Power System Operations and Control
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Module -2
Equipment and Stability Constraints in System Operation
Lecture 5

Welcome to lecture number five of module two. In this module, the name is equipment and stability constraints in power system operation. So, this lecture is completely related to the stability definition concepts and its fundamental. And we will see that what are the various stability concerns and their definitions, why they are very important for the power system operation and control.

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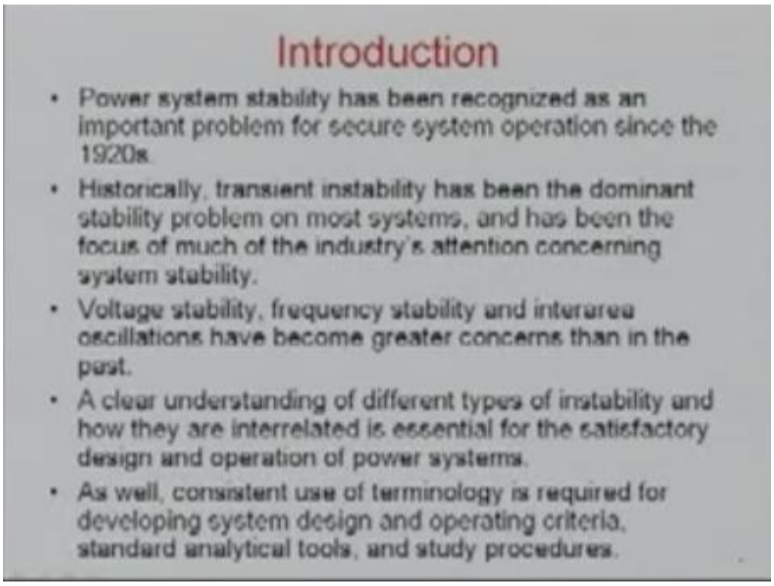

To introduce with this definition, let us see why this stability is required at all, the stability analysis I mean power system stability has been recognized as an important problem, for such operation of system since 1920's. In 1920's the first case of the system instability, and after that it has gain momentum, and now are having a lot of instability and instability analysis of the system, to say that system is stable or not. Historically, the transient instability has been the dominant stability problem on most systems, and has been the focus of much of the industry's attention concerning system stability. In the early days, people were only recognizing the instability phenomenon is as a transient stability. So, they were concerning in terms of that analysis, their mitigation, and their other related issues on only the transient stabilities.

But due to the increase inter connections, the stress power system; that is keep on loading and keep inter connections, the voltage stability as well as the frequency stability, that even though along with the inter area oscillations, had become greater concern than in the past. And as I said it is more and more due to the interconnections highly loaded and the complex power system. The voltage stability frequency stability and the inter area oscillations are also very important, and that is that is why we have to go for various stability analysis. A clear understanding of different types of instability, and how they are interrelated is essential for the satisfactory design, and operation of power systems.

So, we have to understand what are the various instability problems, and how they are interrelated; that is very important for the power system design and operation; means you have to design a power system that should be stable, and you should operate your power system in stable manner ,along with other criteria already we had seen, that the power system design and operation criteria include your power system quality, power system security, stability, reliability, and also that we should operate the power system in the least economic rate, means economical fashion. So, the cost of electricity is cheap and uninterruptable, and it should be better usable in terms of customers use. As well consistent use of terminologies is required, for developing system design and operating criteria, standard, analytical tools, and study procedures.

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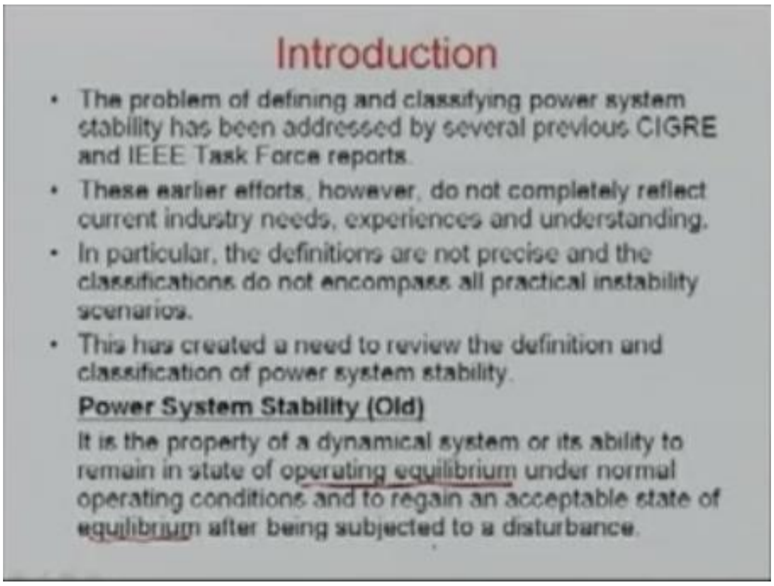

So, the problem of defining and classifying, power system stability has been addressed, by several previous CIGRE and IEEE task force reports. Here, IEEE this institution of Electrical and Electronics Engineers task force. So, they have already defined, but again it is keep on reviewing this. And again those early days, means these earlier efforts; however do not completely reflect, the current industry needs up to now. So, we have to go for the clear definition again, based on the industry needs, experiences, and the understanding. In particular the definitions are not precise, because in the previous definitions were not precise. And the classification do no encompasses, all practical instability scenarios. As I said in the beginning, only we were concerned about the transient stability. Later on we introduce the transient stability, steady state instability, and also the voltage instability, but now a days again some more instability, and their basis may be a time frame depends upon the disturbance nature and so on so forth.

So, we have to define and understand the various instability and stability phenomena's in the power system. So, that is why this has created a need to review the definition, and classification of power system stability. So, we want the power system stable; in terms of designing, in terms of operation. So, whatever the kind of instability in the power system, is that must be reduced, that must be removed, so that we can have secure and stable operation of the power system. If you will see the power system stability old definition, as per the, it is the property of a dynamical system or its ability, to remain in state of operating equilibrium. This is very important operating equilibrium, under the normal operating condition, and to regain an acceptable state of equilibrium another equilibrium here, after being subjected to a disturbance.

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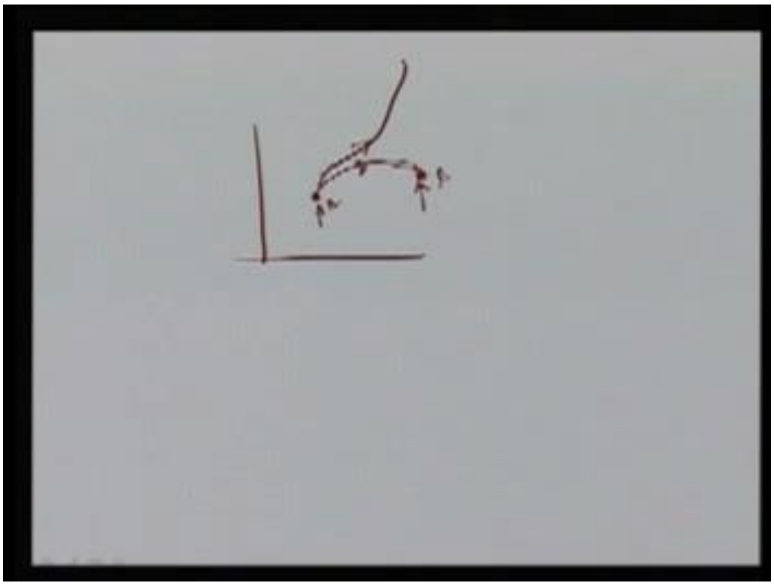

To understand this let us see here, let us suppose in a multi here directional plane, you are here your power system is operating at this point. So, this point is stable, initially in the normal condition. And if there is a disturbance in the system, and your system is moving to another system, here that is also stable. But there is a possibility that this trajectory, this state is stable this state is stable, but it may not always possible that the transition from this stable, stable A to this stable B is possible. So, it may be possible that, this may go for somewhere else, and then we can say our system is unstable. We know that this is you pre fault condition; initial normal condition where your system is operating, if there is any disturbance, then your system should go to another stable point B.

B may be the different, again it depends upon the system scenario, change in the topology, change in the generation and the load scenario. It may be the same A point of course, but the disturbance one it is clear, then your system must go to your another stable point B, then we can say the system is stable, if it is coming to this point here through any region, but there is a possibility that this point no doubt the post disturbance is stable. Your initially stable, but your system can go somewhere else. It is not coming to your stable point, because it is time which is coming keep on going, and finally, it is unstable. So, here that is why it is a definition it is said, that your operating equilibrium under the normal operating conditions, means initial condition. Your system is in the equilibrium point, and it should regain or acceptable state of equilibrium after subjected to disturbance. So, it should come here stable then we can say our system is table, if this is not then it will be go away.

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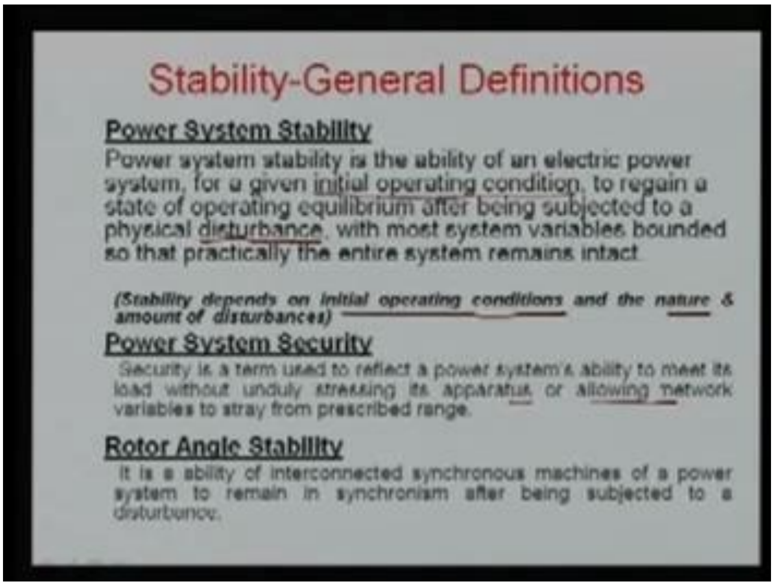

Now, the new definition has been given recently, there was again another IEEE task force. It gives again concise definition of the power system stability. It includes all the stability concern, and the various stable analysis techniques are given in that paper, and this is again this committee was headed by the Prabhakundur, and even though we can see his book by stability is very. He defined all the stability in the very precise manner. So, as per new definition the power system stability, is the ability of an electric power system for a given initial operating. Here they have written the initial. Earlier it was the normal operator. Normal means the system at which your system is operating. So, it is better to say that the initial operating condition to regain a state of operating equilibrium, after being to a physical disturbance. Again the physical disturbance is of different types again there may be some fault, some loss of load, something happening you can say some loss of power, transmission line tripping, short circuit etcetera. So, if there is any disturbance, then it should regain another stable operating equilibrium, with the most system variable bounded, so that practically the entire system remains intact.

So, your system should not lose the synchronous, and it should be in stable condition. The stability basically, depends. Now realize depends upon here initial operating condition, and the nature and the amount of disturbance, again the amount of which type. For example of a small change in the load is another type. There may be a severe load change. There may be small change in generation. There may be severe change in the generator; means suppose there is a one generator is out. another the nature, it may be the power outage, it may be load change, it may be the short circuit, it may be the tripping of the transmission line, it may be the tripping of any other equipment in the power system. So, the stability in total depends upon the initial state, where your system is operating right now, although it is no doubt it is stable, but at what label, means at which point how close to the instable position, and then the nature and the amount of the disturbance. We saw this power system security as well in our beginning lectures in module one; what is power system security. So, to recap it security is a system use to reflect a term power system stability, to meet its load demand, without unduly stressing its apparatus, or allowing network variable to stray from the prescribed range.

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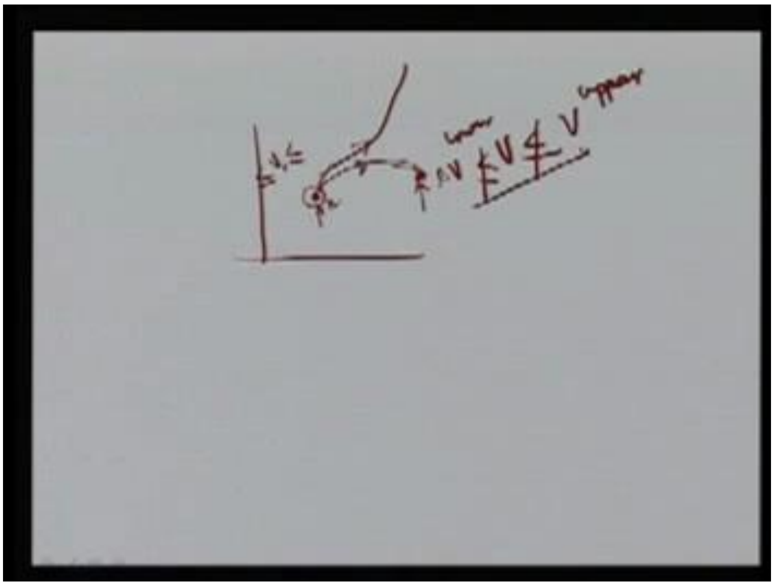

Here this security is one step ahead. There is a possibility that your system here. For example, simple you are here, you are operating at here the voltage, well with your limit and your system is stable. Now, after the fault, after the disturbance you have to reached another point D, where this your V is not, means here this is you are not satisfying its limit; that is V limit upper, and here it is your V lower limit. So, system is stable, but it is violating the operating constraints. In this case I have taken the voltage, it may be your line flows, it may be the overloading of line flow as well, it may be violation of the reactive power limit and so on so forth. So, this pong is stable, this point is stable. In terms of stability we can say our system is stable, but in terms of security here this point is stable, this point is stable, but system is not secure.

So, it is one step ahead, where we have to check the operating limits as well that it should be well within limit. So, that is your power system security. So, already we define the power system security, and we get the different kinds of security in terms of line, or megawatt security, or reactive power or voltage security, and then we have get the several states based on the security; that is normal state security state, alert state, emergency state restore it even so on so forth. So, you can see security is one step ahead than your stability. Now, this power system stability again can be classified in the different way different, again depends upon the quantity which were monitoring, and that can be one is your angle, another here that is called your angle. It may be your frequency it may be your voltage.

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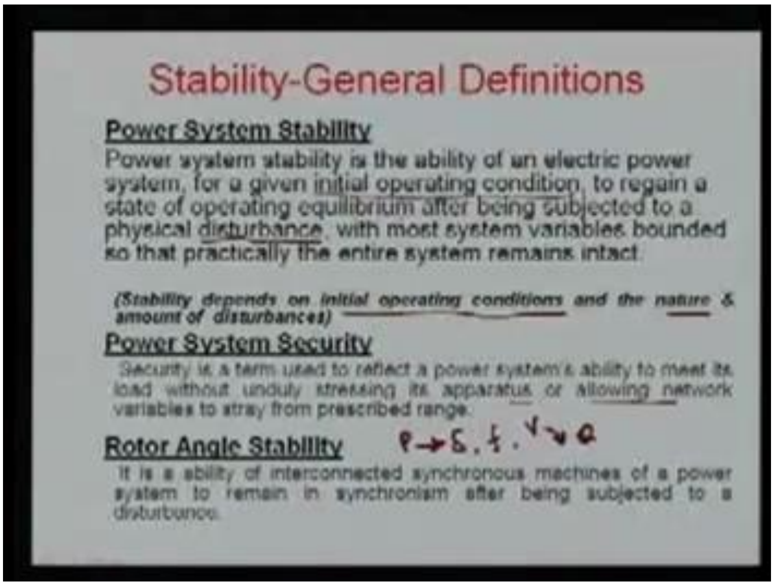

So, if your monitoring quantity is your angle, then it is called your rotor angle stability. Means monitoring means what, I am just going to say means this parameter is more concern, than other these two parameters, then we can say this is rotor angle stability. And you know this rotor angle stability is directly angle, here this is related with directly your real power flow; however, this voltage is directly related your reactive power, you will see later. So, the rotor angle stability is a ability of interconnected synchronous machines of a power system, to remain in synchronism after being subjected to a disturbance. So, whenever there is a disturbance to your whole operating system, including your synchronous machines, your whole intact system must be in synchronous, then we can say it is rotor angle instability of the system.

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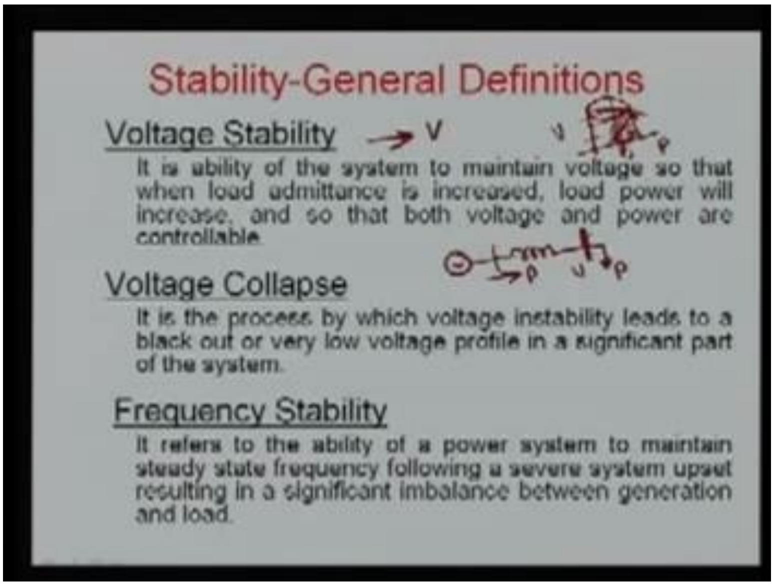

Now, what is the voltage. Here out monitoring quantity is the voltage rather than delta. So, the voltage stability is the ability of the system, to maintain voltage, so that when load admittance is increased load power will increase, and so that both voltage and power are controllable. What is voltage stability. To understand this is very. If you will see the two bus system, this is your real power, this is your voltage, and if you draw the Pv curve we will come to this voltage stability in detail, in later lectures of this module will come detail. So, better to understand here, let us see a voltage variation. We have our system let us suppose our generator, and here we have a transmission line, and this is your infinite bus, or you can say here we have a load here. So, we can draw the power which is flowing here, it will keep on increasing that will that is here load, then the voltage at this terminal this is your side bus this V as we can draw as per this characteristic, what does it mean. It shows that for one power. Let us suppose P naught here you have two voltages here as well as here; one voltage here, another voltage. Now which one is your operating voltage which zone is stable, which zone is unstable, you can see the top most.

When the power is increasing your voltage is decreasing; that is obvious, but in this case you can see if your power is increasing the lower portion, this point is called nose point. So, the lower portion power is increasing voltage is increasing. So, this is a reverse one. And here what is happening, your admittance is increase when your load power is increase. So, this zone, the lower section here is called unstable, and it is you can say the voltage instability in this zone only operating voltage will be in this zone. So, this related with the voltage, when we monitor the quantity, where the quantity of concern is much voltage than your delta and the frequency, then it is called voltage stability. Another term is widely used; that is voltage collapse, people say the system is collapse or black out, whether due to the angle stability, or whether due to the voltage. So, the voltage collapse is the process by which voltage in stability leads to a black out, or very low voltage profile in a significant part of the system. Means when the system voltage go beyond its permissible limit, and it is persisting for a longer time, and then it is called the voltage collapse. It nearly to some times, the black out in that area. So, this is your voltage collapse definition.

Now, in the frequency stability, as I said the three terms; delta, voltage, and frequency. So, the delta is related to your angle stability, voltage related to your voltage stability, and the frequency is related to your frequency stability. No doubt the delta and the frequency are directly related with the real power; however, there voltage is related to your reactive power. When we are just talking about the delta, we are observing the delta of the machines, it is basically angle of stability, when we are talking the frequency, where the delta everything is in normal state, but frequency is changing; that is severely, then it is your frequency stability. So, the frequency stability refers to the ability of a system, to maintain steady state frequency, following a severe system upset, resulting in a significant imbalance between generation and load. Basically, the frequency stability is concerned with this imbalance in the power. Means this instability occur, when there is a severe search, severe outage of your system generation and etcetera. So, what normally we do, we go for the islanding of the power system. So, there may be a possibility one island may not having the balance reserves, balance supply, and that may have the frequency instability. So, this is basically the severe faults whenever arise, then the frequency instability term comes into picture.

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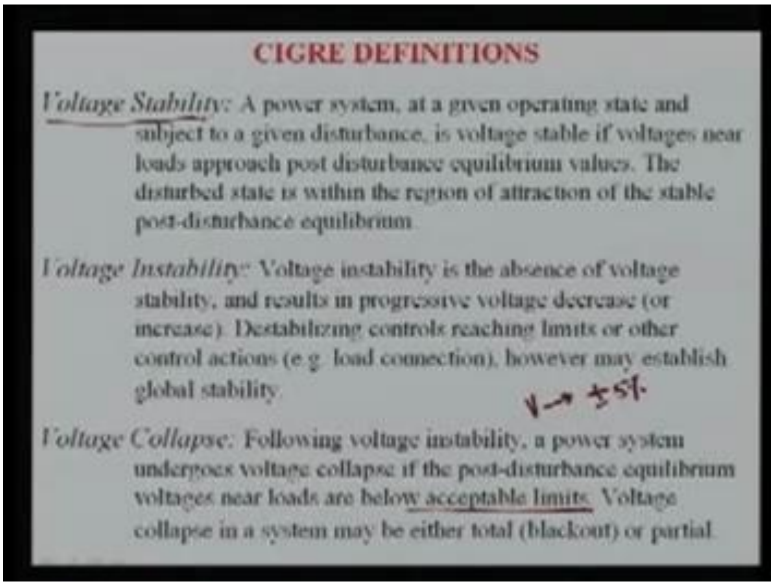

let us see the, again the voltage stability voltage instability and the voltage definition as per the CIGRE. Voltage stability; a power system at given operating state, and subject to a given disturbance, disturbance includes your fault, may be variety of faults you know, is align to ground fault l l fault triple l fault. So, all the varieties of faults, tripping of the heavily loaded transmission line, outage of power generators. So, all these are the disturbances, is voltage stable, if voltage is near the load approach post disturbance equilibrium values. The disturbed state is within the region of attraction of stable, post disturbance equilibrium. Means here once the disturbance is there initially your system is operating in the instable mode, without violating the voltage, and after the disturbance. if the voltage is also well within limit, then it is called, and that equilibrium is must be stable, then we can say it is a voltage stable, and your system is, voltage stability is there.

However, the instability the voltage of the instability. The voltage instability is the absence of voltage instability means there is no voltage instability and result in progressive voltage decrease or increase in both side. There may be voltage excessive increase. There may voltage decrease. Destabilizing controls reaching limit are other control actions line load connection load shedding; however may establish the global stability. Here in the voltage instability what happens. There is a possibility that the voltage of the fewer area, certain zone may increase, or decrease heavily, and that may destabilize the control actions. You know we have a lot of devices those are working on the voltage measurement. If the voltage is less, so under voltage really may operate picked up, and they may give you trip support command to the load shedding etcetera, because we under voltage or under frequency, the release are there, and they are normally go for load shedding etcetera.

So, it may go for the load disconnection, then what will happen, then it is called the voltage instability. Means voltage has gone excessively down, or higher than its prescribed limit. So, the voltage collapse as per CIGRE definition, the following voltage instability, a power system undergoes voltage collapse, if the post disturbance equilibrium voltages near loads are below acceptable limits. Acceptable limits, here it is not only this operating limits. We can operate the system, smoothly even though outer than you voltage limit. As I said, the voltage limit here should be plus minus five percent, for ehb line, but in the voltage here is more than six seven eight percent it will not hamper your system stability your system can operate, but we do not want to operate, because that is a station that may lead to the instability phenomena later on. So, it is the acceptable limits normally it is again depends upon the system to system, how stress your system, at what loading your system is operating that is defined.

So, the voltage collapse in a system may be either total; that is total black out or it is a partial. Partial again it is a confuses, and for whole let us suppose for our Indian case, we have the as I said in the previous lectures, that we have the five regions, we have the northern NREB northern regional electricity board, we have eastern regional electricity board, we have western, we have southern, we have north eastern as well as the eastern. We have five regions. So, in all the regions other states are connected, like in northern Uttar Pradesh people are connected in the northern region, it is your Rajasthan, Haryana, Punjab, Jammu and Kashmir, and Himachal Pradesh, of course Delhi is also inside that. So, they are connected. So, what happens, there may be possibility that few portion of whole this northern region is in out, means in dark black out. So, it is called the partial. If whole this region has gone, then it is a complete black out, even though some of the feeders, those are feeding to some village, some area, some municipality, something your urban area, and that feeder has gone due to the instability and the problem then it is called the partial. So, your this voltage collapse may be your partial or complete, again it is due to the voltage if it is beyond acceptable limits.

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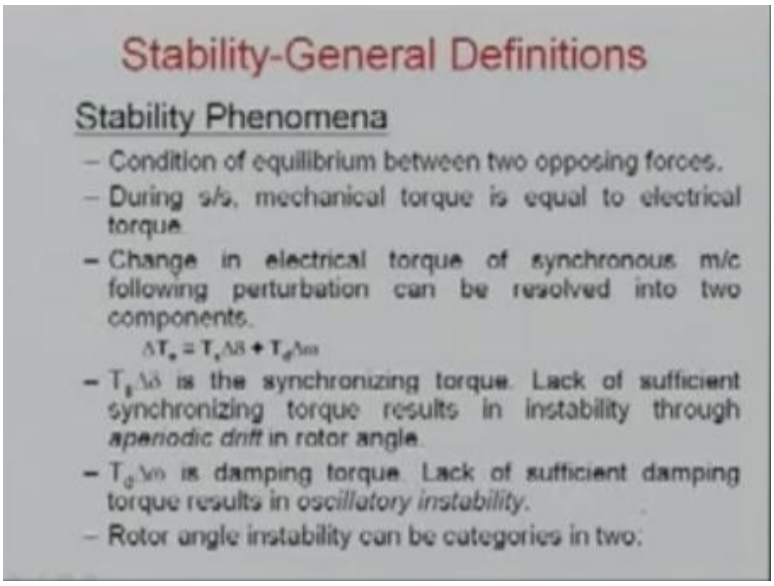

So, the stability general definitions, let us see what is the stability phenomena. Basically the stability, is can be defined, can be understood by looking at the condition of equilibrium of two opposite forces. So, stability phenomena, basically can be realize by understanding the condition of equilibrium between two opposite forces, to understand this, here for any system here.

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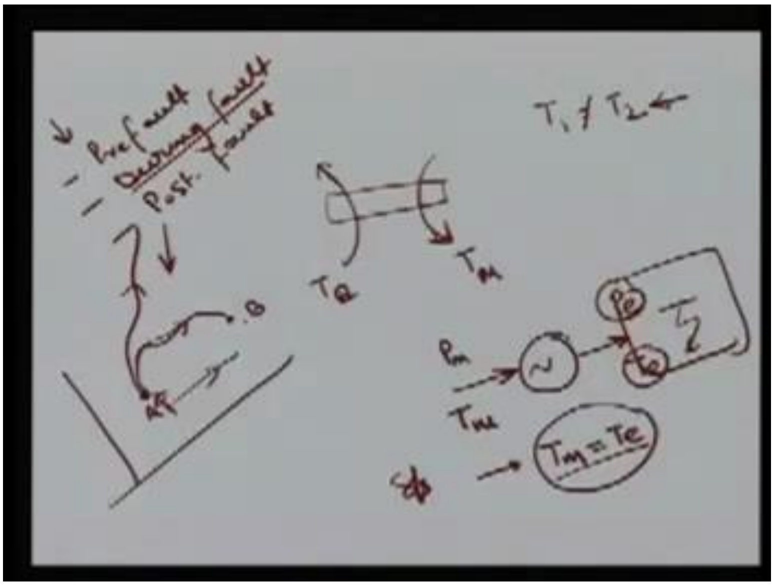

Let us suppose you have a mass here, this let us suppose it is rotating. So, to hold it if one direction of torque is this, and another is opposite, then it will not rotate and their system will be intact, simple for one revolving. If you are having one force here, then it will keep on moving in unidirectional, but if you have another force, that you is trying to resist it and if both are equal. Here let us suppose your T 1 and your is the T two. If your T 1 is equal to the T two, then we say the system is stable, it is not moving. If one force is there, another force is opposite, but there is a possibility if anyone of this is increasing or this equation is not satisfied, it is not this, then it will be adding one motion in any direction. Here, again if T 1 is more than T 2 it will be rotating in this direction otherwise T two. So, it is basically the equilibrium condition of two opposing forces.

During the steady state, the mechanical torque is equal to electrical torque. Now come to the machine part normally this T 1 is nothing, but your Tm and this is your Te. Tm is the, in any machine. Here let us suppose your synchronous machine here, what happen here we give here you are the mechanical power and we get out electrical power. Means the power once the system is rotating, is the rotating the mass and this power we can say we have the torque, that mechanical torque, and here we are getting the electrical torque. So, if both during the steady state, the Tm is equal to your Te, and then it is called the steady state. But during the disturbance, this relation may not satisfy. And again I have one system is stable we will get this condition satisfy. So, during the disturbance period, when this is not satisfying, what will be the system behavior, and that is basically we have to study the behavior of the system during that one.

Means we have the three conditions; one is called your pre fault condition, another is during fault condition, and third one is your post fault. So, these conditions, here the pre fault conditions it is satisfying this Tm is equal to Te. Your post fault must also satisfy this, if it is not satisfying, means your post fault system is not in equilibrium condition. So, the pre fault and the post fault is in equilibrium condition, but during the fault, means as I said in the multi directional here, multi variable space, your point here is the pre fault condition is A, the post fault condition here is B now during fault, whether your system is coming here, with the following trajectory or it is going somewhere else are unstable condition. So, basically the stability phenomena, is related with what is the condition here, it is also very much depends upon what is the condition of your pre fault, what is your condition of your post fault, and during what is your condition, what is your system behavior.

So, we try to analyze these trajectories, if you can get this trajectory in this time domain. Then we can say and we can just whether system is stable or unstable. So, the change in electrical torque of synchronous machine, following perturbation or disturbance, can be resolve into two components, that the two components that change in the electrical terms. Whenever there is a fault in the system as I said here, there is a some fault in the system, let us suppose this is generator, and it is connected with your power system, if there is any fault in the system, this Pe or you can say Te will be changed.

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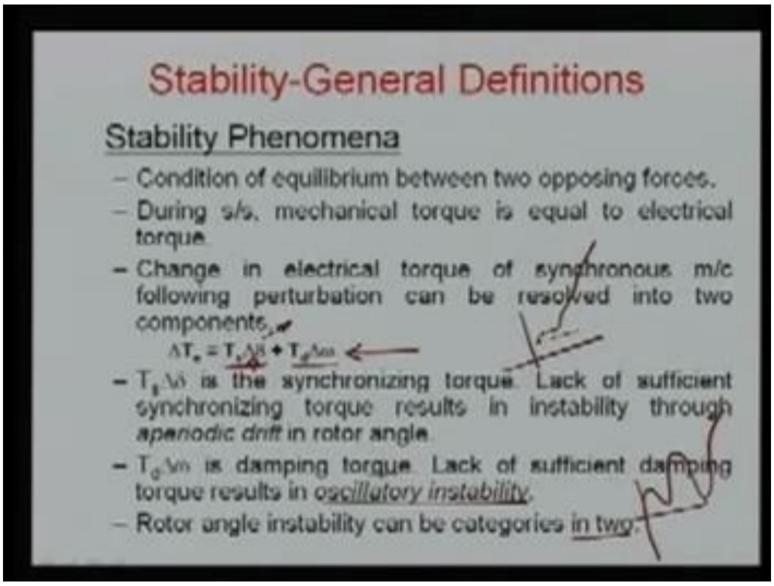

So, the change in this change in this Te, will be related with this equation, means we have two component; one component is called the synchronizing component, this is your synchronizing component, or synchronizing torque, and another is your damping torque. The damping torque; that is Td here, it is in the phase with the change in the speed deviation. How about your synchronizing torque; that is in phase with your angle deviation difference in angle. So, the lack of sufficient synchronizing torque, results instability, through a periodic drift in the rotor angle. Means if there is a lack of your synchronizing torque Ts, then it will give you this change in delta which is moving. And it is aperiodic, means you system here like this, it may be form here it may go like this. It will be not, you can say not oscillating in nature. So, it is aperidoic drift in aperiodic change.

Another component is your Td del omega is the damping torque, and this damping torque basically if there is a insufficient damping torque, then it will result in the oscillatory instability. Means your system here will be what will be going, it will be keep on increasing, and it will be oscillating, because it is a change in the speed here, and means change in the delta means, if speed is changing, so change in delta also there. So, the rotor angle instability can be categorized into the two, based on the large or smaller disturbance, and those are here I can say small signal or we will see the transient stability.

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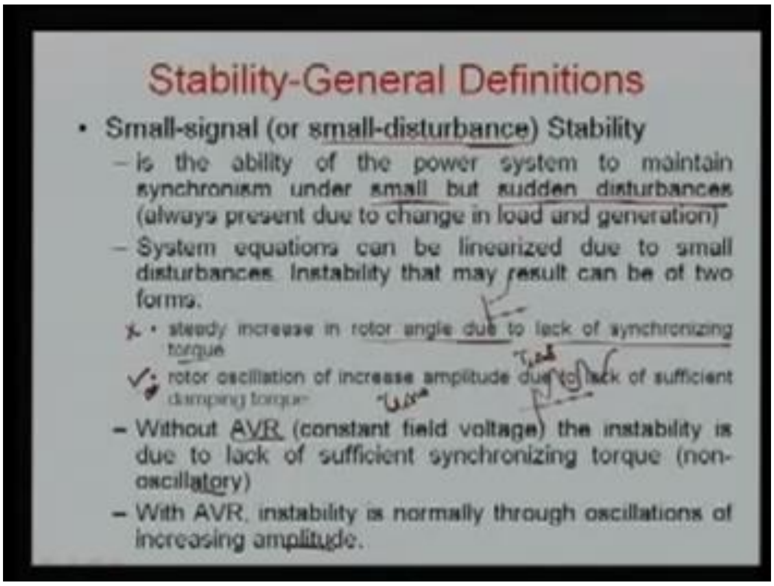

There are two types of rotor angle instability; one is your small signal instability. Basically in this we analyze with the small disturbance. Small disturbance is nothing, but change in your load, and change in generation, this is small, but the certain amount is small, but the certain change, and it is always happen in the power system, because in the power system, you know this load it is keep on changing, and generation is following that. So, generation and load are keep on changing and that is always there in the system. So, we have to analyze the behavior of the system with these changes, and that is always there. So, the small signal also known as by small disturbance stability, is ability of power system to maintain synchronism under small, but sudden. So, that is why here I am saying it is a small, but sudden disturbances, and those are always present due to the change in load and generation.

In this case the system equations are linearized due to small disturbance, means we have to linearize as you know the power system is non-linear equation, non-linear phenomena. So, those non-linearity can be linearized, and then stability can be studied. Instability that may result can be of two forms; means again it can be two forms; one is the steady increase in the rotor angle, due to lack of synchronizing torque. As I said the synchronizing torque that is your Ts here delta S, and another is your rotor oscillation of increase amplitude due to the lack of sufficient damping torque; that is Te delta omega. So, it can be due to this region or it can be with this region. So, this is no doubt it is oscillating, and you can here, it is keep on increasing with the oscillation and system become unstable. Here your angle basically keeps on drifting to change in delta continuously or it is over periodic change, and that is due to the lack of synchronizing torque.

Normally the first one; means if you see without AVR, the constant field voltage the instability is due to lack of sufficient synchronizing torque; that is non-stability. So, the previous as I said the lack of synchronizing torque, will give your over periodic drift of the rotor angle, if there will be no AVR automatic voltage regulators, but now a day's modern power system, they are having automatic voltage regulators. So, that type of concept here, this is normally is not happening. So, only the small signal stability, is of this concern, and we always go for the oscillatory type of instability appears. So with the AVR that is automatic voltage regulators means excitation system, automatic voltage regulators you have to control the voltage automatically, and that is basically due to the excitation system; that is allowable with the generators. So, all the modern generators they are equipped with the AVR's. So, the instability with the AVR is normally through oscillations of increasing amplitude, means the second type of here, is small signal stability. Again this small signal stability, can be classified into the two forms, not two forms, it is four forms.

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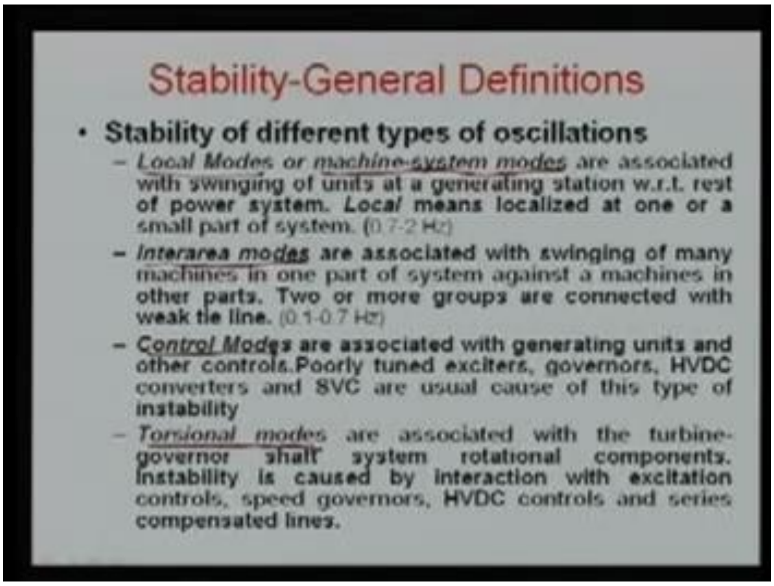

That is first one is your local mode, or sometimes also called the machine system modes. Another is your inter area modes. Third one is your control modes, and forth one is your torsional modes of oscillation. Now, let us see what is your local mode. The local modes are associated with the swinging of units at generating stations, with respect to the rest of the power system. The local means localized at one or a small part of system, and this frequency of oscillation is normally 0.7 to 2 hertz.

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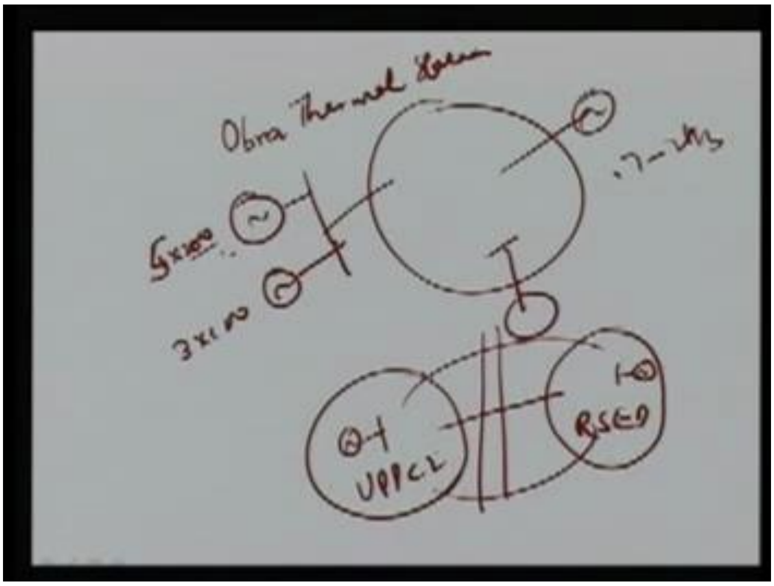

To understand this here, let us suppose here a power station system; let us suppose we have a OBRA power station; that is thermal power station we have. This is generator at OBRA, it is not one there are so many generators in OBRA, means we have here we have 4 into 200, we have 5 into 200 we have, and then we have again 3 into 100, and also we have fifty also those are not working now a days, and it is connected with the rest of the UP and this NRB system. What happens we have other generators here, we have other generators here, in the system we have a more than 40 50 generators in a NRB region. So, if the any one of the units here at OBRA is oscillating, with respect to other system here. Means you can take this system as a standard, and then you can see the oscillation in this, any unit of OBRA then we can say it is a local mode oscillation. Another one is your inter area modes; means inter area modes of oscillations are associated with swinging of many machines, in one part of system against a machine in another part of systems, and two or more groups are connected with weak tie line, and this stability oscillation is normally 0.1 to 0.7 hertz.

To understand this here for example, let us suppose we have a one area here, and another area here. Means we have here UPPCL. Here we have a Rajasthan state electricity board, and we have the several lines those are connected with the different. There is a possibility, the generators in this area, and the generators are here, they are oscillating to each other. So, it is inter area, and this is due to the weak tie line between these two. So, it is called inter area modes of oscillation. So, the different between your local mode, local mode unit means one unit of any power plant is oscillating with the rest of the system, and that here it is 0.7 to 2 hertz. And here in the inter area modes of oscillation, the one area. Area may be your few generators may be a complete state, they are degenerators in that area or oscillating, with here the generators in another area. So, it is called inter area.

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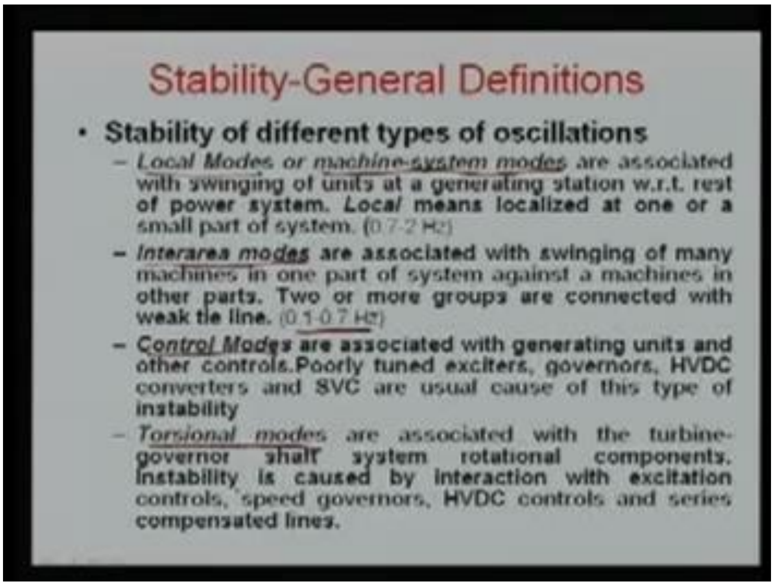

Another term is called control modes of oscillation; the control modes of oscillation are associated with the generating units and other controls. The poorly tuned excitation system, governors, HVDC converters, SVC are usual cause of this type of instability. Basically this is related with the control functions, because if a generating units is here due to the control of that particular unit, and it is oscillation, then it is called control modes. Means due to the control, because various control in any generating units, it is your excitation control, it is your governor control. In the other, let us suppose you have some other extra devices like HVDC terminal is going on, and there we are having some SVC etcetera.

So, all the controllers here they are oscillating to each other, and that is basically it is called control modes of oscillation. Another mode of oscillation is the torsional modes of oscillation, and those are associated with the turbine governor's shaft system rotational components. Instability is caused by interaction with excitation control, speed governors HVDC control, and series compensated lines. So, this is torsional modes of oscillation. So, torsional mode of oscillation can be understood by knowing this generating station, is driven by the various types of turbines. It may be your high pressure turbine, or it may be your low pressure turbine, it may be your intermediate pressure turbine. Again depends upon the size of the generating power plant, it depends upon the whether we are going for the three stage, or two stage. Let us consider a big power plant, which is having units of 500 or 200 megawatt.

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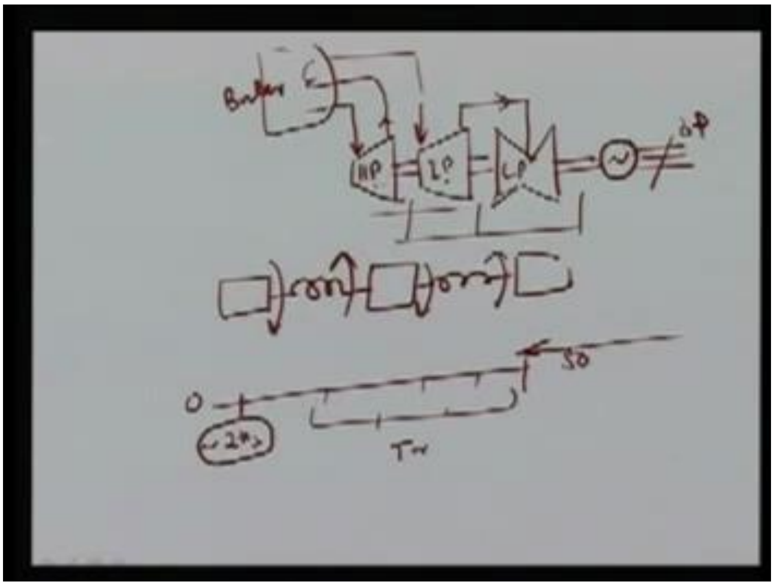

So, this is your synchronous alternator which is rotated by the turbines, and all the turbines here we can say this is your IP, this is your HP means high pressure turbine, that is coupled with another shaft, and we are having here your intermediate perfect turbine; that is your IP and then we are having your LP; that is low pressure turbines and then here it is connected with your shaft. So, this is your LP low pressure turbine, then we are getting three phase supply three phase power system that is connected. Here we know your steam is coming here to your IP, and once it is expanded here it is coming going out. Again your pressure is coming here, and then it is going out and finally, it is coming here. Normally again it is going to be a reheated, and then finally, it is coming here and this is your boiler. So, we have here shaft, and that is all this HP that is high pressure turbine, intermediate pressure turbine, low pressure turbine. All are on the same shaft, where your alternator that is your synchronous machine is connected. We had here the four rotating mass. So, all these four rotating mass, they are connected with the shaft, and that shaft is having some stiffness constant, it is not infinite.

So, they are behaving just like it will take this example like here. So, this one mass it is connected between a spring and here is another mass. So, here it is rotating, and that another is opposing, and then finally, another mass here and then it is and so on so forth. What is happening if we analyze, then we have some critical frequency corresponding to all these masses. So, here we will get the one two and three; the frequency will be arising and that is called the torsional modes of frequencies, and that is some oscillation. So, this frequency if your system is here from zero hertz to, your operating system is 50 hertz. Normally we will find some frequency if you analyze complete system damn means including the turbines etcetera as well, then you will find some here you will find at the range of 2 hertz, and the remaining you will find intermediate less than 50 hertz per cycle. So, these basically frequency of oscillations are the torsional modes of oscillation.

Normally one term is very popular from synchronous resonance, because if your system which is compensated transmission line, there is a possibility that due to this here some synchronous, some frequency that is the current which is entering into the system that may coincide with these frequency of oscillations, and then there will be huge resonance. What will happen if there is, that frequency is matching with the torsional modes of frequencies, then there may huge torque that is developed inside the shaft, and the shaft may be broken, and that is called your sub synchronous resonance, because at that frequency the resonance has occurred. So, this is basically your torsional mode, and here this is your; that is two hertz as I said is a local oscillation mode. So, this is your torsional mode of oscillation.

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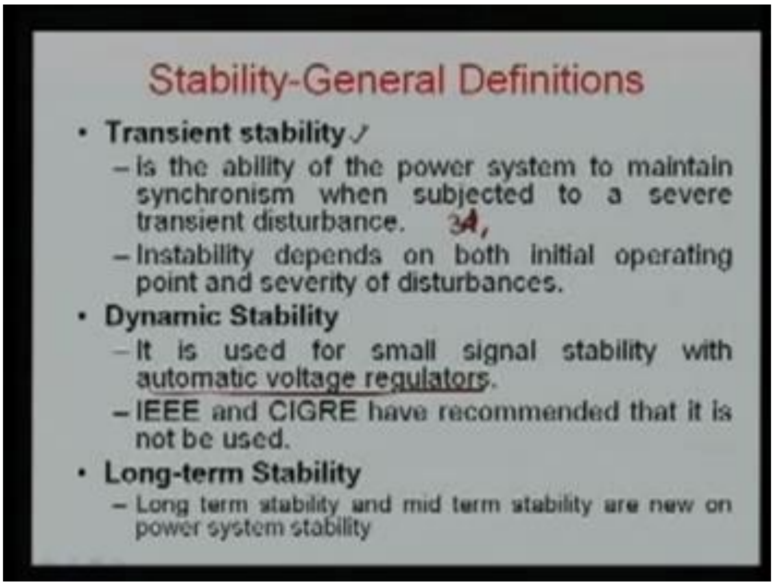

Now, let us again go back to the various stability phenomena's and that is defined as a transient stability, as I already discussed the small signal stability, means small disturbance stability concern. Here the transient stability is also known as the large disturbance stability, and it is the ability of the power system to maintain synchronism when subjected to a severe transient disturbance, severe. Again the severe I am just telling from beginning, that it may be your three phase fault; it may be severe power outage, and it may be other type of fault, it may be some trimming of some severely highly loaded some transmission line, then your transient stability phenomena will occur. In this case we cannot linearize the system, and we have to solve the system with taking the non-linearity of the system as well. So, instability here depends on the both initial operating point as well as the severity of the disturbance.

So, we have to go for again the modeling of the load, modeling of the power system, including you generator system, including you excitation system, and that will be clubbed together and then we have to analyze. Normally these transient stability phenomena, we normally go up to 3 to 10 seconds; however this small signal stability phenomena analysis is require up to 10 to 20 seconds. Another is your dynamic stability concern; it is used for small signal stability with automatic voltage regulation. As I said the small signal stability again can be with the voltage regulators AVR's or without AVR's, but not this dynamic stability concern is not raised and IEEE as well as the CIGRE recommended that it cannot be used the dynamic stability, because most of the power generating stations they are equipped with the AVR, there is no question of talking about this with or without AVR. So, whatever we are going to make analysis with the AVR; that is your small signal stability if your disturbance is small, and if your disturbance is severe and transient in nature, then we have to go for the transient stability analysis.

Again, the stability phenomena as I said it depends upon the severity of the difference we defined, and again this definition I am talking about the angular stability. So, from the looking at the point of view the severity of the system, severity of the fault we categorize into two; one is your small signal; that is small disturbance, and another is your large disturbance or your transient stability. But if you are going for the time frame, then it is called the long term stability, and it is your. Another is your short term stability, or it is your medium term stability. Long term stability and the midterm stability are now new in the power system stability, and that is basically due to the frequency stability. I will come to the total background of stability phenomena, and we will see no various again at concise way.

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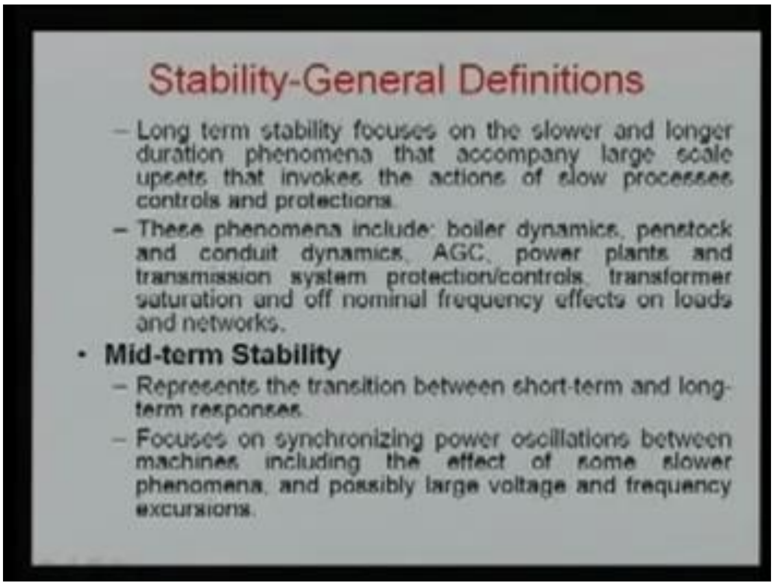

So, long term stability focuses on slower and the longer duration phenomena, that accompany large scale upsets that invokes. The actions of slow processes controls and protections schemes. Basically in the power system, there is a various protection schemes, and if they are activated due to those, there may be different control action. This is slow and longer duration phenomena occur. So, it is called long term stability phenomena. This phenomena includes the boiler dynamics. You know all the boiler dynamics, all these mechanical devices. You must be very careful all mechanical devices, including governors, boilers, penstocks, consume dynamics. They are basically having the high time constant, large time constant compared to your electrical system. So, if you are going to include, and they are going to impact your instability of the system, then it is called your long term stability phenomena, and then you have to take into account the various dynamics; like value dynamics, governor dynamics etcetera along with your AGC, power plant, transmission system protection and controls transformer saturation off nominal frequency effects on loads and the networks all they are going to be included in the long term stability phenomena.

In the midterm stability represents, basically the transition between the short term and long term responses, and focuses on synchronizing power oscillations, between machines including the effect of some slower phenomena, and possibility large voltage and frequency excursions. Here the large voltage and frequency excursions as I said, the frequency stability is due to the severe frequency deviation. So, if your frequency is suddenly changes, normally this situation occurs when there is a lot of balance in the power and supply. So, if there is a large voltage and frequency, then your this time long term and midterm stability is concerned, and normally they come into the now in the new definition they are coming in your frequency stability concept.

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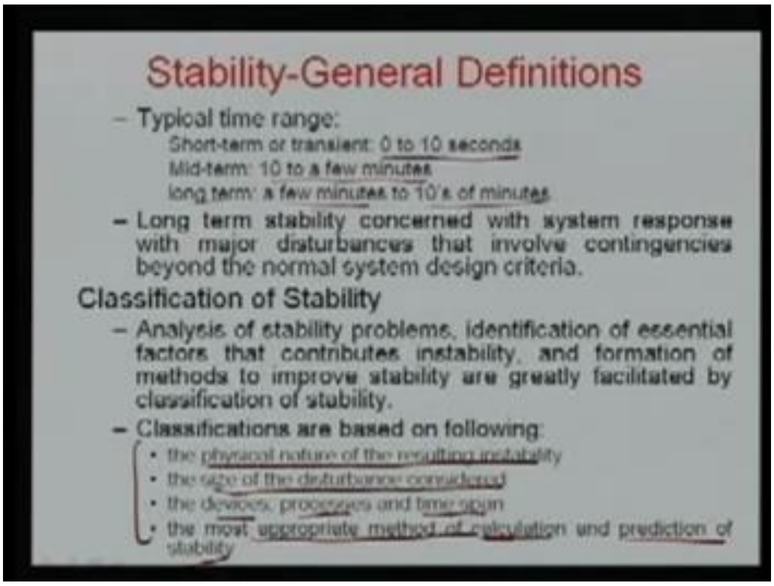

So, typical time range you can see, for the short term or your transient, it is 0 to 10 second. For midterm it is 10 to few minutes, and long term it is few minutes to ten's of minutes, normally this times of range of interest. So, if you are analyzing the long term stability, then you have to go for the several minutes. If you are going for the short term, then it is few up to ten or to twenty seconds. Long term stability concern with the system response, with the major disturbances that involves contingencies beyond the normal system design criteria. Now, one thing we should always be concern, it is not possible to design a system, that can sustain all the possibility of the contingencies, all the possibilities of the faults. And again if it you are going to design a system that can sustain all the possibilities, all the faults, all types of trippings, all the consideration, then it is not possible and then it will very expensive if you are going to design that. So, what we normally go, we normally try to analyze the system with the most provoked, and the most credible contingency in the system, and based on that we analyze whole your stability phenomena. You can say it is your transient. Small frequency or voltage stability as well.

So, the classification of stability analysis. The analysis of stability problem, identification of essential factors that contributes instability, and formation of methods to improve stability are greatly facilitated by classification of stability. So, classification are based on the following, that the physical nature of the resulting instability. The size of the disturbance considered, the devices processes and time span of your analysis, and most appropriate method of calculation and the prediction of stability. Here this calculation methods are also very important, sometimes your calculation methods, because all these methods we are normally suppose some stability for designing you are analyzing your system whether your system will be stable or not, then we have to solve certain sets of differential equation. So, for solving the differential equation that there are various methods, and again these methods are very much related with the initial guess.

So, if your initial guess is very bad, then there is a possibility that you will not get the stable solution, but the system is effectively it will be stable. So, it does not mean you solution is not giving a stable solution, you can say your system unstable. So, appropriate calculation methods are also very important that which method you are applying, what is your initial guess etcetera that should very close to the post disturbance equilibrium, and again which type of stability you are predicting. So, what is the type of fault what is again, what is the size of disturbance consider what are the devices and processors that are going to be consider. So, these all are included in the classification of the stability problem. So, far we had seen the various type of stability classification, and again now I can summarize.

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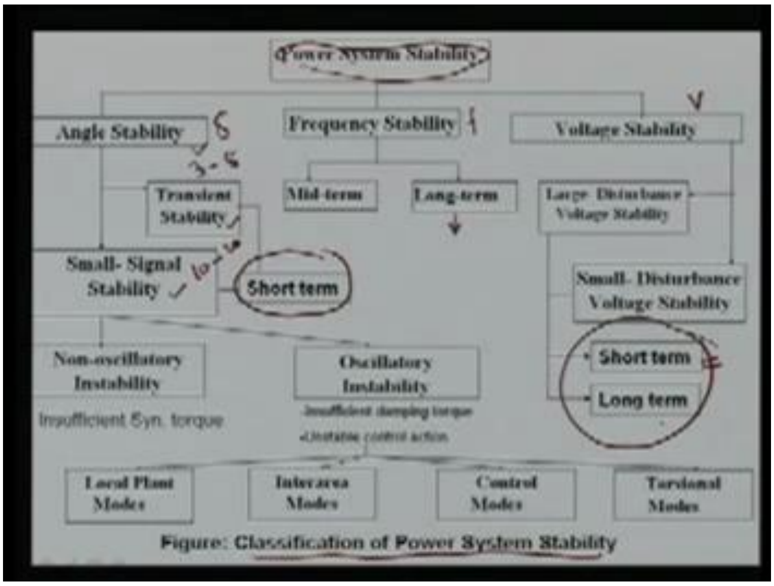

So, you can see the power system stability here in this diagram. It is basically can be categorize in three groups; one is your angle stability, where we are concern about the delta. Another is your frequency stability, it is basically related with the frequency, and another is your voltage, there is voltage stability. So, again this angle stability can be classified into the two categories; one is your transient stability, and another is your small signal stability. Again to remind you the transient stability is also called your large disturbance stability phenomena, and the small signal is your small disturbance stability phenomena. All these two are basically related with the short term stability phenomena, and this basically related with your, this normally required 3 to 5 second, and here we go for the 10 to 20 second. So, whole this analysis is if you are going for the time frame, then this your angle stability is your short term phenomena, because it is less than one minute.

Again, this small signal stability can be classified into the two group. As again I will claim one is your called the non-oscillatory instability, and another is your oscillatory instability. Here non oscillatory instability is due to the in sufficient synchronizing torque, if the automatic voltage regulators are not there, then this concern arise. But now a days most of the generators they are with the AVR's; that is automatic voltage regulators. So, oscillatory instability is the major concern in the modern power system, and this is due to the insufficient damping in the system. And if there is insufficient damping term, so there will be some sustained oscillation in the power system, and if that oscillation is keep on increasing, then it is called oscillatory instability. But if this oscillation is keep on reducing r is stable then it not increasing, then we can say system is instable and it is oscillatory stable.

Again here that oscillatory instability can be classified into the four categories; depend on different criteria; first one is your local or you can say plant modes. Again I said that it is due to the one plant one unit oscillate respect to the rest of the system. here inter area means two areas or oscillating to each other, again due to the weak tie lines, and the control modes if any power station there is various control various controllers are there they are oscillating and various control modes, and the torsional modes due to the rotating mass different turbines are there, and they have some critical frequency if they are some oscillations are critical frequency between that and that is called your torsional modes. To come to the frequency stability, here it is your midterm, or it is included in the short term, and then another is your long term.

Long term here when we go for the long term stability, basically it is. Again here within here the midterm it is less than one minute, and long term it is more than one minute here it is note. Here what it is in the long term normally, we take the dynamics of your boiler, your governors all the dynamics and the slower dynamics processes if they are included, then it is called long term stability. Here in the frequency stability, basically it is due to the huge excursion, again of the frequency in the system. Normally if the systems become islanding, there in unbalance in real and reactive power huge power, then we can say this frequency stability phenomena is occurring, or you can say the system is frequency instable. Another third one is your voltage stability, and that voltage stability can be categorize into two part; one is your large disturbance voltage stability, another is you small disturbance voltage stability. Here again based on the disturbance. So, if your disturbance is severe, then if you are analyzing your stability, then it is voltage stability with the large disturbance, another is your small disturbance voltage stability.

So, large disturbance voltage stability just like a large disturbance, that if there is a tripping of transmission line, tripping of your generators, or there is a some three phase fault, then it is if you are analyzing then it is voltage stability with large disturbance, and for the small disturbance; means if there is a change in the small loads, there is small gradual change in the voltage etcetera, then it is called the small disturbance stability. Again this voltage stability in terms for time frame. Here just I have taken combined together, means we have two type; it may be short term voltage stability problem or it is your long term voltage stability problem. The short term voltage stability involves the dynamics of fast acting voltage components; such as induction motors, electrically control loads, and HVDC conductors. The study period of interest is in the order of several seconds, and analysis required the solution of appropriate system differential equations. This is similar to the analysis of rotor angle stability, dynamic load of angle is often essential in this case, and in contrast to angle stability the short circuits near load are important, it is recommended that that the transient voltage stability not been used.

Normally we should not say it is transient voltage stability. So, always we had to call it is a short term voltage stability. In the long term here the voltage stability involves the slower acting equipment; such as a type changing transformers, thermo statically control loads, generator current limits etcetera. The study period of interest may extend to several or many minutes, and long term simulations are required for analysis of the system performance. The stability is usually determined by resulting outage of equipment, rather than the severity of initial disturbance. Instability is due to the loss of long term equilibrium, when the load try to restore their power beyond this capability of the transmission network, and connect the generation. The post disturbance steady state operating points, being small disturbance unstable, or a lack of attraction to or they stable post disturbance equilibrium. So, this is complete your power system stability definition, and then broadly classification of the power system stability.

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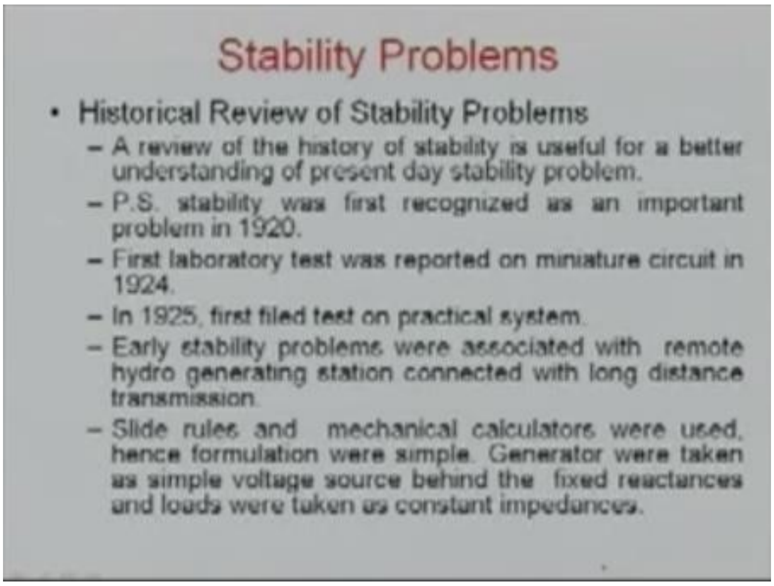

Again to go for the next chapter and next lecture of this module, let us see the history of system stability problems. So, historical review of historical problems, or review of the history of the stability is useful for the better understanding of present day stability problem. So, our power system stability was first recognize, as an important problem in 1920. The first laboratory test was reported on miniature circuit in 1924. In 1925, the first filed test on the practical system. Means first filed test on the practical system, they reported. Means first reported first reported test on the practical system. Early stability problem were associated with the remote hydro generating station connected with long distance transmission line, because earlier hydro generators were very prominent and then we had a long generating transmission lines, and then it was associated with long distance transmission slide. So, slide rules and the mechanical calculators were used at that time; hence formulations were simple. Generators were taken as simple voltage source behind the fixed reactances, and loads were taken as constant impedances.

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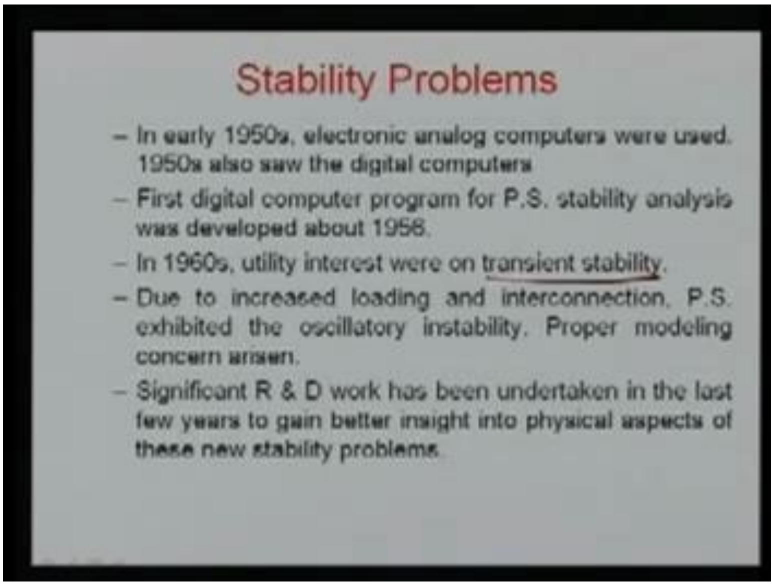

In early 1950s electronic analog computers were used. In 1950s also saw the digital computers. First digital computer program for power system stability analysis, was developed about 1956. In 1960s utility interest were on the transient stability. So, before 60s people were only concerned about the transient stability. Due to increased loading and interconnection, the power system exhibited the oscillatory instability proper modeling concern arisen. The significant R and D work has been undertaken in the last few years to gain better insight into physical aspects of these new stability problems. So, now a day we are going more and more detailed modeling calculations, and then we are analyzing the system, stability concern, and then we are designing the power system based on those criteria's.

Thank you.