Power System Operations and Control
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Module - 4
Lecture - 1

Welcome to module number four that is introduction to power flow control and this is the first lecture. In the previous module, just we saw that the frequency and voltage control problem, we did not discuss about the power flow control and we assume that power will flow over the lines as per minimum impedance path. In this module, we will discuss slightly about this load curve unit commitment HVDC facts, already I have discussed in the previous module. Then, I will discuss about some optimization technique those are used in the power system analysis.

So, to begin with power flow, just we must know what our load is so that we can plan our generating station. Therefore, we require the evacuation system; we require transmission system that transports power from generating station to the load center. Again, our main criteria is that we should operate our whole system in your economic reliable, secure and stable, along with that we have to provide the better quality of the supply to our customers.

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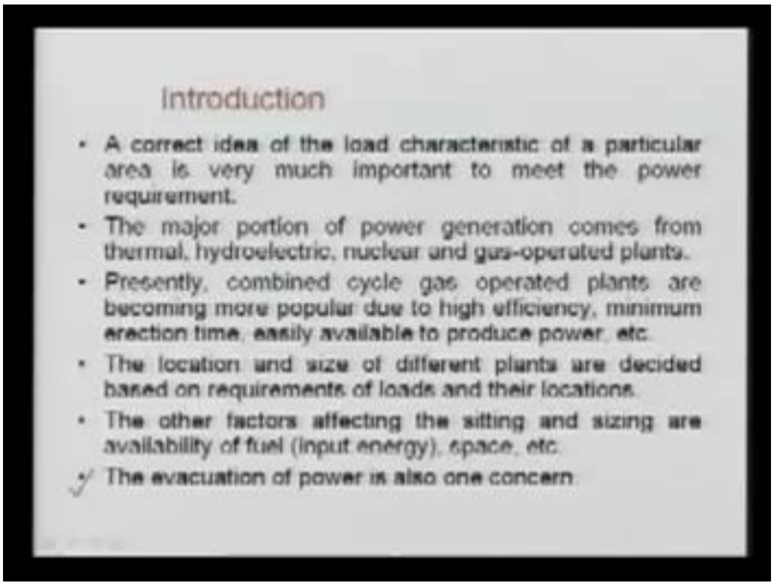

Now, here the correct idea of load characteristic of a particular area is very much important to meet the power requirement. You know the load of any utility or you can say any customer as well keeps on changing throughout the day if you will see the load is not constant and it is keep on changing. So, in any particular area or in any substation the load keeps on changing, so we must know the correct idea of load characteristic so that we can meet that power requirement with the minimum cost. The major portion of power generation that is whatever the load, we have the major portion comes from your thermal hydro nuclear, and the gas operated plants, these are also known as the conventional power plants.

However, nowadays they are more emphasis to use the non conventional energy sources like the wind biogas solar fuel cells and other type of energy resources like wave tidal etcetera geothermal. You can say presently the combined cycle gas operated plants are becoming popular due to the several reasons such that they are having high efficiency minimum erection time, means easily we can constrict with the minimum time. They are easily available to produce power, means they can be quickly started quickly; they can go into off state etcetera high efficiency. If you can see our conventional thermal power station, the maximum efficiency is not more than 35 percent.

Even though practically they are not more than 24 or 28 percent, whereas this combine cycle gas operate power plant even though efficiency may be more than 55 to 60 percent, so they are double than that. So, they are very we can say cheap and we can reduce the cost of production another important concern is the location and size of different plants. Basically, they are decided based on the basically the location is decided by where is your load and the size is decided by what amount of the load that you are going to add into the system. So, the location and the size of different plants are decided based on the requirements of the load and their locations.

The other factors those are affecting the sitting and sizing of generating stations are availability of fuel that is the input energy space etcetera. The availability of fuel for example, the input energy I am talking it is not always fuel, it may be even the water that is the input energy, so it is water energy or coal energy or gas energy or oil energy where they are available. What is you are transporting? That oil from one point to other point or you can generate the electricity at that point, and then transmitting in terms of electrical energy, then always our techno economical analysis is performed.

Based on that, the location etceteras are decided another constraint that is you have decided that these generating power plants should come at particular location and its rating is decided based on your load curve. Again I will discuss this load curve later in this lecture, then we require some evacuation system and basically it is nothing but the transmission system so that we can transmit power of generated power to the load center. We can connect, we can feed into the main grid system always, we go for the more reliable system, for example if you are having one generating station of 100 megawatt, then we can have one line that can be rated upto 100 megawatt and it can flow the power.

Always, we provide them redundantly, we go for the two lines, if one line is insert down, then still we can operate, and we can operate our generator and then we can feed the power to the main grid even though if required to the particular customer. So, the equation evacuation system is also one of the major constraints for sitting and sizing of generating station.

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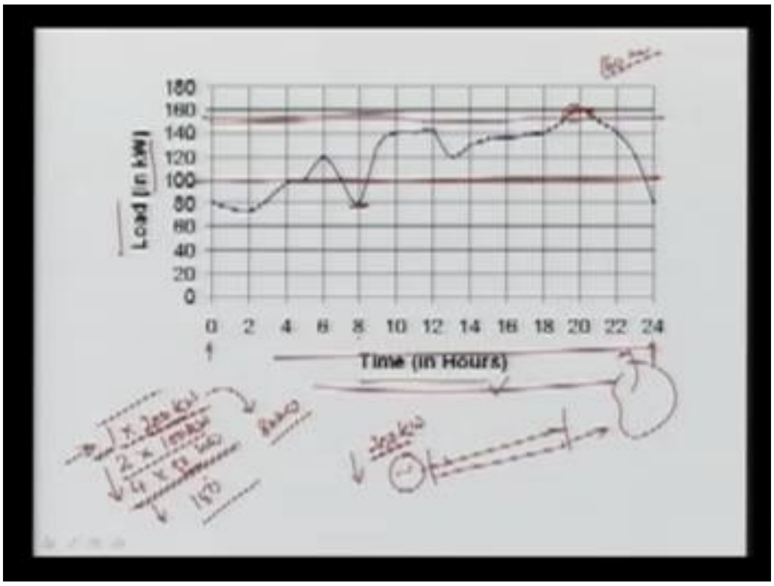

Now, we can see the typical load, just here I have the represented very small amount of load that is in watt at any particular substation. This disturbance substation here, the time in hours starting from 0 that is midnight to here, again we are coming here to the midnight. So, you can see this here the variation keeps on changing and sometimes it is a peak, may even occur in the evening may in mid, it depends upon what type of load you are using.

For example, you can say if you are using if your industry or commercial organization, your peak always will occur in the office hours time, but if you are using the domestic etcetera. If you are going for domestic weather substation if feeding the domestic load, normally it comes in the evening time because whenever all the lights and fans etcetera and the TV, your refrigerator is on. So, always at a particular station, normally the complex load mixture of various load are connected, and therefore we should have a load characteristic.

A characteristic is between the times in hours for whole day in terms of load, it is called your load curve, and since we are talking about the daily, it is 24 hours. So, it is called your daily load curve, here this maximum demand is let us suppose 160 here, 160, you can see this is your 160, so 160 kilowatt is load, so the maximum let us suppose it is isolated substation and it is fed by one generator. Then, here you can say this is your generator, and then we are having a transmission line and this is your load for which we have this variation, what will happen? Your maximum demand is 160.

So, this your generating station must be more than that 160, why? More than that because we must go for some reserved margin in case of some transients, some disturbance sometimes it may increase. So, then it should not be collapsed, it should not be dropped, so normally this maximum you can go about to 160, but it is always more than that, so here what we have to do? When you go out generator of 200 kilowatts, no doubt we all provide here the two lines because if the one line is dripped, so we can provide the power to this load through the other one so that we can increase the reliability or security of the system.

So, always the rating of the that station should be this maximum that it should be more than that now there is possibility in this, here it is possible that we can go for one unit up to 200 kilowatts. Once it is decided, this will be the maximum that is the capacity of the genetic units are here, then we can go for 1 unit or 200 megawatt, 200 kilowatt here load is only. There is a possibility that we can go for two into kilowatts or we can for even the four into all the several possibilities are there, now the question is which one will be the better. Now, you can take the example as certain duration here the load is even though lesser is equal to half of its capacity, so at this eight I am in the morning it is here the load is only 80, so, what will happen?

You are running one unit continuously for all 24 hours; however, at one time it is maximum loaded and other remaining type it is half loaded or the partially loaded. If any generator is partially loaded, the efficiency will be not better efficiency is always when it is loaded with full capacity. So, the efficiency will be less, then what will happen the cost of electricity generation will be more also another problem with one unit that if this unit fails. If there is some problem in this unit, we will not supply you will be not able to supply even the single mega kilowatt of a load. So, it has a less reliability and it also it is lightly loaded in several hours of time, so the efficiency will be less.

So, the cost of production will be more, but another option that if you are going for the more unit smaller size. Certainly, you will get the more reliable supply suppose here, the two units you are hiding if there is one problem in one of the unit still, you can feed 100 megawatt and you can feed 100 kilowatt here. You can meet up to this portion for this period at least you can provide, so it is not completely dropped, you can meets this much demand for full 24 hours, again you can see if you are going for four units, one unit is dripped. There is some problem, then you can supply 150 and mostly you can see you can meet here only during this period you can send few kilowatt load and remaining you can supply.

So, you can say if you are going for the more and more units your reliability of providing uninterrupted supply will be more, then question why whether we should go for 1 or 2 or more. If you are going for one then the capital cost is capital cost, here it is less per unit kilowatt is less compared to here for 4 units. So, the cost of install capacity will be reduced at the same time here the operational and maintenance cost that we hear will be less because we are going to maintain four units, here it is only one unit. So, maintenance cost will be also less, so always there is a compromise between whether smaller unit or larger unit and then always we make compromise.

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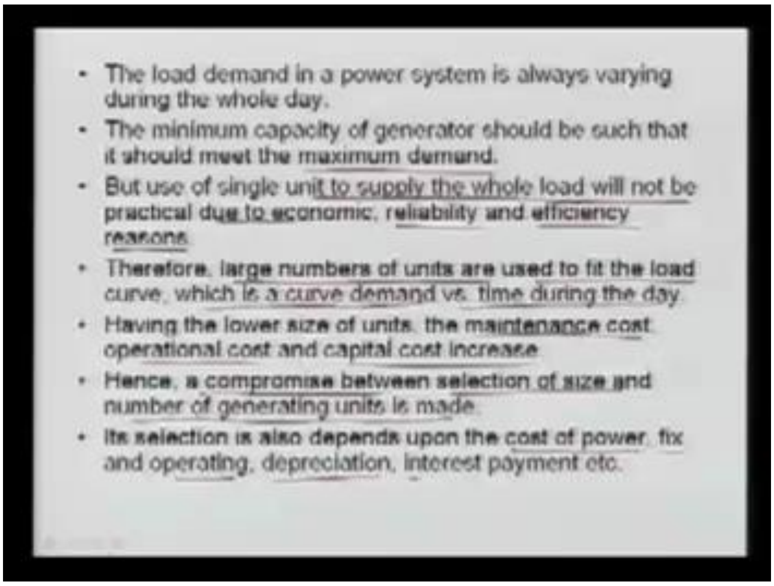

So, those statements are written here again that I said the minimum capacity of generators should be such that it should make the maximum demand. Use of single unit to supply whole load will not be practical due to economic reliability and the efficiency reasons as I said therefore, large number of units are used to fit the load curve, which is a load curve versus load demand versus the time during the day. That is called load curve having the lower size of units the maintenance cost the operational cost and the capital cost increases, hence are compromised between selection of size and the number of generating units are made. It means what size and thus always we go for the compromise between these two.

Its selection also depends upon the cost of power fix and operating cost depreciation interest payment etcetera. So, there are so many factors and always we go for the techno economic analysis. Then, we decide this is the optimal and suitable size of your generating station. So, load curve is very important, based on that normally we decide the rating and even though sometimes it is sitting also is decided by the load curve.

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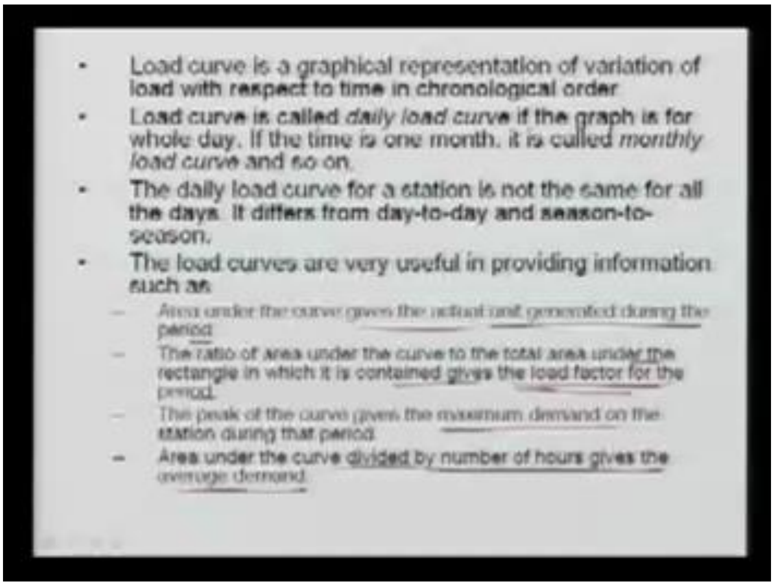

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So, load curve is better graphical representation of variation of load with respect to time in chronological order means it is not 0 hours to 20 hours it is increasing load curve is called daily load curve if the graph is for whole day. As I said if your x axis is for 24 hours that is say whole day, so it is daily curve if the time is one month means from first day to thirtieth day or thirty first day, then it is called monthly load curve and so on so forth. Similarly, we can go for yearly and means for twelve months daily load curve for a station is not the same for all the days, it differs from day to day and season to season.

So, normally for the analysis purpose, we will always go for the various seasons like summer or winter or monsoon season, and based on that we go for analyzing of that one. So, load curves are very useful in providing information such as the area under the load curve gives the actual unit generation generated during that period, means here as I said here let us suppose this is your demand.

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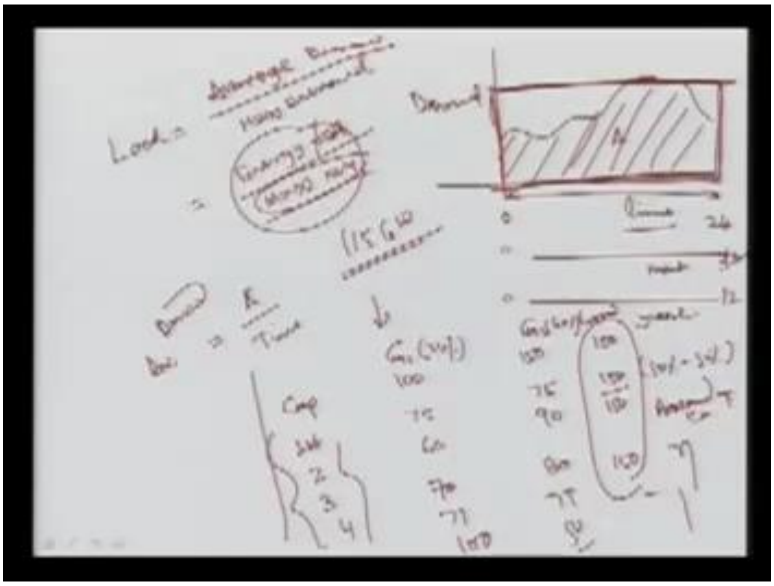

This is your time this is your demand and this is your load curve, so the area completely what is this? This is demand multiplied by time, so this area gives you the total energy produced during that period here completely. Let us suppose here 0 to 24, so it will be for one day if you are going for one month, then it is from 1 to 12 months. If you are going for one day means here 30 if you are going for this is now it is called monthly if you are going for yearly then here 0 to 12 months and then here. So, the area gets your total energy produced during that period the peak here gives the maximum demand through which I have said, and also we can calculate the other things like here the ratio of area under the curve to the total area.

Under the rectangular in which it contained gives the load factor of the period means what I want to say here the load curve here, if this rectangular area maximum. Then, this area a divided by this complete area will be here, it will be giving you load factor. So, load factor you already must know, here it is called average demand divided by maximum demand, so this average demand is nothing but the energy divided by total time. So, here what we do this energy the total energy produced divided by the total time here I can say is let us suppose 24 hours here, now this I can say the maximum demand here.

Now, this 24 will be coming here, so what is happening? This complete multiplied by this maximum demand, so this area under this maximum here value will be giving the maximum total energy maximum. So, this is your energy that is produced means area under this sided portion divided by this area in this rectangular here will give you the load factor on that substation. Of course, this average demand is nothing but the area A divided by time will be giving your average demand the peak of the curves gives as I said the maximum demand on the station during that period.

The area under curve divided by number of hours gives your average demand, so this gives lot of information it gives your average demand, it gives your maximum demand, it give your load factor, and also it gives the actual energy generated during that period. Here, this load factor actually I want to remind you must be knowing the load factor is the strictly different than the power although load and power is same, then how much power two kilo watt? What is the load? 2 kilowatt, but the inner definition in the power system the load factor and power factor are totally different power factor is nothing but it is a cosine of angle between current and the voltage at any particular point in the AC network.

However, the load factor is nothing but it is the average demand divided by maximum demand. So, both are different, so it is load factor not the power factor. Another term which also defines the load loss load factor that is a another the loss during the peak hours, means average energy loss divided by the loss during the peak hours. So, this is your loss factor, so various factor are used again in the that is the economic aspect of the power system that is normally discussed.

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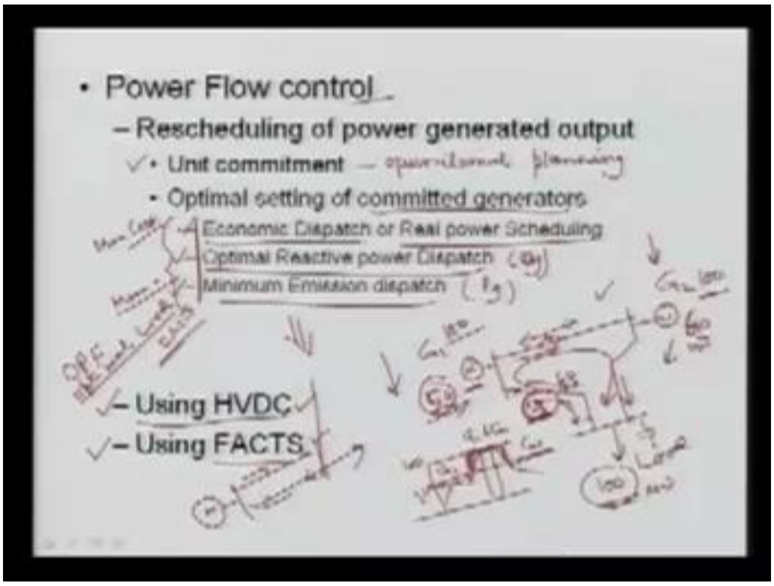

Now, let us come to the power flow control, now it is decided that you are having this load you are having the generating station barriers, now in the complete system what happens? Here, let us suppose for example, I will show you a simple example. Let us suppose this is your generator here, we have a transmission line here we have another generator here and we have here let us suppose load here we have the load, what will happen? This is your generator G 1, this is your generator G 2. Let us suppose this is your load, so let us see this example, where we are having two generators and there is one load, now the power flow here let us suppose your demand is 100 megawatts, this generator is giving 60 megawatt.

Let us suppose this is providing 40 megawatt, this is not the installed capacity, it is actual generation that this megawatt, this megawatt and this megawatt and talking about the megawatt power. Installed capacity may be different, let us suppose this are having 100 megawatt, it is also having 100 megawatt, but we are generating in this fashion, so what will happen? The power will be coming here this will be coming here and the total here will be the 100 megawatt load we are supplying. Now, whether the current here will flow here or in this direction, we do not know, and that is decided by the impedance of these lines itself. So, you do not have control because these lines are constructed once these lines are constructed.

Then, if you are adding the generator, they will follow the minimum impedance the current will follow the minimum impedance path, and it will come to the load center and the total is balance of course. Here, 60 megawatts, 40 megawatt and 400 hundred megawatt of course this will be more than that generation, always more than the load because there will be some losses in the line. Now, let us suppose I want to control the power as I said we can control the frequency, how the frequency here? As I said, this generation if you are increasing, the frequency of the system will increase because if load is fixed generation is increased frequency of the system increases.

Similarly, just I discussed about the voltage control in the previous module that is module number three. In that, we were talking about the voltage control, how we can lift the voltage by the excitation control of the generators? We can put some capacitors here or some other devices, and then we can leave the voltage that is different phenomena. Now, I want to control the power flow, now what are the ways that we can reschedule these, we can reschedule these generating stations, and then let us suppose here I can say only it will be generating 50. This will be going for 60, what will happen? Here, this power will be changed, and then we are controlling, but this is not always possible, so what we have to do if you are changing the scheduling?

If you are having more generation in the power system, then the option is that we have to utilize those resources optimally because this megawatt is not fixed, this megawatt keeps on changing. As I said here the load profile of here, may be you are going for this one and this is let us suppose your 100 megawatt, so you can say only for the one or two hours it is 100 megawatt, for the remaining portion it is less. So, we have to there may be possibility even the one unit is sufficient, why we should not that is the condition unit, so we can decide that what will be the unit should be on which should be off.

So, that problem basically is known as your unit commitment problem this unit commitment problem is nothing but it is called operational planning problem it is related to operational. So, operational and it is since planning, so we have to plan which units will be on and which units will be off that is called commitment. Commitment means which unit will be coming at what time which will be going down which will be set off at what time this is called your unit commitment problem. Again, for that, our criteria is that we have to commit or de commit the unit based on the minimum cost.

Why the cost is involved in the committing and de committing? If you are going to turn on a generating station although it may be very less, the cost is of course nil because water is free important. You can assume the gas power plant nuclear power plant, and also you can imagine about the coal power plant, coal within the boiling for several hours without producing anything because we are going to synchronize. We have to generate that pressure up to certain level so that we can pass it to your turbine. So, these issues start up cost, at the same time there is shut down cost is also tremendous because whatever the pressures are in your pipe that will go in the air, and that energy is wasted.

So, there is a start up and start shut down of cost is involved, so we have to optimize to meet that our load curve we have to meet our demand at any particular station, and then we have to commit the unit accordingly. Once units are decided, then we can change the loading on that so that again we can follow the load at that time. For example, you can say for this hour it is your 15 megawatt it is powerful that is only one unit is sufficient here during this period because 100 megawatt is there. So, we can generate one unit and, then we can go up to this period, and when this is exceeding, we can turn on this expensive one and then again we can off.

So, we can say here generator one is on then generator 2 and 1, both are on and again generator 1. So, here I can say generator one here generator one and generator 2 is on. Here generator 1 is again on we saw, so this is generator 2 is only on for this period, so it is called unit commitment, now still you can say generator 1 is on, but it is again loading this how much we have to load. This is example of 2, but, in this actual practical power system, there are more than 20 or 30 generators even that too sometimes count for smaller generators will be more than 100 in units. So, this unit commitment problem is very important and once unit commitment problem is solved, again it is an optimization problem that we have to solve.

Again, that is why I discuss about optimization algorithms later on of this module, so once they are decided now we have to go for the setting this optimal setting of the committed generator, means those are on how much we have to set their output so that we can achieve our objective. Objective may be different, for example objective may be your minimum cost of the entire thermal power generator that is gas nuclear coal everything, another one we can set their reactive power in such a way that we can reduce the losses of the system.

We can set these generators so that we can achieve the minimum emission level of the generation we can go for the minimum control actions, so many alternatives are of this discrete functions are possible. So, if your objective is to minimize the cost, it is called economic dispatch problem or real power scheduling if your objective is to minimize to operate with minimum emission level, then it is called minimum emission dispatch, where also we go for the setting of the real power output of the generators. You know the thermal power station if you are changing the output the emission level will be the difference.

Emission level means emission of various hazardous gases like, so two and oxidizes co two etcetera. So, that is called your minimum emission dispatch another that is called optimal reactive power dispatch means it is nothing but the real power. It is with your reactive power output of these sources and based on that we said there are reactive power outputs in such a fashion that we can minimize the losses in the system as you know the voltage is very important factor in the minimizing losses. So, we can set the voltage and then we can achieve our minimum loss or you can say the increment in the voltage profile and that is called your optimal reactive power dispatch these entire objective here if you will combine.

Normally, in the general term, they are called off and it is called optimal power flow or optimal load flow, it is your optimal load flow or power flow. Now, here optimal means we are now it is again I will just remind you the optimal power flow or optimal load flow are different than the load flow. In load flow, there is no minimization, no optimization only we solve the set of power flow equation. Here, we try to minimize means in load flow the generator outputs are fixed, and then we solve it. So, it is load flow here, we try we change the output in such a fashion that we achieve our objective that is whatever the objective is.

Then, along with the power flow equation, means your power balance equation must certify at each and every node of the system means your real and reactive power balance load flow equation must satisfy at each node. So, this is the difference between your optimal load flows as well as normal load flow here the main idea. Whatever you are doing or setting here, this our main idea is your energy conservation means to save of energy saving of the minimum cost. The cost of water is freed of course,,, but, the quantity of the water may be limited.

So, normally we go for the optimal hydro thermal scheduling, means we have to coordinate hydro along with the thermal to meet our demand in such a fashion that total, we can meet our objective for hydro also because water is also used for another purpose. It is not possible that you can discharge water continuously, because the water which is stored that can be used for the regulating purpose. So, we have to coordinate that when it is required what will be the discharge rate how much you are getting inside the poundage. How we are going to plant for whole year? So, it is if you are going to make combine your thermal power station along with your hydro, then it is called hydrothermal scheduling problem.

To see the importance of this, I will put one example here, for example let us suppose we are having the two generators, means we have committed the two generators we have decided our various generators. We have decided that the two generator are sufficient to meet our load, let us suppose the g one is this and another g two and your total load, here I can say is 150 mega watt. Now, the installed capacity here let us suppose capacity if I will write the capacity of this is let us suppose 100 and this capacity is 150, now if I will say the case first here, what I can say? I am going to load these generator 50, 50 percent to meet 150.

So, I can say we can load 75, 75 and we are very heavy means again the total of G 1 and G 2 is your equal to your load. This is based on 50, 50 percent load 50, 50 percent without any problem. Another criteria, let us suppose second what I can do? We can load according to the capacity according to capacity, this is 100 this is a 150. So, we have to load here is 60 here, we have to go for 90 and again our load demand, just we are maintaining. So, it is loaded according to the capacity that is capacity is less load, here capacity is more you can load more. Another here let us suppose the efficiency of this is your 35 percent and the efficiency of the power plant is 40 percent.

So, we can load according to the efficiency again our objective is meet our loading demand that is 150. If you are going for the efficiency, then we have to load 70 and this must be loaded 80 and again we are meeting this, you can say your 40 more loading less efficient less loading. Another various combination of power flow here I can say 71 y not 79 and so on so forth. So, there are thousands infinite number of possibilities to load these generators in there to meet 150 megawatt.

So, there is a several possibility again, here we are meeting 150 megawatt in all the cases now the question is why? So, this is basically called we had to adopt some criteria here I said different criteria there. Then, we can load them accordingly here always we try to go for economic dispatch means we have to run so that we can achieve the minimum cost, those are the cheaper. That will generate 100 percent loading, and then other will be expensive, and then there will be reducing. For example, you can say this is very cheap lets suppose g one is very cheap. So, it will go for the 100 megawatts and the remaining fifty will come from the expensive generator so that we can achieve the minimum cost generation that is the major criteria for this.

Now, as I was telling, now to see the implication this see even though you are going to change the output, I can show you that are huge potential huge potential, means we can save crores of rupees even for small change. Even though you can go for 1 percent saving of this complete installed capacity that we have right now, 150 giga watts in India even though you are going for 0.1 percent. If you are saving that one, then you can save crores of rupees in which you can install another power plant. So, this is very important you can just calculate 1 percent and load factor will be taking as a value, we can see it very easily. So, now question here as I said that here that we had to set the generators to operate our power system economically.

Then, we have to have some minimum cost criteria or your minimum loss criteria or we can go for combination of these, we can trade of values to control the power, always it is not feasible once you have decided then in this line it is not a smooth control. Always, it is not preferred once you have to go for optimal one we have to fix it, still you want to control the power why we want it, and sometimes for this example you can always see here. There is a possibility here 60 megawatt is flowing in this line, but the rating of this line is 50 megawatt only this line is exceeding and why it is exceeding because it has the minimum impedance.

So, whole more most of the current is flowing here, so we want to control because we cannot operate continuously on the more than its rating then we have to use some control mechanics so that we can re drive the power here through the lines. We can restrict up to 50 megawatts because more loading more losses and always we cannot go for more than its rating because that will trip your line, and then the whole system will be in chaos.

So, here we require some control mechanics to redo the power flow in the line that is called your power flow control, here generation are fixed load is fixed frequency of the system is fixed no change. We are just redirecting the current, you can say or power over the different lines so that we can meet our objective. So, you have that various control we have only option that we can go for either using HVDC or facts controller. Already, I have explained facts controller basics of facts controller that they can control the power in any of the line or in any of the sub system or the designated controller corridors.

Similarly, the HVDC they can also do power flow control even though not control it can reverse the power in different direction means power which was flowing here it can be reversed in the other direction. So, it has the potential it has the capability to do any sort of control and that sometimes is very useful because sometimes here due to this overloading, suppose you do not have the control capability, you cannot load this generator up to this level, what will happen? Then, you have to go for the lower, and then you have to increase here so that you should not exceed the rating of the line and, finally what will happen? You are not meeting your minimum cost of operation because you are going to use your expensive generator more than your cheap generator.

So, this resource is not reliable this is cheaper, so for that we utilize the resources very properly efficiently. We should have some power flow control mechanics and options are that either we use HVDC or the facts controller to control the power over the line. Another option also to control the power in the line, but that is not feasible for example, let us suppose here we have a line, we have two lines and here is a load, what will happen? If you want to control power here in this line, you can drip this line, the power completely going here. So, this is discrete control and this is not possible, it is not dripping one line because purpose is not solved, we are not meeting the reliability.

So, the best way that we have to use the HVDC and the facts about those flexible this facts controllers are nothing but it is a flexible ac transmission system controllers or devices those are used in the power system to control the power flow. Thereby they enhance the power system performance both static as well as the dynamic and already we have seen for your stat com and svc we will also see few facts controller here in this module like your UPFC and TCSC the VSC controllers. Before that, what I will do? Just I will discuss about the HVDC, and then we will see how this HVDC will control the power and how it is a beneficial.

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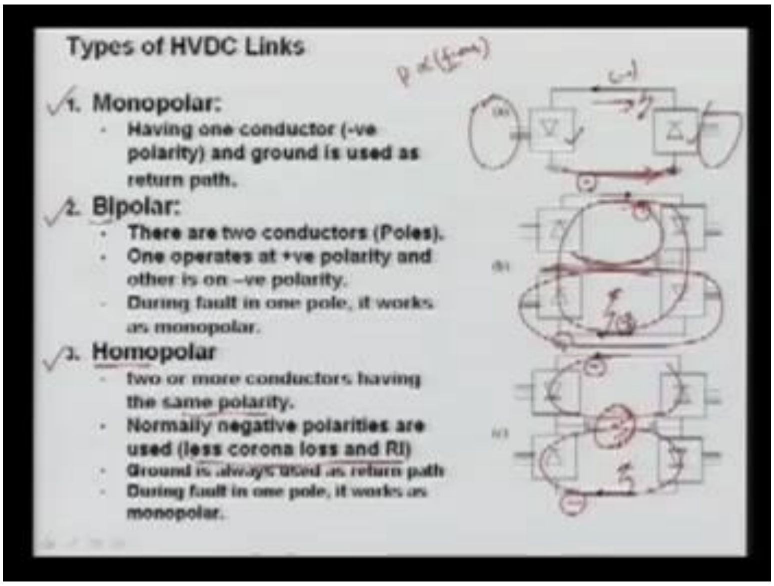

To see this, let us go about the HVDC various links, then I will come to the main control schemes of HVDC, and what are the application, what are the uses of this HVDC links? Now, you can see the HVDC links can be categorized and be into again three that is your mono polar your bipolar and your homo polar name are very simple. Mono polar means whole is one here you can say this is your means here. There, we are having only one overhead line and the return path is your ground is used here. So, having one conductor and always this conductor, we go for the negative one, now question why negative we know the negative conductor, suppose you are having same potential let us suppose you are having 500 kilovolt transmission line DC line.

If you are having the positive polarity, then it will have more corona than its negative one. So, we go for the negative polarity and we can use the ground as the return path, so this is called your mono polar HVDC link because only one mono means one. We know it very well here, we are adding one rectifier, one inverter, and then they are using even though the direction of the current here can be changed from here to here. We can also change here by controlling the firing angles of these two converters. Another is your bipolar in the bipolar again your name is bi means two poles are pole, here you can say we are having pole 1 and here pole 2, there are two conductors two poles one pole operate at positive here and another operates at negative.

During the fall in one pole, it works as a mono polar at main problem here if there is some problem here in the later fault of this line you have to isolate the fault; you have to stop this operation of this HVDC link. This whole the two areas here, they are not transferring power over these lines. So, completely you can say chaos and the system will be unreliable. So, here in this bipolar as I said the two poles are here. Major advantage is that let us suppose one pole is faulted here, what we can do? We can stop the operation of this whole this one pole, and then we can operate this bipolar into just like a mono polar, means we can have ground here and we can have return path.

Then, we can feed half of the power during the emergency condition here is fault it is there. So, it has advantage over the previous one because it was complete shutdown here, we are able to provide 50 percent of the power from one area to another area, and we can control efficiently. So, it has advantage over mono polar mono polar, but the problem is that here the cost is double than the mono polar because here you can see another problem here in the mono polar if you see here, we are using the ground as the return path continuously. That is very bad, sometimes it may provide some corrosion to your pipelines which are passing it may go for the interference with the other communication another lines.

So, it will create lot of problems here, if we are using ground continuously as the return path; however, in this bipolar we are not using ground as the return path continuously. We are operating in the normal period here you can say the current is going here and it is going like this. So, it is nowhere it is passing through the ground, but only we are using ground in the emergency condition and that we can use that. So, it is better than your mono polar operation. Another is your homo polar here also we use two poles, but the polarity is again is obtain means here we are using the negative polarity and the other is also your negative polarity.

We are using the negative polarity again to have the minimum coronal because in high voltage transmission line whether it is AC or DC. We are having corona no doubt the corona in AC system is very high compared to your DC system because it is the frequency dependent loss. So, your corona loss that is p is proportional to f plus 25, if your f is 0 in DC. So, it is again it is a minimum in the DC, so 2 or more conductors having same polarity here two conductors, I have shown and then we are having the homo polar.

Normally, negative polarities are used due to the less corona and radio interference here. Another problem is that every time we are using ground as the return stages current will flow in here like this. This current is flowing like this, now you can see this ground every time you are using the ground as the return path and that is not good or basically it was safety factor. So, during fault here advantage over the mono polar is that in mono polar also the ground was used as the return path here. Again, if there is a fault in one system then we can operate into the mono polar operation, and then we can feed the power to the other area and we can control this. Now, let us go for the basic principle part of your HVDC system, now I will show this figure first see this.

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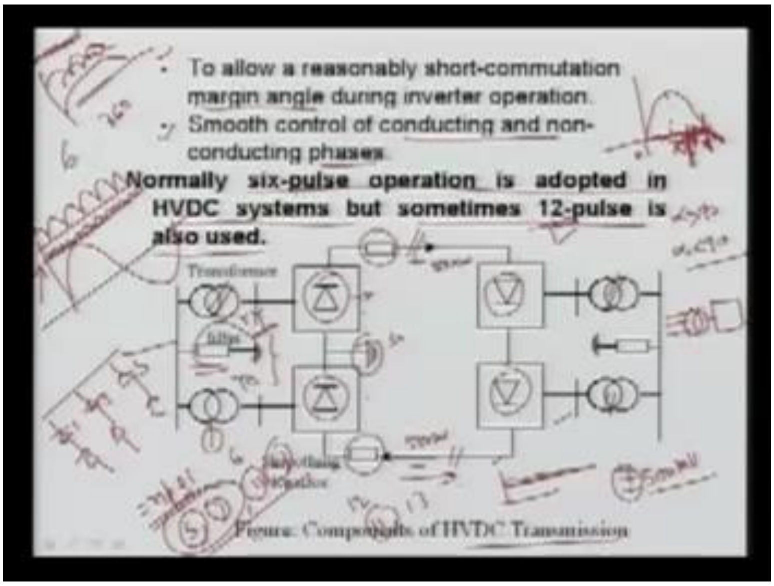

That is a component of HVDC transmission, here you can see just I have not shown it is a bipolar, normally it was take it here plus here it is minus. Normally, the bipolar the voltage is written as the plus minus voltage of one pole, let us suppose I have written 500 kV it show here that here it is your 500 kV with respect to ground and here it is also 500 kV with the negative channel. So, plus minus is shown for your bipolar operation, means automatically if you are using plus minus means it is a bipolar if this one is positive, another is negative with respect to ground. So, the total voltage difference between these two lines is 1000 kilo volt and we have one line that is from rihand to dadri this plus minus 500 kV line and feeding 1500 mega watt power.

So, the major component in HVDC transmission system one is that is you are here, you can say converter these are the converters. Here, there is a converter this is your converter this is converter, here converter can be used as rectifier can be used as inverter, but converter is a global name for both rectification and inversion operation. We require the transmission lines these are the transmission lines, we require the smoothing reactors here this is a smoothing reactor you can see. Why is smoothing reactor? Because we want to have a smooth DC current over this line because during the firing the current will keep on changing.

So, normally here the current variation is there, but we can use the reactor. So, that the current is a perfect DC we are using the here transformers these are the transformers it is also transformer, and these are called converter transformer. These transformers are in design different than your normal conventional transformer because I will see that this transformer is highly stressed because here the DC current is flowing. Sometimes, this windings are highly stressed so that saturation may take place. So, we have to go for all these we also use some filters, we require the filters to filter out the harmonic because these converters will inject harmonic into the system.

So, we have to use the filters to filter out the harmonic means only we allow the fundamental component from the system and also other sort of you can say lightening arresters grounding because here grounding part is there. We should have the grounding rods etcetera. So, all these are major part of your HVDC transmission system, so let us go back first with converter.

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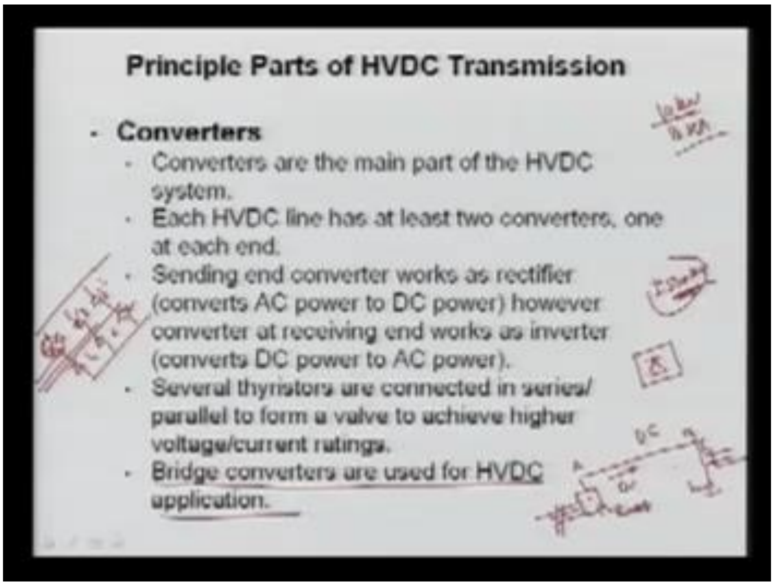

The converter is main part that is heart of any HVDC system, it is very expensive device because we use the power electronic devices and also due to the huge power rating there will be effective loss and in conventional devices. So, we have to cool them properly and the small operation or you can say any problem in the conversion that will lead to the complete shutdown of that link. So, it is very carefully and the operated properly, so each HVDC line has at least two converters one at each end as said, so I suppose this is one line DC line is there. So, we must have on converter here we must have converter one at least here, and then here the three phase AC supply and the converter here. So, we must require at least two converters, both are station at the both end of the transmission line.

Sending end converter works at here, let us suppose power is flowing from here, then it is said this is your rectifier, and another is called your inverter as it is usual. So, this sending end here the power is flowing from this end to here that is from A to B. So, this is called your rectifier, and it converts from here AC to your DC here is a DC and however, at the receiving end it converts from DC to AC and it is called inverter operation. Now, we know that even though in facts controller devices when I was talking about the various devices I said that we are having the one single thyristor unit of this 8 kilo volt, we are expecting, and we are having this kilo ampere of rating.

I said HVDC link here, let us suppose plus minus 500 kV, so current may be in kilo ampere several even though mega ampere, so what we normally do? We go for various addition of the thyristors, we have to add in series to provide the proper voltage level, and also we have to go for the parallel communication to provide the complete current rating of the link. So, the several thyristors are connected in series and are parallel to form a wall, now is whatever I showed here the before here if I write here in this box, this is your converter circuit and that converter.

We are using the different link normally the bridge converters are used again it has the several advantage over the configurations. So, in one length one length there may be several series thyristors and also we provide some safety factors suppose required here. We are having 10 kilovolt thyristors and our require in one lag it is a 500, then it is not 50 we can go for 60, 7 because if one thyristor fails or punctures, we should not take it out we should only take out when maintenance is taken place. So, we have to go for some safety and redundancy in this, so we have to go for the series and parallel edition of this valve and that here calls one valve.

You normally know the bridge converters here, normally if you are having this is your bridge converter or you can say bridge rectifier that is a three phases, so we are having this looks here the three upper and lower. There is 1, 3, 5 numbers, I can say 4, 6, 2 here even the one here I have shown one thyristor, but it is not one thyristor, it is called one valve. Valve means it is a edition of several thyristors in series as well as the parallel to make its proper rating in voltage and the current. So, bridge converters as I said are used for HVDC application.

This is a bridge converter here using a thyristor valve, and then it is your rectifier and inverter end. Also, we use the bridge converter again it is a 6 pulse or 12 pulse again required depends upon what is your power rating what is your harmonics filter etcetera, so it is decided based on that.

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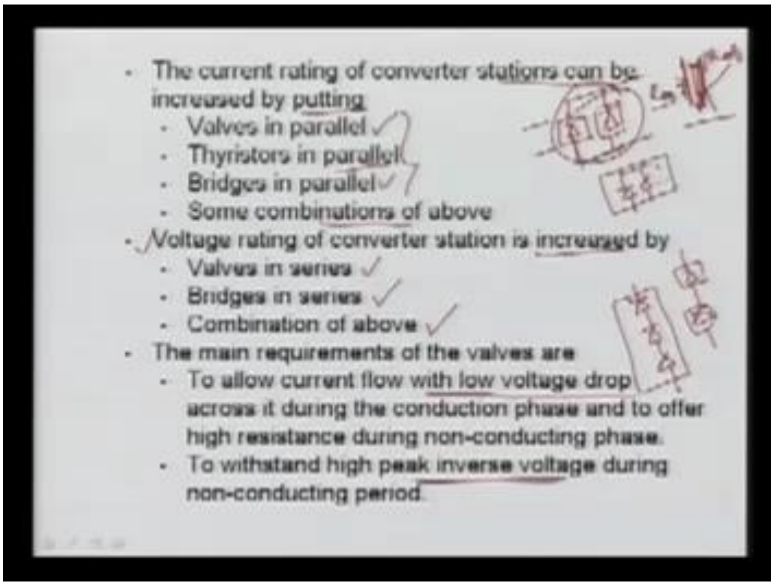

So, the current rating of converter station can be increased by putting valve in parallel means we can have the two valve here this is let us suppose a valve. We can have the two valve in parallel, so this is a parallel, and then we can have we can increase there is a possibility that we can use the thyristors in parallel means one thyristor here one thyristor here. We can use several and then it is one valve, so in one valve we can use several parallel and other valve may be in the parallel and again even though sometimes the bridges are in the parallel, means six here in one bridge.

So, we can have the two bridge inverters parallel to increase the current rating sometimes you can say combination of all these three is also possible. So, for the current rating enhancement, we have to go for parallel connection for the voltage rating of the converter station can be enhanced by the valve in series bridges in series or thyristors in series and combination of above. It means for here you can say this is your valve we can have various thyristors here. So, this is one you can say valve where we can add several thyristor or we can have this is a various bridges they are connected here in series with this.

We can also add the bridges and again we go for the 12 pulse operation, basically we add the base to increase the pulse number the main requirement of valves is to allow current flow with the low voltage drop. It means main requirement of valve whatever you are using here that it will allow the current flow with the minimum voltage drop here; the voltage drop must be minimum across during the conduction period. It should offer the high in resistance during the non conductors conducting phase or blocking, so when it is on it just like a short circuit when it is off juts like this open circuit. So, it should be idealistic characteristic we want, but since ideally it is not possible.

So, when it is on, it will offer very or on it is very less when it is off, so on off its specifically very high not infinite. It also should withstand the high peak inverse voltage during the non conducting phase once this bridge is not conducting voltage is 0 across still almost 0 because all are nil very less. Once it is not conducting, the voltage across this we can see, this huge voltage is appearing across this valve, and then withstand that peak high inverse voltage during the non conducting because this inverse voltage is appearing across that. There may be some possibility if it is not withstanding, it may puncture and it will get fast impedant. So, that creates another problem, so this is another characteristic requirement for this.

Another requirement to allow a reasonable short commutation margin angle during the inverter operation now what is this normally what we do if you remember for any this here this is sinusoidal. If the voltage across any thyristor is going to appear vastly what we can. So, we can here alpha is 0 w can turn on and any period here during this period that is 0 to pi. If you are just turning here before pi by 2, this will give you positive voltage if you are turning on just after this it will give you negative voltage.

So, the inverter operation normally we try to just see the advance angle here, and we find here that is the alpha should be more than 90 degree. For rectifying operation, this should be less than 90, so what happens? Once this is because before that it must be off otherwise the negative polarity will appear and that it may again start conducting. So, it should have your some margin that we should have that is called commutation margin angle during the inverter operation that is inverter operation is very complex and tedious operation than the rectifier operation.

So, there is no small operation very less possibility of small operation; however, inverter there is lot of small operation and malfunctions and in that if it is your small operating lot of harmonics voltage distortion everything will be arising there. So, we should be very careful there another requirement that is smooth control of conduction or non conducting series means from one to another because always we use the bridge converter as I said here it is a bridge converter from one to let us suppose 1, 3, 5. Here, shifting from one three it should be smooth, it should not be jump, otherwise, there will be some transient etcetera normally 6 pulse operation is adopted in HVDC system.

Sometimes, 12 pulse is also used again what do you mean by pulses, pulses means 1 AC cycle here. Let us suppose this is your AC cycle, your DC voltage here I can say here it is if it is 6 pulses, it is called 6 pulse. If you are going for 12 pulses, what will happen here? Here, now you can say 12 pulses, so this is a smoother and less harmonic here it is more harmonic. So, we can go for the 12 pulse, and then harmonic maintenance required is very less because always the harmonic content which are in turn the AC system it is N p plus minus 1 what is that? P is number of pulses n is 1, 2, 3. So, what will happen if it is 1, then let us suppose for 6 pulse.

Here, we are getting 5, 7 and it is 11 and thirteen harmonics if you are using twelve pulse what is happening we are eleven and thirteen and so on s forth. So, we are not having the harmonics automatically eliminated, otherwise we have to go for the filters for sixth and seventh harmonics along with 13 and 11 here only we require the harmonics filtering scheme for 11 th and 13, 15. So, this converter operation is very as I said very important and it must withstand its reverse voltage. It should have the inverter operations should have the commutation margin angle sufficient and it should operate just like a ideal switch and the conduction from one to another switch over should also vary smooth.

Here, the number of again 12 pulse if you are going to put in it is not possible for the transformer because the transformer connection will be different the beauty of here one system, I will tell you what happens normally. If you are using three phase here three phase supply system here, and then you are having a bridge converter here for example, here this is one bridge converter here we are having another bridge converter. Normally this is let us suppose star here if you are hiding the star delta connection, then already there is a phase shift of 30 degree and you are adding the voltage means two 6 pulse converters if where they are connected by here star and star delta.

If you are adding the voltage automatically, they will provide the twelve pulse in advance. For example, I will show you here, let us suppose here we are having your the voltage, let us suppose say 12. I am talking only three and then we can see we are adding what will happen if you add you will get this 6? So, similarly, you can go for this one positive cycle in backing, and then remaining here, so what will happen here? Automatically, the two 6 pulse converter with connecter because we have the inherent pro property of this three phase connection 30 degree lead.

So, here it was the 360, earlier it was 60, 60, now we have shifted 30 degree and 60. So, increase 60, we have 12 pulse operation and 10. The same transformer three phase its very good for using the 12 pulse, and normally we go for the 12 pulse operation rather than using 6 pulse to 6 pulse this converters. So, this converter operation and its analysis its performance is very very important and we will see if you have a time, then we will discuss about that one as well.

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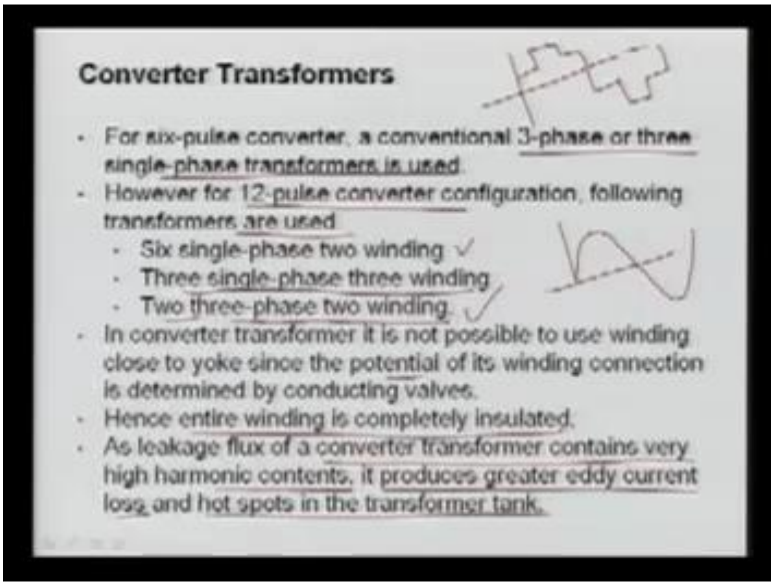

Another is your as I said the converter transformer that converter transformer for the six pulse converter. A conventional three phase or three single phase transformer is used means we can use the three phase or we can use the single three phase transformer for 6 pulse converter; however for the 12 pulse as I said configuration. The following the transformers can be used we can use the 6 single two phase transformer two phase 6 means 12 phase we can give we can use the three single phase transformer with the three windings. We can use two three phase winding, normally this is used in converter transformer it is not possible to use winding close to yoke, since potential of its winding connection is determined by the conducting valve.

If you are using the very varied yoke, what will happen? The voltage sometimes difference is very high and there is a insulation failure. So, the converted transformer is not possible used for winding close to yoke due to the potential problem. Hence, entire winding is completely insulated complete winding should be insulated because due to the huge potential difference as the leakage flux of a converter transformer contains very high harmonics contents. It produces greater eddy current loss and hot spots in the transformer tank because there is a huge leakage flux as I said there is sometimes voltage very high and also is a sudden this is fluxes.

It is not a smooth here for example, the voltage which is appearing normal transformer this, but here the possibility that voltage here will be and current will be like this it is not a perfect. Although it is you can go for this, so it is a huge circuit and also sometimes the DC will be appearing in the mall operation sometimes it is dead short circuit in the dc circuit. So, that is appearing huge current will flow in the transformer.

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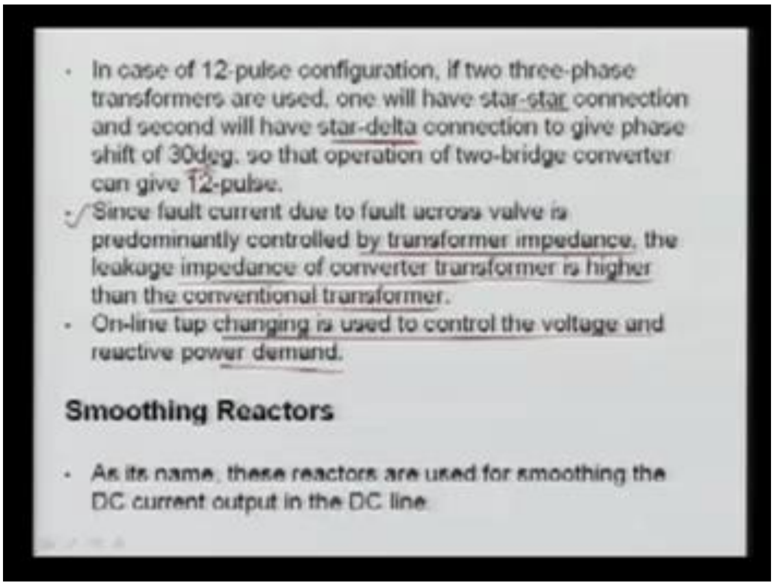

So, the transformer must be capable of that one. So, since the fault current due to the fault across the valve is predominantly controlled by the transformer impedance. The leakage impedance of converter transformer is higher than the conventional transformer as I said during your short circuit or sometimes small operation when your u is more than that. Here, there is a short circuit and then only the option that we have the leakage impedance here in the case of twelve pulse configuration if two three phase transformer are used the one we will have star star. Another will have star delta already explained because we have the inherently 30 degree phase shift that we can achieve the 12 pulse by adding two 6 pulse of this converter.

On line tap changing is used to control the voltage and the reactive power control, we use online tap changing transformer to control the voltage. So, we saw in this in this lecture number one that the various components of HVDC also we saw the load curve. Here, I explained the converter as well as the converter transformer those are very important components of the HVDC link in the next lecture we will see the various other components like the smoothing reactors. We will see the filters, and then we will again go for the various control mechanics in the HVDC link.

Thank you.