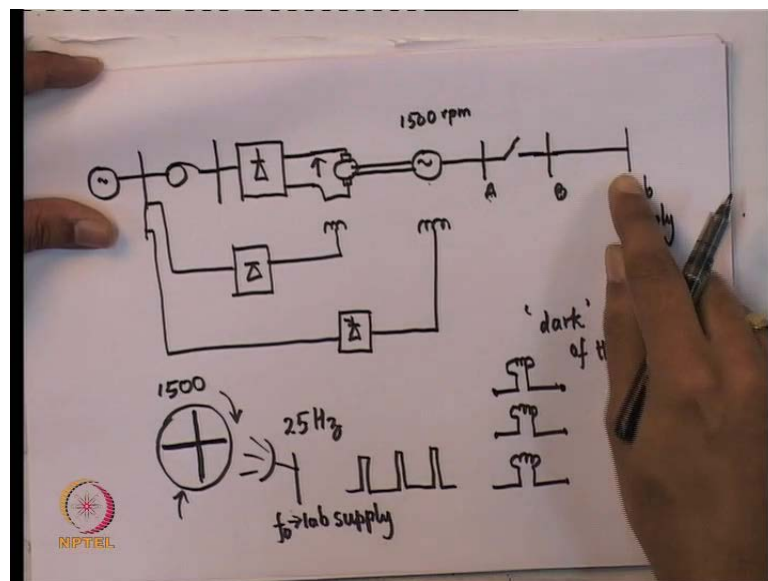
What we have in the laboratory is a synchronous machine, the synchronous machine I will just show you a very simplified kind of single line diagram will be interconnected to the laboratory 3 phase supply it is a 3 phase synchronous machine running at 1000 r p m roughly run 1500 r p m it will be interconnected to the lab supply.

The lab supply of course, is obtained from the western region power grid of India. So, here when I am going to connect this synchronous machine to the lab supply I am in fact

connecting it to the huge western regional grid of India. This synchronous machine is run by a prime mover. In a real power system this prime mover could be a steam turbine, it could be a hydro turbine. In the laboratory it is in fact a d c machine, a d c machine which is connected to a rectifier, which gets its supply from a transformer, which is again being fed from the laboratory supply. So, what you have here is the laboratory supply is supplying power to the d c machine, the d c machine runs as a prime mover to the synchronous machine and eventually of course, we will put this power back to the lab supply.

In the real system this would be a turbine, a steamed or hydro turbine. We are able to vary the voltage applied to the d c machine by actually this is not a two winding transformer actually it is a it is actually, we will just redo this.

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This is a laboratory supply it is in fact connected to an auto transformer. So, this is in fact connected to an auto transformer, it is connected to a diode rectifier, this is in fact connected to a d c machine. The d c machines run the synchronous machine. The same lab power supply also feeds the field winding of this d c machine.

So, the field winding of this d c machine is actually being fed from the lab supply also. This auto transformer of course, is a variable auto transformer. So, actually I can change the voltage to the d c machine by changing the auto transformer tabs. The field of this synchronous machine is also fed through a control rectifier which is also being fed from

the laboratory supply. We can actually control the field current to this field winding of the synchronous machine by controlling it through a controlled rectifier the reason why we need to control it actually is that once we load a synchronous machine the voltage tends to fall at it is thermal.

So, we are actually having a close loop regulator which roughly not perfectly regulates the output voltage of the synchronous machine. The synchronous machine is driven at roughly 1500 r p m which is the frequency of a laboratory supply, I would say 50 hertz is the a lab laboratory supply frequency and this is the 4 pole machine.

So, we have actually run it at 1500 r p m. The synchronous machine has to be connected to the lab supply now it is connected to a lab supply but, can you connect it directly you must have done this experiment in your under graduate years it is called synchronization of a synchronous machine to a power grid, you have to do it carefully in fact if you do not do it carefully you will you may find it the transients may be undesirable and unwelcome and you may not be in fact able to synchronize properly also to the grid.

Besides giving a big shock to the shaft of the synchronous machines so, you have to actually do this synchronization process very carefully one thing you have to check is that the voltage at this point, the voltage phasor here and a voltage phasor here should almost be equal. So, if I connect this synchronous machine when the voltage phasor here and a voltage phasor here is almost the same then you will find that it will be a fairly bumbles transfer. Of course, it is simplest that this is a 3 phase system so, actually this has to be insured at all 3 phases.

The frequency of both the systems, the lab supply as well as the synchronous machine output also must be mere equal and a phase sequence also should be the same.

In that case we can have a steady state power flow. We can actually have a steady state power transfer between the synchronous machine and a grid. Now how do we ensure that before you connect the voltages are almost the same, the voltage phasors in each phase are almost the same, you do it by measuring the voltage across both points or one simple way of doing it is you connect some high resistance bulbs in each phase.

So, if you have got point A and B in parallel with this switch you connect a bulb. If this bulb is always dark absolutely dark it would mean that the voltage is across a and b is

equal all the time. And in that case it is a good time to switch on this but, of course, if the frequency of this synchronous machine and the lab supply is slightly different from each other the phasor voltage a with respect to the phasor at b will be continually changing and you will find that the lamps will glow bright and dark.

So, you should connect at a point or you should adjust the speed. So, that the voltage is here and here are almost equal. So, you should switch on it a point at which the voltage is here and here are almost equal and that occurs when you have got a dark appear. This will become very clear when we actually do the experiment, now one or two small points. The synchronous machine on a shaft I mounted a plate on which made a cross mark.

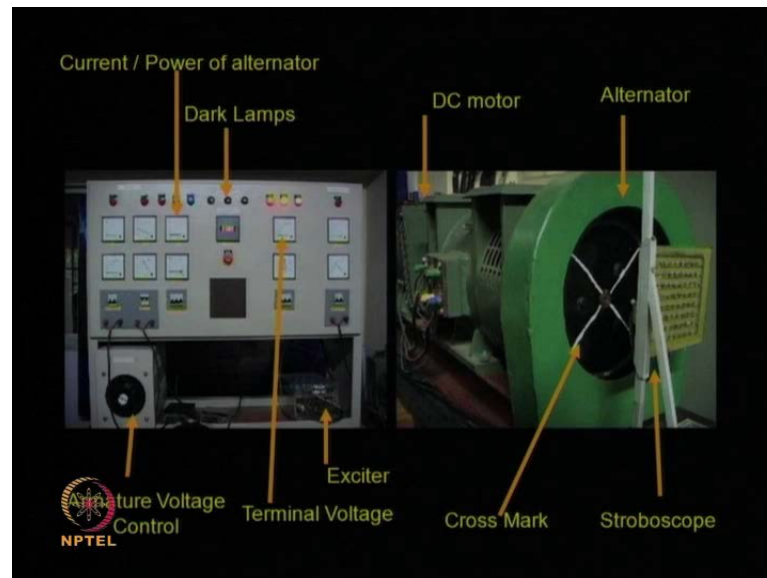
When the machine rotates you will not see this cross mark normally, because it rotates at a fairly high speed you will not actually be able to make out the cross mark it is a white cross mark but, if I got a device called a stroboscope. The stroboscope which is essentially a device which gives flashes of light at the frequency, at a certain frequency you will find that suppose for example, this is moving at 1500 r p m and this flashes at 25 hertz. It gives a very narrow pulse of light at 25 hertz so, it is giving a narrow pulse strain in fact of light at 25 hertz.

So, what you will find is that whenever there is a pulse of light you will see this cross. The next time the pulse of light comes this cross would have completed one revolution and it will exactly at the same point again. So, using a stroboscope with which is flashing at 25 hertz. If you look at a cross mark which is rotating at 1500 r p m which is again 25 hertz, you find that it is look stationary. So, in fact if I connect this stroboscope such that it flashes at the frequency of the lab supply. So, it flashes at the frequency of the lab supply I can make out whether I am in synchronism or not by looking at whether this crosses stationary or not.

If these crosses slowly moving it would mean that the frequency of this rotation is almost equal to the frequency of the lab supply. So, what I will do is that I will arrange so, that this stroboscope is in fact flashing very narrow pulses of light at the same frequency. At this lab supply in fact it senses of 4 pole machine I will be actually reducing the frequency by half and making it flash at 25 hertz or whatever the laboratory frequency

half of it. So, this is something you will notice in this experiment before we show you the video clip I will just show you how this setup looks like.

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So, this is the still photograph of the laboratory setup. I will quickly show it to you this is the synchronous machine this one here, this is the d c machine, this is d c motor which is the prime mover, this is the cross mark I was talking about, this is the stroboscope which flashes at half the frequency of the laboratory supply. So, that if the 4 pole machine runs at the same frequency or rather the electrical frequency if it is near 50 hertz which is near about a laboratory frequency you will find that this cross mark is moving very slowly and when of course, the frequencies are equal this cross mark appears absolutely stationary.

This is the panel which we use to control and measure the synchronous machine parameters. Using this auto transformer I am able to do armature voltage control of the d c machine. Remember by changing the armature voltage I can increase the amount of torque provided by the d c motor at a particular speed. So, if the d c motor is running at a particular speed and I increase the armature voltage it will increase the armature, it will increase the torque of the d c machine motor. So, I can actually increase the amount of power, mechanical power available at the shaft of this machine.

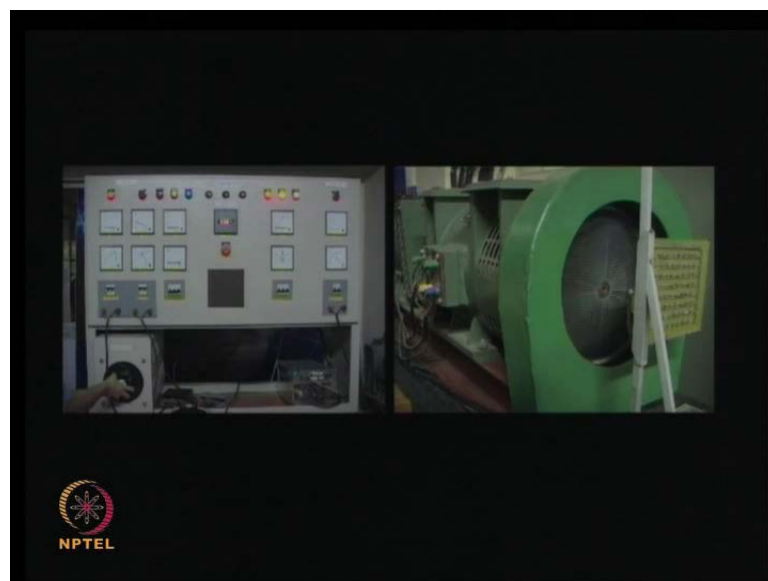
Once I synchronize this synchronous machine to the grid I will in fact increase the power input to the d c motor by increasing the armature voltage and I will try to push more

power into the laboratory supply. The current and power of this alternator are few by looking at these two meters, this is the frequency, this is the synchronization switch, this is the dark lamp corresponding to the 3 phases, this is the terminal voltage of the machine, this is the field voltage and field current of the machine.

So, I hope you will get a kind of a feel of the lab laboratory setup which you are going to see. Now over to the video clip, what you are going to see here is that if I, once I synchronize the machine to the grid, if I increase the power flow beyond a certain point you will find that the machine which actually is in synchronism with the grid after it is connected, falls out of synchronism.

The important thing is that while I am increasing power a little bit this synchronous machine does not lose synchronism you will only find at the cross mark is moving showing that there is some temporary acceleration of the machine but, the machine still remains in synchronism once it is connected to the laboratory supply.

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But, after the point you will see something happening so, over to the video clip. We start the machine the d c machine by armature voltage control. The d c machine field has already been switched on. So, the machine has started the cross mark on the machine is not stationary indicating that the speed of the machine is not equal to that of the grid. We now excite the synchronous machine, the voltage builds up in a controlled fashion we are

increasing the field through a controlled exciter. So, it gradually increases, it is a ramped up there it goes approximately up to 150 it is programmed to increase that way.

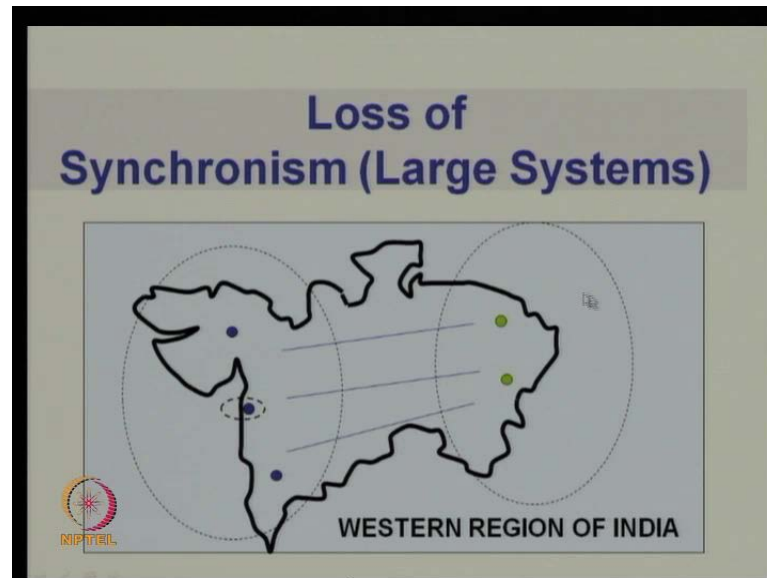
We now give step changes to the voltage reference of the controlled field. So, that we get the voltage near about 230 volts which is equal to roughly the voltage of the power supply, the lab power supply. We now switch on the laboratory supply and as I mentioned in my some time ago, the dark lamp starts start glowing at and a bring can glow at a difference frequency we control the speed of the armature by armature voltage control. And we get the speed almost equal to that of the grid and we synchronize and you will notice now that the cross mark is absolutely stationary.

Once they are synchronized we can feed power into the grid by increasing the power output of the synchronous machine this is done by actually increasing the power input to d c shunt motors.

So, you see how the power is increase and simultaneously you will find that the cross mark is moving. If we increase it beyond a point. However so, he is doing that so, increasing the power input beyond a point. And after a point it just loses synchronism, see how the current and power meters move quite widely even the terminal voltage of the machine keeps jumping around note that we are still connected to the lab supply but, we have gone out of synchronism.

And we cannot operate this way actually because the torques, the power, voltages all fluctuates very widely so, eventually we have to disconnect. So, this is basically a illustration of the loss of synchronism phenomenon of a synchronous machine connected to the lab supply. What we saw was if we synchronize the machine it locks on to the frequency of the lab supply but, if we go on increasing the power beyond a point the machine can lose synchronism.

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So, we now stop and shut down the machines. A natural question which may come to your mind is when you have a large system can you use synchronism in the same way as the synchronous machine in the laboratory which we saw some time ago, the answer is yes.

For example, in the western region of India, we have seen that in the past decade they have been several instances where this is happened. When there is a large disturbance groups of machines on one side of the grid fall out of synchronism with other groups of machine on the other side of the grid. Here of course, I have just shown you a few machines there are lots and lots of synchronous machines interconnected by lots and lots a c lines what I am showing here is just a schematic. So, you find a group of machines the big group of machines fall out of synchronism with another group of machines.

This is in fact the manifestation of the same phenomenon which you have seen in the laboratory. So, you have got a set of machines they tend to remain in synchronism when connected by a c lines when the synchronous machines connected by a c lines but, when subjected to a large disturbance these may fall out of step.

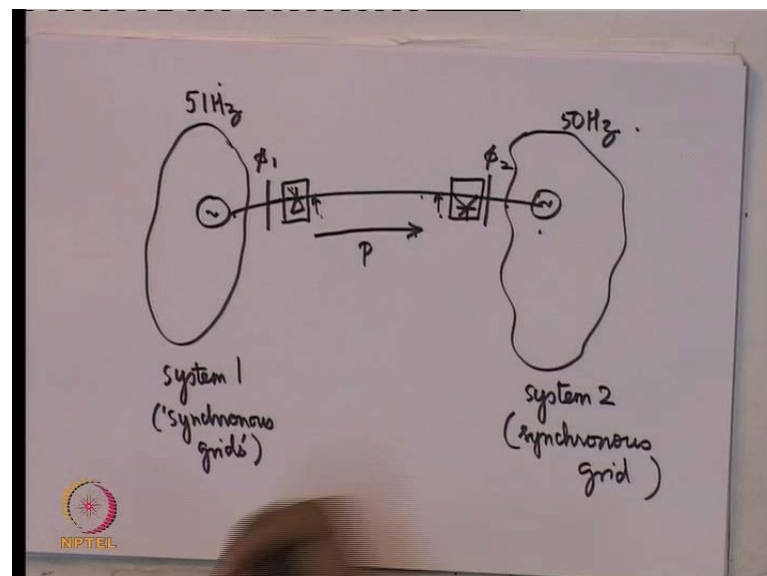
Once they fall out of step the power flow in the a c lines as well as the midpoint voltage keep on jumping around and you will have to actually separate out this systems, you cannot operate that way in fact when machines lose synchronism they can cause large transient power and therefore, shaft darks which may damage a synchronous machine.

So, that is the reason why we do not, we cannot continue to operate under losses synchronism conditions but, as you saw in the laboratory when you connect a machine to a laboratory supply it does tend to remain in synchronism and slight changes or disturbances which occur do not cause the machine to go out of synchronism right away. Only after we go beyond a certain limit or the system is subjected to a large disturbance that you may fall out of step. If it fall out of step as I said some time ago you have to separate out the machines which are fallen out of step.

Although I have discussed a particular phenomenon of interest that is loss of synchronism. It is important to point out that you can have a synchronous operation that is synchronous machines not running in synchronism under certain circumstances and still be stable.

So, you can have synchronous machines interconnected to each other but, they are still stable every power flows are stable, terminal voltages are stable, when can this occur? One of the most notable examples is when you connect synchronous machines via what is known as an asynchronous link. So, if you have got two synchronous machines say two synchronous machines or two systems.

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So, you have got systems 1 and system 2, consisting of a large number of synchronous machines interconnected by a c lines. So, if you got this is only a schematic if you have got a large number of system synchronous machines interconnected by a c lines the

frequency throughout here that is the electrical speeds of all the synchronous machines will have to be equal if they are interconnected by a c lines. Similarly, here so, this is system 1 and 2 themselves are synchronous grids. So, they have got many synchronous machines interconnected together by a c lines.

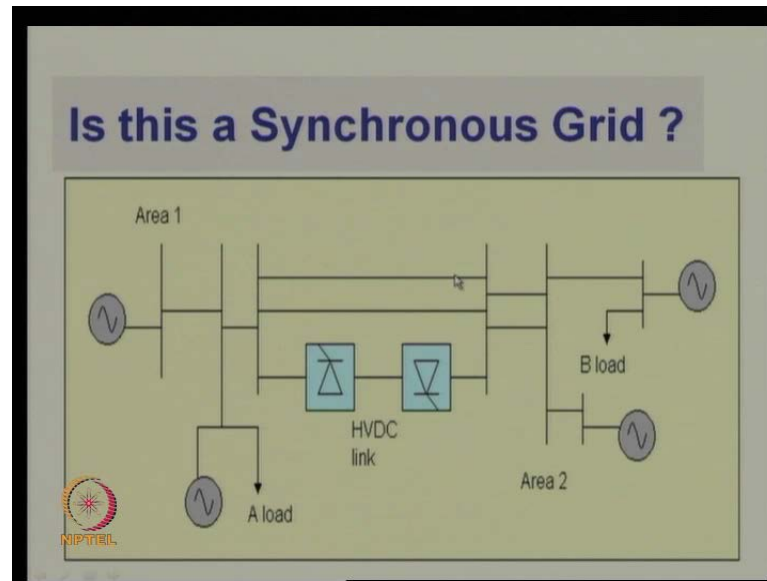
Suppose this is running at 51 hertz and this is running at 50 hertz they are happy happily running at different frequencies but, if I decide to interconnect them by an a c line that is going to be a problem I cannot just connect them just like that they may not synchronize and the second thing is that if they do not synchronize you are going to have a large number of power and voltage variations.

So, instead of doing, what is known as an a c interconnection instead if I rectify the voltage here and I invert the voltage here using control rectifiers, higher state based control rectifiers I can have what is known as an asynchronous link. The asynchronous link basically uses rectification of a c into d c and again inversion of a c into d c but, the important point is power flow through the link is no longer a function of the phase angle here or the phase angle here nor is a dependant on the frequency because you are rectifying the a c voltage and making it into a d c voltage.

So, really the frequency at this point and this point do not matter power flow is actually going to be determined by the d c voltage and a d c voltage magnitude here. The difference of the d c voltage magnitudes is actually going to determine the power flow the line. So, in fact you can operate stably with this at 51 hertz and this at 50 hertz or any other pair of frequencies. The power flow will not fluctuate in fact the power can be maintained constant by controlling the firing angle of these rectifiers which in turn control the d c voltage at the two ends of the d c lines.

So, this is what is known as an asynchronous link. So, remember you can have an asynchronous link in case you have got what is known as a d c interconnection. So, the question which I would like to ask you is, Is what I am going to show you in the next slide is it a synchronous grid or is it an asynchronous grid? please have a look.

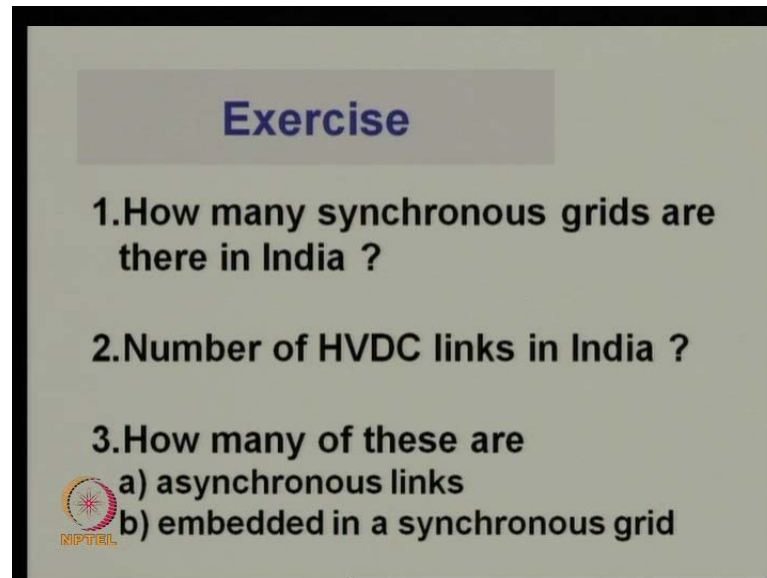
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So, you have got a d c line as I mentioned some time ago, two areas connected by d c line but, importantly in this particular example there are a c lines in parallel as well. So, is this a synchronous grid or is it an asynchronous. The answer is that it is a synchronous grid. The reason is that the power flow in the parallel a c line is still determined by the phase angular difference at the two ends.


So, if the frequencies of the synchronous machines on either side of the grid are different you will find that the power flow will keep will be unsteady in the a c lines and as a result we will not be able to operate stably in this fashion. So, this what I showed you was an example of a h V d ceiling embedded in a synchronous grid in such a case this is still a synchronous grid.

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Exercise

- 1. How many synchronous grids are there in India ?**
- 2. Number of HVDC links in India ?**
- 3. How many of these are**
 - a) asynchronous links**
 - b) embedded in a synchronous grid**

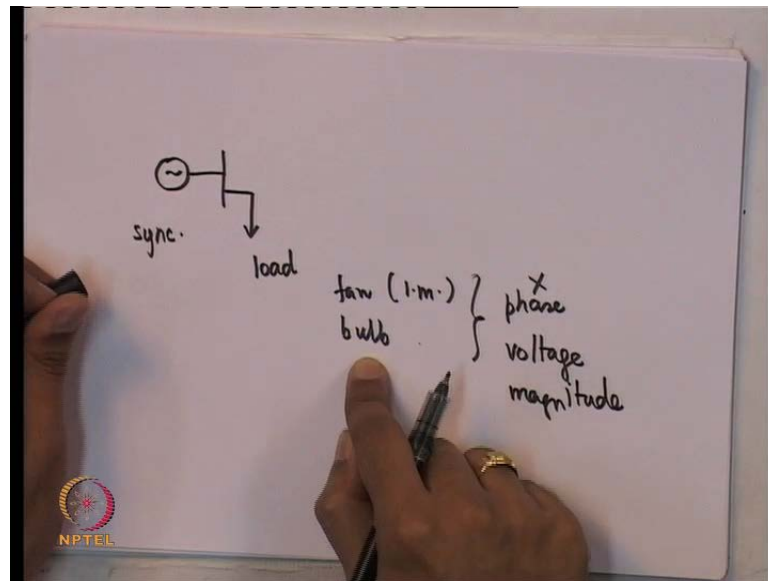
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An exercise for you, find out how many synchronous grids are there in India and how many h V d ceilings are there in India? Out of this h V d d c links, which of them are embedded in the synchronous grids and which form an asynchronous grid? So, we will try to answer these questions in the next lecture but, I request you to survey it and find out these answers to these questions.

You can have a look them again, how many synchronous grids are there in India this number of h V d ceilings in India and how many of these h V d ceilings in India are asynchronous links and how many are embedded in a synchronous link? You can of course, if you are not a student of India you can do the same exercise for your own country.

So, the point is I have given you in one case of asynchronous grid in which loss of synchronism is not an issue because if you have got a two synchronous machines or two synchronous grids connected only by a d c link they can be operated at independent frequencies. Similarly, the mole cases which you can consider in which synchronous operation is not necessary.

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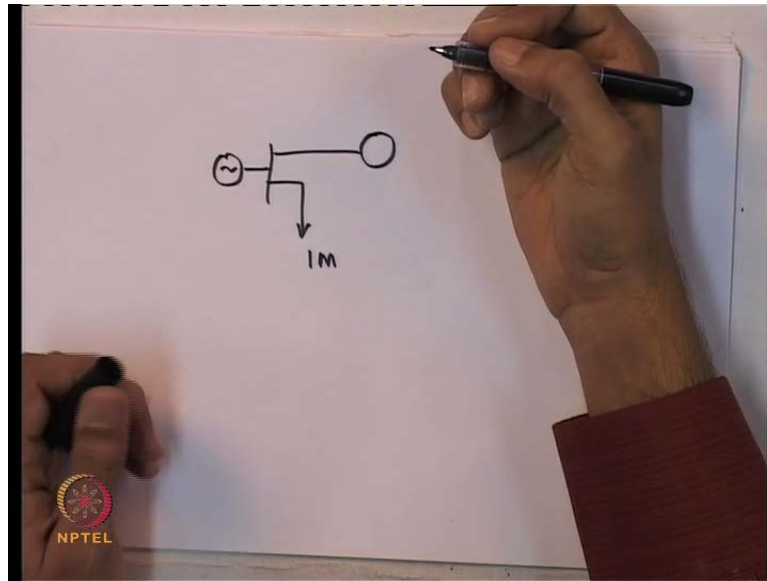
The first case is a single machine a single synchronous machine which is simply connected to a load. So, it is a synchronous machine connected to a load. For example, if the load is a fan which is an induction machine typically or an incandescent bulb these loads, they are not functions of phase angle but, they are functions of voltage magnitude.

So, if you have got a single incandescent machine connected to a bulb or a fan in that case loss of synchronism is not an issue, loss of synchronism is only when you have got two synchronous machines connected to each two or more synchronous machines connected to each other.

This is the situation in which loss of synchronism is not an issue but, remember if you have got a synchronous machine motor, generator connected to a synchronous motor you can have a loss of synchronism situation under certain circumstances. Remember just a small point just because you have got synchronous machines connected to each other does not mean that you always have a loss of synchronism problem. Loss of synchronism can occur if there is a large disturbance some large disturbances not always.

So, that is something you should remember. I am just hinting to you and showing you possible scenarios wherein a large disturbance causes a loss of synchronism. Now for example, the lab supply is steady and a lots and lots may be hundreds of synchronous machines in our grid and they are all running in synchronism so, loss of synchronism takes place under certain disturbances certain large disturbances.

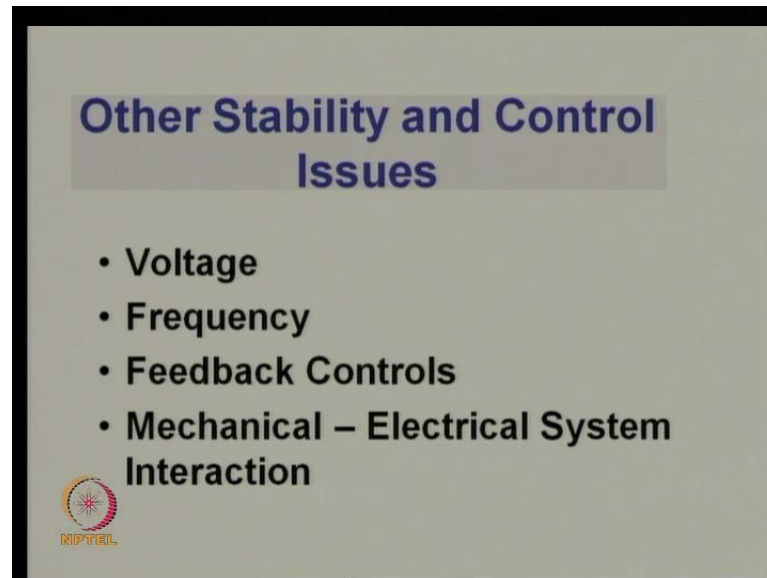
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One more situation where loss of synchronism does not occur is when a synchronous machine is connected to say an induction machine, an induction motor or a induction generator for that matter. For example, you have got wind generator, wind mills which are actually driving induction machines which are connected to your synchronous grid.

These machines are in fact not running in synchronism with the synchronous machine in fact in a induction machine generates for only if the frequency of it is slightly different from the synchronous machine. So, these are two situations in which loss of synchronism is not an issue in fact we shall see later that there are issues even in these ball systems they are related more to voltage and frequency that something we will do in the next lecture.

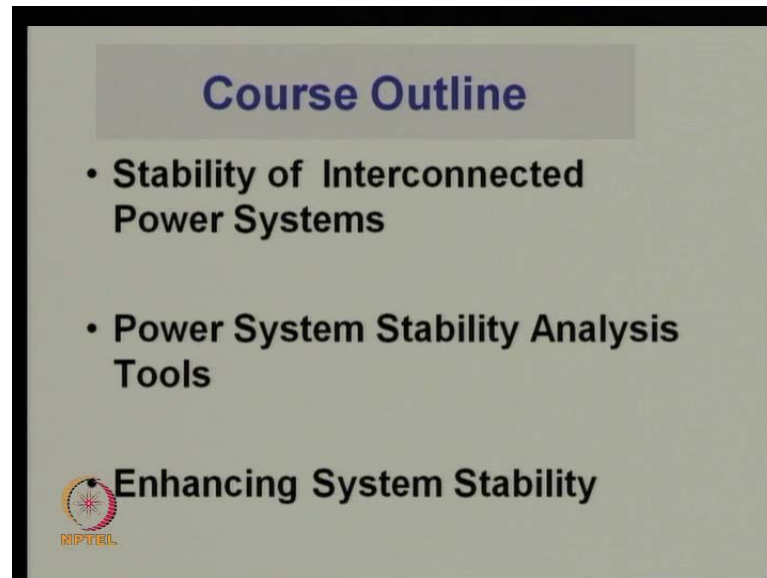
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You may have got the impression that the major problems rather the only problem in the system is loss of synchronism of synchronous machines connected by a c lines. The answer is no. They lot many other stability issues which may crop up in a synchronous grid. In fact you may have problems of unsteady or unstable voltages, unsteady or unstable frequency even if loss of synchronism is not an issue.

So, these are independent issues stability problems which you do encounter in a power grid. Then, you have the effect of feedback controls or improperly designed feedback controller used in a power system can in fact cause loss of synchronism. Also in certain circumstances you can have adverse interaction between the electrical part of the system and a mechanical part. For example, the shaft connecting the turbines to the generator may have problems of torsional oscillations when connect to electrical grids which are series compensate by series capacitors.

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So, these are some phenomenon which do take place which hopefully this course will give you adequate background to study. The course outline is as follows initially I will of course, give you a introduction to power system stability which I am, which is already on going and we will also of course, learn a bit more about this in the next lecture.

We will also learn in the next lecture a bit about power system operation and control and then in the third lecture we will start move on to the nuts and bolts of this lecture that is modeling of physical systems, the principles of modeling and simple analytical tools which I will use to analyze dynamical systems.

So, we will try to understand basic concepts of equilibrium, stability, in fact a interesting point is that I am not actually describe to you what is stability or what is equilibrium? but, I hope that you, with a intuitive idea of these concepts at least intuitively you would be able to understand but, we will do a formal analysis of these things in the lectures to come.

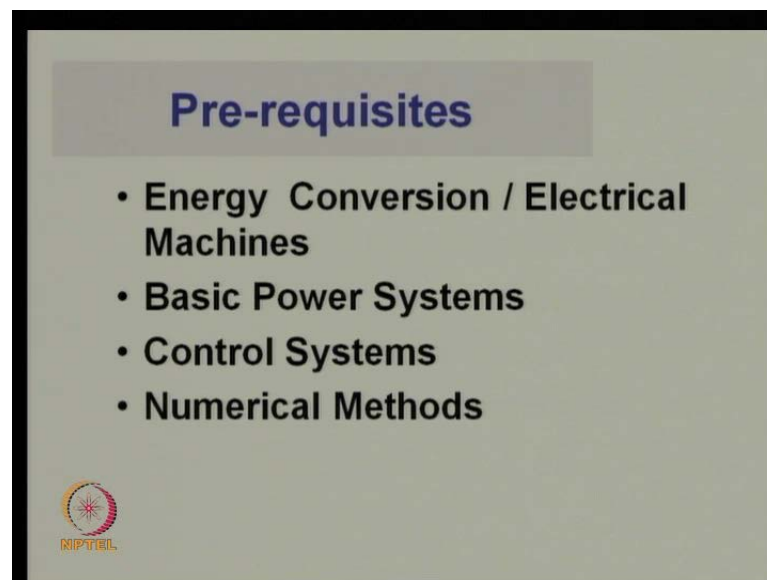
A major chunk of our course is going to be in the modeling of synchronous machines excitational prime mover controls, transmission lines, loads and other components. So, this will in fact take out take a big chunk of our time. The important point is that in modeling all these the most important thing is of course, what approximation do we made? We will course not be able to model all systems in the full glory otherwise you will find that soon the problems become intractable.

In fact we will set ourselves the goal of trying to analyze a fairly large system, let us say with the tools which you and modeling which you learn in this course you should be able to analyze a fairly large grid. For example, the western region of India or the complete central synchronous grid of India, which is fairly large? So, let us set ourselves that kind of a target in this particular course.

The other things of course, once you learn about modeling we learn all the stability issues a new, when you interconnect power system in fact the phenomenon which I showed to you today will do it in much more detail and much more rigorously later on.

We will also learn a few stability tools common stability tools for analyzing rotor angle stability or even electromagnetic transients. And eventually of course, we should the whole aim of this course is not only to understand power system stability problems rigorously but, also try to find out solutions for some niggling power system stability problems. So, that is the last part of this course so, we are setting ourselves to a very very big target in this course but, I am sure you will enjoy it.

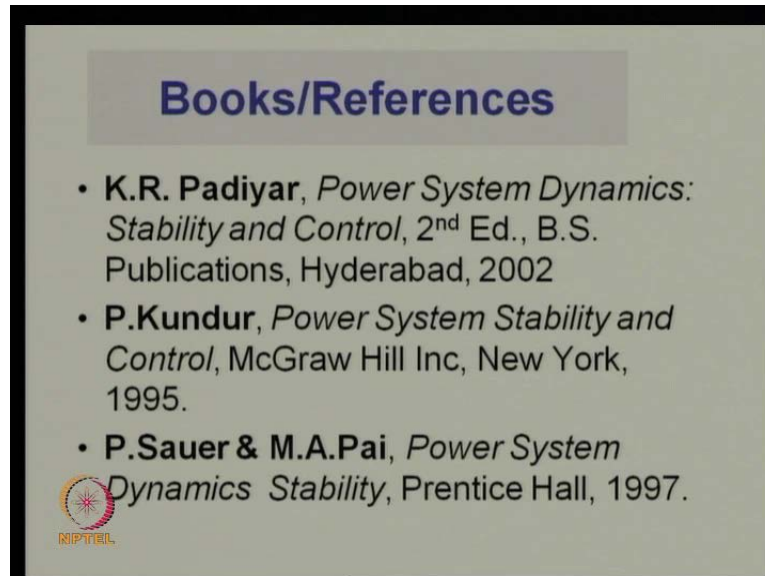
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The prerequisites which you need for undergoing this course is basically knowledge of electrical machines, synchronous machines, d c machines, induction machines, basics of power systems, transmission lines modeling at least the sinusoidal steady state modeling of most components, control systems and numerical methods. So, these are things you


would actually need to know if you want to really understand the power system, power system dynamics.

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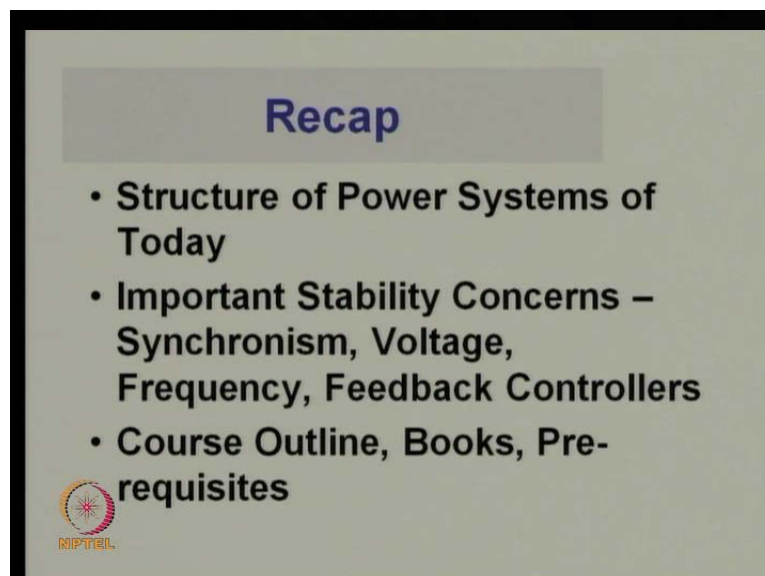
Books/References

- **K.R. Padiyar**, *Power System Dynamics: Stability and Control*, 2nd Ed., B.S. Publications, Hyderabad, 2002
- **P.Kundur**, *Power System Stability and Control*, McGraw Hill Inc, New York, 1995.
- **P.Sauer & M.A.Pai**, *Power System Dynamics Stability*, Prentice Hall, 1997.




There are many books on power system dynamics and control, I would recommend three of them but, of course, there are other books which are just as good but, I will follow the notation etcetera of the first book by K.R. Padiyar, but, all the books which I mentioned here are good and I am sure it is a good idea to read from all the books so, that you get a good variety of topics which are covered.

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Recap

- **Structure of Power Systems of Today**
- **Important Stability Concerns – Synchronism, Voltage, Frequency, Feedback Controllers**
- **Course Outline, Books, Prerequisites**



To recap what we have done today is analyze not analyze, I would say just had a brief overview of the structure of power systems and in particular synchronous power systems. And we just mentioned hinted at several problems which are (()) encountered in power systems but, we concentrated on a particular very interesting and retrieving phenomenon which is the loss of synchronism phenomenon in a power system and of course, I gave you a course outline books and the prerequisites.

So, our journey begins in earnest now and I think all of you will enjoy doing this course we will not sacrifice too much on rigger we would like this course to be not just an overview as in the first lecture but, allow you at the end of the course to actually use some of tools or even develops some of tools from scratch to analyze power system stability problems. With that we come to the end of this first lecture. See you again for the second lecture.