Electrical Distribution System Analysis
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Lecture - 40
Applications of Distribution System Analysis

This is the last lecture of this course. In this lecture is on Application of Distribution System Analysis. So, in this particular lecture, we will see; what are the applications of these analysis.

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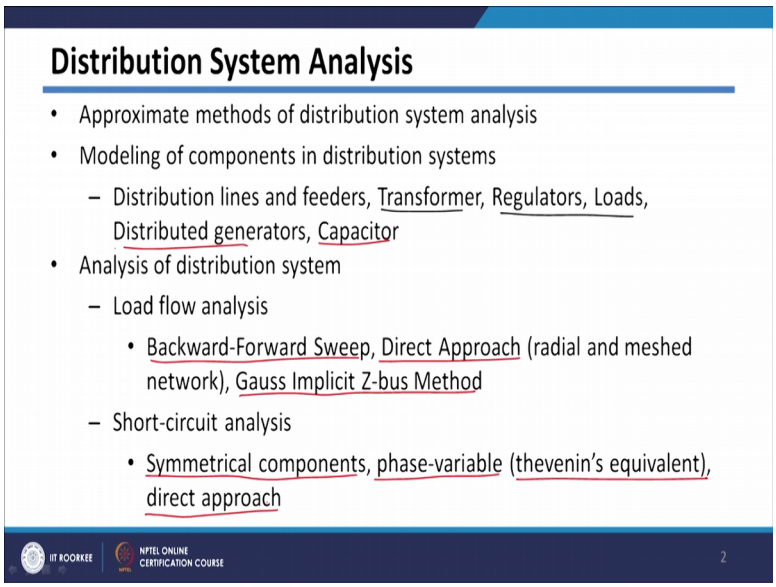

So, basically we have seen various methods of distribution analysis starting with approximate methods. So, in approximate methods, we are actually approximated your distribution system. And using the simplified models of distribution system, we try to calculate voltage drops, and power loss in the distribution system.

However, they will not be accurate for detailed analysis. So, we have seen detailed analysis of distribution system components, or you can say modeling of distribution system components, and these models include distribution lines, and feeders transformers, regulators, loads, distributed generation, and capacitor. So, we have seen detailed modeling of these components of distribution system.

And then after that we have gone for analysis of distribution system. So, two types of analysis we have seen, one is load flow analysis, and then short-circuit analysis. So, in load flow analysis, we have seen backward-forward sweep base based algorithm, then we have seen direct approach for load flow analysis, in that case, we have seen it for radial as well as meshed network. And then finally, one more method, which you have seen that is gauss implicit Z-bus method.

Then we have gone for short-circuit analysis. Initially we have seen traditional symmetric component based analysis, which can be used for distribution system. However, we have seen that there are many drawbacks in distribution system analysis, using symmetrical component because here the lines are untransposed, and they create non-negligible error in short-circuit analysis.

So, in generally, because of that it may introduce 7 to 8 percent errors in calculated fault currents, that is why we have seen that we can go for phase variable based analysis, which is based on, first we have seen method, which is based on thevenin's equivalent circuit. And then, if the system is very large, then you can go for direct approach based analysis, which is very generalized kind of modeling method. And in that case, we are try to calculate fault current, and post fault voltages.

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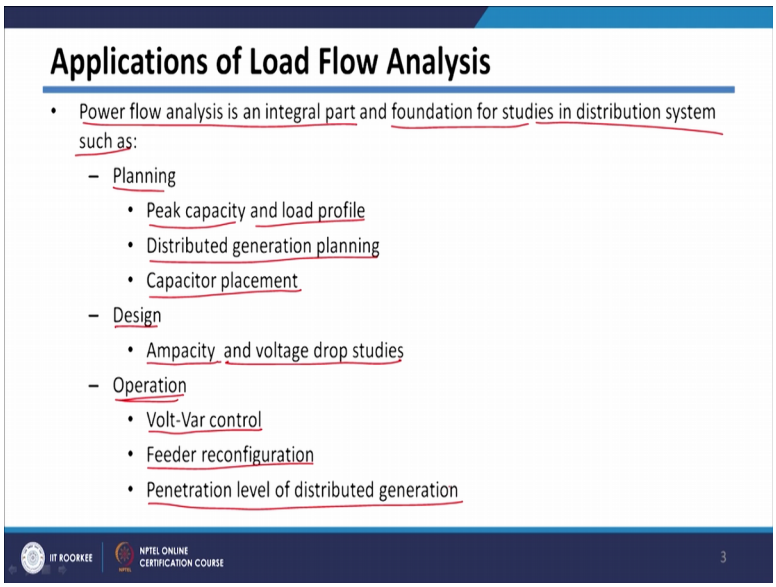

In today's lecture we will see; what are the applications, or where we can apply these tools developed like, we have developed tool for say pauses the distribution system

analysis, which include power flow studies and short-circuit studies, where we can use it. So, we can see that this power flow analysis is an integral part, or foundation for various studies in distribution systems. And these studies can be related to planning, design, or operation.

So, in planning studies, like peak capacity planning, or load flow profile planning, we can use load flow analysis, distributed generation planning, and capacitor placement. These are related to planning studies. Then related to design studies a calculation of ampacity requirement, voltage drop requirements in the distribution system. Then during the operation, we can use volt-var control, where the load flow studies in integral part, then feeder reconfiguration, and to calculate penetration level of distributed generation. So, one by one we will see these topics.

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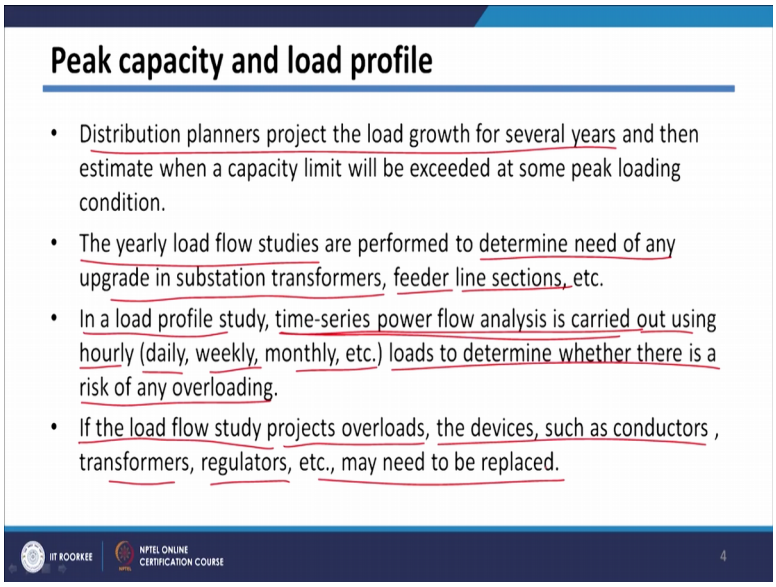

First let us say peak capacity and load flow profile planning. So, in this case, distribution planner project the load growth for several years. And then estimate, when a capacity limit will be exceeded at some peak loading. So, over the period of time, suppose you are planning this distribution system for 15 to 20 year. In that 15 to 20 year, there will be some load growth, and because of this load growth, some of the equipments will be we will get overloaded. So, during the peak load condition, we need to calculate how much loading is happening on each feeder, each transformer, or each of the series element, which are connected to the distribution system.

So, in this case, a yearly load flow studies will be carried out. So, each considering the peak load condition, yearly we can calculate load flow studies. And determine need of any upgrade in substation transformer, feeder, and line section. So, depending upon load flow studies at peak part, we can calculate very loads in a various parts of the distribution network. And we can see that is there any component, which is getting overloaded, and it if it needs some kind of replacement.

Then in case of load profile study, time-series load flow analysis is carried out. Time time-series load flow analysis nothing but load flow analysis is carried out at each time instant. So, suppose it can divide whole day into 15 minutes interval, and load flow will be carried out at each 15 minute, but by not considering the dynamics of the system. So, it is just steady state analysis at each 15 minute load, it will be carried out.

So, in that case, it will be called as time-series load flow analysis, which will be called at each time. So, it can be carried out say hourly, or it can be carried out daily, weekly, or monthly. So, if we are considering year, you can calculate at each of the month, if you are considering day, it can be calculated at each of the hour, or even it can be calculated each 15 minutes.

So, in this case, this time-series load flow analysis will be carried out using hourly, daily, weekly, or monthly, depending upon how much time period you are considering. To determine, whether there is a risk of any overloading. So, you have to find out any component is getting sustained overloads, the always there actually some overload capacities available with each of the component. But, if there is sustained overload, then there is problem. So, in that case, we need to replace those devices

If the steady load flow study projects overload, the devices such as conductor, transformer, regulator, may need replacement. So, if the from the load flow studies, if it projects overloads, then those devices need to be replaced.

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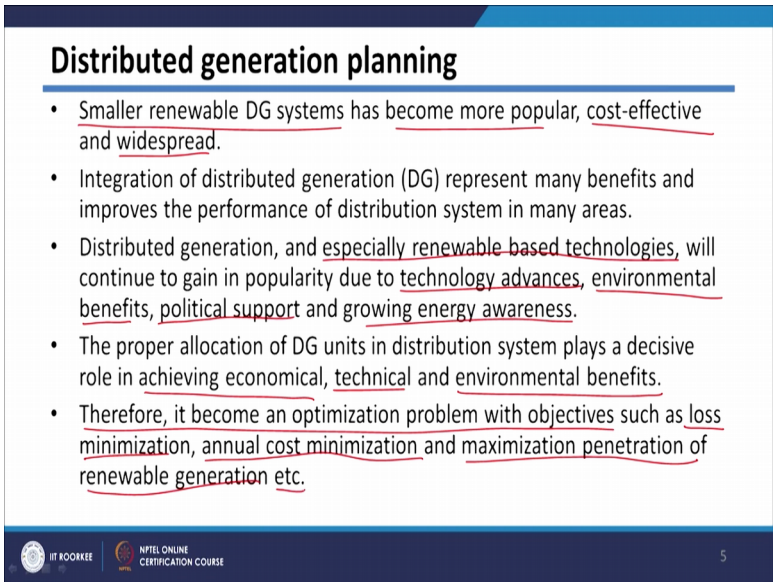

Then distributed generation planning: so we have already discussed various benefits of distributed generation, placed in distribution system. So, we have seen that these are nothing but small renewable generators, which are connected to the distribution system. And nowadays, they are becoming more popular, and cost-effective, and widespread solution to get various benefits in distribution system. We all seen many benefits of the distribution system, it improves the performance a lot.

Especially technologies, which are based on renewables, they are gaining more popularity, because advancement in technologies like we have seen that over the period of time, the cost of solar panel, or wind generator, wind turbines, they are going down, and because of technology advancement. There are many environmental benefits like reduction in carbon emission, it is gaining lot of political support, because of various benefits, and then growing energy awareness of consumers, this is gaining a lot of popularity.

However, a proper allocation of DG units in distribution system is very important, and it plays very important role for achieving economical, technical, and environmental benefits, because if you planned, it if it is not planned properly, then whatever benefits, which want to get you may not get it.

Therefore, this distributed generation planning becomes optimization problem means you want to place distributed generation in distribution system. So, your choices will be

the locations of distribution system, where we need to place this distributed generation in distribution system, and what size. So, it is called as sizing and sighting problem of distribution distributed generation during the planning stage.

So, this sizing and sighting, or distributed generation planning will be having up these objective functions such as loss minimization, annual cost minimization, maximization of penetration of renewable generation etcetera. So, as I told you this becomes your optimization problem that is selecting the locations of distributed generation, and the size of this disease is becoming your optimization problem. And that can be solved to reduce the losses, minimize the overall cost of the operation of distribution system, or to maximize the renewable integration of generation renewable generation.

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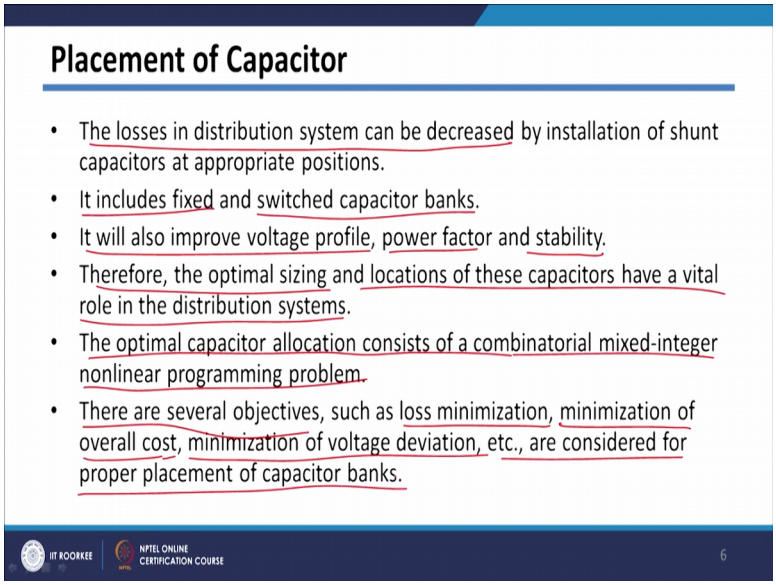

Next thing we have seen that placement of capacitors is also planning problem, because we are considering the placing the capacitors in the distribution system. So, first we need to calculate, how many capacitance we know need, what are the location, where the suite where the capacitors can be placed. So, this new location should be optimal.

So, we have seen that after placement of capacitor losses in the distribution we will get decreased. This includes fixed capacitor, or switched capacitor banks. This will not only improves the voltage profile, but power factor as well as stability. Therefore, optimal sizing and location of this capacitor have vital role in distribution systems. So, getting

the location, and size of these capacitor is very important, and that is why it becomes your optimization problem.

Therefore the optimal capacitor allocation consists of combinatorial in mixed-integer nonlinear programming problem, which need to be solved, because we need to find out location, which are integer values. And we need to find out the size of capacitor, which we need actually real value.

In this case also there are several objectives, such as minimization of losses, where we want to minimize the losses in distribution system,. Minimization of the overall cost, because whenever putting the capacitor we need to compare the cost save due to reduction in losses, and cost increased due to placement of the capacitor, because capacitor also will be having some kind of cost. So, minimization of overall cost means, we should get some benefit more than cost of the capacitor.

Then minimization of voltage division, if you are using the capacitor for voltage support, then your objective may be minimization of voltage deviation, are considered for proper placement of the capacitors, because we have seen that if the capacitors are not placed properly, or switched on and switched off not properly, we have seen that there will be voltage raise problem, during the low load condition.

And because of that loss may also increase, because during the low load condition, this capacitor will keep on carrying the leading reactive power. And because of that leading reactive power, there will be currents flowing through the feeder, which will be basically creating the losses in the distribution system. So, proper allocation and switching off and switching off the capacitor banks is very important to get maximum benefits.

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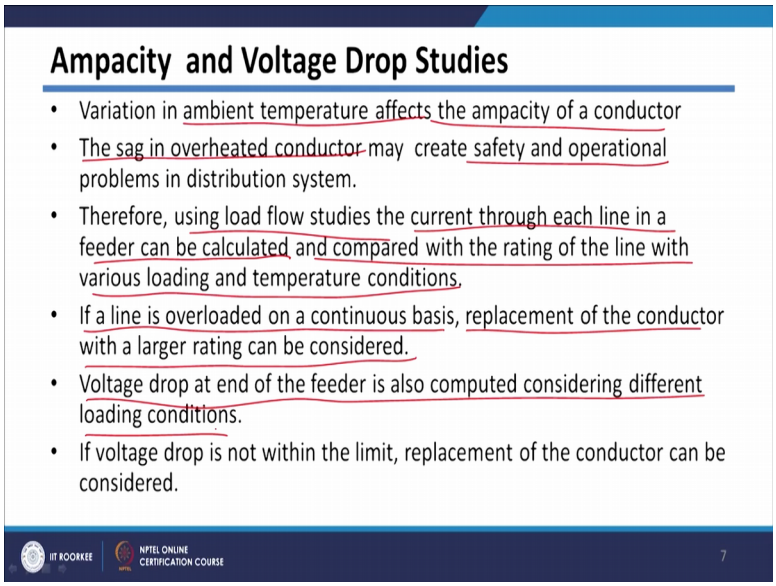

Then third is ampacity and voltage drop studies. Ampacity is nothing but current carrying capacity of your conductor. However, these current carrying capacity depends on ambient temperature. So, whenever temperature increases, your resistance of the conductor changes, or increases, and because of that resistance your ampacity decreases.

Also whenever there is of overloading happens, or whenever there is high current as well as high temperature condition comes, then there is actually sag of this distribution conductor increases. When the sag increases, your conductor will be or clearance between conductor and ground decreases, and this may create some safety as well as operational problems in the distribution system.

Therefore, using load flow studies, using load flow studies, current through each line in a feeder can be calculated, and compared with the rating of line with various loading and temperature condition. So, for various loading and temperature condition, we can run the load flow studies. And based on these load flow studies, feeder current can be calculation calculated, and these feeder currents can be compared with rating of the line. So, if there is continuous overload, if the line is continuously overloaded, the replacement of conductor with larger rating can be considered, or we can plan for putting another conductor in parallel with that conductor.

To study the voltage drop, we can calculate voltage drop till the end of the feeder, and if this voltage drop is more than limit specified in the standards at various loading

condition, then we can replace the conductor. If this voltage drop is more, or if the voltage drop is not within the limit, we can see that we can place some more conductor in parallel with it, which will decrease the overall impedance, or we can replace that conductor with low impedance connector. So, this can be done by various load flow studies.

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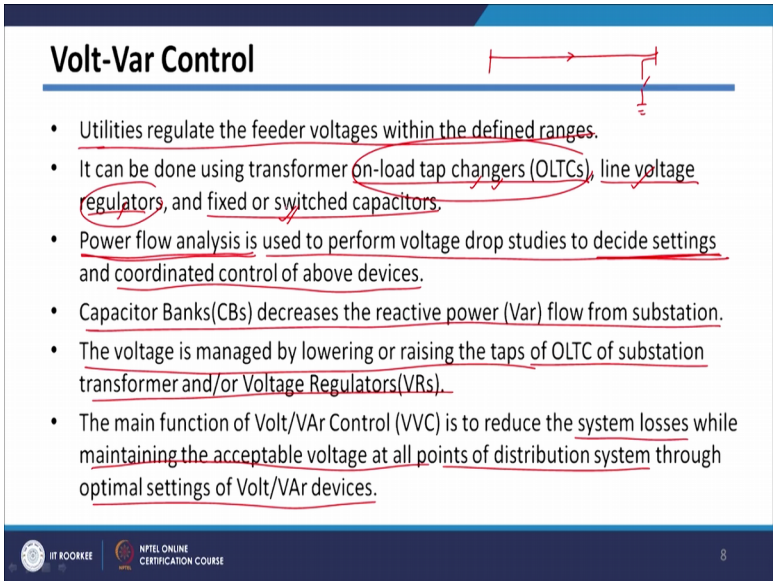

Another important operational issue is volt-var control. So, we know that utilities regulate the feeder voltages within the limits. So, we have we have seen that standard specifies at various countries, standard specifies these limits of voltages. So, voltages of the distribution system should be vary within that limit. There therefore, I have written utility regulate the feeder voltages within the defined ranges.

And this can be done using on-load tap changers, line voltage regulators, and fixed and switched capacitor. So, to control the voltages as well as the reactive power in the distribution system, because reactive power is also responsible for changing the voltages on the distribution system; so by changing the voltage voltages using on-load tap changer, line voltage regulator, we can change the voltages. And we can using the capacitor, we can feed reactive power to change the voltages at particular bus.

So, in this case, power flow study is very useful, because this will be used to perform voltage drop studies, which will basically decide, settings of these devices, because at what tap position this OLTC will be set, or at what tap position these regulators will be

set, as well as this capacitor should be switched on or switched off that will be decided based on your load flow studies. So, load flow study is very important in this case also, which will be used to decide the setting, as well as to do the coordinated control of above devices.

Capacitor banks, decreases reactive power flowing from the substation. So, if you are having this one, so if you are providing some capacitor bank here, it will decrease the reactive power, which is coming from the substation. And voltage is managed by lowering or raising the tab of OLTC of substation transformer, and voltage regulators. So, voltage can be managed by on load tap changer, as well as voltage regulator.

Therefore, main function of volt var control is to reduce system losses, while maintaining acceptable voltage at all the points in the distribution system through optimal setting of volt var devices. So, we need to find out optimal setting of all the on -load tap changers in the system, all the voltage regulators in the system, and all the capacitors in the circuit. So, we have we are calculating overall setting of all the devices, so that the overall losses in the distribution system will be minimum. And the voltages will be in acceptable limits at all the distribution buses.

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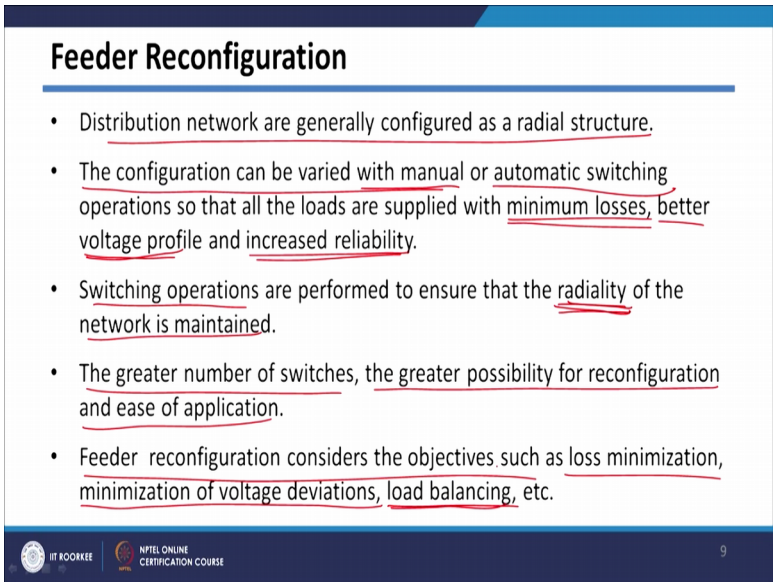

Next problem is actually distribution reconfiguration, or it is also called as feeder reconfiguration. We know that these distribution networks are generally radial in nature. And if you can provide switches at various lines in the distribution system, and if there

are some tie lines in the distribution system, so by switching on tie lines and opening some other lines, we can reconfiguring the system.

And then there will be one configuration in the distribution system, which will be having minimum loss value. So, to find that minimum loss value configuration, again it becomes your optimization problem. So, here the configuration can be varied by or with manual or automatic switching. So, by switching it on or switching it off, some lines as well as tile lines, we can reconfigure the system. And it will be reconfigured such that the losses in the system will be minimum, voltage profile will be better, and it will increase basically your reliability of the system.

However, whenever switching operation is done, here radiality of the network is maintained. Means, whenever you are switching some tie line, it will form loop. So, whenever you are switching some tie lines, some other line need to be opened. So, one switch is open, so that structure of the distribution system will remain radial in this case.

So, if you are putting more number of switches in your distribution system, you are having a lot of flexibility to reconfigure, so greater possibility of reconfiguration, and ease of application. So, in this case also as I told you it becomes optimization problem, because to get the configuration with minimum loss condition, it needs optimization.

So, feeder reconfiguration considered objectives such as loss minimization, minimization of voltage deviation into system, or balancing of loads on phases as well as feeders. So, this is about feeder reconfiguration. And the load flow studies plays very important role in feeder reconfiguration also.

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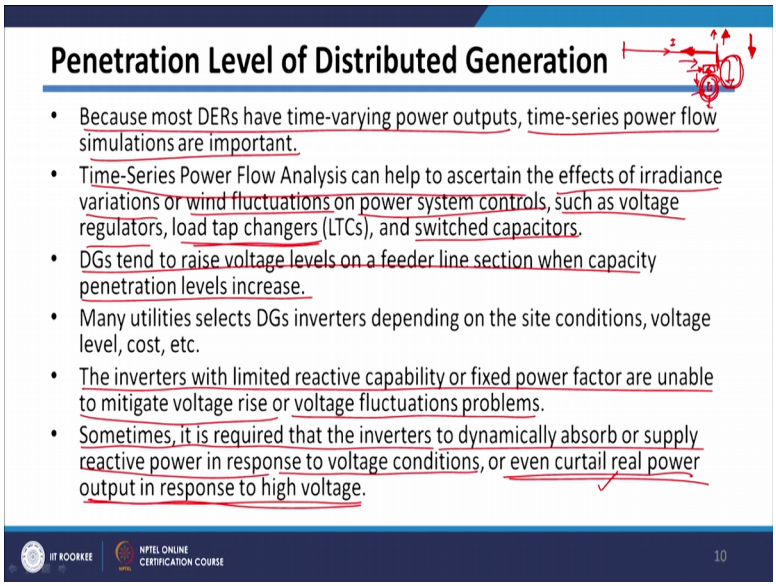

And then next is penetration level of distributed generation. So, once the distribution generation is placed in the distribution system, it will try to feed real as well as reactive power into distribution system. However, how much power, which will be absorbed in the distribution system, depends on system condition. Means, whatever power, which is generated by distribution distributed generation may not be absorbed by distribution system, because it depends upon the voltage and other conditions in the distribution system.

Like what happens, whenever you are connecting some DG, so if you are connecting DG here, and then some load is here, then what will happen is the current, which is flowing through this part will get decrease, because some part of the real and reactive power will be provided by DG. And because that that your drop across this will decrease, and because of that there is possibility at voltage of this bus will get increased.

Now, if there is low load condition at this DG bus, there is possibility that power will be flowing in opposite direction. In that case, the voltage of this bus will go beyond some limit. And if your inverter of this DG is based on voltage cutoff at upper cutoff the voltage is DG will be taken out of the system.

So, even though the sun is available, and solar pvdg is installed there, you cannot feed the power, because of upper cutoff limit of the voltages, your DG is getting disconnected from the system. So, because of operational condition you cannot absorb whole power

which is generated by DG. So, in that case to increase this absorption level, we need to control the voltages at the DG bus.

So, because of most of the DERs having time-varying output, time-series load flow simulations are important. So, in this case, the radiation level of sun is fading, as well as wind velocities varying, because of that output power of this DERs is actually varying. So, at each time instant by taking the snapshots of various time instant, you can find we can do the load flow studies. And based on these load flow studies, we can optimize the settings of various devices in the distribution system, such that voltage profile in distribution will maintain. And we can absorbed maximum available power from the renewable generation.

So, time-series simulation, can be help in certain effect of irradiance, variation, wind fluctuation of power system control, such as voltage regulator, tap regulator, tap changers, and switched capacitors. DGs tend to raise the voltage levels on a feeder line section when capacity penetration level increases. As I told you penetration level increases, and if the load at this bus is lower, then it will backfill the power. And current will be flowing in opposite direction, which will raise the voltage at this particular bus, and will create over voltage condition into the distribution system.

In that case, if this inverter, which you are putting at DG terminal; soif this inverter, if it is having reactive power capability also, then this reactive power capability of the inverter will be used to mitigate this voltage rise. So, by absorbing some of the reactive power at this end, the voltage of this bus can be brought down to required value, which will actually ease your voltage fluctuation problem.

However, sometimes to do this means, to increase the reactive power, or dynamically absorb, this reactive power dynamically absorb as well as supply the reactive power, due to the voltage conditions. It is crucial that the real power output of the generator can be curtail, means even you can curtail real power output of the generator in response to high voltage.

So, whenever high voltage is going of you need to supply or absorb, the reactive power depending upon voltage condition. In that case, some of the during the absorption or supplying the reactive power, some real power penetration can be curtails, some amount of real power presentation can be curtail.

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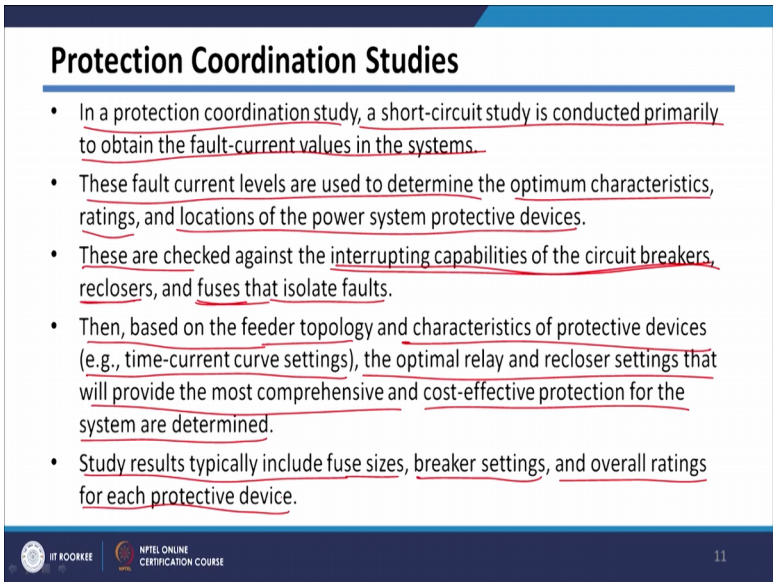

And then, we have seen the short-circuit analysis also. Let us see, what are the applications of the short-circuit analysis. So, main application of short-circuit analysis is protection, coordination, studies. So, in a protection coordination study, or short-circuit study is conducted primarily to obtain low fault-current in the system. So, we have seen various methods based on which we can calculate fault currents in the distribution system.

These fault currents levels are used to determine optimum characteristics, ratings, and location of power system protective devices. So, based on these results, which we have got that is calculation of fault currents, as well as post fault voltages, we can determine the characteristics, ratings, and locations of power system productive devices

Now, this after getting this, they will be checked against inducting capabilities of circuit breaker, recloser, and fuses that isolate fault. So, the characteristics, which you have got locations, as well as rating of the devices will be compared or checked against with capabilities of circuit breaker, reclosers, and fuses. These are basically disconnecting devices in the distribution system.

Then based on topology, feeder topology, and characteristic of protective devices, example time-current curve settings; the optimal relay and recloser setting that will provide the most comprehensive, and cost-effective prediction for the system are determined. Means, in this case, if you see the overall distribution system, the circuit

breaker, reclosers, and fuses, there will be many circuit breakers, reclosers, and fuses in the system, and they need to be operated within coordination.

And this study results typically include fuse sizes, what size of fuse, I need to put breaker setting, what breaker setting need to be done, and what will be the overall rating of each protective device. So, based on this study, we can get the size of fuses, breaker settings, and overall rating of each protective device. So, based on whatever fault current, which you have calculated we can do these studies to get better protection of your distribution system.

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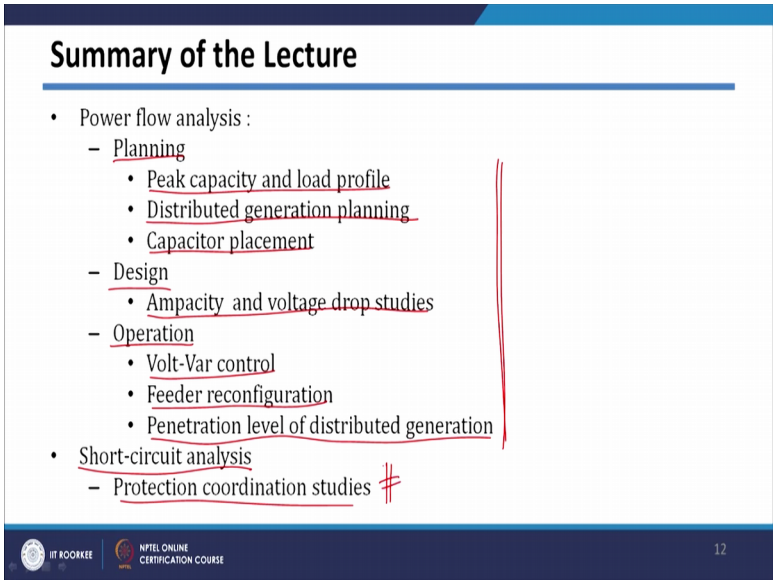

So, in summary of this lecture, we have seen various applications of power flow studies. This application includes planning, design, and operation. In planning, we have taken three cases, one is peak capacity, and load profile planning, second is distributed generation planning, and capacitor planning. In design stage, we have taken one case study, where ampacity and voltage drop studies can be done. And then in operation, volt-var control, feeder reconfiguration, and penetration level of distributed generation.

And we have discussed how load flow studies will be beneficial, or how the load flow studies are integral part of these studies, because all these studies will be based on load flow calculation that is calculation of voltages all over distribution system, as well as line flows in the distribution system. These various studies can be carried out.

And then you have seen, the short-circuit analysis also, and its application in protection coordination studies. So, in protection coordination study, whatever short-circuit analysis, we have studied in this particular course, can be effectively used to do the better coordination, or to select the better protective devices for your distribution system.

So, with this our this is end of our course. So, as I as we discussed in this particular course, we have started with simple introduction to the distribution system. After introduction, we have seen simplified or approximate methods of distribution system analysis, which will actually give simple calculation, or methods based on simple calculation to get voltage drop, and power losses in the distribution system.

And then, we have gone for detailed models of distribution system components, where we have seen the model of distribution lines, transformers, regulators capacitor banks, loads, distributed generation, we have seen them in detail. Then we have gone for various tools for distribution system analysis like load flow analysis, we have seen it in detail. We have seen three methods, one is based on backwards-forward algorithm, second is based on direct approach, and third based on gauss implicit Z-bus matrix.

And finally, we have gone for short-circuit analysis of distribution system, where we have seen analysis based on traditional symmetrical component. Then we have seen based on phase variable, but simplified Thevenin's equivalent circuit. And then finally, we have gone for direct approach for distribution short-circuit analysis, which can be used for any large distribution system. So here we end our, this course.

Thank you very much.