Power System Operations and Control
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Module - 01
Lecture - 01

Welcome to power system operation and control course in which the lecture module one consist of structure evolution, and also we will see the main requirements for the power system operation and control. Before going as you know, this electricity is one of the important essentials for any development of any country and also for the mankind. The commercial use of electricity is started in the late 1870s; however, the invention of the electricity took place very beginning.

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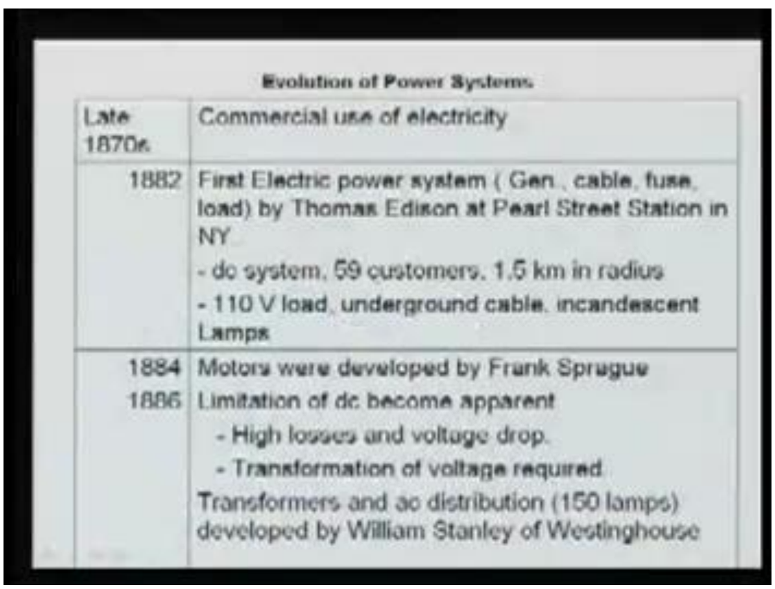

In the early phase of electricity development or evolution, this was only use for the lightening purpose. There were generators as well as the loads; there were together, and it was localized to certain local areas. The first electric power system which started in 1982 and it was invented by Thomas Edison at the Pearl Street Station in the New York, USA. This power system was the DC system, and it was consisting of the

DC generators, the cables, fuses and also the load. It was feeding the power to the 59 customers, and it was feeding in a radius of approximately 1.5 kilometer in that one.

The operating bold is it was 110 volt and mostly it was giving loads to the incandescent lamps means simple bulbs. And at that time, the four generators are 25 hp were used, and it was the DC generator. In 1884, these motors were developed by the Frank Sprague, and there were added to this power system, and again, these were basically the DC motors. After addition of the motors, the use of electricity was very prominent, and the people thought that electricity is the better way to utilize the inertia.

But here in 1886, the limitation of DC became apparent. The main problem of the DC either the high losses because it was not possible to raise the voltage in the DC; it was only that the people were using for increasing the voltage by the several series DC generators in the cascade way. And adding this cascade, again there is a lot problem in the insulation that is between the different generators, and also it was not safe. At the same time, it was required that anyhow if we can increase the transition voltage or the required voltage so that the current requirement is less at the same time we can reduce the voltage draft.

At the same 1886, the transformers as you know the transformers are used for the AC power system, and AC distribution system was developed by the William Stanley of the Westinghouse and the Westinghouse basically here, the purchase the complete pattern of this whole DC system.

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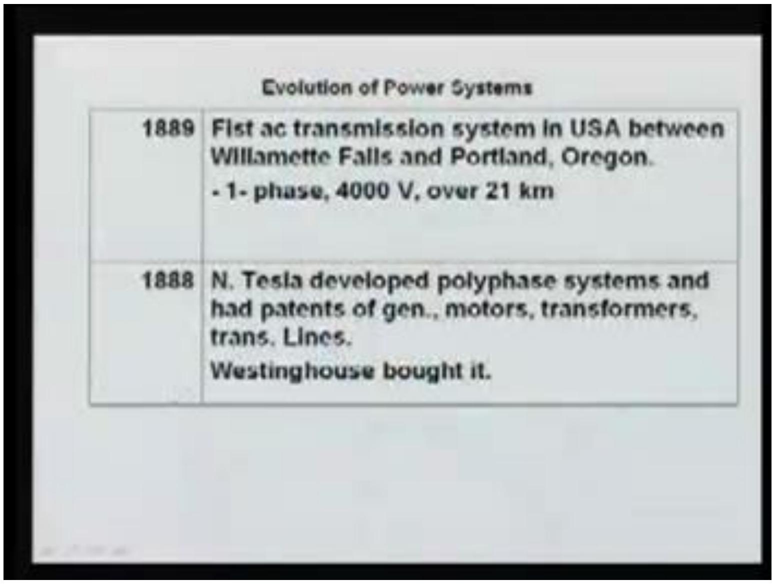

In 1889, the first AC transmission system was developed in USA. It was basically in between the Willamette Falls and the Portland Oregon. At that time, it was not possible to use the DC system, because the distance from this Willamette Falls and the Portland, it was more than 21 kilometer. So, the DC was not possible that is we can have the DC generators as well as the DC transmission. So, the first AC single phase transmission system which was the 4000 volt and it was for these 21 kilometers.

Then the DC becomes it was not feasible; it was not even possible to power flow over the long distance with the DC. At the same time, there were the other development for the poly phase DC system which was developed by the Nicolas Tesla, and he had the pattern of all these AC generators, motors, transformers and the AC transmission line. At the same time, Westinghouse purchased it. Then the controversy is started whether we will go for the DC system or we have to go for the AC system.

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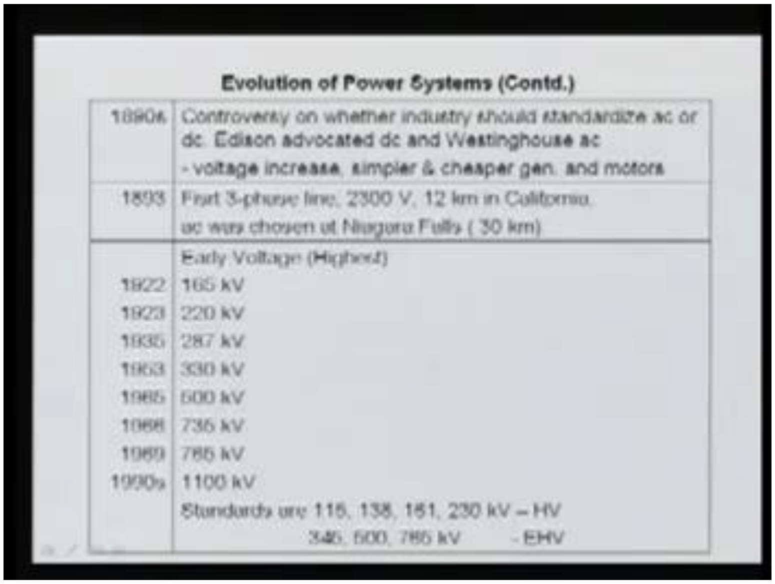

Evolution of Power Systems (Contd.)

1890s	Controversy on whether industry should standardize ac or dc. Edison advocated dc and Westinghouse ac - voltage increase, simpler & cheaper gen. and motors
1893	First 3-phase line, 2300 V, 12 km in California. ac was chosen at Niagara Falls (30 km)
	Early Voltage (Highest)
1922	165 kV
1923	220 kV
1935	287 kV
1953	330 kV
1965	500 kV
1966	735 kV
1969	765 kV
1990s	1100 kV
	Standards are 115, 138, 161, 230 kV – HV 345, 500, 765 kV - EHV

This DC is invented by the Edison. He advocated for the DC system, but the Westinghouse which had the pattern for all the AC systems, then it was advocating for the AC system. At the same time, even though Edison wrote in the magazine that the AC is used for the killing of the people, because at that time in the very beginning, AC was used to giving the shock to the people. But no doubt this AC own the match own this whole scenario due to the several reasons that the voltage increase was possible; at the same time it is a simple to generate and to utilize the AC power compared to the DC power.

So, then slowly and slowly, this AC power becomes prominent, and the DC was paced out. In 1893, the first three phase line was again invented and developed, and it was between this Niagara Falls that was 30 kilometer from California, and it was operated at the 2.3 kilovolt of the supply. This first three phase of transmission lines was again it was the remarkable achievement in the three phase system, and you can see right now, we have three phase transmission system rather than the single phase transmission system especially in terms of the transmission.

The early voltage if you see that witness that up to 1921, we had the voltage of the different voltages like we had this 16 kilovolt, 44 kilovolt even though 60 kilovolt. But later from the 1922, the voltage keeps on increasing. The reason behind this increasing the voltages that we can introduce the current, and therefore, we can reduce the losses of the system at the same time we can reduce the voltage drop. So in 1923, the 220 KV voltage level was invented, and it has came into the operation.

Similarly in 1935, it was 287 kilovolt, and in 1953, it was here 330 kilovolt. So, you can see it is a continuous here voltage is keep on people are trying to go for the higher voltages. Again these were possible due to this insulation level and also the right of way problem and the insulator, etcetera, the development at the same time. Then in 1990, this we achieved this 1100 kilovolt AC transmission system. So, at that time, it was realized that we should go for some standard because it is a witness that the loads, there were very near to loads centers. The generation as well as the load, they were put together.

So, then it was realized to have interconnection, and then for the interconnections, we should have the standard voltage level. So the standard voltage level again adopted the different standards for the different country, and normally, the voltage level 115 kilovolt, 138 kilovolt, 161 kilovolt and up to 230 kilovolt came into the category of high voltage transmission lines. And more than that that 345 which is very common in this USA than in Canada country; here the 500 and 765 kilovolt transmission line, they were known as the extra high voltage transmission lines. Again if you see the frequencies, the frequencies also since the generators which were feeding load very near to that and it was not interconnected; so, the frequency also it was varying.

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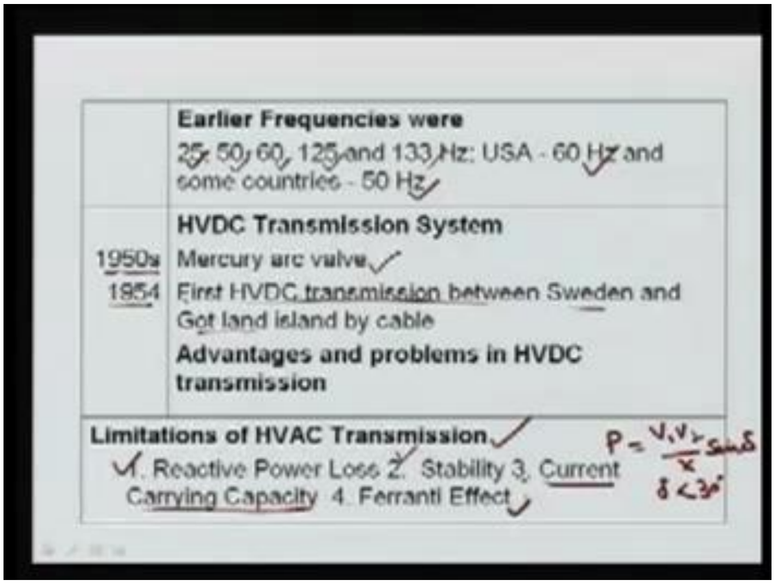

It was 25 hertz. You can see here 50 hertz, 60 hertz and 125 hertz along with the 133 kilohertz was also possible, but we know for the integration, we should have the same frequency throughout the system. So, some country like here in India and other Asian country and European country, they adopted for the 50 hertz operation. And the USA and the Canadian country, they just use the 60 hertz. So, again if you see that in terms of generating voltages, since generators were earlier the DC, later they were invented the AC generators. And voltages also, they keep on increasing; they had the different voltage levels and again it was possible.

So far, we have up to the 33 kilovolt transmission and the generation of generating voltage. And here in India, even we have the 21 kilovolt generation. Then what we do? Then we use some generating transformer to lift the voltage at the higher voltage and then we transmit power to over the transmission level; finally, it goes to the customer through the distribution transmission lines. So it is well established that the generation as well as initialization is suitable in terms of the AC part; means AC generation as well as the AC distribution is economical, cheaper and efficient in terms of operation and its maintenance.

But the transmission part, again there is some doubt that whether we can go for the only AC or whether we can go for the AC as well as the DC. If we will see, there are some advantages of DC; I will come to that point later. HVDC system, basically what we do? Normally, we connect two systems with the different frequency we can do for. So, the first mercury valves basically there were invented here in 1950s. Then the first HVDC transmission between the Sweden and Gotland Island of the Sweden itself, it was came into the operation in 1954.

So, this first HVDC transmission between the Sweden Mainland and the Gotland Island; it was not possible to interconnect with the AC transmission line, because this Gotland Island, the operating frequency was 60 hertz. However, the main Island it was the 50 hertz and also this distance was the 60 miles. So, it is not possible to have a cable of more than even the 50 kilometers. So, only the option at that time left that we should go for the HVDC; high voltage DC transmission system was came into the existence, and this is the first which came into 1954.

If we will compare the advantages and the problems in HVDC transmission system, let us first go what are the problems in HVAC transmission system. The main problem in HVAC system is as we know, although, I have written on the second point, it is your instability. We know this one equation here that is the power it is the approximate equation that is v 1 v 2 upon x; that is the reactance between these two lines. Here it is the other sin delta, and delta is angle between the voltages here v 1 and the v 2.

So, we know this here, the maximum power which can flow in AC transmission system depends up on the voltages and this angle and reactance of the line. This delta cannot be more than pi by 2 degree that is 90 degree. So, the stability constraints here are one of the big issues. Even though here the delta can be theoretically 90 degree but we cannot operate our power system at 90 degree, because if there is some deviations some fault in the system, our power system will lead to the clumsy state and unstable power system. So, always we operate this delta should be always less than 30 degree or 31.

So, the stability is one of the big issues. So, what we do if our system is weak and the less stable, then we use some other devices to improve the stability of the system; another is the reactive power loss. Reactive power loss is one of the normally this first you have to go for you should understand the real power loss. Real power loss is nothing but, it is your i square R loss; normally we call or some time if loss is in the code, it is also real power loss. But the reactive power loss is nothing but the reactive power loss that is i square x; x is the concerned reactance of the line.

And this is the summation of other which is the generator reactive power, and normally, it is voltage square divided by x due to the charging of the transmission line. So, the reactive power loss is one of the concerned in the AC system; another is the point third is the current carrying capacity of the transmission line or the cable. It is you can know if your transmission cable is more than 50 kilometer and you are not taking a load at the receiving end, your sending end current will be even though more than its rating of the cable.

What will happen? If you are going to take even though small amount of power at the receiving end, this current will exceed its rating, and its cable will burnt up, rupture, and it is not possible to transmit the power. So, for the transmission line as well, it is not possible for going for more than 500 kilometers overhead transmission line that is the bear conductors and 50 kilometers for the cable. And this is due to the current carrying capacity and always it is limited in the DC system.

Another concern in the HVAC transmission system is the Ferranti effect. You know this Ferranti effect is nothing but when the receiving end voltage at the no load or likely load is more than your conditional voltage. So, what we do? We normally go for some compensating devices, and normally, we use the reactors. If line is very long, we use the line reactors in the transmission system so that we can reduce the voltage at the receiving end. This normally happens if your system is collapse or you are intern having that line from your sending end, and receiving end if it is likely loaded or there is no load, your receiving end voltage will be higher.

And what will happen again your productive devices; they will sense the voltage, and they will again trip your transmission line. So, it is not possible until and unless you are controlling that voltage; so, this is your Ferranti effect. Now let us see what are the advantages here in this HVDC transmission system? There are so many advantages of HVDC system, but also it has some disadvantages and then we will see some disadvantages as well.

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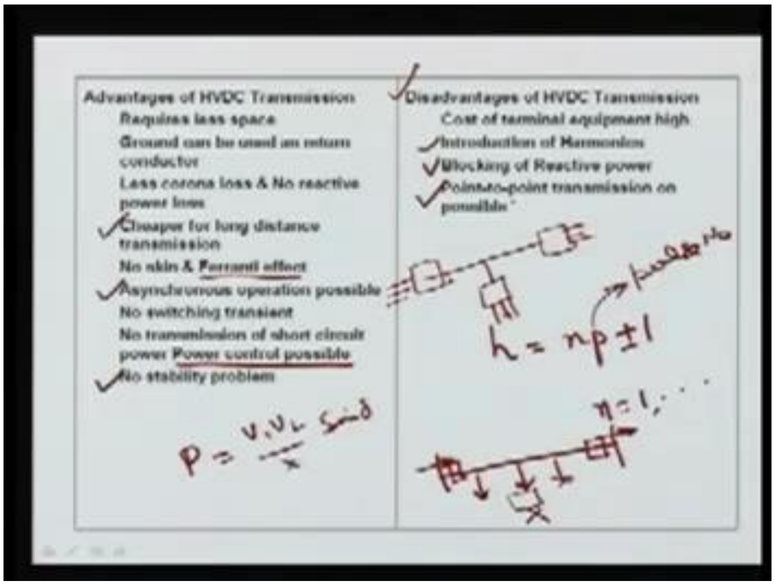

The various advantages of HVDC transmission system that it requires less space; less space in terms that we have normally the two wire system. We may have the homopolar operation; we may have the bipolar operation; we may have the monopolar operation. So, only we require the two conductor’s maximum in the DC system, and also here there is no compensating devices required, although, we require the converter stations as well. So, in over all the DC stations are they require less space.

In this HVDC transmission system, we can also use the ground as a return path. Normally in the monopole operation, this one is the positive current which is they are negative phases there, then ground can be used at the return path where it is not possible in HVDC transmission system. Also if you see the corona loss is minimum in this your DC transmission system, and there is no concept of the reactive power at all.

So, there is no reactive power loss in this HVDC transmission system. It is also cheap for your long distance transmission of power. So, this HVDC transmission is cheap for transmitting the power over the long distance.

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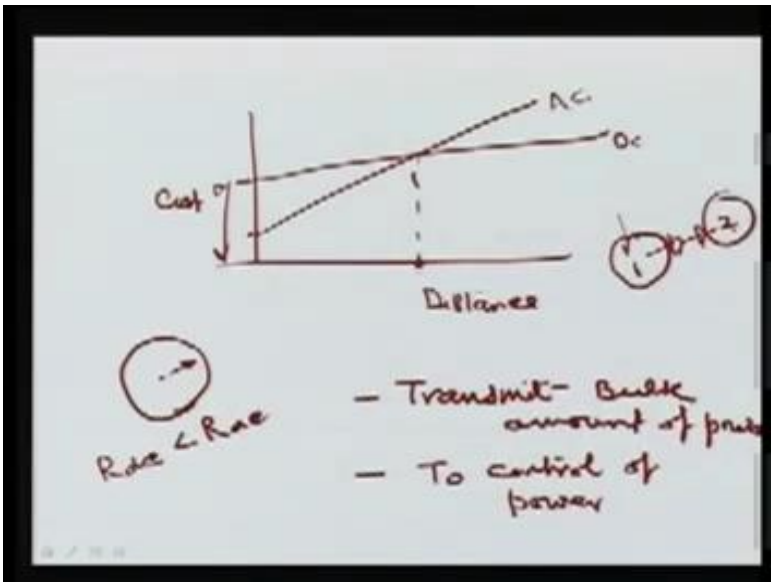

Now normally if we see the cost of AC here, this is if it is your distance and this is the cost, we can write then you are here this is your AC system and this is your DC system. So, the cost here this is your normally it is known as breakeven point here. So, the initial cost of the DC system is transmission system is more than your AC system you can see here. But once its distance is more than this breakeven point, then your DC becomes cheaper compared to the AC transmission system. So, this distance earlier it was somewhere 700 to 800 kilometer.

But now it has reduced to even 605 to 600 kilometer. So, if you want to transmit power more than 600 of 600 kilometers, the DC is the cheaper options for the transmission of power compared to the AC transmission system. Now normally nowadays, it is not only the transmitting power from one end another end, but we can also use this DC for the several other purpose. So, normally the use of DC is to transmit bulk amount of power and another is to control this power; control of power is one of the big advantage of DC system.

In AC, we cannot control the power; you know the current always follows the minimum impedance power. So, if AC system is interconnected, you cannot control the power over the transmission line unless until if you are having the parallel lines then one you contribute. So you can change the impedance, then the power will be different in the different line. But here in this DC system, we can that is control the power; that is one of the greatest advantage of having the like here I have written this power control is possible in the DC system.

Also in this advantage as we are looking at the advantages of HVDC transmission system, it has no skin effect. You know this effect is nothing but here if you are having let us suppose this is your conductor. So, current always follows the outer side of the center to flow in the AC system. So what it does? Normally, the resistance of this conductor is increased because the current is uniformly distributed over this conductor. So, always this RDC that is the resistance if the DC current is flowing in the same radius of conductor is less than your R if AC current is flowing in the same conductor.

So, due to the skin effect of this transmission line and also as we see the Ferranti effect, there will be no Ferranti effect in the HVDC system because there is no charging at all. The capacitance no doubt they are formed, but it is not charging, and it is not falling any charging current over that one. So, for the DC you know, this capacitance just behave as an open circuit in the steady state. Another great advantage of HVDC transmission is that here asynchronous operation is possible. Asynchronous possible here it is nothing but you can interconnect two frequencies system together with the help of the DC system.

In the AC, always we must operate all our power system, all the electrical appliances, operators, elements have the same frequency level. But here in the DC, you can interconnect two different frequencies with the help of HVDC. So, this is called asynchronous operation is possible. As we saw the example of the Gotland Island which was interconnecting your Sweden, Ireland and the Gotland Island that both were operating with different frequencies, and then it was only possible to go for this HVDC system.

So this is one of the great advantages that we can have that two different frequency system we can interconnect. Here also the short circuit power, in the DC, here there is no short circuit power, but in the AC if you keep on interconnecting, what will happen? The short circuit level at that point will keep on increasing, so that you have to go for the larger productive devices like circuit breaker rating you must increase. But here this is not a sort of that concept. Another great advantage which was the limitation of AC system was there is no instability problem.

Here this formula does not apply this here v o 1 v 2 upon x sin delta is no more applicable for the DC system. So, the instability concept is no more there. So, the DC system is much much more stable compared to the AC system. If you see the disadvantage, let us come to the various problems in HVDC transmission system. As we saw in the beginning that the cost of the terminal equipment even though the cost here if you see here, this cost for the DC is more here compared to the AC system. This is due to the terminal equipments of the DC system because we require the converter circuit even though you are going for the shorter distance. You should have the two converters; one is known as rectifier, another can be as inverter.

And again, we should go for other auxiliaries for these converter stations. For example, we should go for the cooling because there will be losses in this thyristors or GTO valves and we require a huge cooling or better cooling; otherwise, this will get burst or puncture. So, here this cost of the terminal equipments are very high, but nowadays, due to the development of very high power semiconductor devices, let us say power electronic devices, then it is possible to reduce that cost as well. So, now as such the cost of the terminal equipment is keep on reducing as we are going for higher and higher rating up the thyristors and other power electronic devices.

Another concern here is your introduction of harmonics. As you know here in the converter, we are using the power electronic devices, and these devices are using some off and on control, so means we have to use the firing circuit. Due to this off and on, they never produce the perfect sinusoidal, and therefore, some harmonics are introduced in the system, and they are not good. No doubt we use some filters to filter out these harmonics; at the same time some of the harmonics, they enter into the system.

Especially we use the filters for the lower order harmonics, but higher order harmonics, we allowed to enter into the system. The reason behind that for the lower order harmonics, they are having a large in the magnitude. The magnitude of the lower order harmonics is higher and also the filters require the size will be less. So normally, we filter out this larger magnitude of harmonics and the smaller magnitude of harmonics being allowed, because it is not possible to go for filters for all the harmonics. And at the same time, there are two types of harmonics. One is your characteristic harmonic, another is non-characteristic harmonics.

If you are using a six pulse converter, so normally this harmonics h is nothing but your n p plus minus one harmonic; here n is nothing but starting from one to it is an integer value, and p is your pulse number. So for six pulse converter here, we are going to have fifth, seven, eleven and thirteenth harmonics. So, the magnitude of these harmonics contents basically these are they are called the characteristic harmonics. Other than that also due to the overlapping of the current because current cannot be changed instantaneously in the wharfs.

So, there is some changeover of current; so, they introduce some non-characteristic harmonics, and it is not possible to filter out. So, but the larger order of harmonics, we are using the filters and they are not allowed to enter in the system. But at the same time, some of the harmonics they enter into the system, and we do not have any control over them. The major problem with the harmonics if they are entering into the system, they will create more loss in the system that means core loss will be more.

There will be i square r loss may be also more, and at the same time, there may be some possibility of the resonance with rest of the AC power system, and that is very very dangerous. Another problem with the HVDC system is the blocking of reactive power; means here as we know, this AC system is connected here. Suppose, we have this is one area and we have another area; this is connected by your DC system. So the reactive power generated in this area cannot be transmitted to this area two because this DC there is no reactive power transmission.

So, this blocks the reactive power of any of the area; means it will be here from area one. It will not flow to area two or from area two; it will not come to the area one. Now question why we want the reactive power? Sometimes in the emergency cases, let us suppose there is some generator outage. Some of the emergency in this case there is some fault; at that time, we may require some reactive power support from the area one or two. But it will block here. So, it is not possible that transmit to the reactive power to the area two or from two to one during the emergency condition. So, it blocks the reactive power.

But in the normal practice, we do not allow that reactive power should flow from one remote place to another remote place, because the reactive power concept is a localized concept, and it is reacted with the voltage of the system. Another major problem in the HVDC system is that it is not possible to go for the typing of the power at the different location; means it is only that we can go for the point-to-point transmission. Means from one node, here we are going to another node. Then the power which is flowing from here, it will be going here; it is not possible to tap the power in between. So, it is not possible.

In AC system, you know once wire is going, anywhere you can tap the power. This is the problem of HVDC system. Why it is so? Because here the control which is one here this station converter station and here converter station; they operate in the synchronous means here the information and here it will be the same. Means we required a very strong communication link between these two converter stations. So, if the power is here going you are taking, then we have to coordinate another here some converter stations.

So, what happens? Till now, although, there are some research is going on that we can go for the multipoint transmission multi-terminal HVDC transmission system. If we are having only here from one end DC to another, it is called two terminal DC system.

If you are taking here another DC system here, you are taking here three phase, here three phase and here we are having three phase. So, this is called multi-terminal HVDC. So, so far we have established only the three terminal HVDC system.

So this is one of the major problems of the DC system as such. So, here the point-to-point transmission is not possible; it is only possible in the DC system. However, in the AC, you can tap the power anywhere in the system.

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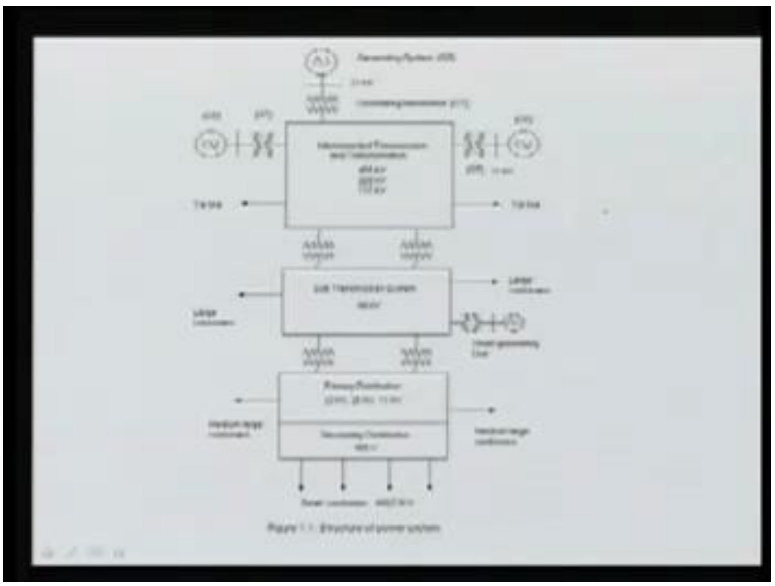

Now let us see your complex in this system. Now we have seen that the generation must be your AC system, because it is a economical, convenient and the cheap to generate. At the same time the utilization part or you can say distribution or load type, we should go for the AC system. Now the question again only remains open for the transmission system means we can go for your AC as well as the DC system. We saw the several advantages of your DC system compared to AC system. So, then we can go for the AC and DC systems.

Just we saw witness that the early power system development was very much localized means generators as well as the loads were very close together, but we realize that there was a continuous development of the voltages as well as the frequency. Then we had the standards for the voltage as well as the frequency and we went for the integration of the system. So, we keep on integrating; we keep on adding the power system. So, the present day power system is a complex, interconnected and also it is varying in the size and configuration.

Now again the question arise, why we started the interconnecting whole this generations as well as the load centers along with the transmission line. If we will see this interconnected power system several advantages; advantage include that in interconnected system that the total reserve capacity can be reduced.

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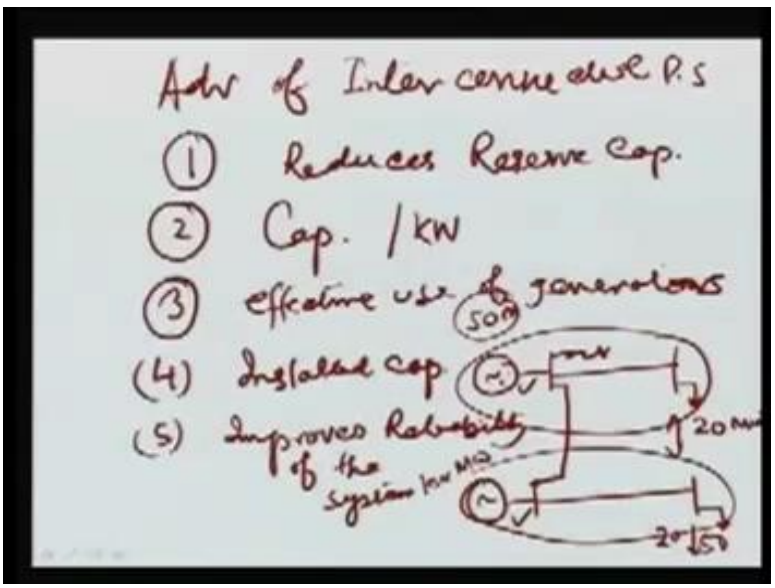

So, the advantages here first advantage of your interconnected power system; first, it reduces the reserve capacity; means reduces reserve capacity. Now if we will see in the, for example, let us take a generating station here. This is our 50 megawatt to understand the reserve capacity is that I am explaining here, and we have our load somewhere here. We have another let us suppose load is your varying that is your 30 megawatts. And we have another station here that is it is supplying here 50 megawatts, and here your load generators should be more than 50 megawatts.

Now what happens; now why we go for more? Because the load is increasing, we are going for the more reserve margins here. Now here also we have the 50 megawatt, and our generating capacity should be more than 50 megawatt. So, if you can connect these two systems, now what will happen? Even though here your load is 70, there is no need of this generator; means here same generator can supply here and still we have the 30 megawatts feature.

So, due to the interconnection, we can reduce the reserve margin of the system or therefore means we can reduce the install capacity of the power system by interconnecting. This is one of the major advantages. Another advantage is that the capital cost. The capital cost per kilowatt is less for the larger unit. So, with the help of interconnection, we can go for the larger units, and therefore, we can reduce the total installation cost of the power system. And therefore, it is possible to have the cheaper electricity generation.

So, the total capital cost if you are going for the interconnected system, so we can increase the capacity of generators. We can go for the larger and larger size; that is why right now we can say we have even our India we have generating single unit can generate more than 500 megawatt. And this is due to the interconnection because none of any city is having even though in UP or somewhere, you can see more than 500 megawatt. So, with the interconnections, we can reduce the capital cost of the power system.

Third advantage is that here that it is a possible because you know this loads here, this will keep on changing. And therefore, if the load is very minimum; let us suppose here the load has reduced to 20 megawatts here and this 20 means only we can run only one unit of generation. So, it is possible that we can run the most effective unit at the higher load factor, and the inefficient station can be used at the peak hours only. So, what will happen? Again the total cost of the electricity generation will be reduced.

Another advantage of interconnection is that that interconnection reduces the requirements of high install capacity; the load curves of the two different stations are seldom identical, and the maximum demand is the less than the sum of the maximum demand of the individual stations. For the two different areas, the maximum demand you can see, they will seldom occur at the same time. For our Indian system if we will see that we have our peak demand that is the 30 minutes different from the north state to central state. So, the peak which occurs here at the 8 pm, it will occur somewhere it is the 7.30 pm in the north state.

So, what happens? Then we can interconnect the power system, and that will reduce the total install capacity of the power system. Also by doing the interconnected power system, we can improve the reliability and that is your fourth, it reduces this install capacity. And fifth advantage here is here that is improves the reliability of the system, and your third was the effective use of generators you can see. So, it can improve the reliability of the system. Now we can see how it can improve the reliability of the system. For example, let us go earlier; here it was not having interconnected.

If there was something problem in this generator if this generator is dripped, your this 20 megawatt load completely it is not possible that we can feed the supply. So, the reliability of this system even though the dripping or there is some problem in this generating station here, it will be once it dripped, it is not possible to supply the 20 megawatt. So, the reliability of the system, it depends upon your this reliability of this generating station. But if we can interconnect here by this one, even though this generator is tripped and there is some problem, it is possible to feed this power through this transmission line and to this here.

But there is a possibility that this generator may not be capable of supplying complete power, but we can maintain some of the emergency services of the system here; means we can feed some of the power or we can reduce the power in this area. And, finally we can supply it. So, this reliability of the system is improved with the interconnection of the system. Now there are several problems in the interconnections. No doubt in any system if you have some advantages; there will be some problem or disadvantage as well.

The first disadvantage or drawback of the interconnection is that fault in one system will get propagated into another system. For example, here if there is some fault here and there is fault here at this bus, what will happen? This will be propagated here, and this generator as well as this generator, both generators will be tripped. So, the fault in one system is getting here in other system, it will be propagated, and that is why here it is sometimes very very dangerous. We should have a very fast and reliable protecting device, so that we can trip here. We can trip here this line, and we cannot allow this fault propagate and transmit in this zone.

But assume that the if there is no interconnection here and the fault is occurring here; okay, the system will be in dark, and we can maintain the power supply in this system here, and this both are operating in isolation. So, here the fault as I said if it is interconnected here this will be then fault will be coming here and to have the more reliable power system complete, there should not be complete collapse. We should have the protective devices here, and so that it can isolate the faults, and then we can maintain the remaining part of the system in the healthy.

So, we saw the first major problem of the interconnection is that fault gets transferred to the other healthy areas, and for that, we should require the very fast and reliable switch care that is including the circuit breaker and the relay protecting devices so that it should not get propagated. Another problem in this AC interconnection system is that the high switch generating is to be implied at the different point of the system. It means if we keep on interconnecting the power system, for example, here if we are having this is your bus and we are having the different lines.

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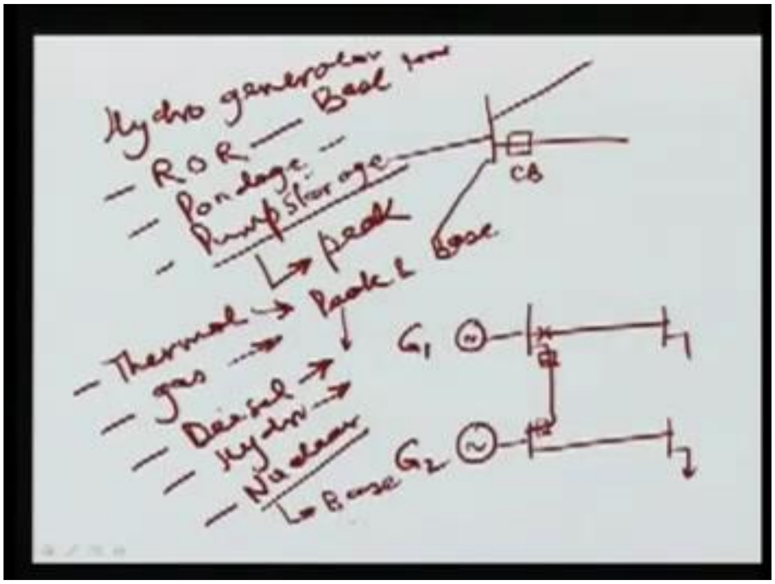

Then the rating of this circuit breaker, we require higher rating; means if you keep on interconnecting more suppose you are adding another line, then the rating of the circuit breaker may change. This is due to the fault label that will increase here at this bus will be increasing. So, if you are keeping on interconnecting, then the circuit breaker requirement will keep on increasing. The example which we took we saw here one generator and it was supplying here the load, and similarly, another generator was here, and it was supplying load at this. Here, if we are connecting this one as like this, so the rating of this circuit breaker earlier which was using, now we have to increase because the point level at this point is increased.

So, we are going for the more circuit breakers here more the transmission lines and circuit breakers, more switch care equipments. At the same time, the rating of the switch care equipments also increases. The third problem now is the proper management requires to dispatch these generating stations. So, here what we require that there should be some energy management system and it is automated so that we can operate these generating generator one here and generator two in the economical fashion.

So, we require the interconnected and the sophisticated tool that is power management in this power system. As you know it is only two generators, but in actual power system, there may be 10 to 100 generators and it is so many transmission lines as well as the transformers. So, it is very much required that we should operate the power system in such an efficient and also to dispatch these generating stations in the economical manner. So, normally for that, we go for the economical low dispatch as well.

Now you can see here in the power system that is more and more interconnected; we are having even more than100 generating stations and generators. So, we require some generator should run as the base load that; means they should continuously run. Some generators may require to run only at the peak load and again this category basically depends upon that what is the cost of that generator or the available freeware. For example, run of freeware generator; means this is the hydro type. In hydro, here we have the different let us go with hydro generators. We have your run of rivet type of generators; we have the pondage type that is pondage or storage.

And another is called the pump storage, storage type of hydro power station. ROR is nothing that is called run of river. Run of river hydro power plants; means it normally if rivers are flowing, they are at the different small dams are there, and we utilize this power. Suppose, if we are not utilizing that power, what will happen? This will go in the waste. So, the run of rivers, they always use at the base load plant; means whenever the river is flowing, you have to utilize; otherwise, this energy will be going in the waste.

So, this ROR will be used at base load power plants; like the pondage, we can store water, and then we can utilize whenever it is required. So this pondage can be depends upon the storage capacity; you can use at the base load as well as the peak load but the pump storage power plant. This is the plant and this is a hydro power plant. They only use for the peak load; means when there is a demand, we use it and when there is a less demand, we can feed it water pipe to be storage. So, this is called pump storage.

So, it is always used as a peak load power plant. Other conventional power plants if we will see; now again we have to come for what are the conventional power plants and what are the non-conventional power plants. The conventional power plants include your thermal power stations, the big thermal power stations. We also go for the gas base power plants and here it is a diesel power plant. They are known as the conventional power plants; other than these power plants here, they are called the non-conventional.

Here hydro also comes big hydro power plants; they come under the conventional power plant. In the non-conventional power plants and they are also called the green power like you solar, wind, fuel cells, they are coming into your non-conventional, and they are also called as green power because they create less pollution to the environment. So, here the thermal, basically, they use the coal and then we burn the coal and then we generate the steam and steam becomes a media of the transfer of power from heat to again go for the mechanical that turbine will run and then turbine runs the generator and then finally we generate the electricity.

So, this power plant can again run both as peak as well as your base load plant. However, you have the diesel, as you know the diesel cost is more than coal. So, it always runs at the peak load power plant. Your gas is also it is very quick in starting. Here in the thermal power station, it is not quick starting. Normally, a thermal power stations if it is in the hot role state means it is running state that it can require even though four to five hours.

If it is in the cold role state means all the boilers, there is no heat in the boilers, etcetera; so, it is called cold role state and then it may require seven to eight hours. So, here the thermal stations require more. So, it is not possible quickly you can turn it on; it requires some time, but the gas and diesel they are very quick and we can start. So, they can be used for the peak load power plants. Another is your here the nuclear that is very important, and nowadays, our government is very keen to go for more nuclear power plants as now we had the limited gas, limited diesel, limited coal. So, the often that we can go for the nuclear because hydro is also very limited.

Limited in the sense that we are facing lot of hesitations for the dams and other things, because they are the environment less people; they are always opposed that we should not build the large dams so that they are so many areas are submerged, and they are creating lot of problems. So, another option is the nuclear and we have the huge reserve of the thorium as well as the uranium. So, the nuclear power plants they can also run as the base power plant and they normally run as the base power plant, because here the nuclear due to the safety and other reasons, it is not possible to quickly stop and quickly turn it on.

So, here the cost of generation of the nuclear power station, the cost of generation is very very cheap. But the total cost is very high, because we go for very safety factor and again people are very much afraid about the nuclear power plant, but now we had the feature for the nuclear power plants as well. So, always here the operation of the power plants depends upon the following criteria that the cheaper electricity generating units should be used as a base power plant. The highest starting time generating plant is also used as the base power plant, and the size on the plants is also a deceasing factor; means what is the size? If the size is very small, then quickly you can start and stop.

But if the large size, then we may require large time as well; so, in this in interconnected power system, the generators as I said, they are normally loaded; they are running based on these criteria that which will be running as the base and which will be running as the peak load. Some of them may run for both purposes again depending upon the requirement of the system. Now we witness that now power system is highly complex, interconnected and due to the increased loading of the power system, it is always our intention to operate power system in most of the reliable, secure and stable condition so that we can supply the power to the customers in the reliable.

And also our intention is to supply the cheap means economical electricity to the customers. In India, the power system in the most of the states are owned and operated by electricity boards. Now again these electricity boards are broken into the different boards. So, earlier this whole generations and transmission and the distribution of walls in the state was responsible by the state electricity boards. They were operating your generating stations, transmission lines as well as distribution system. And again, we have presently the five regional electricity boards. One is your northern regional electricity boards; another is western regional electricity board.

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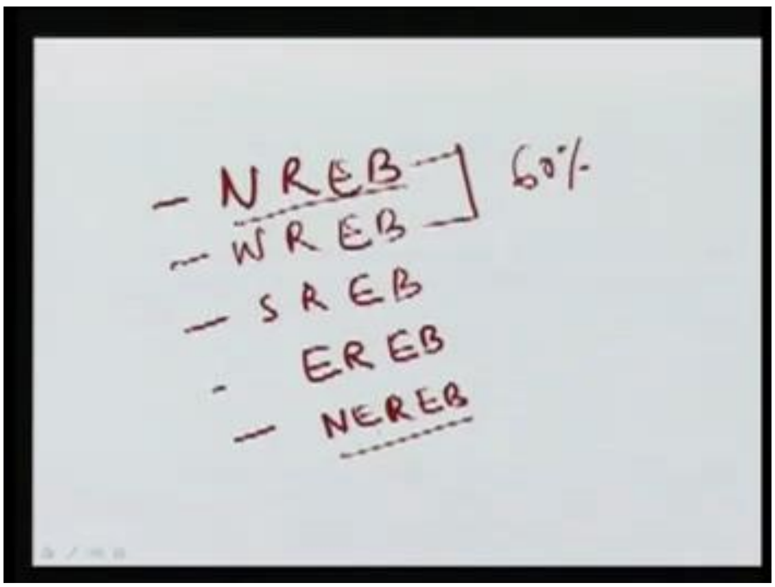

And southern like we have your NREB; that is called northern regional electricity board. We have the western regional electricity boards, we have the southern regional electricity board, we have eastern regional electricity board, we have north eastern regional electricity board. So, in India we have the five regional electricity board; means in northern electricity regional boards, we have the several states. They are interconnected, and this includes your Haryana, Himachal Pradesh, Delhi, Punjab, Rajasthan, Jammu and Kashmir, Chandigarh and Uttar Pradesh and Uttaranchal.

Similarly, we have the western regional electricity board; means the several states are interconnected. In the western regional electricity board, it is Gujarat, Madhya Pradesh, Maharashtra, Goa, Daman and Diu, Dadra Nagar, Haveli and your Chhattisgarh states. They are coming in the western regional electricity board. The southern regional electricity board comprises Karnataka, Andhra Pradesh, Kerala, Tamil Nadu, Pondicherry and the Lakshadweep.

In the eastern regional electricity board, it is Bihar, Andaman and Nicobar, West Bengal, Sikkim, Orissa and the Jharkhand they are coming. Most of the states, they are interconnected and then we are operating the power system in the regional places. And these regions are also now getting connections interconnected. So, most of the region already in the northern and the western regional electricity board, they are interconnected.

Now the goal of India that we should have our national grade; means all these here regional electricity board must be interconnected and then again we can supply and with this grade, we can operate our system efficiently. Again the different state even though your this northern regional electricity board and the western regional electricity board, they comprised together more than 60 percent of your install capacity; means they are having the lines here, and the remaining 40 percent comes under the southern region, eastern region and northern eastern region. Northern eastern region basically comprise of Assam, Arunachal Pradesh, Meghalaya, Nagaland, Tripura and the Mizoram.

So, here we have a good potential of hydro in these regions, and they are having the surplus amount of power; however other regions mostly here the western and northern, they are in the deficit of power. So, now we are just trying to have the interconnection from the northern eastern region to other regions, so that we can transmit power from the north eastern region to the deficit area that is western and the northern region.

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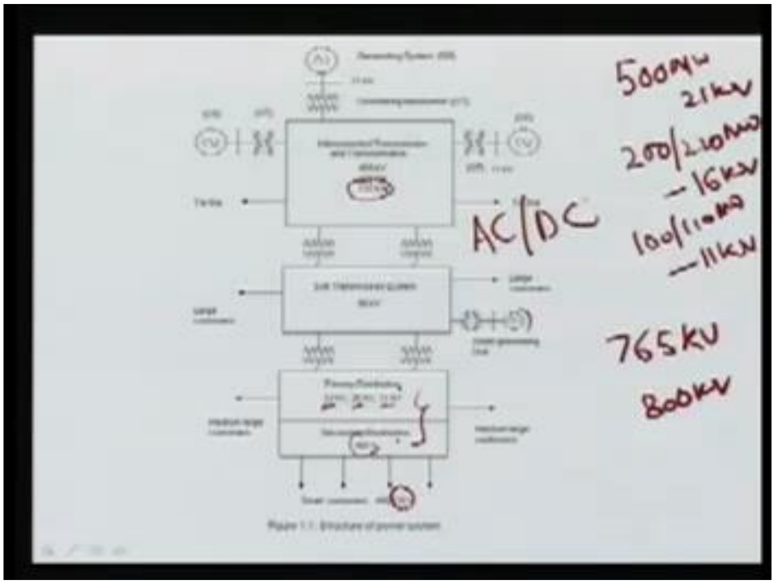

Again now we can see here the interconnection. Now we can summarize how our power system is interconnected. We can see here we have the different generating station like here generating station, generating station, generating station, we have the several generating station, and we have seen that generating stations cannot generate power at the higher voltage. Till now in India, we have the highest voltage generation of 21 kilowatt; however, in the watt it is 33 KV. But we know that if we are going for higher voltage, the losses in the system are less. And at the same time, we can transmit bulk amount of power.

So, our intention to keep on increasing already I give information about the evaluation of power system. There we saw that increasing in the voltage level in the transmission system, it is witness that we have to go for the higher voltage transmission system to reduce the loss and to transmit bulk amount of power. So, these generating stations, they generate power and then we use the generating transformer; it is normally called the GTs, it is very near to the generating stations. So, they step up the voltage of these generating like I have written here 21 KV, here some of the generating stations, they are generating at the 11 KV.

Normally, the 500 class of megawatt generators, they are generating at the 21 KV. Here the 21 KV means it may be 20; it may be twenty one point something means per unit voltage is 21. Those are here 200 megawatt or 220 megawatt generating station; they normally generate at the 16 KV, and the remaining that is 100 or 110 megawatt generating stations, the generating voltages are normally 11 KV also. So, we use the generating transformer to lift the voltage either at the 400 or at 220 KV or even at 132 KV depending up on the equation of power from these generating stations.

Our ultimate aim that these generating powers must come to the small customers and then it will follow the transmission lines it also sub transmission system and then it is here the primary distribution means this is the distribution system. So, our integrated transmission system, it is having presently we have the 80 KV transmission system, 220 KV transmission system and 132 KV transmission system presently. We have our transmission line that is built constructed at the 765 KV class of insulation. Normally, it is called 800 KV transmission system, but presently, it is operating at the 400 KV transmission system.

We have the unparameterized line, it is very near to us; it is the line is built on 800 KV class of insulation, but presently it is operating at the 400 KV volt. Because later it is assumed it is required of the more power equation, we can go for the higher voltage. Once line is constructed, only we have to change the terminal equipment **o**f this rating. Then in this system, we have the several interconnecting transformers. They may be 400 by 200, 220 by 132 and so on, so forth. So, these are the transformers that are existing and normally they are called ICTs power transformers.

Then from lower voltage, we go for this other transformers and then we try to reduce the voltage at the lower voltage. It may be directly 6 KV, it may be 33 KV the distribution side, and we also feed power to the large customers at the higher voltage as well. Even though some of the our customers, they take like your real way takes power at 132 KV even though some big companies like the fertilizer corporation of India FCI, they also take power at 132 KV.

So, we have the intertie lines and also we supply to the very very large and the large customers those require power at very high voltage as well as the high power. Also we go for the medium type of voltages and the medium customers, they take the power at 33 KV or 25 KV like your railway, the tracks and purpose; they normally use 25 KV and the 11 KV transformer. At the same time, you can see there are some small generating units. These small generating units, they are nothing but they are may be the curtly power plants, or nowadays there is another concept that is called the distributed generators.

They are coming into the distribution side so that we can reduce the transmission you can say t and d losses, etcetera. And finally, here after the transformation, we have the two type of distribution system again can be classified in terms of the primary distribution and the secondary distribution. Secondary distribution is your 400 volt, and it is of three phase, and single phase, it is 400 divided by n root 3 that is we get the 220 volt supply, and it is finally given to the small customers. So, the medium customers can take any voltage more than given 400, but the small customers they take here.

So, this is overall practice of you can say the structure of the power system. We have the generating stations, then we lift the voltage with the help of generating stations, and then we have the different interconnecting transformers. And then finally, it is reaching to the small customers as well as other customers. So, nowadays, there are lot of people are interested in the small generating units, and we are putting in the distribution system to improve the system performance. And this is called the distributed generators. We will see again the various advantages of the distributed generators in later lectures.

So, with this now I can conclude I can recap; we saw the evaluation of power system. How we just earlier we had isolated power system with the different voltages, it was AC and DC. Finally, it came to the AC and then we interconnected all the system. And now our generators are mostly the AC; the utilization is AC, but this system that is transmission part is includes your AC as well as DC power system. So, this is highly complex power system that is the generation is AC, utilization is AC; however, the transmission part is AC as well as DC. And since our demand is keep on increasing, we are keep on adding the generating station; this system becomes very complex and very non-linear in nature.

Thank you.