Power System Operations and Control
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Module –3
Lecture –7

Welcome to lecture number 7 of module 3.

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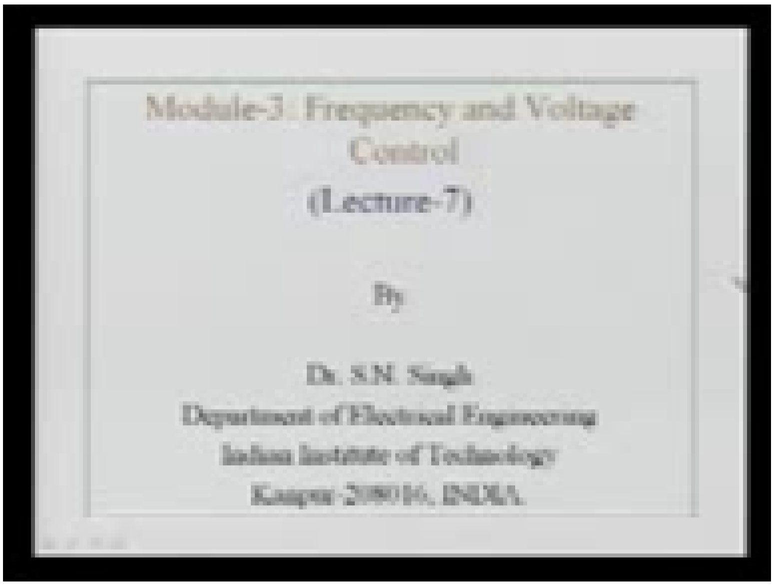

In this lecture onwards I will be discussing about the voltage control. In the previous lecture from 1 to 6; we saw the modeling and how the frequency will be controlled of the system. So, the voltage control basically related with the reactive power control, means: the reactive power and the voltage both are related to each other. Now, let us see that how a generator can control your frequency as well as voltage.

So, we can have this picture.

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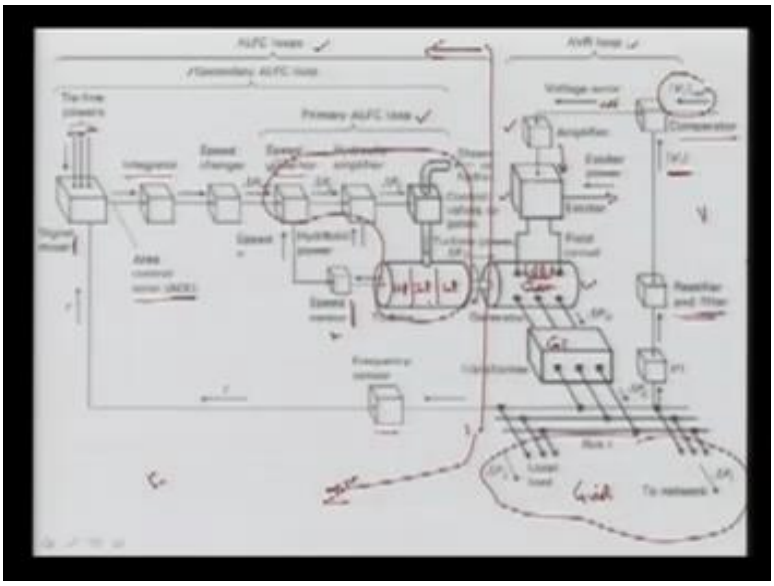

This part you can see now it is your generator here. This is generator which is rotated by your turbine and turbine here may have the different stages. It may be your HP state; it may be your LP state. Basically it is first IP, then it is LP state and the steam is coming here and which is that steam is giving energy in terms of rotational energy and then here your generator is coupled. Now, this generator will be giving supply, through you're here generating transformer and finally, it is going to the grid and or you can say network.

So, this part, you can say your left hand side is started from here. We saw this is nothing, but it is you ALFC loop that is automatic load frequency control loop. And already we modeled the primary ALFC loop and then also we saw the secondary ALFC's loops. So, to see visualize physically, what are the components those are acting here in your secondary ALFC loops or you can say complete this automatic load frequency control loop.

Now, you can see here the system frequency here. This is your network and it is going to here this… or you can say connected with the main system. So, the frequency which is here measured by the frequency sensor. So, this is your frequency sensor and this is giving your F and now finally, it is coming here in that also here we are measuring the tie power tie line power flow. You remember that, we require the tie line power flow as well as the frequency when I was discussing about the AGC logic.

So, here we are measuring the tie line power flows, means: the area where they are connected, what are the various tie lines and then it is signal. Finally then, from here this block is nothing, but if you remember it is giving your area control error ACE if you remember in the previous lecture. That ACE is integrated because; we have to use the integral controller, so that is why it is written here the integrator.

So, we use the integral controller to reduce the error in terms of your frequency and your tie line power flow. Then it is to do this what we do; the speed changer that is the input to the speed changer that, whether we have to increase or decrease; it depends upon what is the input coming here and that it is decided by your ACE that is the area control error. So, a speed changer command will be given. Then this command is passing through the your governor. Here the governor, already we modeled the governor along with the time constant and the governor gain. And then it is coming to some hydraulic amplifier here basically and then it is turbine.

So, hold this block basically this block we model completely in 1 here governor. Then we model the turbine. Here also we can see that, we are just sensing the speed and then we are giving to the speed governing system. So, there the 2 things; here it is measuring your speed thereby frequency and then it is controlling. So, this complete loop up o this part we model here in model analyze in the previous that previous 6 lectures.

Now, we are coming to the AVR loop. This ellipsis of course, it is controlling your frequency F. Now, we are trying to see; what will be the control of the voltage by the generators. Now, here also this system that is s s here, this basically here it is AC voltage. Then we are using some rectifier and the filter circuit and then it is giving your V magnitude at terminal voltage. And once it is compared with the reference value here, the voltage reference is compared with the and that error change in the voltage error is given to amplifier. That will amplify because; this magnitude is very very small. And after amplification here it is going to your exciter and this exciter is providing the field current to your alternator here, this is basically binding will be there and it is doing that.

So, we can also sometimes give some auxiliary signals to the exciter. It is not only voltage; we can give some other signal we will see later on. Then here we can give some auxiliary signal and then it is called some power is given to you. Now, here this exciter as you know it is also require some power and that power basically comes from this router. So, normally this exciter is rotated to this rotating body of the turbine here. So, we give some input power and we will see the model. So, now we will model here this amplifier. We will model exciter. We will model here generator and using whole this loop it is a 1 loop it is called voltage control loop or sometimes called ABR loop, sometimes also called here the system of alternators.

So, here now we are discussing the voltage control. It is the part of alternator. We will see if there are other devices in the system, they are also trying. They can control your reactive power and they are the voltages.

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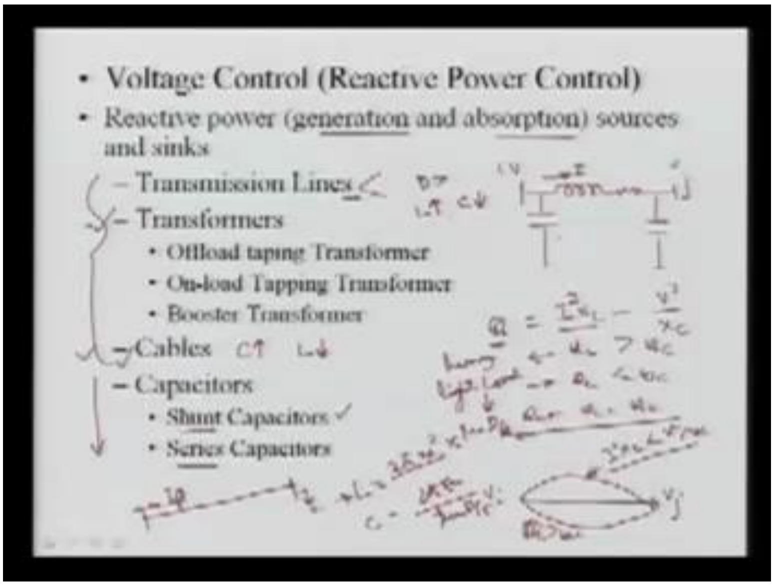

So, see that here let us see; what are the various generation and absorption of the reactive power sources, in your complete electric power system. Electric power system once again I want to repeat that, electric power system consists of your generators, transmit some lines and the distribution system. So, it is complete, so where who are going to generate reactive power. Who are the elements; those are consuming reactive that is we are going to analyze here. Then we will come to the sources and then we will describe accordingly.

First element here of course, no doubt we start from the generators, but I will discuss generator later on. So, we have to start first under is your transmission system elements. And the transmission system elements are normally here, they are these 3, means: the transmission of power is carried over on the transmission lines through the transformers and the cables. Transmission line here; they are they are called that they can generate reactive power and they can also absorb the reactive power. How they can generate and how they can absorb it all depends upon the loading of the system. Why I am calling this because, a transmission line if we can model here; this is your transmission line reactance, then it will have some resistance and that suppose I am modeling as a pi equivalent so here what will be that? This will be the charging capacitance. Here suppose a pi model. This is grounded and this is between pi 2 j.

Now, whether it is this whole element is generating or absorbing; it depends upon how much it is consuming and how much it is generating. Now, the consumption here let us suppose this current is flossing I here and the voltage here let us suppose the V constant at all buses; that is a your sending end bus and the receiving end buses. So, I can say the reactive power absorption is your nothing, but your I square X L will be your reactive power absorption. But you know these reactors are the good source of reactive power absorption, the capacitors are good source for generation of reactive power.

So, these capacitors will try to generate and they will how what they will do; they will generate here x square upon X c, here X c is including both. So, now it depends you're the reactive power here Q, whether it is positive or negative. If this value is negative, then we can say this is generating reactive power, means; if this minus this means this is loss, this is generation, means: absorption minus generation. If this value is negative, then we can say this transmission line is generating reactive power or if it is positive then we can say this transmission line is absorbing reactive power, how come? You can see there is 2 elements the voltage.

The voltages normally the operating voltages are variation is very limited, means: it will only change plus minus 5 percent or maximum plus minus 10 percent in the lower voltages system. But the current it can go from 0 to value. So, this value varies quite high. It is quite more compared to this. This is almost constant. So, hold this queue basically depends upon this current I and that current I you know it is called the loading of that line.

So, if this transmission line is highly loaded, there will be possibility that this component will be more than this and finally, this will be positive, means: this will acts as absorption of reactive power. Similarly, if line is lightly loaded very less loaded, let us suppose this is 0, this will be here negative value is coming. So, in the light load or no load condition once line is energized then what will happen; this component here will be your I can say it is Q L, here I can say Q C and this will be your condition of that 1.

So, under the light load condition this is the condition, when the light load condition is line is loaded lightly light load. And this condition when it is heavily loaded or heavy loading condition. There is a possibility that both this Q loss that is absorption will be equal to your Q generation then what will happen? Your Q will be 0. And that condition is called the flat line, means: when your total power generation and absorption is matches together, means: there is no reactive power generation or loss or absorption, then it is called flat line. And the voltage throughout this transmission line will be the flat and it is constant.

If you see the voltage profile here, let us suppose the voltages at these 2 ends are fixed and these are value as your V, then the condition here that voltage will be like this, here you can say V i, here it is your V j magnitude I am talking. And there is a possibility that voltage will be like this or voltage will be sliding like this. So, this will be the condition when, you’re I here is more, means: this condition when your Q L is more than your Q C because, it is going to absorb and the voltage will fall. So, voltage will you can say; the voltage will be lesser here in the middle of the line.

Here the reverse is true, means: here the basically your I square X L here will be less than your V square upon X C and this is called light loaded condition. So, you can see the voltage profile between the 2 modes; if the voltages are fixed it will be changing depending upon the current, which is flowing through this transmission lines. So, we can say the transmission lines can generate or can absorb reactive power and it all depends upon the loading of the line. Normally discharging is very very predominant, when we are using very extra high voltage transmission line and also if the line length is very very large. For the transmission line, this value will be very less and always they will be either flat or it will be in nature.

So, all we know the transmission line can be categorized as a short line, medium line and long line. Especially for medium and the long line, we can have all these types of possibilities. So, this transmission line can work as a generator or work under absorpter absorption of reactive power, means: both it can do. Now, let us see the transformers. It will draw the transformer equivalent circuit.

The transformer equivalent circuit it will see here, I can simply say if we are some part is ignored.

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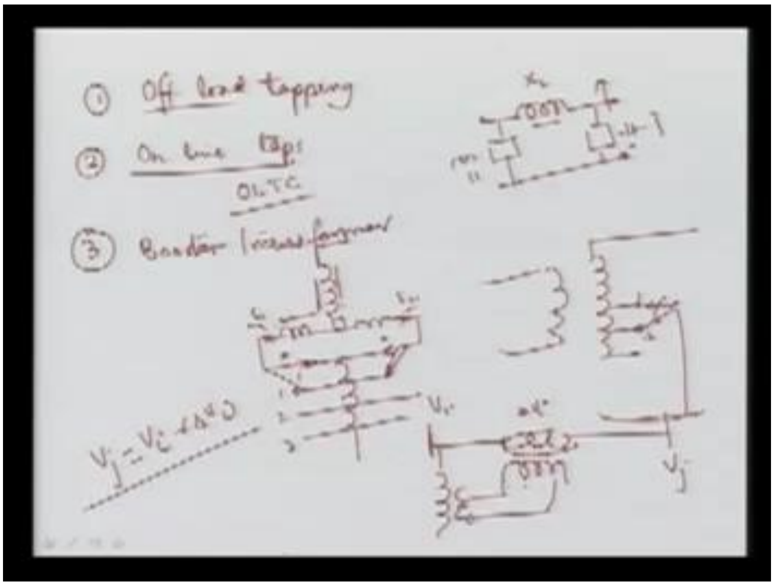

Normally this is simply a transformer. Although there will be part and that some part are basically denoting your this core loss as well as the magnetizing loss and that if we are ignoring, then we can say it is simple your X L. There is no capacitance at all. There will be some resistances, but this X L of the transformer windings are very very high compared to the R. We can even ignore that resistance as well.

So, you can say this is a perfect inductor. So, in all kinds, in all the cases, whatever the loading is this transformer will work as reactive power absorption. So, the transformer consumes the huge amount of reactive power compared to other elements in the power system. No doubt the reactors, reactors are also some sort of transformers, simple windings are there. So, they are also having huge amount of reactive power. We will see later about the reactor.

Now, the transformers again can be of the different type. The transformer here as I said we can have some transformer with the tag changing positions, means; it is called let us suppose your off load tapping transformer, means: normally some transformers are provided with the some tappings, whenever the voltage is going to be less or we can change the tappings and then we can increase the voltage or so. So, what we are doing with the changing of the tapping, it is nothing, but we are trying to provide some reactive power. For example this is your line; with the help of tapping some if you can model here we are providing another device, here we are providing another some sort of generation. So, 1 end it will be working as a inductor and 1 end it may be working as a capacitor, but addition here is always 0.

So, by changing the trans tappings, let us suppose you are increasing this the tapping, this will work as a capacitor and you will try to increase the voltage of this end. However if you want to go for the lower, then it will work as inductor and this will work as a capacitor and they are so on so forth. So, it is called off load because, we cannot change the tapping during the on load condition because, if you are changing the tapping for example, let us suppose here you are having a tap, here these are the values tapped and suppose here just you are having right now and it is your connected. This is let us suppose your primary, this is your secondary. You are just changing from here 1 position to 2 positions. There is some open circuit and that will be will be generated.

So, what we do to avoid that and also there is a huge voltage here difference between these point 1 and 2. So, what we do; first de energize then we move to switch 1 to 2 and then we can again energize. So, it is called off load tapping position or tap changing transformers. And the tapping changes, by the tapping we can change the voltage of that end; either we can increase the tapping voltage will increase. We will decrease the tapping then again it will decrease.

Another transformer here since it is not always possible that to de energize the transformer and then go for the tapping because, again that will create another problem because, your supply will be interrupted. So, if your transformers are small another thing then, we can go for the interrupting small load, but if you are working about the big transformer and the power transformer; those are you can say interconnecting transformer ICT's connecting 400 by 220 lines, it is not possible to de energize and then change the tapping.

So, for that normally we have the online tap changing positions. As you know, online means; that is sometimes called on load type changing, so here it is called OLTC transformer that is type changing transformers. They are used and here we try to do in such a fashion. Again the purpose is same that, we can change the voltage by changing the pattern of the transformer. For 1 example I can explain you how they are done.

Let us suppose you are having here the transformer winding. Here we are having also some winding and they are the different tappings are there, here you can see. Now, what we do here we have some 180 degree here. There is 90 degree bindings are there and then let us suppose we are having positions here as well as here. Now, this is your position 1. You can say right it is position 0. Here 1 2 and 3, what will happen? This is now only this binding is coming into the picture and the voltage is there.

If you want to change the position from here 0 to 1, we have to again as I said if you are suddenly changing there will be huge spot and there will be possibility of the breakdown of the insulation. So, what we do; we normally put here with the some features S 1 and S 2. First what we do; we open this, then we change here. In that condition what will happen? You can open this and then you can change here; however, it is connected. So, in that condition here, we are there’s some mismatch in the voltage here. This voltage is added here with this voltage.

So, that amount is very very small no doubt. So, but once you are here you have moved here then, what you can do; then you can open here, you can close this, you can open here and then you can shift here. So, in 1 operation you have to open close open and close. Hardly 6 and 8 operations required and then we can move in to this position and there is no need to de energize, means; in working condition we can change the tapping. This is called your online tap changes transformer.

Another transformer is also called the booster transformer. Booster transformers are basically nothing, but if you are having a transmission line, let us suppose here this is a transmission line. If any how we can change the voltage; we are injecting a series voltage in the transmission line here and that value basically coming from somewhere here where transformer and we are having some tappings here you can say, different tappings voltage we are adding. So, this voltage here this end basically we are adding with this V i here in this phase. And then here it is called the boosting transformer, means: voltage at the j, here it is your i will be nothing, but your V j will be your V i plus change in the voltage i and then if the voltage is boosted.

So, this is basically called the booster transformer. You again change the boosting the voltage. This is here we are adding the series voltage in that transmission line to increase the voltage control. Another device here as I can say, another device is your cable. We know that, the difference in the transmission and cables; the transmission is having the wires 3 different phases they are quite apart, almost it is 4 5 meters in that case they are 3 phases are allocated. So, what happens; the distance between the phases are very high. So, the capacitance formed here this value is very very less.

However in the cables they are very close to each other, again they are insulated by thick insulators, but they are very close. So, the charging value is very very high, but at the same time in that value will be very very less. We know that the distance, you know this L here how it is related with the distance. You know this capacitor here it is your 2 pi epsilon naught upon L n d upon R. Here we know the 2 pi into 10 power something into L n d upon R. This is some factor here we are using.

Now, if the d is more L will be more. So, in this transmission line d is more larger than what we do; here we get L higher value and C is smaller value. However in cable we will get the reverse here C higher and lower and what happens here, what about the loading? This x value is very small. This value is very very small because, this C is very large. So, the cables normally they generate huge reactive power. And that is why you can say the cable we cannot have more than 50 kilometers cable because, what will happen; a cable if you are having more than certain distance, normally it is 50 60 kilometer, here there is load is 0. You will be getting here the I fully rated current, means; if you are increasing the load here even though fraction of megawatt this line will function. This cable will function.

So, we have to go for the smaller distance cable and that is why the DC is suppose you want to have a bigger cable than required that is suppose you are connecting 2 islands, they are let us suppose 100 kilometers apart. So, what is the option? Only the DC cable. So, we have to have the DC transmission for that. So, these are the problems in AC already we have discussed in the very beginning. But the cables they are normally only generate reactive powers; they never absorb whatever the loading will be.

Another device is capacitor. Again the capacitors are used very widely in the distribution of system. Again they can be connected in the center of the system that is connected to the bus, to the ground in between or they are connected in the series of the 2 buses. So, if they are connected as a shunt, then it is shunt capacitors and other are series capacitor.

Now, let us see how we can analyze them.

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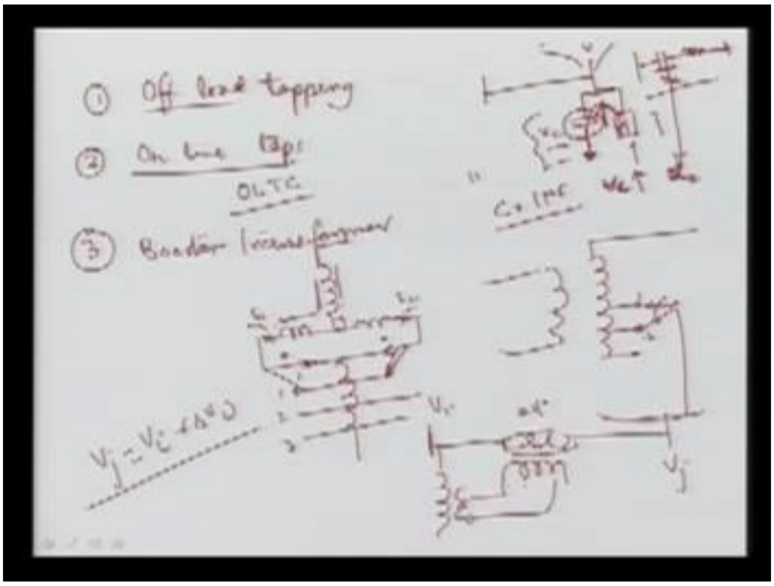

Now, this capacitor here; what I am going to do this capacitor if it is connected let us suppose here your this is your transmission line, we are connecting a capacitor here and this is your ground. So, this capacitor is known as a shunt capacitor and as you know this shunt capacitor means it is shunted from bus to this. Series capacitor; however, thus it is the transmission line and then we are connecting here and this is your I can say X C, here it is your X C .So, this is series, this is your shunt.

Again the purpose of these 2 connections are different. Normally if you are connecting the shunt here the purpose is to improve the power factor or to inject the reactive power here and to improve the voltage profile of the system. If voltage of the system is changed, there will be possibility the voltage of connections; they will be also affected and they will be modified. So, the putting this we are what we are doing; we are meeting the reactive power requirement luckily if let us suppose load is here connected and it is has a poor power factor. So, the reactive power it will be provided here. We do not require reactive power that flow and the transmission line.

So, the reactive power support provided by shunt capacitor, let us suppose for same value, let us suppose c value is you 1 micro ferret. If you are using as a shunt for same volt is here bus system, then the reactive power support here Q C, it will be larger than Q C supplied by the series here. So, always if your intention is provide the reactive power support you have to use shunt. Here X C is provided to compensate the reactance of this line. And then what happens? By this X C we can go for more loading of the transmission line because, you know this loading of the transmission line is nothing, but here what I can say it is your P.

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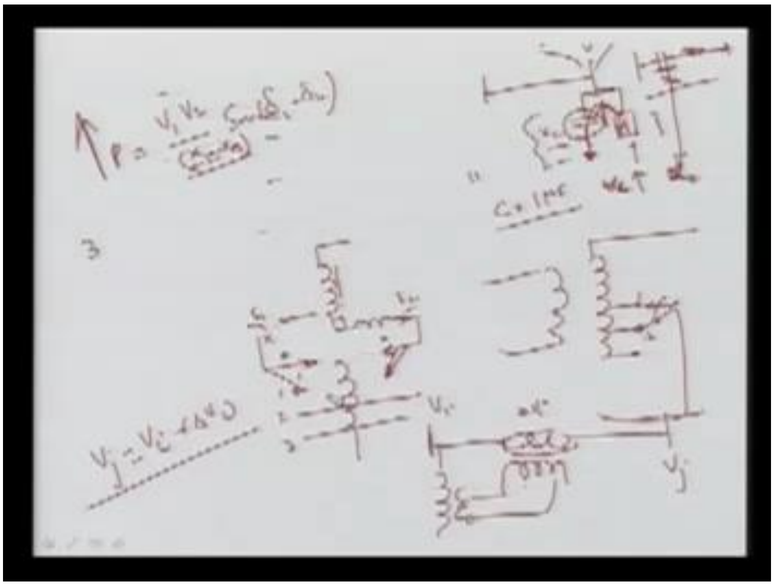

It is your V 1 V 2 upon x sine delta, delta or you can say delta 1 minus delta 2. That is a change in the here bus 1 and here. Now, this x if there is no capacitor this is your simply x L that is inductance of the line this reactance. So, what we are going to do; if you are putting this X C, then here I can say minus X C will be there and this value is now reduced. Then the power flow over this line is increased. However the power flow control effect of this capacitor is very very less.

So, now I can summarize here. Putting the shunt and series capacitor, means: your shunt capacitors.

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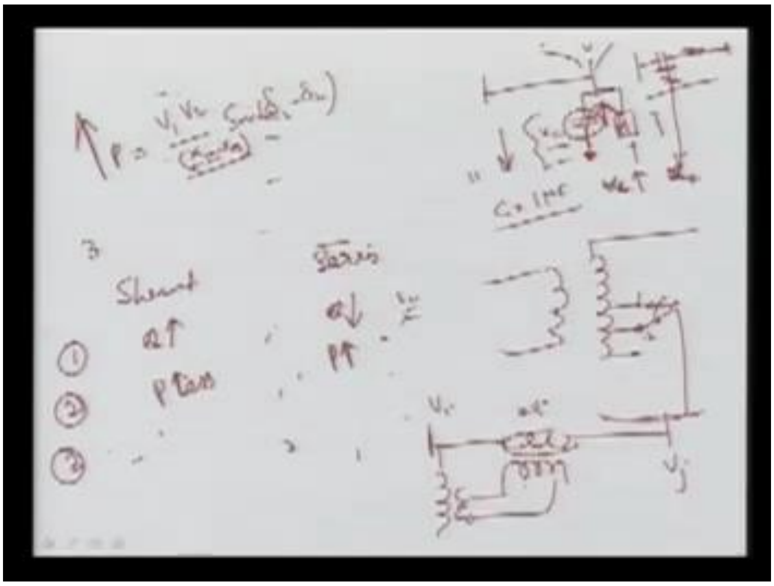

Here I can say shunt capacitors and here your series. Here it provides more reactive power and here it provides less reactive power, first difference. Here second here it increases the power flow over the transmission line. Here it is impact is less. So, I can say less power flow control, here it is more powerful control over the line also, here the insulation level. The third comparison you can see the in series here, this is if line is 400 then you have to provide this capacitor of the 400 level from here line to ground.

So, they must be protected very carefully and insulation level must be proper. Here no doubt this 1 is grounded here the high voltage and we have to go for that. So, normally if this capacitor is short circuited the is transient and never problems are caused, but here if short circuit, this will no doubt this will work as a fault, here this will not work as a fault. So, we can compare and we can go for the advantages and disadvantage. We will find the application of these 2 type of capacitors are different. Here for the voltage control always we go for the shunt. However if we want to control power in that line the series is better.

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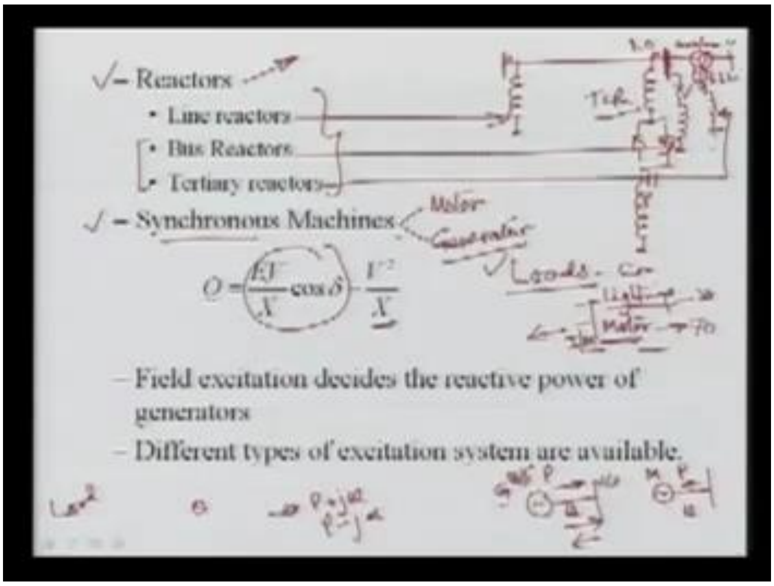

So, another device that is very popular and it is used especially in the extra high voltage system. It is never used in the distribution system. However the capacitors are very common in the distribution system. Always we try to meet the reactive power demand locally because, your loads basically they are the good source of reactive power consumptions. So, they are basically that reactive power must be met locally to take care of that. Another is you're here your reactor.

Again the reactors as I said they are nothing, but here these reactors are normally connected at the bus. Here this is your transmission line and the reactors here you can say simple here reactor and it is just looking like a transformer if you see. So, the reactors are basically used in the transmission line whenever there is a excess voltage, when you want to absorb the reactive power. And that situation occurs especially, when your loads are light means lightly loaded transmission session, at that time the lines are generating reactive power and the possibility of getting voltage of these will be very high. During that condition, means: during the light load and the no load conditions, we normally put the reactors and the reactors can be categorized again depends on the location will be the difference.

So, first 1 is your line reactors. They are basically the permanent connected reactors. Here in the lines they are connected, here they are reactors. So, at the both end normally are the line, the reactors are connected. These reactors here they are called the line reactors. And the purpose of that, they will absorb the reactive power and whenever there is some switching transient done in voltages; they will try to reduce that 1. So, they are used to reduce the dynamic power voltage as well.

Another is your bus reactors. Bus reactors here normally; this is your bus, here normally we use with some switch and here that bus reactors are there. These bus reactors are not permanently connected, means: they are normally in the off condition and whenever they require we can switch in and then we can switch it out where they are not required. So, this is your bus reactors. They are connected at the bus and normally they are connected in the service station. So, this is your bus reactor.

The primary objective is to maintain the voltage. When there is suppose your line is there going to be energized, this is your line is left suppose off condition, you are connecting your line, there is a possibility due to the fact. The voltage of receiving end will be higher than the sending end and then there will be the cost if, you are not reducing the voltage because they will picked up. High voltage, over voltage the relay will take care and then again it will be energized. So, we have to put the all the reactors in the system, then we have to energize the line. We have to connect the line with the synchronous system.

Another is your tertiary reactor. There is a possibility that, here we are having a transformer. And this transformer will have another tertiary binding and if you are connecting here the reactor in the tertiary binding, with the front switch here then it is called your tertiary reactor. Why we are going for the tertiary reactor? The main concern of these reactors that, these reactors are rated at the line voltage here. This is the voltage of the bus, so the here the insulation level and the cost is very high. But here what we can do if the tertiary bindings normally, let us suppose we are using here 400 by 220 transformers and it is having a tertiary binding of 33 KB.

So, this insulation level of this reactor is very very less and then it can provide this reactive power absorption whenever required. At the same time this tertiary binding can absorb the reactive power. That is triple n harmonics current in that can be circulated here. So, this is your tertiary binding. So, these bus reactors and there were tertiary bindings reactors; they are used especially when the overloaded condition, but the line reactors are permanently connecting the lines, whenever it is energized it will be connected. It is immaterial; what is the loading of the system.

Nowadays, again we are feeling there is a huge thrust in the voltage, means: voltage variations are very high. So, now we are talking that, why not we can put some reactor with the some we can put some TCR that is the control reactor. That is called TCR, means: we can control the reactance value. Why? Sometimes unnecessarily we are trying to reduce the voltage so that, we can maintain the voltage here to any control value that is per minute. But putting these, the cost will increase and nowadays in several places in here in India, we are having the TCR rather than simple your inductor that is reactor. So, that is also possible.

Another that is reactive power consumption or generation we can say. So, this device always absorbs reactive power. Inductor always absorbs, capacitor always generates. If combination of that, then we have to see what is the condition, which 1 is higher. Now, another that is before going to the synchronous machines, I will just discuss about the loads. Loads here you can see in your whole system. What are the loads available, we can go for the lighting load, lighting loads and another is called the motor load.

So, the loads can be categorized into 2 ways. The motor load or lighting loads. Some loads are also there like arc furnace that is the heating load. So, we can also go for the heating load, but mostly this motor load is accounting for almost 70 percent, almost 20 percent of this load and the remaining load here of the other purpose like arc furnace heating purpose heaters etcetera. So, the motor loads are the more. And the motors widely that is 2 types of motors AC motors are labeled, that is, your synchronous or it is induction.

In the most of the condition you know we use the induction motor because, it is a very very versatile, rugged and reliable. So, we use the induction motor and you know the induction motor is nothing, but it is just like a generalized transformer. A transformer consumes electric power. So, this consumes reactive power every time if you are using the induction machine. Here induction motor I am talking.

If you are using synchronous motor, no doubt you can operate in this both leading and lagging condition, means: even you can generate the reactive power. But the induction it is not possible, every time it consumes reactive power. Lighting load again depends upon which type of lighting you are using. If you are using simple bulb, power factor is unity and it is not neither consuming nor generating reactive power. But if you are using the florescent lamps under the types of lamps what happens; here you can see yourself, they consume huge amount of reactive power. And that here that again comes to in the picture.

So, the loads mostly, if you are going to add all the loads, the loads also consumes reactive power, means: you are adding all the loads. I am not talking about the single load. If you are adding all the loads then, this is your consuming reactive power. Another device in the system, that is, your machine. That is the synchronous machine. I said synchronous machine. Why I am writing machine not generator because, the machine can be your, it can work as your motor or it can work as a generator.

The difference between motor and generator we know it very well, means: if you are connecting 3 phase AC supply to a synchronous machine, it will work as a motor and it will do the mechanical that is rotational speed it will give, it will do the mechanical job and that electrical energy is converted into the rotational energy. In generator we rotate it and then we get the electrical power.

So, in the machines, now what normally we can just we can go for, here this is your machine. Now, it is connected with the system. If the power here it is going to the system, it is called your generator. If we are, this is your synchronous machine and the power coming from the system, you can say it is a motor. Now, the reactive power expression; this P I am talking here about the P, here it is your P. Q can be anything as I said, Q can be your negative and positive. It is the optional in the machine that we can either generate or we can absorb with the synchronous machine and this is the beauty of this. And this is only possible because, we are having doubly excitation system. Synchronous machine it is single excitation because, only AC that is coming, but in the synchronous machine we provide the DC excitation along with the AC. There is a 2 field of difference. So, it is called doubly excited machine.

So, here the power is injected to the system and here we are getting power generated the motor, here it is the generator and then we can use the synchronous machine. Now, the reactive power that Q is related here in this machine, then it is again expression is true for both here as well as here. And now if you write here the Q and this is also Q, if this Q is positive that is expression I have written that is reactive power. That is E into V, E is your internal voltage, V is your terminal voltage divided by x in between the reactance that is reactance of generator cos delta means delta is angle between this here, let us suppose this is 0. Here we are having E angle delta. So, this is angled and V square upon F. This is the expression. So, this value can be positive, this can be your negative.

If this value is positive, then for the generator case, we can say it is generating reactive power to the system, means; it is generating here. If here this value is less than this value, then we can say it is absorbing reactive power and this is coming here. Now, again this leading and lagging concept we can decide and we can just I will explain you how it will the leading. If P and Q I can say P plus j Q, I can say it is lagging. If it is P minus j Q, I can say it is leading.

So, the weaker is 1 approached by which we normally say whether it is leading or lagging.

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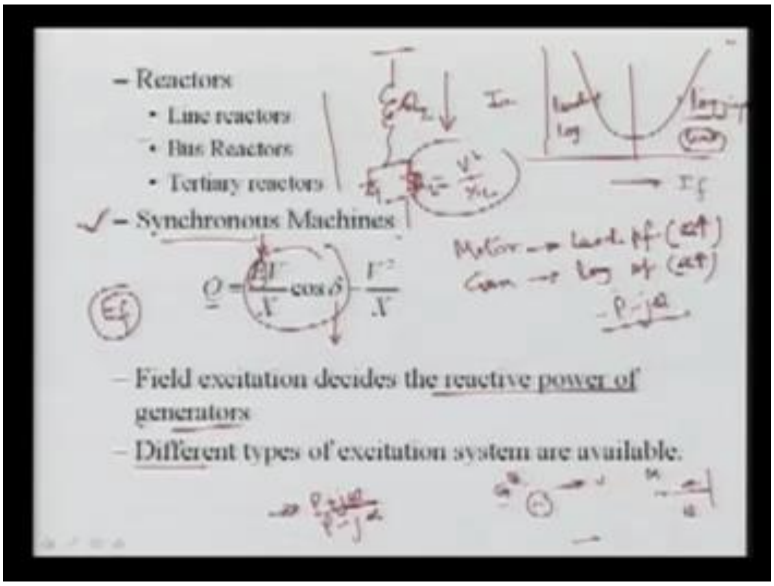

Let us see the leading and lagging. Normally that is decided by here your, it is known as the V curve that is very very popular. Here if you're the field current here, if you go for the field current IF, here I can say your R nature current if they are going to be related, then we normally a V curve here like this. So, again whether it is the leading; 1 sided is leading, another side is lagging and this here IF is directly proportional to E, we will see later.

So, if IF is more, means; this component is more than this then it is positive and in the generator case it is called your lagging case and this 1 is your leading. So, we operate the generators in mostly the lagging case of the generator no doubt. Remember here lagging for the generators. However, for motors why here the lagging you can see the plus j Q is there. For the motor the lagging will be only because, the P which is coming out minus minus j Q. In that case what we require the Q here in the different direction. Here this will be less than this and then we say here it is lagging and here it is your leading of the motor.

So, this motoring case here; the leading is required because we can generate the reactive power. So, in case of motor, here if you write motor, so motor here we want that, for the reactive power generation, it must operate in the leading power factor mode PF. Then it will be generating the reactive power, means; reactive power injection to the system it will try to inject. However for the generator, if you are operating the lagging PF, then it will the Q will be injected in the system. Reverse is also true and it all depends upon what is the value of E here. Normally the delta as I said, delta is decided by the power flow. So, only this E which is the excitation voltage and this field excitation decides the reactive power of the generator as I have written here. S

So, this E can be controlled in a such a fashion that, we can make this component more than this or we can make this component less than this or we can make it equal to this will be 0. So, this E control is basically called the excitation control of the system of your load. In other here the devices which I explained earlier 1 there was no control. If you are not using any other extra power electronic devices because, if you are for example, your reactor once reactor is connected here in the system, then it will be providing the reactive power support, means: here it will be absorbing reactive power from the system. Now, you cannot have control. Here your this Q L this of absorption will be nothing, but your V square upon reactance of the inductor.

So, X L is fixed, omega is fixed. Then V the voltage whatever the system voltage will be there, it will be absorbing, you cannot control, similarly for the capacitors, similarly, for the load. Load can be changed because; the motor load will be the different then, reactive power consumption can be changed, but we normally never control because, the real power is fixed.

Transmission line; here you need not you cannot control the parameters. Parameter X L and other things are same and the loading you can of course, can be changed, but it is not in our hand because, load are keep on changing. So, the only the control option, which are your we are having; either we can have the reactors with the some controllable devices.

For example as I said here let us suppose we are having some firing angle control and we can change the reactance here. Similarly, the capacitance can be changed. Then it is another device which is called flexible AC transmission system; fax devices, means: we are using any power electronic devices that are known as flexible AC transmission systems. Then we can control, otherwise it is not possible al the devices are the passive devices and they are fixed. So, you cannot control anything.

Now, this machine here, without any other things we can control the power, we can control the voltage. And the voltage basically it is controlled by the reactive power and this reactive power is can be controlled by this E. So, this E is basically sometimes denoted as E of that is called field excitation or field voltage. And that is basically controllable quantity as already explained in the first slide that, this is your field voltage, we have to excitation we have to control and that is the field binding of the generator that we have changing the field current, this E F will be changed.

No doubt in the generating stations or generators, we are having the different type of excitation system, with the very classical conventional excitation system, having your rotatory excitation system, having some DC type excitation system, we have the static excitation system and also we are very popularly known; that is the brushless excitation system. To have this let us view 1 excitation system which I am going to show you.

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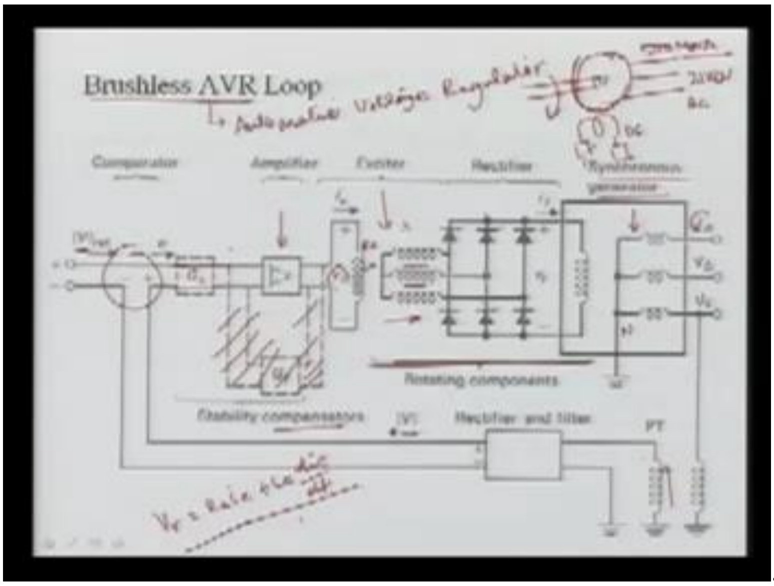

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It is brushless excitation system. Why it is called brushless because, we are not having any brushes here in the excitation system. 1 thing you must be very aware because, here your generator this is your big generator. What i am saying; this is your generator. This is the armature binding is on a stator, so we require some rotating part, so your rotor which is rotating here. So, the shaft here which is connected here that is rotating. So, your filed binding can be on a stator or it can be on stator. But your armature binding normally we keep on the stator. It has several advantages we know it very well because, for higher voltage the rotating brushes etcetera is very very difficult and very difficult to manage.

So, normally since we are going for very huge power sometimes 500 megawatt power megawatt m b a you can say or its voltage is sometimes 21 KV, very high voltage. So, on the stator 1 static we can provide the good insulators, means: insulation between windings your core. So, all it is very easy and also very easy to cool it. So, always the synchronous machines here generators, we put the armature bindings on the stator and the field binding on the rotor.

Now, if you are having the field, basically we provide here the field and then it is rotating. So, if you are having the rotating, means: you are should have some brushes here to make it rotation and that we do not want because, the brushes you know there will be lot of contact carbon problem sparking problem brushing of this 1 and reliability will be very poor. So, another is called your brushless excitation system. Let us see here that I am going to explain you.

Now, this is your as I said we will start from here. This is your synchronous generator or it is also called synchronous alternator or simply alternators. They are here generating your 3 phase supply your V a V b and your V c and we are having the armature binding here; A binding B here and your neutral, this we have shown it is a grounded. The armature is on your stator as I said. Now, your field binding is on rotor. To avoid this if, you can rotor on binding there it keeps on rotating. So, then there is no need of here the brushes, if it is rotating field binding.

So, here you can see the field binding rotating and this field binding we require the DC. You also always very careful, here we are getting DC AC, we are providing the DC supply to the field. It is a doubly as I said, here not AC and AC, it is a DC in AC. So, we must provide the DC and where we can get DC? It is not possible that we can provide from the batteries. So, what we do; we can have another generator and that is rotating on the same speed and mounted on the shaft here and then we can use some rectifier.

So, you can say we have a rectifier, you can say bridge rectifiers 3 phase. This is all the diodes or you can say we can control also if they can be. So, here is a field winding and this is armature winding of exciter. It is also a simply alternator. This alternator is again rotating. So, what we have done this exciter, here the armature is rotating it is field is static, means: now we are putting the winding on armature on the rotor. And then here we are generating 3 phase that is we are here the rectifier and finally, we are getting here the DC current that is a field current and this field current is generating your field voltage and then it is generating your E F excitation voltage.

Now, since it is another alternator, it is no doubt it is a small power because, the field power is very very small. So, this rating is very small and then we can go even for your armature bindings on your rotor and here the field binding is on a stator. That field binding is now getting supply from somewhere. So, what we are doing here; we are some c t 's and p t's. Now, we will come later this part. Here we are just the potential transformers are there and then we are just using filter and rectifier circuit; we are just getting the voltage. This voltage here we are comparing here, this is your comparator means: comparing this reference what we want from the voltage of this terminal voltage.

To have this we are comparing the actual voltage and then we are just comparing and this aerial signal is given to an amplifier.

Now, for the sake of simplicity, you should forget this G S and G F functions. Normally they are used and they are called the stability compensators. They are this is a feedback gain and this is a series transfer function gain. Because we try to stabilize this load, we will see later this loop is sometimes very critical; it may not be stable, so we have to go for some compensator.

But normally if they are not there, so simply it will be your this is your this value is coming and this is not there. Let us then do not consider this, then what is happening; this error is coming to your amplifier circuit. This amplifier is used because; the error signal is very small. We require the field current that requires some power. So, that here field current is this amplifier and then it is given to your field binding of this exciter.

The other energy, the energy here for the field winding is taken from your state rotor which is rotating, so energy from rotational we are getting of course, but we require some field current as well here and that field current is coming here and that it is again it is rotating. So, you can see whole this part is on router and there is no brush. And that is why it is called brushless excitation system and it is very widely used brushless excitation system in machines alternators.

Now, to see whether this control loop, that is, an automatic voltage here AVR is your automatic voltage, sometime called regulator loop the area loop or sometimes called excitation loop. So, this is whole loop you can say feedback is there and keep on trying to maintaining this voltage to … Now, to see its performance, to see whether we require some stability devices or not, we have to model each and every component. We have to model amplifier. We have to model the exciter and we have to model this synchronous alternator dynamics.

The rectifier dynamics is very fast. There is no need to model. So, we can directly take this current here and we will see the time constant of rectifiers are very very small compared to the other because, this is the rotating mass here also some rotation part is involved amplifier we require some gain. So, to and that gain is sometimes very very critical and then we have to decide what should be the gain and we will see the stability and the accuracy criteria are conflicting together and then we have to go for some compensating mechanism and here may be your series compensation or some compensation you can say feedback compensations are required.

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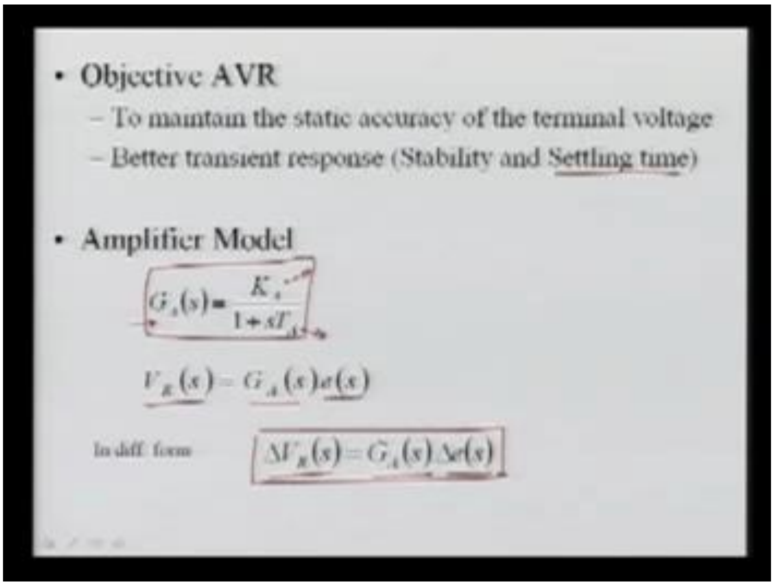

So, to start with the modeling, the major objective of AVR loops are to maintain the static accuracy of thermal voltages and also to have the better transient response. And the transient response in terms of it should be stable and also it must be settled in reasonable time. So, the settling time should be less. So, first component as I said is your amplifier model. Amplifier may be anytime. It may be amplifiers and so on so forth. And we can have the first order amplifier model and here I can say the transfer function of amplifier that is G a, it is nothing, but K a that is the gain of amplifier over 1 plus s T a and this T a is the time constant of amplifier. We will see the time constant of amplifier later on.

So, we can have the first order model of your amplifier and it is available in the several literatures and then we can say this 1. So, what value of V r, from here again you can see this is your V r voltage. This voltage here that is coming your E is coming here. So, E multiplied by G s we are getting V r. So, I can simply here. So, V r will be you R e that is error signal. This error signal is nothing, but it is the difference of your reference minus you actual terminal voltage. This is that 1 and then it is multiplied by the transfer function of your amplifier.

So, we can say here; we can write in this V r that is excite some filed voltage here, excite a field voltage not generator field voltages. Here V r is the G a multiplied by E a or in difference form if you are talking about the small change, we can write change in the V r is equal to your G a into E s and this is your 1 transfer function model we will see. And then we are we can relate it.

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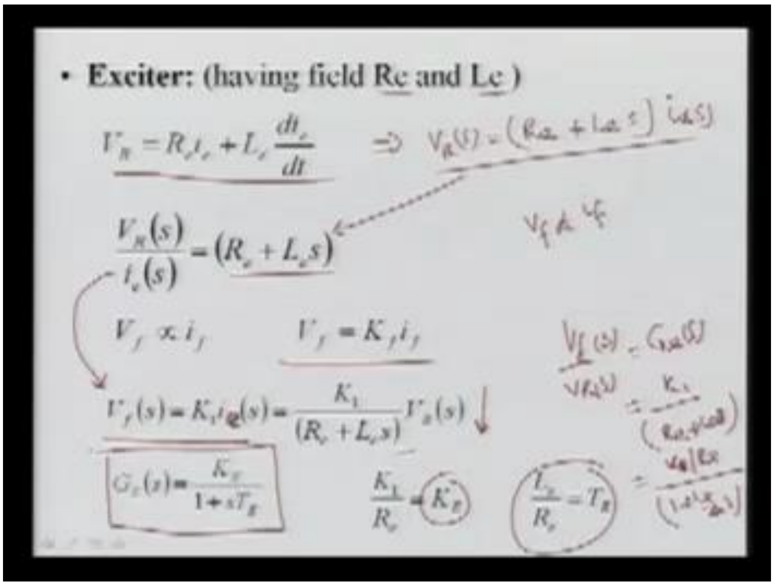

So, next component is your exciter. And now we have to model the exciter as well and now we can assume that, the field is having your R e and L e, means: if you will see here in your previous case, this block diagram; this here value is having R e and the L e. L e is the inductance and R e is the resistance and then we can write here the voltage equation, means: I can write this V r will be nothing, but your R e i T plus your L e d i e upon dt. So, this we can write this differential equation.

For this V r we know we got from previous states and this here we can write equation in term of time derivative. So, from here what we can do; we can now some to this. What is the change here; we can write as I said V r is equal to R e multiplied by current in that excitation field, L e into the differentiation of your excitation current field current here divided by dt. So, we can take the Laplace transform then and we can simplify means we can write here. It is nothing, but your V r s will be equal to your R e plus here your L e s and we can say it is your I e s here, this value will be coming.

So, from here we can take this and V r upon I is nothing, but your R e plus L e s, s is your Laplace s variable. We also know this voltage that is a field voltage which is we can directly write that V f will be proportional to I f. This V f is nothing, but your it is I f means: whatever the current which is coming here, that is, you're is related with this proportional to this. I can say this V f is some constant K f multiplied by I f.

Now, this V f is will be equal to your I 1 into R f. Why; we will again coming back to this see this picture. Let us see them again block diagram bigger 1 here. This V f and I f this voltage here related. They are basically directly related here. What will be the current here? We can relate this V r with this 1 I f and I f is the proportional to the V f which is coming here.Tthis time constant is very very less negligible.

So, I can say here; this transfer function that is your V f will be in other terms it is terms of your I r that is current here and then we can replace the value from here and we will get this value means we can put the K 1 here. Here we can put this I r and we can get this value very well. So, here V f s here it is your E basically and this E we can replace from here in this equation and then we can get K 1 upon R e plus L e V r.

So, now we can say it is you're here V f upon I can say V f upon V r s domain, here it is you nothing, but your excitation transfer function and now I can say here this K upon 1 plus s T e gives you the transfer function, means; here it is nothing, but your K 1 r e plus L e s or we can say if you divided R e in both ways I can say K 1 divided by R e over 1 plus L e upon R e s. What is L e upon R e? It is a time constant here as I said, here the time constant of excitation winding basically and this is some gain. So, we can write the transfer function of this here, your excitation winding.

Now, after that again we have to model this excitation. We have modeled excitation. Now, we have to model alternator and that we will discuss in the next lecture. In now I can recap. In this lecture, we say we saw the various sources and things of reactive powers generation and absorption. We saw the transmission line, cable, load, reactors, capacitors, transformers and also we saw the synchronous machine that is your alternators and motors. Then we started with the AVR loop that is admitting voltage regulators loop or excitation loop. And then we model amplifier, excitation. And next we will model the generators and then we will come to a complete loop and then we will analyze the behavior, means: static as well as the dynamic response of that loop in the next lecture.