Power System Operations and Control
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Module - 2
Lecture - 8

So, let us see lecture number eight. In previous lecture, this lecture number seven of this module two, we saw that. So, we had the differential equation of the second order and we require some algorithm or solution methods to solve those equations because those are the non-linear differential equation. So, the various methods as I mentioned maybe your Runge-Kutta method, maybe your Euler method, maybe your modified Euler, that is also very important and maybe another one your trapezoidal methods. So, to see that, let us first consider the various numerical integration methods.

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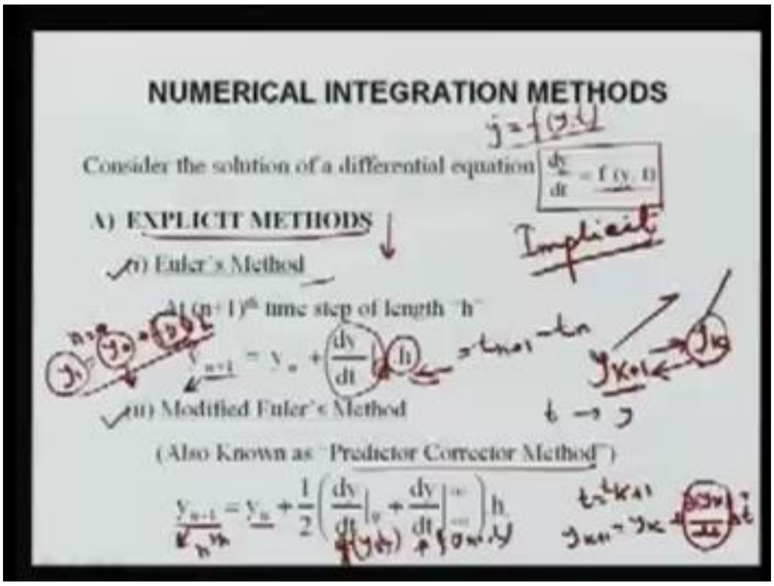

Here, that is required to understand, how we are going to utilize the Runge-Kutta method or any other methods. So, there are the two type of methods for solving this integration differential equations, one is called your explicit method, another is called your implicit methods that is called implicit.

This is explicit method, the value of variable x or you can say variable y at any time t computed from the knowledge of y from the previous time step, means in the explicit method, your step for example, if your variable is y is the differentiation of y. So, this value you can any time step, you can say k plus 1 is determined using your y k and this is called your explicit method. So, this method is easy to implement, but sums suffer from the numerical stability. Basically, the stability is the numerical stability implies that the error in the each step does not propagate to the future time means maybe the error which are you calculating it is keep on integrating, keep on adding.

Then, your system your solution becomes absurd and that is called numerically unstable. So, these sum implicit methods, they are basically suffering from your stability problem. So, any method that should have a different criteria that which method you are going to use. The method can be based on your accuracy maybe based on the stability and method based on efficiency. Efficiency means how fast you can get and how reliable solution you are getting, so the two methods that is implicit method here and another is your explicit methods. So in the explicit methods the Euler methods modified Euler methods your Runge-Kutta methods are the very common.

However, in your implicit method, there is a trapezoidal rule of integration is very well known and this methods the interpolation technique is used. Here, in the implicit, knowing this value we try to interpolate if yk you are knowing, then we can here interpolate that value to get you an every step. However, in these methods, we use this value to get this y k plus 1, so this is the different and the example of implicit method is nothing but your trapezoidal rule of integration and that is your linear interpolation is used. To see this, first the explicit method first one as i said it is Euler's method here this function we want to solve, we can write this is as your y dot is equal to some function of y t.

Here, this y can be the vector set of vectors means it maybe y 1, y 2, y 3 and so on and so forth it maybe a vector, so different variables it maybe of n variables. So let us take here a simple variable x y here that is y dot is equal to your f y t that is a function of y and t. We want to get the value of y, we want to solve that, we want for different of t, we want the value y so that we can plot and we can know the nature of this function. So, here what we can do the any at any time t is equal to t k plus 1, we can write this y k plus 1 we can using the Taylor's series expansion that is your y k plus here your del y k over d t.

Here, some value of difference in the time and plus some other higher order terms. If you note that higher order term what is this? This is nothing but your ft, so we can get here y n plus 1, where n is your n t h that is iteration. It means your n is starting n is equal to 0 means at y 1 means after this first iteration y 1 here will be your y naught plus your y d y upon d t, this is nothing but, your function f y t. This at your value here, we are just going to calculate at n th state, means here it is your f y t into h and that h is basically the difference in the time. This is the time step means here we are just t n plus 1 minus t n will be equal to your h.

So that is your time step, so this time step is also very important, then after that you can go for the very small time step here, then your computational time will be very high. If you are using large, then you will not get the exact function and then your solution may becomes diverge and you will not get exact function. So, the choice of this h is also very important normally we go for the compromise between the smaller value as well as the higher value. So, this is your Euler's methods using the simple Taylor series expansion of function y that can be retained here and then we can solve because this value, we know at your not value.

So, this is known to you using this value previously state you are starting with some initial guess and you can calculate your y 1. Similarly for your y 2 you are keeping on getting value for the different time step. This method is not so accurate and normally what we do basically this methods suffer from the several things. Basically, the extended Euler methods give inaccurate results due to use of its derivative at the beginning of interval because this is at the beginning of interval this is x n here. So, this gives inaccurate result, so what is under the modified Euler method has been proposed using the predictor and the corrector states.

In the predictor, this is your let us see the modified Euler method, this is also known as the predictor and corrector method means at one step we predict in second step, we will correct it, means after prediction, there will be some correction. Then, it is known as predictor and corrector method, so at the predictor step we calculate the value of y n plus one as usual this is the y n means we are calculating at n th iteration. So at n th iteration here, this y n plus 1 means we are getting a value here that is your previous step value then that is plus half y del y upon d t.

This is nothing but your function here f y t means I can write f y sorry f y t and that is n means that is n value y n plus here we are getting another value this your f y n plus 1 t then multiplied by h.

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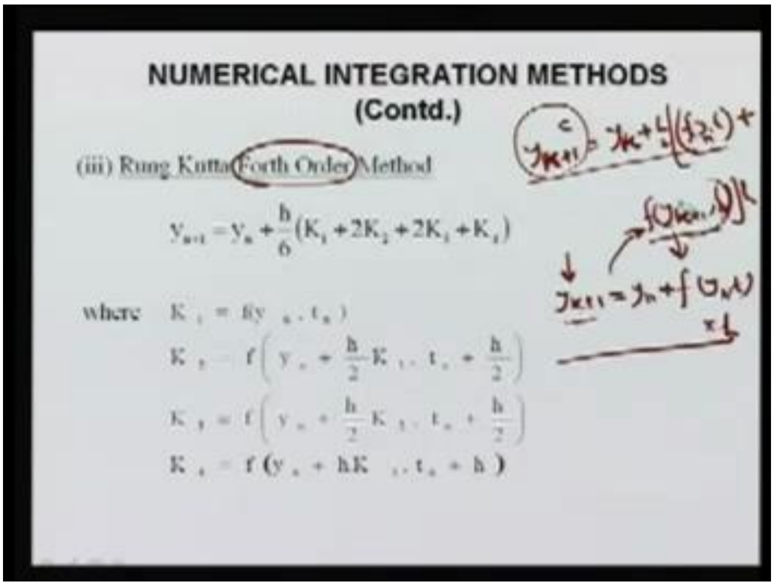

So, this is called your predictor step in your corrector step what we de we write normally this your y k plus 1 that is a corrector step here will be equal to your y k plus half of your values your f y t that here it is at your step n or whatever. Here, n and k slightly it is confuses this n is again the same your iteration count. So, I am writing y, y n t plus here your f y n k plus 1 t again here t k plus 1 and then it is your h. So, this is your corrector step, so there is a some first your predictor step, here we are using this value, means this is your corrector in the predictor, I am talking again the previous one. Here, it is your y k plus one in the predictor, it will be your y n plus function here y n into t into h.

So, this value is known to you so this value knowing then we can get this value. So, in this character step this value is known at the previous step in this step after your predictor we have predicted this value knowing this value you can calculate this. After calculating this, you can calculate the corrector value of y k plus 1 and that is basically used and then it is very reliable and normally it is used. Another method that is your Runge-Kutta method and again it is of different order it is even the second order Runge-Kutta method, fourth order Runge-Kutta methods. Again, it depends upon the how much Taylor series expansion variables we are going to take.

So, the modified Euler's method is the simplest of predictor corrector methods there are some higher order predictor and corrector methods are available, but these methods suffers from a number of limitations. They are not self starting and needs more memory storages and requires small time step then the Runge-Kutta method. So, Runge-Kutta method is very popular and very widely used method. It does these methods Runge-Kutta, again different kind means second order fourth order and so on and so forth. So, Runge-Kutta methods do not require evaluation of higher order derivative, but the effect of these derivatives is included by several evaluations of the first derivatives.

Depending on the order of Taylor series terms, different order of Runge-Kutta methods is obtained. So here in this transparencies, I have shown here y k plus 1 is, it is now the fourth order, you can see is here it is a fourth order. If we are using second order, what we can do in the second order, I can show you this.

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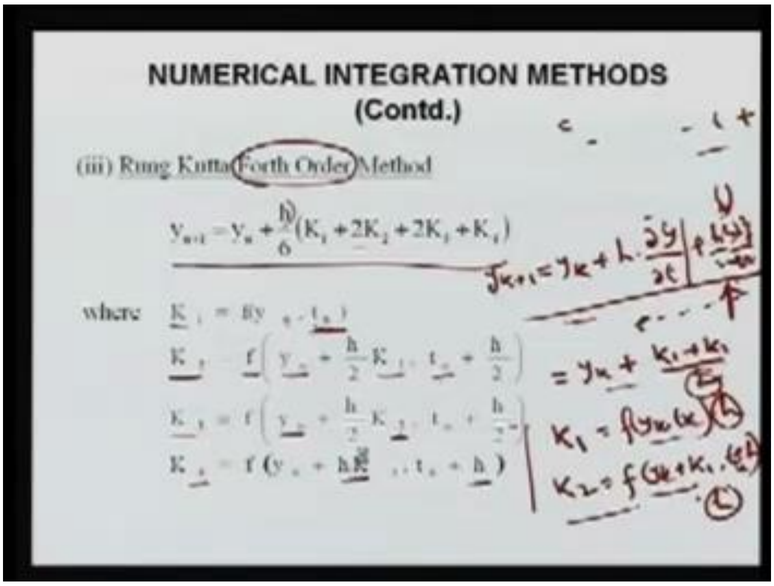

Let us suppose your y k plus 1 means again this y can be expanded in the Taylor's series expansion form and that we can write here y k plus here again h into del y upon del t and again here at the k plus higher order term and that is your higher order term. I can say it is your h square upon two and double differentiation of f upon d t square. So, we are having here different order plus here again other order. So, if we are taking the second order then it is known as the second order Runge-Kutta methods.

We can write this will be equal to your y k plus your k 1 variable plus k 2 divided by 2 where your k 1 in this case will be equal to here your nothing but your f y k into t k at that time into h and your k 2 will be your f your y k plus your k 1. Again, we are getting at the k 1 into t plus h your t k into h, so these two values are knowing this used here and this is called your second order of Runge-Kutta method. Another that is a fourth order Runge-Kutta method is very widely used and we go for the fourth order, means we are going up to the fourth order of the Taylor series expansion. Then, we can write similarly, after solving using basically this method is invented by Runge-Kutta and here this y n plus 1 means n th iterations that y n.

The previous iteration value plus 1 upon h 6 here earlier it was 2, so 6 here, k 1 plus 2 k 2 plus 2 k 3 plus k 4, here you can say 1, 2, 3 and 2, 5 and 1, 6, so here divided by 6. All the terms are either divided by 6 means this is the average of this k 1, k 2, k 3 you can say weighted average. So, the k 1 is nothing but your f y and t your k 2 is your f, this because h, I have taken common here we here included h you can say here in this case, so k 1 here, it was included, but here we have taken h outside. So, your k 1 is your simply a function y and delta t n your k 2 is a function y n plus h by 2 k 1 and your t n plus h by 2 here your k 3 is here h by 2 k 2.

Now, we have used and here it is again by 2 and k 4 function is h k and here is your h value. You can see here that half we are using and that is why it is 2 here which is used here h completely used. So, this is your fourth order Runge-Kutta method, now let us see another method that is a trapezoidal method.

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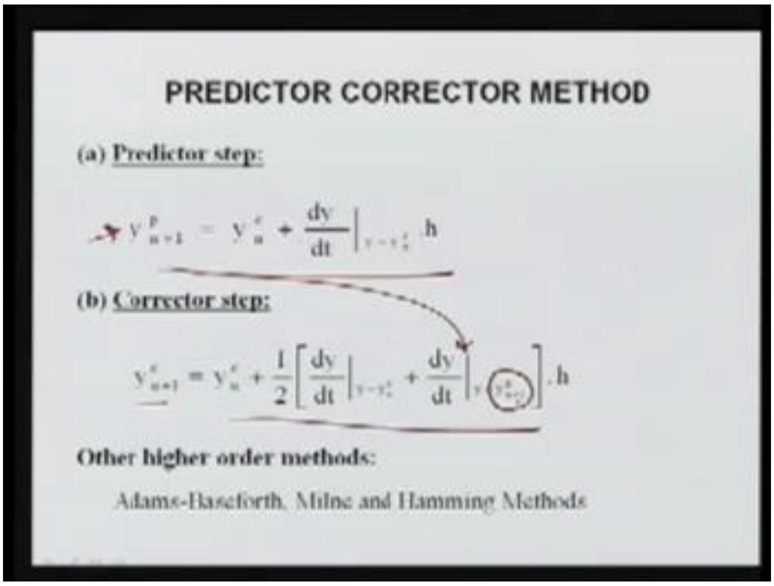

Here, again just predictor and corrector methods of Euler methods just I will here as explain this predictor step. We predict this and we corrector step, we correct here using this value here you can say this y p n n plus 1 and then this is other higher methods are also allowable that is Adams-Bashforth Milne and Hamming methods etcetera.

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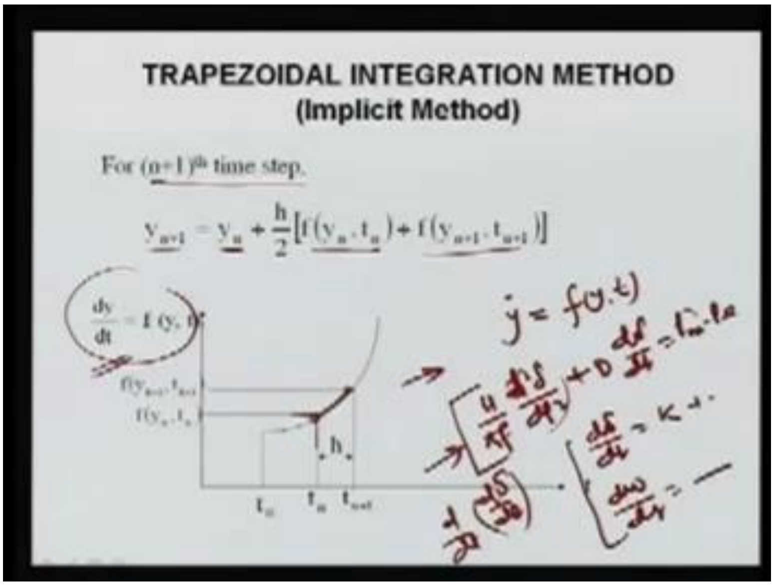

Another method is here, normally this trapezoidal integration method that is the one example of implicit method. Here, what we do this value for any n plus n th time step this value can be written as the y n plus h by 2. The function here at this value and the function value at this value here we are taking the average of this. So, this is called the trapezoidal methods because here this value plus this we are taking average plus added here the value which is the function of this value. So, this is called your trapezoidal mea method, so this is the method normally used either Runge-Kutta most probably Runge-Kutta method is used and if you are using the implicit method, you can go for the trapezoidal method.

Now, again now question arise our set of equations are second order, so far here I am using the first order differential equation that is here d y upon d t means I have used here the single this dot means d y upon d t here, I had used the function of y that is t. In our case, what was the equation? If you remember, it is nothing but your h upon pi f this upon d t square plus if you are adding the damping term here d delta upon d t that is speed term here pm minus p, so you are having a double differentiation.

So, what we can do, this double differentiation term, we can write the two sets of differential equation means we can write here d delta by d t over some function here k plus delta term. We can write here d omega by d t with another function of f because this d by d t here d delta upon d t this is nothing but speed. So we can transform this double differentiation second order equation in the two single order equation and then we can apply here using any of these methods. So, in the multi machine system, we have to go for that and we can utilize these methods for the solving the differential equation. Now, let us see the various factors those are in influencing the transient stability of the power system.

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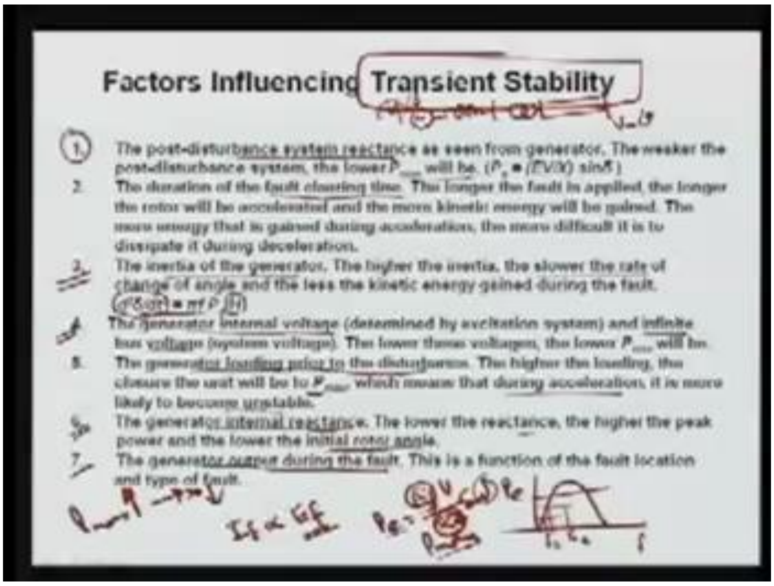

We have seen the stability constant we saw the stability margin we saw the various ways to analyze the stability. Now, let us see how we can improve, I mean what are those factors those are affecting the transient stability if we can know then we can try to see that how we can mitigate how we can reduce the instability of the system by incorporating those things. So, first factor which influence the tangent stability is the post fault disturbance reactance as seen from the generator. I mean the generator from here what will be the impedance seen by the generator. The weaker the post disturbance system the lower p max will be there and the p max will be lower.

We saw in our previous slides that here it is your angle delta curve that is your p e here, it is your delta. Now, your post disturbance fall we say the once one line was striped, then we had the less stability margin I explained at that time.

If the system is intact then means your x is less and this p max will be higher, so your system will have more stability margin and your system will be more stable. So the post disturbance system reactance seen by a generator if it is intact the same as the pre fault then it is a better even though if your x here, is reduced in anyhow. However, it is not possible because either you can trip the line or that system will be intact. Then, if system is line is tripped, your reactance will be increased and then your p max, this p max will be decreased and your margin will be reduced.

So, post disturbance system reactance as seen from the generator if your this post disturbance system is weaker this p lower p max and then it is influencing your post fault system first point. Now, second the duration of fault clearing time is we saw that is very important means if you had your fault is delayed there are very big possibility. Then, your system will land up in unstable mode or in other words, you can say your system fault is cleared before the critical clearing time. Your margin will be if it is very quickly cleared, means you will have more stability margin, if it is cleared at the clearing critical clearing angle or time, then we will have the system stable beyond that your system will be unstable.

So, the duration of fault clearing is very important, means here your delta naught is this and when you are going to clear that at what point this this delta c the fault is clear. The longer the fault is applied, the longer rotator will accelerate. Of course, if your fault is persisting for longer deviation, your machine is keep on accelerating your I delta will be very high that we keep on increasing and that may that maybe difficult. That deceleration energy will be not on your is not sufficient and it will be not dissipating during the deceleration and your machine will keep on accelerating and that means your system is unstable.

Another factor is you are the inertia that is a h, so inertia of the machine is also very important because this higher, the inertia lower the rate of change of angle. Of course, this is lower rate of change of angle and the less kinetic energy gained during the fault, means you are here less kinetic energy gained during the fault that you can understand by this one. This is your change in the speed basically rate change of a speed and divided by h. So, if your higher inertia is there, so the slower rate of change of angle here, you can see h is higher your slower change, means your system will be more stable.

So if your inertia of the system is very high, now you can say the system is highly stable. Fourth factor which is influencing that is your generator internal voltage that is your ef determine by the excitation system. This ef as I said in our generation system, these are used, this is your generator here, this is a reactance of generator, then we have another transformer here, and then we have two lines thus we took that example. Now, what is happening? This x at this point this excitation voltage that is angle delta, here v infinite angle 0, this EF can be changed by the changing the excitation of the system, this alternator.

In alternator, we have the two control rules, one is controlling your real power and that is related your stream, which basically if you want to increase the input power generated, then you have to increase the input power. That is basically you have to open the value at the turbine that is going inside the turbine, your electrical input will be increased and thereby you will injecting more power into the system. That is called the governor loop or lower frequency control loop and we will see that one in our module number three lower frequency control how it is accomplished. Another controls is the sensing the voltage and it is normally going to the excitation field that is the voltage we applied to the field mining.

That is the basically directly, it is EF that is directly proportional, the current, which is flowing in the excitation circuit. So, this EF can be changed and if this EF is more again you can say your p e, it is nothing but your EFV infinite here divided by x sine delta. So, if this is more then you are having p max more and therefore then you will have the more stability margin. So, the generator internal voltage that is determined by excitation system and the infinite voltage system, the lower these voltages the p lower p max will be there and therefore it will affecting your p max means your stability. The generator loading point before the disturbance means before disturbance if what is your loading, means where your system is loaded at this point, loaded at this point.

If it is lightly loaded, then your system is more stable, if it is highly loaded, then it again the stability will be very less and we have to be very clear. Again, we have seen by increasing the initial loading and I showed that one example using the equal area criteria. So, loading is also very important the higher the loading closure of unit will be this one, which means that during acceleration, it is more likely to become accelerate unstable.

Another is your generator internal reactance that is x here x, once machine is designed, it is very difficult to change that x you cannot change, but while you are designing your system while you are going to your generating system you have to see what is x value. If this x is less what happens, this x is less, means you can feed more power and this here p max that is if x is less, what will happen? This p max will be more means your p max will be more if your x is less, so the generator internal reactance is also very valuable, means your lower reactance higher peak power and the lower your rotator angle, means for this p is a constant, here this is less.

So, your delta will be reduced and again you are operating very close to this, you will have more margins for the fault clearing, but no doubt if you are going to reduce this. It is not possible that we can reduce very less fine, if there will be fault at the thermal of this generator, it will be used and that may damage your binding. So, normally we go for the compromise between x here. Again, this x is arrow also very important while we are calculating the reactive power because once reactive power is directly related with this x, how much loss in that system because I square x is the reactive power loss.

So, this x is basically at one hand if it is less we are more stable, but x is more what is happening more reactive power and less fault current if less this x is less the fault current will be more that is not desirable. So, we can say again we have to go for the compromise that which value is suitable. Another factor that is the generator output during the fault means during the fault, during the fault, if it is the circuit and it is unable to feed the power, huge acceleration will be there, but if it will be feed power something to the system, then still it is less severe.

So, this is a function of fault location and the fault type which type of fault has occurred, where is the fault all these are the dependent so that you can say fault location. Fault type is also the factor which influence your transient stability of your system.

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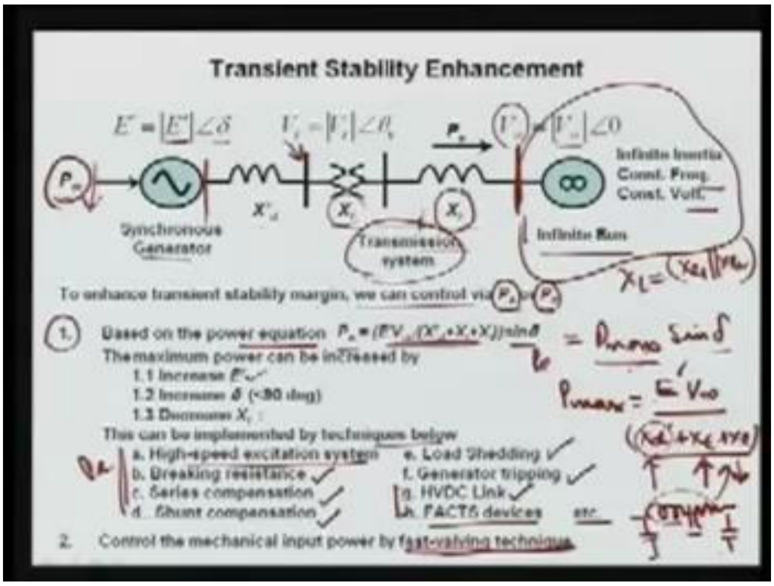

Now, once we have seen the various factors again to recap, you can say the post fault reactance is one factor the fault clearing time, second factor inertia of the generator third factor internal, thermal voltage as well as the infinite base voltage magnitude. Here, the loading prior to the disturbance, the internal reactance of generator and the generator during the output during the fault all these seven factors influence. Now, to improve the stability, these factors can be looked upon these factors, how we can go for the better that we can improve the transient stability of the system?

To understand this again, we have to take a simple system here I have taken only one line so that we can see what is that going to be that is why it is very easy basically or you can say you have the two lines and the equivalent area is represented by xl. It means if you are taking the same previous example, so this xl is nothing but your xl 1 parallel to your xl 2, very simple we have represented by a single here transmission line. This is your synchronous generator that is pm is your mechanical power, so into this alternator this is x d prime is a internal reactance of this generator, x t is the this reactance of the transformer and this is your terminal voltage of the generator.

This is your internal EF prime, just I have written just delta this is the infinite this v infinite it has a magnitude v infinite angle 0, we are taking all the quantity with reference to here 0 at this bus. So this has another you can say theta here is theta v and we have represented this completely. So, this is your generating system this is your transformer this is your transmission line or you can say including the transformer as well as transmission line is called the transmission system. Then, we have the infinite bus means we have resistor the system, an infinite bus is as again I should recap that it is a having the infinite inertia of the system constant frequency and constant voltage that whenever we are taking power from that bus.

They will be not changed and that is why it is called infinite to enhance the transient stability margin, we can control via p or pm we can control here that we enhance transient stability margin, we can control via either pm p e or here it is a pm. So, first one is the based on the power equation that is p e and p e is nothing but it is the voltage here magnitude. This voltage magnitude divided by the total reactance here this x d prime plus x d plus x l here, sine delta is angle between this bus and here at this bus that internal line to maximize the power. It means this p max the maximum power can be increased here, this is value this is your p max or we can say it is p max sine delta.

So, this much we can maximize if this value is maximum, then we can say the system is more stable, you must always clear this, if it is more means system is more stable. So, this can be maximum if we can increase e prime because your p max is nothing but it is your e prime here I have used v infinite here we have this x d prime plus x t plus your x l. So, here we can this can be increased by increasing this e prime, we can decrease the x l or even though anyone if we can decrease any of the impedance, then p max will be decreasing.

So, these are for the p max or we can increase this delta, then we can increase the electrical power. That electrical power can be maximized by increasing because here x d once machine is generated machine is constructed machine is installed we can adjust this transformer is used, we cannot do. So, x l here we can do somehow means using some compensation technique, we can use something but effective xl can be reduced. Once line is constructed, it will have some here resistance and some inductance and some charging here as well. These parameters are the line constant and they cannot be changed this is a physical parameter, but the effective value.

Suppose you are putting some capacitor here, then what will happen this x is compensated with this negative reactance of this capacitance so we can reduce this x l by using some extra apparatus extra device or extra element in the system. So, how we can do this? So, this can be implemented by the techniques below, first we can use high speed excitation system means very effectively, if can increase this e prime, so we require the high speed excitation AVR that is automatic voltage regulator. We can have some breaking resistance, we can use some series compensation, we can use some shunt compensation, we can use some load shedding, we can use the generator tripping we can use some HVDC link and we can use some FACTS devices.

Well, again this FACTS device we will discuss in module number four and we will see all these to in that module. So, this is etcetera several other terms other can be implemented, so the two control this is the basically for the electrical power just controlling this. Another is to control the mechanical input power by fast valuing technique means when you are the fault is there the machine is accelerating. Anyhow if the pm can be reduced during that time effectively very fast because here we have taken in our analysis, this pm is the constant during that 5 to 10 second because though it is a mechanical device that stream is coming to your turbine, it is not possible to stop.

So, if you can use some fast valuing techniques, then we can reduce this during that period, so the acceleration during the fault will be minimized, so the delta change again can be minimized. Once this delta change is minimized, means the change in the deviation is less, so the acceleration energy is minimized. So, you require the less deceleration part and then your system will be very stable. So, we have to go one by one, first I said we require the high speed excitation system means automatic voltage regulator.

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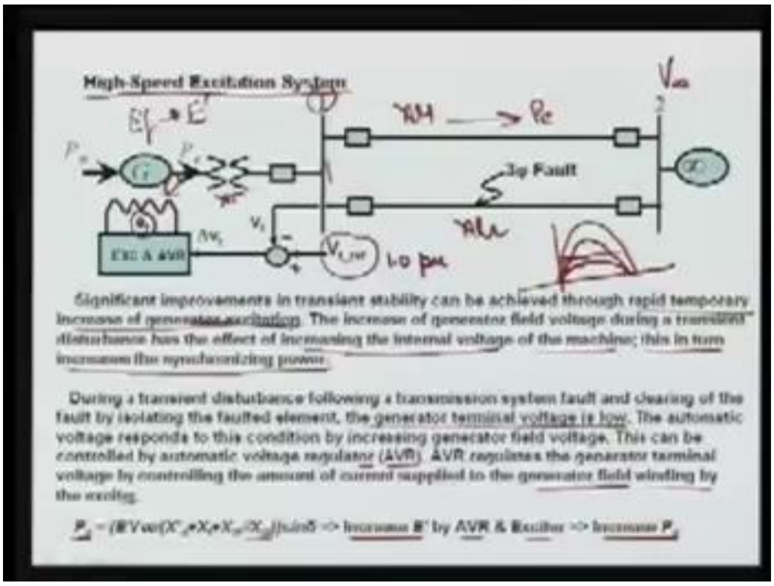

So, this is your generator the terminal voltage is measured and this terminal voltage basically compared with the some terminal voltage reference value. Normally, this voltage, let us suppose is one per unit or it maybe 1.5, 1.05 per unit and this voltage is measured. So, this is basically here this plus minus this is varying some difference in reference setting this terminal voltage is not equal to your reference setting. Then, some error signal will be coming here and this is your excitation and the AVR system will change your e of Er. So, this is our called the in the in the air loop of the system or you can say excitation system of your alternator.

So, the significant improvement in the transient stability can be achieved through the rapid temporary increase in the excitation system of the generator. I am not saying that you should operate your excitation system, every time higher value because that may lead to another problem if your excitation is every time higher, what will happen? The field current is very high and that field current will cause more loss in the system and that may your system your generator alternator may not operate properly and it maybe you have to cool down, means you have to have a proper cooling for that so far.

For the temporary purpose, once fault has occurred, then you can increase the Efr momentarily for few seconds that is no problem. With that, there is a there will be not excessive heat, but in history state excitation increasing every time higher value may not be possible and that is also not advisable.

So, during temporary period you can even though this excitation can go very high value and then you can increase the pm, and once you can increase the pm, means you will have the more stable system. So, the increase of the generator field voltage during the transient disturbance has effect of increasing the internal voltage of the machine, and thus in turns increase the synchronizing power. So, it will increase the synchronizing power and therefore your system will be more stable. During a transient disturbance, following a transmission line fault and the clearing of the fault by isolating the faulted element the generator terminal voltage is low.

The automatic voltage responds to this condition by increasing generator field voltage this can be controlled by automatic voltage regulator that is AVR. AVR regulates the generator terminal voltage by controlling the amount of current supplied to the generator field winding by the exciter. It means during that transient disturbance, following a transmission line fault and once it is cleared by isolating the faulted element, this generated terminal voltage is very less because let us suppose this line is faulted. It is tripped the power, which is going here this p e the x more, so this voltage is normally reduced because we are feeding the power.

This voltage due to the drop etcetera this fault is this voltage is reduced, so by this we can changing this excitation, we can increase this voltage, and then we can again we can improve the stability of the system. You can see this p e that is equal to your e prime v here, this is your v it is written here, v del infinite this is your e f. Here, in this case means e f is nothing but your e prime divided by all these three here your x t, x t of this. This is your parallel of x l 1 and this is your x l 2 here, I have written sine delta so that to increase the e f by AVR excitation, we can increase the p e during that time.

If the p e is increased again, we can see you can see this curve here this was your here and now during the fault this and this was like this. So, if you can increase this your system was operating here, it was coming here, if you can increase this by this, then your area of your e will be reduced. So, again the acceleration part will be minimized and once it is less your system will be more stable in that chance. Now, let us see the impact of AVR and with and without AVR, we can see how the system is stabilized with the help of AVR.

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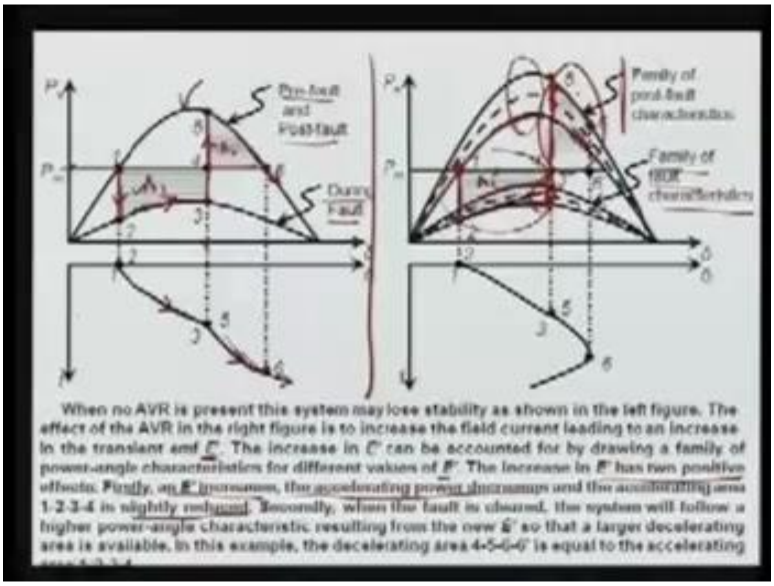

Here in the left hand side, you can see this picture here this is the graph I have shown. In this case, again I am assuming here, this previous case here the fault is there, but this line is intact after the fault is cleared, means this is the three base bus fault that is I have shown in this case, what is happening? The post and the pre fault curve is this one this outer curve is a pre fault and the post fault condition. It means your impedance is not changed, means lines are intact g t is intact and your of course, generator is connected to the system. During fault, let us suppose we have this consideration this fault that is during fault this curve.

Now, we can see if you do not have AVR and the by the chance there is fault is not clear before the fault clearing angle means your here machine is loaded with the pm means your operating point is one during base state. Once fault has taken place at the bus, one you are and then it is coming to this because during the fault your p e curve is following this one. So, what will happen? Now, this will go and it is accelerating means now you can see delta is keep on changing with the time. So, it is reaching at the point 2 here in the delta, lower is the delta curve with respect to time, this is the power with the delta curve, so you have reset here and now your fault is clear.

Once fault is cleared, now you can see from here this curve will jump to 0.5 because post fault condition is similar to your pre fault condition, so it will follow the p e curve of the top one.

Now, here this was accelerating this was a one that is your accelerating area, now this will try to go here and this is your area two and you will find let us suppose your a 2 here is less than your a 1, so what happens? Your system is unstable, you can understand with this what is happening from 5 to 6 again your angle is increasing, but the machine is retorting this letting because the p e is more than pm. It means you are taking the more power than you are feed, so what will happen? Machine will try to retort, but still it is more than synchronizing speed. So, it will be coming here at the point 6 and still it is fine that is a lot of kinetic energy is stored and it is not relive that energy, which was they stored, here it is not relieved in this area is less than this.

So, it will keep on moving and you can say once it is a crossing the point 6, what happens after crossing? Again, this machine is going to accelerate, so this happens that it was trying to this delta was increasing it should come back, but it is keep on moving and it is going beyond the control and therefore, machine become unstable. Now, let us see the impact here and then your right hand side, so the effect of AVR in the right figure is to increase the field current leading to an increase in internal EMF that is e prime or ef we are trying to increasing. Now, you can see a different family of curves we have, means all these here this three curves they are the family of post fault characteristic.

Here, all these three are your the family of faulted characteristics means during the fault curve and again if we are keep on increasing f, so you will have the different magnitude and different curve stage will be getting. So, increase in the E f can be accounted for by drawing of family of power curves for the different value of e primes. The increase in e prime has the two positive effect firstly the higher e prime increases the accelerating power decreases. Now, you can see during this condition means this is let us suppose your machine was operating at this point and this was your pre fault condition. Now, once machined, there is a fault here it was coming here and in the previous case and it was going like here.

Then, it was coming here; it was your complete area like a one in this case when it was in this case I am talking. So, now what I am going to do? If we can increase the field excitation, what will happen? Here, the peak of this lower curve that is the family of fault is curve here it will be going up and then we can have the dotted line. So, what is happening? Let us suppose we have increase, then we are having this characteristic.

Now, what happen your accelerating energy that is energy stored during the acceleration is reduced. Now, this a one prime is less than the a prime of the previous case, so the first effect is by increasing the e prime the accelerating power decreases and the accelerating area here is reduced slightly. Secondly, when fault is cleared now in this case in this zone, now we will let us see we have seen here a one prime is reduced means area of accelerating is reduced that is very important means the energy stored is less.

When fault is cleared in this zone, the system will follow a higher power angle characteristic resulting from the e prime so that the larger decelerating area is available. So, here what is happening this larger if we are increasing this E f we have increased, let us suppose here after this clearing we have increasing here what is happening this area, you can say now increased obviously it was only this area. So, we have these letting area is increased, so this machine will go back and it will be one area a 1 will be area a 2 here.

It means we are going to increase the margin and we are increasing the stability margin of the system. So, in this example that decelerating area that is a 4, 5, 6, 6 prime is equal to that rating 1, 2, 3 here in this case, so by increasing this AVR, using this more excitation during the fault and the post fault your system is stabilized. Once system is again stable stabilized, then again you can operate to it is a normal value there will be no problem. So the with the help of AVR automatic voltage regulator we can improve the stability of the system. Now, another impact let us see the breaker resistance, means here there is a breaker which is having some resistor.

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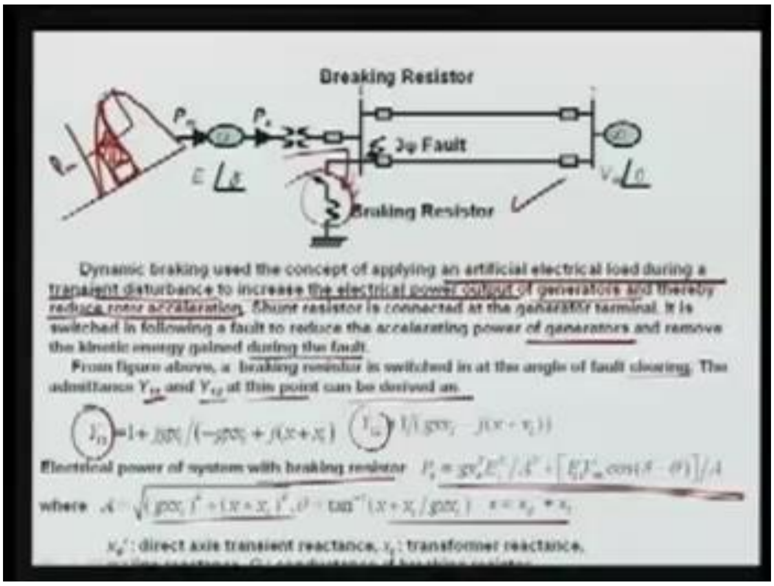

So, the dynamic breaking used concept of applying an artificial electric load, during a transient disturbance to increase the electrical power output of generator, thereby reduce that rotor acceleration what we are going to do. If there is some fault in the previous case, we saw that if it is a voltage fault at the bus, what is happening? It is suddenly you can see here your system is operating like this, here is your pm, it is suddenly coming to 0 and then it is going and then it is accelerating like this. So, what is happening? It is suddenly 0, so anyhow if we can this P e that is can be increased means we want some P e value, means we can do something here up by using some dynamic resistance.

Some putting some resistance in the circuit using the help of the breaker here some breaker here dynamic resistance is used, what will happen? This will deliver some electrical power and thereby this area is now reduce here it is less than previous area here it was this area. So this breaking resistor is basically dynamically added to the system and once the fault is cleared then we can remove this resistor. So, the shunt resistor is connected at the generator terminal, it is switched in following a fault to reduce the accelerating power of the generator.

It means now accelerating power of the generator, means the electrical power which is taken out is increased so that we have the less accelerating power and remove the kinetic energy gained during the fault from above figure means this figure this I am talking. Our breaking resistor is switched in at an angle of fault clearing the admittance y 1, 1, 6 and y

26 at this point can be derived here. In total, just I am not going in the mathematical complexity, it is better that we can see the effect of this means simply we are of what we are doing the electrical power. We are taken from here and thereby we are reducing the accelerating we have seen and that means your delta increase is during the fault condition.

So, we can here at this bus we can form the y 1, 1 and y 10,here and we can get what we will be seen impedance at this bus. Then, the electrical power of system with the breaking resistance can be calculated by this equation, where a will be this it can be mathematically solved and which should not go in the ma complex mathematical derivations.

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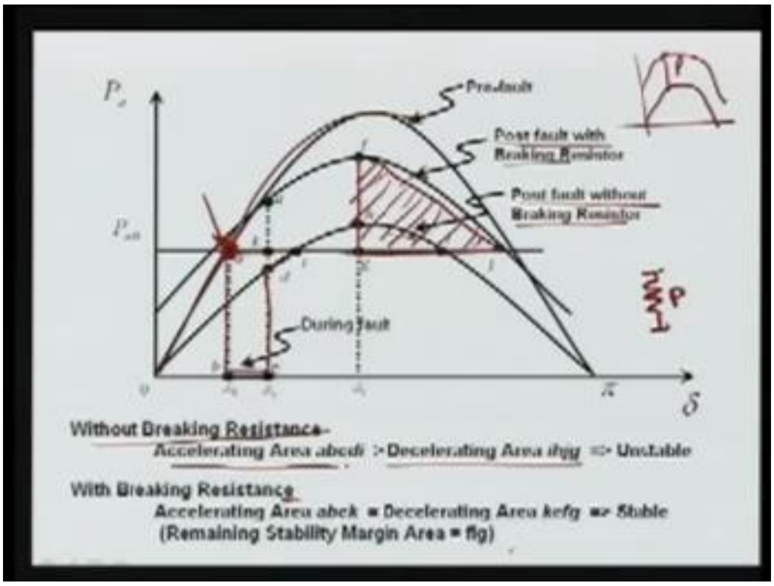

Now, here you can see with the breaking resistance and the without breaking resistance, with this curve, I think it is more clear this is your pm where the machine is loaded. This is was your pre fault system this is your pre fault system and here your point is your operating point. Now, once fault has occurred during the fault it is suddenly here it is coming to the 0 this is from b 2 c means without breaking resistance the accelerating area abcdi, abcdi here because here the post fault without the breaking resistor this is your post fault. So this area that is more than the decelerating area that is your i j where is i this i h j and g means this area.

So, here your this area basically d c d i this area here this area is your less than this area and this area is more than this area and unstable case, but if you are using the breaking resistance, here what is happening? Your post fault with the breaking you had increased your resistor parallel. You have increased some more resistive power, it is not ax it is resistance power that is added here directly this real power. This is the resistance you must know this is resistance, so the only this real power p and this p is added together on this curve. It means you are here, this is your p delta curve, if you are adding some resistor at this, so this curve will be like this it will be added this p that is going in the resistor.

So, this curve is lifted here and then you can see the ac accelerating area ab is ABCK will be equal to the decelerating area KEF apna ciket here this area we getting and then we have more margin you can see here this is the margin just we are having. So, your system will become more stable, so this is you can say the impact of your breaking resistance.

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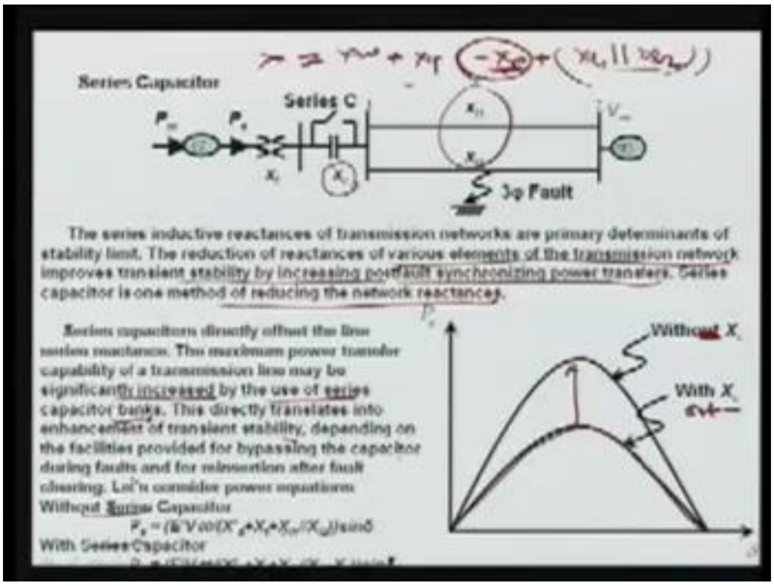

Now, we see your series capacitors means we can use in series capacitor we can also improve the stability of the system and we can also say that we can improve the stability margin of the system. It means your system will be more stable if you are using series capacitor or you can say series compensated lines. The series inductive reactance of transmission line network are primarily determinants of stability limit because we have added this x. The reduction of reactances of various elements of the transmission network improves transient stability by increasing the post fault synchronizing power transfer.

The series capacitor is one method of reducing the network reactance as a now if you are using this x c here this parallel impedance your x l parallel to your xl 2. Now, you are using here plus here it is minus of this line plus your x t here plus your x d prime. So, this is your total x, so what is happening this minus x c is reducing your x, so we can see width is here if your x here is a.

I think this is shrunk here, this the width x c you are getting more because your x c is reduced and without x c here you are getting less p max means p max is changed. So here this is without x c and with x c, your p max is increased and thus the system is going to be more stable A series capacitor directly offset the line series reactance directly offset means directly reduce here x is simply it is reduced here. The maximum power transfer capability of transmission line maybe significantly increased by the use of series capacitor banks.

This directly translate into enhancement of transient stability depending on the fault depending on the facilities provided by bypass the capacitor during the faults and for the reinsertion after the after fault clearing. Let us consider the power equation without series capacitor and the with series capacitor without series capacitor. Here, there is no minus x c, but here we have used x c component as well, so what is happening now? The P e here is the with x c is this one and without here this is your x c.

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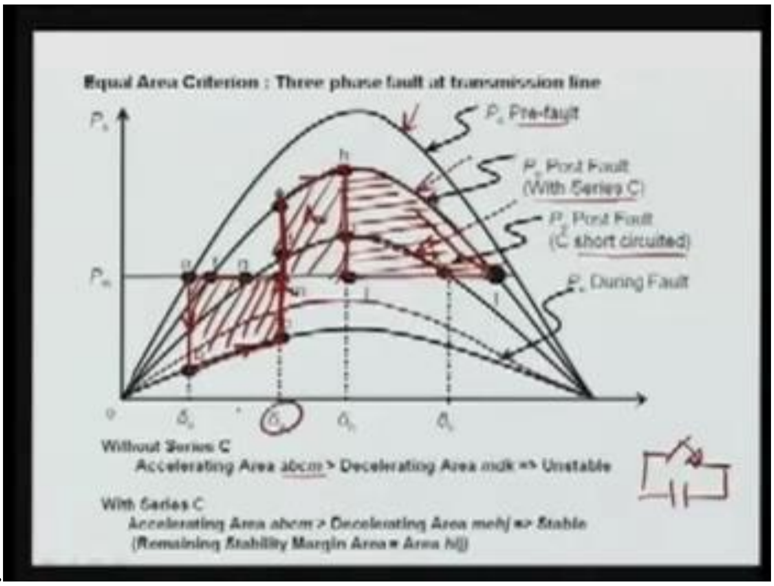

To understand this with c, without c, you can see this is your pre fault curve this curve outer curve your post curve here we have the two post fault with your series capacitor and here post fault with c short circuited means without capacitor. It means your capacitor is here you can have some switch here. You can start it by closing or you can open then it will be inserted into the circuit and this is your during fault condition.

Now, we can say without here means without capacitor what is your condition here, this is your system after fault is coming, once your fault is cleared this is going at this point and then it is now going to accelerate here. So, now you can see your area here this area your ANCM your ABCM area, this area here that is more than this area that area that is a decelerating area it is your MDK, this area is less means your system is less stable. It means here is the area is less means it is not a stable at all, but there is a possibility if clear your fault this then you will have the less margin. If they are using the series and again this is after the fault or we should mind during the fault if we are putting this what will happen this may create another problem.

So, here this value if we are putting the c what will happen? This will be another curve here and again this may be used in that in the period. So, if we are using the capacitor, what is happening? Your operating point at this now after this here it is going like e point so this is your area. Now, it is coming here and you will find if this area here this shaded area a 1, now will be equal to your a two this area two here your system will be again going back and system will be stable.

Now, you can see you have this much margin is a huge margin you are having this is your margin and your system is very stable. It Means you have a more stable region even though your fault is cleared after delta a still your system is stable. So, you can say the series capacitance that can improve the transient stability of the system or in other wards you can say it will increase the transient stability margin of the system, means it will be more stable.

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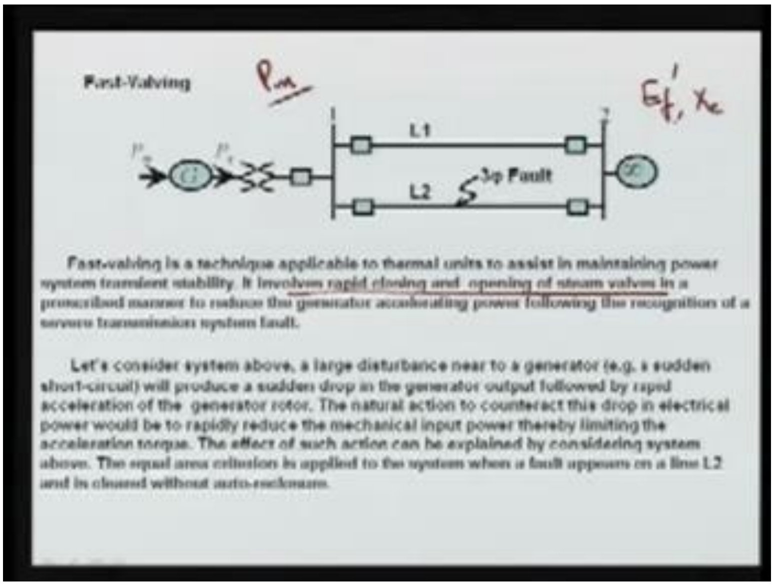

Another, let us see the impact of your fast valuing of your pm that is we are going to till now just we are looking at the P e now here we are going to see the pm correct. So, let us see the impact of the fast valuing action in which previous three slides and three cases for improving the transient stability. We say that we can change we can improve the transient stability by E f or you can say e prime by you are changing your x c, means you can put this x c in the system and we can improve the transient stability of the system.

Now, it is a and the another side that is your pm that we can change the mechanical output of the system during the fault and the post fault, what is happening? If it is it can be basically done by the rapid closing and opening of the stream valve in a prescribed manner to reduce the generation accelerating power following the recognition of a severe transmission line fault, let us see this.

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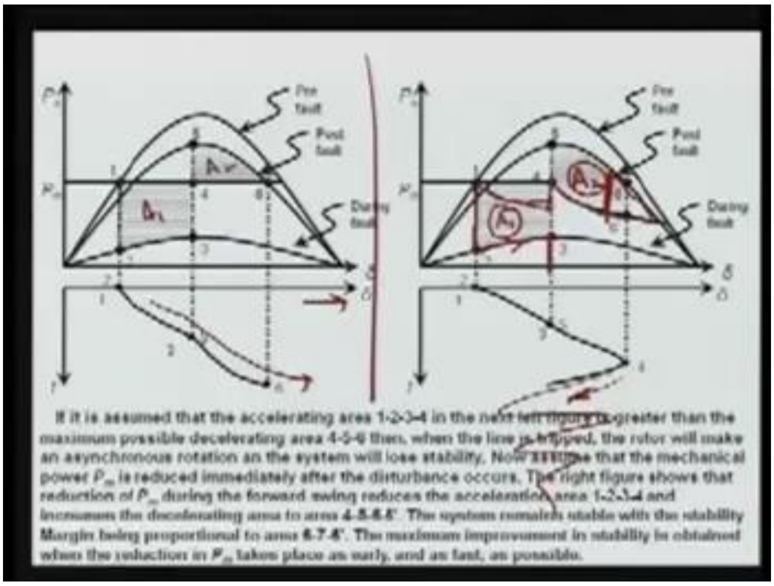

Here, this can come here this is the left hand side is the diagram when there is a no fast valuing action is there. You can see this area a one is more than your area two and your system is unstable already I explained this when I was explaining your E f system means with AVR action. Now, in this your right hand side you can see when the fault occurs here means your system operating at the point one and the fault occurs means your point is coming here and this is your though it following your P e this. Now, again if you can have a very fast action, so you can change at this point 1, fault has occurred, you can reduce this pm as well, here for example you can reduce the pm.

So, what will happen? Your this isolating area will be reduced, but this time is very fast and it may not be possible let us suppose, but even though they are fast fault is cleared at this point. Then, during that period again we can reduce this pm, and then what will happen we are increasing here. The decelerating and here we are increasing your decelerating area a two and we are decreasing your accelerating area. So, what is happening we are improving the stability of the system, means again it can be you can have more margin, means you can have even though system clear before and your system will be stable means you will have more margin here.

So, you can see the here delta which was keep on increasing beyond this point 6, but here at this point your delta is going back and we can say here you delta is stable. So, this is your delta with reference to the time, so we can see with the help of this fast acting value means ripe it closing them opening of the stream valves. We can again improve that transient stability of the system, so we have seen in this lecture that how we can improve the transient stability, what are the various methods to improve? It means we can solve the differential equations.

First, we discussed about the various methods including your Euler's method, modified Euler's method, Runge-Kutta methods and then of course, the trapezoidal methods. Then, we saw the various way to improve that transient stability, along with that we also saw the various factors though the influencing the transient stability of the system.

Thank you.