Power System Analysis
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Lecture – 17

Now, on this lecture number 14, which is the last lecture of this module, as well of the module number 2, that is 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 instability, what are the various methods or you can see measures. And along with also one example, with the plus points of static var compensator, how it can improve the dynamic as well as the static voltage instability of the system.

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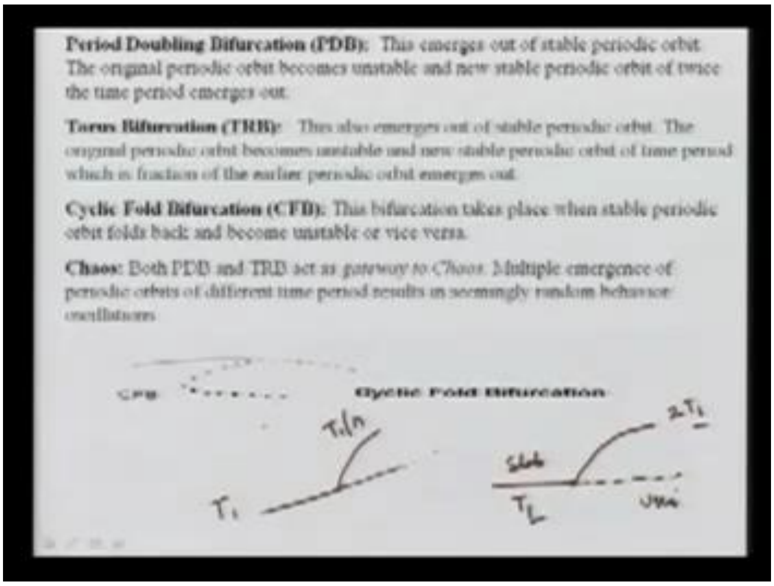

So, other dynamic bifurcations are period doubling bifurcation. It is also called the PDB; this emerges out of stable periodic orbit. The original periodic orbit, becomes unstable and the new stable periodic orbit is are twice time period emerges out. Means for example, if you can see here, if you have something here, this is your coming. This is the stable and from here, this here the period is let us supposed, 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 unstable. So, it is your unstable and it is emerges out another. That is a twice of the period of this T 1 and that is 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 stable periodic orbit. The original period 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 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 a torus bifurcation. The cyclic fold bifurcation, this bifurcation takes place, when 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 going back means, folding, just you can say, here stable now it has become unstable. So, this bifurcation takes place, when a stable periodic orbit folds back and become unstable. So, it is becomes 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 orbit is of the different time periods, results in seemingly random behavior and the 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 a chaos of the system.

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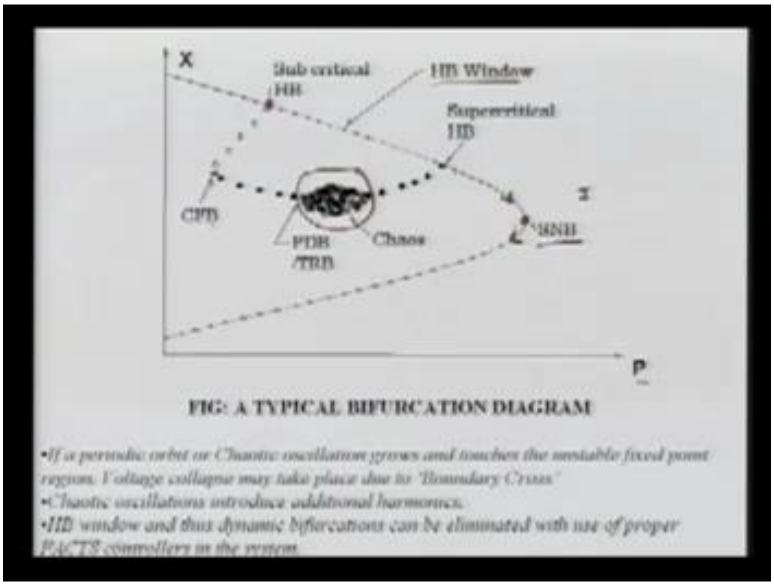

Now, all these dynamic and static bifurcations, which we can see here in one diagram, so this is a typical bifurcation diagram. First, I explain the saddle node bifurcation point, which is here and that I am trying to give you in some play. So, this is your real power, here it is your voltage, that is X factor. 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 ((Refer Time: 04:34)) are 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 become singular. But, here the Jacobian, before this Jacobian is not singular and there is a possibility. That the two 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 explain the two Hopf bifurcation, HB is Hopf bifurcation. One is your sub critical and another is your supercritical and in between it is called your HB window is this one. So, this is your sub critical occurs, before your supercritical. Because, here it is unstable is surrounded by stable point. Here, unstable point is surrounded by stable one. 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 point is called your cyclic fold bifurcation. So, it was unstable and now it is holding back and here it is 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 double 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 on the system. And finally, here you can say, this is your supercritical and point Hopf bifurcation point. So, if a periodic orbit or 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, and then voltage collapse, may take place due to boundary crisis. The chaotic oscillations introduce additional harmonics into the system. That is not desirable. This Hopf bifurcation window and thus bifurcation can be eliminated with the use of 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 compensators, how it can improve your dynamic stability. Here, you can put and this can be, the window can be eliminated and then, we can load your system up to the SNB. That is a singular node bifurcation point.

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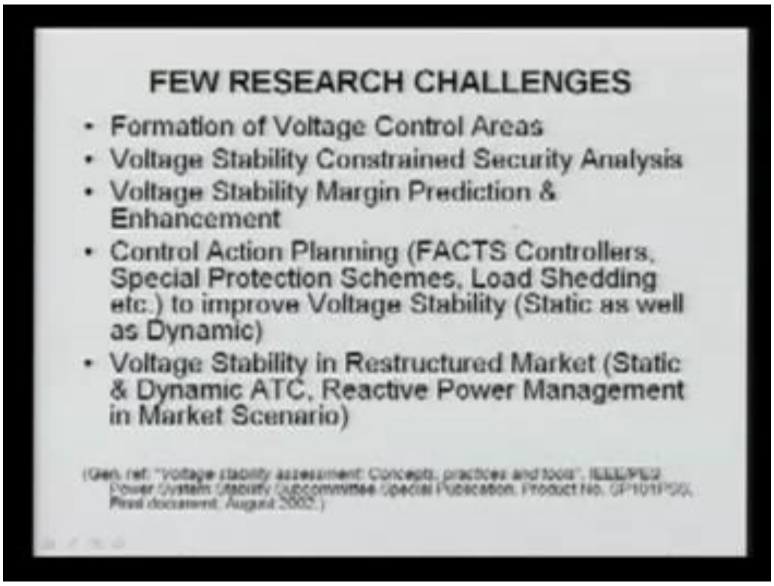

Now, here the lots of people are doing the research in these areas, for the various purposes. First, normally they go for the identification of the weak buses. And therefore, they form the voltage control area. The voltage control area is nothing but, where we want to put the reactive power source minimum. That benefit maximum to the system. So, we form the voltage control areas, means we are putting reactive power source somewhere, that area is benefited much. So, that is called one area.

As you known the reactive power is a local phenomenon. However, the real power injection etcetera is your global phenomena, because if you are injecting real power at one point. It is changing the frequency of whole system. However, if you are changing the reactive power, you are injecting or observing, reactive power, the voltage is change is localized one.

So, the formation of the voltage control area, there are lot of works already exist in the system. But, still some more simple and the relevant 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 constrains and then, we can analyze. Now, if you are the adding voltage stability constraints. If you are adding the dynamic constraints, then your system becomes very, very complex and getting solution is also very, 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 control of that can be used, that we can improve the voltage stability margin as well. So, the control action planning, that is FACTS controller, special protection scheme, load shedding to improve the voltage stability, static as well as the dynamic.

So, lots of works already have been done 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 is any sort of stability in restructured market. Restructured, means the power system deregulation, where the electricity is traded and the electricity prices are changing every interval; Interval may be every half an hour or it may be 1 hour. And it is sold and purchased based on the competitiveness of the biddings of both supplier as well as the consumer side.

So, this who is going to take care of the voltage stability and since, your system is despised, means you are getting information, that how much load you are going to consume and which generator is going to generate how much. And then, whenever there is some contingencies are 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 managements in the market scenario are also very complex and that must be addressed. So, that we can have free and fair electricity market. So, normally, when paper, that is came here, that is a final document. That it is a, I triple E, PS subcommittee and special publication and the product number is SP 101, 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 over view as well as the classification of these area.

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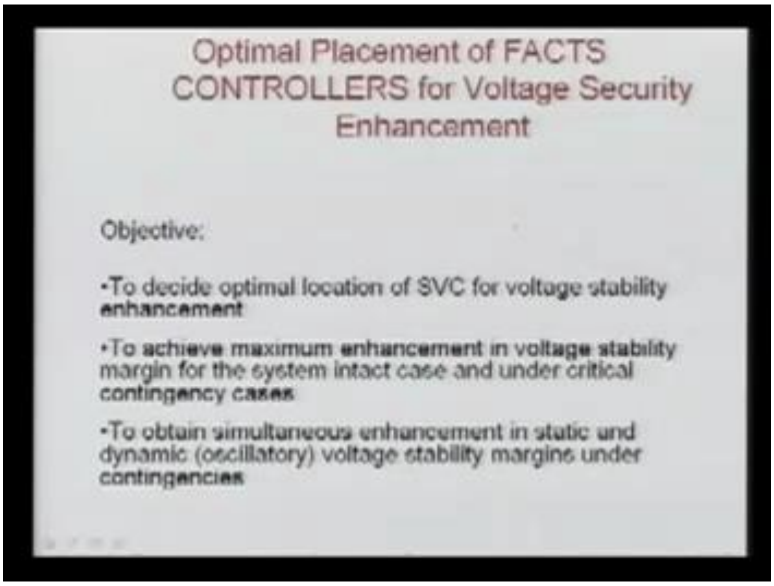

To see this enhancement of these FACTS controllers, for the voltage stability, again just one thing is very, very important for the FACTS controller. These FACTS controllers are not cheap. So, that you can put in each line or you can put at each bus, again this type of FACTS control controller you are going to put. There are two type of FACTS controller, one is shunt and another is your series type FACTS 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 the 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, very extremely high. So, it is not possible to put at each bus and in each line. So, we had to decide the suitable location and if it is possible the optimal location incomplete system.

And also I want to mention, it is may not be possible, that only one device is sufficient for whole system, whole lot system. So, what you have to do, you have to go for multiple FACTS controllers. Again, you can, it is not that it is not only one controller at two locations, means the SBC, SBC etcetera. Means, you can go for combination of several devices. To again, to improve your dynamic performance of the system, damping performance include your stability and as well as the static performance, that how you can control the power in efficient and reliable manner.

So, in this lecture I am going to show you, one FACTS controller, that is static var compensator, that is a very, very popular. And it is a basically working in more than 400 locations in whole world system. And this is a shunt 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, dynamic again the dynamic stability is nothing but it is an oscillatory voltage stability margin, under the contingency cases.

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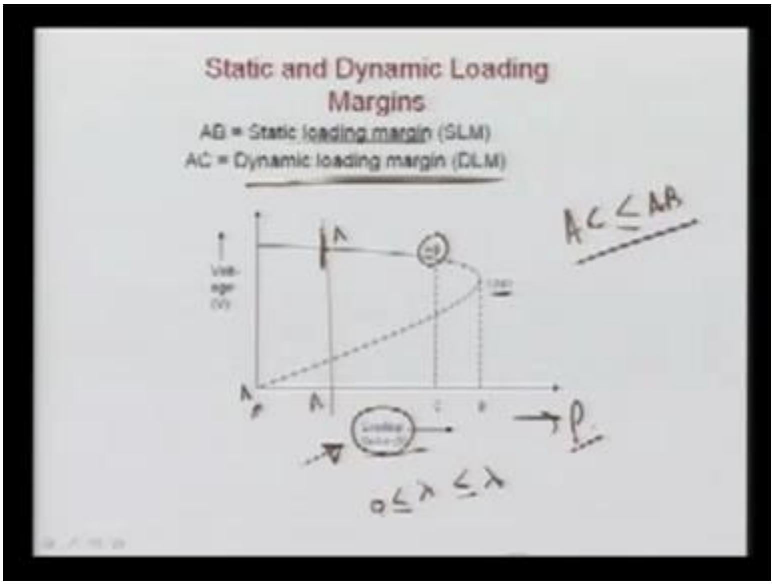

So, here again, you can see this saddle node bifurcation here. And if your system is loaded at this point, you are operating here at A, then this margin here this is an A. So, you’re a B is your static loading margin. This is the P and this is your voltage and your AC is your dynamic loading margin. So, always this A C is either less than or equal to A B, this is true.

Sometimes, this Hopf bifurcation may occurs near to the saddle node bifurcation point. So, that you’re a C will become you’re a B. 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 margin loading. Here, it is a loading factor.

So, real power you got increasing or you can see, if you are using the loading factor, then you have to start from here. If you are loading at the P, because earlier you had 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 factor is 0, means you are operating here at the base scale.

So, your A will be here and this will be A B is this one saddle node bifurcation, this margin you are having. But, if you are using axis 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 axis, whether it is a loading factor or the load.

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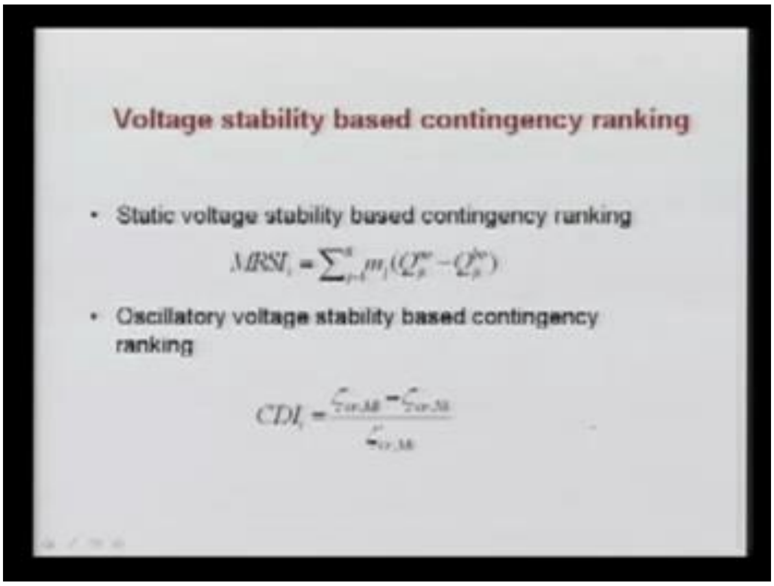

Now, this voltage stability based contingency ranking. Now, voltage stability based contingency ranking, means what we have to do, in the power system. We had to rank the contingencies, again I have discussed about the power system security aspect, where, normally, we rank the contingency according to the severity. In the power system there are may be the 1000’s 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 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 modifier reactive power stability index. Stability index, basically and that is a basically in terms of the reactive power, with the ((Refer Time: 17: 36)) voltage with branch voltage with the some factor,, and then it can be used.

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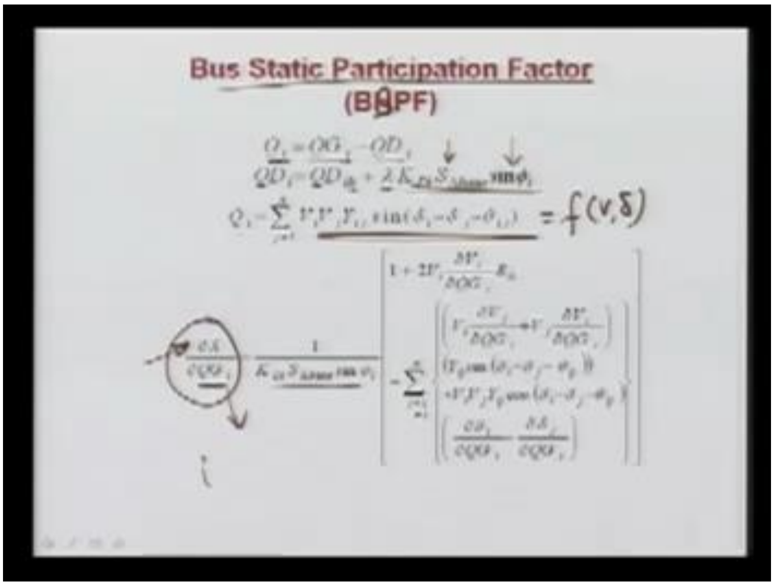

So, to locate this, what we can do, we can go for this bus static participation factor and that is your BSPF. Now, here, you can see what we are doing, this reactive power injection at any bus Q i here. That will be equal to the reactive power generation at that bus, minus the reactive power demand at that bus. This reactive power demand can be retained as the reactive demand at the bus in that 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 have had some factor. That is how much here, you are changing this base, you are doing and this power factor you are changing. Means, you can have some power factor change, as well of the real power loading. So, this is a KDi, some factor, we are adding. And this Q i is no doubt here, we can write this Q i is a function of your voltage and the delta.

Now, if you are simplify this, here if you are putting Q D i here and Q i here. Lambda, you are getting a function of a lambda as well and then, if you are differentiating change in the lambda with the Q G i here. What you are going to get, here this Q G i will coming here and this whole value will be coming here and you will get 1 complete here this is scalar term. Your 1 plus 2 V i changing to V i upon del Q G I, B i i, means you have taken one factor here the remaining we are writing here.

So, this factor is one factor based on that we can send 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 you bus static participation factor. Means, this value if highest, then we have to locate that ith where it is the highest. And then that is your stable location for the shunt device and that is your static var compensator here we have used, but you can also use your STATCOM as well.

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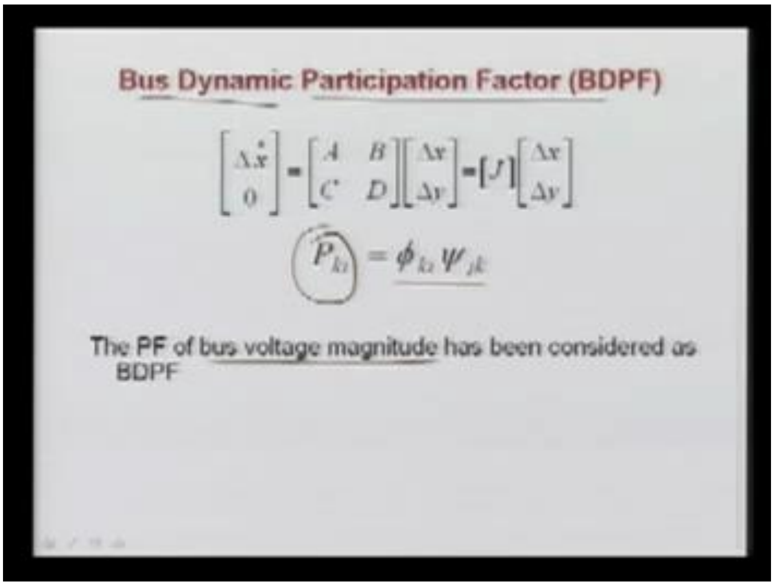

Again, for the dynamic, what we can use, we can use this bus, participation factor for the bus voltage magnitude, can be considered and this is called your bus dynamic participation factor. Here, we have to use, if you are using the dynamic, means you are using the dynamic equation. And then, participation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

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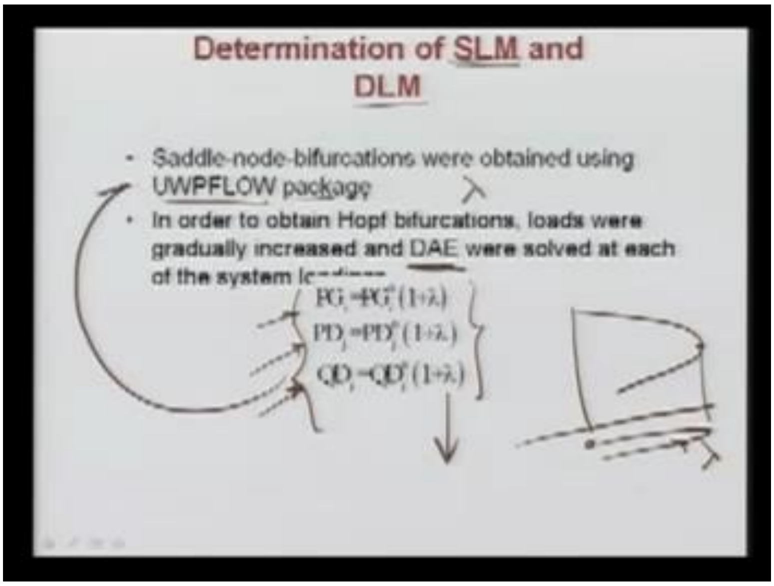

So, based on this, what we can do, we can we can go ahead here and we can determine this, your static load margin and your dynamic load margin. To determine this static load margin, as I said, we can use this one package. That is a university of water loop power flow, the UWP FLOW. That is a university U, W for the water loop, P for this power flow, power and flow package. That is a free of charge and that can be down loadable.

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. And 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 were obtained using that package.

In order to obtain the Hopf bifurcation, again it is a dynamic load margin. Just we are going to determine, the loads were gradually increased, means load we will keep on increasing and the differential algebraic equations, were 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 these were used for here as well.

So, this whole concept, just we have applied for 75 bus Indian systems. Here, this, it is a UPSCB system, this we have considered. This area is you are here, this is your obra, here it is empera, singouli, rehan and here is the panki side, this is a panki, panki NTPC, panki here. So, this is complete 75 buses, we have only considered 400 KV system and 220 KV system. Again, this data is old, but into we are more lines are added here together. So, it is a compressing of 100th transmission lines, 114, and then 75 bus and we are having 15 generators.

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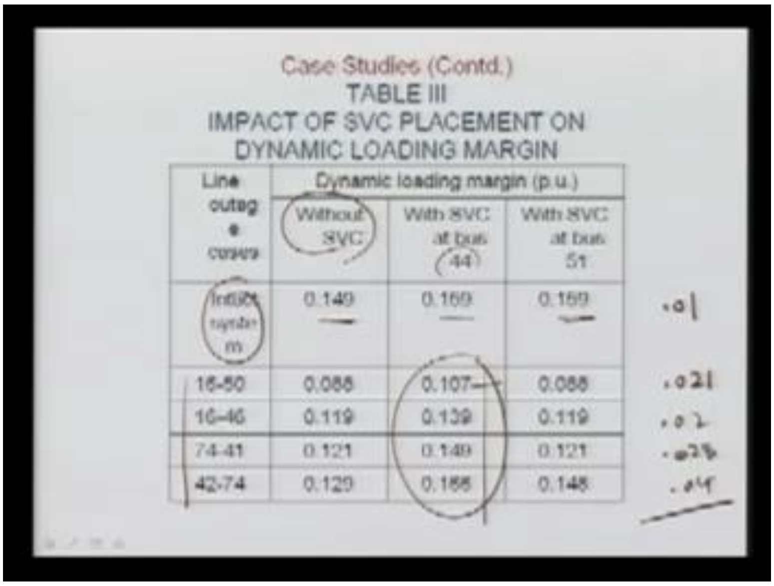
Case Studies (Contd.)
TABLE III
IMPACT OF SVC PLACEMENT ON DYNAMIC LOADING MARGIN

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

For this case, what we have done, we have located, where we can put the SVC. So, the case in that this we have used, this bus habit participation value for the two 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 of means outage of 29 to 30.

This is a Luck now to one line here, you can see, this 29 here, this 29 is somewhere in this shown 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 one is your 44. So, keep on doing the 44, 42, 44, 42, 44 and 54. So, 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 as bus number 44 and this 44 is nothing but, you can say where is the 44, 44 is this bus. There is one generation here and this generation is your nothing but, I think gas power station. So, after putting at the 44, now you can see how much static loading margin, that had 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, there is no contingency, no outage. So, without SVC, the static load margin is only point 144, per unit, per unit again here is 100 unit areas. 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 one 73.

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 compared to 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 outages 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 it is 42, it is more here 48, it is only 22, here 6. So, it is basically the most locations as I said, it is not possible that only one static var compensator is sufficient for whole large system, it may be the 2. So, we can go for the 44 and 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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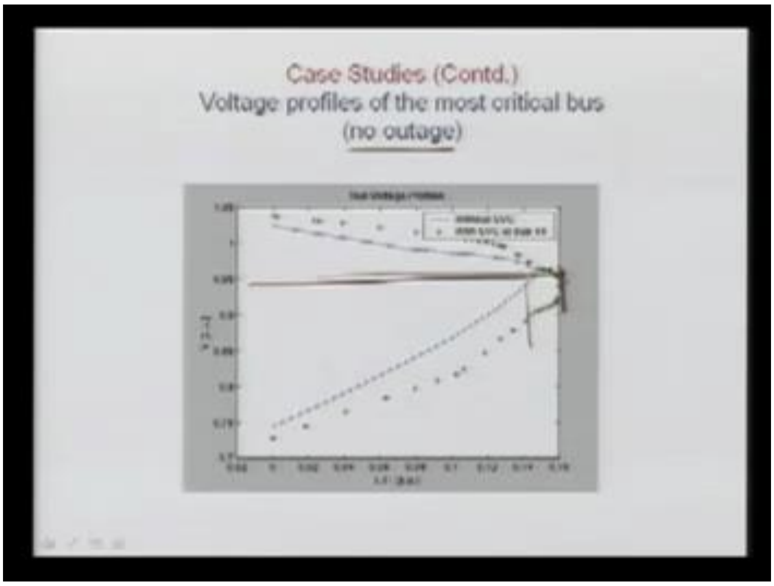

If you see this voltage profile of the most critical bus here and that what we are going, it is a no outage means, it is a base case. So, you can say without SVC, it is your this blue line and with SVC at 44, this is here. So, you can see the loading factor is increased here up to this point. And also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

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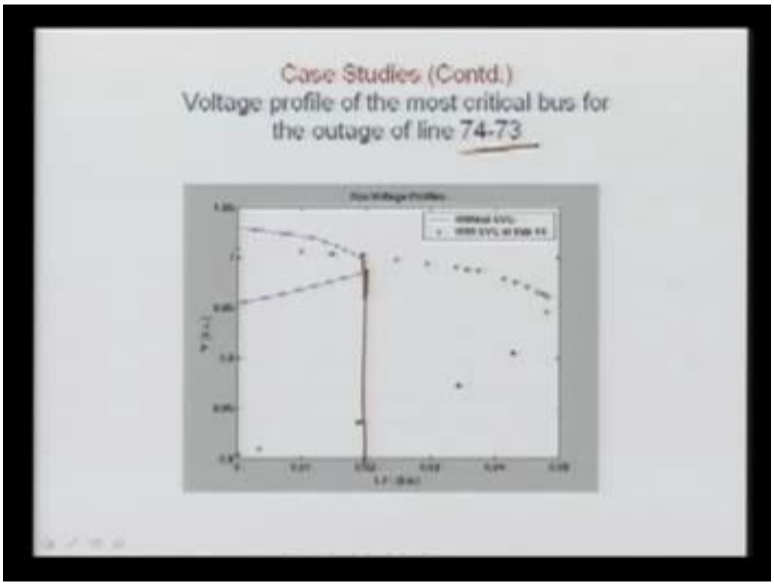

Now, let us see for outage of line 74 to 73 and this 74 is very big line. This is a Kanpur, I think Kanpur NTPC here to this line.

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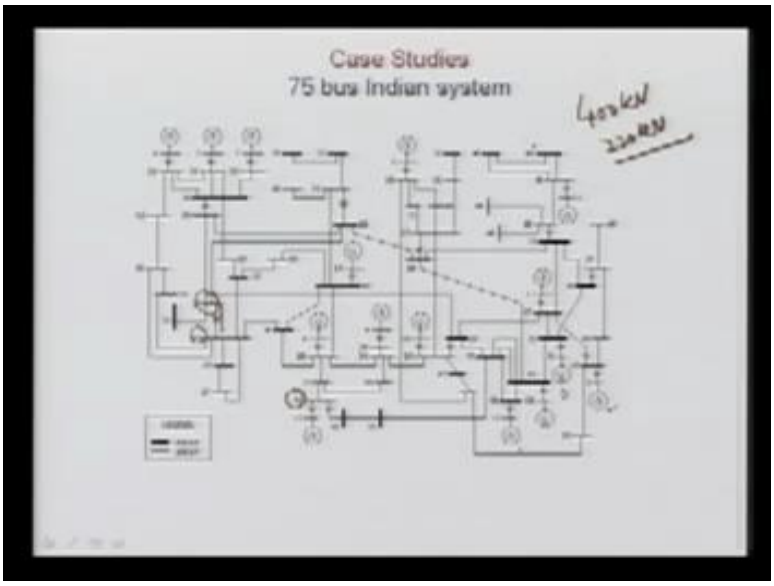

You can see from this figure, here this is a 74 and your 73 is here, near to Agra. So, outage of this line is very, very critical and here it will out this line and now you can see much change. Here, without SVC this margin is up to here 0.02, but if you are doing this you have increase up to 0.5. And how about the voltage improvement, you can say, there is no big voltage improvement, at this line voltage, even though lesser, but we had increased the margin.

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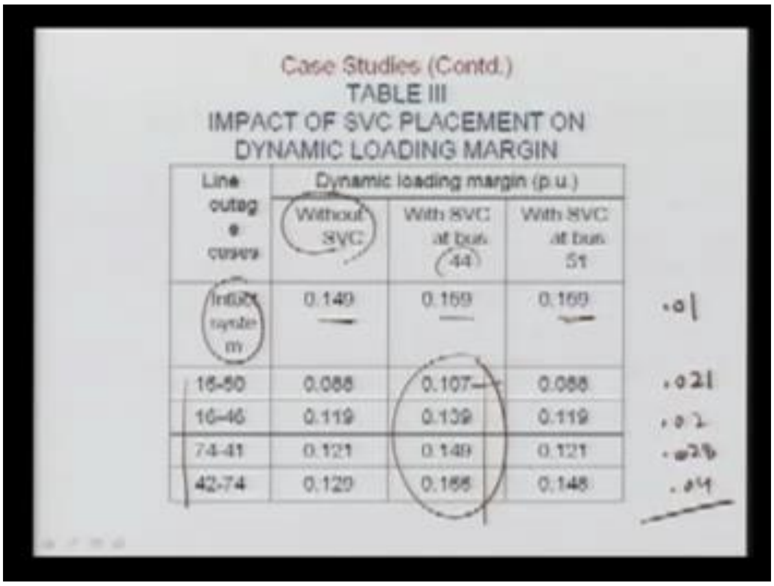

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Now, to see the impact of SVC placement on the dynamic loading, we have again done for these various contingencies cases here and the intact system. That is a base scale, without loading here; you can say this margin is point 0.149. And here, with the SVC at the 44, we are getting 0.159; however at the 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 is 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, 0.1 from here to here, I am just calculating here it is nothing but 0.21.

Here, you can say if you are going for 0.02. In this case, you are going to point 0.28 and in this case you are getting 0.04. So, in total, it is 100 per unit base, if I multiply it by 100. So, maximum, you are getting 4 mega. 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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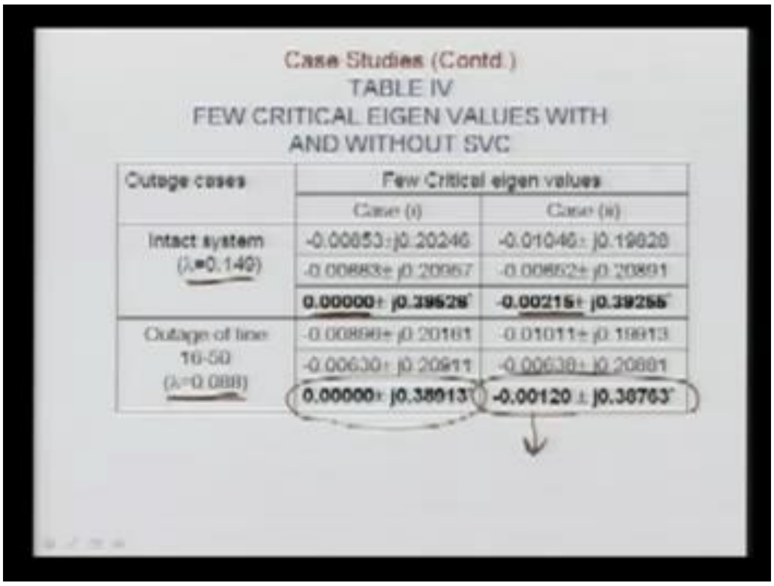

Case Studies (Contd.)

TABLE IV

FEW CRITICAL EIGEN VALUES WITH AND WITHOUT SVC

Outage cases	Few Critical eigen values	
	Case (i)	Case (ii)
Intact system (λ=0.140)	-0.00853±j0.20246	-0.01046±j0.19828
	-0.00883±j0.20967	-0.00862±j0.20891
	0.00000±j0.39528	**-0.00215±j0.39255**
Outage of line 16-50 (λ=0.088)	-0.00898±j0.20181	-0.01011±j0.19913
	-0.00630±j0.20911	-0.00638±j0.20881
	0.00000±j0.38913	**-0.00120±j0.38763**

Few critical Eigen values, you can see for the index system, when the load was this, you can see this value becomes this Hopf bifurcation, this become 0. However, if you are putting in the case 2, where you are putting this value you are getting this 1, 0.01. 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 index case even.

For the outage of this line, again at this loading, we found that this Hopf bifurcation is occurring. But, at this loading, you can say, why did Hopf bifurcation and this value, is not 0. So, we can see that the dynamic as well as the static voltage stability are improved with help of FACTS controller, correct. ((FL))

Student: 29.

29, 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 can have improved the dynamic stability.

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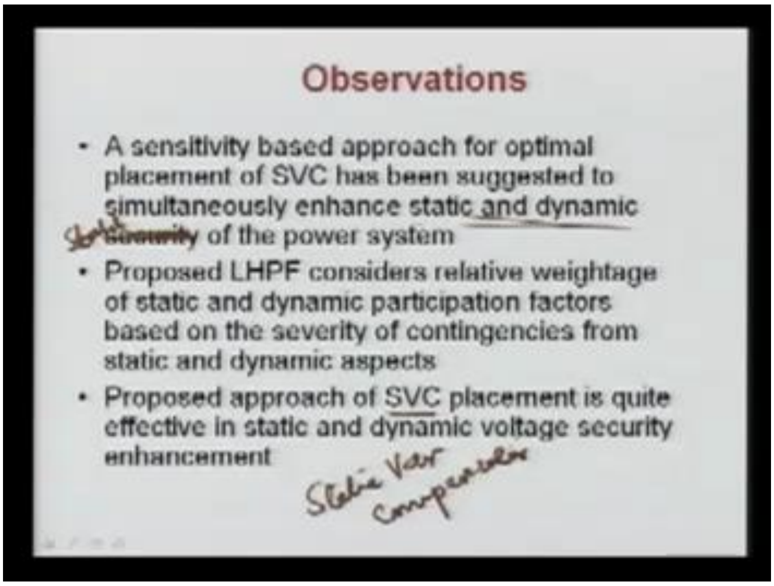

So, we made the following observation with help of placement for this SVC. Our sensitive based approach for optimal placement of SVC has been suggested to simultaneously enhance static and dynamic stability of the system. Here, it is not the security; here we are talking about the stability of the system. The proposed this hybrid participation factors, consider the relative weight age of static and the dynamic participation factors, based on the severity of contingencies, from static and dynamic aspects.

What is happened, there is a possibility, if you are considering, 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 different location. However, for contingency cases the location optimal location will be different. So, you have to again compromise and for all the system scenario, you have to choose a suitable location. So, 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. This we saw that FACTS controller the series, here it is not series, it is a shunt. That is, we see static var compensator. So, this SVC is called your static var compensator, basically 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 a STATCOM. STATCOM is a function wise, it is a similar to static var compensator or SVC, but the STATCOM are better. They give better performance than SVC at the several regions, several locations, they are very, very important. But, the STATCOM are very 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 our Chakkarpur station, that is a power grid station and that is having rating plus, minus 2 A T. We are having two unit is of pulse minus A T and V R and that is improving your system no doubt very well. Now, one is this is from very beginning, just we studied the various stability. That is a transient stability, small signal stability, also we discussed about, how we can improve those stabilities.

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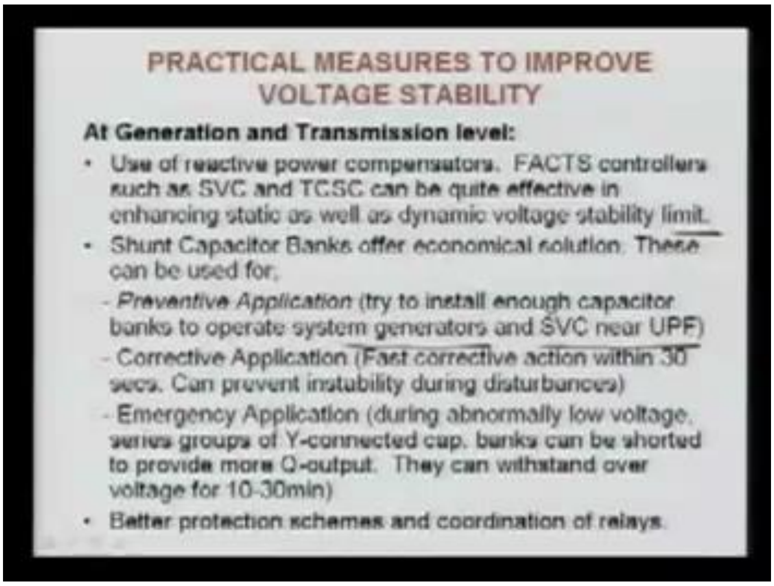

Now, here also, just I am going to discuss the practical measures to improve the voltage stability. Again, we can improve this voltage stability; again we can divide into the two locations. Once, just I want to see, that if you can do something at the generation and the transmission levels, another is at your distribution level. So, here I am talking about the first generation and the transmission level.

The use of reactive power compensator, as you known 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 state com and sometime the TCSC. All although, it is a series device, can be quite effective in enhancing static, as well as dynamic voltage stability limit is 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 deficit. In sometimes, means 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 absorb the reactive power, during half peak loads.

Because, their excessive reactive power charging up the transmission line, with the reactive power and generators are also allowed to absorb the reactive power. So, that we can have the healthy system. But, in the 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 this can be used for the preventive application. Try to install, enough capacitor banks to operate system generators and SVC, near unity power factor. What we do this; again there is a two type of applications. One is the preventive application; another is your corrective applications. So, we can use the capacitor banks, again for the ESV transmission line, for 400, if you are using the capacitors very, very expensive

So, we can go for the lower voltage and we can improve at especially near to the load. We can put 132 or we can go for the 33 KV bus bars. We can put the capacitor banks and again, we are putting the shunt capacitor. We know the shunt capacitors 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 stability very much. That 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 less than 30 seconds. Then, there is a possibility during the disturbances, you can prevent the instability.

Means, you can prevent the casket tripping of the system. And therefore, you can prevent the instability during disturbances. So, that is called the corrective action. In the preventive, already you 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 a preventive.

In corrective, you have to use the exact 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 voltages system is stable. But, it is operating very close to the low voltage limit.

So, we can use the series groups of Y connected capacitor banks, can be shorted 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 a 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 also the coordination of relays.

As you know, if there is a due to the low voltage profile, if one line or one generator is tripped. Then, there may be the casket tripping, that is the voltage will keep on going down and there will be a casket tripping. And then, your whole system may be in the collapse or dark. So, the better protective schemes and the coordination of relays are also very, very important for improving the voltage stability of the system.

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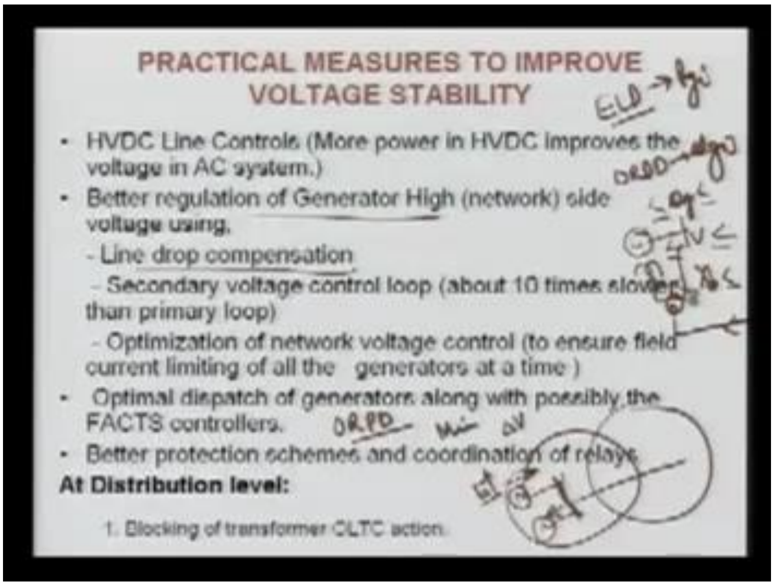

Now, HVDC line control, if your system is having HVDC line, as you know in our UP. We have one HVDC, big HVDC line carrying more than 1500 mega watt power and that is from ((Refer Time: 39:02)) it is a plus minus 500 KV, that is bipole operation**.** So, if you can control, that power as you know, we can main advantage of HVDC, that we can control power very efficiently.

So, we can more power in HVDC, improve the voltage in AC system. If you are dragging more power over the DC line, your AC system will be relived and you can load more and you can have more stability margin. So, loading or you can say controlling the HVDC, we can load more HVDC lines; we can improve the voltage stability of the system.

But, again if your HVDC line is loaded to it is rating limit. So, again you do not have margin. Better regulation of generator high site voltage using line drop compensation. Secondary voltage control loop, about 10 times slower than the primary loop. Optimization of network voltage control, to ensure field 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 I 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 and the high voltage side. We can use the line drop compensator. That is one signal. That is used in the exciter. That is coming; we can control the bus voltage at very far from generator. We can take that signal and then, we can set the exciter 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 somewhere far from generating station. Normally, what happens, if your generator is here, this generator just as we feed here the excitation? And that excitation, here the fill, that is, we get, that is from your terminal voltage here and we feed here, we can control the terminal voltage. So, the exciter is used to control the terminal voltage of the generator.

But, at the same time, what we can do, we can use another ((Refer Time: 41:15)) signal here. That is, we can add that signal comes from anywhere in the system and that is called your line drop compensation. Secondary voltage control, about the 10 times slower than 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 the network voltage control, to ensure the field current, limit current, limiting of all the generator at a time. You know, because 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 capability curve of alternators, that we had this field hitting limit.

If your current is hitting that maximum value, we cannot operate more than more field current. Because, it may damage the field binding, because heat will not be dissipated and that may damage, your field binding. So, it is called your current limiting, that is the field current limit. So, what we can do, we can have a complete coordination of all the generator, it is not that one generator. We are keep on encouraging the excitation and other generators, we are not changing.

What will happen for example, I can tell you, let us suppose here, one here generator is there and we have another generator here and this is the complete system, though that connected. If you are keep on encouraging 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 as 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 the field current. So, we have to go for the coordination of all the generators. So, that we can ensure the field current limiting of all the generator 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 margins 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 FACTS controllers. Now, optimal dispatch of generator, one is that is optimal dispatch, again optimal dispatch, can be delineated into two types. One is your economic dispatch, that is a 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 generator, as well as other devices in the system. Means, we have the red capacitors, we are having static var compensators or we are having other FACTS controller. 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 changing the voltage deviation, minimization may be your changing minimization of the loss, subjected to the various constraints. Those constrains are your real power limits.

Again, we are not touching the real power limits, because this economic dispatch, that is a called ELD economic load dispatch, is we are we are setting 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 changing 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 limit is and also other let suppose FACTS controllers parameter 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, we have seen this reverse action of the transformers that OLDC 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 an unstable case.

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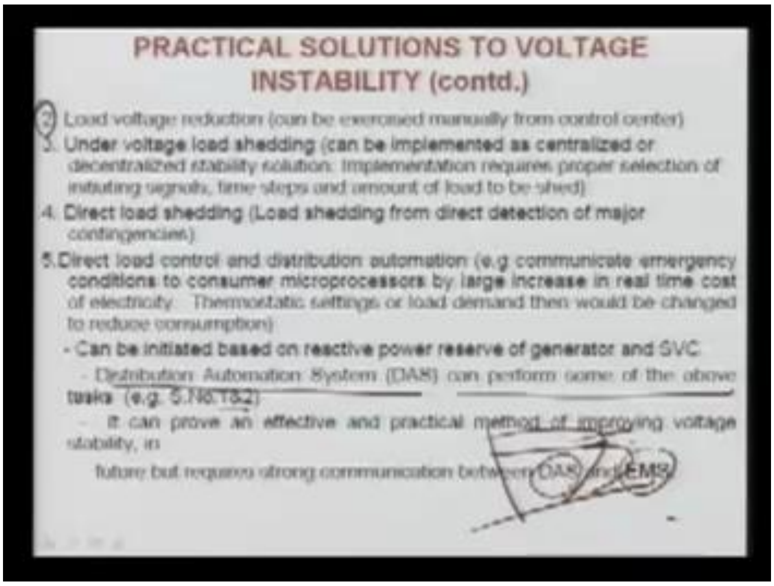

You see this, here, what I can explain you, let us suppose here, this is PB curve, this is your PB curve, at one tapping at another tapping, you are having another curve here like this. Here, if you are operating somewhere and you have changed the voltage suddenly here, let us suppose you are operating here. And you have changed from you are tapping here from one to this point to this, what happens you are landing here in this negative 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 at the 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 PB curve. So, you can block that OLTC, especially during the emergency cases. Now, load voltage reduction, can be exercised manually from the control center.

Now, this load voltage reduction means, you can, if your voltage is reduced at the load buses, you can again and you can reduce the load of the system. And that can be exercised 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 to reduce, means you can improve the voltage stability of the system.

Under the voltage load shedding scheme, as you know, there is a two types of load shedding schemes are there. One is the load frequency control, where there is a frequency falls down. Normally, we try to shut 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 have that if voltage is load low and it can shed the load, then we can again improve the voltage stability margin. So, under the 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, that is, how much load you are going to shed, 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 a that margin. You are very close to the voltage instability margin, then you can take this action.

Another is direct load shedding, the load shedding from the direct deduction of the major contingency; means suppose there is a one contingency has occurred. That may lead to the severe voltage problems in the system. So, with that contingency, if you have any sense in mechanics and then, based on that you can directly trip few of the loads. You can trip it out, and then what will happen, it will try to improve the voltage profile.

And therefore, you can have more voltage stability margin and you can have the improved voltage stability system. Direct load control and the distribution automation, that is a DA is communicate emergency condition to consumer's microprocessors by large increase in real time cost of electricity. Thermostatic settings or the load demand, then would be changed to reduce the conjunction.

Because, here, again this voltage stability, can also be improved either from the generation and transmission end and also it is possible from the distribution end. So, in the generation end, already I discussed that we can improve the reactive power settings. We can use the optimal setting of the reactive power outputs of generators along with 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 the OLTC. So, the direct load control or you can have the distributional automation system. That automation means, you will have some RTU, remoter terminal unit is and they will sense the system voltage etcetera. They will give the information to DA system. And that DA system, will decide how much load and which are the loads are to be shed and then, we can improve your the voltage stability of the system. And can be initiated based on the reactive power reserves of generators and SVC. The DA system, that is distribution automation system.

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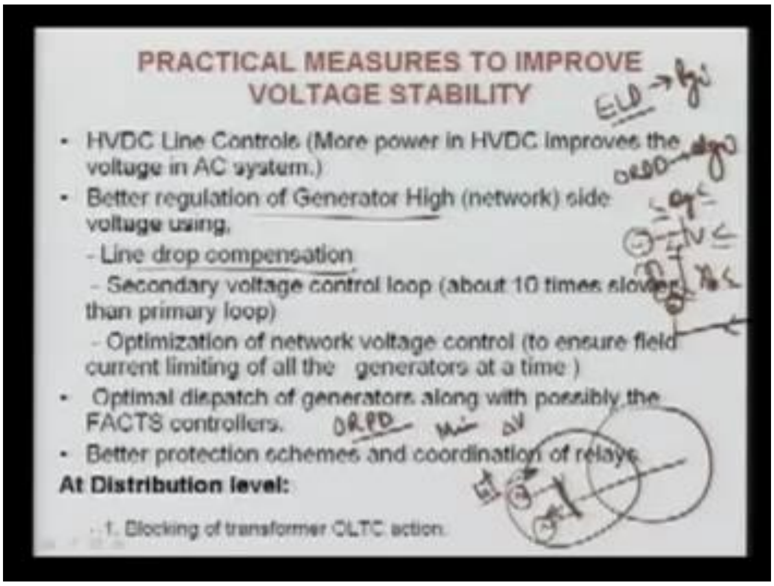

DAS, namely we call, can perform some of the above tasks, that is a serial number 1 and 2. 1 and 2, one that I was said, it is a OLTC here, it was this. Here, the blocking of the transformer OLTC action and that is always, we are taking about the reverse action. Second one is, this means load voltage reduction scheme, that can be done. This DA system can also prove an effective and the practical method for improving the voltage stability.

In future, but require strong communication between the DAS and EMS. Here, it is not only the distribution automation system, but also the energy management system. Both must be coordinated, because it is a coordinated system, means how much load it be shed and again, how much generation, you are having. So, all this 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, 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, one example, where for 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 solutions to the voltage stability 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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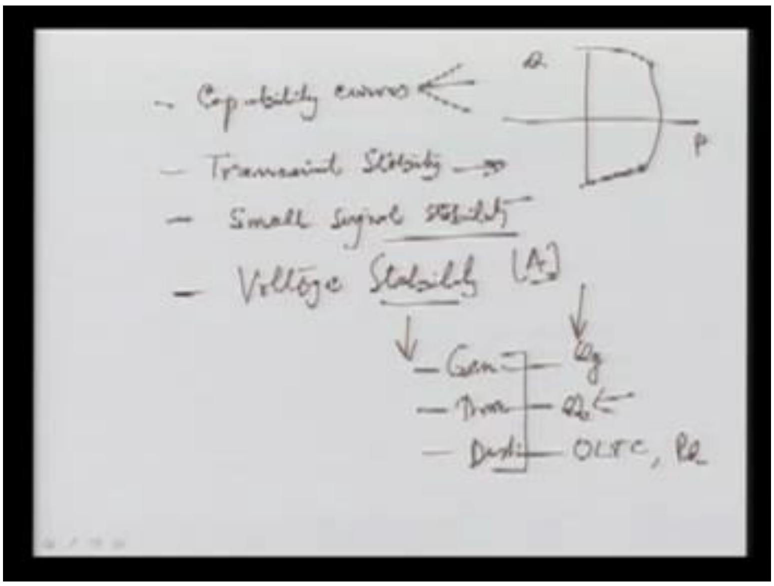

First, we discussed the capability curve of generator. This is the capability curve, in that we saw the various limiting of an alternator. That is your field hitting limit is the various field hitting limits, I derived and if you remember here I draw here it is your P, here it is Q. So, this is your field hitting limit, then we have the armature hitting limit and the finally, here it is your end hitting limit.

So, this is your capability curve of alternator, I explained I derived and then I explained in the detail. Second then, I used the modeling of alternators for purpose of your transient stability that is a transient stability. We described this swing equation; also I described the equal area criteria, for the single machine infinite bus system. I also gave 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 the sudden and the severe disturbance and then, we again we saw the various approaches. And then, very 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 small signal stability, small signal, signal stability. Here, in this stability the sudden, but the small disturbances take place.

Then, here in the transient stability, we analyze with non-linear equations differential equations. But, here in the small single stability, we can linearize and we linearize the system, around the operating point. And then, we solve and we go for this transient 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 the small signal stability, especially related with the small oscillations in the power system.

So, how we can improve, already we discussed some of the moral analysis, we also saw some improvement methods for the small single stability as well. In this small signal stability, we describe that how we can go for the participation factor, what are the roles of various Eigen values and then, we solve one problem as well for small signal stability. Another, which I discussed, that is the voltage stability. I took almost three lectures on that voltage stability.

And in this voltage stability as it is related with the voltage in terms and in these we explained the various static, as well as the voltage stability criteria’s. We also discussed various the bifurcation. I discussed the various method to analysis the static voltage stability. We discussed your condition number or you can say singular value decomposition techniques, minimum singular values which I said. We also used the saddle node bifurcation approach.

I discussed the continuation power flow techniques and also the various L index and various proximate index are used for the voltage static voltage stability checking and enhancement approaches. The dynamics voltage stability, I used the again Hopf bifurcation is one criteria and for that Hopf bifurcation I have considered only Hopf bifurcation.

And then, we saw that how an FACTS controller, FACTS controllers are useful to improve the voltage stability. Again, the FACTS controllers 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 three angle means here, we can say at the Q g s at generation, here we can go for the Q source and you have some capacitor or static var compensator. Here, we can go for the OLTC and as well as the P demand if you can go for. So, these are the various control measures by with, we can improve the voltage stability of the system.

So, in the total here, we discussed starting from the capability curve, modeling of the synchronous machine. Then, we utilized the transient stability; first I used this classical model, where we used the then single machine infinite bus. Then, I went for the multi machine system, and then I discussed the various approaches to improve the transient stability. Then, I followed by small signal stability and finally, I discussed the voltage stability where various methods were discussed.