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Advancement & Role of DG Technology in Distribution System

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***Abstract*— As the yearly electric energy demand grows, there is a significant increase in the penetration of distributed generation (DG) to fulfil this increase in demand. Interconnecting DG to an existing distribution system provides various benefits to several entities. DG provides an enhanced power quality, higher reliability of the distribution system and can peak shaves and fill valleys. However, the integration of DG into existing networks has associated several technical, economical and regulatory questions. Distribution system design and planning are key features for determining the best expansion strategies to provide reliable and economic services to the customer. Transfer of electric energy from the source of generation to the customer via the transmission and distribution networks is accompanied by losses. The majority of these losses occur on the distribution system. Placement of distributed generators on the distribution system can lead to a reduction in power losses. Reduction of I^2R losses in distribution system is very essential to improve the overall efficiency of power delivery.**

***Keywords*— Distribution System, DG, Losses, Energy, Voltage profile**

I. INTRODUCTION

The liberation of the energy market and the new conditions in the energy field are leading towards the finding of more efficient ways of energy production and management. The introduction of new ideas capable of evolving in the new conditions might lead to more suitable solutions compared to any possible malfunctions the new market model can create. Energy demand is expected to grow at an annual rate of 1.4 percent between now and 2020 [1] and central plants could arguably no longer deliver competitively cheap and reliable electricity to more remote customers through the grid, because the plants had come to cost less than the grid and had become so reliable that nearly all power failures originated in the grid. Thus, the grid had become the main driver of remote customers' power costs and power quality problems, which became more acute as digital equipment required extremely reliable electricity [2-3]. Efficiency gains no longer come from increasing generating capacity, but from smaller units located closer to sites of demand [4-5]. For example, coal power plants are built away from cities to prevent their heavy air pollution from affecting the populace. In addition, such plants are often built near collieries to minimize the cost of transporting coal. Hydroelectric plants are by their nature limited to operating at sites with sufficient water flow.

Distributed Generation (DG) or the alternate energy systems is expected to play an increasing role in the future of the power systems. The term Distributed Energy Resources (DER) is used to refer to DG along with storage technologies such as batteries.

The DG is defined as small-scale generation (10MW or less) and can be interconnected at different load levels (substation, distribution feeder or customer).The centralized generation remains the main source of electricity while the DER provides reliability, resilience and transmission & distribution grades to the grid. Large power plants are capital-intensive and require transmission and distribution grids to supply the power.

The technologies for DG are based on reciprocating engines, photovoltaic, fuel cells, combustion gas turbines, micro turbines and wind turbines. The technologies are also called alternate energy systems as they provide an alternative to the traditional electricity sources i.e. oil, gas, coal, water etc. and can also be used to enhance the current electrical system. DGs are becoming increasingly popular due to their low emission, low noise levels and high efficiency. One of the main advantages of DG is their close proximity to the customer loads they are serving. DG can play an important role in improving the reliability of the current grid, reducing the losses, providing voltage support and improving power quality.

The 'growing pains' of this transformation – price instability, an ageing infrastructure, changing regulatory environments – are causing both energy users and electric utilities to take another look at the benefits of distributed generation (DG)[6].

II. LITERATURE SURVEY

Distributed generation (DG) provides a more efficient alternative to the traditional energy system. In the previous sections, distributed generation was loosely defined as small-scale electricity generation. But what exactly is small-scale electricity generation? Is it possible to give a more concrete definition? A short survey of the literature shows that there is no consensus. The literature acknowledges the flaws of the traditional power system and explores new methods for electricity generation and distribution.

Many papers have investigated the importance of the distributed generation (DG) and its applications in enhancing the electrical system. The authors of [7] discuss different applications of DG and its cost analysis. The paper presents different DG technologies and the potential benefits of DG that include reliability, deferral of power delivery investments, and environmental benefits. Also, in [8], the potential of distributed generation to provide ancillary services is discussed. The paper demonstrates the potential of different types of DG along with proper power electronic interface to provide ancillary services to the main grid .

Chambers [9] also defines distributed generation as relatively small generation units of 30 MW or less, such units being located at or near customer sites to meet specific customer needs, to support economic operation of the distribution grid, or both. Dondi et al. [10] define distributed generation as a small source of electric power generation or storage (typically ranging from less than a kW to tens of MW) which is not a part of a large central power system and which is located close to the load. These authors also include storage facilities in the definition of distributed generation, which is not conventional. Ackermann et al. [11] define distributed generation in terms of connection and location rather than in terms of generation capacity. They define a distributed generation source as an electric power generation source connected directly to the distribution network or on the customer side of the meter.

The penetration of DG may impact the operation of a distribution network in both beneficial and detrimental ways. Some of the positive impacts of DG are: voltage support, power loss reduction, support of ancillary services and improved reliability, whereas negative ones are protection coordination, dynamic stability and islanding. In order to maximize benefits and minimize problems, technical constraints concerning the interconnection of DG units and their penetration levels are being adopted worldwide. Furthermore, the presence of DG in the deregulated market has raised new regulatory issues, concerning financial incentives, cost allocation methods, generation management techniques, etc.

There are a number of approaches proposed for placement and sizing of DG units. Chiradeja and Ramkumar [12] presented a general approach and set of indices to assess and quantify the technical benefits of DG in terms of voltage profile improvement, line loss reduction and environmental impact reduction. Khan and Choudhry [13] developed an algorithm based on analytical approach to improve the voltage profile and to reduce the power loss under randomly distributed load conditions with low power factor for single DG as well as multi DG systems. Hung et al. [14] used an improved analytical method for identification of the best location and optimal power factor for placing multiple DGs to achieve loss reduction in large-scale primary distribution networks. For optimal placement of DG, Mithulanathan et al. [15] presented a genetic algorithm based approach to minimize the real power loss in the system and found a significant reduction in the system loss. The optimal sizing and siting of DGs was investigated by Ghosh et al. [16] to minimize both cost and loss with proper weighing factors using Newton-Raphson (NR) load flow method. Ziari et al. [17] proposed a discrete particle swarm optimization and genetic algorithm (GA) based approach for optimal planning of DG in distribution network to minimize loss and improve reliability. Kamel and Karmanshahi [18] proposed an algorithm for optimal sizing and siting of DGs at any bus in the distribution system to minimize losses and found that the total losses in the distribution network would reduce by nearly 85%, if DGs were located at the optimal locations with optimal sizes. Singh et al. [19] discussed a multi-objective performance index based technique using GA for optimal location and sizing of DG resources in distribution systems.

Celli et al. [20] proposed an algorithm to determine location and size of distributed generators by minimizing different functions related to cost of energy losses, cost of service interruptions, cost of network upgrading and cost of energy purchased. Devi and Subramanyam [21] used fuzzy logic for DG placement and calculations at given power factor. Dasan and Devi [22] used fuzzy adaptation of evolutionary programming to find size of DGs. Wallance and Harrison [23] presented the optimal power flow based technique to determine the maximum capacity of generation that can be accommodated in a network. Dent [24] used optimal power flow based method incorporating voltage step constraints for determining the capacity of network to accommodate DG. A hybrid method employing genetic algorithms and optimal power flow is presented by Harrison et al. [25] to find sites in a distribution network for connecting a pre defined number of DGs. A multi-objective performance index-based determination of size and location of DG in distribution systems with different load models was presented by Singh et al. [26] and implemented using GA. A methodology based on GA was presented by Singh and Goswami [27] to accommodate DG in distribution network by maximization of profit, reduction of losses and improvement in voltage regulation. Implementation of Distributed Generation was proposed by Khan and Choudhry [28] to find optimal size and location of DG in presence of non-uniformly distributed loads. The size and power factor for DG were found by using analytical expressions in [29-30] to minimize losses. In [31], a mixed integer linear program was proposed to determine of optimum location. A determination of the allowable DG penetration level is carried out based on harmonic limit consideration in [32], which is restricted to radial distribution feeders with uniform, linearly increasing or decreasing load pattern. The placement of one DG unit with specific size in [33] was explained. In this paper multi objective function such as power line losses, modify of voltage profile, line loading capacity and short circuit level were considered. P-V curves in [34] have been used for analysing voltage stability in electric power system to determine the optimum size and location of multiple DG units to minimize the system losses under limits of the voltage at each node of the system.

Distributed generation is any small-scale electrical power generation technology that provides electric power at or near the load site; it is either interconnected to the distribution system, directly to the customer's facilities, or both.

DG can provide a multitude of services to both utilities and consumers, including standby generation, peak shaving capability, peak sharing, base load generation, or combined heat and power that provide for the thermal and electrical loads of a given site. Less well understood benefits include ancillary services — VAR support, voltage support, network stability, spinning reserve, and others — which may ultimately be of more economic benefit than simple energy for the intended load.

Here some of the DG technologies, which are available at the present: photovoltaic systems, wind turbines, fuel cells, micro turbines, synchronous and induction generators are introduced.

A. *Photovoltaic Systems*

A photovoltaic system, converts the light received from the sun into electric energy. In this system, semi conductive materials are used in the construction of solar cells, which transform the self contained energy of photons into electricity, when they are exposed to sun light. The cells are placed in an array that is either fixed or moving to keep tracking the sun in order to generate the maximum power [35].

They produce no emissions, and require minimal maintenance. However, they can be quite costly. Less expensive components and advancements in the manufacturing process are required to eliminate the economic barriers now impeding wide-spread use of PV systems. Photovoltaics are currently being used primarily in remote locations without grid connections and also to generate green power.

Commonly known as solar panels, photovoltaic (PV) panels are widely available for both commercial and domestic use. Panels range from less than 5 kW and units can be combined to form a system of any size. These systems are environmental friendly without any kind of emission, easy to use, with simple designs and it does not require any other fuel than solar light. On the other hand, they need large spaces and the initial cost is high.

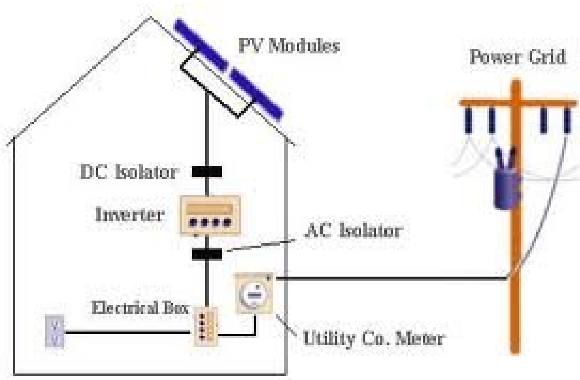

Fig. 1 Photovoltaic System

B. *Wind Turbines*

Wind turbines transform wind energy into electricity. Wind turbines are currently available from many manufacturers and range in size from less than 5 to over 1,000 kW. The wind is a highly variable source, which cannot be stored, thus, it must be handled according to this characteristic. A general scheme of a wind turbine is shown in Fig. 2, where its main components are presented [35]. They provide a relatively inexpensive (compared to other renewable) way to produce electricity, but as they rely upon the variable and somewhat unpredictable wind, are unsuitable for continuous power needs.

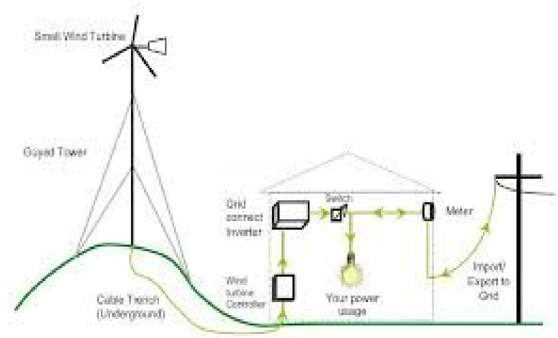

Fig. 2 Schematic Operation Diagram of a Wind Turbine

The principle of operation of a wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity.

Development efforts look to pair wind turbines with battery storage systems that can provide power in those times when the turbine is not turning. Wind turbines are being used primarily in remote locations not connected to the grid and by energy companies to provide green power.

C. *Fuel Cells*

Fuel cells are not only very efficient but also have very low emission levels. A fuel cell operates like a battery. Fuel cells operation is similar to a battery that is continuously charged with a fuel gas with high hydrogen content; this is the charge of the fuel cell together with air, which supplies the required oxygen for the chemical reaction [35].

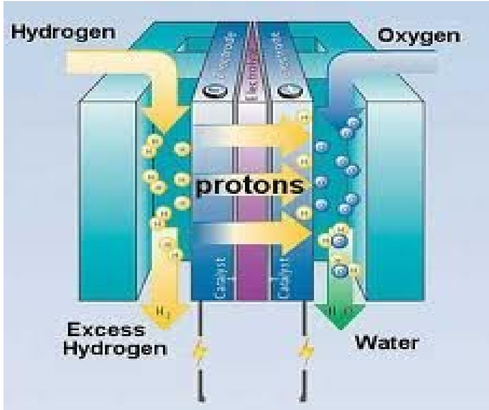

Fig. 3 Schematic Diagram of a Fuel Cell

It supplies electricity by combining hydrogen and oxygen electrochemically without combustion. However, while the battery is a storage device for energy that is eventually used up and must be recharged, the fuel cell is permanently fed with fuel and an oxidant, so that the electrical power generation continues. The final product is pure water; the electrochemical reaction generates electricity and heat without a flame ("cold combustion"). The fuel cell utilizes the reaction of hydrogen and oxygen with the aid of an ion conducting electrolyte to produce an induced DC voltage. The DC voltage is converted into AC voltage using inverters and then is delivered to the grid. A single cell provides currently being used provide premium power.

D. Micro turbines

A new and emerging technology, micro turbines are currently only available from a few manufacturers.

A micro-turbine is a mechanism that uses the flow of a gas, to covert thermal energy into mechanical energy. The combustible (usually gas) is mixed in the combustor chamber with air, which is pumped by the compressor. This product makes the turbine to rotate, which at the same time, impulses the generator and the compressor. In the most commonly used design the compressor and turbine are mounted above the same shaft as the electric generator. This is shown in Fig. 4.

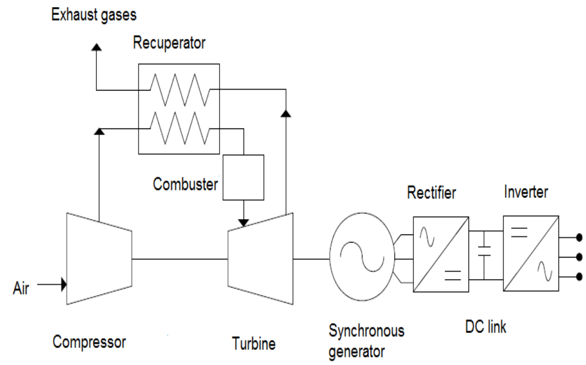

Fig .4 Schematic Diagram of a Micro-Turbine

The output voltage from micro-turbines cannot be connected directly to the power grid or utility, it has to be transferred to DC and then converted back to AC in order to have the nominal voltage and frequency of the utility. Other manufacturers are looking to enter this emerging market, with models ranging from 30 to 200 kW. Micro turbines promise low emission levels, but the units are currently relatively expensive. Obtaining reasonable costs and demonstrating reliability will be major hurdles for manufacturers. Microturbines are just entering the marketplace, and most installations are for the purpose of testing the technology. The main advantage of micro-turbines is the clean operation with low emissions produced and good efficiency.

E. Induction and Synchronous Generators

Induction and synchronous generators are electrical machines which convert mechanic energy into electric energy then dispatched to the network or loads.

Induction generators produce electrical power when their shaft is rotated faster than the synchronous frequency driven by a certain prime mover (turbine, engine). The flux direction in the rotor is changed as well as the direction of the active currents, allowing the machine to provide power to the load or network to which it is connected. The power factor of the induction generator is load dependent and with an electronic controller its speed can be allowed to vary with the speed of the wind. The cost and performance of such a system is generally more attractive than the alternative systems using a synchronous generator [36].

Fig.5. Synchronous Generator

The induction generator needs reactive power to build up the magnetic field, taking it from the mains. Therefore, the operation of the asynchronous machine is normally not possible without the corresponding three-phase mains. In that case, reactive sources such as capacitor banks would be required, making the reactive power for the generator and the load accessible at the respective locations. Hence, induction generators cannot be easily used as a backup generation unit, for instance during islanded operation [36]. The synchronous generator operates at a specific synchronous speed and hence is a constant-speed generator. In contrast with the induction generator, whose operation involves a lagging power factor, the synchronous generator has variable power factor characteristic and therefore is suitable for power factor correction applications. A generator connected to a very large (infinite bus) electrical system will have little or no effect on its frequency and voltage, as well as, its rotor speed and terminal voltage will be governed by the grid.

IV.DG Applications

Distributed generation (DG) is currently being used by some customers to provide some or all of their electricity needs. There are many different potential applications for DG technologies. For example, some customers use DG to reduce demand charges imposed by their electric utility, while others use it to provide primary power or reduce environmental emissions. DG can also be used by electric utilities to enhance their distribution systems. Many other applications for DG solutions exist. The following is a list of those of potential interest to electric utilities and their customers.

A. Continuous Power

In this application, the DG technology is operated at least 6,000 hours a year to allow a facility to generate some or all of its power on a relatively continuous basis Currently, DG is being utilized most often in a continuous power capacity for industrial applications such as food manufacturing, plastics, rubber, metals and chemical production. Commercial sector usage, while a fraction of total industrial usage, includes sectors such as grocery stores and hospitals.

B. Combined Heat and Power (CHP)

Also referred to as Cooling, Heating, and Power or cogeneration, this DG technology is operated at least 6,000 hours per year to allow a facility to generate some or all of its power. A portion of the DG waste heat is used for water heating, space heating, steam generation or other thermal needs. In some instances this thermal energy can also be used to operate special cooling equipment.

CHP characteristics are similar to those of Continuous Power, and thus the two applications have almost identical customer profiles, though the high thermal demand here is not necessary for Continuous Power applications. As with Continuous Power, CHP is most commonly used by industry clients, with a small portion of overall installations in the commercial sector.

C. Peaking Power

In a peaking power application, DG is operated between 200-3000 hours per year to reduce overall electricity costs. Units can be operated to reduce the utility's demand charges, to defer buying electricity during high-price periods, or to allow for lower rates from power providers by smoothing site demand Peaking power applications can be offered by energy companies to clients who want to reduce the cost of buying electricity during high-price periods. Currently DG peaking units are being used mostly in the commercial sector, as load profiles in the industrial sector are relatively flat. The most common applications are in educational facilities, lodging, miscellaneous retail sites and some industrial facilities with peaky load profiles.

D. Green Power

DG units can be operated by a facility to reduce environmental emissions from generating its power supply. Green power could also be used by energy companies to supply customers who want to purchase power generated with low emissions.

E. Premium Power

DG is used to provide electricity service at a higher level of reliability and/or power quality than typically available from the grid. The growing premium power market presents utilities with an opportunity to provide a value-added service to their clients. Customers typically demand uninterrupted power for a variety of applications, and for this reason, premium power is broken down into three further categories:

F. Emergency Power System

This is an independent system that automatically provides electricity within a specified time frame to replace the normal source if it fails. The system is used to power critical devices whose failure would result in property damage and/or threatened health and safety. Customers include apartment, office and commercial buildings, hotels, schools, and a wide range of public gathering places.

G. Standby Power System

This independent system provides electricity to replace the normal source if it fails and thus allows the customer's entire facility to continue to operate satisfactorily. Such a system is critical for clients like airports, fire and police stations, military bases, prisons, water supply and sewage treatment plants, natural gas transmission and distribution systems and dairy farms.

H. True Premium Power System

Clients who demand uninterrupted power, free of all power quality problems such as frequency variations, voltage transients, dips, and surges, use this system. Power of this quality is not available directly from the grid – it requires both auxiliary power conditioning equipment and either emergency or standby power. Alternatively, a DG technology can be used as the primary power source and the grid can be used as a backup. This technology is used by mission critical systems like airlines, banks, insurance companies, communications stations, hospitals and nursing homes.

I . Transmission and Distribution Deferral

In some cases, placing DG units in strategic locations can help delay the purchase of new transmission or distribution systems and equipment such as distribution lines and substations. A detailed analysis of the life-cycle costs of the various alternatives is critical and issues relating to equipment deferrals must also be examined closely.

J. Ancillary Service Power

DG is used by an electric utility to provide ancillary services (interconnected operations necessary to affect the transfer of electricity between the purchaser and the seller) at the transmission or distribution level. In markets where the electric industry has been deregulated and ancillary services unbundled (in the United Kingdom, for example), DG applications offer advantages over currently employed technologies. Ancillary services include spinning reserves (unloaded generation, which is synchronized and ready to serve additional demand) and non-spinning, or supplemental, reserves (operating reserve is not connected to the system but is capable of serving demand within a specific time or interruptible demand that can be removed from the system within a specified time). Other potential services range from transmission market reactive supply and voltage control, which uses generating facilities to maintain a proper transmission line voltage, to distribution level local area security, which provides back up power to end users in the case of a system fault. The characteristics that may influence the adoption of DG technologies for ancillary service applications will vary according to the service performed and the ultimate shape of the ancillary service market [37-39].

V. IMPACT OF DG ON SYSTEM BEHAVIOUR

This section of the will show the impact of distributed generation on the voltage profile, system losses, and system reliability.

A. Voltage Profile

The distribution systems are usually regulated through tap changing at substation transformers and by the use of voltage regulators and capacitors on the feeders. This form of voltage regulation assumes power flows circulating from the substation to the loads. DG introduces meshed power flows that may interfere with the traditionally used regulation practices.

Voltage profile is improved by increasing the size of the distributed generator, but the sizing needs to be limited through careful study of the system or through the generator regulating itself as over voltages can occur for oversized generators.

B. Losses

DG causes a significant impact in electric losses due to its proximity to the load centres. DG units should be allocated in places where they provide a higher reduction of losses. This process of DG allocation is similar to capacitor allocation to minimize losses. The main difference is that the DG units cause impact on both the active and reactive power, while the capacitor banks only have impact in the reactive power flow.

In feeders with high losses, a small amount of DG strategically allocated (10-20% of the feeder load) could cause a significant reduction of losses [40]. With the connection of DG in a system power losses are reduced. For a particular DG capacity there is a location in the system such that if we connect DG at that location power losses are minimum in comparison when same DG is connected at any other point. An increase in system losses is especially noticeable with voltage-controlled synchronous generators as this type of generator will begin to "motor" and absorb reactive power produced on the system to regulate voltage. Another study found that the location of the distributed generation is important in reducing system losses and that increasing the sizing of distributed generation generally results in fewer losses, but the gains slowly diminish [41]. An additional study confirmed the results of the sizing study and also found that increasing penetration and power output of DG can result in increased system losses [42].

C. Reliability

The goal of a power system is to supply electricity to its customers in an economical and reliable manner. It is important to plan and maintain reliable power systems because cost of interruptions and power outages can have severe economic impact on the utility and its customers. Traditionally, reliability analysis and evaluation techniques at the distribution level have been far less developed than at the generation level since distribution outages are more localized and less costly than generation or transmission level outages. However, analysis of customer outage data of utilities has shown that the largest individual contribution for unavailability of supply comes from distribution system failure.

One of the main purposes of integrating DG to distribution system is to increase the reliability of power supply. DG can be used as a back-up system or as a main supply. DG can also be operated during peak load periods in order to avoid additional charges.

VI. CONCLUSION

Current existing electricity networks, in particular distribution and transmission systems, have been designed in radial distribution system with centralised generation as the power source to supply the load .Considering the rapid growth and installation of distributed generation in the power system network it is critical to make the grid more smarter and evaluate its performance precisely thus it can be applied appropriately and degradation of power quality and reliability can be avoided.

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