High Voltage DC Transmission

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Module No. # 04

Lecture No. # 03

HVDC System Faults and Protections

So, welcome to lecture number 3 of this module 4. In previous two lectures of this module, we discussed the various voltage, various faults in the hole system and as well as we saw the mall operation of converter circuit itself. Today, I am going to discuss the protection schemes those are used for the various faults.

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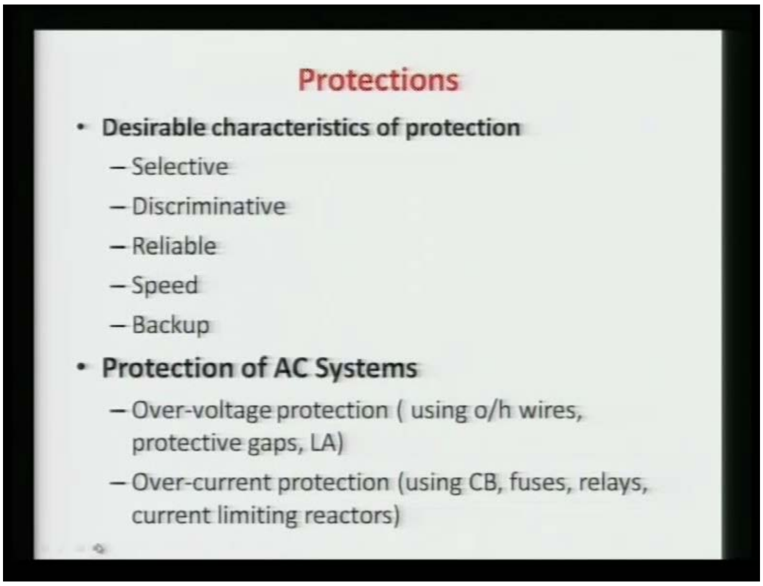

Now, the protection, as its name, we require some desirable features for the protection schemes. These are the five important or desirable feature or characteristic of any protection scheme or system. First, it should be selective and then, it should be discriminative. It should be reliable and it should have a fast speed and there should be some back up protection.

Here, the selective means, your, this, where the protection system is designed for a particular zone or particular operators, then it should only operate if there is some problem in that zone or that operators. So, it should be selective. If the disturbance is outside that zone, it should not operate.

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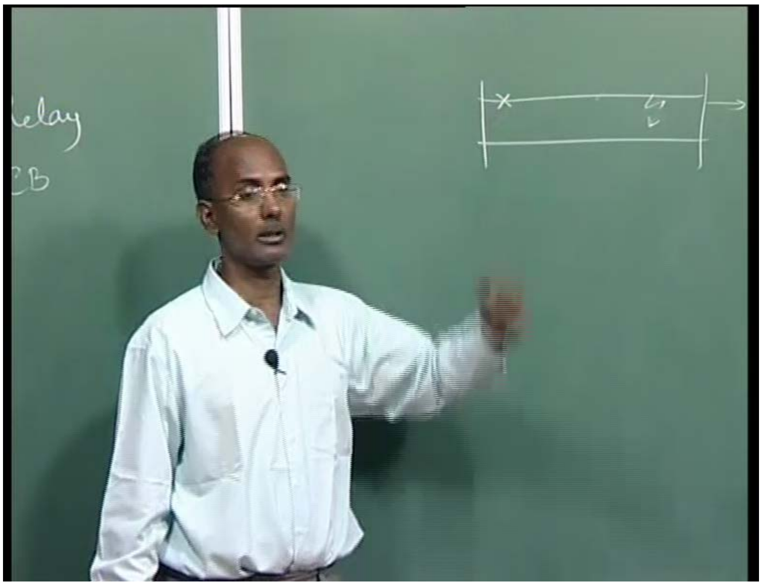

Even though there is, let us, suppose I can say here, simple, let us, suppose this is your bus and this is line in ac system. This is your protection scheme. If this relay or protection scheme is designed to have the fault only in this line, so it should only operate here, in this zone. So, it is called selective. It means, whatever the disturbance here or outside of this zone, if it is operating, then it is called, it is not selective. So, it should select for which it is designed. So, the selective zone, it is called the relay. It should be selective.

Another is a discriminative. Discriminative means, there are two types. One is the, for example, let us suppose, there is some fault here. The current in this line will increase. There is also possibility that, due to the over loading, there is no fault and the current increases. So, the discrimination of relay, it should clearly discriminate where there is a fault or there is an overload.

So, a relay should discriminate between the fault weak condition and the healthy condition. It means, in healthy condition, there may be disturbance. May be, some, let us suppose, the current is higher. So, your over current relay should not operate for the over overloading. Only it should operate once the fault is there. So, the discrimination of relay should clearly discriminate weather there is a fault or it is not fault. Reliability is a concern, that we should design our scheme in such a way that the relay should operate for which it is designed to. If it is designed for a fault here, for the current, then it should operate for the current. If it is designed for over voltage, somewhere here, it should operate in the overvoltage mode.

So reliability, basically, is related to the design and it should operate successfully, when there is some fault or some problem is occurring in the particular zone. So, we can say relays is reliable or protection scheme because, protection scheme consists of your relay, which is a sensing device. Then, it is your circuit breaker in AC system. It should open and operated. If there is a fault here, it should open here, in both ends and then fault can be cleared. So, this is including these two, it is called your protective scheme. So, I am just talking in a general way right now and then, will move to our HVDC system and we will see. So, your relay scheme means your protective scheme and it should be reliable that it should operate whenever it is desired to. It should not operate in the undesirable conditions. Then, we can say our relay is reliable. The fourth criteria or characteristic is the speed. It is very ambiguous that your, always we say that, if there is any disturbance, our relay or protective scheme must isolate the faulty section as early as possible.

So, we require our protection scheme should be fast enough to isolate the faulty section, so that, there should not be any damage to the operators or any other device in that zone. But, now the question arises, how fast? If your relay is operating very fast, what happens? There are some conditions. There is very minor transients are there and it will basically die out and if your relay is operating. So, what happens? It keeps on operating, which we never wanted. So, it should be fast but, not be extremely fast. Because, extremely fast, sometimes, even though it is not necessary to operate, if it is operating, if it is very fast, even the small disturbance or may be for example, let us suppose there is some transient is coming and it is spurious signal is coming and it is dying out. We do not want our relay should operate, because, it is not going to damage. You are here, the healthy system and all, and then we should not operate.

So, we want our relay scheme or protection scheme should be fast enough but, not be very extremely fast. No doubt it should be not slow. If it is slow, then what will happen? Let us for example, if there is a fault here, huge current will flow. This line or your operators, which is connected here, may damage. Another is, we should have the backup protection. Backup means, that if the primary fails, then backup should take over. Because, this is a relay which is having your, may be, it is a digital relay. It may have some analyzing devices and there is a possibility that it may fail.

So, as you can imagine, if there is a fault and this relay is not operating to the circuit breaker, what will happen? This is a huge current will be flowing and your operators may be damaged. Here may be transformer or another device are there may damage or drop. So, we want, if it fails, then after certain time a backup should be there, because this is a very expensive system. You know, the fault of, if it is persisting, your system may lose the stability. So, we want that, if here, it is first; it is designated for the particular section here to operate. It should operate in case there is some problem. If relay is not operating, then there should be a backup relay which should operate here and then we can isolate. But, that back up relay should operate only after if it is not operating. So, there is some time line. So, it will see when the current is exceeding due to the fault, and then it will wait for certain, may be 5.5 seconds and then, it will operate and it will isolate our that is why.

So, we should always design our protection scheme such that there should be one backup. If the privity fails, the backup should be there to have the complete reliability and security of the system. So, these five are the desirable characteristic of the protection scheme. This is the base. This is used either it is your AC system or it is DC system or even for any other purpose, if you are having some protection. Even though you know this also, you can see, this can also be applicable for protection of some area due to the security threat and other things. All we require is, this be selective and the dedicated work of any person should be discriminative whether really some terrorist attack etcetera. It means, in general, I can say, it is applicable to your electrical system whether it is AC or DC or it is to everywhere.

Now, we have to come back to our main. Here, now, let us see in the AC system, basically, it can be broadly classified; we are having two type of problem in AC system. That is, one is your over voltage and another is over current. It means all the protection schemes basically, are based on either over voltage or over current. We never operate our system with the under voltage and the under current because, under current, if there is no load here, the current is 0. I do not want to open this line.

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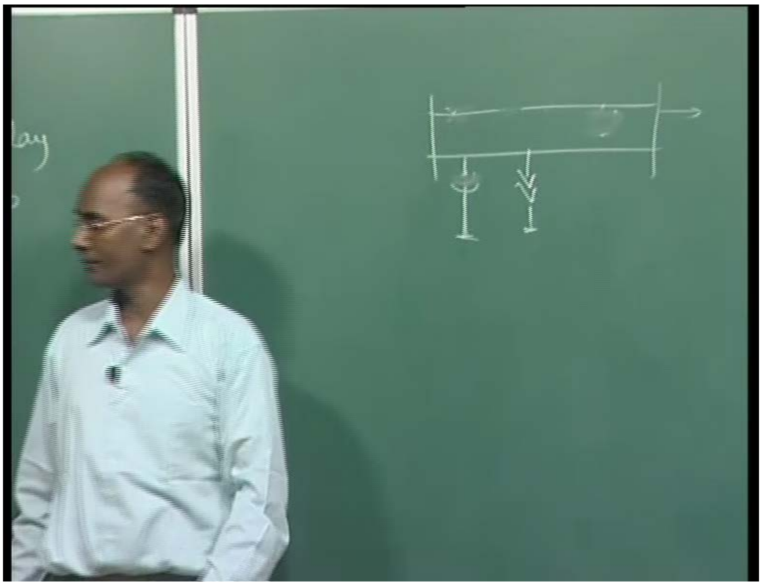

Sometimes, we also try to see that, for example, let us suppose, you can see in where the current is 0. But still, want we want the protection. You know, we have two types of faults in the AC system. What are those? They are open circuit or short circuit. Open circuit means, this, let us suppose, this is broken and current is 0. Your over current will not operate. Your over voltage will not operate. Under voltage will not operate but, how to know this? and this it is no If potential is huge potential and it is falling on the ground and this is creating problem, so normally, this possibility is very very rare. Because, opening of your wire in between, it is very rare. As I said in the last term, it is normally broken especially at joints and joints normally made near to the poles. So, if this is there, so normally, how to know? It is basically, this we may go for the distance relay and some other relay. We can see here the current is 0 and some charging etcetera is there. Based on that, we can calculate some other relays are there. But, not on normal condition, relay will not operate. So, this is very rare and it is not to have the protection for all these types of sections for open circuits.

So only, we design our protection scheme especially for the short circuit. Short circuit, once it is happening, it means there is a huge current. If there is a short circuit is happening, suppose lying to ground fault is there, so unhealthy lines may be the voltage will be higher. So, the over voltage and the under voltage, under voltage we never over. So, over voltage and over current protections are used in AC system.

So, the causes of over current here, over voltage, you know, if it is lightening is coming on this system, then this huge energy, because a stiff current is falling on your wire, so this is troubling on the conductor and huge voltage is generated. So, that is called lightning voltage, over voltage. Another over voltage is due to the switching. Because, if you are opening and closing this, there is a voltage generated on this circuit breaker, because there is a energy exchange between inductors and capacitors.

So, this switching over voltage and your lightning over voltage are the two concerns. Another is, even though due to this normal operation, if one there is lying to ground fault is there, other phases voltage may go high. So, we will come back and will see here. Then how to protect it in AC system? If a lightning surges, which is causing your over voltage, then we use the overhead ground wire on the top of the wires because, you see, your substation as well as most of the substation I can say, e h v they are exposed to air in the environment.

So, there is the possibility of the falling the lightning strokes. But, that is why we have so many fans, and there is so many spokes and there is so many lightning arresters are there. So that, it can get the ground pulp without affecting your operators. But, the wires which are flowing, which are going between the substations, it is exposed to air again. Then, we put some ground wires on top of that, if there is a lightning stroke is there. So that, they can protect your line and finally, it goes to the towers and finally, discharge it.

But still, it is not possible to protect completely. Then, we go for other protections as well. So, we use here overhead wires for this. Normally, even though substations are also protected with the some overhead wires, sometimes, we put the arresters, so that, we can provide the ground path. We also use the protective gaps. Protective gaps, we also use in the DC system. What it means is, here, this is your, I can say this, this is here and this is a grounded and this is the gap. A simple and very small gap. Now, if the voltage here rises, what happens is, the air which is here, it will get ionized. Once it is ionized, then it will follow this. It will follow a conducting path and this is grounded.

So, it is a plain gap. We call it gap here and normally it is used here. But, this is very cheap and a very conventional approach to protect the over voltage here. It has a problem. You know, this is a dead saw circuit. When it will be deionized, it is very difficult to say. So, it is some sort of a fault here, which is no doubt, for that it is a protecting but, you require that it should go off when voltage is normal.

But normal voltage is also very high. Once it is ionized and it is falling in path, this will be always ionized and it will follow the conductor. So, it is very difficult sometimes to have this very proper protection. So, what we use? We, this only we go for very high voltages. If it is rising, so we try to increase the gap. If the voltage is normal, then it should be deionized, so that, they can be cleared. Another scheme here we use is the lightning arrestor itself. Lightning arresters are again follows the similar concept, but here, this is normally, we denote like this. Here we use the non-linear resisters. We use the stakes of registers, so that, when voltage rises, its characteristic changes and it provides the ground path. When it is normal voltage, it provides an open circuit.

So, its resistance value of this here, it changes and that is lightning arresters. So, very widely we use the lightning arresters but, it is expensive. Then here, it is here very simple one. So, very very high voltage in the near to here, we put the light, the protective gaps. So, this is basically the over voltage protection scheme in the AC system. Now, if you are going for the over current protection, what we do for the over current is, if there is current is steady, then we have to open the circuit breaker. It is very common. The fuse is there and huge current will flowing. Then due to the I square hour, this will be blown up and fuse will be opened.

So, we can use the fuses or we can use circuit breakers or we can use relay, some sort of and you can basically, circuit breaker is operated on the relay operation. So, use the relay circuit and then, circuit breaker is opened. We sometimes use the current limiting reactors also to reduce the over current. Because, if rate of rise current is very high, so we can use the limiting reactors that can, you know, safeguard. It means, current will rise but, it will be limited by this reactor value and then, we can protect our system.

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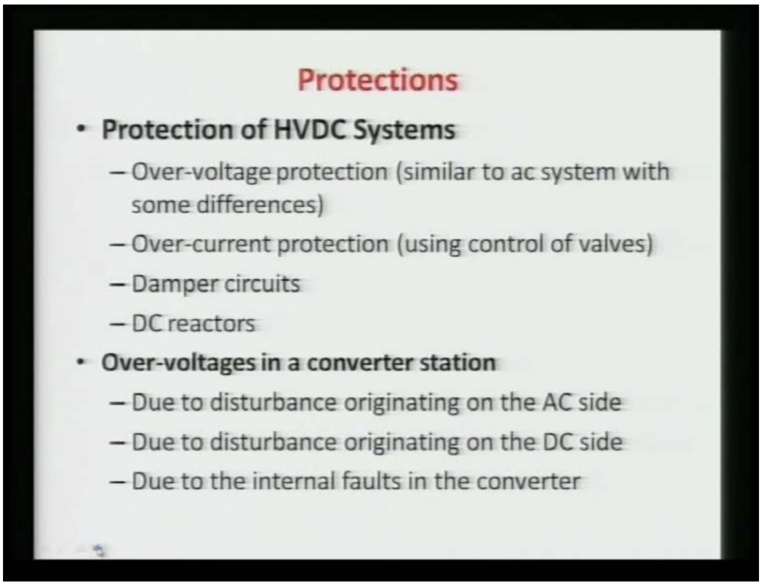

Now, coming to this here, in the HVDC system, HVDC system is again, you can see, we are having two types of here. The over voltage protection we require and we are having the over current protection. So, the over current protection and over voltage protection is similar to the AC type with some small differences. AC side is same but, the DC side over voltage is happening, then we use the different schemes for over voltage protection. We will see over current protection. Here we can use over current here, as I said in the DC line, if the current is increasing, what you can do? We use the valve control. Very similar, we can use valve control and thereby, we can reduce the voltage. That is faster than your circuit breaker. So, we use here, normally valve control to control the over current.

Now, another here, the two more protection systems are used once you use the damper circuit. Damper circuits are basically used whenever there is oscillation in the power. There is a, I will discuss more detailed later, may be not today, may be next lecture. So, the damper circuits are used if there are oscillations of the current in the DC link. There are oscillations, if we need the AC system also happening, so we have to go for the damper circuit. The damper circuit basically damp out those oscillations. So, you will find this damper circuit in the DC side that we are using. Another we use is the DC reactor. DC reactors basically control your rate of rise of current.

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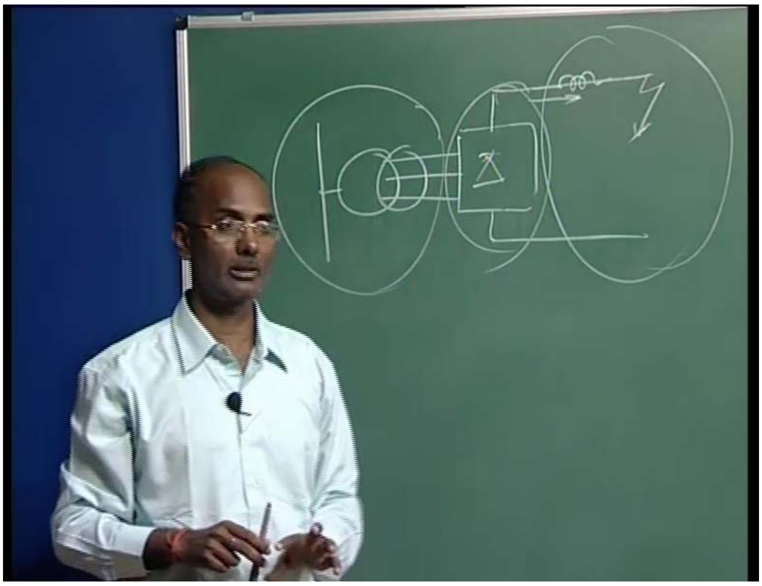

Because, this is a DC current, you know, we are not having here, as I said this is your converter station. This is your line and here we do not have a circuit breaker. If the current here is increasing, so to control the rate of rise of current, we use here smoothing reactors. No doubt, that is giving your constant repel is also reduced by this smoothing reactors or you can say, DC reactors because, it is in DC side. We also use reactors in the AC system as I explained in the very first lecture. We use the reactor for the purpose and that is different. In AC system, the reactors are used to control the voltage. We use those reactors at, basically, this line to ground. So, we use the line reactors and we use the bus reactor and we use treasury reactors. All the reactors purpose is to basically absorb the reactor powers in that one in AC system. So, those are the AC reactors. Here, I am talking about the DC reactors. Here, the reactors l is used but, the purpose here is to control the repels in the DC side, so that, we can have the constant DC current. It also limits the rate of rise of current whenever there is a fault here, because, if it is not there, then huge current will be there. So, we will see the DC reactors and how the values are calculated to limit this current.

Another problem other than this. We are having some other problems here. Like DC system, we are having here AC as well. We are having the transformers and then, it is your bus here. We are having another side. So, we are having the problems in the AC side and we are having the problem in the DC side and we are the having the problem inside here as well. In AC system, we are having only problem this side that is over voltage and over current. Now, in the DC system, this line is exposed to the air and there is lightning surges on this line. Also, there is a problem here. One bridge is, one pole, one bridge is not operating. The current also will be mismatching and the ground current will be there. So, we require the differential protection etcetera. That we will see later on. So here, so there is a possibility, that is, you are having problem, that is the disturbance this side it is originated. Once it is originated this side, it will be reflected this side as well, because, your thirstier are firing. Whatever voltage rises here, it will come this side reflected.

So, that is why here I have written as disturbance originated on A C side. Here at the rectifier side, and similarly it happens to the inverter side. So, it will be coming reflected in the DC side and thereby, the disturbance will be there. So, if the huge voltage is here, what happens is, this voltage will be transmitted to this side through the transformer and finally, it is reflected here. If there is some problem here, this will be the inductance and again this will be coming here. So, second one here, the disturbance originating on the DC side. It means, there is, let us suppose there is some problem here, pole to ground fault is there. This disturbance is here. But again, it is coming through here and it is reflected this side. So, this is going to create a problem in your convert circuit.

Due to the internal faults inside, the converter itself, means there is a misfire. There is your communication failure. It may arc through or back fire. All the things happens inside here. Also, that is also the disturbance. It means, we are having the different currents here. We are having the different voltages and those are also reflected in your AC side. So, in whole, DC system I can say, now we have this problem. This side problem and this side again, here the problem in this side and then, we should have the protection scheme for all the three differently. So that, we can protect it and we can operate our HVDC system satisfactorily.

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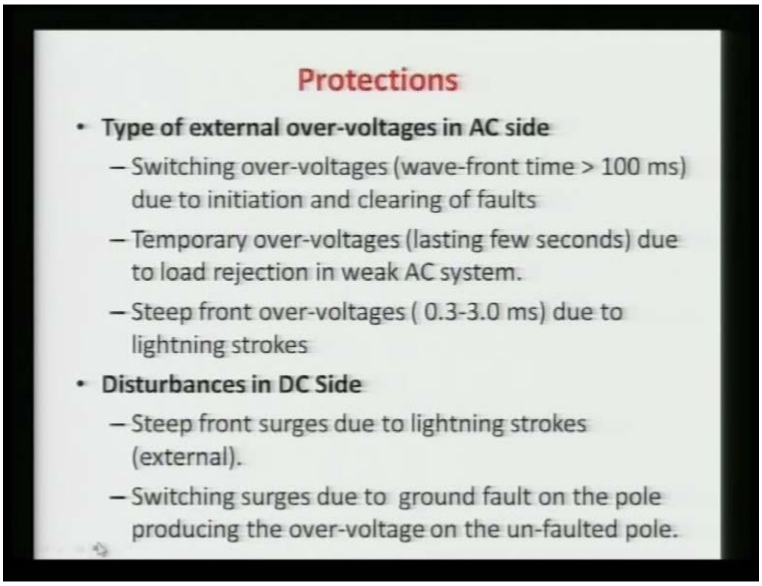

Now, we can categorize the disturbance in two categories. One is the external and another is internal. External means, it is coming from outside. So, it is external. So, you can see the external, basically here, we are having in the AC side, we are having only external and that is reflecting in your DC side. So here, I can say the switching over voltage. Now, you can see the time range. We are having the over voltage very fast. Over voltage is due to the lightning strokes. You can see, it is 0.3 to 3 millisecond, due to the steep rise and decrease here. So, this lightning, over voltage is there and we are having the switching surface. It means, whenever you are opening and closing the circuit breaker, there is a surges are rises and that is reflecting and there is a flowing in the whole AC system. That is also coming in the DC side as well. This wave front, this is more than 10 milliseconds.

Another is called the temporary over voltage or also called the dynamic over voltage. The dynamic over voltage here, basically it is lasting for few seconds due to the load rejection in weak AC system.

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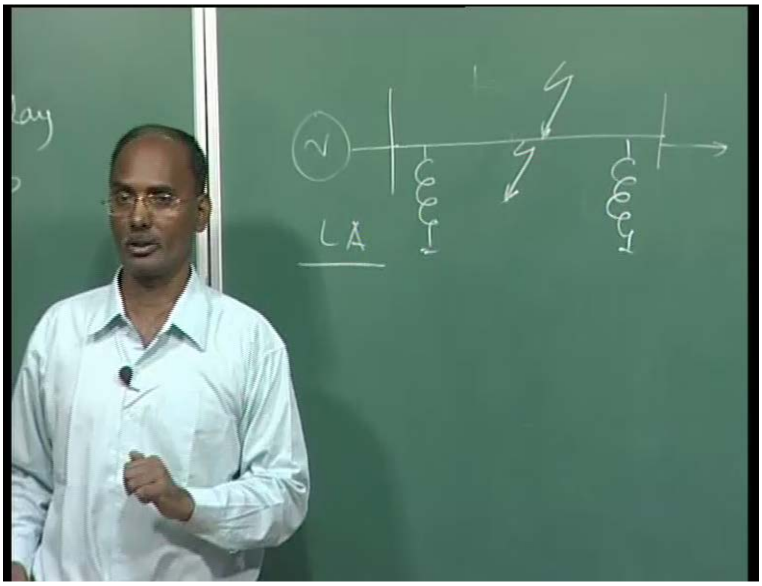

It means, to understand these over voltages, you can see here, this is your system. This is your load and you are having your system, which is fitting power here. Now, to have the over voltage here, one is coming here and that is a lightning stroke. That is, due to this over voltage, it will be rises here because, huge energy clone peer is coming and it is flowing here. That current multiplied by impedance will be added over that and voltage will go very high but, it is very short duration.

Another is here, that you are having some fault here. Then, the voltage here, experienced here, will rise and will be different transient voltage will be there. So, it is called switching over voltage because, there is some fault or` due to some switches here opening and closing. Another is, your load rejection here. The load is thrown off suddenly. It was operating the system very successfully and here, load is 0 again. There is a voltage will be there and it will be oscillating, that is dynamic over voltage. That is called temporary over voltage or dynamic over voltages.

So, we have the different time scale. This is very fast, then the switching, then you are having here the load rejection and that is called your dynamic over voltage or temporary over voltage. It will last here for the longer period that is for few seconds basically. I can tell you with these three conditions, this normally we do go for all these studies. No doubt. This we go for this here and that is, the steep front over voltage lightning stroke. This basically, we do this analysis, we go for the study for this type of over voltage and that will be used for deciding your lightning arrestor rating. Because, it basically depends upon how much energy is going to come in the system that must be taken by the lightning arrestor.

So, because there is a kilo ampere current is falling here and that is huge energy is there and that energy is basically rating of this. It is a rated voltage here and then, its rate, normal voltage transient, over voltage and then, the energy rating of this. So this, we analyze our system for the lightning stroke to design the characteristic or rating of this lightning arrestors. This switching over voltage, switching over voltage normally we also perform here and will see our system stability concerns, weather your system is stable or not. Based on that, we go for the fault clearing and how much its duration is there and system will be stable or not. This voltage will be also higher and we go up to certain millisecond.

Another here, we go for the temporary over voltage. Basically, that is a deciding factor here for the rating of your reactors. That is, may be line reactors or bus reactors. Because, that will control this voltage here and because, it will be during this over voltage, more reactive power and voltage will be reduced here. More reactive power, it will be absorbed by the inductor. So, this will give your lightning arrestor decision. This will give your reactors rating and this gives your system stability and the concern and all. Sometimes, this will be used to decide the insulation of the system because, this ten millisecond is more than enough and sufficient to breakdown the insulation. This is not very small here and it will be the insulation is not very much affected. Very narrow time this is. The voltage is less, so insulation is also not affected. So, insulation coordination and insulation etcetera will be decided on stability concerns and is basically analyze by this.

So, these are the three broad criteria for the over voltage analysis. The disturbance which is the DC side here, as I said now, in the AC side, the over voltage will be only due to the faults switching and also due to the load rejection and so on. Then, we can have some lightning stroke this side, so, this will be a rising. The DC side, now we are coming here. External will be again, some lightning surges coming on the DC tower. Once it is energy is coming, it should go in the both direction. Another here, the switching surges due to the ground fault on the pole producing the voltage on the unfaulted pole. It means, if the fault is here and we are having two poles, then this voltage here will be different and it will give the relay rate of rise over voltage in this pole. One here is your lightning one and second one is due to the fault. So, two here are basically, this is external because is coming here and this is basically internal because, due to the line to ground fault here inside the system.

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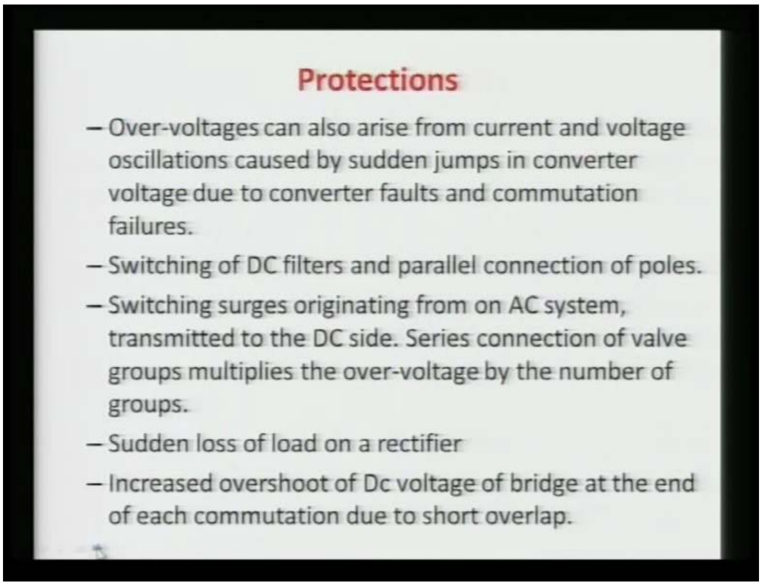

So, over voltage can also arise from current and voltage oscillations caused by certain jumps in the converter voltage due to the converter faults and the commutation failure. You know, we saw the commutation failure and we also saw the converter faults, all your this misfire, or through, back through, or quenching etcetera, in all this there is sudden jumps. Sudden jumps are there. There are inductors and there are some capacitance is formed even in the ground to this high pole and that should be there. There is some oscillations and that will give you some rate of rise and some over voltage will arise in the current and as well as in the voltage.

Switching of the DC filters. Because, even though we use the DC filters this side, we also use the DC filter, which we will see, that will also gives some over voltage. The switching surges originating from the AC side, transmitted to the DC side is also the concern because, the over voltage here, you are protecting. No doubt. But, during that period, it is stable this side and since it is very fast here, it will be coming this side as well. So, this side also over voltage is going to occur and whatever voltage is going to transmit here. So, that is one concern. So, series connection of the valves group multiplies the over voltage by the number of groups.

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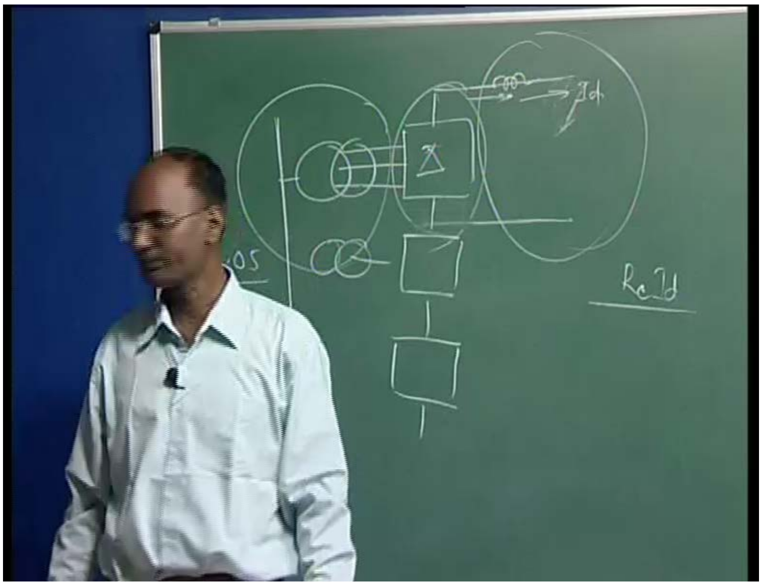

I mean to say that here, let us suppose you are having various bridges. All this here, even the voltage here, the groups, this is going here. Number of it is going to be added. This is the bus, if the voltage is here increased. What will happen? This voltage is going to be added and this voltage is going to added and this voltage, DC here, is going to be multiplied. If the voltage here is increased by 1.05, let us suppose, voltage has gone, now here it is 1.15 because, this voltage here, this is going to be added. These are in the series connections. So, that is why it is said that, the over voltage, it will be the number of groups. It means, here in the commutation group, one this here, that is going to be added. Therefore here, that is a more serious concern.

That is, number of bridges is more. Sudden loss of load in the rectifier circuit. Let us suppose, there is some problem. This is a trip and the sudden loss in that inverter side. If here, the loss is there, then the current will be made 0 at that time suddenly. Because, otherwise what will happen? The voltage will keep on reducing. As I said here, we maintain the current constant but, if suddenly, your load is thrown off in the inverter side, what will happen? This will be your power is 0, voltage is same and current should be 0. Then, the converter will try, because it is trying to maintain the current and try to reduce the voltage, so that finally, power will be 0.

So, whenever the sudden load is throw off, what happens is, the voltage here, this voltage that is going to be dropped. You know, commutation circuit, this R c Id, this voltage is going to be increased because, this was the voltage which was included here. So, this minus this voltage was there and this voltage Id is 0. So, voltage is going to be rise. So, there is some rise here in the sudden loss but, this is very less. Because, this value is less. This is less, so it is not more than 78 percent I can say. So, this is not a big concern. Now, increase overshoot of the DC voltage of bridges at the end of each commutation due to the short overlap. If overlap is short, what happen is, the voltage rise dv by dt is very high. Due to this dv by dt, the voltage here is going to be, can also be increased. So, this is basically at the commutation, if your current is suddenly changing. It means, your u is less. That means, the time duration of the takeover apparent is very less. So, sudden change and again the voltage will be going to rise and this is the concern of this.

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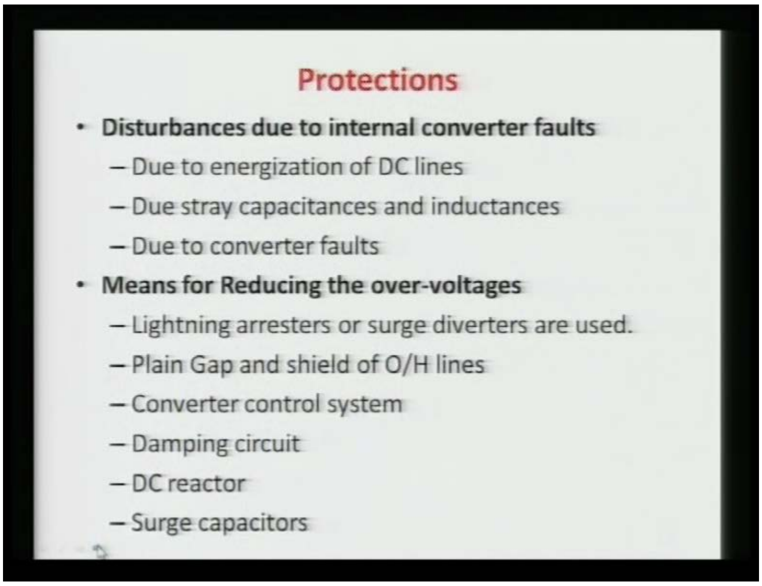

Another over voltages and another transients in DC system. Whenever you are energizing your DC line, it means you are slowly and slowly you are building it. Energizing this. At that time, you can see, the voltages wave ship is not in the proper order. It means, it is not a symmetrical output. That DC side and AC side current are all sometimes, DC short circuit means, AC side, there is a short circuit. This side also, the voltage is not uniform and if there is a short circuit, other phase voltage may be increased.

So, energization can be also one concern. Another is due to the stray capacitances and inductances. Due to the DC side here and there is your voltage wave ships and currents are changing suddenly here and there. So, due to this, voltage rise will be there. So, this is also a concern. Converter fault, already I have discussed. So, in total, I can say here, for the over voltage, we have to reduce it. Over current is not a big concern because, we are controlling the converters here. The converters here, the valve control, we are only controlling the current by the valve. So, we can, it is very fast. It is even faster than your circuit breaker and it will take care of the current to maintain this. But, the rate of rise, sometimes, it is very high. Then, we have to have some protection for this and we have here the DC reactor for that.

So, major concern here in HVDC system is the over voltage. That is why we should have the various, here you can, see now, we are having the lightning arresters or we should have the surge diverters are used. Surge diverters and your lightening arresters are same because, its surges are not going to the system. It is coming down to this, your ground. Then, we use plain gaps. We use in the DC lines, the gaps here and then, we can use the ground wire on the top of the conductors to protect the over voltage due to the lightning strokes. Here, these two protections are used. This is also for same and this is basically, the primary here and the secondary we use here for size control and the lightning arresters. But, there is some problem here in the DC lightning arresters. Because, AC lightning arresters are very clear because, you know, the current is also going to be 0, that is, one cycle. But DC, the current is DC.

So, the deionization process is difficult here in your DC. In AC, it is possible. Another we control the over voltage by your converter control system. Because, if the over voltage is there, this side, you can control the voltages here as well. Very well you can control. Then, we can use the damping circuits, if there is oscillation in the voltage, over this oscillating voltage, so we can use the damper circuits in the DC side. Normally, we use the DC dampers and we can use the DC reactor here to limit the rate of rise of current here. Then, we can use, sometimes surge capacitors, if there is some surges. The capacitor voltage will increase it. Basically, the surge capacitors are some sort of storing the energy devices. So, if it is very huge energy is there, it will store some voltage will rise and then, it can be released. Resistance or another circuits and finally, we can safe guard oscillation.

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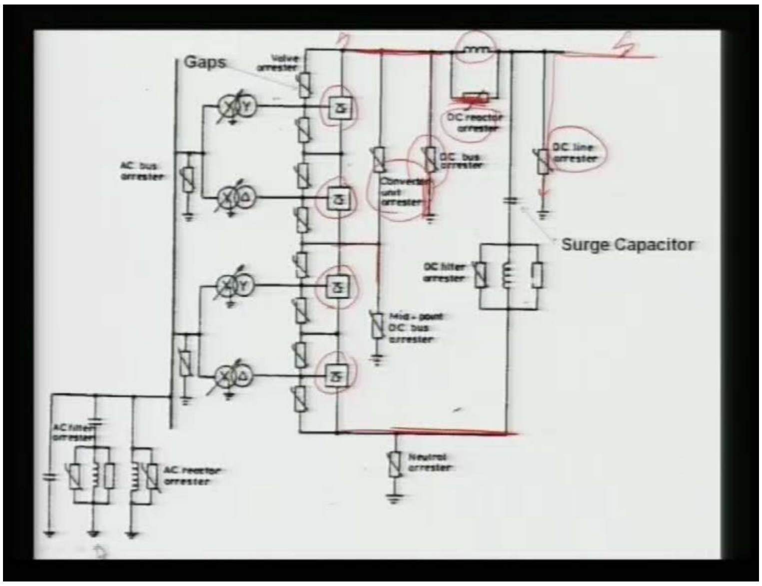

So, this is the over voltage protection scheme. You can see here, what we have here, you can see, we have the, this is a bipolar augment. We are having one pole here and we are having one pole here and this is your ground. You can see it simply this is grounded. Now, we are having the, in this scheme, you can see this is a bridge one, bridge two. It means two bridges per pole. We are having another pole here and this is, this we are having. Now, this is your, you can see the DC reactor arresters or we are using, this is a reactor basically. The reactor should also be protected because, if there is huge current rises there, huge voltage induced across reactor and if it is very high and this quail will be pot. Insulator will be pot. So, we should have here, if the voltage is there, so what this is non-linear resistance? It will try to provide the path.

So, we should always protect the reactor. Because, reactor is looking simple winding but, it is not so. It is very huge and very big. You know, two ampere current is flowing through this. If the rate of rise of current in the DC is very high, then huge voltage will be produced here. Then, if the voltage is there, then what will happen? It will by pass it. So, this is a register circuit basically, non-linear. Some energy is dissipated here and finally, voltage will be reduced. So, we are having the DC reactor as well. This DC reactor is basically, we will discuss later on that. It is used for the ripple control. It is used for the rate of rise also and the values are decided accordingly.

We are having here the DC line arresters. If there is any problem in the DC line here, what happens is, let us suppose, some lightning stroke is there. Then, it will be here. It will provide the ground path to that and it should not go to our converter station. We should protect it, otherwise what will happen is, your converter circuit will be damaged and then, you whole, you have to shut of DC link.

So, we provide here, means before this, even though smoothing reactor and after also you can say here, we are having the bus, DC bus reactor, because this reactor is also exposed to air. It is outside. It is not inside. But, this converter circuit, most of the time it is inside the building. So, there is no possibility of falling any where here. There is no possibility of falling the lightning stroke.

Only this reactor, so that is why from both side of the reactor, we are having this value. So, this is your, you can again provide the ground path, if it is happening this side of the your DC reactor and it will be grounded and energy will be released. Then, it should not pass through this side. We are having here, you can say, converter unit, here arresters. This will be basically limiting, if the voltage across here, I think I should explain here. We are having across this complete pole here, if there is, due to certain problem in the voltage here is rising, as I said, if the voltage is increased this side, it is passing through this converter circuit and it is going to be multiplied by number of bridges.

So here, even though there is 0.5 percent increase, here the 10 percent increase is going to be there, because due to the 255 percent here finally. So, then if it the voltage is exceeding, excreting, now it is suppose 500 plus minus 500 kilovolt, if it is exceeding very high, then this will provide a path here. Otherwise, what will happen is, huge voltage will appearing across this, even though outgoing valves and that may also damage your converter circuit.

So this, we require the converter unit arresters, we call it. It means, this is a converter circuit here. No, yeah. Similar, yeah, similar. We are having this side also. Then, we are having, you can see, this is your valve. We are having another here and that is called your valve arrester. It means, individual valves are protected. If this voltage with this and this voltage, this is with the ground we are having, so, this valve arresters. So, we are also having the voltage here individually exceeding, then it will be providing the safe guard to this. The arrester, you know, simply it is providing the ground path and sub energy will be released. So, we are having the various here, your valve arresters, then we are having converter unit arresters and thereby, we are having sometimes, midpoint also here, the DC bus arresters.

Now here, another, here you can see, we are having the neutral arresters. Because, the current which is going here, so if there is some voltage, another neutral here itself, then it will be here, and that is also going to be there. This side is AC side and this is a trans converter, transformers, you can say this is your 12 pulse and 12 pulse. I think we are having is a mono polar operation. Basically yes because, this is a 12 pulse and this is 12 pulse and we these bridges are added is series.

So, it is a twelfth period. So, this is mono polar operation and that is why it is neutral is coming here. So, you can see here also we are having the AC bus here and arresters again, it is lightning arrestors. If there is some problem in the transformer, this side, then it will be providing ground path here. We are having this AC reactor arresters and the reactor arrester means, here we are using reactor as well as the arresters. Here we use the reactors. For what? This is basically nothing but, this is related with the filters. It provides the reactors at the sub stations.

So that, we can have some harmonics current due to the capacitor and here, it can flown down. So, this reactor is also protected. Here, this capacitor and inductors are there. We also have a, here, so we have lot of protection schemes. So that, we do not want any of the individual components should fail. If any of the component will fail due to the over voltage, we have to simply replace. We have to shut off this line and finally, go for the replacement. Here, we can have, you can see the DC here. The filter resister, we use the DC filters. As I said, we are having the AC filters. We are having the DC filters also to smooth the current here, in this one and this filter is there. So, in this filter, you are having the combination of inductor and your capacitors and then, we use again here, the arresters. Because, the voltage here, it can increase and then, because there is some more current will be flowing here and then, the voltage will rise here and then, it will take care.

So, we are having this, you can see, for over voltage, we are having lot of things to protect whole of our system.

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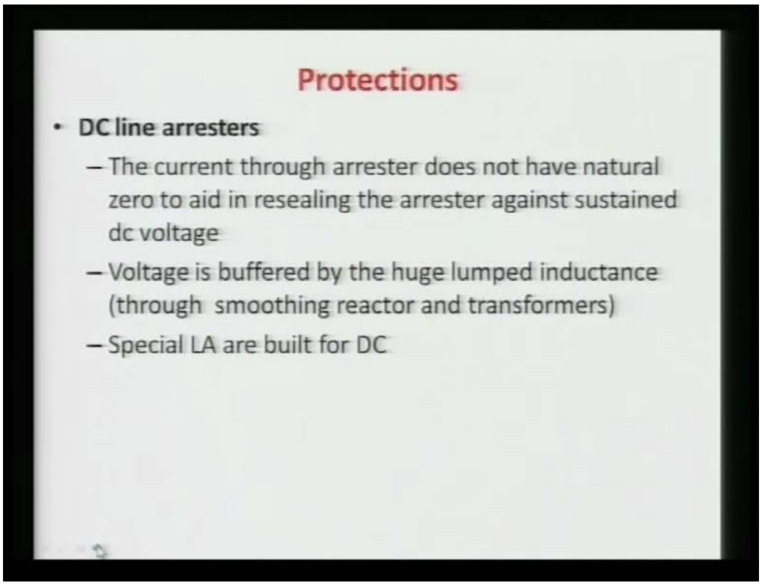

Now, this is all about your over voltage. Let us go to the your over current protection. But before, here see the DC line arresters. Why the difference between the AC line arrester and DC line arrester. The major concern here in the DC arrester is, here we do not have any natural zero. In AC, always you are having a natural 0. What happens? You are getting some 0 somewhere and then, it can deionize your, whatever the ionize path. But here, we do not have a natural zero to aid the releasing of arrester against the sustained DC voltage. If it is voltage is increasing, the DC voltage, so we do not have any thing that it can switch off automatically. So, what we do is, we go for special arrangement to provide some oscillating current in this, here arrester, so that, we can get some natural. What happens? It is always possible.

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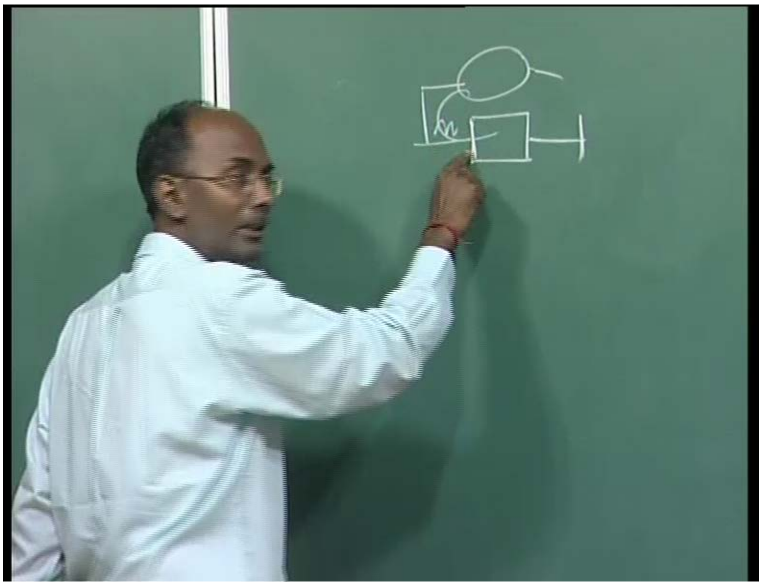

Let us suppose, you are having here, your DC current. DC here, this is your arrester, let us suppose, you are having. We can add some here, voltage with the some circuit that current, which is oscillating here and the DC, it is added. Then, we can have the 0 somewhere here crossing. Once 0 is crossing there, then we have to deionize it. Because, the 0 and this is the big problem in the DC circuit breaker also. Because, no 0, so the r quenching is very difficult. We cannot r quench it. Once it is ionized path, it will be continuous ionization.

So, we make a special augment to make it 0 somewhere, and current also in that. So, in DC, if you are adding here, so will get somewhere 0. Voltage here is buffered by the huge lamped reactors through the smoothing reactor and transformer, which is not in case of the AC system.

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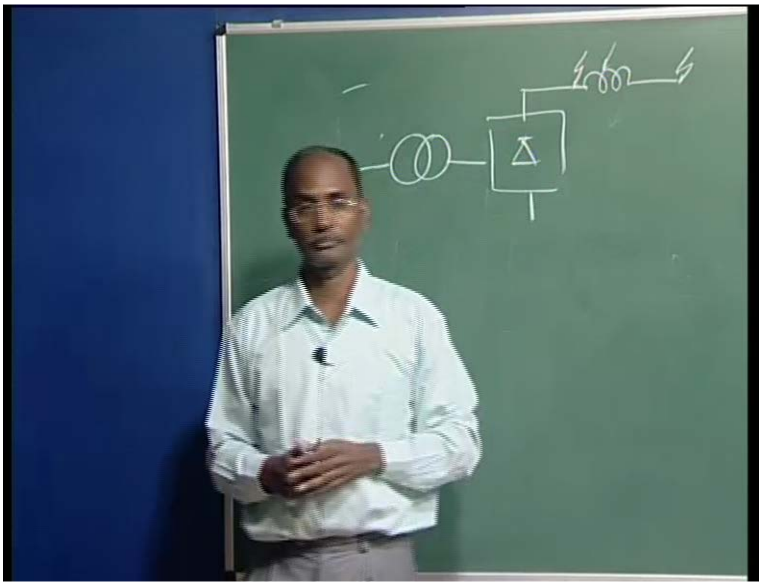

I mean to say that here your converter circuit is there. Here, this inductor is the lumped react inductor. In the AC line, the inductance is there. It is distributed. So, whenever it is falling, let us suppose here or it is falling here, then it is falling here but, this value is only if it is inductance falling here. It means stroke. If stroke is falling here in this one, it is not causing any problem. It means, here the voltage is very high. But, in the line here, which is AC lines, the inductance is distributed. Here, we are having the lumped inductances. This is different than the AC system. Also, if there is the transformer here, this inductance is also just like a lumped inductance.

So, if some voltage here and there, what is limited to this portion and then, it is injecting this. So, in the DC line reactors, we consider these two concepts and we modify it, so that, it can be taken care and similar to the AC system. So here, we try to provide the natural 0 here. We try that the inductance here, the rate of rise should be such that limited, so that, we should not face any problem. So, that is why here, special lightning arresters are built for the DC lines with the some modification. But, again the purpose is same.

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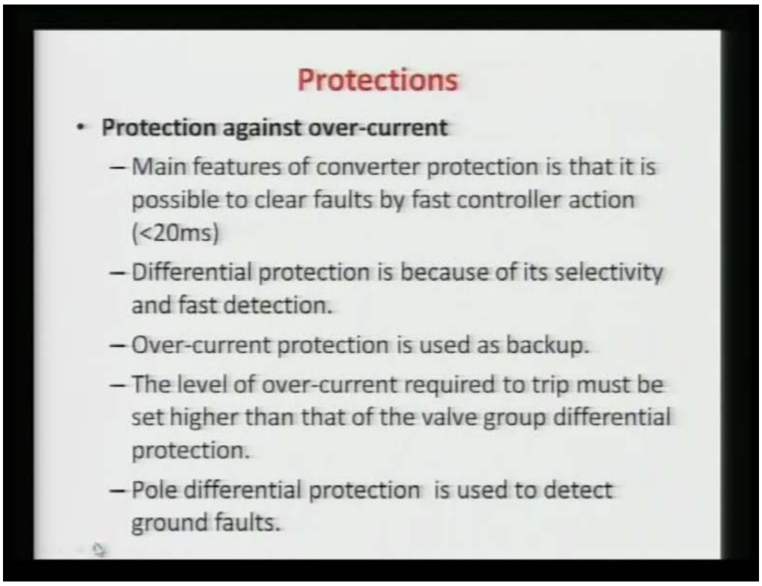

Now, coming to your protection against over current. The main feature of converter protection is that, it is possible to clear faults by fast controller action less than 20 milliseconds. It means, you can see why I am saying 20 milliseconds. If it is 50 hertz cycle, then one cycle are some of the faults are automatically cleared. Your side commutation failure, it is self-clearing. Misfire is also self-clearing and all the faults are almost self-clearing. One cycle, if there is no persistence problem, then after one cycle, it will go off. So, if it is persisting, then we have to have some protection scheme to control the over current as well. Differential protection is used because, it is selective and the fast detection.

The differential protection are basically used for the, that is called the unit protection. It is used for your normally any of operators, like used for transformers. It is used for generator binding. Sometimes earlier, it was used for the transmission lines also. But, it is not used because, you know, it requires the pilot wire for this. But, if your operator is very small, we can use the differential protection. Here also in HVDC, we use the differential protection, if the currents in the two poles are different or there is some faults in the AC side. Over current protection is used for as a backup always. If the current is exceeding somewhere, then we can use over current protection and also where these protection schemes are applied. The level of over current require to trip must be higher than that of the valve group differential protection. The pole differential protection is used to detect the ground faults if there is. Let us suppose here, the fault is there. Then, we have to see the, here there will be current and in other pole, the current will be not there. We have to go for the differential protection. You see, this is schematic diagram for this current protection.

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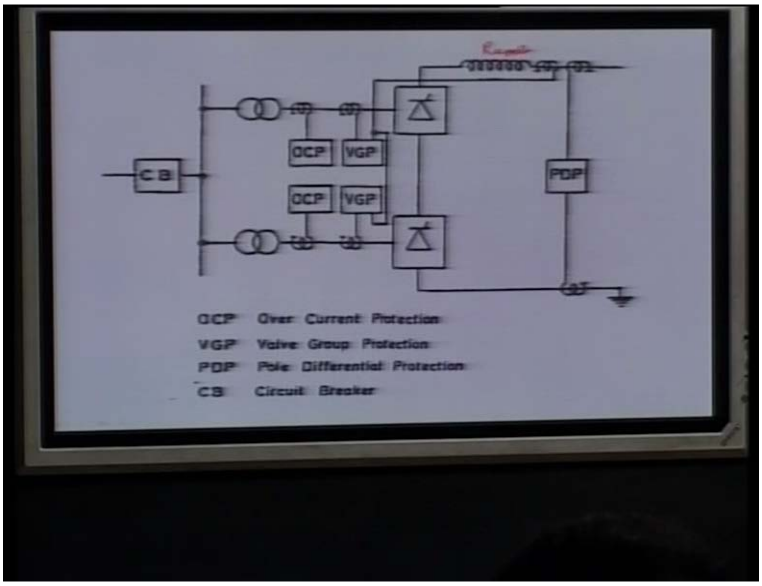

You can see this, we are having here, the smoothing reactor here. We are measuring the current here by the c t. Now, you can see, if it is a DC current, the c t will be 0. The current, because it is only the transformer what is in the your AC. But, I mean to say that, we can possibly, we can measure even the DC current with some other measuring instruments. It is not a c t here, but it is, we can use the hall effect. We can use some other devices and based on that, the field etcetera, we can measure the current. What is a current flowing means, we have the DC instruments that can measure the current and that can be transformed in different fashion. So, we require the measuring of the current here. It is shown as a c t but, it is not c t because, c t is only used in the AC systems. So, we are measuring the current here. You can say, we are having here, the pole differential protection. If there is some current mismatch here, then there will be some difference and this relay will operate. It means, if the current will flow here, if both the current coming here is the same, then induce voltage here and here will be the same. There will be no current here. Then, relay will not operate. But, if there is some mismatch in the pole currents here, then it will operate and then, we have to, it will give the signal first. If there is a small value of the difference is there, then it will indicate. If it is large, then it will trip. It will give the trip command to somewhere in the circuit breaker.

Now, you can see, we have the valve group protection here. We are also measuring the current here and this current here and the difference is taken here. We are using this group, valve group here. This is one valve and it is another valve here. The bridge, we are talking. So, this is the, basically, current difference here. No doubt, the current here, the AC side, we are talking. Here is the DC side, we are talking. But here, we are taking the value and there is some factor we are using, so that, this current and this current should have the synchronize one. If there is some mismatch, and based on that, then they should operate this value.

So, this is over current here. Now, another we are using here, the simple over current protection scheme. If this current is exceeding high, let us suppose, there is a fault here and that is our circuit. Then, the current will be more and this will trip it here. Similarly, we are having over current protection scheme here of this transformer.

So, in all this, here you can see what is happening. This thing will be giving command to here, bus, AC bus here. This is the system to be isolated. If again, what is your fault level? How much high value we are going to put? So, that is why, it is your over current protection scheme. Earlier, I showed you this over voltage protection scheme of this DC circuit, HVDC link basically.

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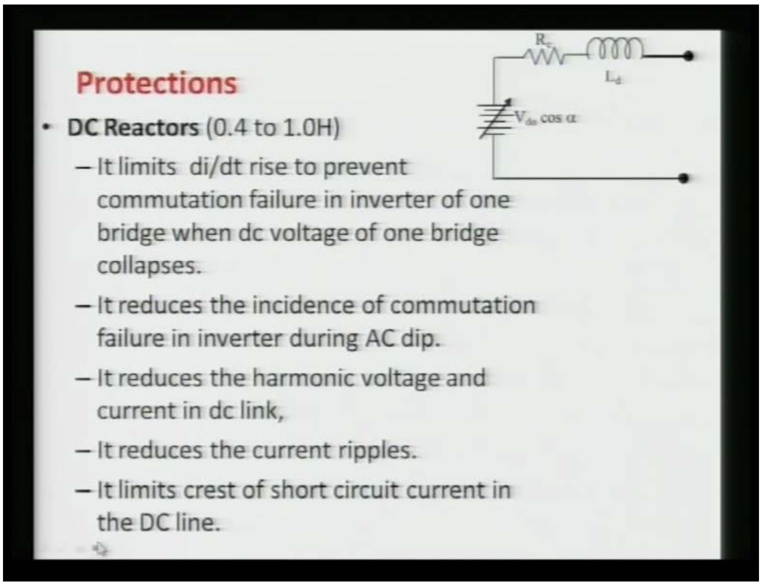

Now, one thing is, here is very important. That is, the DC reactor. Normally, this reactor value, you can see, it is in Henry. It is in 0.1 H to 1 H. Henry, it is basically required in this reactor. This reactor is basically, is a limiting value of a fault occurring here. It is also used to control the ripple. But, it is more important, if there is some fault here and if this inductance is not there, what will happen is, this voltage divided by the impedance, this R and the impedance of the line, it is very high value current will be there. But, if due to this inductance there is a fault here, current is going to increase. Thereby, this is trying to introduce the voltage. This voltage minus this voltage is going to appear here.

So, current is very fast and this voltage is very high. So, it is trying to reduce the voltage here and trying to limit rate of rise of current. Once it is limiting, current is rising. Meanwhile, your converter circuit will take care and it will try to reduce the current. So, this inductance is basically, you can say, it limits di by dt here. It tries to prevent the commutation failure in the inverter of one of the bridge, when the DC voltage of one bridge collapses. Because here, one option is that, there is a fault. Another is, there is a possibility that the problem is in the inverter side. If inverter side here, the voltage is gone down and the current will exceed. You know, if the inverter side voltage has gone down, current is exceeding. Now, what will happen? The commutation failure is one of the big concerns.

So, this inductance basically is decided that, it should, the value of l d is calculated, so that, it can prevent the commutation failure. It means, it will try the firing angle and your minimum angle is given. Then, how much it is exceeding, so that, commutation failure can be avoided. We will see how to calculate this value. It reduces the incidents of commutation failure in inverter due to the AC dip. No doubt. It reduces the harmonic voltage and the current in the DC link. As I said, it can, the DC voltage here, this, whatever the ripple is there. So, it is working as a smoothing reactor. That is why, it sometimes known as, so the current here is almost constant. This, made by this ripple is reduced. It reduces the current ripples. The DC current is almost maintained constant. The voltage also is reduced, the harmonic voltage. It also limits the crest of the circuit current in the DC line, when it is a fault. So, when there is a fault, it is limiting the fault current. If the inverter side voltage is reduced, then it is trying to reduce. Basically, it is nothing but, di by dt control and that is a very useful, this inductor.

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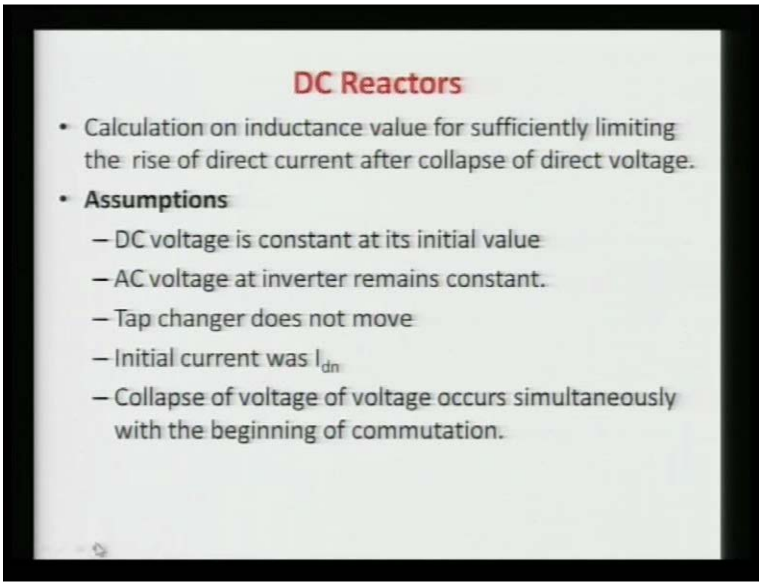

To see this here, we can calculate what will be the inductance value for sufficiently limiting the rise of DC current after the collapse on the DC side voltage. Then, based on the various assumptions in the next lecture, we will see, how this l d will be the, what will be the suitable value of l d for the inverter side. It means, that assumptions, we will see, your DC voltage is, it is assumed the constant when the collapse has occurred. Before that instant, the AC voltage at inverter here becomes the same, because it is constant we are talking. The tap changer is not operating. Otherwise, tap changer will also control, will action, will operate. The initial current was I d normal current. Then, the collapse of the voltage of the voltage occurs simultaneously with the beginning of the commutation takes place. With this assumption, basically will try to calculate, what will be the value of inductance of this smoothing reactors or DC reactor, so that we can limit the commutation failure.

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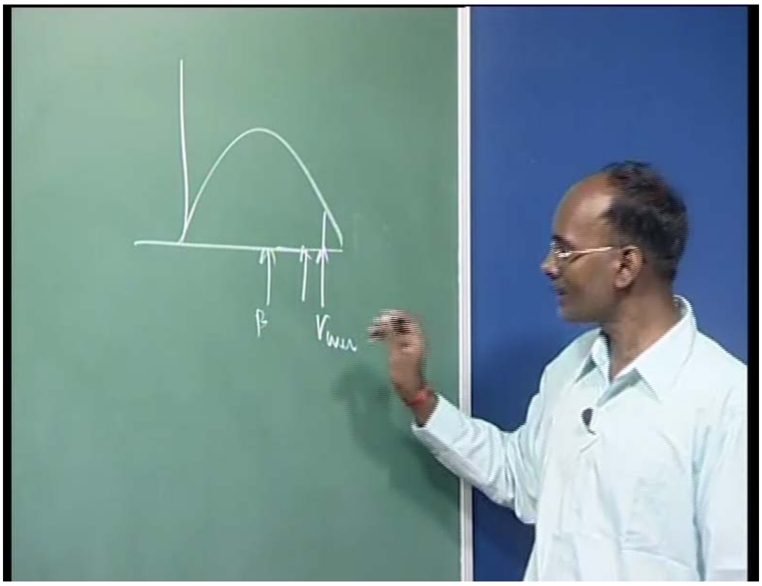

Because, the commutation failure here, always we know that this is your, here the beta is the firing. Then, we maintain here the gamma minimum. Beta is calculated, even though at certain here, it was the gamma here in the normal condition. But, due to the u, it will try to increase. This value, if it is exceeding here, then there is a possibility that this minimum is decided that if it is coming this side, the commutation possibility of commutation failure will be there.

So, will see that, this is a normal gamma it was operating. It is fired here and u was there, this value. It was thirstier was off. That valve was commutation was successful. But, due to certain problems, say collapse of voltage, this may exceed here. Finally, coming this side and the commutation failure will may occur. So, will calculate based on this criterion, what will be the value of l d in the next lecture. So, the next lecture will be the end of this module lecture and that will be next hour. Thank you.