Operation and Planning of Power Distribution Systems
Dr. Sanjib Ganguly
Department of Electronics and Electrical Engineering
Indian Institute of Technology, Guwahati

Lecture - 30
Distribution networks with the integration of Distributed Generation

In this particular lecture, I will start a new module that is a distribution systems with distributed generation, ok. So, at my introductory lecture, I mentioned that distribution networks are slowly upgraded or slowly changed what it is presently ok and what it was just 5 years back.

Why these changes took place? The reason is the integration of distributed generation system, ok. So, in this particular module, we will learn what is distributed generation, how to define distributed generation and what are the challenges involved with the integration of distributed generation or penetration of distributed generation into distribution networks, ok.

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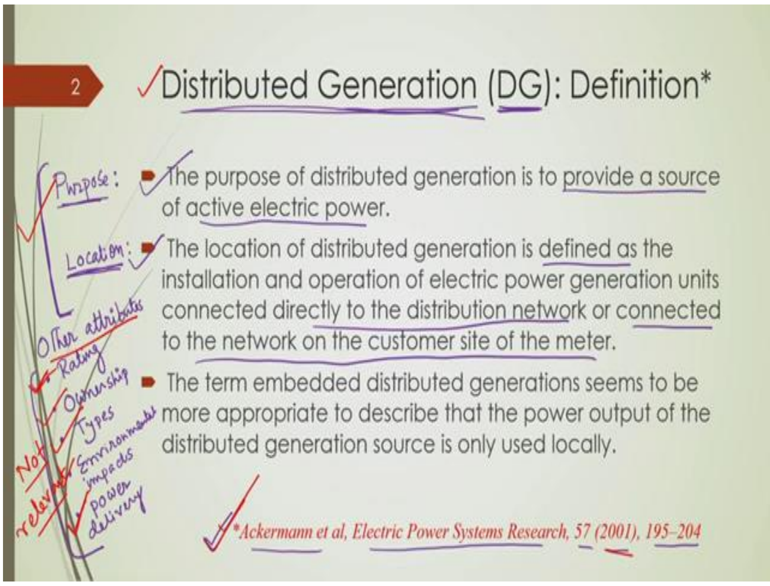

So, first let us define what is distributed generation? Let us define what is distributed generation? So, this definition you can get in this paper authored by Ackermann, published in electric power system research journal, volume 57, page number this, in the year of 2001. So, this paper if you follow, it will give you a nice overview on what is distributed generation and how can we define distributed generation, ok.

So, there are, in fact, in this paper if you follow, there are various attributes in which the authors defined this distributed generation, ok. First of this attribute was purpose, purpose of distributed generation. What is the purpose of distributed generation?

The purpose of distributed generation is to provide a source of active electric power, which is you know very precise and one needs to understand. What is the use of distributed generation? It is a source of active power, it provides active power to a network, ok.

Then second attribute was; what is the location, what are the locations for distributed generation, ok? So, the location of distributed generation is defined as the installation and operation of electric power generation units or distributed power generation units connected directly to the distribution network or connected to the network on the customer site of the meter.

So, this is very important, in fact according to this Ackermann, these two are most significant attributes while defining distributed generation, ok. And in it is acronym is very famous used in several of research papers, which is called DG ok, which is called DG, ok. There are some you know nomenclatures to specify the same thing that is distributed generation I will come to that, ok.

But these 2 are the important attributes to define distributed generation; one is what is the purpose of distributed generation? Its purpose is to provide active power to a network. And what is the location or what are the locations for distributed generation? So, distributed generations are located directly at the distribution networks or at the customer site of the meters, ok. And if you follow this particular paper, this is very very useful paper; then you will find there are many other attributes and the authors claim that those attributes are not so significant or relevant while defining the distributed generation.

What are those attributes? There are many attributes like I can write other attributes; first of all rating, then ownership, third type, next is environmental impacts, and then next is power delivery, ok. So, these are the other attributes and according to this author, they are not relevant, they are not relevant while the defining a distributed generation, ok.

And what do you mean by rating? Many people think that a distributed generation is a smaller version of what conventional generation is. For example, you know that conventional generations or conventional generation units are of 500 megawatt or even higher or maybe 250 megawatts smaller unit. And some people feel that a distributed generation means, it will generate a few kilowatt up to 1 megawatt and so, ok. But according to this definition of Ackermann, he said that the rating is not important. Why it is not important? He argued that suppose there is an industrial customer ok and this industrial customer is basically directly connected to subs transmission networks.

Let us say 132 kV or 110 kV networks and it is fed from this particular sub-transmission network, 132 or 110 kV. Now, if those industrial customers integrate a distributed generation source, a large solar photovoltaic panel or a wind park at premises and it is connected to the customer site of the meter. Then also, its capacity may be 100 megawatt and so. In that case als,o that particular system should be categorized as distributed generation; because this is connected to customer site of the meters, irrespective of the size of the general distributed generating units or irrespective of the voltage levels of the networks or irrespective of the whether it is a, irrespective of the fact that whether it is a transmission network or sub transmission network or distribution network, ok.

So, that is very important. So, the rating does not matter here; ownership also does not matter. In fact, distributed generation can be owned by a distribution utility or can be owned by some local independent authority or whoever; that does not matter at least in the defining that distributed generation terms ok and that is not relevant.

Similarly, the types of distributed generation, I will come to that in the next slide. In fact, there are various types of distributed generation units, which may be categorized as conventional types or non-renewable types and renewable types, ok.

So, renewable types include solar photovoltaic, it includes wind turbine and so and so. So, those are not important. So, we cannot categorize or we cannot define a distributed generation in view of it is types or in view of the technology used; it can be solar, it can be wind, it can be fuel cell, it can be anything, ok.

As long as these 2 attributes satisfied, we can categorize that or we can define it as distributed generation system. Now, as I said, there is no point of environmental impacts or there is no relevance of environmental impacts while defining a distributed generation terminology.

In fact, some units are having higher impact or higher emission and some units may not have any emission at all. So, those things cannot influence or cannot be relevant in defining distribution generation. Similarly, this point of the power delivery also does not matter; it can the common belief is that distributed generation means that, it has to deliver power locally.

But actually it does not; it may so happen that a distribution generation unit provides or feeds power to the grid as well ok, when it has surplus power. So, that point or that attribute that distributed generation has to deliver powered locally does not relevant while defining the distributed generation.

According to this Ackermann paper and this is very you know first paper of this kind; before this 2001, there are many you know research papers published and they are available in the literature, where people use different different terms to define this distributed generation.

Somebody may call this embedded generation, somebody may call that dispersed generation, somebody called it a distributed energy resources and so and so; but there is no standardized definition, before this Ackermann define this, Ackermann and it is co-authors defined in this particular paper, what is distributed generation and how to define this distributed generation, ok.

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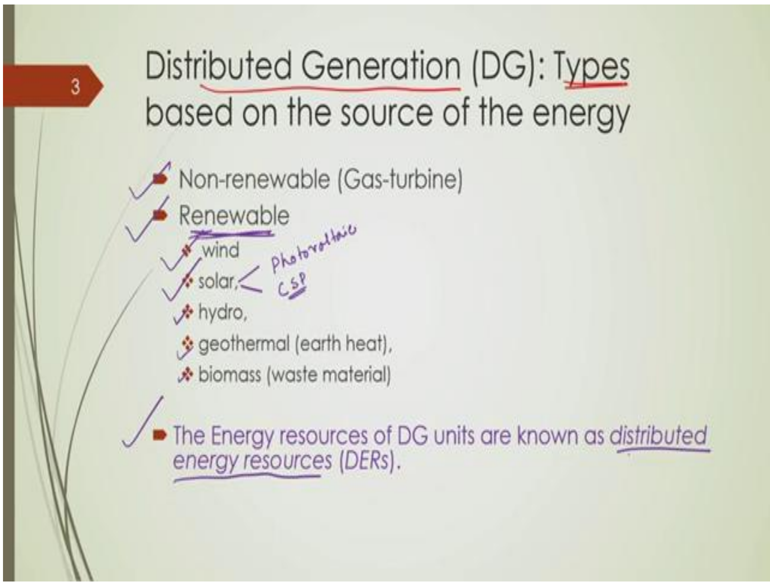

Now, as I said, where although types are not significant or relevant while defining the distributed generation; but we have different types of distributed generation units or different types of DG units. Which can be categorized as these 2 group; one is called non-renewable type, which are conventional type of gas turbine units having smaller capacity, but directly integrated to the distribution networks or may be renewable type of distributed generation units.

Now, again the question is what do you mean by renewable energy source or renewable type of distributed generation unit? The answer would be those units which run by those sources, which are not subjected to depletion, are called renewable type of the distributed generation unit.

For example wind; how this wind turbine based distributed generation unit works? I will explain in the further lecture; but you might be knowing that it as long as the force in wind exists on the earth, it is possible to extract power from that and that is what exactly wind turbine based distributed generation system is doing, ok.

Now, solar is another renewable type of distributed generation unit, in which this solar irradiation or solar insulation, solar light is basically used to convert energy, ok. There is another form of solar energy which is concentrating solar energy, in which the heat available in solar irradiation or solar insulation is used.

But here the intensity of the solar is irradiation is used, that is called photovoltaic. In fact, these are 2, there are 2 parts in solar, there are 2 forms of solar based distributed energy source or solar distributed generation unit; one is called photovoltaic unit, one is called photovoltaic unit, another is called concentrate concentrating solar plant that is CSP, I will come to that, I will discuss this.

The small hydro, geothermal, biomass, they can be categorized as renewable energy source; because they use the resources which are not expected to deplete, ok. Now, there is another term which is used often in similar type of literature, that is called distributed energy resources DER, ok.

Now, what do you mean by DER and what is the difference of DER and distributed energy source; sorry what is the difference of DER and DG? So, the basically in many papers you can find DER is often called as DG unit; but DER is basically whatever type of energy resources which are distributed ok in nature, which may include DG or may include batteries or storage units as well, ok.

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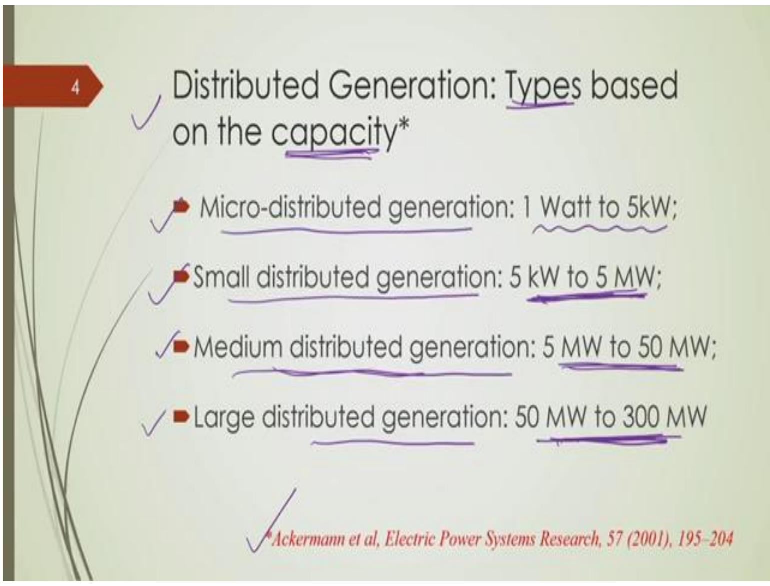

Now, although as I said, the types of capacity or rating or types and capacity both are not relevant in defining distributed generation. In fact, distributed generation can be of different types, can be of different ratings; we cannot define, we cannot restrict that ok that much capacity or that much megawatt should be the upper limit to define distributed generation unit or that much kilo watt or megawatt should be kept as the lower limits.

We cannot simply define distributed generation with upper limit and lower limit, but there exists some you know categorization. And one of them is provided in that same paper Ackermann paper, where you can find based upon the capacity, this DG units are categorized into 4 different groups; one is called micro distributed generation, which is of the capacity of 1 watt to 5 kilowatt.

It means that this type, this micro DG can be directly integrated into a domestic customer at their rooftop, ok. Nowadays, you may find this is a common practice that even domestic customers also intricate rooftop photovoltaic panels and they are directly connected at the customer site of the meter ok and the surplus power is even fed to the grid, ok.

And this type is basically called micro DG. And small distributed generation is those which are having capacity of 5 kilowatt to 5 megawatt. See these are very specific values I am talking about that 5 kilowatt or 5 megawatt; but actually, this is not so precise, but one needs to make some classification or some categorization and this can be a way to do that, ok.

Small distributor generation units are of 5 kilowatt to 5 megawatt, which can be directly integrated to a typical rural distribution networks even, ok. And medium distribution networks, sorry medium distributed generations are of the capacity 5 megawatt to 50 megawatt, which can be integrated to even r 1 or metropolitan distribution networks, which are having higher demand, which are having higher capacities as well, ok.

And large distributed generation as I was talking about it is from 50 megawatt to 300 megawatt. According to this definition which can be as the example I gave to you that, a typical industrial customer can directly connect, can be directly connected to a higher voltage; because this 50 megawatt and 300 megawatt are very big value, very high value to integrate in a typical 11 kV primary distribution network; this is not feasible.

So, one needs to connect this to a typically higher voltage distribution network, which may be 110 kV or a 132 kV, which are often categorized as sub-transmission system, ok. So, if an industrial customer is directly connected to a sub-transmission network of having a 110 or 132 kV voltage level, one can connect large distributed generation as explained.

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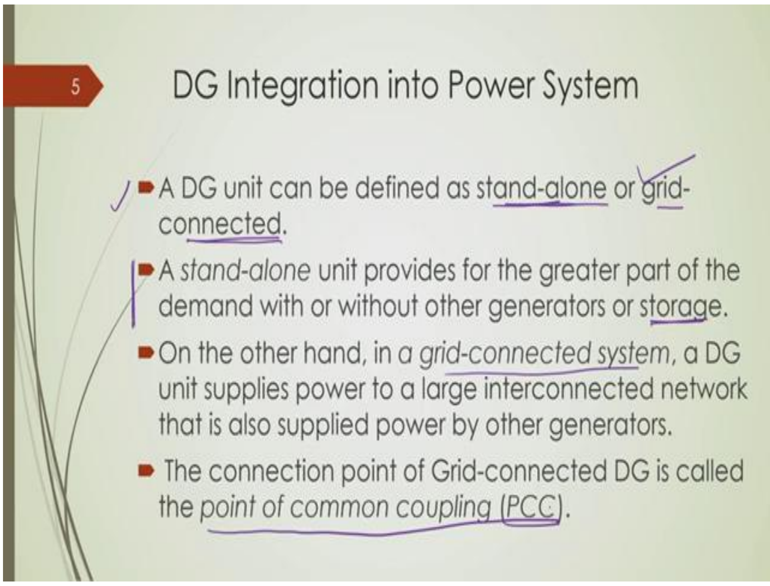

Now, I will discuss some sort of challenges and some sort of impacts which are very important of integration of distributed generation into distribution networks, which are very very important. And that is why I kept this you know part in this syllabus, ok. We have to understand, what are the impacts and what are the challenges as well to integrate or with the integration of distributed generation into distribution networks, ok?

Now, before that one can also understand that a DG unit can be defined as standalone unit or grid connected unit; but, we are talking about mainly grid connected unit. If it is a standalone unit, then it is directly connected to the customer, we do not bother on that; then it is the customer responsibility or whoever the owner of that DG, it is their responsibility to properly operate.

But grid connected DG will have some bigger impact on distribution networks, those thing we will be discussing here. So, a stand-alone unit always provides some demand and it needs of course storage, so that if there is an imbalance between demand and generation, then part of the energy can be either stored or delivered by the storage unit.

But grid connected system does not require any type of storage and that is why it is more relevant to connect it to the grid; because grid itself in finite system, ok. So, there is another terminology which is used in this context that is called Point of Common Coupling PCC; it is the point or connection point, where a DG unit, a distributed generation unit is connected to the network.

For example, if we have, let us say 10-node distribution network and at node number 7 a DG unit is connected; so the point of common coupling for that DG unit is node number 7, ok.

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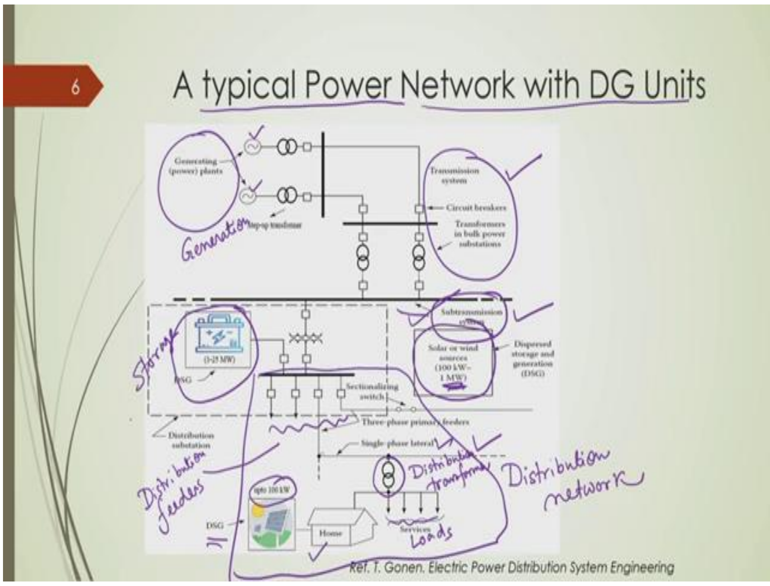

This is a typical illustration of distribution network with DG units; in fact this part is basically distribution networks. So, this is our distribution network, this part is sub-transmission network as it is mentioned and this part is transmission system and this part is generation system.

So, this figure is giving you an idea that where and where we can connect typical distributed generation unit or some typical distributed generation units or DG units in short, ok. So, this is you know generation or generator generation.

So, we have conventional generators, which are of synchronous generators mostly, which are used in conventional power plant in India. And then we have typical transmission systems; we have then next level that is sub-transmission system and finally we have distribution network. So, in this distribution network, you can see, we have these are the feeders, these are the feeders; these are the distribution feeders, here 4 number of feeders are shown.

And one of typical feeders is shown over here, which is having a single phase lateral here; this is our distribution transformer distribution transformer and these are the loads, these are the loads. And one typical load is shown is as home where we can connect photovoltaic system or solar photovoltaic system, which is a one of the DG units in that network.

So, we have a number of loads there. It may so happen that each of the house may have the similar kind of photovoltaic system, as distributed generations unit, ok. But apart from that, we may also have you know storage which is located in the substation itself. So, this is located in the substation itself, so this is a kind of storage.

And we also have large amount a large rated distributed generation system directly connected to the sub-transmission system. So, here you can see a solar or wind, a large photovoltaic system which consists of multiple numbers of photovoltaic panels and aggregated capacity may be in the level of 100 megawatt and so can be directly connected to the sub-transmission system.

Similarly, you know not even 1 megawatt, it can be 100 megawatt as well; even if we have a large wind park of and this can be directly connected to the sub-transmission system.

So, you can find identify that in a typical power network, where are the potential locations to integrate DG; it can be located in sub-transmission network or it can be located directly in the distribution networks. And it can be connected in a distribution network directly or it can be connected to the customer site of the meters, ok.

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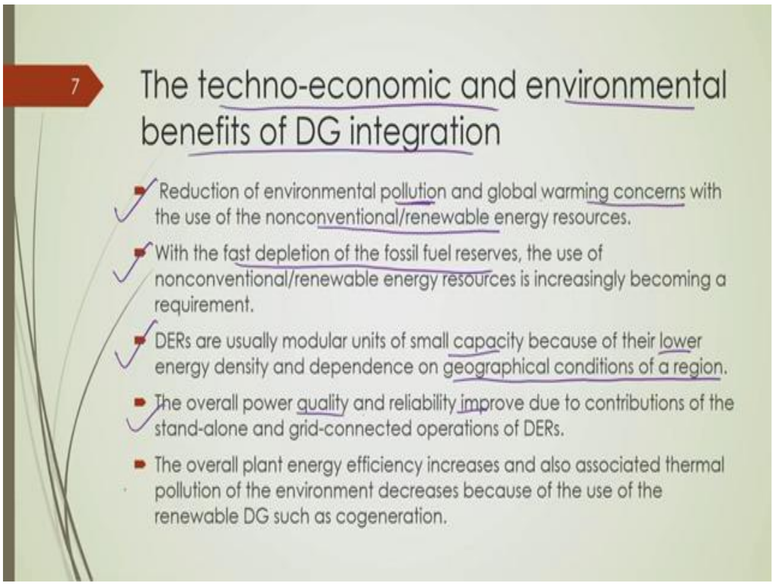

Now, we will go to the techno-economic and environmental benefits of DG integration ok; because DG integration, we will have some challenges and some benefits, ok. So, one of the benefits is of course the reduction of pollution, particularly with the use of renewable energy sources, ok. So, as you know that global warming concerns with the use of non-conventional or non-conventional energy sources particular like thermal power plant.

And this can be somewhat mitigated, if we have a good number of DG units, ok. Also this as I said, the first depletion of fossil fuel reserves is one of the concerns, ok. And since this renewable type of DG units run with the resources which are not to be depleted and which are not to be at all concerns of this operators or owners of these generating units, so we can use them.

And also DERs are usually modular units, it has you know lower energy density and it has molar capacity and it depends upon the geographical condition ok. As I said, so this is not benefit, this is one of the challenges. And also this power quality and reliability improved. How it is improved? I will come to that. And if energy efficiency also improved with the integration of DG I will come to that.

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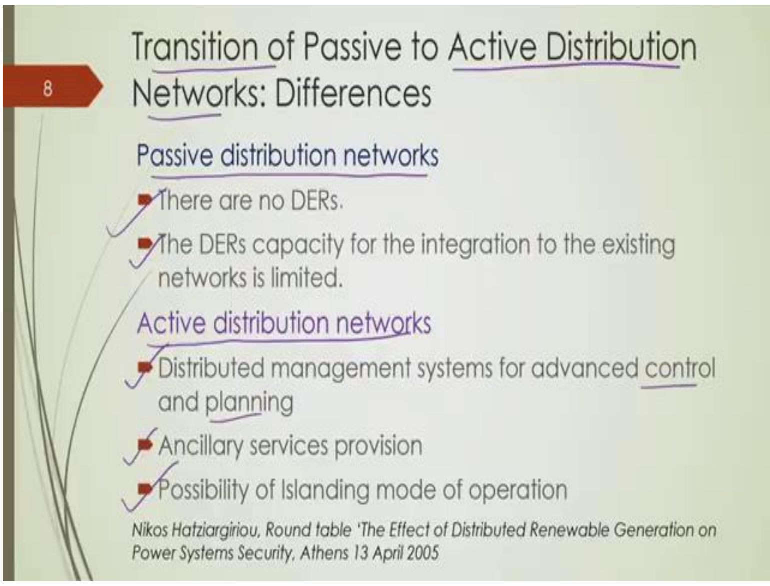

Now, with the integration of DG, with the integration of distributed generation, our distribution networks are slowly in the process of transition, in the process of transition to active distribution networks from the usual passive distribution networks.

So, till now in most of the part of our country distribution networks are of passive. So, there is no active source anywhere and it is directly connected to the grid with a substation and we consider in our analysis, so far that substation is our feeding point and there is no other feeding point and that is why you know since our distribution networks are of radial.

So, power flow is unidirectional starting from the substation towards the customers or towards the loads, ok. So, for passive distribution networks, there are no DERs and DER capacity integration to the existing network is also limited ok. But active distribution networks are up well equipped and they are particularly designed to integrate higher amount of DG, higher amount of distributed generation, ok.

So, they have distributed management system for control and planning of their operation of the network with this distributed generation units. And if they have the provision of ancillary service they have the possibility of islanding operation of the whole system.

It means that if you have sufficient amount of generation, which can supply all the customers load, even at the peak condition, even during the peak time, then we can go for islanding operation, whenever there is a disturbance in the grid or whenever the there is a blackout in the grid.

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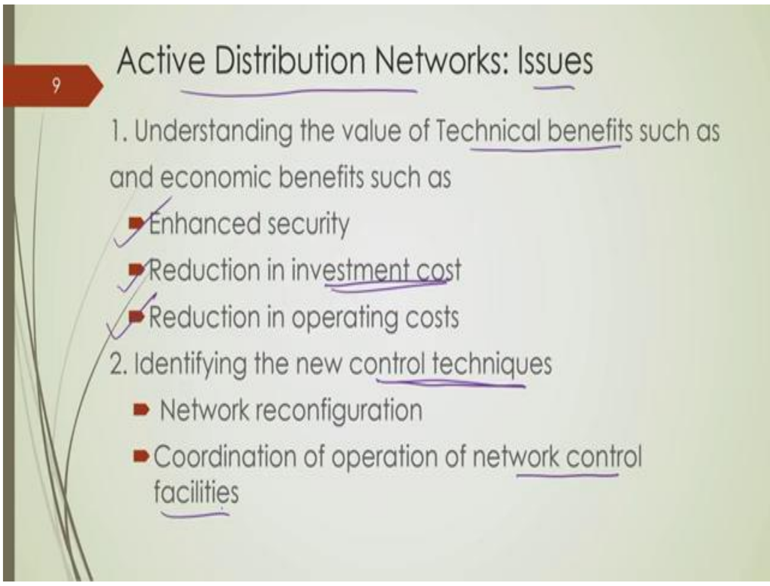

So, this active distribution networks, there are some issues. So, we have to understand several benefits, you know technical and economic benefits, for enhancing security, for reduction of investment cost because why it is so? Because due to this presence of the distributed generation, we may differ some of the infrastructural changes which are inevitable in a typical distribution network.

For example, if you have you know that a distribution network, which is located where there is a continuous growth or very steep growth of the load, then of course, to cater or to accommodate this higher amount of demand within next few years, these distribution networks need to have infrastructural change and that is called reinforcement of equipment.

Now, this can be differed if we have a local DG, which will cause somewhat reduction of power flow of a particular feeder; how it is happening I will come to that with my simulation results. And also due to this particularly renewable type of DG units integration, the operating cost would be somewhat reduced.

So, these are the economical and technical benefits, but we need to have new control techniques; because you know this is very important that conventional type of passive distribution networks as I said various times, it is operated with the idea or with the property of unidirectional flow of power. And that is why its protection system is designed considering the fact that this unidirectional flow of power, ok.

But due to this integration of DG unit, no longer this unidirectional flow of power will exist and therefore, this protection system needs to be redesigned, completely redesigned, ok. And also the control new control technique is to be there.

Another important issue is that this you know in distribution network, there are various small number of you know sensors connected, so that we can have an advanced level of control and monitoring of a particular equipment. Not many distribution networks are fully connected with Supervisory Control and Data Acquisition system, SCADA system.

So, therefore, it is very difficult to get a centralized control of all whole system ok and that is a one of the challenges; particularly in active distribution networks, which are having DG unit, ok.

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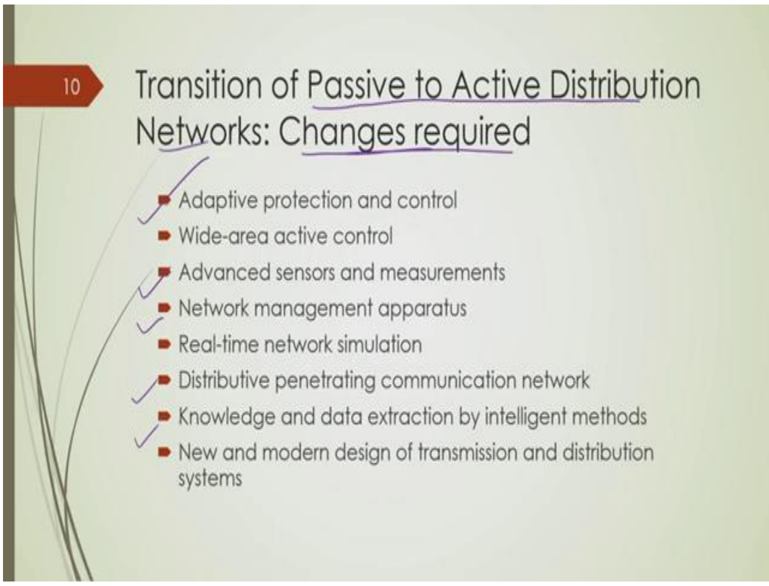

So, we need some changes; we need some changes, in order to have this smooth transition from passive to active distribution networks. Now, what are the changes we require? As I said protection system should be completely redesigned and accordingly new control strategy is to be devised, ok. So, many sensors and measurements should be required, so that the whole network state would be fully visible.

And also network management you know communication system and data acquisition and data extraction system, those things are inevitable in order to have a smooth operation for this active to so called active distribution networks.

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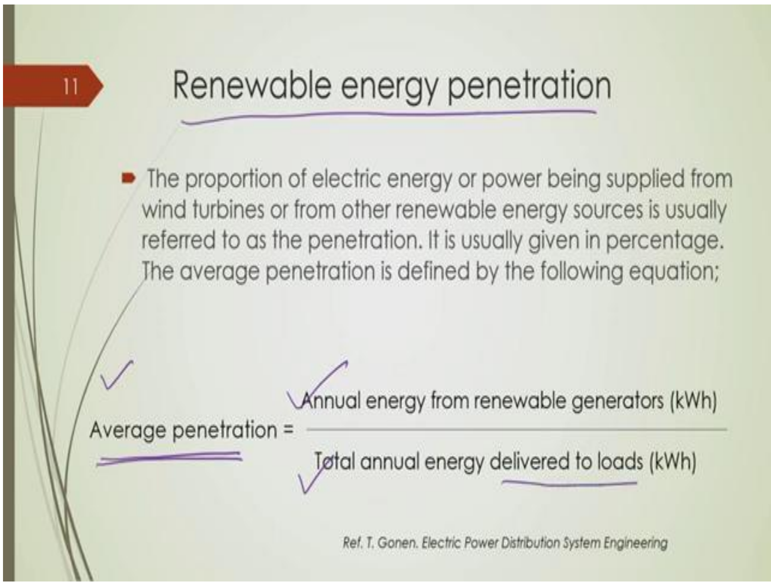

Now, there is a definition that is renewable energy penetration. And this definition is basically the average penetration. This average penetration of renewable or any type of distributed generation unit is defined as that annual energy; it is the ratio of annual energy generated by those generating units or those generating the stations to that total annual energy delivered to the load. Or it is basically the fraction of energy which is being supplied by the DG units in a particular year ok, that is called average penetration, you can get it from Gonen's book.

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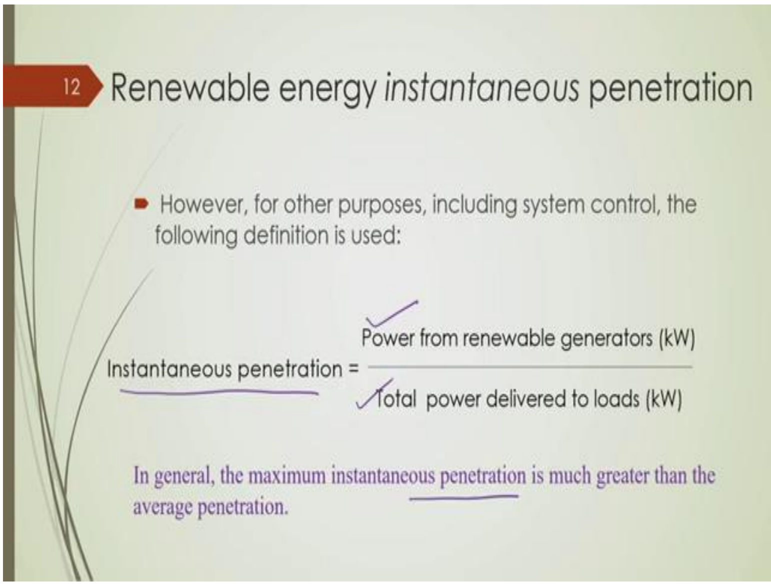

And instantaneous penetration is basically that it is a time varying quantity. So, it is ratio of power generated by a renewable generating unit to the total power delivered to the load, ok.

So, typically instantaneous penetration is used to be much higher in a particular instant of time and it is variable throughout the day. So, instantaneous penetration is variable throughout the day, throughout the minutes even and it is maximum value is somewhat higher than the average penetration.

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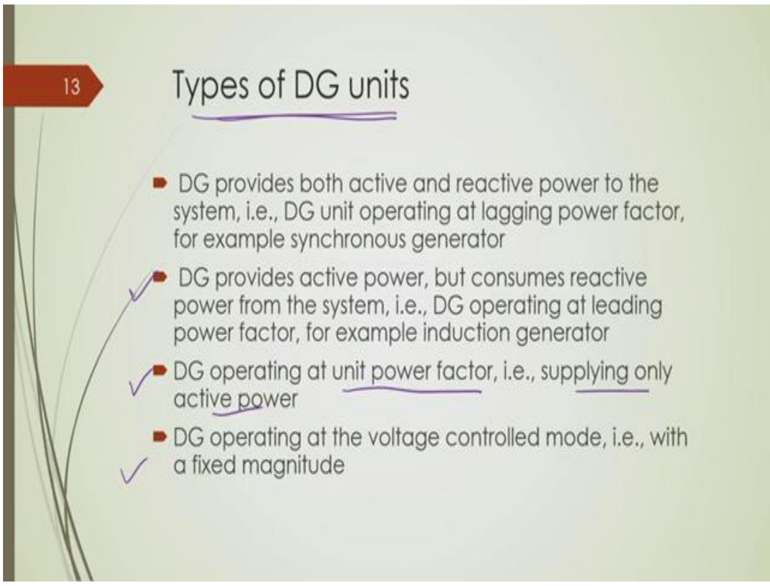

Now, we can also define different DG units on the basis of their operation or their ability to provide reactive power. So, one type of DG unit, in fact as I should say at this point that, the conventional power stations in India or even in other countries, the conventional generation comes from the fossil fuel based power plant, where we have synchronous generator, where we have synchronous generator.

Now, the changes that, the main change that you can see in this distributed generation system is that, no longer we use synchronous generator ok, no longer we use synchronous generator. We use different types of generators and we also use converters to generate this power or to feed this power to the network at this point of common coupling, ok.

And therefore, we can categorize, these DG units are of 3 different categories; in one of the categories of course, we can keep it similar to a synchronous generator, which can deliver active and reactive power. But there are some DG units, which can only operate at unity power factor; thereby it can supply only active power, it cannot supply reactive power.

And there are some DG units which will supply active power, but it will consume reactive power; particularly if you have an induction generator type of generating system ok and we can categorize like them. And there are some DG, which can be operated as voltage control mode that is with a fixed magnitude of voltage, which is basically rare; the controlling voltage at the DG level is very much rear and it is subjected to the regulators, are subjected to the regulation, ok.

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So, DG integration capabilities is a type of plug and play, it supports active and it can support reactive power as well; it can improve power quality, it can have fault ride through capability.

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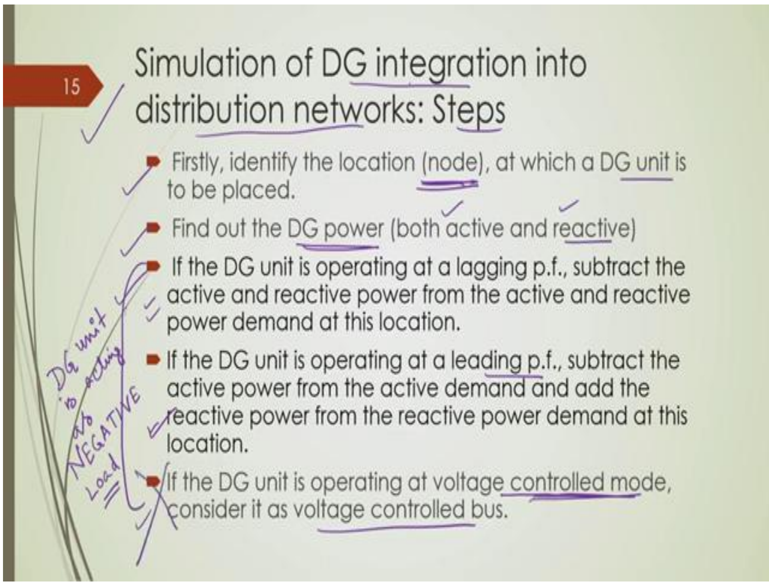

Now, I have some simulation results for this DG integration. First let me tell you how I have done this simulation for this DG integration, in order to understand the impact of DG integration into distribution networks, ok.

So, this slide will give you how I have done this simulation; in fact whatever I will be showing, I will give you, I will show you three different systems and out of which two works are of our personal works, ok. First of all, how do we simulate the DG integration into distribution networks? These are the steps, ok.

Firstly, you should identify the location or note where I should put a DG unit, ok. Then, you should find out what is the generation of the DG; whether it is providing both active and reactive power or it is providing only active power, ok.

So, if they are providing both active and reactive power, then how much active and reactive power it is providing. Then third step is to find out, if the DG unit provides both active and reactive power; then it is considered to be a negative load assuming that it does not have this constant voltage or regulated voltage capability, ok.

So, it is considered to be a negative load and the point where you are basically connecting this particular DG unit, this point might have some load demand as well. So, what you can do, you just subtract this generation from this load demand, assuming that this DG is a kind of negative load. So, here, we can assume that DG unit is acting as negative load. So, whatever power demand you have this particular location, you subtract this DG active power in all these 3 cases; but in one case, if DG is supplying reactive power as well, you can subtract this reactive power from this reactive power demand as well. But if it is operating at leading power factor condition or it needs reactive power to operate it, so you just add this as a additional reactive power demand.

And if it is operating at voltage controlled mode, which are very much rare, in fact, I should say; then you can consider this voltage magnitude of the bus as well. So, I did not consider this exercise; I consider basically this, assuming that a typical DG unit can provide both the active power and reactive power, ok.

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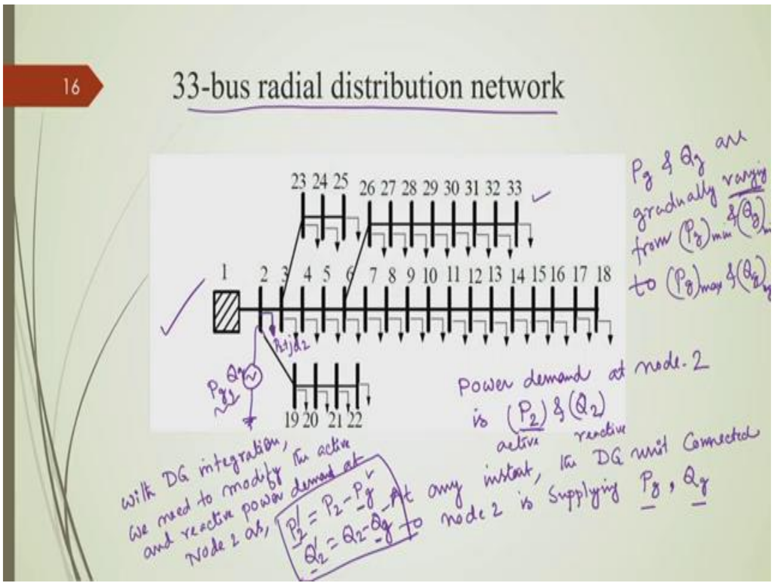

And we have simulated this by 33-node distribution network, as this network is known to you. So, what we did actually; starting from this bus number 2 to bus number 33, I exercise by connecting one DG unit at a time. For example, at one instant of time, I connect a DG unit at this bus number 2 or node number 2, ok.

And so, suppose this power demand power demand at this node 2, node 2, is P 2 and Q 2, that is reactive power. So, this active power demand, this is active power demand and this is reactive power demand, ok.

And at a particular instant of time, this particular generator is providing this P g amount of active power and it is also providing Q g amount of reactive power. So, at any instant the DG unit connected to node 2 is supplying P g and Q g; this is active power, this is reactive power, ok. And we consider this as a negative load.

So, what we will do in the simulation? We will modify this demand; because at this node 2, we have some active and reactive power demand, you have seen. So, we what we will do? We consider this active and reactive power supply of this generator as negative load, what we will do in modify the net demand of this active and reactive power at bus 2 or node 2.

So, what we will do? With DG integration, we need to modify the active and reactive power demand at node 2 as P 2 dash; P 2 dash is the new demand is equal to P 2 minus P g and Q 2 dash is equal to Q 2 minus Q g. So, here you can look this P g and sorry this Q g; you can see this P g and Q g they are considered as negative load.

And thereby whatever generation they are providing, this generation is subtracted with this demand. So, it may so happen this both P 2 dash and Q 2 dash can be 0, can be positive, can be negative. So, if P 2 is higher than P g; that means the net demand of that particular bus or node that is at node 2 is higher than this generation at that instant, then net demand would be positive.

But if it so happen that, if this generation P g is higher than this demand that P 2, then this P 2 dash would be negative, ok. Similarly, this if this same thing is applicable for Q 2 dash as well. And so, it may so happen that P 2 dash and Q 2 dash can be both positive or both negative or one is positive, one another is negative or both can be 0; if whatever generation is basically providing by the generator is owned by the it is basically consumed at that particular location loads only, then it should be 0 and whatever.

So, considering this situation and considering this possible location of this DG in different nodes, one at a time, I will consider one generator at a time, but at every location we have done the next simulation.

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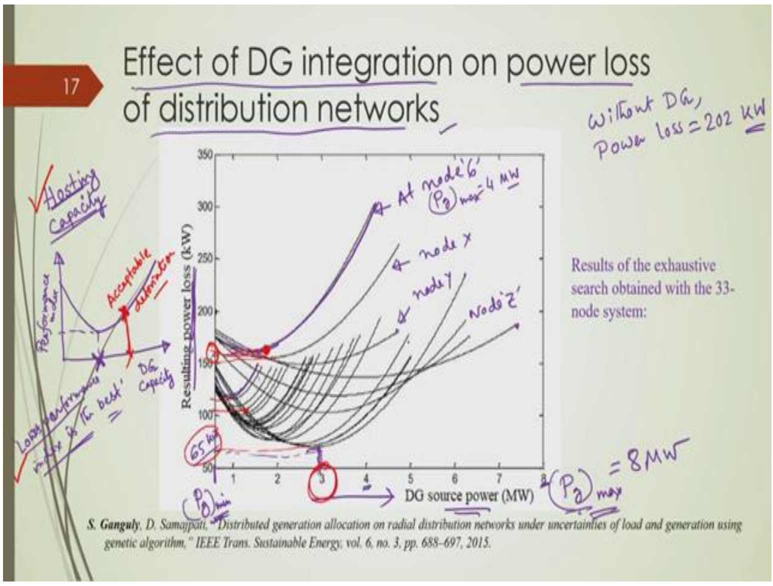

So, in order to understand this DG integration or in order to understand the effect or impact of DG integration on these different operational features of power distribution networks, what we did, we first determine these power losses with respect to this, with respect to different size of the DG, ok.

So, what we will consider here? We consider this you know P g and Q g are gradually varying, P g and Q g are gradually varying from some P g min and Q g min to P g max and Q g max. And this variation, we consider as smooth or continuous variation; we are continuously varying this generation both active and reactive power of that particular DG unit, starting from a minimum value to a maximum value.

And this is the minimum value, this is you know P g min; P g min can be 0 as well and this is P g max. So, P g max is here considered to be 8 megawatt, ok. So, what we did by varying this P g, that is active power which that DG unit will supply from a minimum value to a maximum value; we have done this forward backwards, we have performed this forward backwards with load flow.

And we computed this network loss; it is not loss of an individual line, it is an overall network loss. And if you can remember this this 33 node system, without DG the power loss was power loss was around 202 kilowatt ok, around 202 kilowatt. So, what we will do? We will integrate this P g and slowly varying P g from a minimum to maximum value and for every variation we will compute this power loss and we will plot that.

And this same exercise, we will be doing for all the buses by connecting one DG at a time. So, what we will see in the in this particular figure; you can see that for example, this is suppose you know I do not know, I am just arbitrarily considering, this is suppose the plot of this power loss versus DG power at node 6 let us say.

So, what you can see, with this increase in this DG power; you can see this power loss is initially getting reduced and there exist a point, where we have this minimum power loss and then again it starts increasing, ok. And you can see we have not done beyond this 4 megawatt or we consider here P g max is equal to 4 megawatt; because beyond that you know power losses significantly increase.

So, same thing you can see for the other node. So, this is node x, this is node y or this is node z whatever node you have. So, there are 33 characteristics and each of the characteristic is of similar pattern that if we connect a DG in a particular location, it is power network power loss is initially getting reduced and there exist a point, where you get the minimal power loss and beyond that power loss starts increasing ok, beyond that power loss start increasing.

So, we consider this resulting power loss and which is total network power loss with this DG integration at each and every location for this distribution network and the pattern is same. So, there are some buses where you can see this power losses and we did not do it beyond this point and there are some other buses; we in fact all the buses we consider this P g max differently ok and that is why they are terminated in different points, ok.

And in fact, there exists some of the locations, where you will get the minimum value of power loss; it is as low as near to this you know, it is let us say 65 kilowatt and this corresponds to the optimum value of you know DG power, which is near to the 3 megawatt, ok.

So, there is some location or there are some locations, where you get this minimal value of power losses and of course, out of which one should be the best and the best one can be considered as the best location for DG integration in order to minimize the power loss. So, here our criterion is to minimize the power loss, ok.

And there is a concept that based upon the same analysis, there is a concept called hosting capacity, ok. So, in hosting capacity, it is the capacity. Because suppose I am a distribution network owner or I am a operator then the question should be how much DG, how much distributed generation I can accommodate or I should accommodate.

This is the important question for all these distribution network operators or distribution network owners. Now, in order to answer that, there is a concept called hosting capacity. In hosting capacity, there is a plot; in one axis, this is this axis this is performance index and this axis is DG capacity. And suppose I consider that lower performance index is better. So, low performance index, performance index or lowest performance index is the best, as we have in network power loss. So, in network power loss, the lowest power loss is the best solution for us; because we are in fact trying to minimize the power loss.

So, here also the lowest performance index suppose is the best. So, what you can do? Similar to this you know this characteristic, you can see this perform index. For example, it is reducing or it is decreasing with the increase of DG capacity and there is there will exist a point, where we will be having lowest performance index which is the best value and corresponding to that we have the DG capacity here. And this DG capacity you can consider as the optimum DG capacity.

So, according to this the hosting capacity concept that it is the capacity of DG, which can be integrated into a distribution network, without deteriorating the performance of the network, ok, so, if you consider that you know I will consider the this DG capacity corresponding to the best performance index; one of that is best power loss, then this is the optimum point for DG integration or optimum capacity for DG integration, ok.

But if you consider that this much of this in order to maximize this DG capacity or in order to increase the DG capacity, this much of deterioration in performance index is acceptable, here you can write as, so, suppose this is the point corresponding to acceptable deterioration.

So, you can accept that much of deterioration. So, this is not corresponding to the best capacity in view of the performance index; but if you can accept that much of you know deterioration, then this could be your hosting capacity, ok. So, this concept of hosting capacity is another new concept, where you know this concept you can get in various works ok and people are using to maximize this hosting capacity or maximum utilize for the maximum utilization of DG.

Now, as I said in various nodes, I get different types of minimum power loss. So, for example, at this node 6, for example, at node 6, I get, this is corresponding to minimum power loss. This is for node x or that can be x can be any value, so this is the minimum power loss. Similarly, corresponding to this particular node, this is the minimum power loss.

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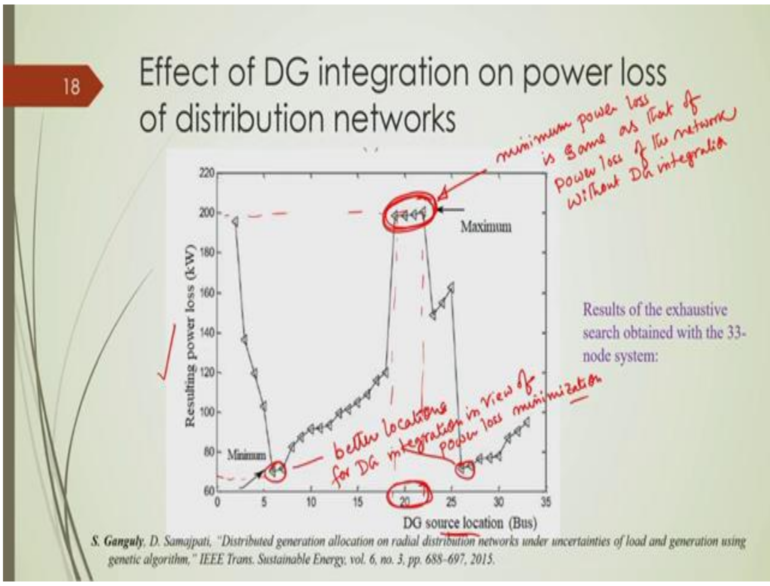

So, different locations, we get different minimum power loss and these minimum power losses are plotted, minimum power loss with respect to different locations of different nodes. So, you can see there are some locations, we get minimum power loss as same as the actual power loss without DG integration.

So, in this location minimum power loss is same as that of power loss of the network without DG integration, it is close to 200 kilowatt, ok. So, thereby you can understand that this location, that is starting from node number 19 to node number 20 to 23. So, these are the locations, where DG integration will not be beneficial in view of the performance index that is power loss. So, if you integrate DG in these locations, it will not be beneficial in view of power loss minimization. But there are some locations, for example, these locations and this locations, where you can get the power loss as low as near to 70 or 65 kilowatt, which is significantly lower as compared to the original power loss that is 202 kilowatt.

So, these are the locations, these are the locations. So, the best these are the better location for DG integration in view of power loss minimization, ok. So, one concluding point is that, if you consider power loss as a performance index and if you consider that, of course DG integration will definitely improve power loss for some location, there are some locations, where you will not get any improvement for DG integration in view of the power loss minimization.

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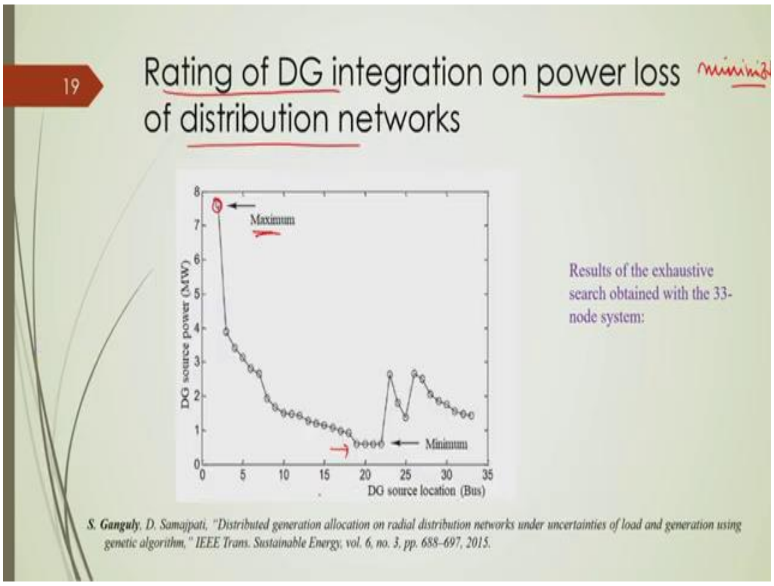

Also these are the ratings or these are the capacity of the DG, are corresponding to the minimum power loss point. So, these are the DG in view of power loss, in view of power loss minimization, power loss minimization.

And you can see, even you know near to the substation that you know DG capacity would is higher. And, if you go to these nodes distant away, the DG capacity corresponding to the minimum power loss that means this is the minimum power loss that is this point, this point and this is the DG capacity that is basically this point, ok.

So, every minimum value of power loss corresponds to a minimum power loss as well as a DG capacity corresponds to the minimum power loss. So, minimum DG power, minimum power losses for DG integration are plotted over in this characteristic and minimum or DG capacity corresponding to the minimum power loss is plotted towards this characteristic.

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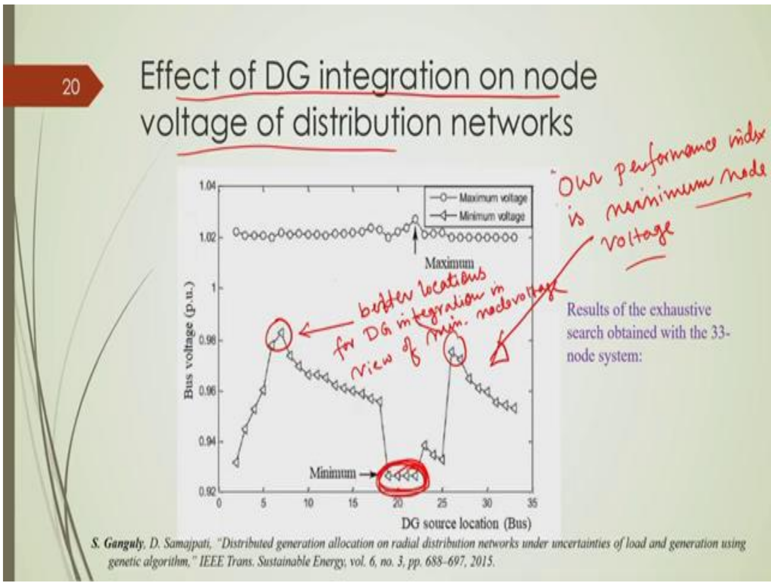

Similarly, we can also check the effect of DG integration on node voltage, ok. You can see here we consider minimum node voltage as the performance index. So, here our performance index is minimum node voltage, ok. So, this is the performance index. And you can see you know there are some locations, as well, where minimum node voltage was similar as that of the case without DG integration ok, but there are some points here and here you will get.

So, you will get the best location or better locations for DG integration in view of minimum node voltage, ok. But here you cannot get any benefit in view of this performance index that minimum node voltage. So, they are minimum node; even if you integrate DG, minimum node voltage would be similar to the network without DG.

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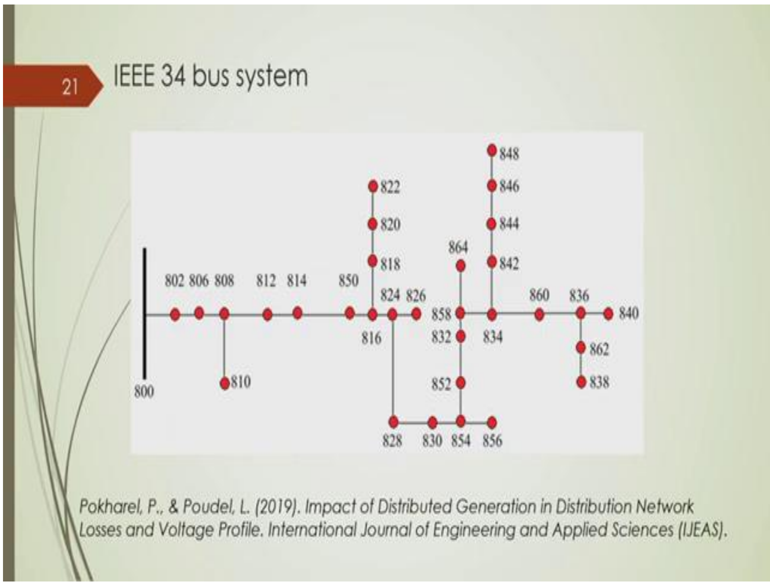

Now, we have another system, that is IEEE-34 bus system, which is I took from this paper.

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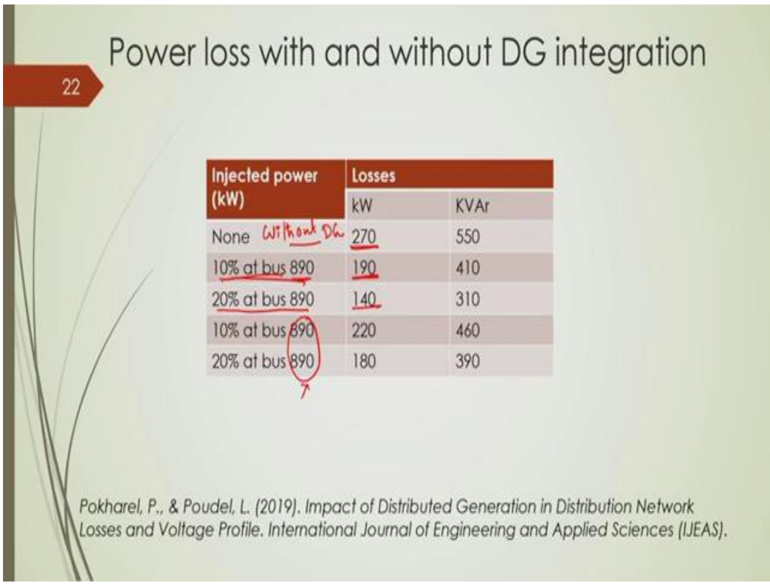

So, this is a typical IEEE-34 bus radial feeder. And this author said that, again if you go for DG integration for 10 percent penetration; this power loss is improved to this is without DG, this is without DG. So, without DG power loss was 270 kilowatt; with 10 percent DG at this bus 890, power loss is improved to 190; with 20 percent DG penetration, power loss is further improved to 140. So, this is at bus number 890. So, this is probably bus different buses; even this 10 percent and 20 percent penetration, this shows that power loss improved.

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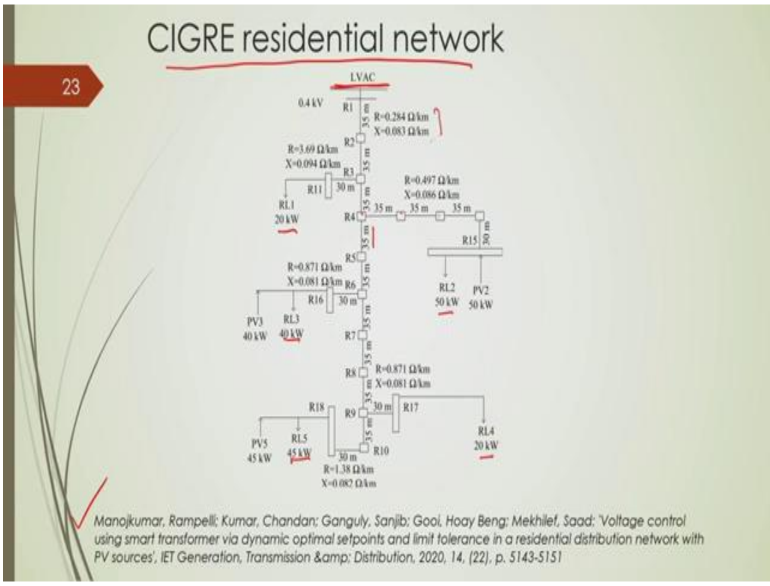

Now, we have another network that is CIGRE residential network, this is also working a power group. So, what you can see, in this particular network, this is the feeding point and this is also radial network and there are some radial loads which are shown over here RL 2, RL 3, RL 5, RL 4 and RL 1, ok. And these are the transit midpoint, where we do not have any load demand, but they are connecting point, ok. And individual locus length of this line section and also this resistances and reactances are given.

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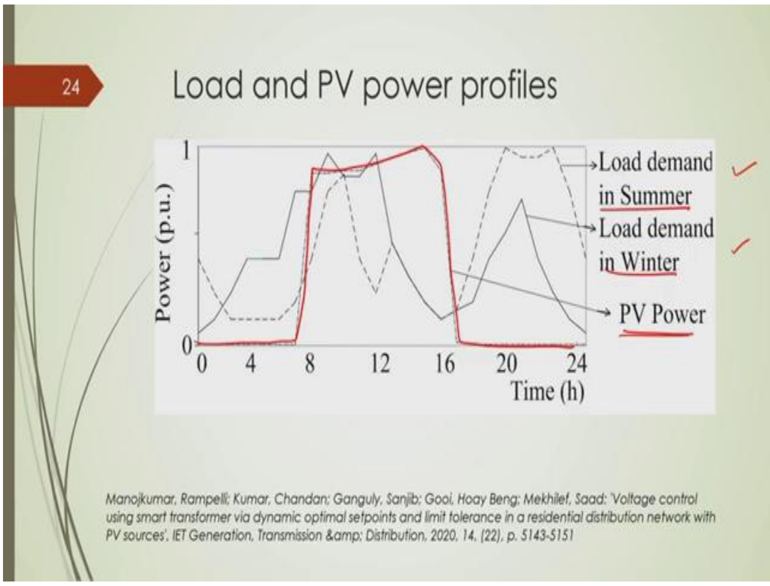

In previous case studies what we did, we considered this load demands are of fixed or the peak load demand and accordingly we studied this DG location and all. Now, what you we do here? We consider load is varying and we consider a typical load curve and also we consider a PV type of that is photovoltaic type of DG unit, where the generation is also varying throughout the day.

Because you know this renewable generation systems or renewable generator generation units they are having intermittency and variability, I will discuss this later on so; that means their generation is very variable throughout the day and it is uncertain.

So, here we consider this is this characteristic; it is basically the characteristic which shows this PV power generation and here we have 2 load curves; one is during summer, another is during winter and we consider this loads are varying according to this load curves, ok. So, here our objective is to find this voltage profile throughout the day ok; not any particular instant of time, which we did in the previous example.

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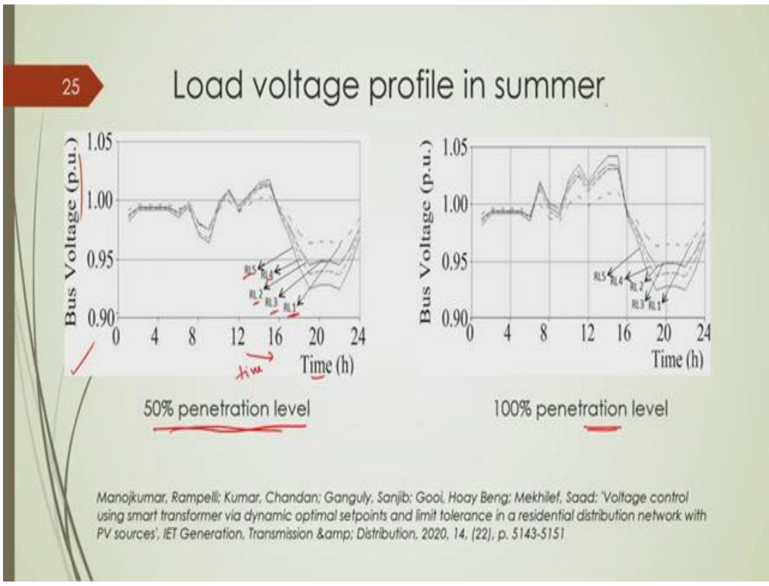

So, what we can see here with the 50 percent penetration level, these are the voltage profiles individual voltage profile; these are the time and these are the voltage profile in per unit and these are the voltage profiles in different you know loading points RL 1, RL 2, RL 3.

So, with 50 percent penetration level, you can see although here minimum bus voltage is not specified; but you can see with this location of different locations of DG, one is RL 1, another is RL 2, another is RL 3, another is RL 4, and RL 5, the network voltage profile is improved, ok.

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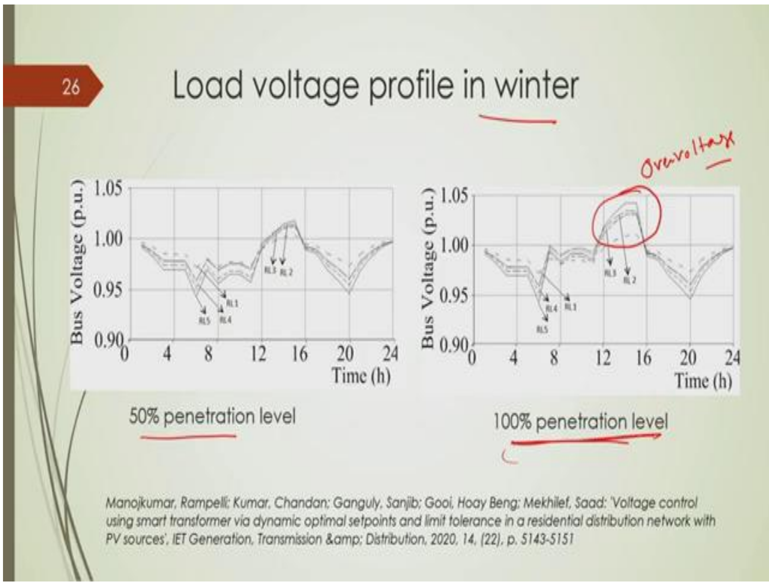

And similarly with 100 percent penetration, you can it is further improved, ok. And this is profile in summer and same thing is observable even in winter, where usually voltage profile used to be better with reduced amount load demand and with the integration of DG in both 50 percent and 100 percent penetration levels, these bus voltages are further improved.

But with 100 percent penetration level, some of the time, some of the feeders experience over voltage. This is another issue that excessive DG integration that 100 percent penetration of DG integration may cause over voltage, I will discuss this also later on.

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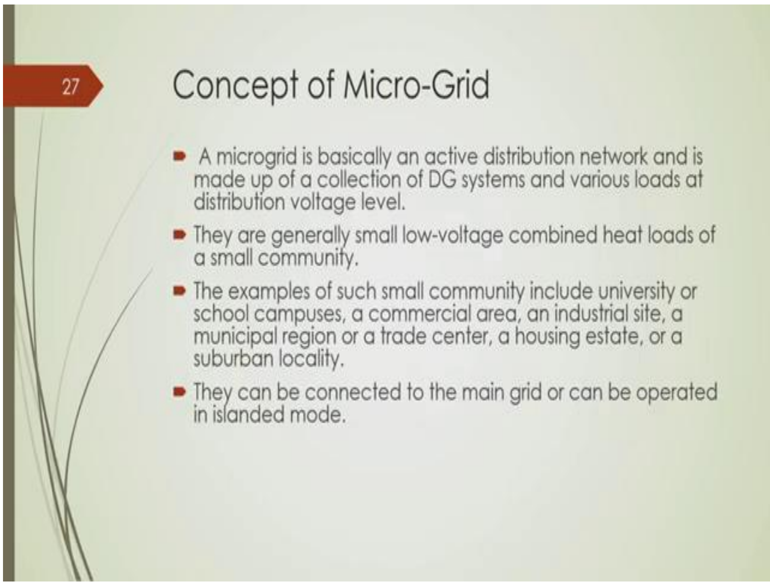

So, with this, I will stop today; I will continue, I will extend this part on the next lecture onwards.

Thank you.