High Voltage DC Transmission

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Module No. # 06

Lecture No. # 04

Transient Stability Analysis

Welcome to lecture number 4 of module 6, and this module; I will be discussing about the transient stability part having the HVDC along with the AC system. So, before going for the complete analysis, let us see some stability definition as well as the importance of the stability.

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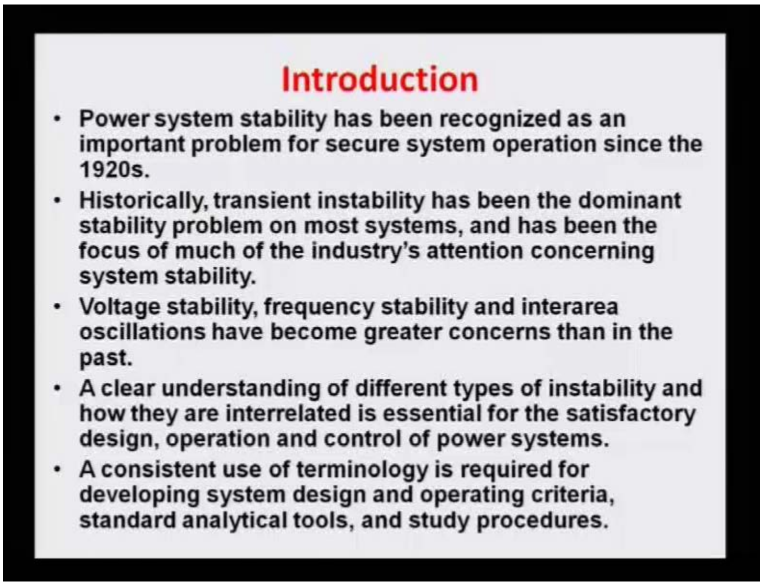

So, power system stability has been recognized as an important problem for secure system operation since 1920's. That time, even though HVDC systems were not very popular, only the AC systems were there and the transient stability was the only concern at that time. But now a days it is different and we will be discussing later part of the various other stability as well.

Historically, the transient instability has been the dominant stability problem in the most of the systems and has been focused of much of the industry attention concerning the power system stability. Later on, the voltage stability and the frequency stability and the inter-area oscillations have become greater concerns than the past, due to the increased loading as well as the interconnections of the power system. These other stabilities also noticed and the then people went for the analysis instabilities studies as well.

A clear understanding of different type of instability, how they are interrelated is essential for satisfactory design operation and control of power system. A consistent use of terminology is required because people use the different terminologies for different aspects. So, that is also required for the developing the system design and the operating criteria standards for the analytical tools and the study procedures.

The problem of defining and the classifying power system stability has been addressed by the several previous CIGRE and the IEEE task forces; these earlier efforts; however, do not completely reflect the current industry needs, experiences and understanding, in particular, the definition are not precise and the classifications do not encompass all the practical instability scenario.

This has created a need to review the definition and the classification on power system stability, and that is why the lot of task force has mentioned that they have defined, what is the various stabilities based on their time, based on their fault, based on other the power system parameters for example, voltage, angle and the frequencies. If you will see the power system stability, the old definition was that power system stability is a property of a dynamical system or its ability to remain in state of operating equilibrium under the normal operating conditions and to regain an acceptable state of equilibrium after being subjected to a disturbance.

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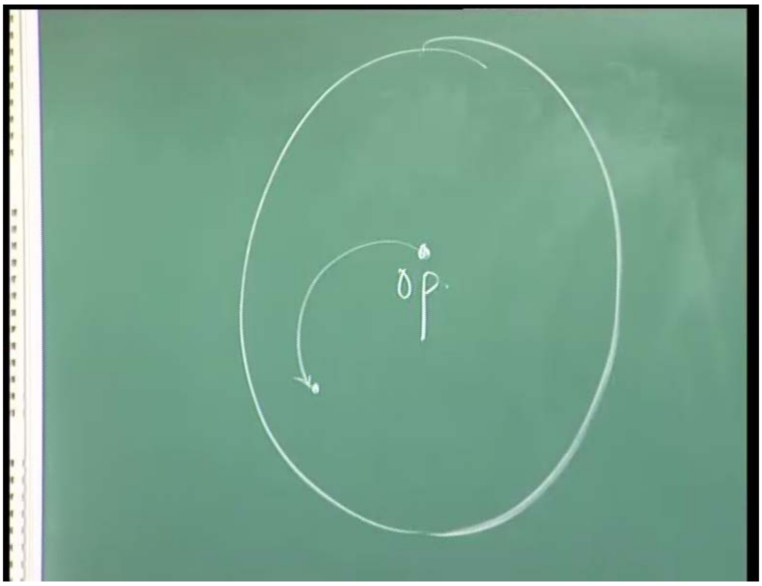

To understand this power system, I can explain on this board, there is a power system, here I can say this is your operating state, this is your boundary where your system is stable. So, in this, it is your initial operating state and your post disturbing operating state is this. So, how your system is moving here and this should come here after taking some trajectory. So, your post as well as the pre-operating equilibriums is in the normal operating conditions.

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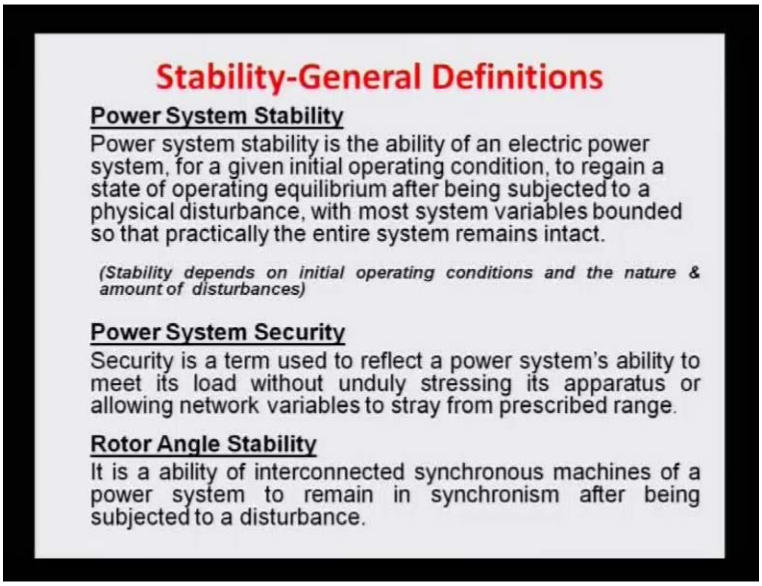

So, whenever there is if disturbance, your system will move from the initial operating conditions may move to another operating condition or even though sometimes moreover the same original operating conditions, but after certain disturbances it may follow a different trajectory. So, that is why this old definition is there, and if some other definitions like the power system stability is a ability of the power system in general of an electric power system for a given initial operating condition to regain a state of operating equilibrium after being subjected to the physical disturbance, with most system variables bounded, so that practically, the entire system remains intact.

Basically the system stability depends on the initial operating condition and the nature and the amount of disturbance. As I said, this is initial condition is also very important at what is the initial condition of the power system and also what is the nature of fault, what is the type of fault, and what is the duration of fault along with the system condition is very important.

To another word is also appearing in the power system; that is, a power system security, and this security is defined as a term used to reflect a power system's ability to meet its load without unduly stressing its apparatus or allowing network variables to stay from the prescribed range.

Security means, if your system is in normal condition, if there is any contingency; contingency means there is outage of any element and element can be your transmission line or your transformer or your power outage, that is called your outage of generator, outage of any reactive power source like capacitor, condensers or static wire compensator or you can say fax devices, then your system should be in the normal state if it is a going to happen. So, from your system is in the normal state, we call it the normal state. Again we can define the normal state is the state when your both operating and inequality constraints are within the limit; means your operating constraints are basically your limits of the voltages, limits of your tapings, limits of reactive power and the limits of the power flow; however, the equality constraints are the low demands both real and reactive power.

So, your normal condition is the said to be normal when your both equality and inequality; equality means your load constraints as well as inequality means your operating constraints are satisfied. So, in security, if your normal state, basically if your system is in normal state, and if there any contingency takes place; again the contingency means your outage of any branch or your power outage, then your system is in the normal condition of the that outage, then we can say a system current state is in the secure state. So, depending upon the number of outage like one outage at a time, two outage at a time, then we say the security is N minus 1, N minus 2 and so on and so forth.

If we are considering one outage or one contingency at a time, so, it is called N minus 1 contingency. If you are taking two, then it is N minus 2. So, the security is totally different than your power system stability. In the power system stability, as I said, this rotor angle stability is the oldest one and this concept and this phenomena was observed somewhere in 1920s and it is defined as an ability of interconnected synchronous machines of power system to remain in the synchrony after being subjected to the disturbance. It is a very general definition of rotor angle stability.

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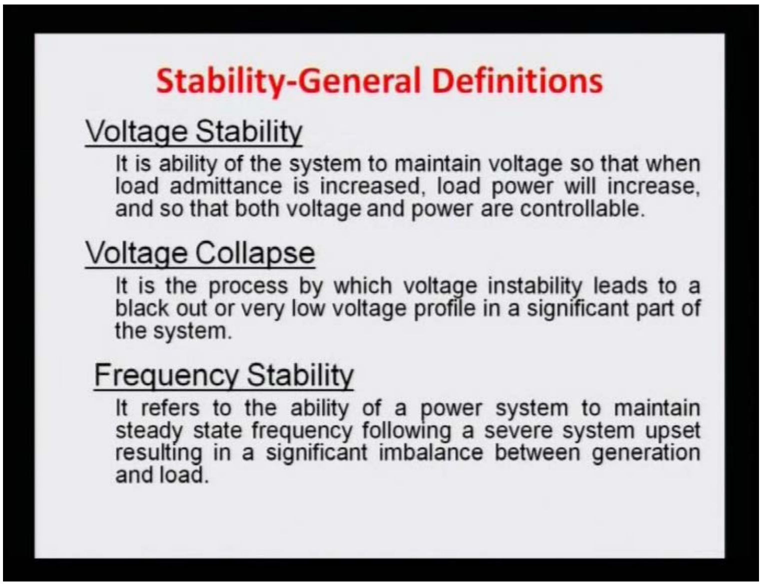

In terms of other stability, as I said, the voltage stability and the frequency stabilities. So, voltage stability is ability of power system to maintain the voltages, so that when a load admittance is increased, the load power will increase and so that both voltage and power are controllable. I mean to say that here if you are increasing the admittance; means if you are decreasing the admittance, the power drawn by that load will increase; this obvious one.

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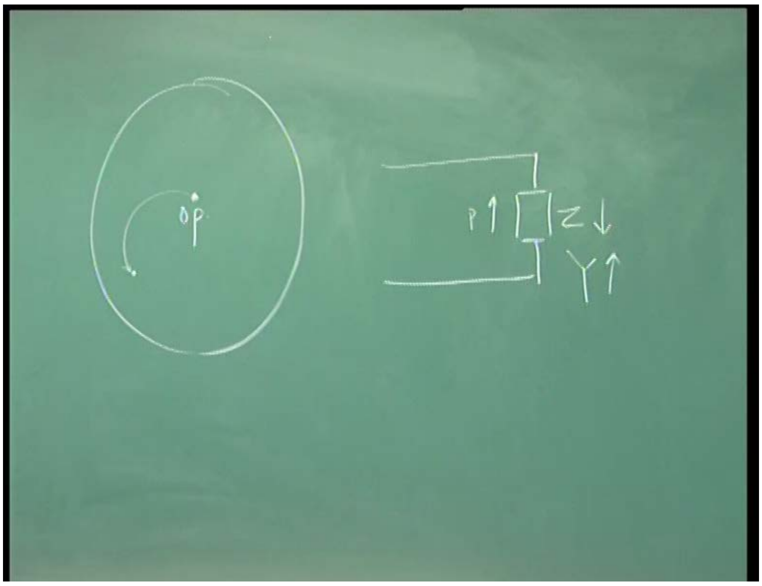

For example, if you are having here one impedance, here this is your, this your z, if z is reducing, then power drawn here, this P will increase or you can say your admittance here is increasing, then power is increasing. But if this is not controllable, if this is not happening, if your impedance is decreasing and your power is not increasing, then it is called the voltage instability. So, in this way, both power and the impedance are controllable to each other.

Voltage collapse is the process by which the voltage instability leads to the blackout; means the most of the part is in dark or very low voltage profile in the significant part of the system that is called voltage collapse.

However, the frequency stability is referred to the ability of a power system to maintain steady state frequency following a severe system upsets, resulting in a significant imbalance between the generation and load. You know, if there is any load mismatched, frequency of the system will change. This will change because when there is a mismatch in the power drawn and the input and output; that difference is basically is either gained by the kinetic energy or the loss in the kinetic energy.

Whenever there is a gain or loss in the kinetic energy, the frequency of the system will change. So, and this is due to the in steady state we talk if there is a load increase, suppose the load is more than your generation, frequency will fall down or reversed is also true. So, the frequency is basically related to the load generation balance and that is we normally this is studied in the automatic generation control concept.

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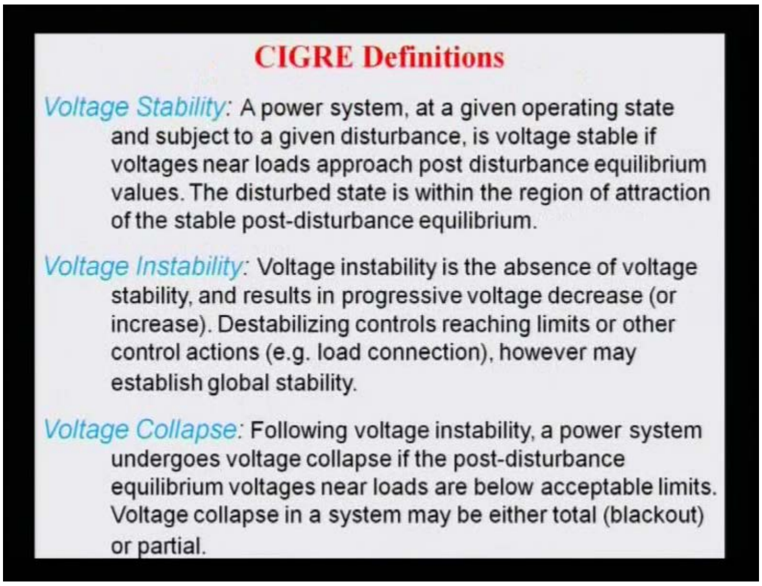

Let us see the various definitions of various terms by the various task forces. First one is let us talk about the CIGRE definition and in the CIGRE definitions, the voltage stability, voltage instability, and the voltage collapse are defined as follows.

So, the voltage stability of power system at a given operating state and subject to a given disturbance is voltage stable if voltages near loads approach post disturbance equilibrium value. The disturbed state is within the region of attraction of the stable post equilibrium.

Voltage instability; the voltage is defined as follows. The voltage instability is the absence of voltage stability of course, it is the reverse of voltage stability, and results in the progressive voltage decrease or increase, destabilizing the controls reaching limits or other control actions such as load connection; however, may establish a global stability.

So, voltage instability normally people concerned about the low voltage, but in some of the cases, it was also found that the voltage increase is also some sort of voltage instability and that normally happens when this offloading conditions, voltage going to be very excessively increasing and that is why the voltage instability in the high voltage side as well, but most of the practical cases, the voltage instability is due to the low voltage cases.

Another term which is defined as the voltage collapse and the collapse is defined as follows. The following the voltage instability, a power system undergoes the voltage collapse if the post disturbance equilibrium voltage near the load are below the acceptable limits, and voltage collapse in a system may be either the total; that is, called blackout completely or it is partial. So, if it is a voltage is low for the longer period in some of the network, then it is called the voltage collapse.

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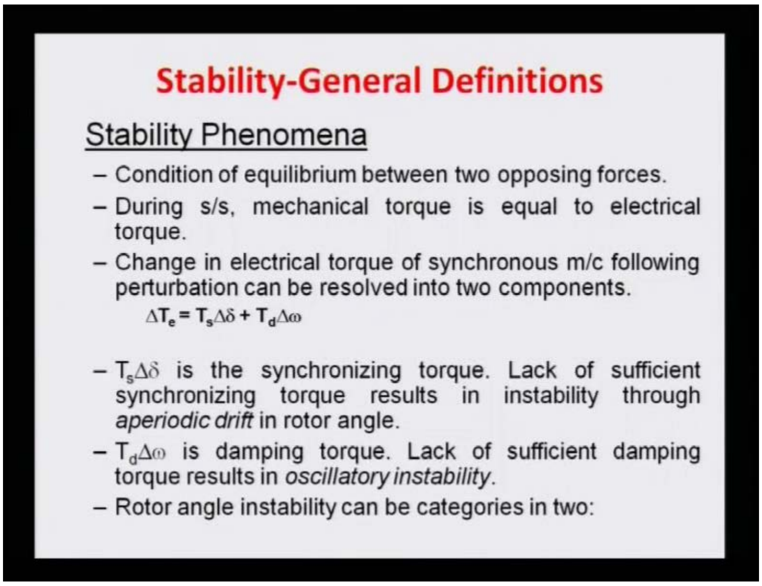

To define this stability in terms of general definition, if I will define the voltage, not voltage, it is a stability phenomena, in general any stability for either in electrical or mechanical system, this is the condition of the equilibrium between the two opposing forces is very well defined, and during this steady state basically, the mechanical torque is equal to the electrical torque in the electrical power system, and change in the electrical torque of synchronous machine following a disturbance can be resolved into the two components; that is, del T e is equal to your del T s into del delta plus T d into del omega. Here these two terms; one term is first term; that is, T s into del delta is synchronizing torque, and this is due to the lack of sufficient synchronizing torque which results in instabilities through a periodic drift in the rotor angle.

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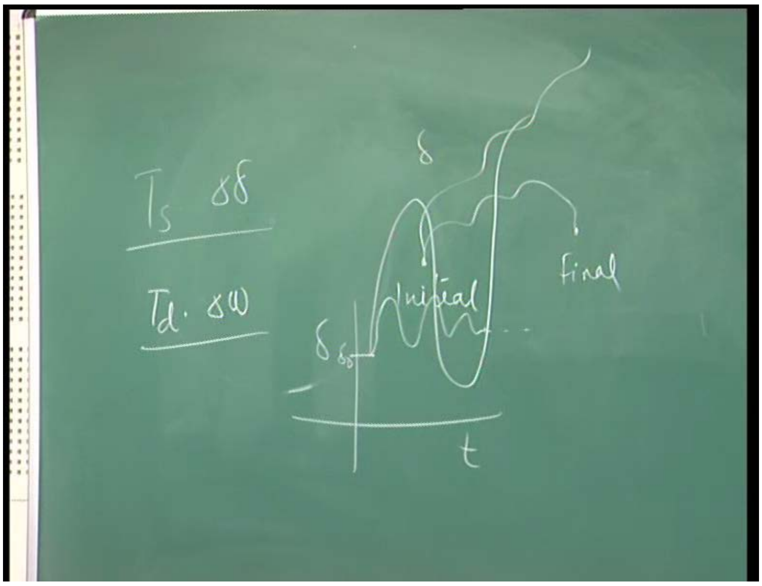

So, this term which is I am talking here this T s into del delta; it is not an oscillatory, here your equilibrium point is initially there and your final equilibrium point is here that is called the final, and this is your initial, then if there is any disturbance, then your system may either go here at the final or it may go somewhere else. So, this is called the stable case; however, another it is unstable case. Here there is no oscillation and finally, it is aperiodic drift in the rotor angle. So, this is the deviation of your angle that is the delta which is going.

So, this case is so called due to the lack of sufficient synchronizing torque, and if this is there, then we can say, system can come from the initial equilibrium point to the another final condition. It may be even though the same both can be the same point or it can be different one depending upon the nature of the system after the fault condition.

Another term here in the stability; that is, your T d into del omega. So, this is the T d is into that is del omega is damping torque and this is due to the lack of sufficient damping torque results in the oscillatory instability. In this case, what happens, this your see this figure of your delta with respect to time, this is your initial delta, and it should go somewhere your final delta. So, this is basically your oscillating and finally, coming here then you can say it is your oscillatory and this is a stable case.

But there is a possibility that the system is oscillating and going away, and then it is called your unstable case. So, this is happening, this is oscillating due to this omega and this omega is the frequency. So, in this case here, we are having not having a sufficient damping, so that it is oscillating and system becomes unstable.

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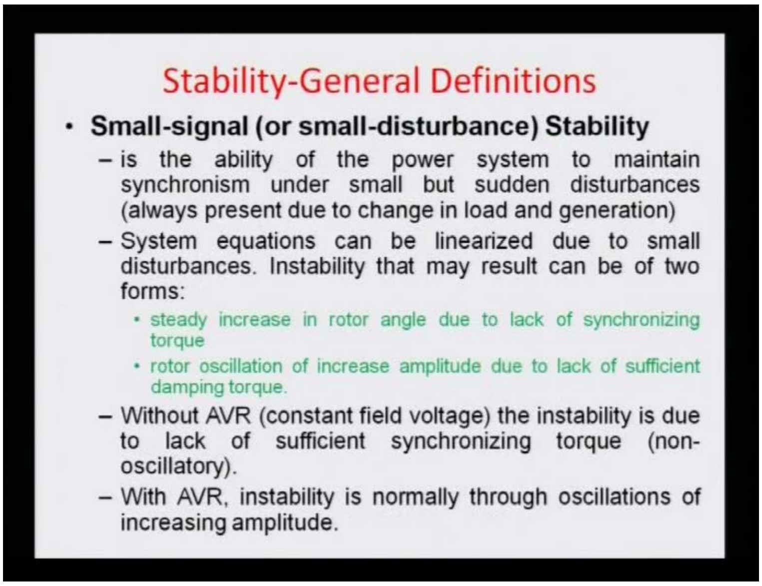

So, rotor angle can be categorized into the two; one is called the small signal or small disturbance stability and other is called your large disturbance stability. So, let us define and see what the small signal stability is. The small signal stability is the ability of power system to maintain synchronism under small but sudden disturbances, and that is always present in the system whenever there is a load and generation changing. So, power system always load and generation is keep on changing. So, this small signal stabilities always present in the system and that is why we have to analyze whether due to this, your system is stable or unstable or always there is some oscillations or there is some drift in the angle.

In this case, the system equations can be linearized due to the small disturbance because we are assuming the disturbance is small. So, all your differential equations can be linearized, and then we can form in terms of state space representation, and then we can analyze this small signal stability.

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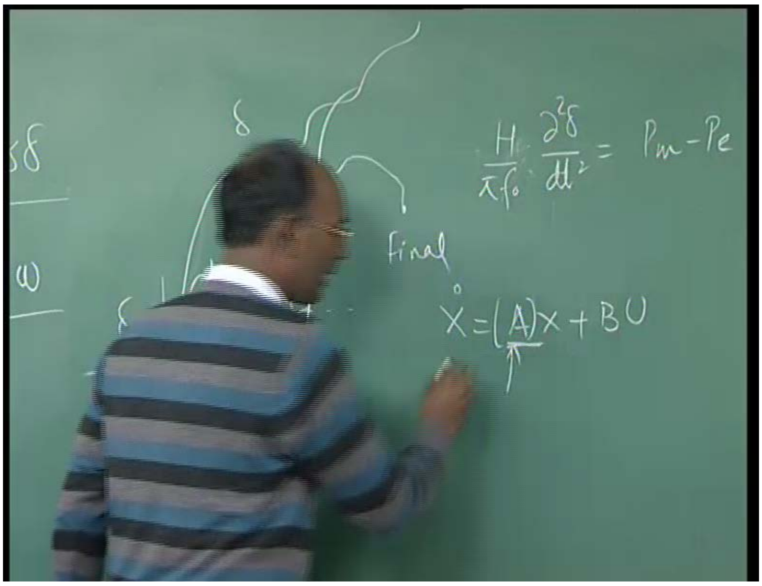

So, if you know this is, we can write your some constant k here, change in your delta here that is square d T square, we know this P m minus P; this equation we always know, here sometimes we write omega difference delta here or in the per unit form, you can say H upon pi f we write here. So, this equation is a differential equation and it is a non-linear equation because the P is v 1 v 2 upon x and delta, if you take this.

So, we can linearize this equation and also other equations for example, if you are going further modeling of your other elements, we will see in the later part of this lecture, the modeling of exciter, modeling of governor, of modeling of the power system, modeling of synchronous machine; different levels of modeling also there.

So, we can linearize this differential equations and we can form the instate space form; this is x dot equal to A x plus B u and this you know this is a transition matrix or A matrix here, and based on this A matrix, we can analyze this small signal stability conditions and also we will see another lecture will be the that is your small signal or sometimes; also called dynamic stability analysis that will perform.

So, based on this behavior of A matrix; that is, we can again analyze into two parts that are explained. The steady increase in the rotor angle due to the lack of synchronizing torque and another is your rotor angle can oscillate; means rotor can oscillate of the increase in amplitude due to the lack of sufficient damping torque. So, this if there is a insufficient damping torque here, then this can your lead to the oscillation of your rotor and that may lead to instability. If you are having not sufficient having synchronizing torque, then there will be your delta will keep on drifting and that is keep on increasing, that will also lead to this instability case.

So, again we can analyze whole this scenario with the help of the two; one is the without automatic voltage regulators; we call it A v r, and with A v r. So, without Av r means we are having the field voltages constant. So, if there is no automatic voltage regulation, means whatever the field excitation is constant, and the stability is due to the lack of sufficient synchronizing torque and that is always non oscillatory.

But if you are using the A v r; that is automatic voltage regulation are there, means you are controlling the field voltage as well due to the system. (( )) the instability is normally through the oscillation of increasing amplitude means that is A due to lack of sufficient damping torque. So, if you are not using the A v r means without Av r, this is especially this is due to of the synchronizing torque and if you are using A v r means, it is some sort of your lack of sufficient damping torque instability.

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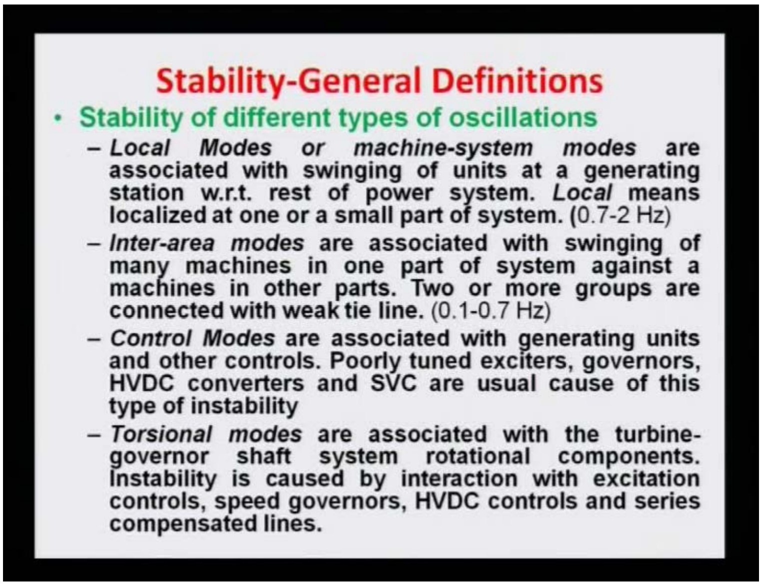

In this small signal stability, thus we can have the different type of options if you are having not sufficient your damping torque. So, there are four types of instability or oscillations are observed in the power system, and those are local modes of oscillation. That is called local modes or machine system modes. It can be your inter area modes, it can be your control modes or it can be your torsional modes of oscillations.

First see this what is the local mode or it can also be known as… It is also known as the machine system modes, and these are associated with the swinging of units at a generating station with respect to rest of the system. The local means; localized at one or small part of system and the frequency ranges specifically 0.7 to 2 hertz oscillation. I mean to say in power system that we are having large units or also we are having variety of power plants, even though each power plants we are having the different units, there is a possibility of one unit or may be a power plant complete unit, they are oscillating with the rest of the system, and that is called the local modes of oscillation.

Another oscillation is also observed; that is, your inter area modes of oscillations and it is associated with the swinging of the many machines in one part of the system against the machine of other parts. Two or more groups are connected with the weak tie lines and the frequency range normally varies; that is, 0.1 hertz to 0.7 hertz.

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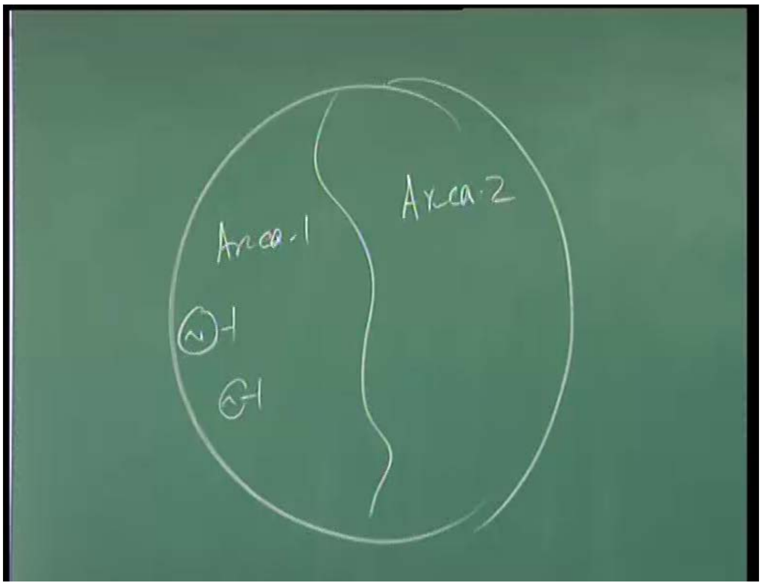

Here in the inter area modes of oscillation, I can say here we are having this complete power system where we have can divide in the two areas; suppose its area 1 and this is your area 2, in area 2 here, the machines are there. We are having the various machines; they are connected with the buses. They are oscillating with respect to the area 2. So, this two areas are oscillating to each other and that is called your inter area oscillations. Even though not only two, it can be even though three areas. They are oscillating to each other. So, it is called your inter area modes of oscillations.

Third category of oscillation is your control modes. Control modes of oscillations and these are associated with the generating units and the other controls; other controls such as that is it is a purely tuned exciter, governors, HVDC converters or you are having if a static wire comes or usually cause of this type of instability.

So, the control actions of the various controllers including your HVDC converters control or you can have the fax devices control or you can have even though generators control itself including your exciters as well as the governor control may lead to the control modes of oscillations. 20:43

The fourth category there is the torsional modes of oscillation, and this is associated with the turbine governor shaft system, rotating rotational components. The instability is caused by the interaction of excitation control, speed governors, HVDC controls and the series compensated lines. This torsional modes of oscillations; this is basically related to the mechanical and electrical interactions, and you know we are having our alternator is coupled another various turbines on the same shaft, and there is some torsional modes of oscillations are observed which is less than your 50 hertz oscillation.

So, these four types of oscillations are observed if you are going to analyze your system with your linearized differential equations.

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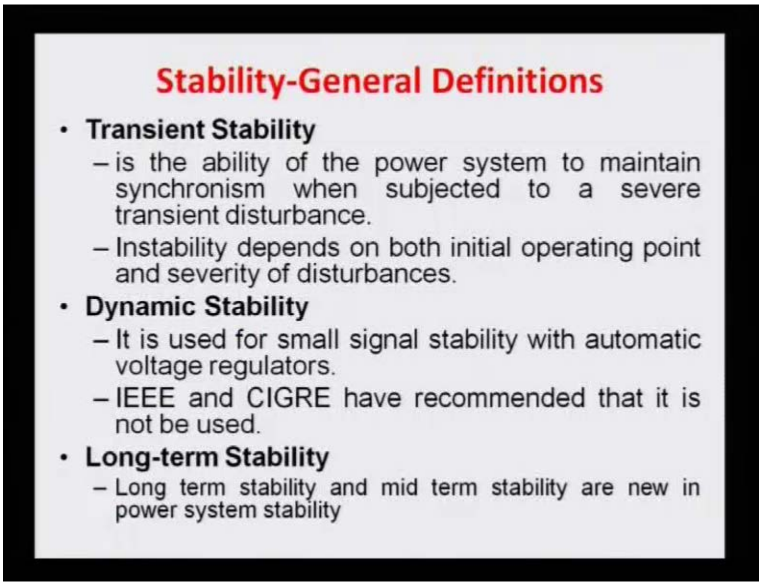

So, normally in the broad sense, the stability is classified as the transient stability and also people say another term; already we saw the stability that is small signal stability, then the transient stability and sometimes earlier people were also using the dynamic stability.

In that, already we saw the small signal stability. Now let us see what the transient stability is. Transient stability is the ability of power system to maintain synchronize when subjected to a severe transient disturbance. As I said, this small signal stability is related to the very small variations or disturbance in this system but the sudden and here it is a very severe disturbance or transient disturbance that is occurring, then the transient stability is going to happen.

Instability depends upon the both operating points and the severity of the disturbance already I said, the transient stability is not only based on this the type of disturbance or the duration of disturbance, but also it depends upon the initial operating points and the initial condition of the system as well.

Another term it is used that is dynamic stability which is used for the small signal stability with automatic voltage regulators. If you are using the A v r s and analyzing this small signal stability, then it is known as the dynamic stability, but nowadays people are not using this word dynamic stability at all. They are only categorizing the two parts either small signal stability or the transient stability because already this small signal stability with the Avr is now clubbed with the small signal stability. So, that is why CIGRE and the IEEE have not recommended that it should be and that is why it should not be used.

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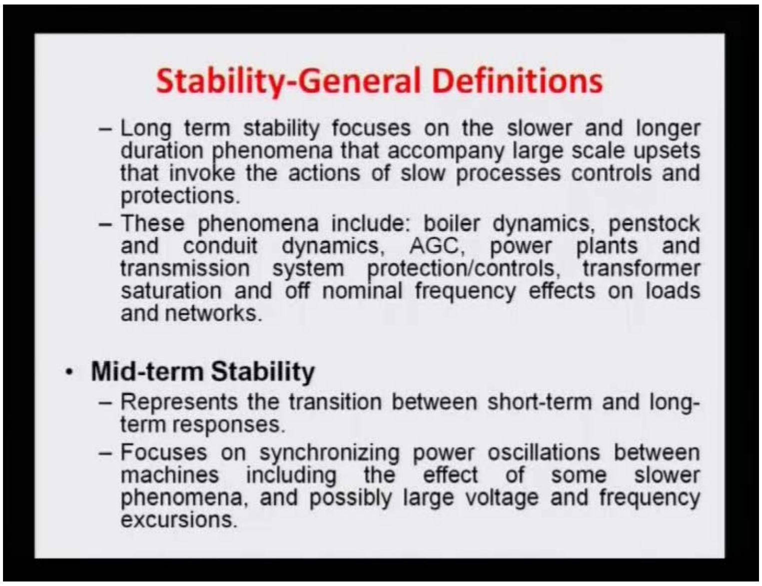

Also we can define this definition in terms of long term, medium term and short term stability power system stabilities. So, let us see what the long term stability is. Long term stability and the medium term stability are the new in the power system stability because the transient is coming even though that term stability. So, let us see what is the your long term stability.

Long term stability focuses on the slower and the longer duration phenomena that accompanies large scale upsets that invokes the action of slow processes; controls and the protection and these phenomena include the boiler dynamics, penstocks, conduit dynamics, AGC automatic generation control, power plant control and the transmission system protection and the control. You can include the transformer saturation and off nominal frequency effects on the loads and the network variables.

So, here you see this larger dynamics; the machines are very slow and the mechanical dynamics like boiler dynamics, penstock and conduit system dynamics are also included because our range of study is the longer and this is called your long term stability.

In the midterm stability which represents the transition between; basically it is between the short term and the long term responses and the main focus is on the synchronizing the power system oscillations between the machines including the effect of the some slower phenomena and possibly the large voltage and frequency excursion.

Here what we are talking there is a huge excursion, but again the effect of the slower phenomena is included. So, we are talking slightly other than the short term stability here. So, typical timing range that we can see, it is short term or transient is basically from 0 to 10 seconds.

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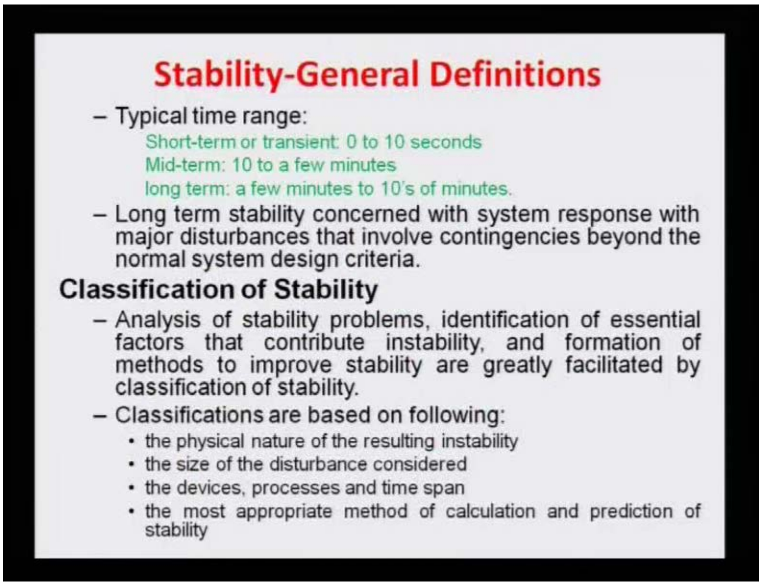

If you are going for the midterm analysis at transient midterm stability analysis, it is basically ten minute 10 seconds to few minutes normally we consider, and in the long term, it is from a few minutes to tens of the minutes is included because we are including the power system dynamics as well.

So, long term stability concerned with the system response with the major disturbances that involve the contingencies; contingency I mean to the outages of the elements beyond the normal system design criteria.

So, let us now classify the stability in another way. So, analysis of stability problems, identification of essential factors that contribute instability and the formation of methods to improve the stability are generally facilitated by the classification of stability. So, that is why we have to classify in the people are classifying the different way.

They are classifying based on the time range, classification based on this your different type of power system parameters like your angle, your frequency or voltage and also the classifications are done based on the various other things such as the classification based on the physical nature of resulting instability, the size of the disturbance considered, the device, processes and the time span and the most appropriate method for calculation and prediction of the stability. That is how we are calculating; sometimes the transient stability you have to solve the differential equations for your steady state or small signal stability you have to go for the linearized and then you can analyze the system.

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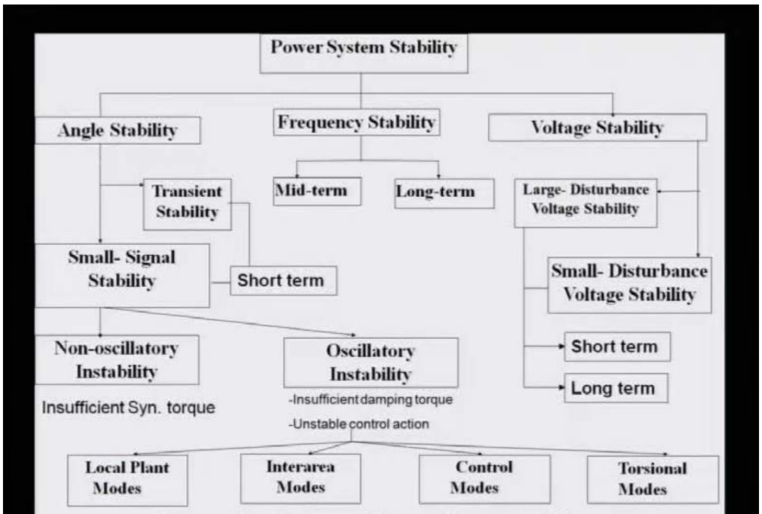

Figure: Classification of Power System Stability

So, whatever the stability definition which I explained in the various words various sentences now can be summarized in this classification diagram. So, this figure shows the power system classification of the power system stability. You can say the power system stability can be classified in the three broader categories and that is based on the three power system parameters. And those parameters are angle, frequency and the voltage. That is why it is angle stability, it is your frequency stability, and it is another one is your voltage stability.

So, in this angle stability, you can see that is two stabilities are defined; one is the transient stability and another is an small signal stability, and these two stabilities are known as the short term stability as well. In this small signal stability, you can see this, we are having the two types of instabilities; one is the non oscillatory; basically this is due to the insufficient synchronous synchronizing torque; that is, here you can see this non oscillatory instability, and another is called your oscillatory instability; this is due to this insufficient damping torque as well insufficient damping torque.

In this oscillatory, again I classified the four types of oscillations are normally observed; one is called the local plants mode; local modes of oscillation, another is called the inter area modes of oscillation, and third one is your control modes of oscillation, and the fourth one is your torsional mode of oscillation.

In the frequency stability, basically it is defined into the two terms; one is the medium term and another is long term instability; however, in the voltage instability, it can be your large disturbance voltage stability or it can be your small voltage stability. So, these are the two; large disturbance and small disturbance voltage stability are there and these again into can be classified again depends upon the time span, it can be short term or it can be your long term voltage stability.

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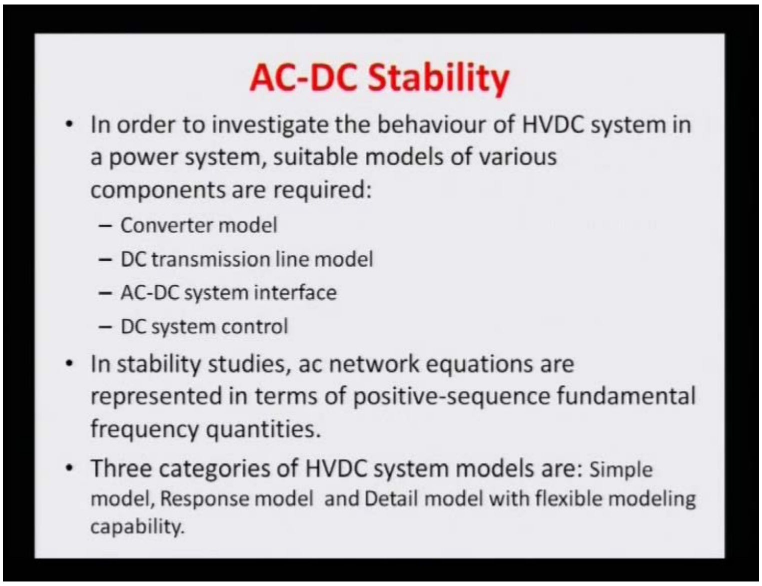

So, now let us come on the main topic; that is, AC-DC system instability. This we have to discuss in this module, and AC-DC stability basically in order to investigate the behavior of the HVDC system in a power system. We require the suitable models of the various components and various components of the DC system because we have to model our AC system as well along with some extra modelings are required; that is, you have to model the converter. So, converter model, DC transmission line model and AC-DC interface systems model is also required along with the DC control. So, these four extra modeling along with your machine dynamics, machine modeling, your AC system modeling are to be done.

So, in stability studies, the AC network equations are represented in terms of positive sequence fundamental frequency quantities. Whenever we are analyzing the stability for the AC network only, then we are just taking care of only the positive sequence fundamental frequency quantities, but when you are going for the DC, then you have to take the DC component as well.

So, three categories of the HVDC systems models are normally people are suggesting; one they call it the simple model, which is very simple thus you can take as simple converter can be replaced by a voltage source; variable voltage source with the impedance. It can be a response model or it can be detailed model with the flexible modeling capabilities.

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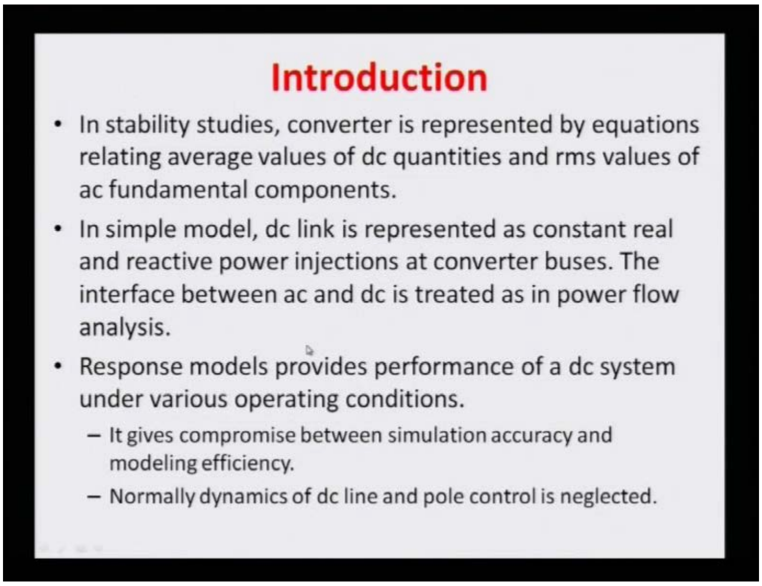

So, in stability studies, the converters are represented by the equations relating to the average values of DC quantities and the RMS values of AC fundamental components. If you remember, that is, we derived all the DC quantitiesas well as the AC quantities relation for the converters. We wrote the various fundamental or independent equations, even though when we discuss about the AC-DC load flow. So, those equations are here used for the fundamental component as well.

In the simple model basically, the DC link is represented by a constant real and reactive power injections at the converter buses and the interface between AC and DC is treated as the power flow analysis.

So, this is a very simple. In the simple model I said, the DC link is represented by a constant real and reactive power injections at the converter buses.

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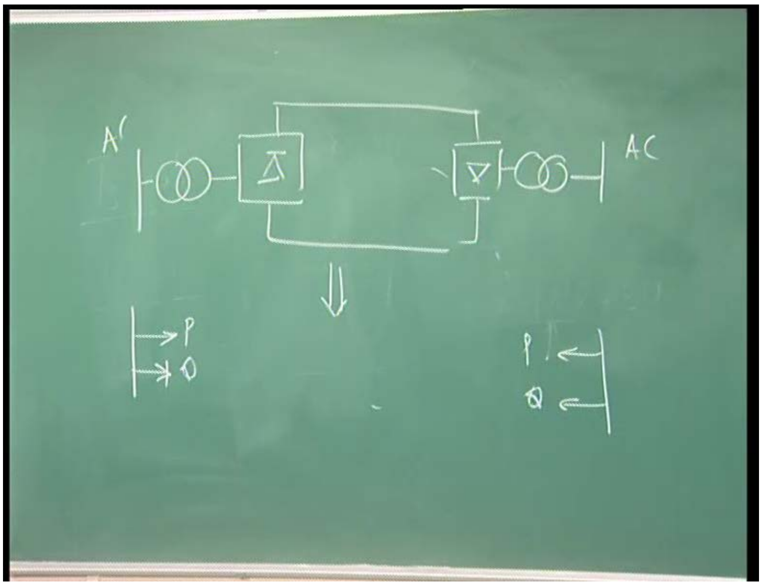

So, that can be understood that if you are having… This say converter transformer, if you are having your the DC link here, this is a normally we represent, and now you are having your inverter here, this is the… Here and this is your transformer, this is your AC bus here this side, this is your we are having AC bus and this is your DC system.

So, what we do in the simple model? We represent this in the very simple way. This bus that we are having this P and this; your reactive power at this bus and this can be represented by here P and the Q. Now this direction of P and Q is decided what is the direction of the real and reactive power is flowing. Mostly the reactive power here, it is taken by this converter. So, it is going this direction, but the real power will be the real power flow will be unidirectional.

So, it is a very simple, we basically ignore the (( )) and the detail modeling of the DC system. Only we are taking the AC system and the bus is where we are having DC; that is, we are representing as the some power injections. So, this is a very simple.

In another model; that is, a response model provides the performance of the DC system under the various operating conditions. So, this is a more generalized, better than this simple model because here we are not including the control dynamics and otherwise the other dynamics of the HVDC system. So, in response model basically, we are… it is a performance of the DC system under the various operating conditions is to be considered.

So, this gives the compromise between the simulation accuracy and the modeling efficiency. Here this simple model is the very fast. In say, (( )) computational efficiency is much more, but the accuracy is not better. But this response model is between the two. So we compromise between the simulation accuracy and the modeling efficiency.

Normally the dynamics of DC lines and the pole controls are neglected. So, we are neglecting the dynamics of the DC line as well as the pole control is neglected and the remaining we are modeling. And lines are represented with the resistance and the pole control action is assumed to be the instantaneous.

During the AC faults, adequate representation is to be done to reflect the DC control action, but we are taking the control action in the response model. The constraints are imposed on the current order limited; that is, the v d c o l constraints are to be taken care.

So, this is the compromise between the simple as well the detailed model. So, this is intermediate stage because we are just assuming some of the things; however, other things we are taking into the consideration.

In the detailed model, the HVDC dynamics is considered and the resistance, inductance and capacitance of DC line are also taken along with the pole control such as constant current control, this the CEA control, etcetera are provided and the converter angle limits are embedded in the control itself.

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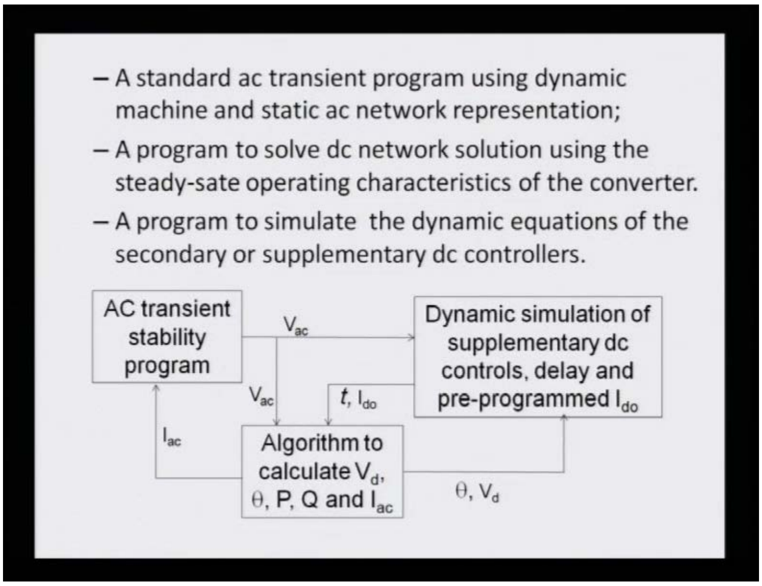

So, in the detailed model, if you are having the complete model of the DC system, you are having the complete model of AC system. So, it is a combined together so that we can have this AC-DC transient stability program consist of now three parts. You can see; one is called standard AC transient program using the dynamic of machine and the static AC network representation, a program to solve the DC network solution using the steady state operating characteristic of the converter and we require another program to simulate the dynamic equation of the secondary or supplementary control of the DC controllers.

So, look at this figure here, where this AC transient stability program is there. As you know then AC transient stability program, what we are getting the AC voltage and this AC voltage; you can say this is used for your algorithm to calculate the DC voltage, this real and reactive powers, as well as the AC current which is again send back to the transient stability program.

We also require the dynamic simulation of the supplementary; the DC controls, delay and the pre-programmed I d o; that is, the DC current initial current which is required from this algorithm; this algorithm to calculate v d that is the theta and v d going here and finally, we are getting the time step along with the v d o which is coming here and then from here, this is AC is going.

So, this is a complete program; this transient stability for the AC system is the separate one and we require the algorithm to calculate this and then we can go for. So, three blocks are there and that is why here the I have written the standard transient program means; this is your standard transient stability program.

Second is your to solve the DC network, here DC network variables, characteristic of the converter that is used here and third is to program the dynamic equations of secondary and the supplementary control here. So, these three different programs are used for the AC-DC transient stability program.

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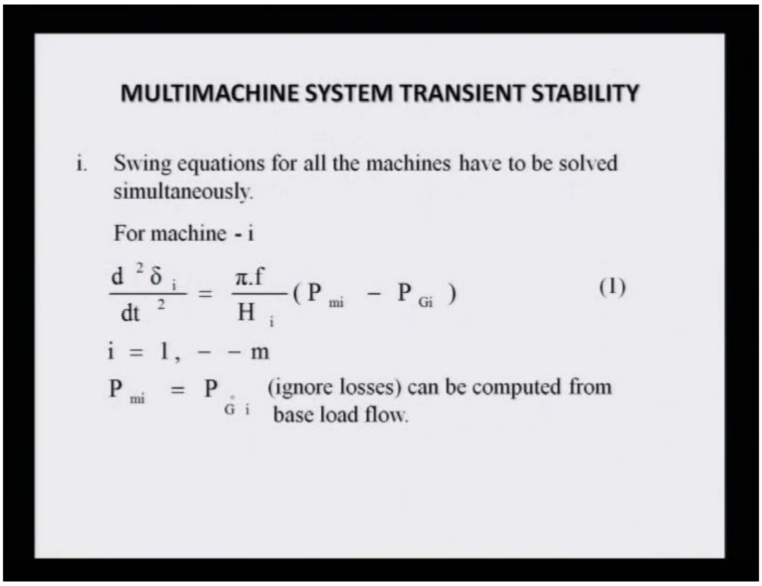

To again now understand the first part of this block here as I said, it is a trans-stability part, since say this module is independent of any other transient stability or any stability course. So, let us just discuss some of the aspect of the transient stability here as well.

So, what happens? This is your swing equation that is very popular that is used in the AC transient stability program, and here the swing equation for all the machines have to be solved simultaneously. For example, for machine 1 or you can say i f machine, I can write this equation in this fashion where i is equal to 1 to m and this P m i is basically P g i naught ignored the losses can be computed from base load condition.

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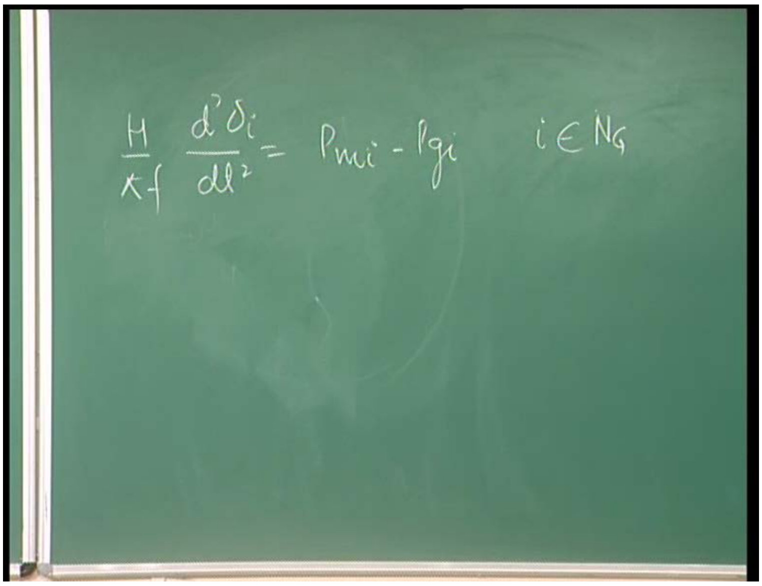

So, this equation, that is, the differential equation here which I am using, this is you can say H upon pi f, here that is the differentiation of the delta with respect to time; that is, your P m i minus P g i. Mind it, here we are writing delta i and here for every I, for every this number of generators. So, in the power system, if you are having large number of generators, then you have N numbers of generators. So, this you have to write N number of equations and this is the classical equation; that is, the swing equation, and this equation having the lot of assumptions that we have derived.

If you are going to the detailed modeling; this is the very approximate model; if you are going for detailed modeling, then you have to consider the various dynamics of the machines along with the other controllers as well.

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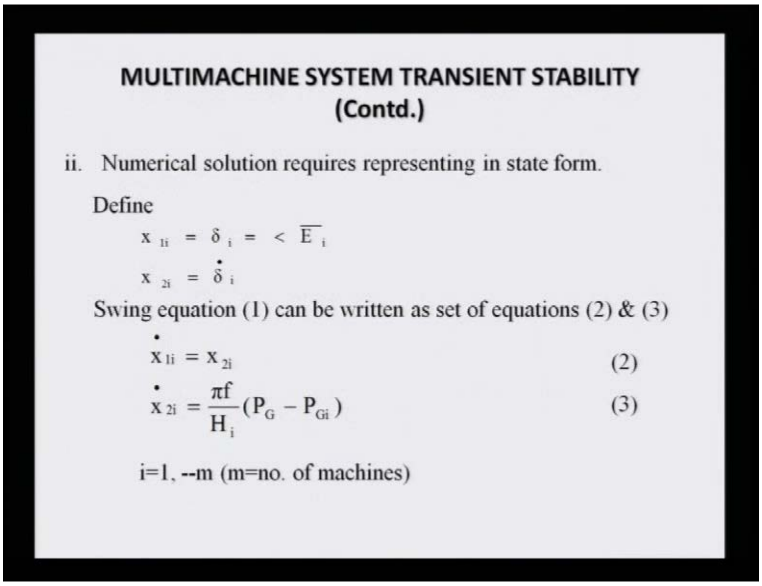

So, this is the swing equation and in this swing equation is the second order differential equation and this can be written as the two single order differential equation.

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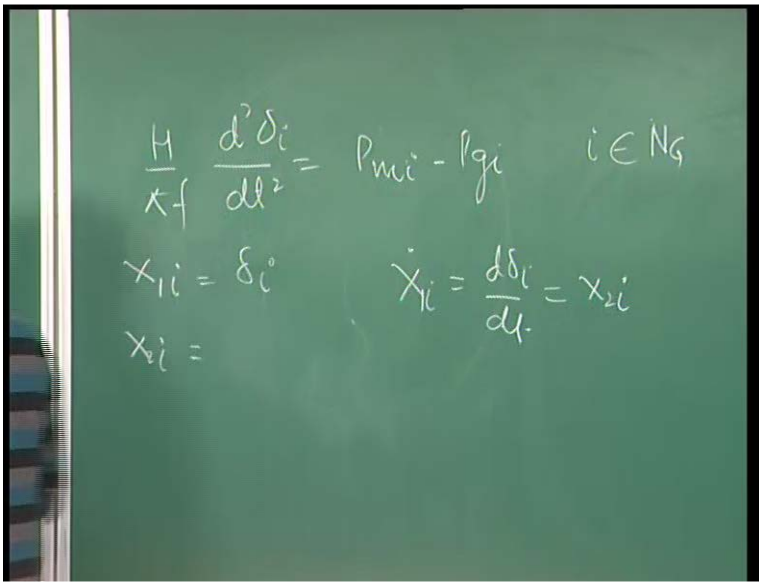

For example, here I can say, this is your x 1 if I can say this x 1 i x for I f machine x 1 and I can say x 2 I, here if I can say this delta i, then we can just differentiate this and we can write here x dot x 1 i dot equal to your d del i over d T. And similarly, we can write the two differential equations here; one is here, this x 2 i we can say, it is nothing but here it is equal to x 2 i.

So, this we can write in the two differential equations, you can see here that is the one is related to your… Am writing one state is x i and here x 2 is the delta dot i and that is related to the frequency.

Based on this two, the equation; that is, swing equation we can write the set of two equations; 2 and 3, here one is the x 1 dot is your omega, here and this x 2 dot is equal to H f upon H I P g i. So, now, from one second order differential equation that we are representing the two singular differential equations and this is for… This two equation for all the machines. So, if you are having m machines, so, it will be the 2 m equations of whether single order differential equation.

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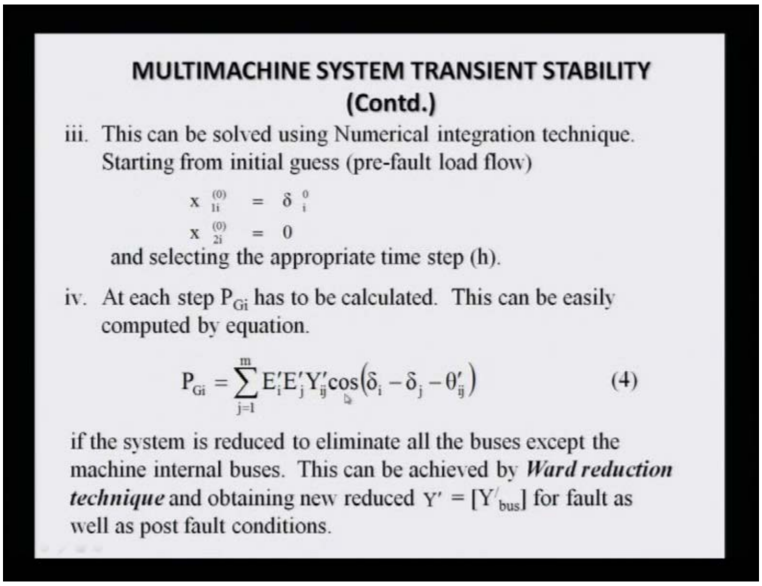

Now, to solve this; that is, again I said this is single machine multi machine transient stability case assuming that classical model. So, these two can be solved using the numerical integration techniques, and again for solving using any differential any numerical integration technique, you require some initial guess. And the initial guess is nothing but they are the pre-fault load flow conditions. And then we can start because the there is no frequency change. So, it is 0, x 2 and x 1 is your initial delta that is the rotor angle here.

Now, selecting the appropriate time step h, that at each step, the P g i has to be calculated and this can be easily computed by this equation. We know it very well, this is the power balance equation. Here you can see, here we have written e i prime e j prime and Y i j primes and also here theta i j prime. Here this e in the normal power balance equation, we write here v, v I, v j and Y, but here I have used prime; means they are this voltages are the internal voltage of the machine and this Y i j; it is the reduced Y based matrix means, this is matrix which is only including your machine buses.

So, you are having N number of buses in the system. So, that can be reduced to only the generator buses, and that can be done by eliminating the all the buses except the machine internal buses, and this can be achieved by the ward reduction technique and obtaining the new reduced matrix Y prime, that is a… That is why here it is equal to Y bus prime for fault as well as the post fault condition. So, this matrix is basically used.

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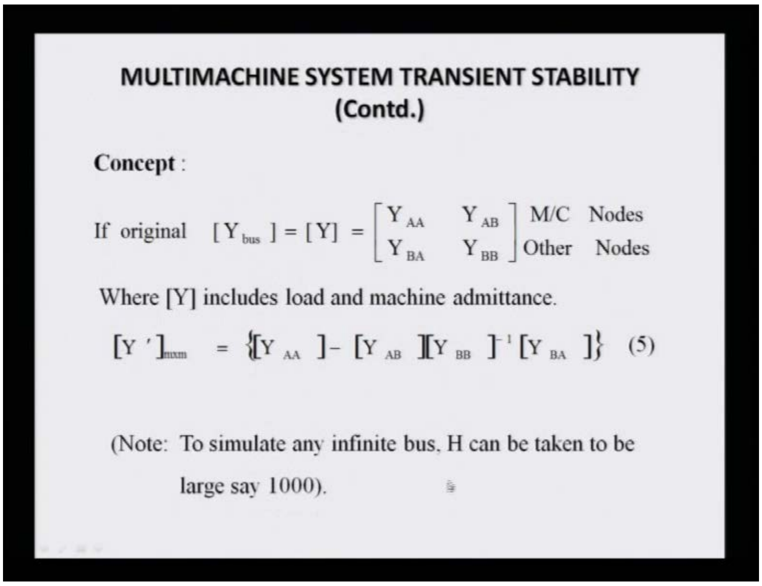

So, how we can do it? Here suppose you are having the Y bus, you can see this Y bus matrix and it can be divided into a rearranged into this some sort of some matrices, where the machines having the A; just we are having thus A are the machine nodes, and other nodes are I can say B B. So, we can just arrange in such a way that in some matrices of the Y A A and Y A B. Similarly, we can write the B A and other is B B. So from here, where Y includes the load and machine admittances.

So, this is full Y bus, but here these are the small one. So, this Y prime that is having m cross m will be this matrix minus this matrix multiplied by the inverse of this matrix multiplied by this B A matrix; we can see the equation 5 here, and this is your reduced matrix.

Note that, to simulate any infinite bus, H can be taken to be the very large normally we take as a 1000. So, this is the way where we can go for only the reduced Y base matrix where we are eliminating all the load buses, only we are taking the generator buses into this one.

So, this your previous your this power bus equation, this Y i j prime is the reduced Y base prime, and then the theta i j prime is the corresponding to that element. So, we can calculate the P g i and then we can solve the equations; these equations we can solve here this two. For each machines, if we are having m machines, so you are solving 2 m equations, and then the P g i here; you are calculating from here and this is variable or internal variable delta i and delta j s.

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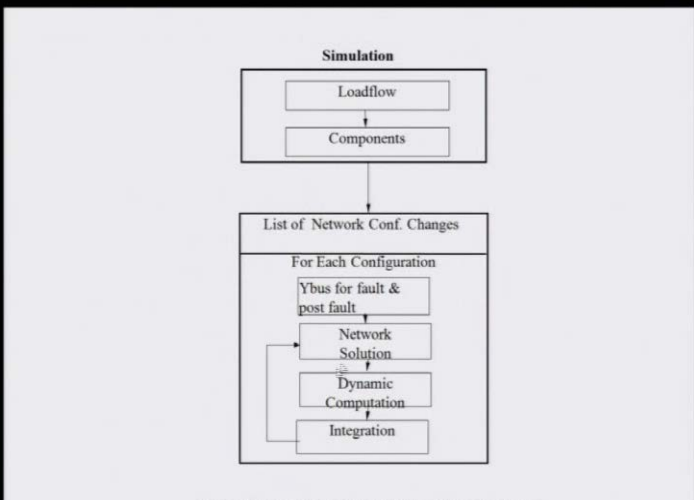

Fig.: Transient Stability Simulation

Now, so, to see here complete simulation that we can do, what we do normally, first we run the load flow. After load flow, we get the initial condition that is used for the starting your the integration or solving the differential equations. So, we do the load flow, we take the internal angle some machine we calculated, then we go for the various compliant modelings.

So, you have to see what are the various components those are involved, you have to model them, you have to write the differential equations for them, and again as I said, you can go for the detailed modeling, you can go for the approximate modeling, again depends upon the nature of studies, we do it and now the component modeling basically includes your the differential equations.

After this, then you have to go for this list of the network configurational changes that how many changes are, suppose there is a fault is happening, then your Y bus is going to be changed. So, accordingly, what we do for each configuration, we have to decide how many configuration for your pre-disturbance, during disturbance and the post disturbance. So, you are having the three categories; one is the pre-fault conditions of the network, then you are having during faults, and the fault is persisting for the longer period and then you are having the post when the fault is clear.

So, for each configuration, you have to form the Y bus for fault, for the fault as well as the post fault, and then you have to go for the network solution. You have to solve the network, then you have to go for the dynamic computation; means here you are calculating network solution; means you are solving the power balance equation, that you are calculating the P g i s and after the reduction, and then you are the solving then differential equations and then you are integrating, and then you keep on doing till your simulation time span is over.

So, this is the transient stability program; simulation program that is giving a flow chart. This gives how we are moving at for the transient stability program. But, if you are having the DC system as well, so in that, what you have to do, you have to include the DC equations, DC components and then you can solve, but the procedure is again same.

So, in this flow chart, you see this; you can summarize that here in this flow chart we are having the various levels. First one you have to do the load flow. If you are having the DC system along with the AC system, then you have to solve the AC-DC load flow so that you can get the initial condition for the fault analysis.

Then you have to go for the component modeling. In the component modeling, you have to do the component modeling; already I described, the components related to the DC system, components related to the AC systems you have to model, and then you have to write the governing equations or that is the differentials equations for that one.

Then here in the network configurational change as I said, there is a three configures are (( )); one is your the pre-fault, another is a during fault, another is post fault, and for that you have to solve it. Here this Y bus, here I am talking here, you have to form the Y bus and then you have to go for the reduced Y bus that you can only have the internal angles of the machine in that Y bus. So, that is called reduced Y bus, and then you have to solve that equation; means you have to calculate the real power generation at the various machines, and then you have to solve the computational equations, dynamic computation you have to do, you have to solve the dynamic equation, here in the network solutions include your not only the P g I; that is for the AC power, you have to also calculate the DC equations and DC variables and that then you can solve this the dynamic computation and dynamic equations solution, and then you have to go for the integration. So, you have to integrate and the time step will be there.

Now, here you will see there is a major difference from the AC to AC-DC transient stability program; here that is we are having the load flow which we have to go for AC-DC. The components that you have go to model both AC-DC and also here the dynamic computation and the network solution corresponding to both AC and DC just we have to solve.

Now with this, I will conclude this module; that in this module we saw the various definitions, and that is very important because people are getting confused to what is the transient stability, what is the small signal stability, what is the frequency, what is voltage. So, all this things we defined, and then we went for this when DC system is clubbed with the AC system or having the AC-DC system, then we have to go for the various level of the DC modeling.

Already I explained, the simple modeling, then we say the response modeling, another is your detailed modeling. So, the modeling is there. Then we have to go for the component modeling; that is, the component including your AC system as well, and then we will see the next lecture, we will also discuss the various components those are model from the AC side and also we review the modeling of the DC system as well, and then we will solve and go for the practical stability studies. So, with this, I just conclude this lecture. Thank you.