International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)
Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585
Volume 5, Issue 03, March-2019

Benefits and challenges associated with DG installation in distribution network: An Overview

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Abstract: ***Since nearly about last three decades, there seems to be trend towards deregulation and restructuring of electricity supply industry all over the world. This has resulted in unbundling of generation, transmission and distribution network. The aim behind restructuring was to increase efficiency and to minimize cost of electricity supply to customers in the deregulated environment while maintaining a desired degree of reliability and quality of power supply. The major challenge before the electric utilities nowadays is to provide electricity of good quality due to advent of power quality sensitive equipments. Also to bridge the continually increasing gap between demand and supply of electricity, researchers had no option except to invent new sources and technologies of power generation. Distributed Generation (DG) which is a small scale electric power generation technology using different type of conventional & non-conventional energy sources that provide electric power at or near the load site is an example. It may be connected to the grid, directly to the consumer or both. DG is found to be a promising source of electricity generation that can completely fulfill the requirement of electricity as and when required around the globe. The Distributed Generation also found to relieve the transmission network indirectly as FACTS devices, detailed ahead. Number of benefits have been found of the insertion of Distributed Generation in the distribution network. But at the same time number of problems also arises in the distribution network by the insertion of Distributed Generation. This paper describes in detail the benefits and problems associated with Distributed Generation placement in distribution network. Few heuristic rules are proposed for sizing and siting of Distributed Generators in distribution network.***

Keyword: Distributed Generation (DG), Renewable energy, Tidal, Solar, Wind, Biogas, Animal energy, Micro grid, Mini grid.

INTRODUCTION:

Basically the electric power system is broadly divided into three components namely Generation system, Transmission system and Distribution system. Here generation system means a generating station located in remote area due to many reasons and generating electricity in huge quantity. Such generating stations are being operated by conventional energy sources such as coal, gas, nuclear fuel etc. Since these generating stations are generally located in remote areas far away from load centres, long UHV/EHV transmission lines are required to transmit electricity over long distances. To send the electricity to end users huge and complex distribution network is required. Also due to so many benefits of interconnection and number of benefits of parallel operation, the generating stations, transmission lines and distribution lines are interconnected at possible locations. Hence electric power system of any country through out the world become very huge and complex. Therefore successful operation of such a huge and complex power system is a challenge before an electric utility. To ensure successful operation of power system, so many factors have to betaken into account such as power loss minimization, quality of power supply, continuity of power supply, proper operation of protection devices as and when required etc.

Due to advancement in technology and due to day by day increase in automization in each and every field, the demand of electricity has increased exponentially during last few decades. All the devices, machines, apparatus being used for almost all activities of our life are electricity operated. Also industrialization across the globe occurs during the last few decades. Hence demand of electricity increase sharply through out the world. Whereas, generation and transmission network capacity could not be increased in proportion to electricity demand due to many reasons such as managing funds, environmental effects, social problems etc. This situation leads to a large gap between demand and supply of electricity. Due to this ever increasing gap between demand and supply of electricity, more than 1.1 billion people worldwide (about 80% population in rural areas including 230 million in India only) do not have access to electricity [1]. In this condition scientists/researchers were forced to discover new sources and techniques of electricity generation and also ways to improve efficiency and capacity of the power system network. Nowadays, the planning and design departments of electric utilities are busy in planning and designing power system that operates efficiently to supply required quantity of electric power at load centres. As stated above the generating stations are located in remote areas far away from load centres and hence huge network of UHV/EHV transmission lines transmit the electric power from sources to load centres.

Nowadays, unfortunately the UHV/EHV transmission line network has been surrounded by the residential colonies, industrial areas, commercial complexes etc. Hence further expansion in transmission network is difficult and even impossible at most locations. Almost the same situation is with conventional generating stations. But the increase in electric power demand is continue and it should be because of overall development of the world. Hence increase in

electric power generation should be in proportion to increase in demand. There is no problem in expanding distribution network at all. Hence it was need of the hour to increase the transmission capacity of the existing network and to find alternate sources of electricity generation without expansion in the existing infrastructure. This leads to the invention and development of the FACTS devices and DISTRIBUTED GENERATION. The FACTS devices have been proved to be successful in increasing the efficiency and power transfer capacity of the existing transmission network so that extra power can be transmitted without expansion to meet extra demand of electricity. In the same way the distributed generators installed in distribution network have given the guarantee to meet ever increasing demand of electricity in the same way as conventioal generating stations are fulfilling the demand.

Since electric current corresponding to the electric power generated by the distributed generators do not flow in the transmission network, hence DG's also indirectly relieve transmission network from overloading and no extension in the transmission network is required. As mentioned in the previous para, the FACTS devices manage to transmit more power in the transmission network without increasing the capacity of the network. Hence both the FACTS devices as well as distributed generation indirectly help the transmission network as well as conventional generating stations from overloading.

The distributed generators are being operated by both energy sources i.e conventional sources of energy such as diesel, Petrol, gas, etc. and non conventional sources of energy such as wind, solar, tidal waves, geothermal energy etc. The conventional sources of energy will finish one day and will become history. Whereas, non- conventional sources of energy are unending. Hence for future the only guarantee for generation of electricity is non-conventional sources of energy. Therefore in this paper focus will be only on the distributed generation by non-conventional sources of energy.

The problem with conventional sources of energy is not only their limited quantity but also these sources pollute the environment. About 85% of electricity required is being generated using conventional sources. Hence there is a great threat to the environment and global warming due to emission of greenhouse gases. And environment pollution, greenhouse gases, global warming are burning issues before the whole world which have to the tackled right now without any delay. Therefore the whole world is concentrating only on the green energy due to environmental and social issues. From this point of view also non-conventional energy source operated distribution generators have lot of benefits. Not only this, the non-conventional energy is unlimited in quantity, unending, available free of cost. Since distributed generators are directly inserted in the distribution network and it has no connection with the transmission network, therefore transmission loss corresponding to this generation is zero. The distribution system loss also reduces up to a great extent because distributed generators are installed near to end consumers. Various non-conventional energy sources and their properties are detailed ahead. The benifits of distributed generation when inserted into the distribution network and also problems associated with distributed generation are also described in section ahead. Keeping in mind the benefits and problems associated with distributed generators, few heuristic rules based on certain assumptions are proposed for placement of distributed generators of suitable capacity at suitable locations in the distribution network.

STUDY OF RENEWABLE SOURCES:

The distributed generation of electricity using non-conventional energy sources is the only ray of hope to fulfill electricity demand in future. As already mentioned in previous sections that non- conventional energy is unlimited and unending. The sun will continue to provide its energy to the earth in the same way as till today upto coming five billion years. Hence solar energy is endless. The quantity of solar energy received by the earth during 1/816000 seconds is sufficient to generate electricity required by the whole world for complete one year [2]. In large number of countries of the world where electricity requirement is high, good solar radiations are normally available for about 300 days in a year. The average intensity of solar radiation recieved is 20 MW/Sq-Km [3]. Hence solar energy is unlimited and no one can quantify it. The electricity can be generated by solar energy in two ways. One way is when rays of sunlight hits the solar cell, solar energy is converted into electricity. The other way is by hitting a parabolic mirror by sun rays and the sun rays reflected to a common point which is a water tank and in this way water is converted into steam. This is being used by steam turbine to generate electricity. Such type of plants are called solar thermal plants. These solar thermal plants have zero emission of greenhouse gases as sun energy which is clean and green energy is used to make steam instead of coal, gas etc. The power generated by these plants is not intermittent in nature as in case of solar PV cell. Also no inverters are required in Solar thermal plants to convert DC into AC as in case of solar PV cells which create harmonics in the supply. Inspite of number of advantages, one of the drawback of solar energy is that power generated per unit area of land required is very low. To generate 5 megawatt of power about 5 acres of land is required. This draw back is not in other forms of non-conventional energies. However, rooftop solar panels found very useful and successful as they are off grid and hence create no problem for the grid and fulfill electricity requirement for the owner. In this way reduce a great burden of electric utilities. Off grid solar PV cell generated power can be utilised in many applications such as heating, cooling, transportation (recharge batteries for many type of electric vehicles), cooking, powering productive loads, solar power water pumps and many other applications which together make contribution of large quantity of the global electricity demand. In this way electricity generated by PV cells gives a large relief to the electric utilities worldwide. Apart from this hybrid solar system (electricity generated by solar panels plus grid supply) is acting as a life saving drug for the small scale industries and cottage industries which depends on grid supply only & whose disruption and poor quality stop work or degrade quality of the product. Also the cost of electricity paid to the electric utilities by the small entrepreneurs falls sharply by this hybrid system. Because when PV generated power is available, no electric metre is in the circuit. The grid supply is required only when PV generated power is not available. Also the cost of the PV generated power is much less than grid power. The efficiency of solar (photovoltaic) cells is going on increasing day by day. The

first solar cell was created in the year 1883 in New York whose efficiency was just 1-2%. Whereas, the efficiency of solar cells available now days has increased up to 20.3 % [4]. Simultaneously, the cost of solar cell is going on decreasing. The governaments all over the world are taking number of steps like tax-exemption, subsidies for solar energy projects for further promotion of this energy usage. Due to these two facts, the cost of electricity generated by solar cells has reduced to Rs 2.44/unit. This is a record down fall in cost of electricity generation [1]. This is the cheapest electricity produced as compared to other sources of energy. The decline in cost of electricity produced by solar cells is as given in Fig. 1.

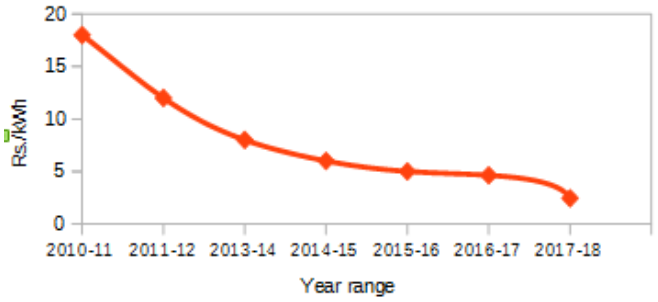

Fig. 1

Globally auction price of electricity produced by solar cells has fallen to three cents (Rs 1.97) per Kwh [4].
Nowdays, the cost of electricity generated by varous sources of energy is as given in the table below.

S. No.	Fuel/Source	Rs/KWh
1	Coal Fired	3-5.50
2	Gas	5.50-7.50
3	Hydro	2.50-5.50
4	Combined Cycle	3.00-5.23

Table-1

The efficiency of solar cells can further be increased by tracking. The sun rises in the East in morning and set in the West in evening. During the whole day the sun's position changes continously. If the solar panel is also set to rotate accordingly called tracking to have sunlight perpendicular to it, the electricity generation by the solar cells can further be increased. Since energy density is maximum when sun rays are perpendicular to the solar panel. The electricity generated by the solar cells is increased as per formula given below.
η_{gain} (%) = $[(\eta_t - \eta_f)/ \eta_t]$ (83)(82)(82)
Average fixed system efficiency (η_f) for a sunny day at many locations in the world is found to be 4.27 and after proper tracking this efficiency (η_t) increased to 7.67. Hence,

η_{gain} (%) = [(7.67 – 4.27)/ 7.67] * 100=44.25%

Hence an energy gain of 44.25% relative to fixed system was obtained. The result justify tracking strategy.
Due to above advancements in the technologies related to solar energy conversion into electricity, projects related to solar energy conversion into electricity of thousands of megawatt capacity are being installed in the whole world at large scale. The implementation of solar Park schemes launched by India in December 2014 is an example. The Solar parks with a capacity of 40000 megawatt will be installed in 21 States. This will lead to abatement of around 55 million tonnes of carbon dioxide per year over its life cycle [4]. Not only this a large number of direct and indirect employment opportunities will be generated by this scheme in solar and allied industries such as glass, metals, heavy industrial equipments etc. and also of course guarantee for a long term energy security for the country [4]. If the electricity generated is not fed into the grid and used independently (OFF-GRID), then there is no threat or problem to the security and stability of the conventional grid. Particularly electricity generated by solar PV cells is being used OFF-GRID in many applications and can be used for a large number of applications. This relieves a very high burden of electric utilities and can bridge a large gap between demand and supply of electricity. The services/loads which can be successfully energized by OFF-GRID solar energy operated DG power are solar street lights, solar study lamps, solar water pumps, solar powered drip irrigation, hybrid solar system for cottage and small scale industries, lightning homes in remote areas where network of conventional grid is still awaited, powering panchayat houses, charging various types of vehicle batteries, fulfilling electricity requirement partly of homes, commercial centres and many other services in developed areas also. This way a very high relief to the electric utilities can be given.

The WIND ENERGY is another unlimited and unending non-conventional source of energy being used to generate electricity. This is also clean and green energy as solar energy. Wind of 2-3 metre per second speed is required to rotate aerogenerator which in turn generate electricity. The cost of electricity generated by wind is also going on decreasing day by day as in case of solar energy. Nowadays, the electricity generated by the wind energy is about 80% cheaper than it was 15 years ago [5].

The main problem with this source of energy is that wind energy available is dilute and fluctuating in nature. Aerogenerators are noisy in nature due to its huge propeller in size. But this energy is available 24 hrs a day. Due to high inertia of huge size of propeller, the fluctuation problem is solved upto large extent. But this problem is more serious in case of solar PV cells. As that is purely a static device & hence inertia of the system is zero. So from this point of view wind energy is more reliable than solar energy. Also no inverters are required in aerogenerators, hence no addition of harmonic contents in the electric supply. The aerogenerators provide A.C power.

The GEO-THERMAL ENERGY is also a form of non-conventional energy and it is also a clean & green energy. It is one of the few sources of non-conventional energies that has the potential to supply continous base load power. Around 6.5 % of electricity required by the whole world can be generated using geothermal energy [6]. Advancement in technology related to the use of geo-thermal energy would make its use more simple and increase its contribution in electricity generation required globally. Also this energy has no problem related to uncertainty and fluctuations as in case of wind and solar energies. The electricity generated by the use of this energy has no threat on the power system security and reliability. No increase in harmonic contents, no fluctuations in the system frequency, no intermittent supply, no effect of day and night as in case of solar energy etc. Inspite of its number of advantages over other form of non-conventional energies, this energy is available in particular regions only not everwhere as wind and solar energies. Plants operated by this energy has high initial cost and have few more drawbacks.
In future the geo-thermal energy is expected to play a leading role in electricity generation. The electricity generated by this energy is also becoming cheaper day by day and will become less as compared to electricity generated by conventional sources shortly. In particular regions, this energy will have monopoly and will compete all other conventional & non-conventional form of energies in all aspects.

Among various sources of renewable energies which are being used globally to generate electricity and other applications. BIOGAS is an important source of energy. This source fulfill energy requirement in many ways. Biogas is being used to generate electricity as well as successfully being used in domestic, commercial and industrial applications. By cleaning and upgradation process, calorific value of biogas is increased and unwanted gases and moisture can be removed which are harmful for the system. All over the world, paddy is cultivated in billions of hectares of land. Billions of tons of paddy straw is produced. Part of this paddy straw is used for Biomass power plants, brick kilns, cardboard making and some portion is used to fuel domestic biomass cook stoves in rural areas, that too in developing and underdeveloped countries. Large part is burnt in open fields and this is a very serious problem as it releases huge quantity of toxic gases making problems for atmosphere. This paddy straw if used for power plants viz biomethanation instead of burning in open fields, then a huge quantity of electricity can be generated and toxification of atmosphere can be prevented. The biomethane and bioethanol potential of paddy straw is as shown in the following table.

S. No	Energy route	Yield/tonne paddy straw(Kg/t)	Total energy yield (GJ/t)	Electricity equivalent #(Kwh/t)	Petrol equivalent (L/t)
1.	Biomethane	144.32	8.000	777.00	166.60
2.	Bioethanol	188.57	5.600	544.25	116.60

Table-2

The production of methane from paddy straw is proved to be the most efficient route of energy conversion as it results into electricity generation of 777.0 kWh/tonne of paddy straw as shown in the above table [6].
TIDAL energy is also a form of renewable energy. It is also environmental friendly and freely available. Currently tidal energy can be encashed by three different ways namely: Tidal streams, barrages and tidal lagoons. The tidal energy gives mechanical power to the turbine as input power and the output is electricity. The turbine takes energy from a flow of fluid. This fluid can be an air or water. Since water is 100 times dense than air, hence tidal energy is more powerful than wind energy. The electricity produced by tidal energy is not fluctuating and intermittent in nature as solar and wind energies. Due to higher density of water, electricity can be generated efficiently even at slow speeds. The life of plants and equipments of tidal energy is much more than thermal and nuclear power plants as well as other non-conventional energy operated plants. This is a predictable and consistent power. Running cost of plants and machinery is also small. However, initial capital investment required to encash tidal energy is very large. Also useful period is only about 10 hours a day out of 24 hours. About 40% of the year. Also the time required to construct the plant and get the plant in running condition is very large.

A typical form of energy which is being used by the human beings from very beginning is ANIMAL energy. In many activities and requirements of life there is no substitute of animals, such as dairy products, leather industry etc. From the very beginning, animals have been in use for transportation, as food products, ploughing, oil extraction from seeds, taking out water from deep wells etc since the life starts on the earth. Due to advancement in technology and automization, animals are no more required in transportation, oil extraction etc. Also due to our religious sentiments in India, Oxen can not be sent to slaughter houses. Therefore Oxen are of no use. But Oxen can be used to provide mechanical power to electricity generators to generate electricity. Hence in this way Oxen and so many other animals can be used to generate electricity. This is a very low cost project. There are number of benefits of such projects, such as electricity shortage problem can be solved upto a large extent. These projects will generate employment in rural areas, farmers which are owner of such animals will be supported, there will be development of rural areas. The animal energy is also renewable, endless, abundant in quantity.

HYBRID SYSTEM: As already stated in the previous sections, the sun energy and wind energy are unlimited and available free of cost at almost more than 90% of the earth's surface. But both these renewable energies are uncertain and fluctuating in nature. This problem can be solved upto a large extent if two or more energy sources are used to generate electricity simultaneously making a micro or mini grid. In this way we can have a reliable electricity grid which can supply electricity to consumers almost continuously. Such a system is called a hybrid system and it is more reliable compared to a single source system. To make this hybrid system more reliable and to make the hybrid system to provide continuous supply of electricity without any doubt, conventional energy source operated generator, such as diesel generator can be added in the hybrid system at the places where continuity of supply is unavoidable. Such type of micro and mini grids are proving to be the best award of nature for the people who have not yet access to electricity through conventional grids. And also to the people who are living in remote areas where electric companies could not develope infrastructure due to geographical conditions till today. Such type of grids not only fulfill the electricity requirement but also boosts local economy of the remote areas which are not connectecd with developed areas via road, rail, airpath etc. Such grids also generate employement opportunities in unserved rural parts of many countries of the world. Particularly in under developed and developing countries. The micro and mini grids work independently i.e not connected to conventional grids and remain stand alone. At the places where it is possible to connect with the conventional grids these micro and mini grids can exchange electric power as per requirement. As stated in the previous sections, due to continuous fall in cost of electricity generation by renewable energy sources, the micro and mini grids are becoming financially viable, very useful and attractive for a variety of power applications. Shortly such micro and mini grids will become the first choice of variety of consumers even at those places where conventional grid power is available since long time. One of the biggest advantage of micro and mini grids is that whenever, there is any disturbance in the conventional grid and conventional grid fails to continue electric supply, micro and mini grids continue to provide electricity as usual. The micro and mini grids are defined based on their capacity to deliver electric power and voltage level. The renewable energy operated grids having generators upto 10 KW comes under micro grid category. Grids having generators with a capacity of above 10 KW are called mini grids.

From the facts related to renewable sources of energy given above, it is clear that renewable energy is unlimited, unending, clean and environmentally friendly. Therefore the target of the whole world is that how efficiently and economically this energy is converted into electricity to fulfill the requirements without having negative impact on the present power sytem structure. The table given below shows the target of generating electricity from renewable energy sources by India upto the year 2022.

Renewable energy conversion into electricity target to be achieved by 2022 in MW.

States/UTs	Solar power	Wind	SHP	Biomass
Northern Regiion	31120	8600	2450	4149
Western Region	28410	22600	125	2875
Southern Region	26531	28200	1675	2612
Eastern Region	12237		135	244
North Eastern Regiion	1205		615	
All India	99533	60000	5000	10000

Table-3

Note:- SHP stands for Small Hydro Power.

The total target is 1,75,000 MW. This is a big target and it shows the potential as well as reliability of renewable energy sources.

In the same way the whole world is keen to exploit renewable energy due to its advantages and gaurantee to meet the requirement of electricity in future.

PROPOSED RULES FOR DG PLACEMENT AND SIZING:

Number of researchers have proposed number of methodologies and techniques for proper placement of distributed generators in the distribution network based on different approaches. The different proposed algorithms are genetic algorithm, simulated annealing, ant colony search, tabu search, switch exchange algorithm etc. [8,9,10,11,12]. Few researchers have applied some mathematical techniques also [13,14,15]. Some of the above proposed techniques are difficult to apply in the system and some are not even practically possible to apply.

Keeping in mind above problems, few heuristic rules are proposed in this paper which are very simple and practically possible to apply. As already mentioned that a DG is small and geographically spread generation of electricity that is placed at or near to the load site. It may be connected to the distribution network, independently connected to the consumer or both.

Due to placement of distributed generators at or near the load centre, significant reduction in power loss is achieved and also voltage profile improves. In a distribution network, there is a prticular location at which if a DG of a particular capacity is placed, then minimum power loss occurs. If the same DG is placed at some other location then power loss increases. The particular location at which DG placement of a particular capacity gives minimum power loss is called optimal location. Therefore the main problem is to decide the capacity as well as to identify optimal location for DG placement as it has significant effect on power loss reduction & voltage level improvement.

It is also important to mention here that the DG's can be considered as inverters which are being used at large scale. But there is a basic difference between the two. The difference is that an inverter acts as passive device when grid supply is available and is charged by the grid supply. Inverter acts as an active element when grid power is OFF. The DG always acts as an active device whether grid power is ON or OFF.

Also the process of DG placement in the distribution network is similar to capacitor placement as far as power loss reduction is concerned. However, capacitor is placed to compensate reactive power only. Whereas, DG units impact on real and reactive power both.

The distribution network of conventional grid are passive and are designed to operate with unidirectional power flow. Whereas, when a DG is placed in the distribution network the distribution network behaves as active and passive network both and power may flow in both directions. If a DG of suitable capacity is placed at optimum location then power flow in both directions can be avoided. Also line losses will reduce, voltage profile will increase with a greater reliability.

Keeping in mind the facts stated above the following rules are proposed to identify optimal location and suitable capacity of a DG unit to be placed in distribution network. The proposed rules are practically applicable.

(1) The capacity of DG unit to be placed should not be more than 50% of the connected load at that location considering driversity factor.
(2) The large consumers in the distribution network should be identified to place DG units first. These large consumers will consume complete power generated by the DG at their premises and there will be no negative impact of DG placement at that location. In this way electric utility will get high support from DG placement as gap between demand and supply will reduce with improved environmental conditions.
(3) Identify the sections of radial feeders having voltage less than the system voltage. A minimum of a node from all these sections should be selected to place a DG unit of suitable capacity as per connected load at that node.
(4) The buses at tail end of the distribution lines normally found to have voltage level less than the required. Such problems occur in the distribution networks having high loads and long feeders. Such locations should be identified to place DG units of suitable capacity as per load demand at that location.

CONCLUSION:

Among renewable energy sources the sun and wind energies are intermittent & fluctuating in nature, even than found to be very usefull for electricity generation. Geo-thermal energy, Bio-gas & Tidal energies are among the few sources of non-conventional energies that have the potential to supply continous base load power and are not fluctuating in nature as solar & wind energies. But the draw back of these energy sources is that they are not available at all locations as wind & sun energies are available. The efficiency of renewable sources for electricity generation are going on increasing & cost of electricity generation by these sources is going on decreasing day by day. The proposed rules for siting & sizing of DG's in a distribution network are simple and practically applicable.

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Biography

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