Power System Dynamics

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Lecture - 40

Methods of Improving Stability (Contd…)

Friends, we continue with the study of methods of improving power system stability. In the previous lecture, we have studied some of the techniques which help in enhancing the stability of system and the techniques which we have already discussed last time are high speed fault clearing, reduction of transmission line system reactance we also talked specifically about the series compensation regulated shunt compensation, we talked about dynamic braking reactor switching independent pole operation of circuit breakers and we came to single pole switching.

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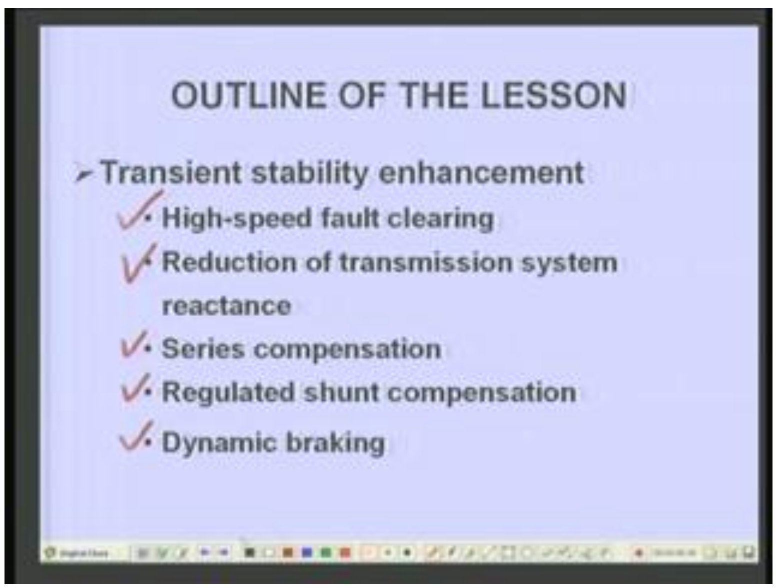

Today, we will discuss the reaming techniques which add in enhancing the stability of the power system. The techniques which we shall discuss will be single pole switching, steam turbine fast valving, under this we will discuss the fast valving logic and typical valve closing and opening sequence. Then, we will see the typical result through simulation studies the effect of fast valving on the stability of fossil fuel fired station, then we will talk technique like generator tripping, control system separation and load shedding, high speed excitation systems. Under this category we will investigate or we will see the performance of two types of excitation systems the ac exciter and bus fed thyristor, exciter then at the end we will talk about the the effect of high speed control of HVDC lines for enhancing stability and at the end small signal stability.

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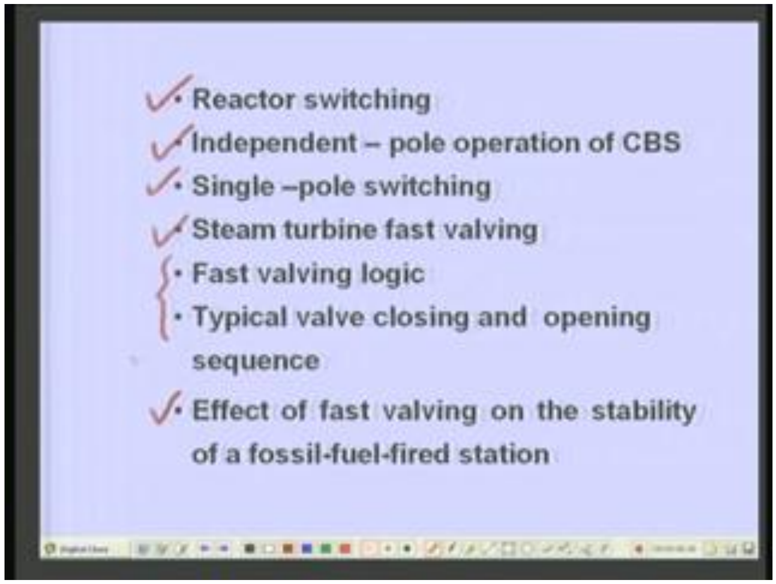

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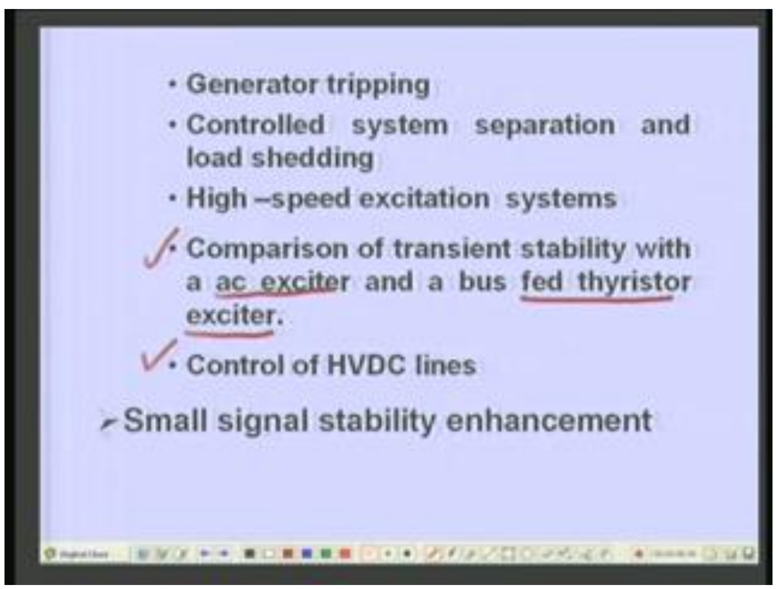

As we have seen earlier the single pole switching uses separate operating mechanism on each phase for single line to ground faults relaying is designed to trip only the faulted phase. Now this is what is the important point that is when there is a line to ground fault right then the protection system will trip only the faulted phase then this will follow a re closer within .5 to 1.5 and in case there is a multiphase fault like say to phase to ground or line to line fault or 3 phase fault then the all the 3 phases will be opened. This is very powerful technique for enhancing stability and it is used in EHV transmission systems.

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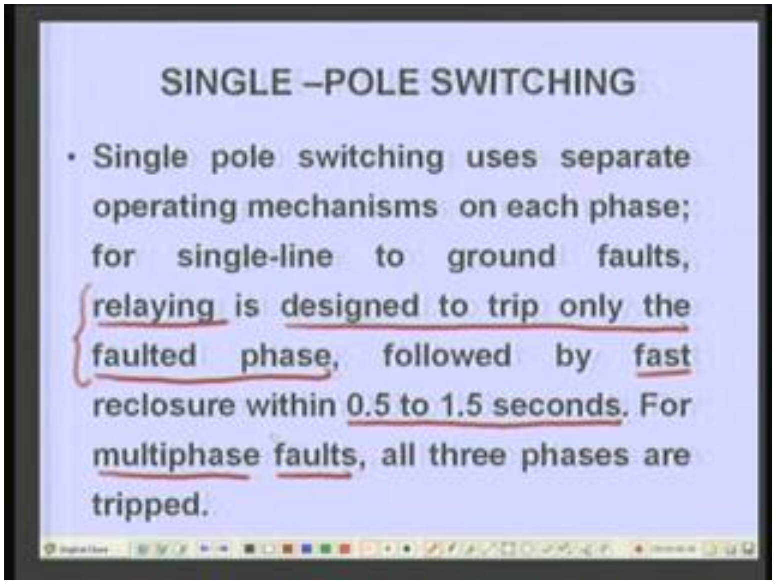

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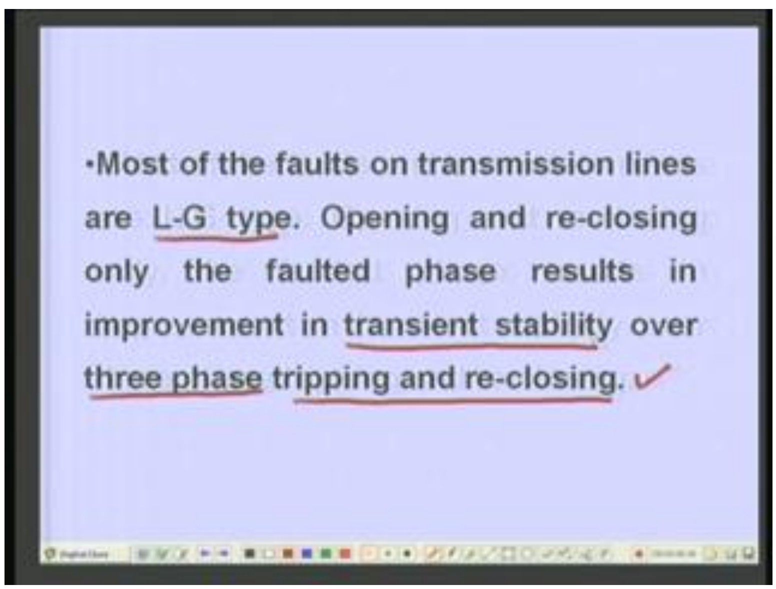

We take the advantage of this fact that most of the faults on transmission lines are line to ground faults and opening and reclosing only on the faulted phase results in improvement of transient stability. As compared to three phase tripping and reclosing some of the some of the features which one has to study about this single pole switching are

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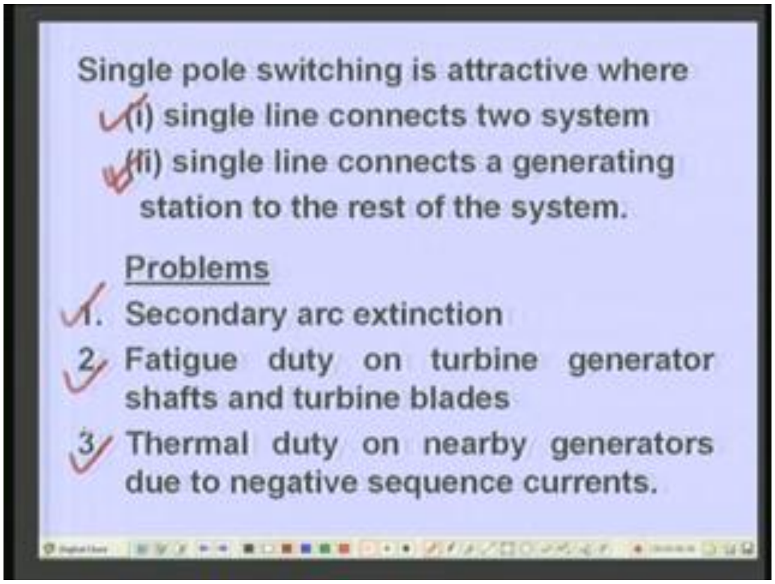

that single pole switching is attractive where where you have a single line connects or wherever the single line connects the 2 systems because if there is only one line connecting the two system then then the power which can be transferred with the stability comes out to be 0 because the moment its one line is faulted and you disconnect that line then the power transfer become 0 right therefore wherever there is a single line which connects the two systems then if you can resort to the single single pole switching then some power is transferred on the healthy phases and the and the the amount of power which can be transferred with the stability is improved that is the transient stability limit is increased another is that if you have a single line connecting a generating station to rest of the system.

Suppose, you have actually a generating station located at far of point and you have connected that station to the system through a single line normally we connect through more than one line but is the only one line connecting then again there is a advantage in going for single fault switching, the problems associated with single pole switching are secondary arc extinction. I will discuss this secondary arc extinction what it is but if it is a problem secondary arc extinction, the fatigue due to turbine generator shafts and turbine blades if you are using because because whenever you go for single fault switching the operation of the system becomes unbalanced right.

Then the because of unbalanced operation the the thermal duty on nearby generators due to negative sequence currents because when this one pole is taken out and only two lines are connected then a stator windings of the synchronous generators carry negative sequence current and that causes the additional heating in the machine then we talked about the power system protection, we did discuss about the capability of generators that is the negative sequence current withstand capacity of the synchronous generators for few seconds synchronous generators can withstand this situation but not on long time basis.

Now when I talked about the secondary arc extinction the problem is something like this that if you have a 3 phase system and you disconnect one phase at both the ends right and there was a fault on the phase which has been disconnected. Now this this phase which has been separated or disconnected from the system remains electrostatically and electromagnetically coupled with other phases and therefore there is certain potential which is developed across the conductor which is isolated from the line and therefore that it is because of this potential the the for at the fault point right the arc will be sustained is called secondary arc this they you know what happened is that when the fault occurred system was healthy before the occurrence of fault and this arc was arc was fed by the system energy but the moment you have taken out the faulted phase right.

Since this is is isolated we we feel actually that there should be no more arc arc should be cleansed but because it remains coupled to the remaining two phases through electrostatic coupling and through electromagnetic coupling there will be certain amount of voltage induced and this is a problem which is very serious problem. So far actually the the single pole switching is concerned because you cannot re-close till that secondary arc persist because if you re-close it again. You will find that it will be unsuccessful re closer because whenever you adapt a technique there with some problems and one has to sort out those problems and accept adapt that technique only when you are in a position to overcome those problems.

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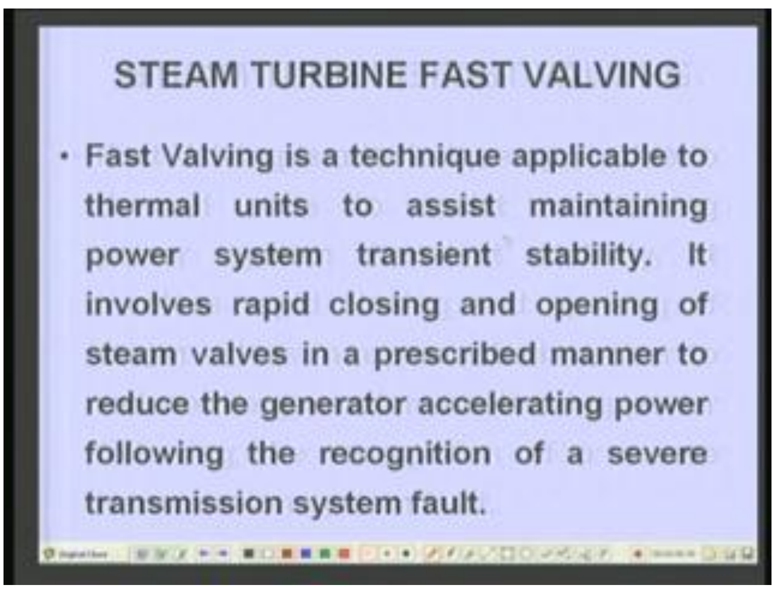

Now we take now another very powerful technique for improving the stability of the system and that is steam turbine fast valving. Historically, the fast valving technique was recognized long back somewhere in 1930 it self as a very powerful technique for enhancing stability but because of certain unresolved problems up to 1960 no attempt was made to apply the fast valving technique for stability enhancement. Let us see the firs fast valving is a technique applicable to thermal units to assist maintaining power system transient stability it involves rapid closing and opening of steam valves in a prescribed manner to reduce the generator accelerating power following following the recognition of a severe transmission system fault that is if you find that there is a severe transmission system fault. So the electrical power out power power output from the generating unit has reduced and mechanical input is same therefore to decrease the accelerating power right one has to control the valves of the steam turbine. So as to reduce the mechanical power generated by the steam turbines.

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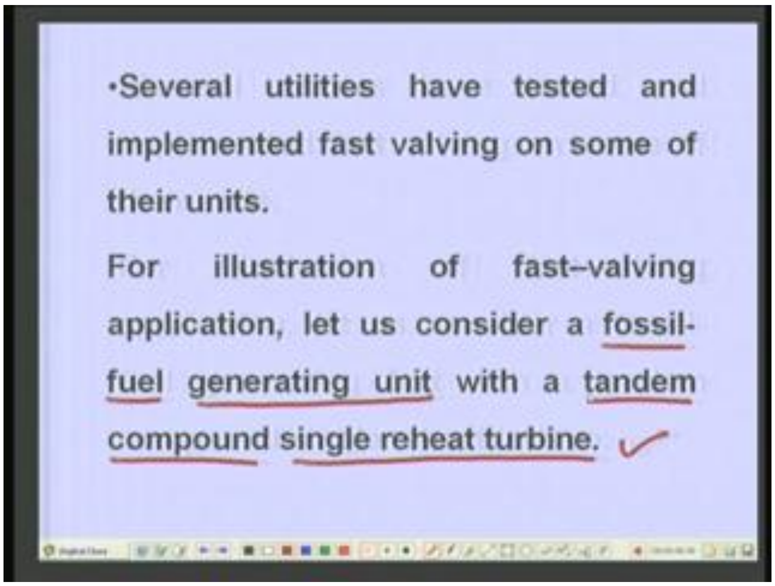

Let us discuss, this several utilities have tested and implemented fast valving on some of their units for illustration of fast valving application, let us consider a fossil fuel generating unit with a tandem compound single reheat steam turbine. In fact steam turbines have different configurations you may have a single reheat double, reheat tandem, compound, cross compound there are so many different configurations are there further the this fast valving technique can be applied to nuclear power stations also right but just for illustrating this technique I have considered this particular system that is fossil fuel generating unit that is a coal fired unit here we will have a single reheat turbine and it is a tandem compound. In tandem compound actually all the all the units are on the same shaft the high pressure intermediate pressure low pressure all these stages of that turbine they are mounted on the same shaft.

Now let us consider this configuration if you see this configuration then the steam enters from the boiler at this point we have a main safety valve here, main inlet safety valve there is a control valve then the steam enters the high pressure turbine after expanding in the high pressure turbine, steam is sent to re heater, this is re heater. Then we have intercept valve this is this valve is called intercept valve and then we have again here this RSV right, this is also a safety valve right a re-heater safety valve we call it re heater safety valve. The steam goes the IP section there are 2 sections shown here after working in the IP the steam will enter the LP stage of the steam turbine and you can easily see that high pressure low, intermediate pressure, this is low pressure, low pressure. All these stages are mounted on the same shaft and at the end is the generator connected.

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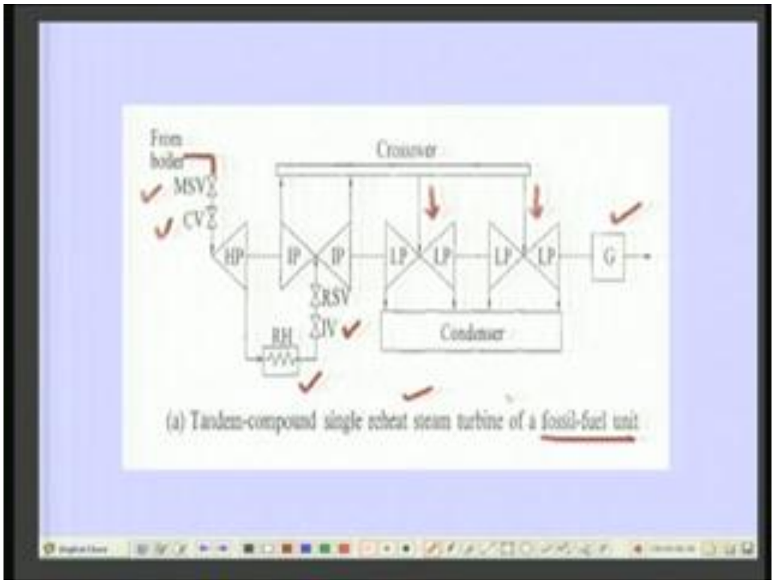

The steam which leaves the intermediate low pressure section goes to condenser and then it is recirculated to the turbine this is what is the configuration of the tandem compound single reheat steam turbine, the fossil fuel it is a coal fired unit.

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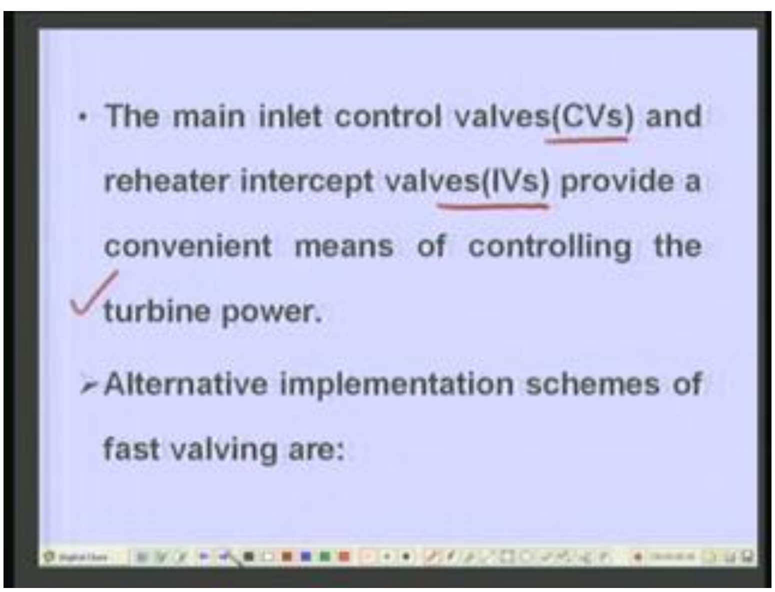

Now here we we have two possible controls one is that you close this control valve if you close this control valve then the steam flow will stop and the mechanical power output will be reduced second is that yes you control not the control valve but you you close this intercept valve this intercept valve when you close again the mechanical power output from the turbine will reduce. We will see the different configurations which can be used that is the main inlet control valves and re-heater intercept valves this I have told you that these 2 valves, one is the main inlet control valve, another is the reheater intercept valve they provide a convenient means of controlling the steam turbine power because we want to control the steam turbine power for a short time momentarily. So that the the system is saved from losing synchronism.

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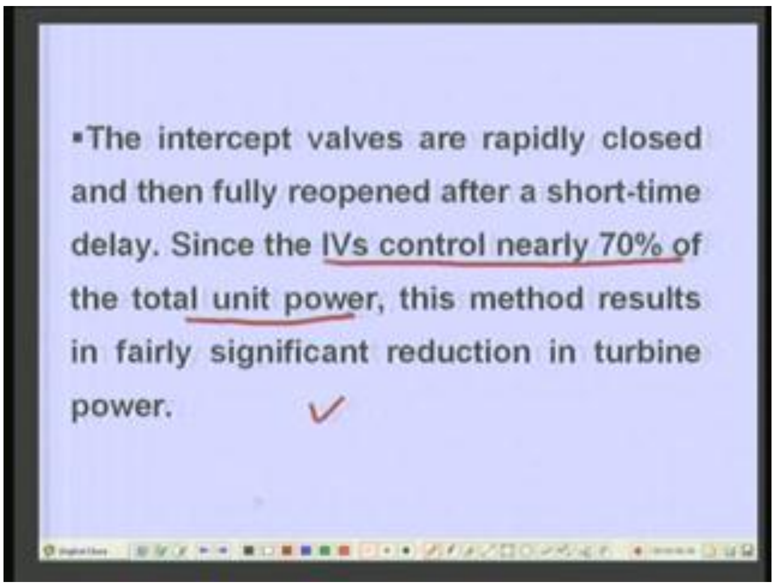

In fact there are two alternative schemes which have been discussed, one is the intercept valves are rapidly closed and then fully opened after a short time, it is not actually open the the main control valve only intercept valve is opened and then closed again that is the other way around intercept valve is closed and then opened fully okay the intercept valves, now since the intercept valves control nearly seventy percent of the total unit power this method results in fairly significant deduction of steam turbine power.

The another arrangement is that or you can say there are more pronounced temporary reduction in turbine power can be achieved through action of both control and intercept valve that is you control both the intercept valve as well as the control valve, you close both the valves. Now this procedure of rapid closing and subsequent full opening in both the cases that is what you do is that intercept valve is closed and opened. Similarly, the control valve is closed and opened okay this particular type of arrangement is call momentary fast valving then there is another scheme which is called sustained fast valving in sustained fast valving what is done is that intercept valve is closed and reopened fully while the main control valve is closed and partially reopened, well what happens is that suppose the post fault system is weak right. So once you partially reopen it means you are reducing the mechanical power input to the system as a whole right. Therefore, that that type of arrangement is called called sustained fast valving valving is fast it has to be fast because you know that if you want to save the system then this mechanical power or the controls should be fast So that they they reduce the acceleration and deceleration okay.

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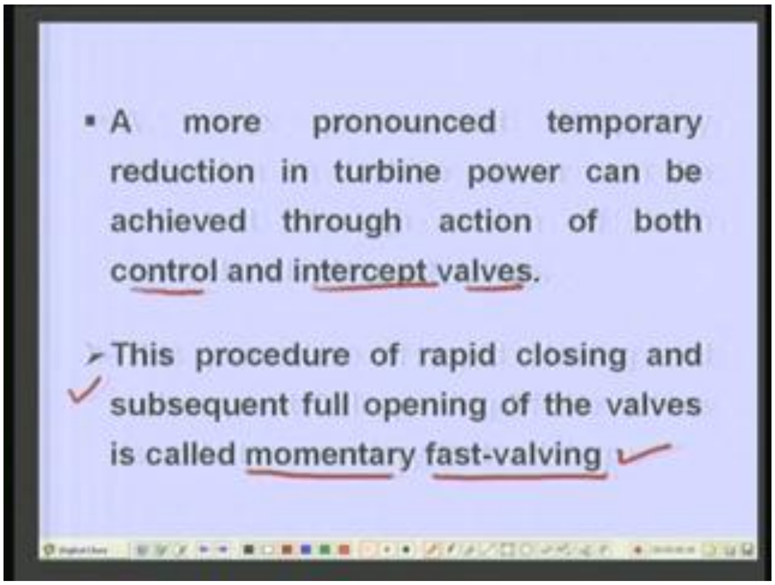

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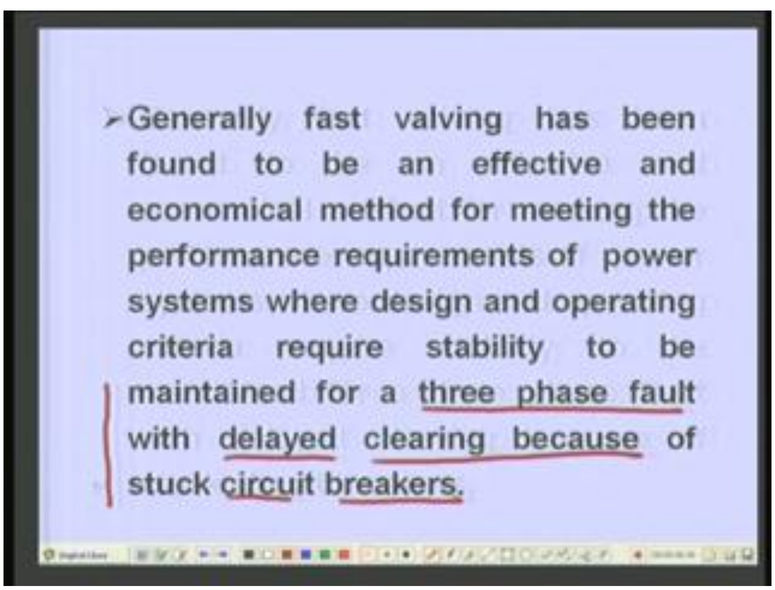

The generally fast valving has been found to be effective and economical method of meeting the performance requirements of power systems where design and operating criteria require stability to be maintained for a 3 phase fault with delayed clearing because of stuck circuit breakers. Suppose, you design your system so that system stability is maintained for this type of contingency where you consider a 3 phase valve with stuck circuit breaker it means the fault is going to be clear with certain delay under such contingency the fast valving is very effective in enhancing the system stability because here the fault remains on the system for a longer time.

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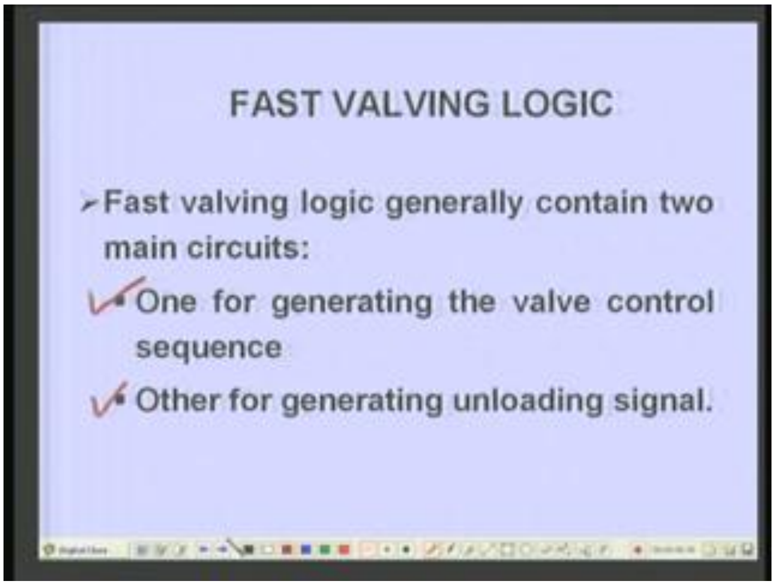

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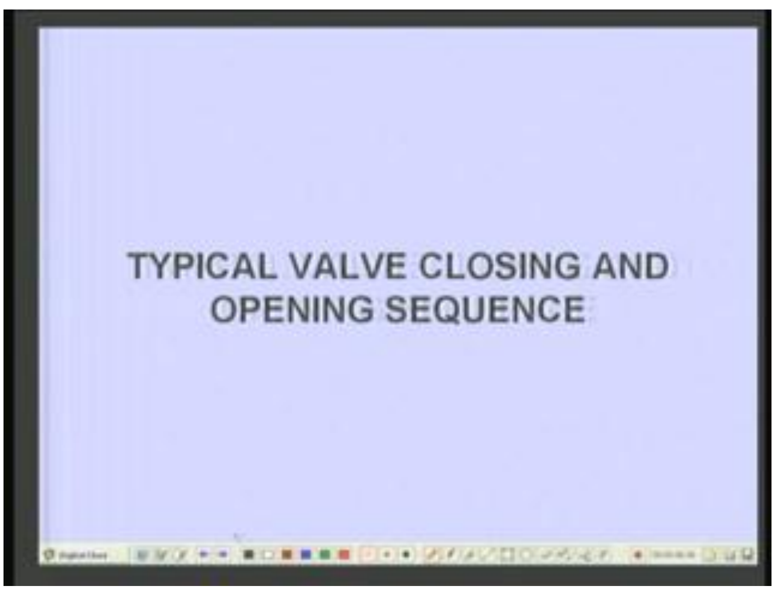

The logic which is used for fast valving are one is for generating the valve control sequence and other is for generating unloading signal right and let us look at the typical valve closing and opening sequence.

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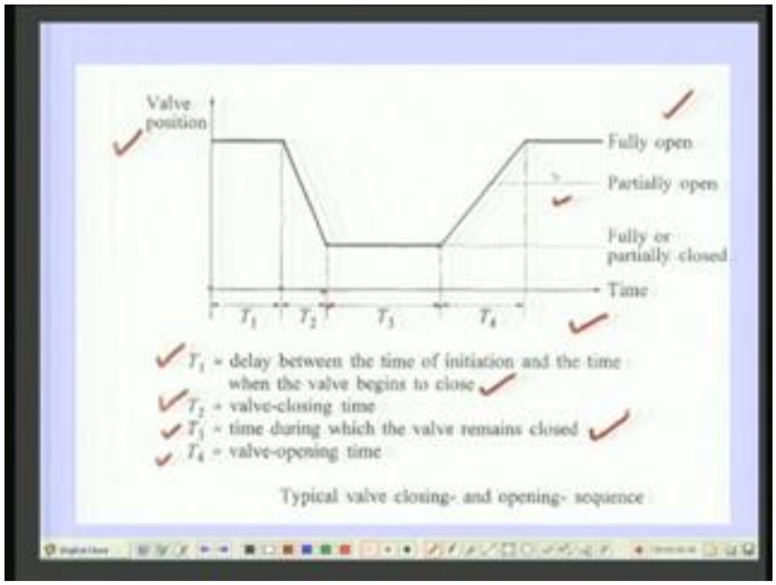

Now this diagram shows a typical valve closing and opening sequence. This is this diagram is a simple diagram in practice you will find that there will always some deviations that is this diagram shows the valve position as a function of time. Now suppose a time T equal to 0, you will sense that yes valve is to be closed then you take a initiation or take take initiate the closing of the valve then for a time equal to T_1, T_1 there is a certain time delay which is required to start the movement of the valve that is you will find at T_1 is a delay between the time of initiation and the time where the valve begins to close. These valves are generally very heavy and there is lot of inertia is involved and the therefore you will find that the moment you give start initiate the action there is certain time delay that is called T_1 then from T_1 to T_2 the valve position is closed,

So that actually slowly the valve is closed at T_2, you come that is T_2 is the valve closing time you can say at this time that is from this point to this point the time is wall closing time T_3 that is from this instant to this instant this is the time T_3 the time during which the wall remains closed and T_4 is the wall opening time that is you a time T equal to 0 you imitate the action for for closing and opening the valve. Then this is the time delay no opening closing takes place while in the same position this is the time which requires for closing the valve from this point to this point that is for time T_3 valve remains closed then from this point onwards it reopens and this is the fully opened condition this is partially open condition this is fully closed position that is when during this period when its partially closed right again you will find actually that during this period the steam is flowing right because its a partially closer and certain mechanical power is developed. The mechanical power in the intermediate pressure and in the low pressure section is not developed during this period.

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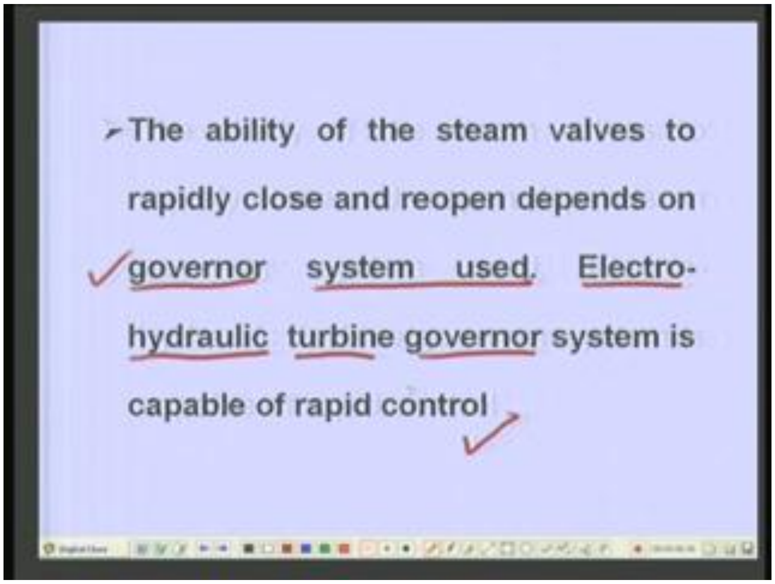

Now here the ability of steam valves to rapidly close and reopen depends upon the governor system which we have used because after all this is going to be actuated through the governor action and electrohydraulic turbine governing or electrohydraulic turbine governor system is capable of this rapid control because you have to close very fast.

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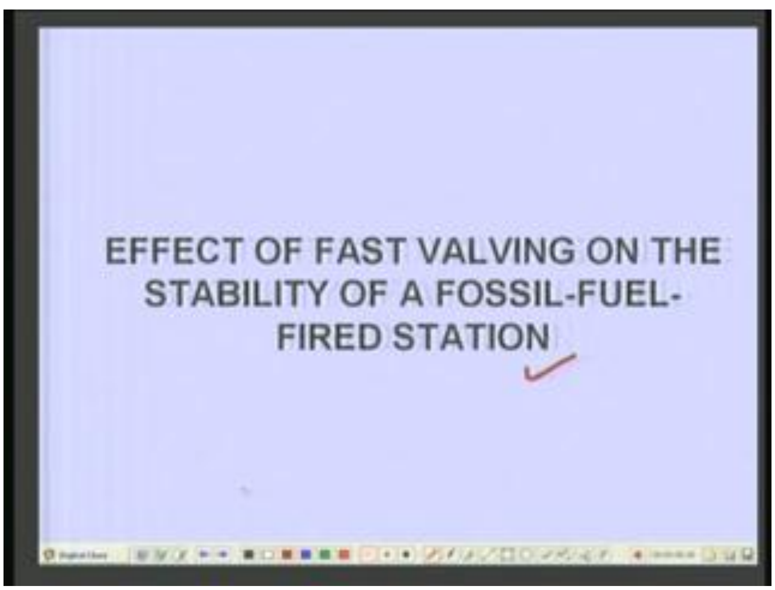

I will tell you typical timings for for closing and opening of this valve but this times are very short. Now you I will just show you the effect of fast valving on stability of fossil fuel fired station. Let us take a typical illustration to see the effectiveness of fast valving on improvement of stability.

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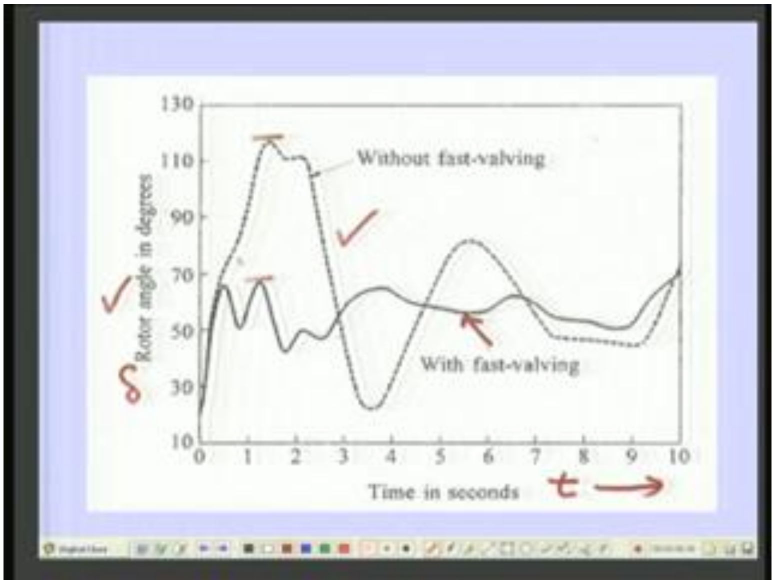

Now, here this really the the example which I have considered is that there is a plant which has 2 units of 500 megawatts and they are feeding power to network and there is a close by a severe fault on the transmission network following that following that the fast valving is resorted and in this diagram shows shows the rotor angle in degrees that is delta delta power angle delta versus time t in seconds I think it is the swing curve of the machines without fast valving this is the graph you can see this is the graph this graph is the graph or a swing curve without fast valving and with fast valving this is the swing curve, this is the swing curve with fast valving.

You can easily see that without fast valving the maximum swing is something of the order of 120 degrees while the maximum swing is now now around 70 degrees and therefore whenever we try to investigate the effectiveness of certain devices for improving stability then the swing curve conveys lot of information and what is the maximum swing that is important right.

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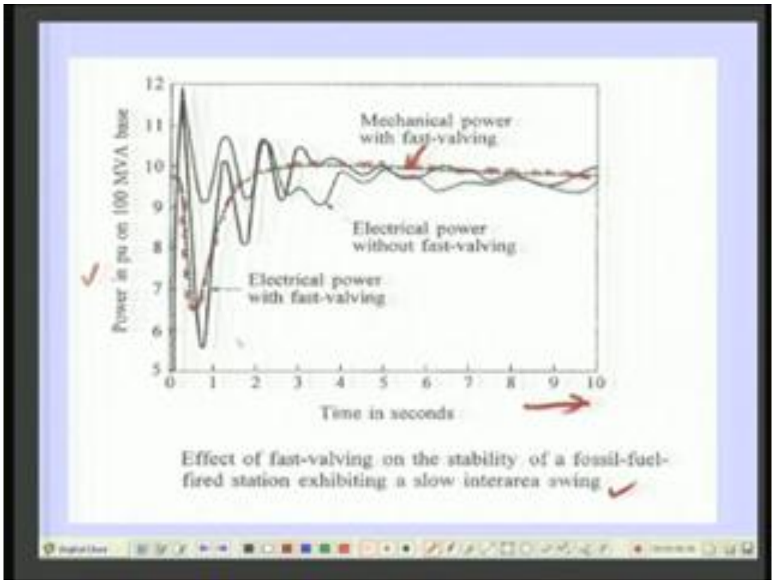

Now this graph shows this graph shows the power in per unit on 100 MVA base versus time on this side that is what has been done is to investigate or to show the effect of fast valving, effect of fast valving on stability of a fossil fuel station exhibiting a slow inter area swing that is the graph which I have shown earlier, you can see actually that the the the swing curve shows that there exists a inter area swing this is very slow, thing type of thing but the point which I wanted to make here is we show here with this dotted graph this dotted graph you can see this this one I will just highlight it here again.

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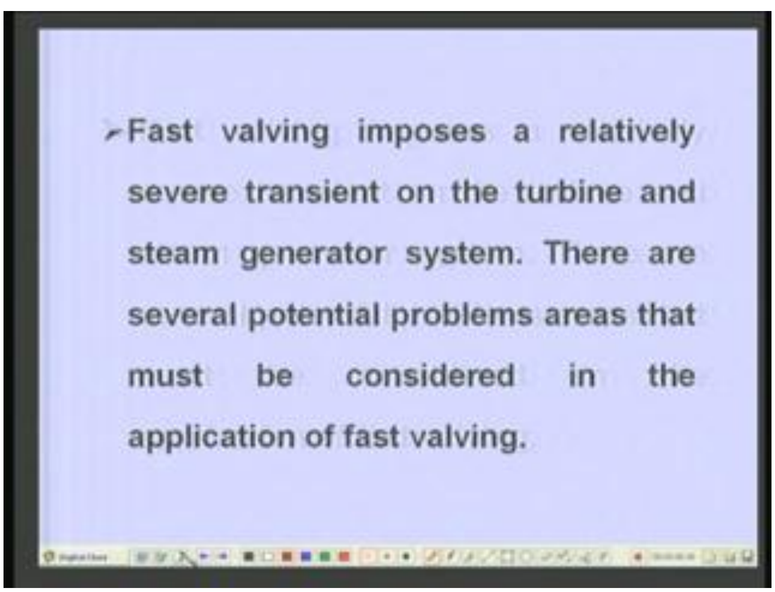

This graph shows the mechanical power with fast valving that is at this point you have initiated the fast valving phenomena, for some time mechanical power does not change then it decreases it comes to from something like 9.8 per unit it comes down to something like 5.5 per unit, 6.5 per unit then slowly it increases and you can see that this whole thing closer and opening has been completed practically in less than 1.5 second. You can see this thing that this graph, this this is the 2 second time in 2 seconds you can easily see that practically it has reached the same level of mechanical output therefore there is a dip in mechanical power which is generated and this dip has helped actually in improving the dynamics of the system that we have already seen.

Now let us look into certain special features of fast valving, the fast valving imposes a relatively severe transient on the turbine and steam generator system what is happening is that you suddenly close suddenly close the interceptor valve then what happens, the steam which is which is coming from the high pressure side and it is actually trapped in the re heater right that steam is stopped suddenly because of sudden movement there will there will be a shock to the reheater and to the turbine side right that is what is the point that fast valving impose a relative severe transient on turbine and steam generator system.

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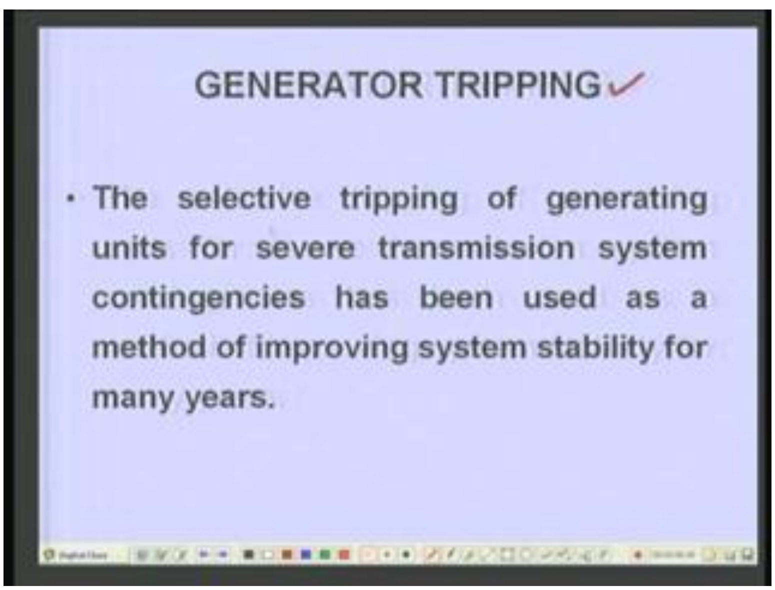

This is steam generator means boiler here boiler re heater and it also imposes on the turbine because in the turbine we are carrying normal steam you will find that actually suddenly mechanical input reduces and therefore this sudden change in the steam flow effects actually the life of the turbine blades and therefore I would mention here that whenever fast valving is applied as the technique for enhancing stability, one has to evaluate evaluate that what will be the consequences of this technique in terms of in terms of the steam generating unit that is boiler, re heater, on turbine that is when we talk about turbine turbine blades fatigue of the shaft all these things have to taken care of and only when certain situation demands that this is effective and can used is applied. Then there are some other techniques which can be used for enhancing stability.

The generator tripping is another powerful technique which can be used but we have to be very careful in using this technique that is let us understand how this generator tripping helps. Suppose there is a large system right and there is severe fault on the system. Now this machines in the system will be accelerating or decelerating depending upon what is the excess power right and all the techniques which we have discussing have mechanical mechanical reduction in power that is you control the steam valves or you apply actually the artificial load in the system right are basically to reduce the acceleration under some situation you will find that you can trip certain amount of generation if you trip certain amount of generation again actually you will find this say the excess power which was there to accelerate the system is reduced right the this is what is the approach here.

A selective tripping of generating units for severe transmission system contingencies have been used as a method of improving stability for many years but again you know the the consequences of tripping a unit have to be examined suppose you trip a unit because tripping a unit is easy, you open the circuit breaker general circuit breaker you will find actually that the whole unit transfer of generator is disconnected from the system tripping is not than take much time time taken is the same circuit breaker and relay operating time right.

But the moment actually the system generating unit which are supplying certain load right immediately you will find that there are certain ill effects to transient on that system speed will increase governor will try to control the speed right and all these effects are there one arrangement is that suppose you you to the machine and follow the normal procedure of shutting down you close the steam turbine you stop the machine another is that you use.

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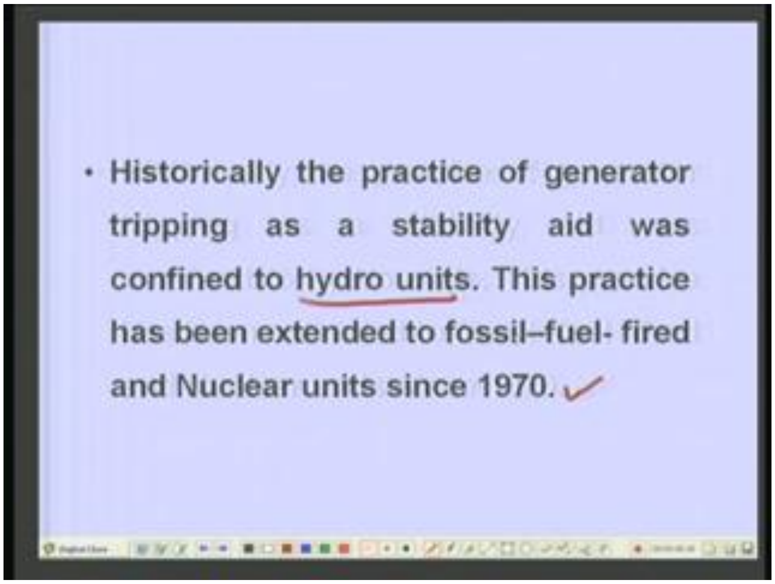

Let the machine continue to run for some time and supply certain auxiliary power or power which is required for meeting the auxiliary requirement right and then resynchronize this machine when the system is becoming healthy that is historically there are practice of generator tripping as a stability aid was confined to hydro units and this practice has been extended to fossil fuel, fired units and nuclear units in 1917 because this is considered to be a very powerful actually in technique for saving the system when system is subjected to very severe contingencies that is not in a position to save the system, sometimes blackout takes place if you cannot take certain measures which have happened in our Indian power system also.

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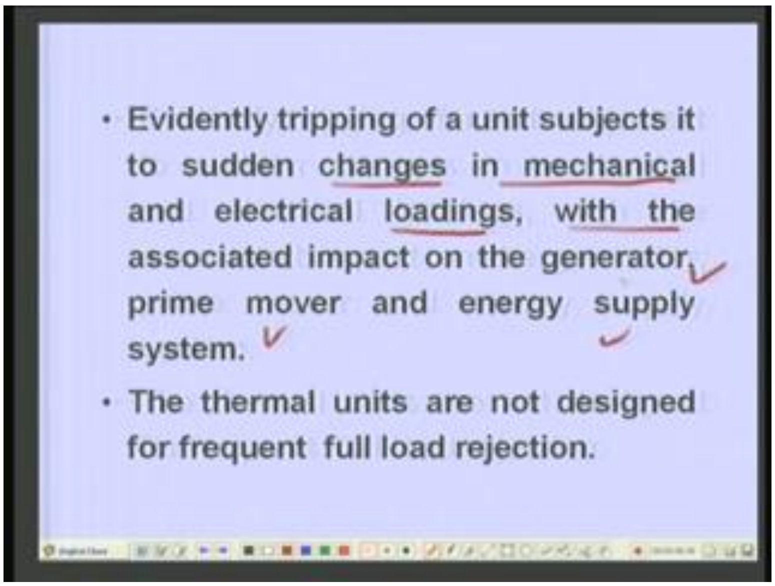

Evidently tripping of a unit subject in in its subjects it to sudden changes in mechanical and electrical loadings you can easily understand this aspect the unit which are supplying certain load suddenly, there is electrical power output is 0 mechanical output is reduced mechanical loading right. With the associated impact on generator prime mover and energy supply system again again as I have discussed actually about the fast valving phenomena. Similarly, when you talk generator tripping right the it affects the steam generating system it affects the turbine it affects the generator all these units and one has to examine very carefully the impact of tripping before you resort to this type of practice in fact the thermal units are not designed for frequent full load rejection. Generally, whenever whenever the machine is unloaded the load is slowly reduced full load rejection means machine is having an 100 percent loading condition and you trip the machine that type of situation is very dangerous to the thermal units.

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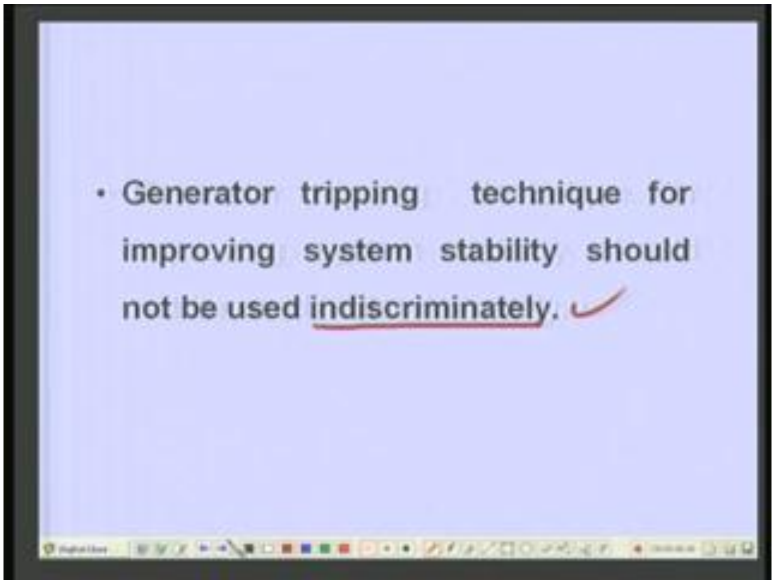

Now this is this is warning that generator tripping technique for improving system stability should not be used indiscriminately okay, you understood actually the following are the major turbine generator concerns the over speed resulting from tripping of the generator, thermal stresses caused by the rapid load changes and the shaft fatigue life consideration, all these are the major considerations they have to be evaluated examined before you make use of this this approach. But this is considered to be one of the very powerful approach or for enhancing system stability under certain certain, I would say severe contingencies.

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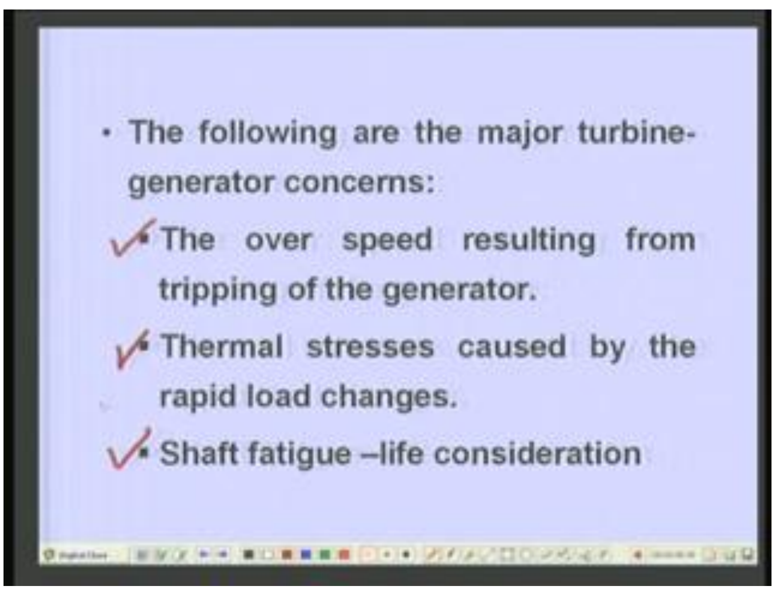

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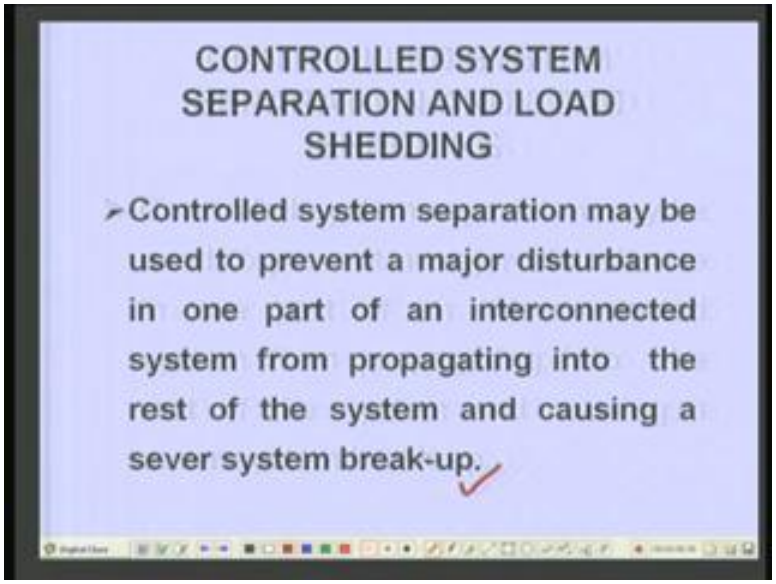

Another approach is controlled system separation and load shedding. Controlled system separation may be used to prevent a major disturbance in one part of interconnected system from propagating into the rest of the system and causing severe system break up. Now this it is something like this this normally we call this islanding islanding therefore you have a large interconnected system and if a disturbance has occurred in part of the system you do you resort to islanding. So that the the disturbance does not propagate to the remaining part of the system and today certain steps are been initiated in our Indian power system also so that we can save part of the system whenever some disturbance occurs in a certain part of the system because in 2002 January the the northern regional grid completely collapsed and no part of the system could be saved from that point onwards efforts are been made to to resort to certain techniques so that at least you can save a certain part of the system and complete blackout is avoided. Globally also certain approaches are been adopted to save the system from complete blackout.

Today the terminology which is used is called wide area protection system which requires actually the synchronized phase measurement units to be used so that you have a common time for the complete system then all system operates in a completely synchronized manner, the timings are all synchronized and they have a synchronized arrangement you can have the synchronized phasor measurements and monitor from central point. So that you can find out whether the disturbance is coming and what to do to save the system from blackout.

The impending system instability detected by monitoring one or more of the following quantities in the sense that how do we monitor that yes a disturbance is coming in a particular system and it is going to propagate into the remaining part of the system, one is sudden changes in power flow through specific transmission circuits there will be one indication on a particular line some power is flowing and suddenly you find that there is wide change in the power flow that is one indicator, change in bus voltage angles rate of power changes these are some of the indicators that can be used to initiate the system separation, a very complex problem in fact it is not that easy to talk about the separation.

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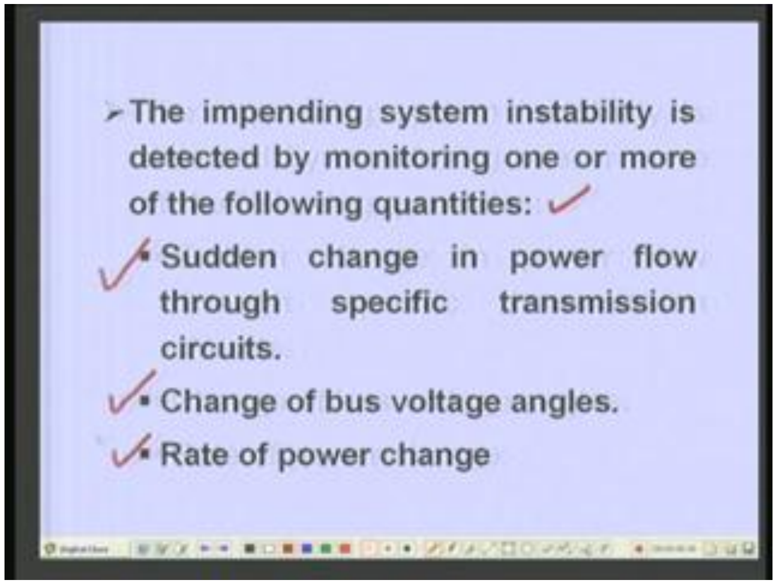

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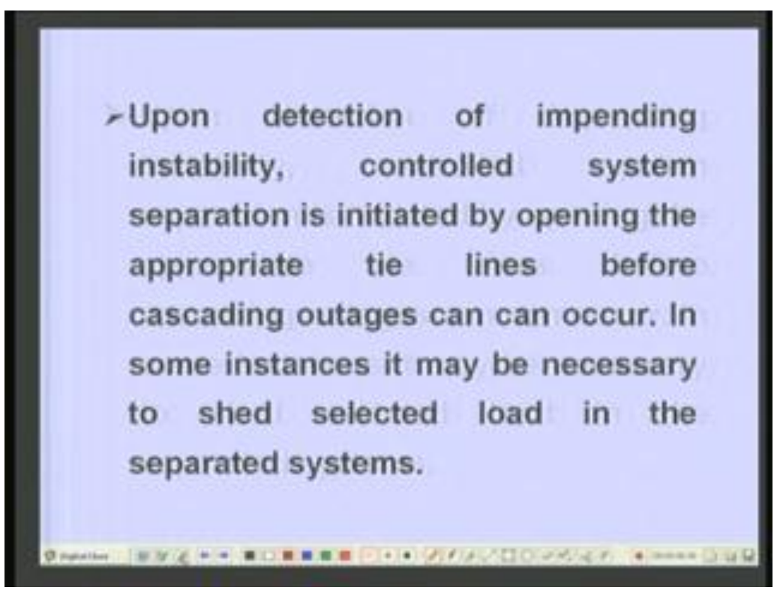

Now upon detection of impending instability impending instability control system separation is initiated by opening appropriate tie lines before cascading outages can occur. Few few selected tie lines have to be opened in some instances it may be necessary to shed selected load in the separated system that is when you separate the system problem may come there may be generation load unbalance wherever you have a more generation and load less you have to shed some generation wherever you find that load is more than generation you have to shed some load right.

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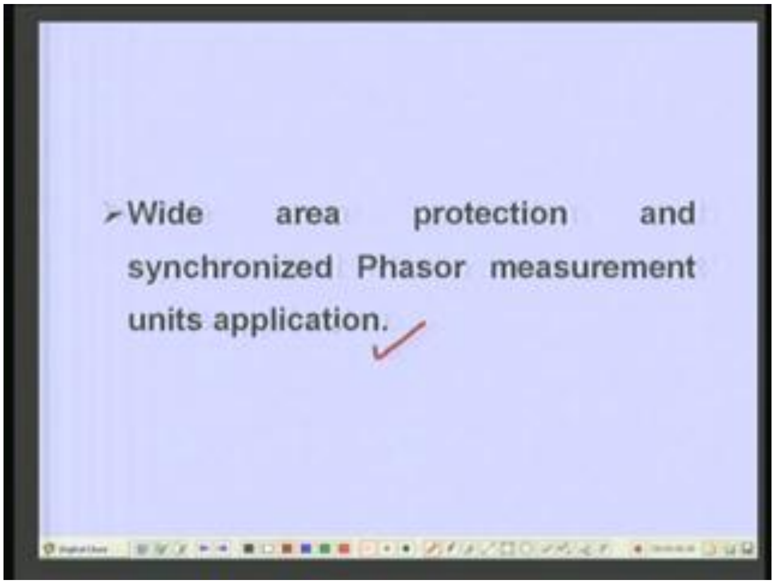

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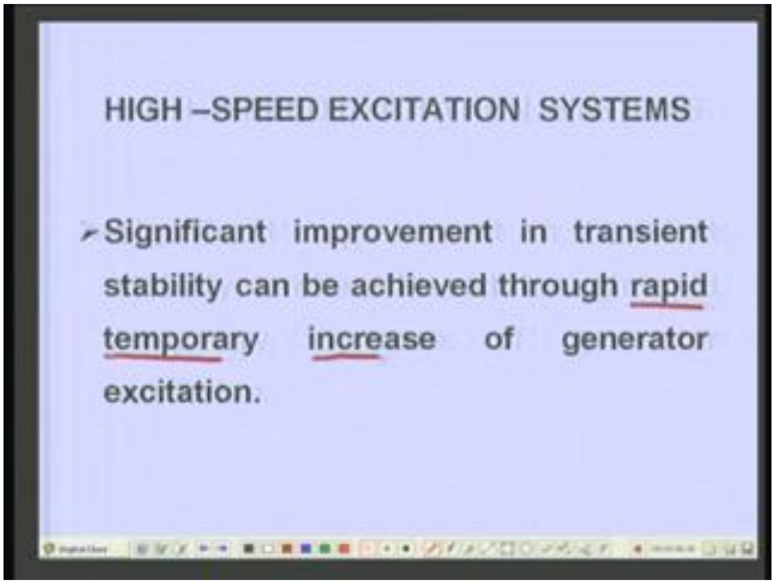

Therefore this is another this is to be approached there is no way out you will find that whenever you do this islanding you will not be in a position to make the island to have a load generation balance impossible, wide area protection and synchronized phasor measurement units are applied for this type of protection purpose or for this type of islanding okay.

Now next is the high speed excitation systems how high speed excitation systems helps in improving the transient stability of the system, over the years there has been development in the in the excitation system technology I have discussed the different excitation systems in my previous lectures I have discussed the excitations systems models also. Now here significant improvement transient stability can be achieved through rapid temporary increase of generator excitation, idea is something like this actually we make use high initial response high ceiling voltage excitation system.

Now normal normal fault conditions what happens is the terminal voltage drops you will find actually that whenever the system fault is there the voltage at the terminals of the generator will be low the automatic voltage regulators will quickly take action and apply to the field winding maximum voltage this is equivalent to the celling voltage which will cause in turn increase in field current and internal voltage. Now this internal voltage which is which is increased by this action will help actually in increasing the synchronizing power when the fault is cleared.

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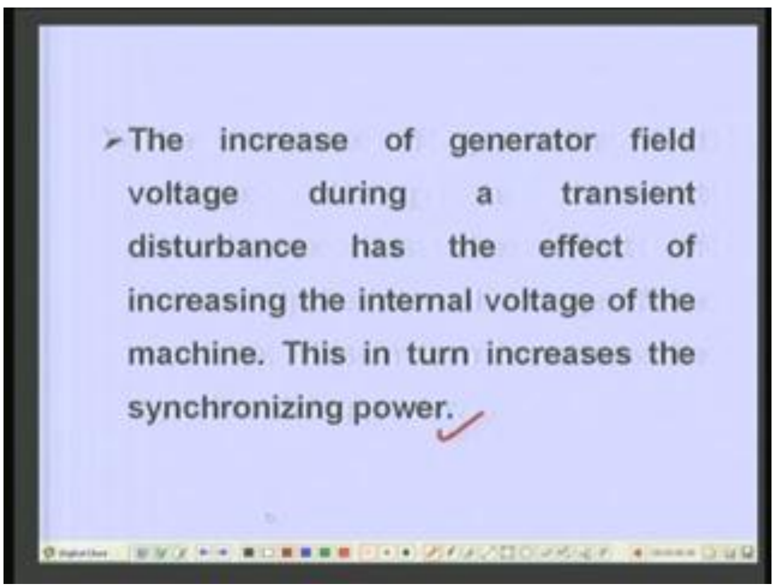

There is a mechanism here that is increase of generator field voltage during a transient disturbance has the effect of increasing the internal voltage of the machine and this in turn increases the synchronizing power. Because we have discussed in the beginning itself that we have to take measures so as to increase the synchronizing power which can restore back the system to the new operating condition, this is one of the approaches. The AVR response to this condition by increasing the generator field voltage and this has beneficial effect on transient stability.

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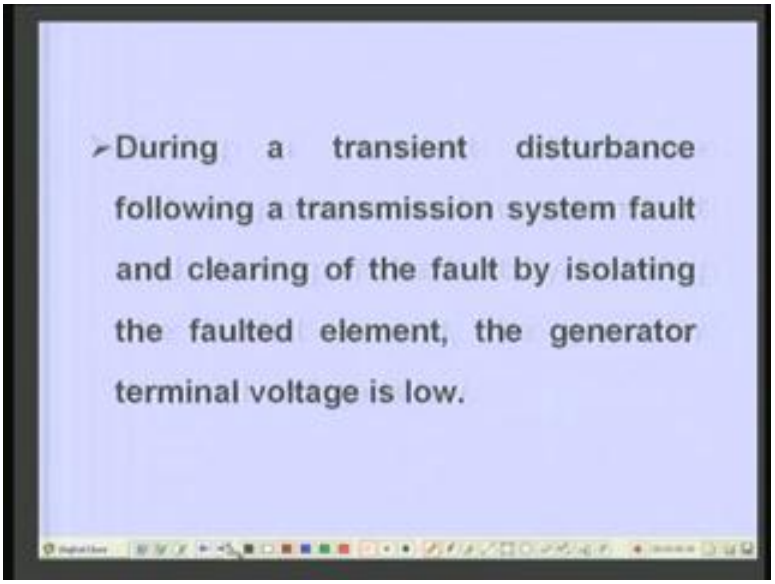

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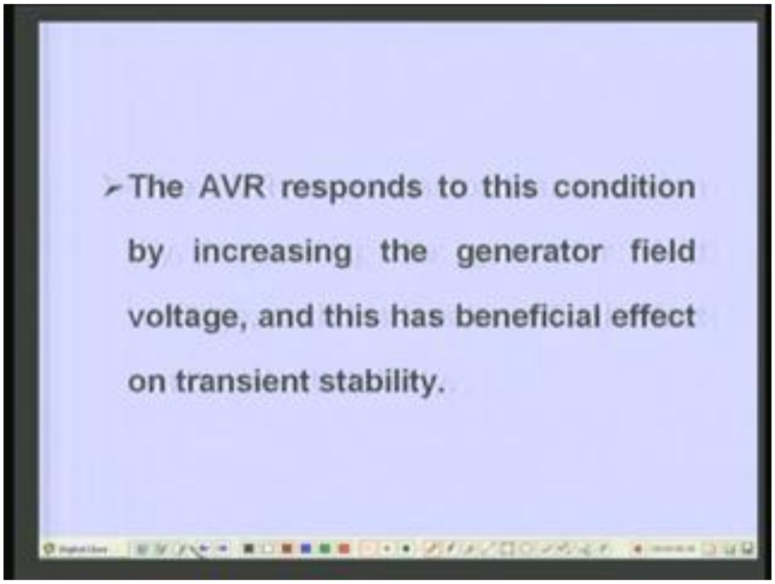

The effectiveness of this type of control depends on the ability of the excitation system to quickly increase the field voltage to its highest possible value that is, if suppose the excitation system is slow you will find will not be effecting it has to be fast that is why the effectiveness of this technique depends on the ability of the excitation system to quickly increase the field voltage to its highest possible value that is to the field we apply the highest possible value that is the celling voltage. Here the high initial response excitation system with high ceiling voltage are most effective in this regard.

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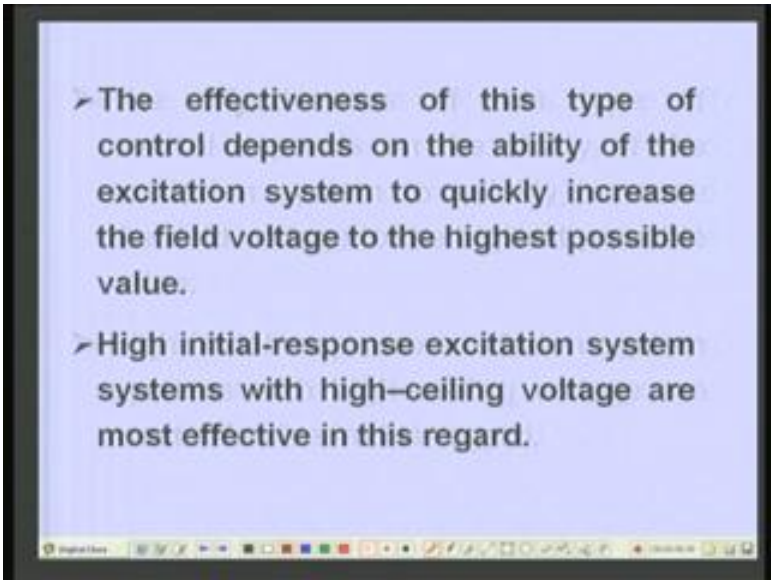

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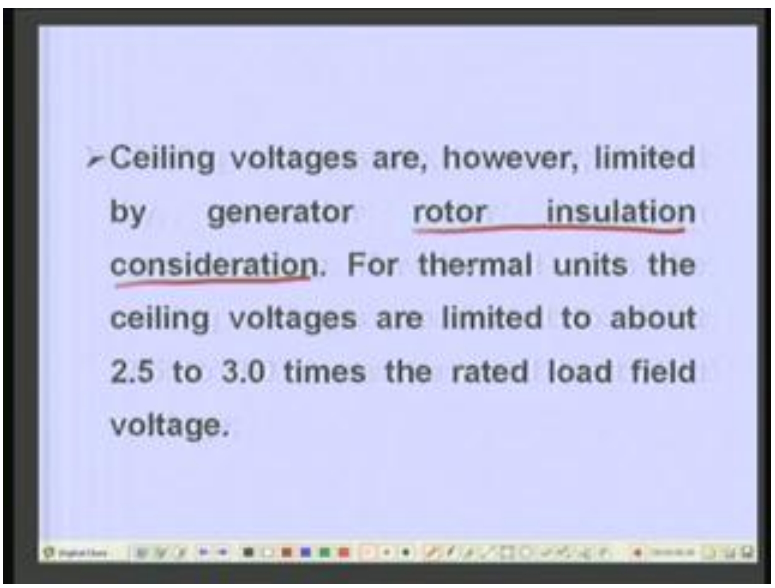

The ceiling voltage again then what should be the ceiling voltages what is the maximum voltage which can be applied to the field winding of the synchronous generator that is called the ceiling voltage? All the excitation systems are designed to have certain ceiling voltage. The ceiling voltage are however limited by generator rotor insulation consideration for thermal units the ceiling voltage are limited to about 2.5 to 3 times the rated load field voltage. Suppose a generating unit has a rated field voltage of say 250 volts right then the ceiling voltage may be

750 volts is three times right this is what is the meaning and this voltage can be raised from 250 is the nominal value to 750 in a very short time.

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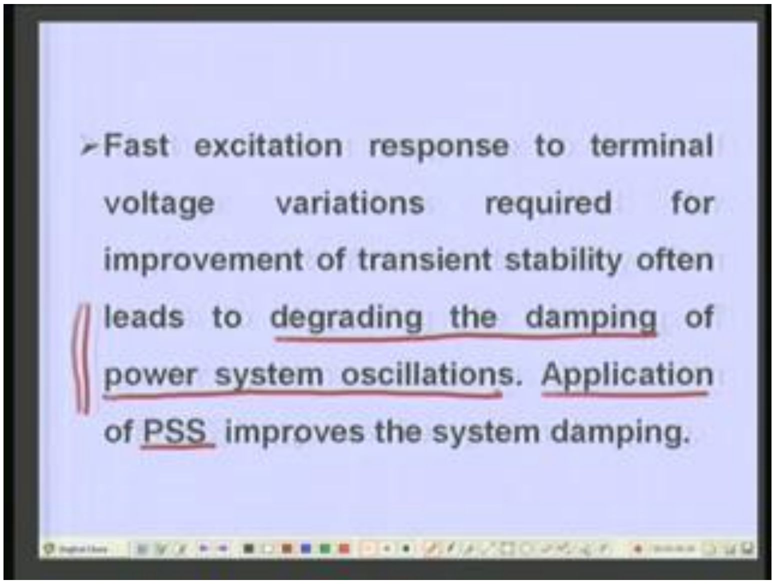

The fast excitation response to terminal voltage variations required for improvement of transient stability often leads to degrading the damping of the power system oscillation, this is the another ill effect of of high response or initial response high ceiling voltage excitation system that causes the degrading of the damping that sometimes it adds negative damping and therefore we need actually the application of PSS to overcome this problem, power system stabilizers a lot of research work has been done on this and we, I have discussed actually the effect of PSS in my previous lectures and the effect of high high or we can say high initial response excitation systems on the stability in previous lectures also.

The high the use of high initial response excitation system supplemented with PSS is by far the most effective and economically method of enhancing the system stability. In fact actually out of all the techniques which we have discussed so far this is a very accepted and tool for for enhancing the system stability you will find today large capacity machines will have high initial response excitation system, high ceiling voltage and along with power system stabilizers the ill effect of high initial response excitation system which enhances transient stability but degrades the damping is overcome by providing PSS.

Let us just look the comparison of transient stability with a AC exciter and a bus fed thyristor exciter system in fact here I will make the comparison between the two excitation systems one is the AC exciter system, where you have a AC generator rotate rotating or stationary rectifier system and another is that you you have a static excitation system which is taking which take input from the bus other than taking from the terminal of the synchronous generator the bus in fed that is the bus fed thyristor excitation system.

Thyristor word of course is used thyristors are required in both the cases but here the meaning is one is static excitation system another is a rotating excitation system.

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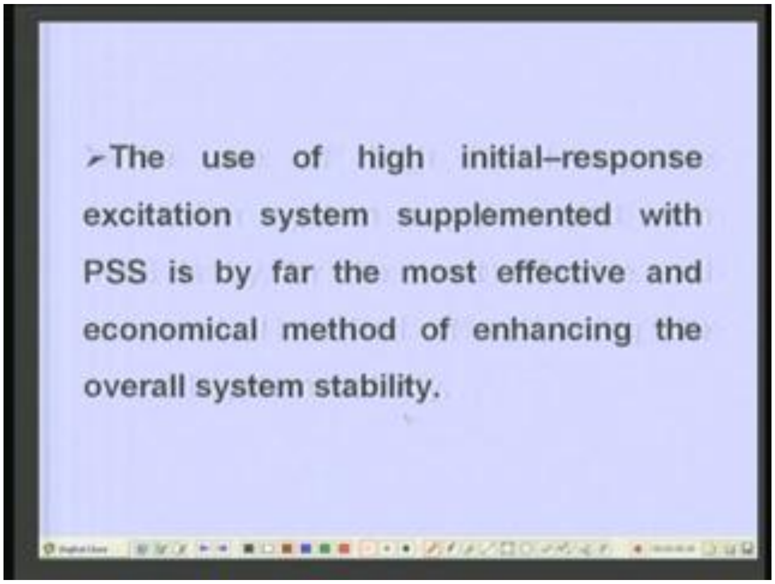

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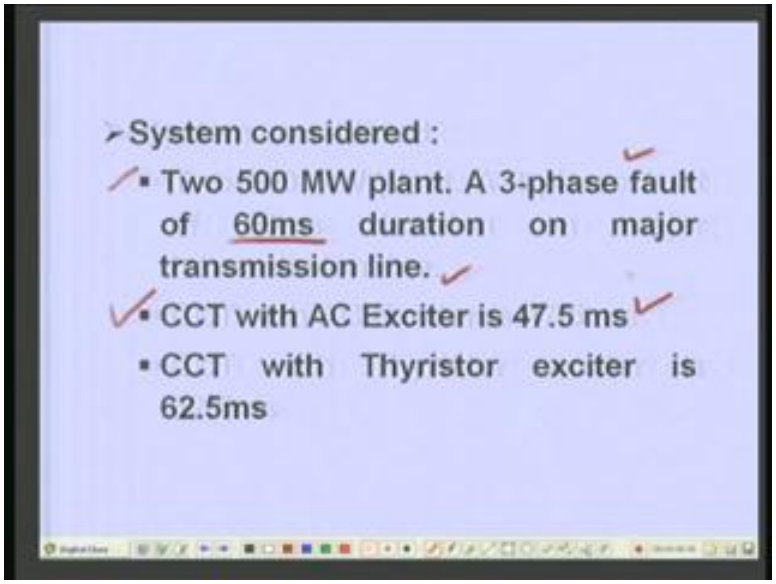

For the purpose of illustrating this thing we have considered a system with 2 generating plants or 2500 mega watt plant there are 2 units of 500 megawatt capacity, a 3 phase fault of 60 milli second duration on major transmission line is considered. For example, I considered certain improvement by using the fast valving same system is here also you have a power plant with 2500 megawatt units and there is a major fault actually in the transmission system and 3 phase fault is considered. The fault duration considered is a 60 milli second if we use for this particular system, the critical clearing time with AC exciter that is 47.5 milli second only.

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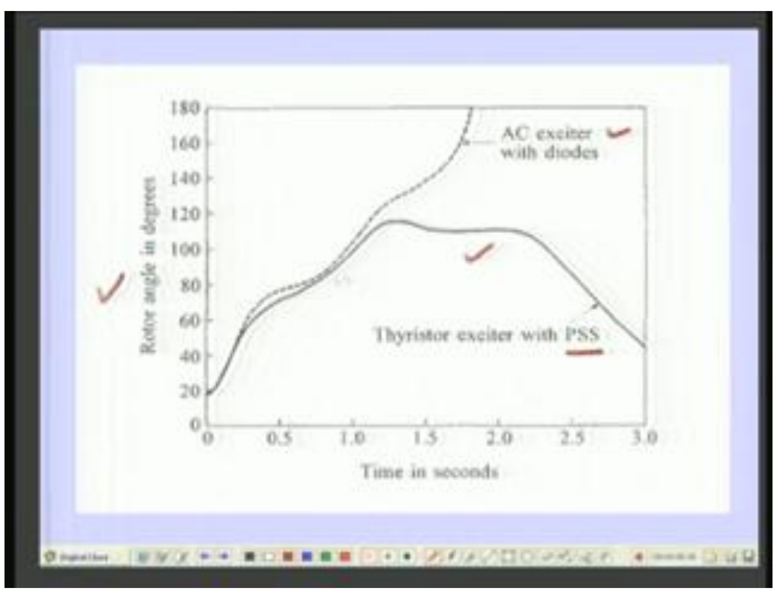

For this particular system with the particular type of fault considered with AC excitation system AC exciter, the critical clearing time is 47.5 milli second while the critical clearing time with static excitation system is 62.5 milli seconds. Obviously, the fault duration is 60 milli second with this AC exciter the system will become unstable with thyristor excitation system system will remain stable. This is illustrated through swing curve again here, rotor angle here, you can see that this firm line shows the the swing curve with thyristor excitation system with PSS and this is AC exciter you can easily. See that the system with AC excitation system has become unstable while the while the static excitation systems remains stable it is a beauty right because normally the stability margin is always judged by knowing actually the critical clearing time and the actual fault clearing time. For example, in this case the with AC exciter there is no margin system is unstable however with the static excitation system the we have a margin of 2.5 milli seconds.

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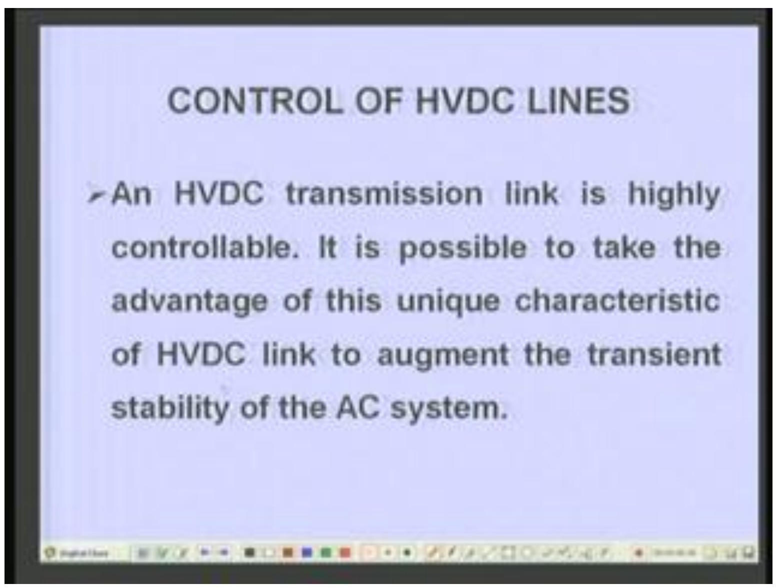

Now we discuss some more techniques one is the control of HVDC lines. Now in some systems we have HVDC lines and wherever HVDC lines are available the we can take the advantage of HVDC lines because HVDC line is one where you can quickly quickly change the power flow on the line the controls are such that you can increase the power flow at a very fast rate. You can say the ramp of the power output or ramp of the power flow on the line or ramp down the power flow on the line this control is very fast this is only clearly by adjusting the firing angle of the thyristor walls you can appropriately ramp up or ramp down the power flow on the line and this advantage can be taken wherever you have HVDC link. I mean I am taking about here actually that this is a AC system with additional HVDC link already operating, it is not actually that we have 2 systems connected by HVDC link it is not that way they are not two asynchronous systems same synchronous system but there is a HVDC link.

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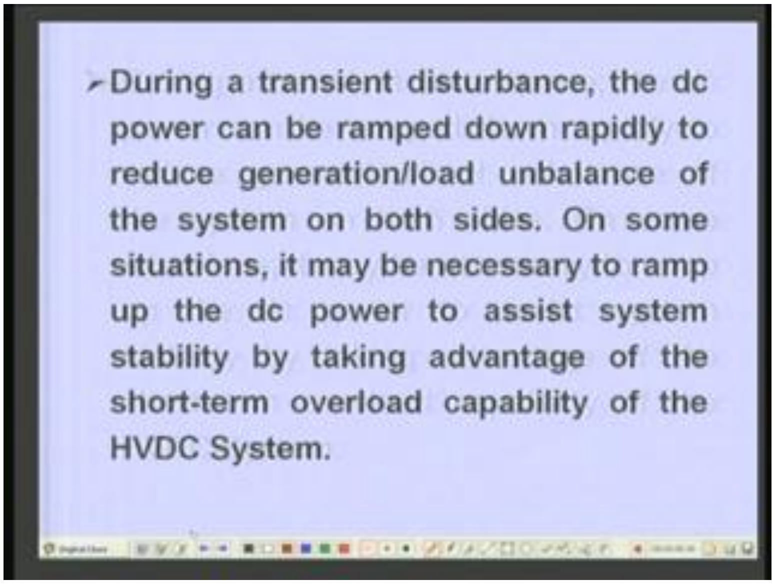

Now when a HVDC transmission link is highly controllable it is possible to take advantage of this unique characteristic of HVDC link to augment the transient stability of the AC system. During a transient disturbance the dc power can be ramped down rapidly to reduce generation load unbalance of the system on both sides, on some situations it may be necessary to ramp up the dc power to assist system stability by taking advantage of short term overload capability of HVDC system normally the HVDC systems have short term overload capacity and all these control measures are only for a short duration.

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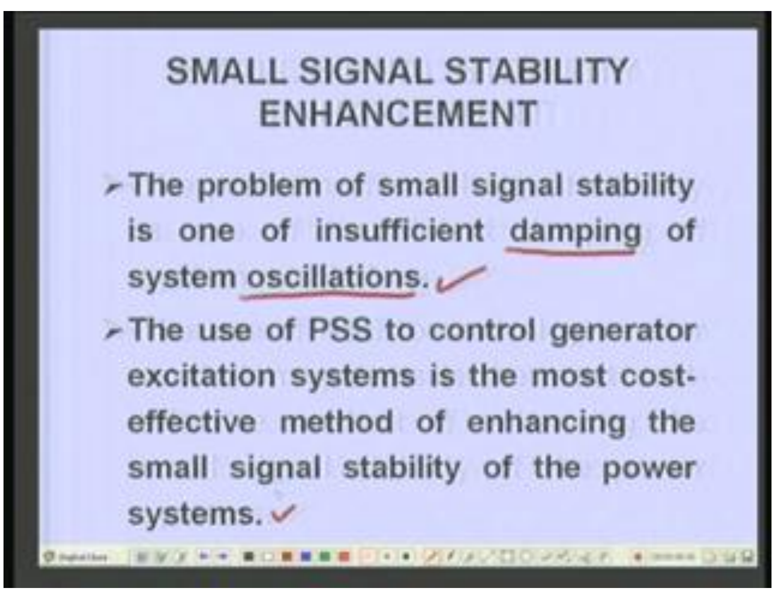

Now just before I close my discussion on the methods of transient stability enhancement. Let us discuss about small signal stability enhancement the problem of small signal stability is one of the insufficient damping of power system oscillations the use of PSS to control generator excitation systems is the most cost effective method of enhancing small signal stability of the power systems. The application of power system stabilizers and their capability in enhancing stability I have discussed in my earlier lectures I am not going to repeat the discussion on PSS but today today all excitation systems which are manufactured by by excitation system manufacturers they provide power system stabilizers as a integral part of the excitation system.

Now the equality companies have to tune the parameters of their excitation systems or power system stabilizer. So that the local as well as internal modes of oscillations are damped out. Now my before I close the discussion on methods of improving the stability of the system. Let me mention that the new technology that is the flexible AC transmission system technology is evolved primarily to have flexible controls on the system. For example, if you whatsoever we have talked till now is either on the generator or on the turbine or on the HVDC line but very little discussion I have made on transmission line.

Now here when I talked about the application of series capacitors or for compensating the transmission line reactances or TCSE for for for control {comp} ((00:50:07 min)) control compensation of the transmission lines in fact actually the application of these FACTS devices whether it is a TCSE or SVC or STATCOM or UPFC or other FACTS devices. All these FACTS devices have the capability of controlling power flow on the transmission line and we can regulate the power flow on the transmission line rapidly and on these systems also we can add certain devices to damp out the oscillations that is I can use TCSC for improving transient stability as well as dynamic stability I can control actually the line impedance for enhancing the stabilities.

Similarly, you can control the STATCOM or shunt connected devices or UPFC where you can enhance both both transient as well as the dynamic stability of the system or improve the damping of the system. Today the lot of research work is been carried out to coordinate the tuning of the FACTS devices as well as the the power system stabilizers. So that we want coordinate the tuning so that the the devices are tuned in coordinated fashion. Now with this I have just complete discussion of techniques of improving the power system stability a variety of techniques have been used for improving the transient stability of the system and dynamic stability of the system and these techniques need to be judiciously used taking care of the system considerations and one only one technique is not sufficient one has choose a a a group of techniques or a combination of certain techniques they have to be used to improve the system stability.

With this I have completed the series of 40 lectures on on power system dynamics or say power system stability during this we have discussed the modeling of the system synchronous generating modeling excitation system modeling, turbine modeling, governor modeling. There are various techniques of analyzing the stability then we have discussed the voltage stability, we have discussed about the power system stabilizers and at the end the techniques for improving the transient stability of the system.