Power System Dynamics

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

Lecture - 03

Introduction to Power System Stability Problem (contd…)

Friends we shall discuss today, 3 important aspects of stability analysis, One is the transient stability voltage stability and long term and mid-term stability. All these topics will be covered in detail in subsequent lectures.

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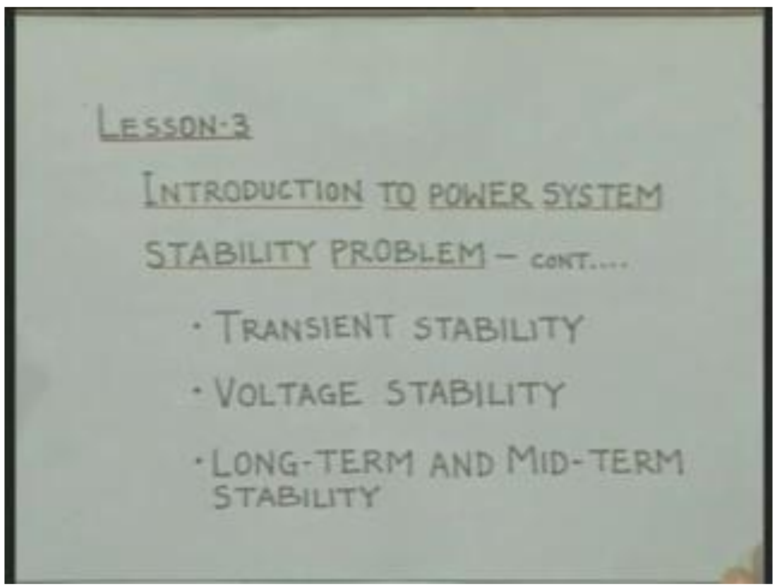

Today I will simply give you the basic concepts related to these three stability problems. First we consider the transient stability. As I told you earlier that originally, the transient stability was the only stability which was of concern and which was analyzed in detail.

The transient stability is the ability of the power system to maintain synchronism when subjected to severe transient disturbances. Let me emphasize here, that transient stability is the ability of the power system to maintain synchronism subjected to severe transient disturbance, the word severe transient disturbance is to be carefully understood the disturbances occur suddenly they are severe in nature.

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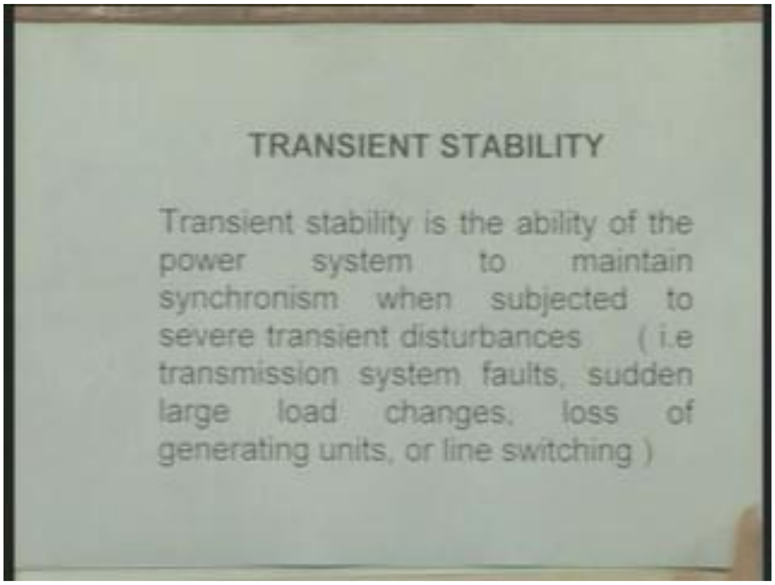

Now the examples of the disturbances are transmission line faults sudden large load changes is loss of generation, generating units and line tripping. Now these are the examples which can be consider which are considered for studying the behavior of the system. Now some of the important features we have to understand about the transient stability are, the resulting system response involves large excursions of rotor angles and is influenced by non-linear power angle relationship.

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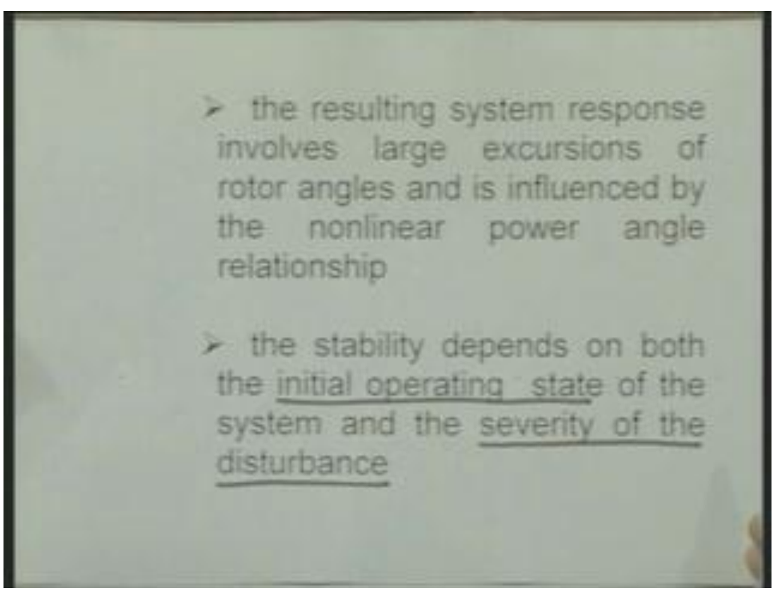

Now here I am again trying to emphasize that whenever large disturbances occur then the, then the resulting response involves large excursion of rotor angles, the delta varies over a wide range and therefore the power output is highly non-linear with respect to delta, this is one important aspect and therefore transient stability analysis require the solution of non-linear swing equations.

The stability depends on both initial operating state of the system and the severity of the disturbance that is for each operating condition the behaviour of the system is going to be different. Similarly, the severity of the disturbance, now severity can be depends upon the type of fault, location of fault and duration of fault.

Similarly, when we talk about the large load change what is the quantum of load which has come on the system. Similarly, when we talk about the generator dropping what is the amount of generation that has been taken out from the system and therefore these two important points we have to carefully understand are that it depends upon the initial operating condition and severity of the disturbance.

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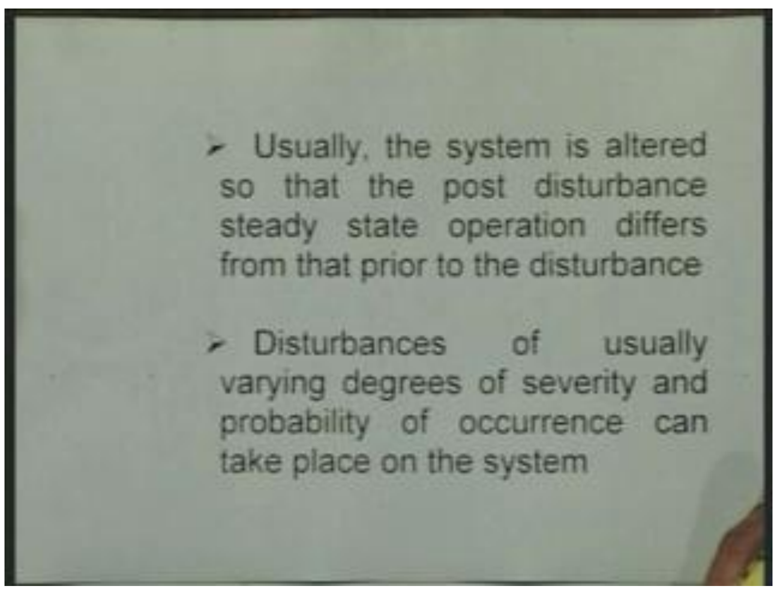

Usually the system is altered, so as so that the post disturbance steady state operation differs from that prior to the disturbance. Here, suppose the system is initially operating in a bulk steady state operate condition, the moment disturbance occurs there will be a change in the topology of the system and therefore if the system is stable, the new steady state operating condition will be different from the previous one.

The disturbances of usually varying degrees of severity and probability of occurrence can take place in the system. Now when you talk about a practical system, the disturbances which occur have different degree of severity and different probability of occurrence. When you talk in terms of what you mean by the probability of occurrence in any power system faults occur in the system but the probability of occurrence of line to ground fault is the maximum and the probability of occurrence of 3 phase fault is minimum right and therefore one has to look into this aspect while analyzing the transient stability of the system and also while designing the system for operation and planning.

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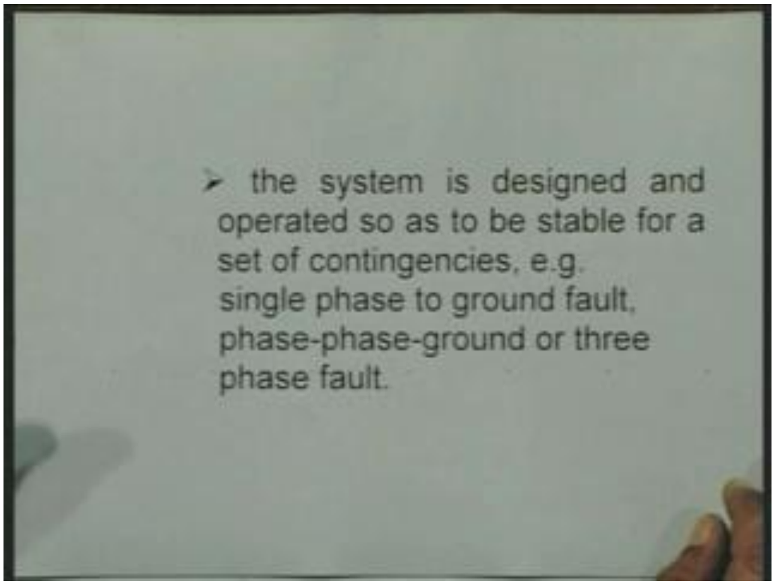

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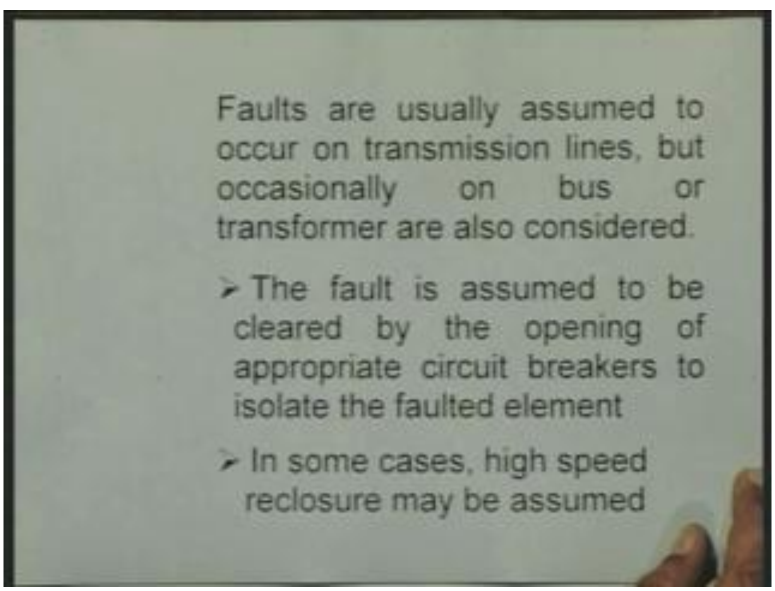

The system is designed and operated so as to be stable for a set of contingencies for example, single phase to ground fault, phase ground fault or 3 phase fault. Now here when we talk about the contingencies, we have to contingency stand for these all abnormal conditions okay and whenever we design the system we have to see that what are the most probable contingencies and the system should withstand those contingencies and it should not loose synchronism when such contingencies occur.

Now when we analyze the transient stability of the system usually we assume the faults occurring on the transmission line, sometimes we consider the faults at the buses or on the transformers. In any system, when the faults occur the faulty system or faulty element is disconnected by the operation of protective system and circuit breakers therefore, we have to be very careful when we consider the analysis of transient stability, the operation of circuit breakers and protective relays. In some cases, we consider the high speed reclosure also that is circuit breakers have the capability to reclose after sometime delay.

Now this reclosure may be successful reclosure or it may be unsuccessful reclosure, in case the fault is transitory in nature and it clears by itself then when you reclose the circuit, you will regain the original operating condition. However, if suppose there is a permanent fault right then the reclosure is going to be unsuccessful we will study the affect of auto reclosure on the transient stability in our late, later lectures. With this basic points related to the transient stability I will just show you a typical response of delta as a function of time for a particular for a given disturbance.

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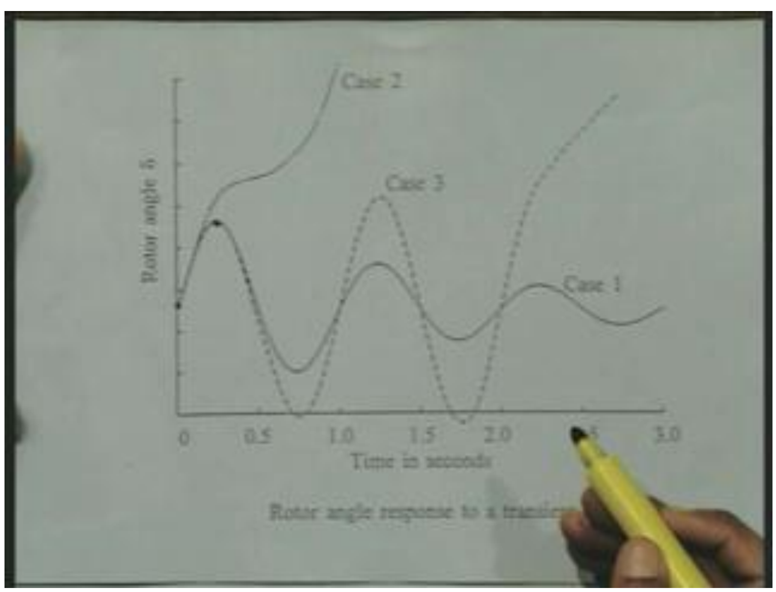

This figure shows the behaviour of a synchronous machine under stable and unstable operating conditions. Now I have shown in this diagram 3cases: case 1, case 2, and case 3. Case 1 shows that following the disturbance, the power angle increases attains maximum value then further decreases and oscillates with decreasing amplitude, this is a stable case. Case 2 is 1 where the response is shown in curve 2, in this case the delta increases continuously till system becomes unstable or till machines loose synchronism.

This type of instability is generally called first swing instability and this happens particularly due to insufficient synchronizing power, the third case is a case where the power angle delta increases attains maximum but subsequently the oscillations grow in magnitude This is a case where system is stable from the point of view of first swing stability but the system is becoming unstable due to, due to lack of damping torque that is the new operating condition is not small signal stable.

Now these curves can be plotted for any operating condition, for any given severity or given disturbance and then we can examine whether the system is stable or not by examining the swing curves, they are all swing curves. These swing curves are obtained by solving swing equation of the system, the method of solving this swing equations we will learn subsequently, okay.

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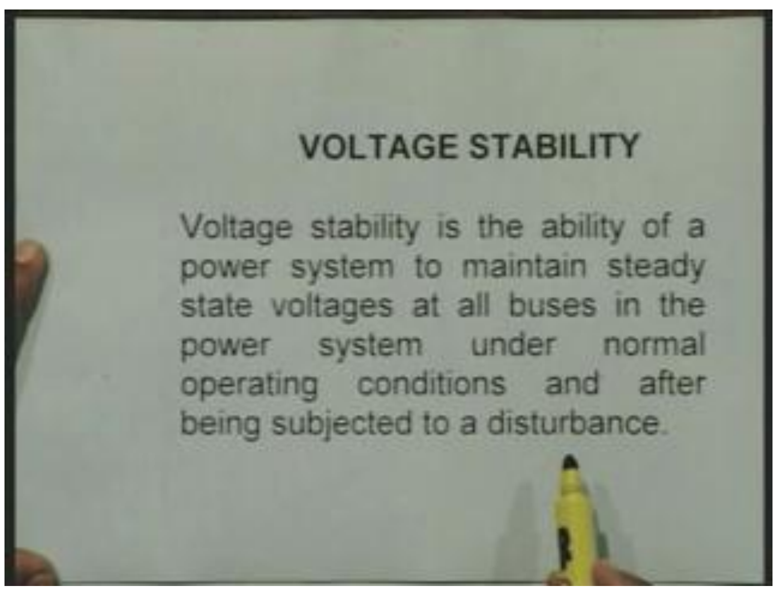

We shall be devoting significant amount of time for analyzing the transient stability of a system in our subsequent lectures. Now we address the problem of voltage stability, the voltage stability has become the subject of studies during the last one decade. Now voltage stability is the ability of a power system to maintain steady state voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. You have to very carefully understand the definition that is again it is the ability, stability is the ability of the system such that it maintains steady state voltage at all the buses under normal operating condition and also after disturbance.

Now here, we will see that actually when we talk about normal operating voltages that means that acceptable voltage profile of the system sometimes the voltage may become very low it will not be acceptable, we call this as a unstable system.

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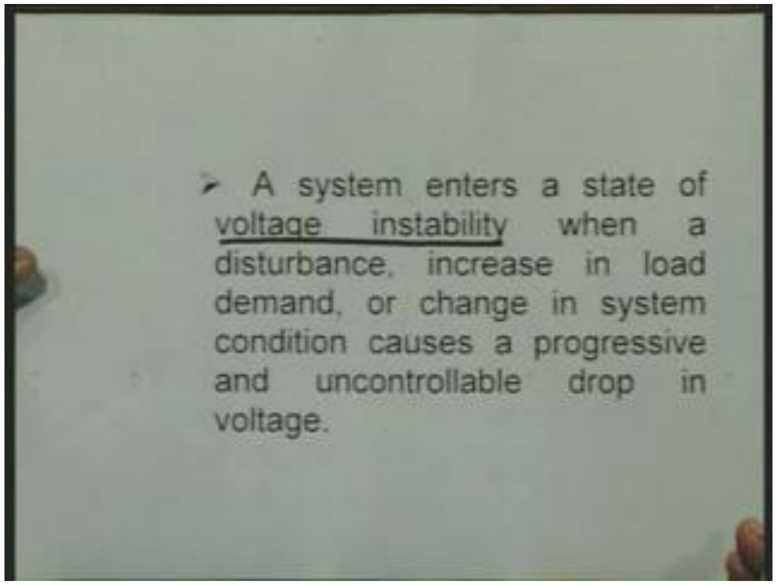

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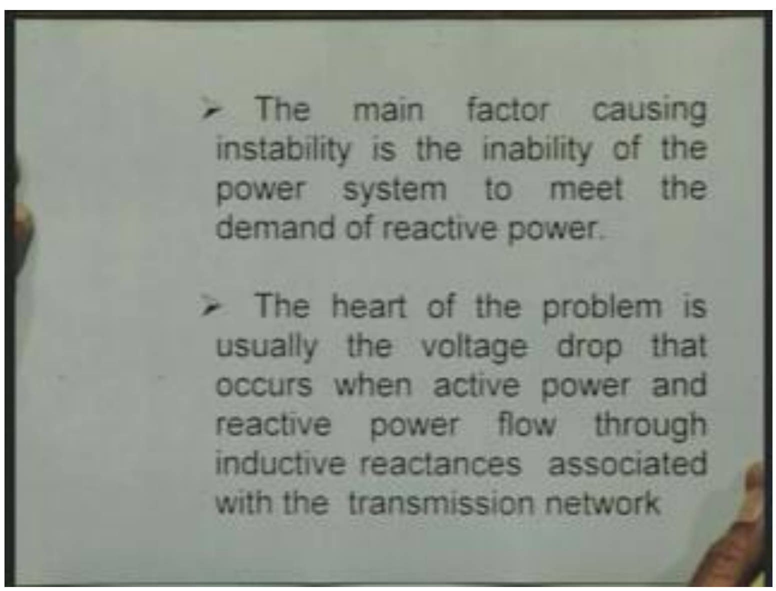

A system enter, enters a state of voltage instability when the disturbance increase in load demand or change in system condition causes a progressive and uncontrollable drop in voltage. Now here we have emphasizing the occurrence of voltage instability that is whenever a disturbance occurs, the voltage drops and it is not controllable because any system, we have certain controllers which control the system voltage but disturbance may be of such in nature. So that the controllers are not in a position to control the system voltage and that is the condition for voltage instability.

The main factor causing instability is the ability of the power system inability of the power system to meet the demand of reactive power. When you talk about the angle stability it is a balance between reactive active power that is mechanical input of the turbine or mechanical input from the turbine must be equal to electrical output from the generator, it is a real power balance, here in voltage stability we require the balance between the reactive power that is reactive power generated and the reactive power consumed in a system and in if in case the system is unable to maintain this balance then the problem of voltage instability occurs.

The heart of the problem is usually the voltage drop that occurs when active power and reactive power flow through inductive reactances associated with the transmission network. When you again look, what are the main causes of voltage drop the, the voltage drop takes place in transmission system in transformers or any part of the ah system due to the flow of real and reactive power and the system has its impedance resistance and reactance and because of this there is a voltage drop in the system and this drop is the primary, primary cause of voltage instability. We shall be studying this voltage stability problem in detail in our later or subsequent lectures however, I will just give you one basic ideas that the criteria of voltage stability.

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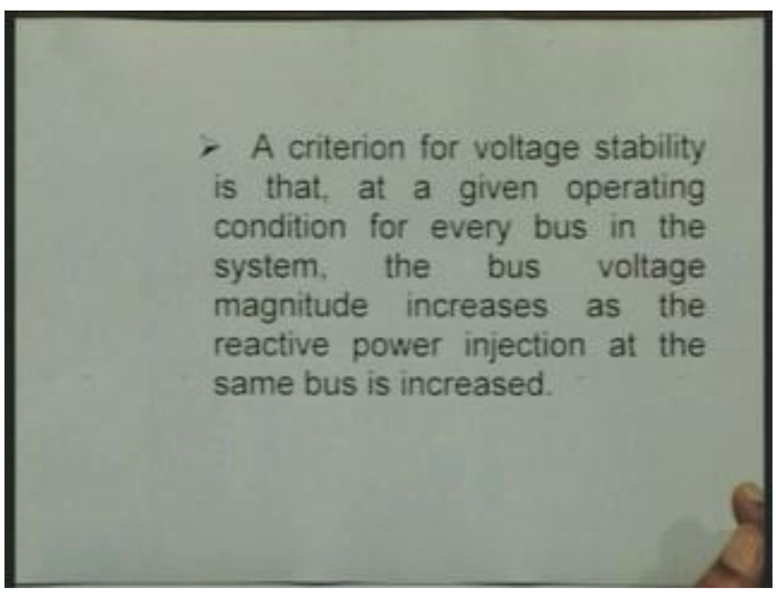

When do we say that system is voltage stable or system is voltage instable? A simple criteria is a criteria for voltage is stability is that a given operating condition for every bus in the system, the bus voltage magnitude increases as the reactive power injection at that at the same bus is increased this point is very important suppose, you have a large system you have number of buses. Okay, if we inject reactive power at a particular bus then the voltage of that bus would increase, if the operating condition is such that by injecting voltage at any of the buses and the just correct me by injecting reactive power at any of the system buses, the voltage should increase there should be no case where where I inject the reactive power and the voltage decreases. This concept can be further stated in the form when we talk about voltage stable to say voltage unstable.

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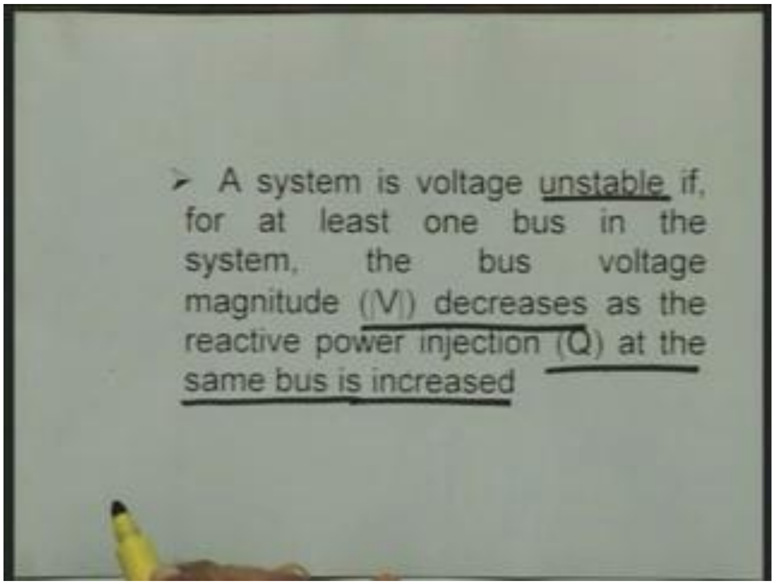

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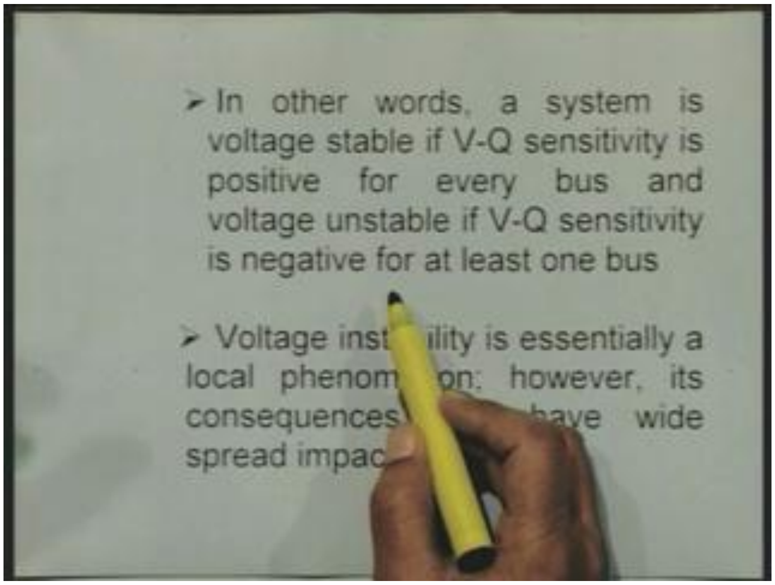

A system is voltage instable, unstable if for at least one bus in the system. The bus voltage magnitude V decreases as the reactive power injection Q at the same bus is increased because when I talked about the voltage stability the condition posed was that at all buses, the voltage should increase when reactive power is injected if at any one of the buses the situation is different that is when you inject reactive power, the voltage decreases right then if any at any of the one buses this happens the system is voltage instable or voltage unstable.

Another way of stating this problem is a system is voltage stable, if V-Q sensitivity is positive for every bus and voltage unstable, if V-Q sensitivity is negative for at least one bus, it may be more than one bus. Okay but if at any one bus, any one bus the voltage sensitivity becomes V-Q sensitivity, we know what is in V-Q sensitivity that is change in voltage divided by change in reactive power injected if you find this ratio right this is called the voltage V-Q insensitivity and if the V-Q sensitivity becomes negative at any one of the buses, we say the system is voltage unstable, voltage instability is essentially a local phenomenon however, its consequences may have wide spread impact.

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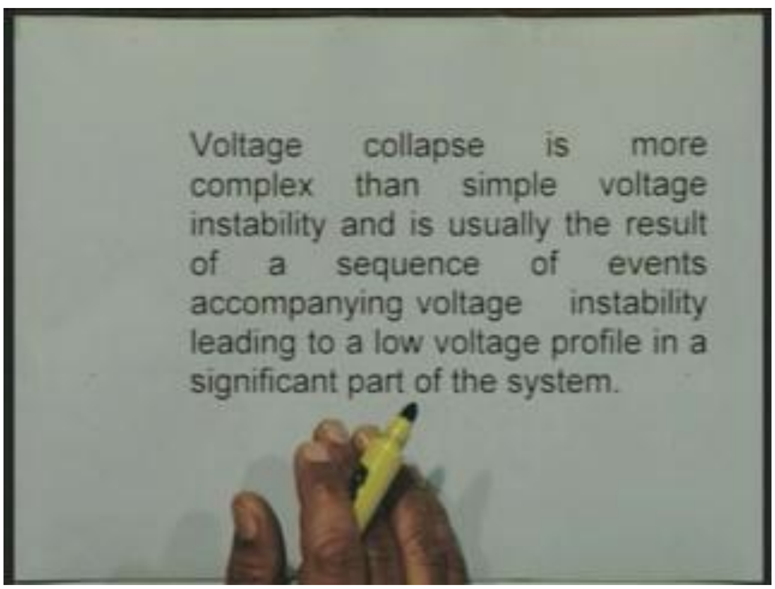

Another next one which I wanted to mention is, the concept of voltage collapse sometimes we say that voltage collapse taken place in the system. Now this voltage collapse is a very complex phenomena which occurs due to occurrence of a sequence of events but when, whenever the system voltage becomes unacceptable, the system voltage profile becomes unacceptable to us we say that voltage collapse has taken place.

Okay for analyzing the voltage stability problem it is divided again into 2 categories, one is called large disturbance voltage stability and another is called small disturbance voltage stability, just like as we had in the angle stability we divided this problem into 2 categories, small signal stability and transient stability, transient stability is particularly related to large disturbance is a large disturbance stability right.

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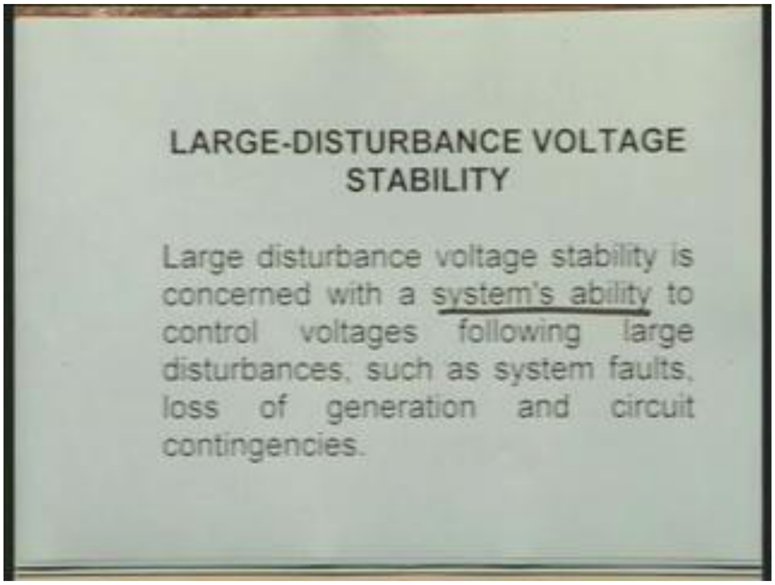

So the power system stability was classified as angle stability and voltage stability. We have studied basic concepts of angle stability, now we shall study the basic concepts of voltage stability. The voltage stability is also classified like angle stability into 2 categories, a large disturbance voltage stability and small disturbance voltage stability. This voltage stability a phenomena has been studied during the last one decade in depth a lot of research work has also been done in the area of voltage stability.

We will just study today the basic definitions of large disturbance voltage stability and small disturbance voltage stability and the factors which determine these 2 stability problems. The large disturbance voltage stability is concerned with systems ability to control voltages following large disturbances such as system faults, loss of generation and circuit contingencies. Here I emphasize that systems ability to control voltages, now in any power system, the power system voltage is controlled by controlling the controllable devices, the controllable devices are the, the automatic voltage regulators on the synchronous machine.

We have online tap changers on the transformers, we have capacitors a shunt capacitors, shunt reactors and other devices are static wire systems and these devices when they are controlled to maintain the voltage on the system and if the system can control the voltage following the disturbance then such system is said to be voltage stable.

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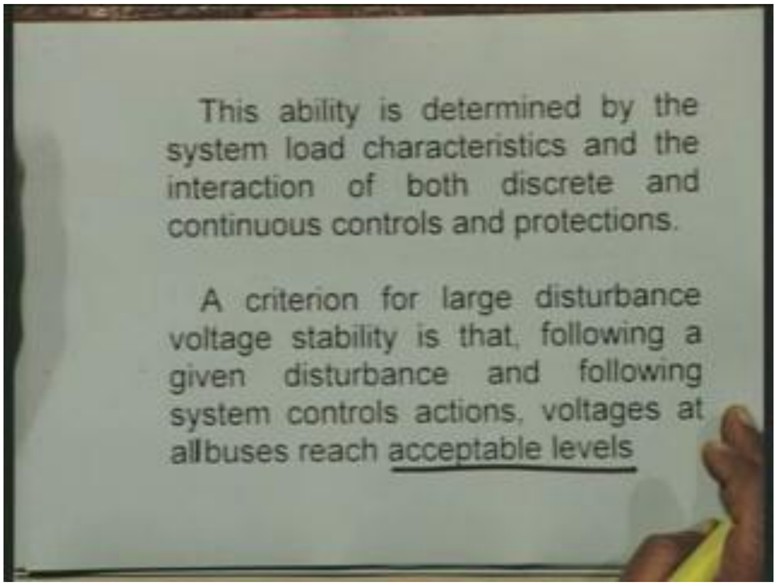

The voltage stability is determined by system load characteristics and the interaction of both discrete and continuous controls and protections when we talk about the system load characteristics, you have to understand very carefully that the power consumed by load depends upon the magnitude of the voltage and frequency. There are some loads whose power consumed depends upon the voltage only, there are some loads whose power consumed it depends upon voltage and frequency both, an example is a heating load, where the power consumed is directly proportional to voltage square.

However, it does not depend upon the system frequency but if I consider the induction motor load, then the power consumed depends upon voltage and frequency both and therefore, when we talk about the power system stability then the power system voltage stability that it is primarily determined by the load characteristic and the interaction of both discrete and continuous control protections.

When I talk about discrete controls these are the on off controls and continuous controls the example is automatic voltage regulators. Similarly, the static wire systems are continuous controls the criteria for large disturbance voltage stability is that following a given disturbance and following system control actions, the voltages at all buses reach acceptable limits. In any system, we can operate the system in case the voltages are within certain acceptable limits, in case the voltages can be controlled within the acceptable limit the system is said to stable. Now we discuss the small disturbance voltage stability.

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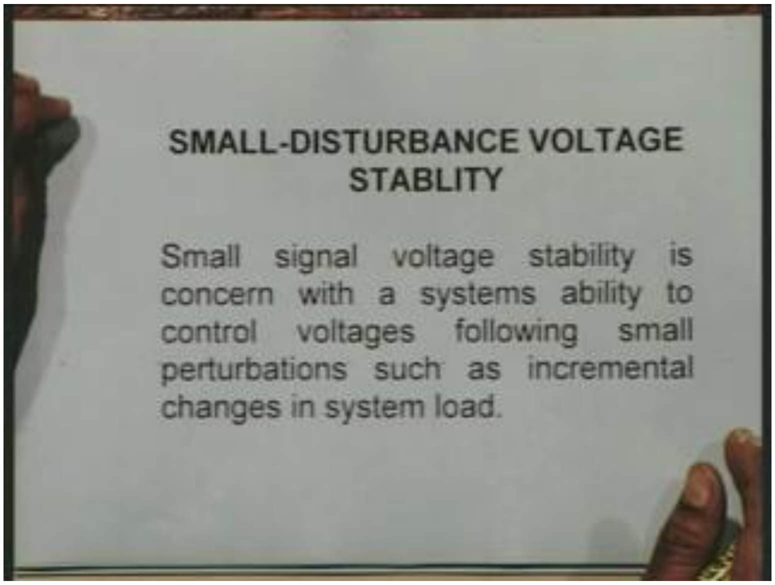

Small signal voltage stability is concerned with a systems ability to control voltages following small perturbations, such as incremental changes in system load. When we talked about the large disturbance voltage stability the disturbances were large in magnitude while here when we talk about the small disturbance voltage stability the disturbances are small in magnitude, the example of small disturbance is incremental changes in system load.

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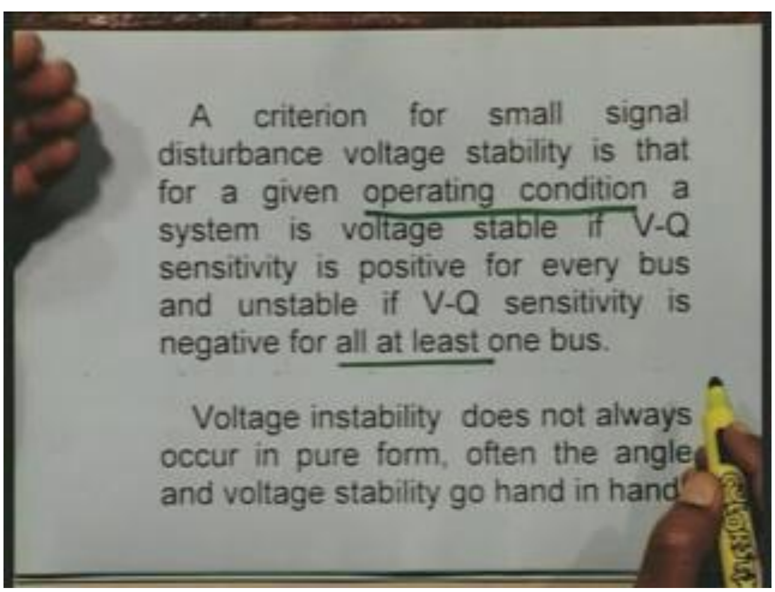

A criteria for small signal disturbance voltage stability is that for a given operating condition a system is voltage stable, if V-Q sensitivity is positive for every bus and unstable if V-Q sensitivity is negative for at least one bus. I will again repeat here the meaning of V-Q sensitivity that is at any bus if I inject a reactive power then the change in voltage divided by change in reactive power injected this gives the V-Q sensitivity and for the system to be stable at all buses in the system V-Q sensitivity should be positive and if V-Q sensitivity is negative at anyone of the buses system is said to be unstable voltage unstable.

The voltage instability does not always occur in pure form, often the angle and voltage stability go hand in hand, here I want to emphasize that system is one and whenever disturbances occur it affect the system angle as well as the voltage and therefore both these phenomenon go together and whenever we analyze the total system stability, one has to take care of both the aspects we shall study the voltage stability phenomena in detail in subsequent lectures.

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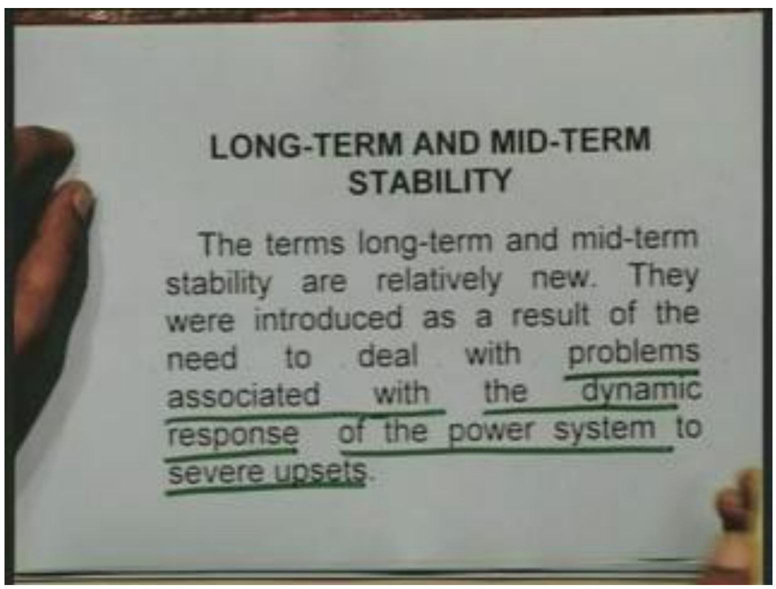

Now we will define another very important term known as the long-term and mid-term stability this is also a new phenomena earlier, the designers and operators of power system did not consider this problem this long-term and mid-term stability has been introduced as a result of a need to deal with problems associated with the dynamic response of the power system to severe upsets. The severe upsets are those disturbances that result in excursions of frequency and voltage and power flow is either so great or so long lasting that they invoke the actions of short ah slow processes protection systems and controls which are not modelled in the conventional transient stability analysis because when we analyze the transient stability problem we do make certain assumptions but however in long-term and mid-term stability problem, the disturbances are so severe in nature, so it results into severe upsets in the system, the frequency and voltages fluctuate over a wide range and this will invoke the action of certain controls which otherwise were not modeled.

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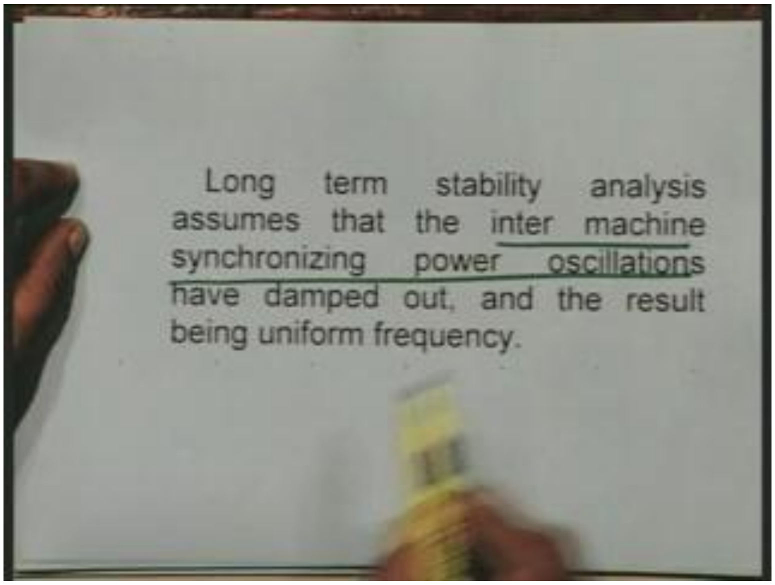

Long-term stability analysis assumes that, inter machine synchronizing power oscillations have damped out and the result being uniform frequency and here I want to emphasize that whenever disturbance occur system is in dynamic condition but the movement sufficient time has elapsed, then the system will settle to a low frequency, low voltage and frequency can be assumed to be reformed all through the system.

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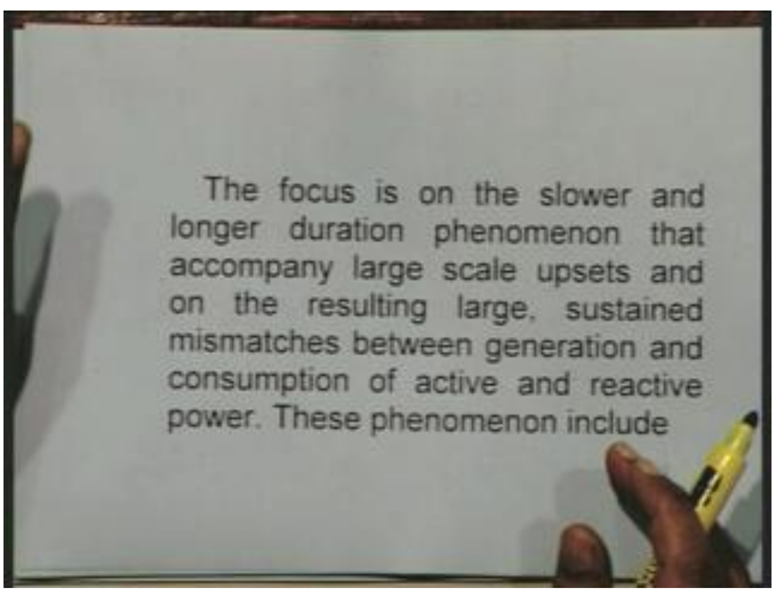

The focus is now on the slower and longer duration phenomena that accompany large scale upsets and on the resulting large, sustained mismatches between generation and consumption of active and reactive power.

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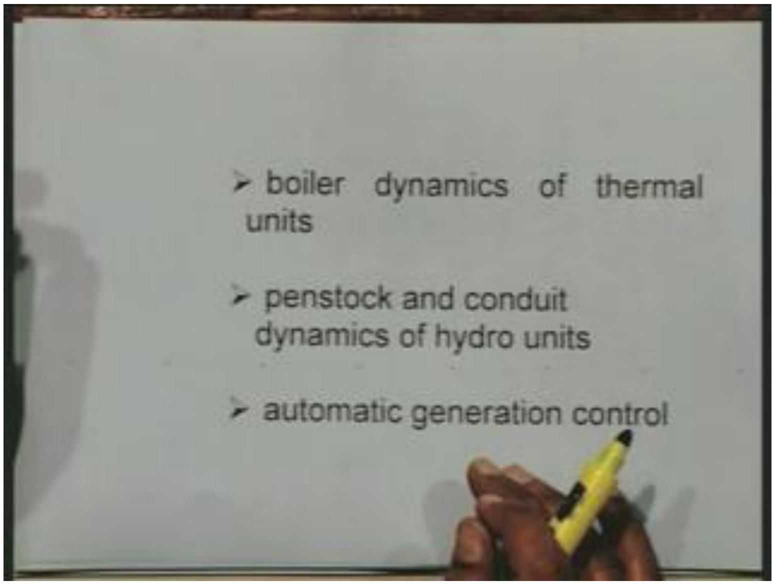

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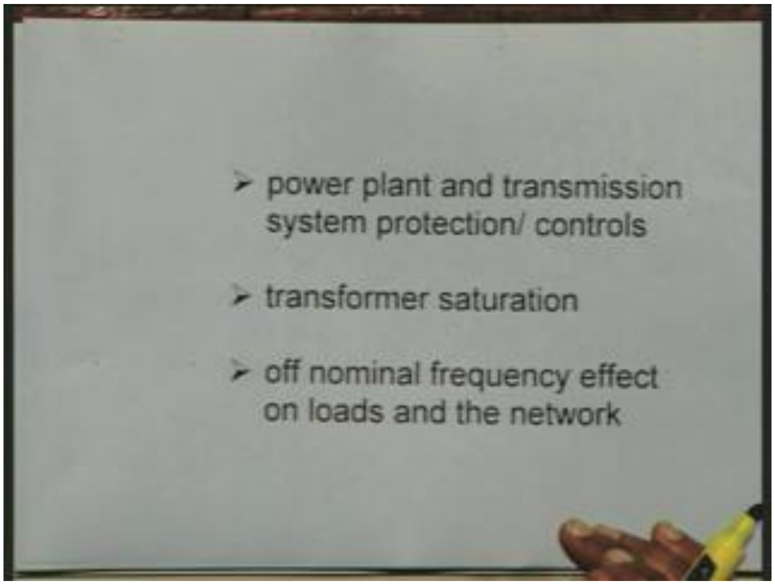

These phenomenon include boiler dynamics of thermal units, penstock and conduit dynamics of hydro units, automatic generation control, power plant and transmission system protection and controls transformer saturation and off nominal frequency effect of loads and the network. This I will just discuss these thing one by one, when we talked about the transient stability analysis, we assumed that mechanical power remains constant. We did not model the boiler dynamics, turbine dynamics for hydro turbines; we did not model the penstock and conduit dynamics. We also do not model the automatic generation control which is a secondary control to regulate the real power output of the generator. We have also not modelled the protection system in the transmission transformer situation and the effect of off nominal frequency effect on loads and network now here, when the system voltage and frequency deviate widely from the nominal value, the transformer core may get saturated and it has effect on the system performance.

Similarly, when the voltage and frequency are low all these controls get activated or invoked similarly, when frequency is quite away from the nominal voltage is away from the nominal it effect the system load and therefore when we analyze the long-term stability, these phenomenon need to be modelled and dynamics need to be analyzed considering the detail models of these devices.

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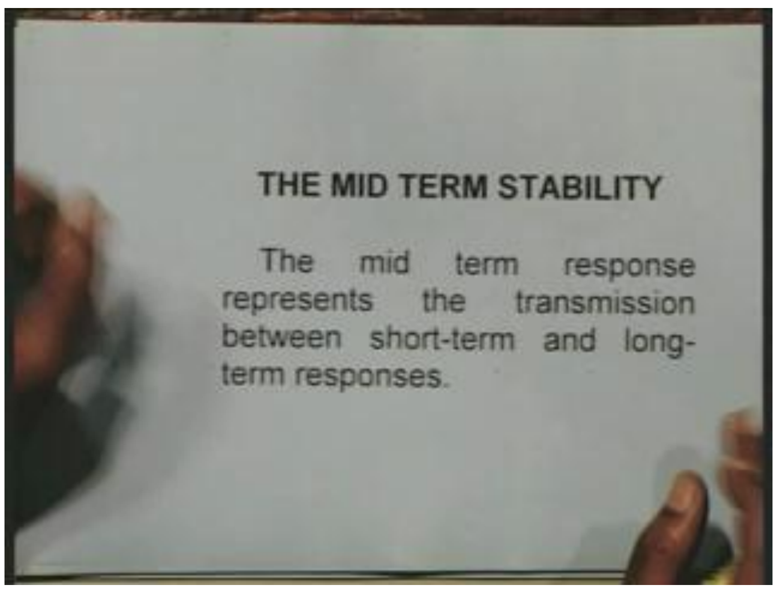

The next point is about the mid-term stability, the mid-term stability is between the transient stability and long-term stability. Now we can say that mid-term response represents the transmission between short-term and long-term responses that is it is basically transition, transition between short-term and long-term responses.

In mid-term stability studies the focus is on synchronizing power oscillations between the machines including the effect of slower phenomena and possible large voltage and frequency excursions. As I mentioned that when we talk about the long-term stability, we do not consider the synchronizing power oscillations while in mid-term we consider the synchronizing power oscillations

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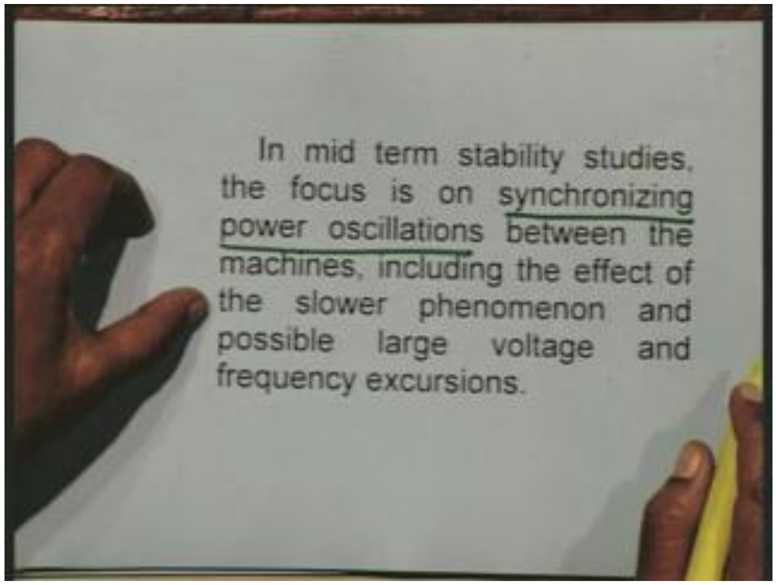

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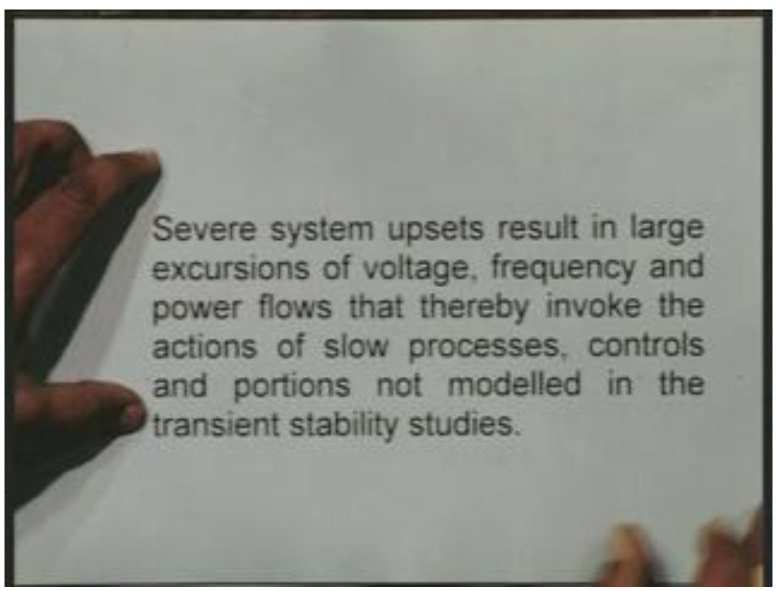

Now severe system upsets result in large excursions of voltage frequency and power flows that thereby invoke the actions of processes, controls and portions of and portions not modelled in the transient stability studies.

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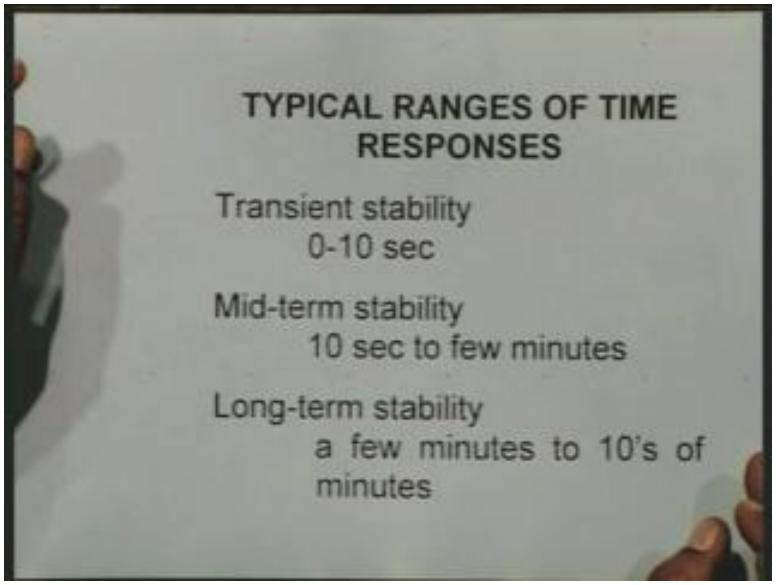

The typical ranges of time responses, the transient stability is studied for a period of 0 to 10 seconds generally it is over a period of 0 to, 3 to 5 seconds only on those cases where we have a large system and there are interior modes of low frequency exists in those cases the time period of oscillations may be large and therefore the transient stability is analyzed approximately in this range of 0 to 10 seconds. It is not a very a very rigid boundary between a transient stability mid-term and long-term stability.

Now mid-term stability is from 10 seconds to few minutes while long-term stability is from few minutes to 10 of minutes. Now with this, I will conclude that today we have, we have addressed transient stability problem, voltage stability problem and and mid-term and long-term stability problem. We have seen actually that the transient stability is the ability of the system to maintain synchronism following large disturbance, it depends upon the system operating condition severity of the disturbance.

Similarly, the small disturbance stability which we studied earlier that also depends upon the operating condition of the system and type of disturbance. The voltage stability we have addressed the basic concepts related to large disturbance voltage stability and small disturbance voltage stability. We have seen actually the primary criteria for analyzing the voltage stability of the system while talking about mid-term and long-term stability which are new in the area of power systems, we have seen actually that whenever there are severe upsets in the system one has to model the dynamics of slow processes controls and the effect of frequency and voltage excursions on the system loads with this one is in a position to analyze the behaviour over a long duration.

Further I would like to emphasize that these 3 stability problems mid-term stability, mid-term and long-term stability, transient stability and voltage stability they are interrelated the modeling is similar in nature with this I conclude my today’s presentation. Thank you!