Power System Operations and Control
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Module-2
Equipment and Stability Constraints in System Operation
Lecture-14

Now, common this lecture number 14, which is the last lecture of the module as well of the module 2. That is the equipment and stability constraints in the system operation. In the lecture number 13, we saw the hopf bifurcation which is a dynamic bifurcation. And in this lecture, we will see other bifurcations dynamic bifurcations. And how we can improve the voltage and stability what are the various methods or you can say measures and along with also 1 example with the placements of a static war compensator. How it can improve the dynamic as well as the static voltage stability of the system?

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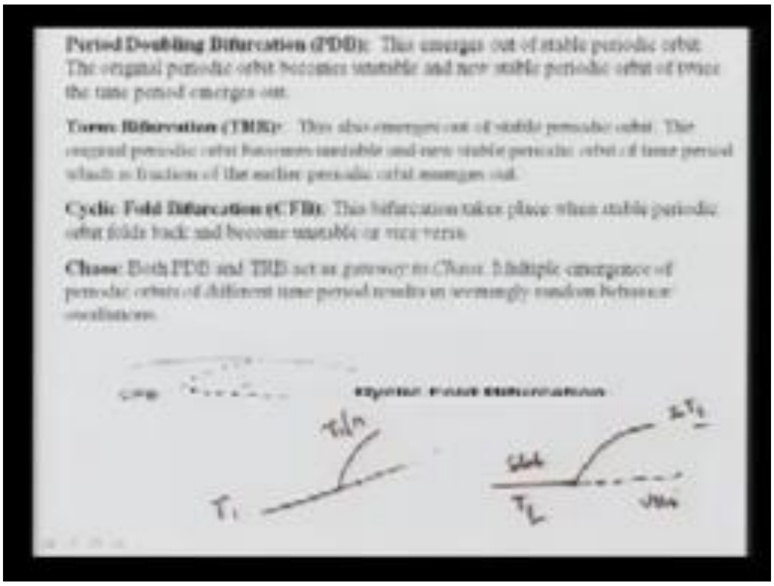

So, other dynamic bifurcations are period doubling bifurcation. It is also called PDB this emerges out of a stable periodic orbit. The original periodic orbit becomes unstable and the new stable periodic orbits of twice time period emerge out. Means for example, if can say here if you are something here this is your coming this is the stable. And from here this here the period is let us suppose T 1 and it is a stable 1 and suddenly if it is going to be stable here. And it is your 2 T 1 and another here the original which was going it is now, on a stable. So, it is your unstable and it is a emerges out another that is a twice of the period of this T 1 and that is the stable then it is called the period doubling bifurcation. So, the new stable periodic orbit of the twice time period is emerging. So, this is called your periodic doubling here.

Now, the torus bifurcation this also emerges out of a stable periodic orbit the original periodic orbit becomes unstable. And the new stable periodic orbit of the time period which is fraction of earlier periodic orbit emerges out. So, this torus and the periodic doubling here is the period doubled. As I said here it is a period is T 1 now it becomes T 2 and it becomes unstable. But in the torus it is your if it is a T 1 and it is a stable and then it is your this becomes unstable. And your stable here is a fraction of let us suppose T 1 about some factor n and we are having another time period. So, it is called torus bifurcation. The cyclic fold bifurcation this bifurcation takes place when a stable periodic orbit folds back and becomes unstable or vice versa.

So, here you can say the cyclic fold you can say it is coming here and then it is a coming going back means folding. Just you can say here is stable now, it is become unstable. So, this bifurcation takes place when a stable periodic orbit folds back and become unstable. So, it is become unstable here. So, it is called cyclic fold. Chaos both PDB and the TRB acts as a gateway to chaos. The multiple emergence of the periodic orbits of the different time period results in seemingly random behavior and oscillations and that leads to the chaos. So, the random behavior leads to the chaos and it is not we cannot able to determine the behavior of the system and that is called the chaos of the system.

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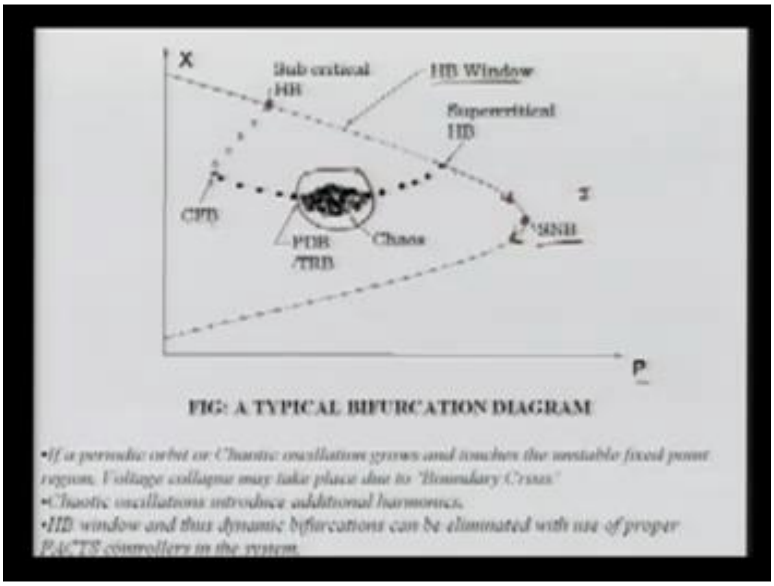

Now, all these dynamic and static bifurcations, if you can see here in 1 diagram so, this is a typical bifurcation diagram. First I explained the saddle node bifurcation point which is here and that I am trying to give you in some play. So, this is your real power here it is your voltage that is it acts better. And this point is your saddle node bifurcation because here it is your stable and this is your unstable. So, it is the point where stable and unstable are meeting and this is notch point or saddle node bifurcation which I explained. Now, the hopf bifurcation as I said it comes earlier where at this point as I said this Jacobian becomes singular. But here the jacobian before this jacobian is not similar and there is a possibility that the 2 Eigen or you can say pair of Eigen value becomes complex conjugate. Means the real part will be 0 and that can here let us suppose this HB that is here. So, again I explained the 2 hopf bifurcation HB is the hopf bifurcation 1 is your sub critical another is your super critical and the in between it is called your HB window in this 1.

So, this is your sub critical occurs before your super critical, because here it is surrounded unstable is surrounded by stable point here unstable point is surrounded by stable 1. So, this is called your hopf bifurcation window. Now, if you are again here this hopf bifurcation I said this is unstable and it is folding going back and now it becomes suddenly stable. So, it is called your cyclic fold bifurcation which just now, I explained here. So, this is this point is called your cyclic fold bifurcation. So, it was unstable and now, it is folding back and here it is a stable now. Now, in the periodic doubling bifurcation as I said it emerges out from the stable. Here this is stable and now, the frequency becomes stable or in the torus it is a fraction. So, here it is original becomes unstable and then here it is somewhere and this point is called the chaos. So, there is so many oscillations and other things system is not defined here this is you can say chaos of the system.

And finally, here you can say this is your super critical and point hopf bifurcation point. So, if a periodic orbit is chaotic oscillation grows and touches unstable fixed point region the voltage collapse may take place due to the boundary crisis. So, in this I want to say that if a periodic orbit or chaotic oscillation grows here. And touches the unstable fixed point here in this region then voltage collapse may takes place due to the boundary crisis. The chaotic oscillations introduce additional harmonics into the system that is not desirable. This hopf bifurcation window and thus dynamic bifurcation can be eliminated with use of power proper facts controller in the system. Means we can eliminate even though this hopf bifurcation at all by using the facts controller and we will see application of static var compensator how it can improve your dynamic stability? Here if you can put then this can be the window can be eliminated and then we can load your system up to the snb that is the singular single singular node bifurcation point.

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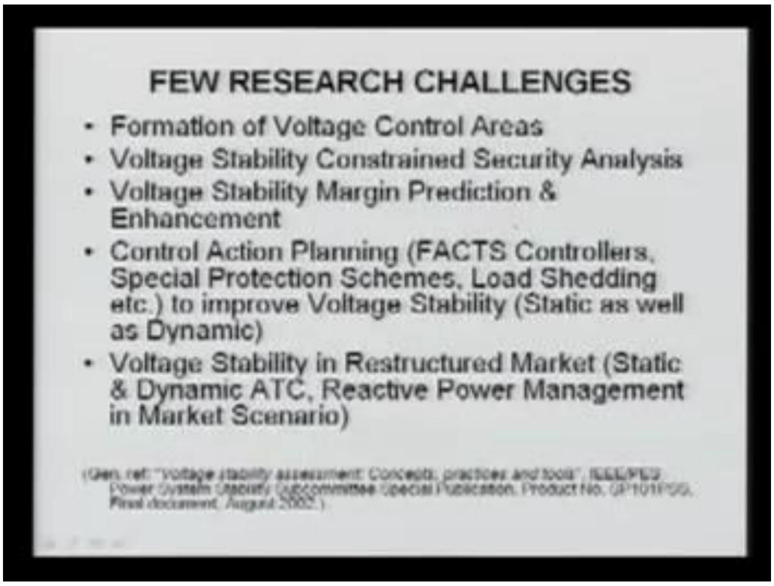

Now, here the lot of people is doing the research in these areas for the various purposes. First normally they go for the identification of the weak buses and therefore, they form the voltage control area. The voltage control area is nothing but where we want to put the reactive power source minimum that benefit maximum to the system. So, we form the voltage control area means we are putting reactive power flow somewhere that area is benefited much. So, that is called 1 area as you know the reactive power is a local phenomena. However, the real power injection etcetera is your global phenomena, because if you are injecting real power at 1 point it is changing the frequency of whole system. However, if you are changing the reactive power you are you are injecting or observing reactive power the voltage is changed is localized one. So, the formations of the voltage control area there are lot of works already exist in the system, but is still some more simple and the reliable methods are required. Another challenge is the voltage stability constrained security analysis.

Normally people go for the security analysis means as you know the security is much demanding than your voltage stability as well. So, we can add some more constants in the security analysis and then we can use the voltage stability constraints and then we can analyze. Now, if you are adding the voltage stability constraints. f you are adding the dynamic constraints then system becomes very complex and getting solution is also very complex. So, we can include the voltage stability constraints in the security analysis and then we can analyze the system behavior. The voltage stability margin prediction and enhancement means you can suppose your system is working fine means it is stable it is operating well. But it is prime duty of operator to know that where they are operating how much margin they are have and what are the ways that they can enhance the voltage stability margin with available resources in the system that is if you are operating the system in the planning as well that you can plan some enhancement devices.

And especially the facts controller that can we use that we can improve the voltage stability margin as well. So, the control action planning that is facts controller is special protection scheme load sheddings to improve the voltage stability as well as the dynamic. So, lot of works already had been turn in that area the load shedding to improve the voltage stability how that we can have the special protection schemes fast and reliable So, that we can eliminate the area which are having the voltage instability problem and also that we can use the facts controllers those can enhance the voltage stability margins as well. Another big concern is the voltage stability or any sort of stability in re structure market, re structure means the power system deregulation where the electricity is shedded. And the electricity prices are changing every interval it may be half an hour or it may be 1 hour the and it is sold and purchased based on the competitiveness of the biddings of both supplier as well the consumer side.

So, this who is going to take care of the voltage stability? And since your system is dispatched means you are getting information thus how much load you are going to consume and which generator is going to generate? How much are then whenever there is some contingencies occurring how that we can take care of the voltage stability concerns in the power system. So, the static and the dynamic atc reactive power management in the market scenario are also very complex and that must be address so, that we can have free and fair electricity market. So, normally 1 paper that is came here that is a final documents that it is a i triple e ps sub committee and the special publication. And the product number is sp 1 0 1 pss and that came in august 2002 that here the voltage stability assessment concepts practices. And the tools they have suggested and they have given very good overview as well as the classification of this area.

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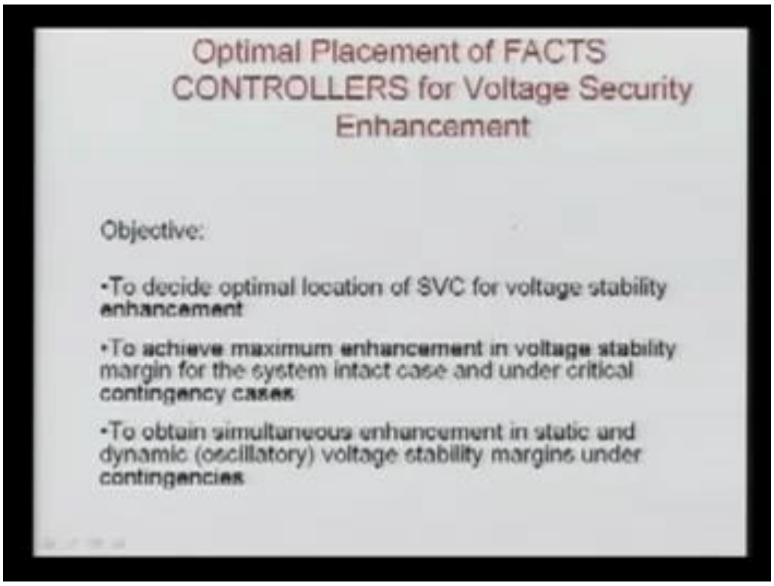

To see this enhancement of these facts controllers for the voltage stability again just one thing is very important for the facts controller these facts controllers are not change. So, that you can put in each line or you can put at each bus again which type of facts control controller you are going to put. There are 2 types of facts controller one is shunt and another is your series type’s fact controller. Shunt type of controllers are put on the bus series type of controllers they are put in the series of the line there are even though combination of shunt and series.

So, shunt part is kept on the bus and the series part is kept on line. So, main as I said the cost of these devices are very extremely high. So, it is not possible to put at each bus and each line. So, we have to decide the suitable location and it is possible the optimal location in complete system. And also I want to mention it may not be possible that only 1 device is sufficient for whole system whole large system. So, what you have to do? You have to go for multiple facts controllers again you can it is not that only 1 controller at 2 locations. Means SVC etc means you can go for combination of several devices to again to improve your dynamic performance of the system.

Dynamic performance includes your stability and as well as the static performance that how we can control the power in efficient and reliable manner. So, in this lecture I am going to show you 1 facts controller that is static var compensator. That is a very popular and it is a basically working in more than 400 locations in whole world system and this is us this is a sun device. And just I want to locate first this for the voltage stability enhancement then to achieve the maximum enhancement in the voltage stability margin for the system. In that case means base case and under the critical contingency just we will see how much maximum enhancement is possible after locating at that bus. Then to obtain the simultaneous enhancement in static and the dynamic again the dynamic stability is nothing but it is a oscillatory voltage stability margin under the contingency cases.

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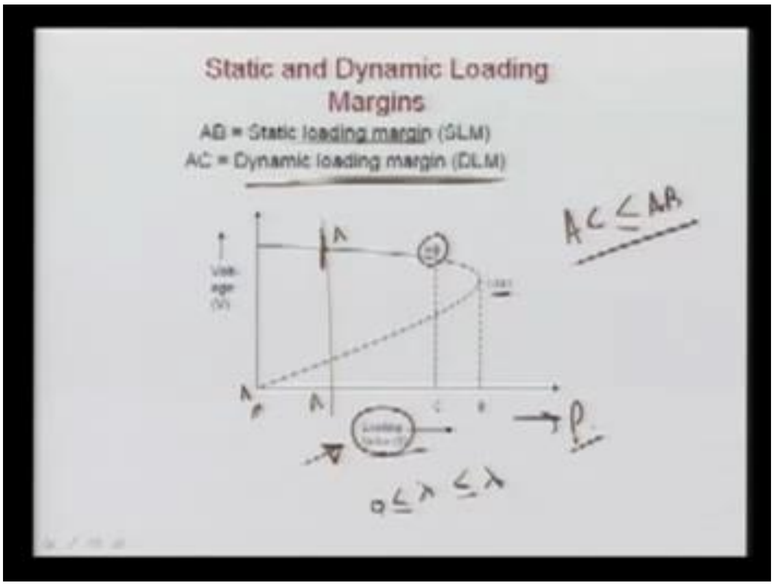

So, here again you can see this saddle node bifurcation here and if your system is loaded at this point you are operating here at a. Then this margin here this is a. So, your ab is your static loading margin this is the P and this is your voltage and your ac is your dynamic loading margin. So, always this ac is either less than or equal to ab this is true. Sometimes this hopf bifurcation may occur near to the saddle node bifurcation point. So, then your ac will becomes your AB. But normally this hopf bifurcation HB occurs much before than saddle node bifurcation and then we have the less loading. So, the dynamic loading margin is lesser than your static mar margin loading here it is a loading factor.

So, real power you got increasing or you can see if you are using a loading factor then you have to start from here if you are loading the P because earlier you are loaded something and then you are loading here. So, if your access is loading factor, because this loading factor here it is going from 0 to some critical value. So, if loading is ze fact that is 0 means you are operating here at a base case. So, your a will be here and your this will be ab is this 1 saddle node bifurcation this margin you are having. But if you are using access at P that is a P load then here you are operating here at certain load then this difference is your margin. So, you have to be very careful what is your access whether it is a loading factor or the here load.

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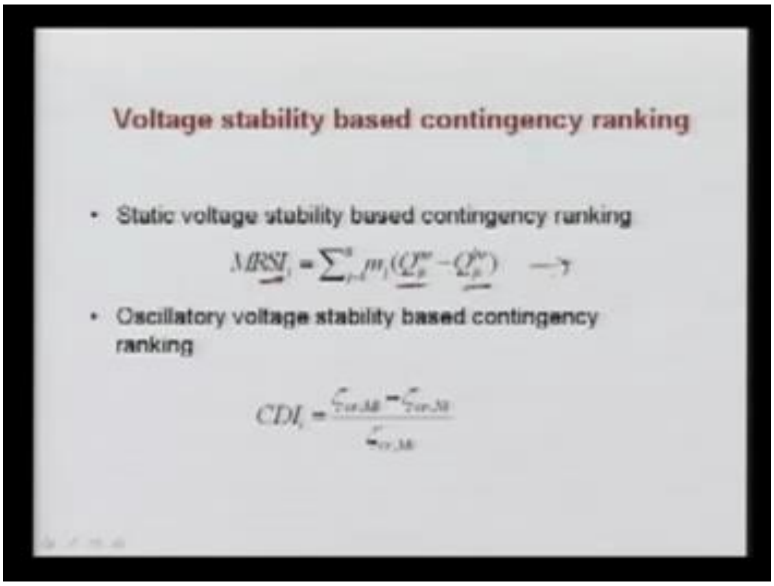

Now, this voltage stability based contingency ranking. The voltage stability based contingency ranking means what we have to do in the power system? We have to rank the contingencies again I have discussed about the power systems security aspect where normally we rank the contingency according to the severity. In the power system there may be the thousands number of branches contingencies. So, it is not possible that we can go for all the contingencies. So, what we do? We go for some analysis some sort of that we can rank and the only we have to consider the critical and most probable contingency for looking at your solution methods. So, the voltage stability based contingency ranking here has been defined that is some index has been defined that is a modified reactive power stability index security index basically. And that is a basically in terms of the reactive power with the no outage with the branch outage with the some factor and then it can used.

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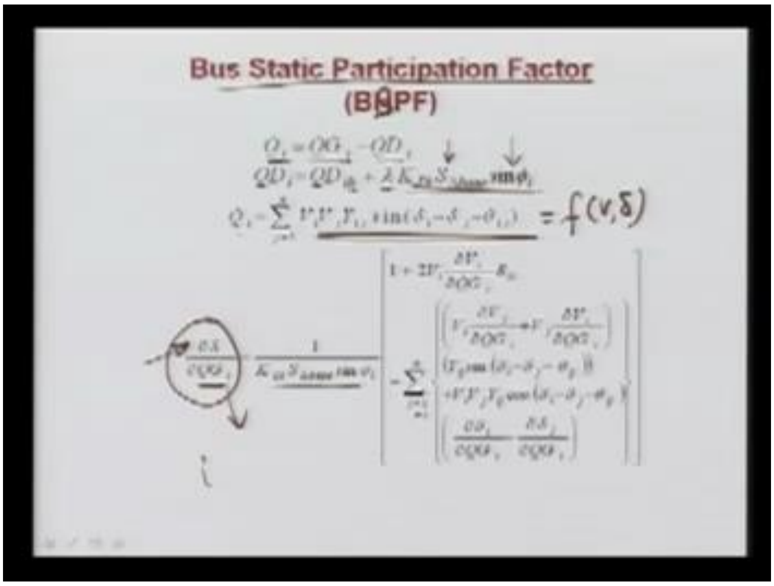

So, to locate what we can do? We can go for this bus static participation factor and that is your BSPF. Now, here you can see what we are doing this reactive power injection at any bus qi here that will be equal to the reactive power generation at that bus minus the reactive power demand at that bus. This reactive power demand can be written as the reactive plane power demand at that bus in the base case plus here the lambda that is the loading factor if lambda is 0 then we are having the base case starting point. And here we are had some factor that is how much here your changing this base you are doing and this power factor you are changing. Means you can have some power factor change as well of that real power loading. So, this is a kdi some factor we are adding and this qi is no doubt here we can write this qi is a function of your voltage and the delta. Now, if you are simplify this here if you are putting qdi here and a qi here lambda you are getting a function of a lambda as well. And then if you are differentiating change in the lambda with the qgi here what you are going to get?

Here this qgi will come here and this whole value will be coming here and you will get 1 complete here. This be scalar term here 1 plus 2 vi change in the vi upon del qgi bii means we have taken 1 factor here and that remaining we are writing here. , this factor is 1 factor based on that we can say at any particular ith bus if you are changing the reactive power generation how much you are changing the loading of the system? If this factor is the highest we have to calculate this loading factor for all the buses. And then we can get if it is the highest one then that location will give your bus static participation factor means this value if highest. Then we have to locate that ith where it is highest and then that is your suitable location for the shunt device. And that is your static var compensator here we have used, but you can also use your stat com as well.

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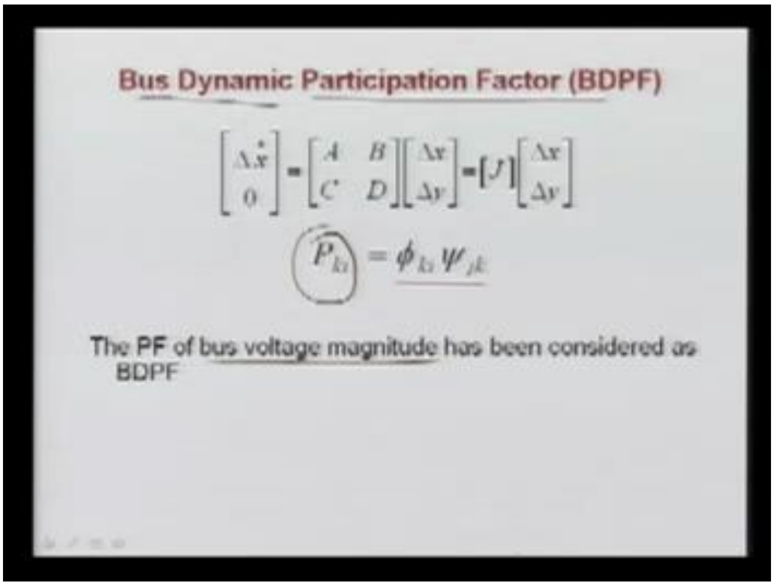

Again for the dynamic what we can use? We can use this bus here participation factor for the bus voltage magnitude can be considered and this is called your bus dynamic participation factor. Here we have to use if you are using the dynamic means you are using the dynamic equation. And then participation factor can be defined again as the left and right Eigen vector multiplication.

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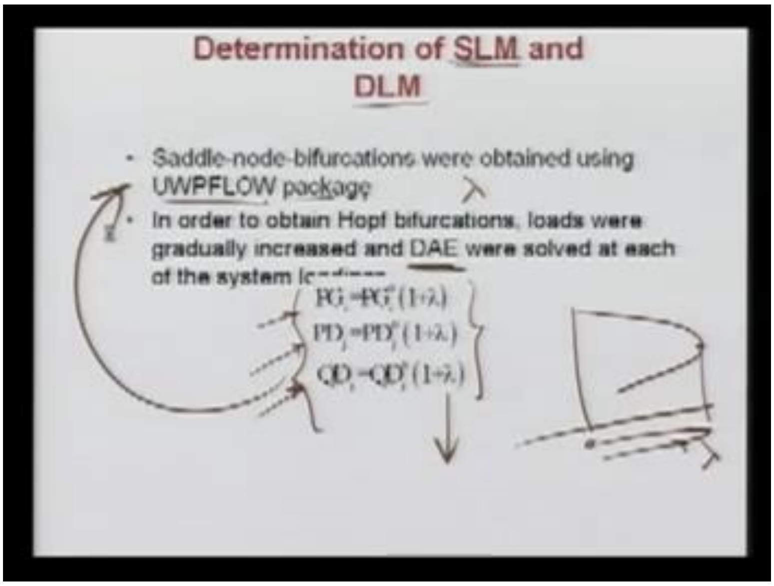

So, based on this what we can do? We can go ahead here and we can determine your static load margin and your dynamic load margin. To determine this static load margin as I said we can use this 1 package that is a university of water loop power flow tsi U W P flow that is a university U W for the water loop P for this power flow power and flow package that is free of charge and that can be downloadable and based on that and it is as you know it is working on the continuation power flow method. So, you can here by changing the load parameter you can get your complete saddle node bifurcation and then you can get the margin from starting let us suppose your lambda is changing here.

So, from here to this point you can get how much this loading? Means you will get directly this loading factor and you can say you have this margin in the system. So, the saddle node bifurcations where obtained using that I guess in order to obtain the hopf bifurcation again it is a dynamic load margin just we are going to determine. The loads where gradually increased means load we keep on increasing and the differential algebraic equations where solved at each system loading. And here this is the change in your power generation change in the demand and change in reactive power for the change in the loading factor and this where used for here as well.

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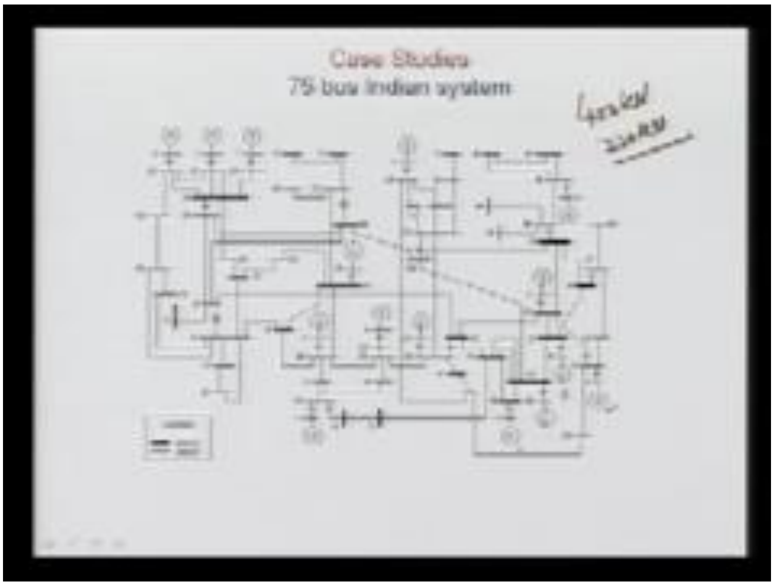

So, this whole concept just we have applied for 75 bus Indian system here thus it is a ups CV system just we have considered. This area is your here this is your obera here it is nepera singrauli rihan and here is the punky side this is punky NTPC punky here. So, this is complete 75 bus we have only considered 400 kb system and 220 kb system again this data is old, but in kV more lines are added here together. So, it is a comprising of 100 transmission lines 114 and then 75 bus and we are having 15 generators for this case what we have done? We have located where we can put the SVC.

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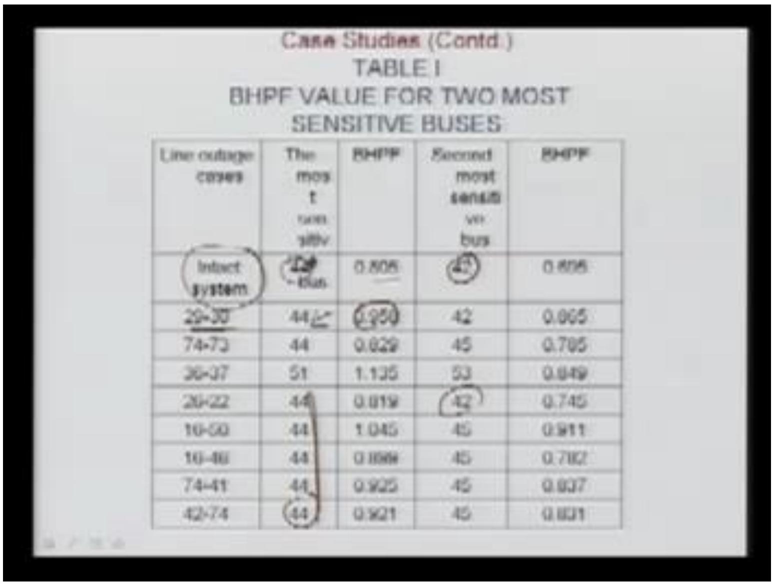

Case Studies (Contd.)

TABLE I

BHPF VALUE FOR TWO MOST SENSITIVE BUSES

Line outage cases	The most sensitive bus	BHPF	Second most sensitive bus	BHPF
Intact system	[illegible]	0.808	45	0.808
29-30	44	0.950	42	0.865
74-73	44	0.829	45	0.785
36-37	51	1.135	53	0.849
20-22	44	0.819	42	0.745
16-50	44	1.045	45	0.911
16-46	44	[illegible]	45	0.782
74-41	44	0.925	45	0.837
42-74	44	0.921	45	0.831

So, the case in that this we have used this bus orbit participation factor value for the 2 most sensitive buses. And here just for the intact case means for the base case we found that most sensitive is 44. And the index we found here this; however, for the contingency means outage are 29 to 30 this is the luck now to 1 line here you can see this 29 here. This 29 is somewhere in this zone and it is here the 29 is here and the 30 is here. This line is basically a transformer if this transformer trips then in that case it is found that this value is this one and the most sensitive bus is 44. So, you can see here and second 1 is your 44. So, keep on doing the 44 42 44 42 44 54. So, and also here you can say 44 and we are getting 42. So, the most sensitive bus seems out to be 44 and then we have decided that we can put the SVC that is static var compensator at bus number 44. And this 44 is nothing but you can say where is 44? 44 is this bus (refer time; 24:06)) this is there is one generation here and this generation is your nothing but I think ((refer time; 24:12)) power station.

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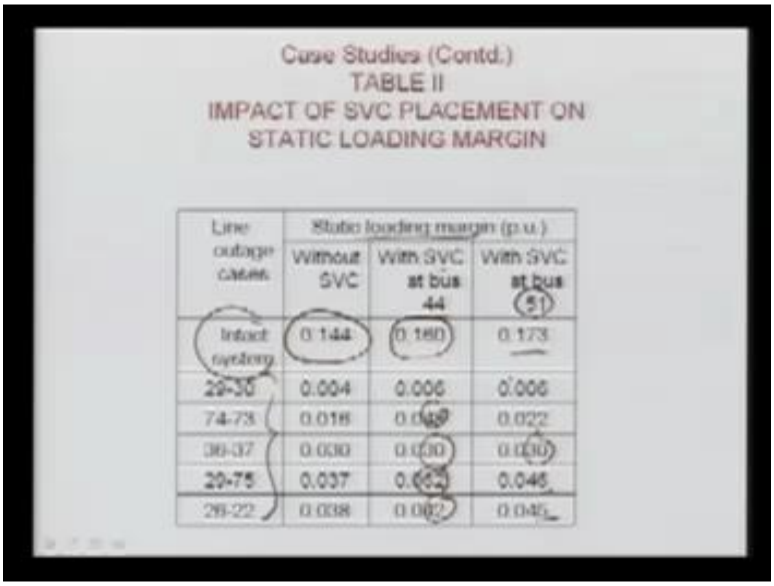

So, after putting at the 44 now, you can see how much is static loading margin that has been obtained. So, we can see the impact of SVC placement on the static loading margin that is a static loading here for the intact case means base case that no contingency no outage. So, without SVC the static load margin is only 0.144 per unit per unit again here is a 100 mbps. If you are with SVC at the 44 we are able to go for 1.60 and if you are putting at the 51 here we are getting 173 although our sensitive case you can see here we are getting 44 and the 51. But the 51 is giving more because here you can say this value is more compare to the other value. So, in this case it is more. So, the 51 is giving the most highest than followed by 44 and we found that putting at the 51 we are getting more and outage of the various cases we have done here. And you can see for the various outage here we are getting the different values. Here for this outage we are getting 30 here 30 here it is 62 here it is less here its 42 it is more here 4 eight it is only 22 here 6. So, it is basically the most locations as I said it is not possible that only 1 static var compensator is sufficient for whole class system it may be the 2. So, we can go for 44 and the 51, but this sensitivity approach is giving idea that these are the buses probable location and then you can again go for the actual analysis by putting that SVC.

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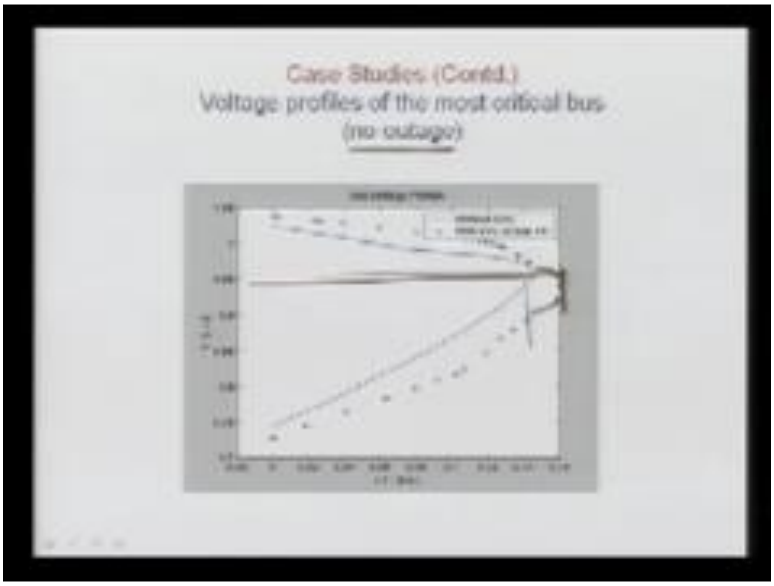

You will see this voltage profile of the most critical bus here and then what we are going it is a no outage means it is a base case. So, you can say without SVC it is your this blue line and with SVC at 44 this is here. So, you can see the loading factor is increased here up to this point and also here the voltage is improved. Here the voltage is improved this operating voltage is this much operating. So, here voltage is also improved as well as we are improving the margin as well.

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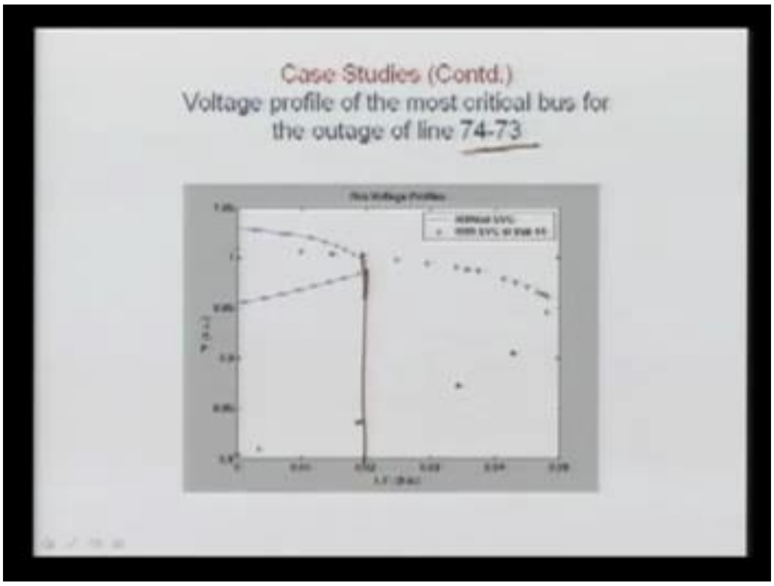

Now, let us see for outage of line 74 4 to 73 and this 74 is very big line. This is a Kanpur ntpc to I thing Kanpur ntpc here to this line you can see from this figure here this is a 74 and your 73 is here is near to Agra. So, outage of this line is very critical and here it will out this line now you can see how much change? Here without SVC this margin is up to here 0.02, but if you are doing this you have increased up to 0.05 and how about the voltage improvement you can say there is no big voltage improvement at this line voltage even though lesser, but we have increased the margin.

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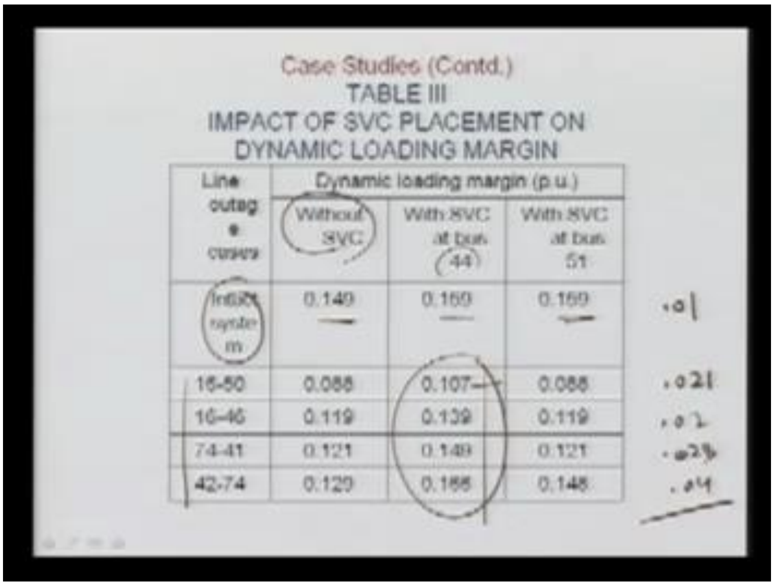
Case Studies (Contd.)
TABLE III
IMPACT OF SVC PLACEMENT ON DYNAMIC LOADING MARGIN

Line outage cases	Dynamic loading margin (p.u.)		
	Without SVC	With SVC at bus 44	With SVC at bus 51
Intact system	0.149	0.169	0.169
16-50	0.088	0.107	0.088
16-46	0.119	0.139	0.119
74-41	0.121	0.149	0.121
42-74	0.129	0.166	0.148

Now, to see the impact of SVC placement on the dynamic loading we have again then for this various contingency cases here and the intact system that is a base case. Without loading here you can say our this margin is 0.149. And here with the SVC at 44 we are getting 0.159. However, at 51 there is no increase and both are getting same. But for the outage here you can say for the various cases this value is higher than this and then we can say the 44 with the best location for the placement and also we have increased we are getting more loading. However, you can see in this case? The loading margin is not so, substantial means you can say here the difference is nothing but 0.01 from here to here I am just calculating. Here it is nothing but 0.021 here you can say if you are going for 0.02 in this case you are going to 0.0028 and in this case you are getting 0.04 So, in total it is hundred for unit base if multiplied by 100. So, maximum we are getting 4 megawatt why it is so? Because this system is highly loaded system and we have very less margin it is very critical system so, that loading is not increased much. But still we are improving in terms of your dynamic as well as the static margin here you can say.

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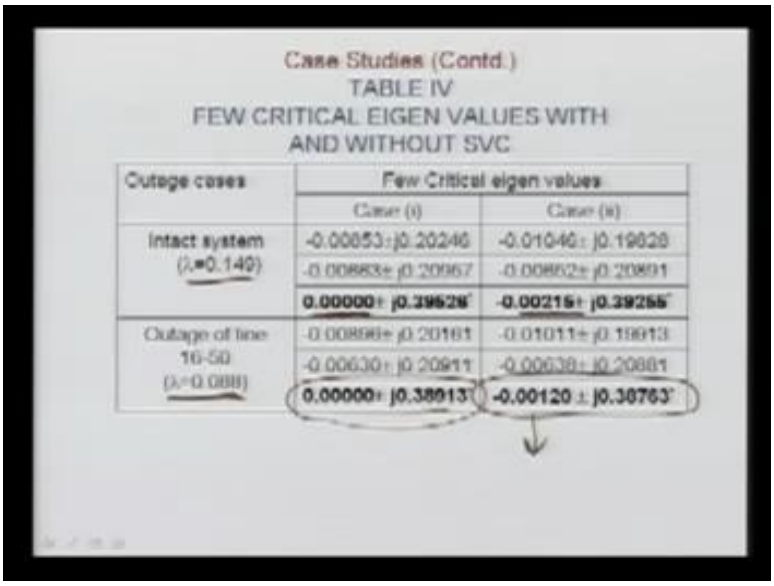

Few critical Eigen values you can see for the intact system when the loading was this you can see this value becomes this hopf bifurcation this becomes 0. However if you are putting in the case 2 where you are putting this value we are getting this 1.01. So, you can see here with and without here means this is without and this is with. Now, the hopf bifurcation is improved means we are hopf bifurcation there is no hopf bifurcation at all for this intact case anywhere. For the outage of this line again at this loading we found that this high bifurcation is occurring. But at this loading we have we can say avoided hopf bifurcation and this value is not 0. So, we can say that is the dynamic as well as the static voltage instability are improved with the help of facts controller ((refer time; 29:53)). So, here we saw that with the help of SVC this hopf bifurcation point is removed eliminated. And we at this loading there is no hopf bifurcation at all and we can say we have improved the dynamic stability.

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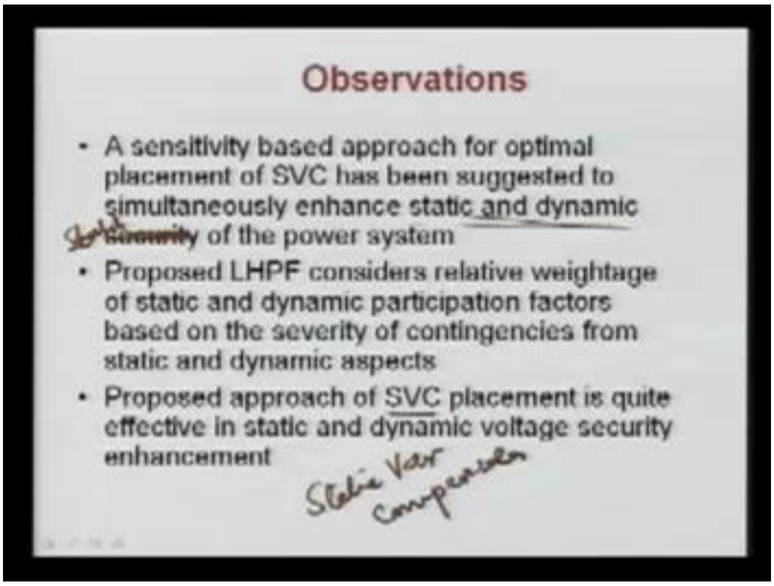

So, we made the following observation with the help of placement for this SVC. A sensitivity based approach for optimal placement of SVC has been suggested to simultaneously enhance the static and dynamic stability of the system. Here it is not the security here we are talking about the stability of the system. The proposed this hybrid participation factors consider the relative weight age of static and the dynamic participation factors based on the severity of contingency from static and dynamic aspect. What is happened? There is a possibility if you are considering k1 is only static criteria your location will be the different. If you are considering the dynamic then your location will be the different. To have one common location for both static and the dynamic stability improvement we can have some hybrid and with the help of some weight factors for the static and the dynamic participation factors has been suggested and it is again for the base case as well as some contingency cases.

Because in the base case there is a possibility that your system is you are locating something in different location. However, for the contingency cases the location optimal location may be different. So, you have to again compromise and for all the systems scenario you have to choose a suitable location. So, that that can give you a maximum benefit and you can achieve from that location. So, the proposed approach for static var compensator placement is quite effective in static and the dynamic voltage security enhancement just we saw the facts controller the series here it is not series it is shunt means that SVC static var compensator. So, this SVC is called your static var compensator. Basically it is we are changing the impedance and is a shunt device compensator another shunt device that is very popularly nowadays people are discussing about that is stat com.

Stat com is a function while it is a similar to static var compensator or SVC. But the stat com are better they give better performance than SVC at the several regions several locations they are very important, but the stat com are very expensive than your SVC. So, in our Indian system even in our ups system we have one static var compensator that is near to a shaakrpur station that is a power grid station. And that is having rating plus minus 2 at means we are having 2 units or plus minus 1 ((refer time; 33:00)) and that is improving your system no doubt very well. Now, one is this from very beginning just we studied the various stability that is a transient stability the small single stability. And also we discuss about how we can improve those stabilities.

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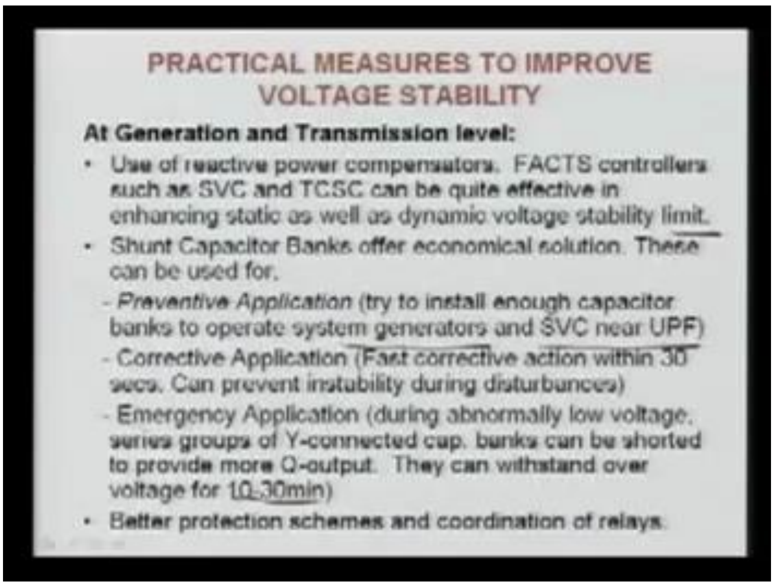

Now, here also just I am going to discuss the practical measures to improve the voltage stability. Again we can improve this voltage stability again we can divide in to the 2 locations. Once just I want to see that if you can do something at the generation and the transmission levels another is at your distinction level. So, here I am talking about the first generation and the transmission levels. The use of reactive power compensators as you know the voltage is directly related with the reactive power. So, you have to do if your system is requiring reactive power support you must provide the reactive power support to improve the voltage and therefore, the voltage stability of the system. So, the reactive power compensator is must and the facts controllers such as SVC, stat com and sometimes the tcsc although it is a series device it can be quite effective in enhancing static as well as dynamic voltage stability limits of the system.

So, in the transmission lines you can use facts controllers and also at the generation level you can generate more reactive power if your system is reactive. Means sometime sometimes there is a possibility that your system is having huge reactive power means your especially that occurs when the loading of the system is less. In that case you have to have reactors and those reactors must observe the reactive power during half peak loads, because there excessive reactive power charging of the transmission lines with reactive power. And generators are also allowed to observe the reactive power. So, that we can have the healthy system, but in most of the cases when the system is peak loaded on most of the time we require the reactive power support. So, the generators must provide the reactive power support as well as we have to use the various capacitor banks facts controllers if they are there again to improve the voltage stability of the system.

Shunt capacitors offers economical solution and these can be used for the preventive application try to install enough capacitor banks to operate system. To operate system generators and SVC near unity power factors what we do this? Again there is a 2 types of applications 1 is the preventive application another is your corrective applications. So, we can use the capacitor banks again for ESV transmission lines for 400 for using the capacitors very expensive. So, we can go for the lower voltage and we can improve that especially in here to the load we can put 132 or we can go for the 33 kV bus. We can put the capacitor bunk banks and again we are putting the shunt capacitor we know the shunt capacitor provide more reactive power support than your series capacitor if you are putting in the line.

So, in preventive application try to install the enough capacitor banks to operate system generators and the SVC near to the unity power factor. If they are operating near to the unity power factor they will enhance the system voltage and stability very much. The corrective application includes the fast corrective action within 30 seconds and can prevent instability during the disturbances. If you are having fast corrective action and that you can take action in the les than 30 second then there is the possibility during the disturbances you can prevent the instability. Means you can prevent the cascade tripping of the system and therefore, you can prevent the instability during the disturbances. So, that is called the corrective action in the preventive already put the enough capacitors. So, that your generators and the svc's are operating near to the unity power factor. So, that whenever there will be disturbance they will have the more margin and they can take care of the disturbances. So, that is the preventive. In corrective you have to use the z value of capacitors.

So, that you can improve your stability you can minimize the instability of the system during the disturbances. Another application is the emergency application during abnormally low voltage means sometimes there is a voltage system is stable, but it is operating very close to the low voltage limit. So, we can use this series groups of y connected capacitor banks can be sorted to provide more q output and they can withstand over voltage for 10 to 30 minutes. So, we can use some groups of y connected that is star connected capacitor banks they can provide more reactive power supports and then we can avoid the emergency situation. So, we require the better protection scheme as well and also the coordination of relays. As you know if there is a due to the low voltage profile if 1 line or 1 generator is tripped then there may be the cascade tripping there is a voltage will keep on going down. And there will be cascade tripping and then the whole system may be in the collapse. Or so, the better protective esteems and the coordination of relays are also very important for improving the voltage stability of the system.

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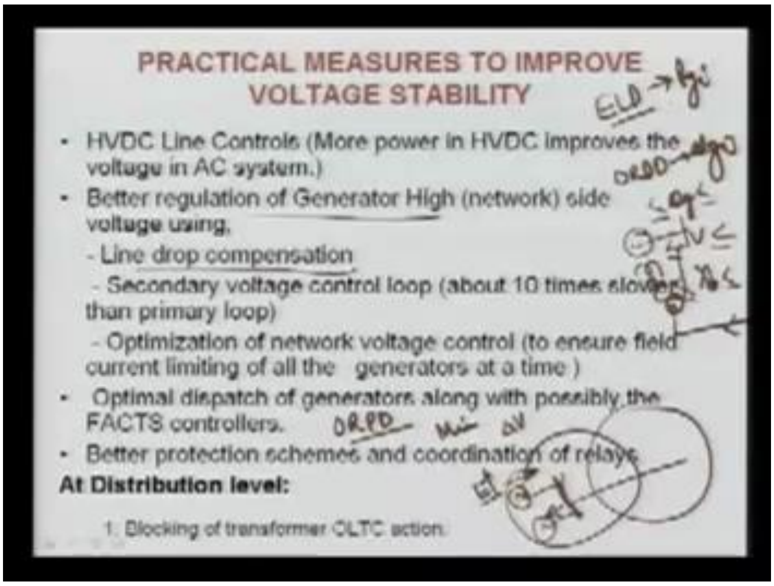

Now, HVDC line controls. If your system is having hvdc lines as you know in our up we have 1 HVDC big HVDC line carrying more than 1500 mega watt power and that is from rigan to dadri it is a plus minus 500 KV that is a bi pole operation. So, if you can control that power as you know we can main advantage of HVDC that we can control power very efficiently. So, we can more power in hvdc improves the voltage in ac system if you are dragging more power over the dc line your ac system will be relieved and you can load more and you can have more stability margin. So, loading or you can say controlling the hvdc we can loading more hvdc line we can improve the voltage stability of the system, but again if your hvdc line is loaded to its rating limit.

So, again you do not have margin better regulation of generator high side voltage using line drop line drop compensation secondary voltage control loop about 10 times lower than the primary control loops. Optimization of network voltage control to ensure fill current limiting of all the generator at a time optimal dispatch of generator along with the possibility of the facts controllers and the better schemes and the coordination of relay already had discussed there. So, here what we can use the various other that is a we can use the regulation better regulation of generators. Especially this network side high voltage side we can use the line drop compensator that is 1 signal. That is used in the exciter that is coming we can control the bus voltage are very far from generator. We can take that signal and then we can set the excitation in such a way that we can improve the voltage of that bus that is called line drop compensation.

So, I explained the line drop compensation means you can control the voltage some where far from generating station. Normally what happens? If your generator is here this generator just it feed here the excitation and that excitation here the fill that is we are get that is from your terminal voltage here and we feed here we can control the terminal voltage. So, the exciter is use to control the terminal voltage of this generator. But at the same time what we can do? We can use another signal here that is we can add and that signal comes from anywhere in the system and that is called your line drop compensation. Secondary bulk voltage control about the 10 times lower than the primary, because this is your primary control we can also use the secondary voltage control to improve the voltage of the system.

And therefore, we can improve the voltage stability of the system. Another is the optimization of network voltage control to ensure the fill current limit current limiting of all the generator at a time. You know, because if you can increase the excitation you can increase more reactive power by increasing the field current. But we have already I have discussed the limiting or you can say copulating curve of alternatives that we had this field heating limit. If you are current is hitting that machine value we cannot operate more than more field current. Because it may damage the field binding, because it will not be dissipated and that may damage your field binding. So, it is called your current limiting that is a field current limit.

So, what we can do? We can have a complete coordination of all the generators it is not that 1 generator we are keep on increasing the excitation and other generators we are not changing what will happen? For example I can tell you lets suppose here 1 here 1 generator is there and we have another generator here and thus this is a complete system though that connected. If you are keep on increasing the field of this here e this terminal voltage suppose you are increasing what will happen? It will try to generate more reactive power, but this voltage if it is not increased there is a possibility or if it is increased slightly it may consume the reactive power here. So, we have to go for and it may limit even though your current and the field current. So, we have to go for the coordination of all the generator. So, that we can ensure the field current limiting of all the generators at a time and we can get the maximum benefit we can get the maximum network voltage control with that one.

So, that we require a optimization problem and we can solve it and then we can improve the voltage stability of the system. Because we will have more reactive power margin and whenever it is required we can supply during the disturbances cases. Another is to improve the voltage stability is the optimal dispatch of generators along with the possibly fact controllers. Now, optimal dispatch of generators one is that optimal dispatch again optimal dispatch can be delineated into 2 type; One is your economic dispatch that is real power dispatch and another is your reactive power dispatch.

So, in the real power dispatch that we can minimize the total cost normally we go for the dispatching so that we can have the minimum cost of generation of electricity. However this reactive power here it is related with the real power of generators up to some extent as already we have seen that the real and reactive power relation of the alternators with this capability curve. So, we can generate the reactive power of the system of the generators as well as other devices in the system. Means we have the capacitors we are having a static var compensator or we are having other facts controllers then we have optimal dispatch of these reactive power sources to improve the performance of system so that we can have more voltage stability margin. So, if you are going for that no doubt we can improve the voltage stability margin by optimal dispatching of generator and this is called optimal reactive power dispatch orpd problem where we minimize again the minimization may be any objective minimization is you can say change in the voltage deviation. Minimization may be you are change in minimization of the loss subjected to the various constraints. Those constraints are your real power limits again we are not touching the real power limit.

Because this economic dispatch that is a called eld economic load dispatch is we are here stating the real power generation output; however, orpd we are setting the reactive power generation of the generator. So, here your objective is the minimum cost of the operation here objective is the different that we are change in the voltage deviation or we are minimizing the loss subjected to the various constraints. And those constraints are nothing but here the constraints are your reactive power limits of the generators voltage limits and also other. Let us suppose facts controller parameters there then we can have the limit and then we can obtain the optimal dispatch. And then by that we can have more voltage stability margin and we can improve the voltage stability of the system. So, this is one of the very good criteria that by that we can achieve that. At the distribution level what we can do? The, we have seen this reverse action of the transformers that oltc action means whenever there is a problem, because as I said if you are changing the voltage from one level to another level there is a possibility that you can land up with the unstable case.

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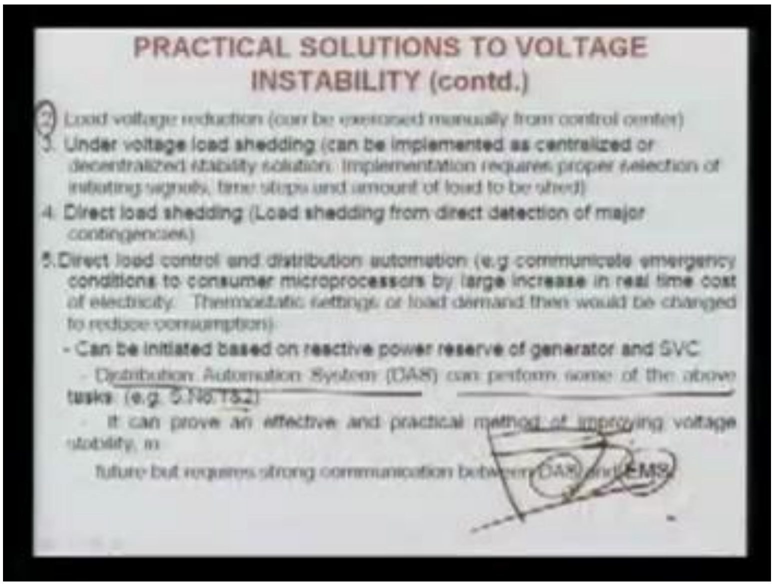

To see this here what I can explain you? Let us suppose here this pv curve this is your pv curve at 1 typing at another typing you are having another curve here like this. Here if you are operating somewhere and you are… you have change the voltage suddenly here let us suppose you are operating here. And you are change from your typing here from 1 to this point to this what happens? You are learning here in this negative zone and your system will be unstable. So, you have to block the oltc action in very severe cases especially when it is going to act as a reverse direction. Means when you are trying to increase the voltage it is reducing the voltage and then it is landing in the unstable part of your PV curve. So, you can block that OLTC especially during the emergency cases. Now, load voltage reduction can be exercise manually from the control centers. Now, this load voltage reduction means you can if your voltage is reduced at the load buses you can again you can reduce the load of the system and that can be exercise manually from the control center.

So, what you can do? You can reduce the loading of the system then you can increase the voltage and then your system will be more healthy more voltage instability it will be means you can improve the voltage stability of the system. Under the voltage load shedding scheme as you know there is a 2 types of load shedding schemes are there. 1 is the load frequency control where that is a if frequency falls down normally we try to set down the loads few loads. So, that we can improve the stability we can improve the frequency of the system and that is we are talking about the transient stability. Similar fashion we can if the, we can have the relays that if the voltage is load low and it can set the load then we can again improve the voltage stability margin. So, under voltage load shedding can be implemented as a centralized or decentralized stability solution implementation requires proper selection of initiating signals time steps and amount of load to be shed. So, the how much time of load this? How much load you are going to set? How much time you are requiring for the shedding this?

So, that based on that again you can improve the voltage instability means you can improve the voltage stability margin here as well. So, this is basically a corrective action approach when you are just leading to that margin you are very close to that voltage instability margin then you can take this action. Another is direct load shedding the load shedding from the direct detection of the measure contingencies. Means suppose there is a 1 contingency has occurred that may lead to a severe voltage problems in that system. So, with that contingency if have any sensing mechanics and then based on that you can directly trips you of the loads. You can trip it out then what will happen? It will try to improve the voltage profile ad therefore, you can have more voltage stability margin and you can have the improved voltage instability system. Direct load control and the distribution automation that is a da is the communicate emergency condition to consumers, micro processors by large increase in real time cost of the electricity. Thermal static settings or the load demand then would be changed to reduce the consumption.

Because here again this voltage stability can also be improved either from the generation end transmission end and also it is possible from the distribution end. So, the in the generation end already I discussed that we can improve the reactive power settings. We can opt we can use the optimal setting of the reactive power outputs of generators along with the facts controllers. Also we put some static var compensators or facts controller in the transmission system that will improve your voltage stability margin. But in the distribution side always it is you have to play with the loads as well as the transformer that is a OLTC. So, the direct load control or you can have the distribution automation system that automation is you will having some RTU remote terminal units. And they will sense the system voltage etc they will give the information to da system and that da system will decide how much load which are the loads are to be shed and then we can improve a voltage instability of the system.

And can be initiated based on the reactive power results of generators and SVC that da system that is a distribution automation thus normally we call can perform some of the above task that is the serial number 1 and 2. 1 and 2 1 that was as I said it is a oltc here it was this here the blocking of the transformer oltc action and that is always we are talking about the reverse action. Second one is this means load voltage reduction scheme that can be d1 this da system can also prove an effective. And the practical method for improving the voltage stability in future, but requires strong communication between the da and EMS. Here it is not only the distribution automation system, but also the EMGR energy management system both must be coordinated, because it is a coordinated system means how much load it to be set and again how much generation you are having.

So, all these must be coordinated so, that we can have efficient and reliable and more improved voltage stable system. So, with this we can now, say with the various preventive and corrective actions and we can improve the voltage stability of the system. In this lecture we saw the various dynamic as well as the static voltage stability criteria's and we saw the bifurcation for the dynamic and the static that is a saddle node bifurcation. Also I showed you 1 example where for a practical system where we put the SVC and that enhance the static as well as the dynamic stability voltage stability margins. And here also I discussed the various practical solution to the voltage instability problem. So, this lecture basically concludes your whole this module 2 and this now, I can recap what we have done from very beginning in this module.

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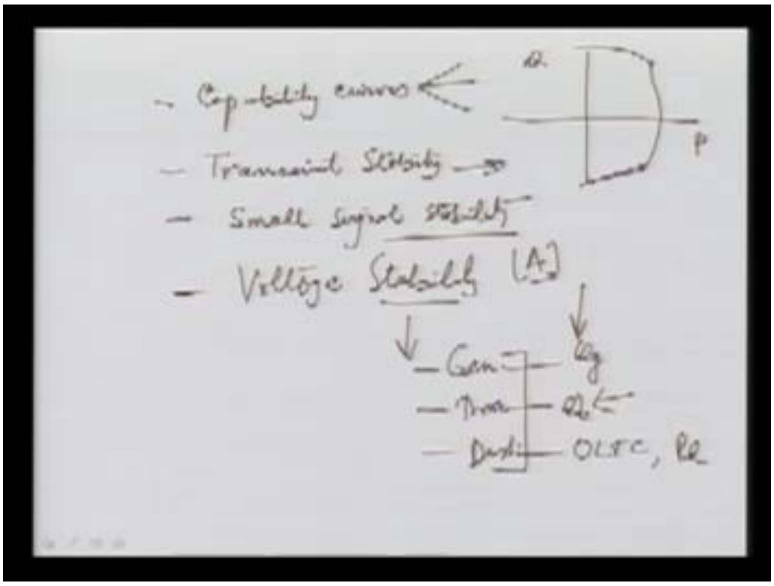

First we discuss the capability curve of generators this is a capability curve. In that we saw the various limiting of an alternator that is your field heating limits the various 3 heating limits I derived and if you remember here I draw here this is your P here this is q. So, this is your field heating limit then we have the armature heating limit and the finally, here it is your end heating limit. So, this is your capability curve of alternator I explained I derived and then I explain in the detail. Second then I use the modeling of alternators for purpose of a transient stability that is a transient stability we describe this string equation also I described the equal area criteria for the single machine in finite bus system. I also give some solution of course, numerical algorithm to solve the multi machine power system how we can solve? And that is more important that also I described that how we can improve the transient stability of the system?

The transient stability is related with this sudden and the severe disturbance and then we again we saw the various approaches. And then I am varying nicely I explained that the transient stability using the equal area criteria. Then we went for the multi machine system and again for the improving the transient stability of the system. Then I explained this here is small signal is stability small signal stability. Here in this stability the sudden, but the small disturbance takes place then here in the transient stability we analyze with the non-linear equations differential equation. But here in the small signal stability we can linearize and we linearize the system around the operating point and then we solve and we go for this transition matrix x and we analyze the behavior of the system. We use

Eigen vectors, Eigen values and the participation factors to go for this. And there a small signal stability especially related with the small oscillations in the power system.

So, how we can improve? Already we discussed some of the model analysis we also saw some improvement methods for the small signal stability as well. In this small signal stability we describe that how we can go for the participation factors what are the roles of various Eigen values and then we showed 1 problem as well for the small signal stability. Another which I discussed that is the voltage stability i took almost 3 lectures on that voltage stability and in this voltage stability as it is related with the voltage here term and in this we explained the various static as well as the voltage stability criteria's we also discussed the various bifurcation. I discuss the various methods to analyze the static voltage instability. We discuss your this condition number or you can say singular value decomposition techniques minimum singular value which I said. We also use the saddle node bifurcation approach. I discuss the continuation power flow techniques and also the various l index and various proximity index are used for the voltage static voltage stability checking and the enhancement approaches. The dynamics and dynamic voltage stability I use the again hopf bifurcation is 1 criteria.

And for that hopf bifurcation I have considered only hopf bifurcation and then we saw that how facts controller facts controllers are useful to improve the voltage stability. Again the facts controller are used for both static as well as the dynamic voltage stability limits then I explained how that we can improve the voltage stability limits? Again at the generator level we can do something at transmission level and at here the distribution level that we can from these 3 angles means here we can say at qg's at generation here we can go for the q shows here some capacitor or static var compensator. Here we can go for the oltc and as well as the P demand if can go for. So, these are the various control measures by which we can improve the voltage stability of the system. So, in the total here we discussed starting from the ((refer time; 58:46)) curve modeling of the synchronous machines then we utilize the transient stability. First I use this classical model where we use the then single machine in finite bus. Then I went for the multi machine system then I discuss the various approaches to improve the transient stability. Then I followed the small signal stability and finally, I discuss the voltage instability where various methods we have discussed.