Impact of Integration of Distributed Generators in Distribution Network: An Overview

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***Abstract*—Extensive depletion of fossil fuels, environmental concerns and increasing cost of transmission/distribution expansion result increasing use of Distributed Generators (DG), which is being sought after as a supplement and an alternative to conventional energy sources. Non optimal planning of DG leads increased power losses, poor voltage profile, problems of stability and protection. An optimal and strategic placement is, therefore, done using various optimisation techniques. The DG integration impacts power flow and voltage conditions of the system. These impacts can be both positive as well as negative. The paper evaluates various impacts of DG on the ecology, economics and technical aspects on the distribution network.**

***IndexTerms*—Distributed power generation, Islanding, Micro-grids, Power Losses, Power quality, Power system reliability**

I. INTRODUCTION

Extensive depletion of fossil fuels, environmental concerns and increasing cost of transmission as well as distribution expansion has propelled significant increase in the penetration of the Distributed Generator (DG). Further, the deregulation in the electric power sector, placement of DER units in distribution system has gained prominence. The International Council on Large Electricity Systems (CIGRE) defines DG as, all generation units with a maximum capacity of few kW to 100 MW, that are usually connected to the distribution network and that are neither centrally designed nor transmitted [1]. The DGs are connected near the load centres. The DG technologies are decentralized, flexible and modular technologies usually comprising of renewable energy resources. Though, static compensators and small onsite non renewable energy resources are also classified in the DGs. Moreover, technological advancement leads the DGs built in smaller sizes with higher efficiency, improved performance, low cost and minimum environmental impact. Distributed generation and storage enables collection of energy from various sources, which lowers environmental impacts and improves security of the supply [1]-[5].

Finally, the world has witnessed a significant increase in deployment of distributed and renewable sources of energies. The global market for the DG technologies is expected to reach 155 thousand megawatts by 2020. The International Energy Outlook 2016 [6] estimated remarkable growth in worldwide energy demand over the 28-year period from 2012 to 2040. Figure 1 shows that the total world utilisation of energy will increase from 549 quadrillion British thermal units (Btu) in 2012 to 815 quadrillion Btu in 2040—a 48% increase from 2012 to 2040. Figure2 shows that renewable energies are the fastest growing energy source over the projected period.

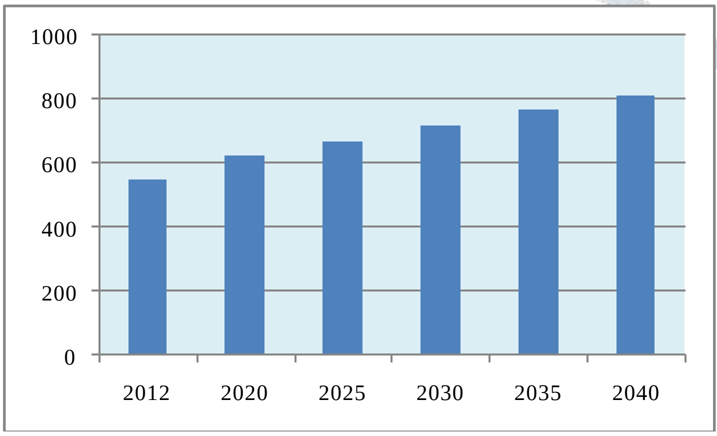

Fig. 1 Projected world energy consumption for 2012–40 (In quadrillion Btu)[6]

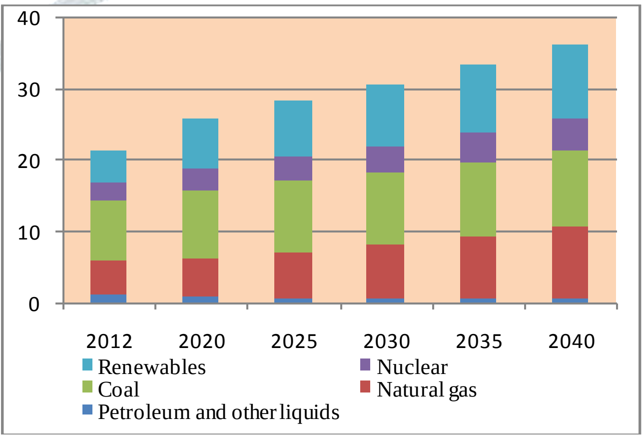

Fig. 2 Projected net electricity generation by energy source, 2012–40 (in trillion kilowatt-hours) [6]

The consumption of renewable energy is estimated to increase with an average 2.60 % per year [6]. In this growth, many important factors have contributed to this phenomenon such as: (a) remarkable being the need to reduce the reliance on fossil fuels,

(b) environmental concerns, (c) cost of transmission and distribution expansion, various advantages of the DGs, and (d) government subsidies.

Introduction of the DGs in the distribution system significantly affects the flow of power and voltage at consumer and utility equipment. These impacts depend on the operating characteristics of the distribution system and the DG characteristics. The most commonly touted benefits of the distribution system with the DGs include voltage support and better power quality, improved system reliability, reduced losses and deferments of upgraded transmission and distribution infrastructure. Though, to harness these benefits, it is very important that the DGs employed are stable, dispatchable with appropriate size and at appropriate bus. It is also required that they are properly coordinated with system operating parameters and feeder design. The larger the DGs capacity (net) with respect to feeder capacity and demand, the more critical it becomes to ensure this coordination. The impacts of the DGs can be categorized in the following three categories, namely as:

1. Ecological Impacts
2. Economic Impacts
3. Technical Impacts

II.ECOLOGICAL IMPACTS OF THE DGS

Emissions of Green House Gases (GHG) result predominantly from combustion of fossil fuels. Now, it is nucleus of climate change debate. It is a well known fact that the conventional energy sources utilize fossil fuels to produce electricity. Since, such generation units produce gases namely carbon dioxide, carbon mono-oxide, sulphur oxides, particulate matter, hydrocarbons and nitrogen oxides. This causes pollution and climate change effects such as global warming. Table I gives the major outcomes of global warming in detail.

The DGs as supplement of an alternative to conventional energy generation units will also insulate the impacts of global warming as listed in Table I. Also, the DG technology provides subsidiary service benefits to the society. The central power generation units emit large amount of GHGs and particulate matter. As mentioned before, DG installation reduces emissions and will result in reduced health care cost.

Table 1
Consequences of Global Warming [7]-[9]

Global warming results	**Description**
Rising sea levels	Global sea levels have risen about 8 inches since 1880 and the rate of increase is expected to accelerate in the coming years. This may cause the migration of people.
Ocean acidification	Increasing CO_2 levels dissolve in sea water, which results in acidifying oceans. Projections suggest a further reduction in average global surface ocean pH of between 0.14 and 0.35 units over this century. This poses a threat of disappearance of coral reefs.
Massive crop failures	Climate change effects agricultural produce due to higher temperatures, altered precipitation, increased frequency of extreme events, and modified weed and pests.
Extensive extinction of species	Researchers fear that 15-37% of 1103 vulnerable plant and animal species will be committed to extinction by 2050 due to change in habitat.
Migration and conflict	Environmental degradation, loss of access to water resources and eventual migration may cause political conflicts and wars.
Economic collapse	Decreased vitality of crops, productions, and manufacturing items will gravely impact the economy. Basic amenities like clean air and fresh water will be more costly.

III.ECONOMIC IMPACTS OF DGS

The DG implementation affects several aspects of economy of any nation. An efficient system saves electricity, thereby, accomplishing the goals of sustainable development. Electricity distribution companies have been striving to provide electricity to their customers in a reliable and cost effective manner. It is also desired that the DG implementation carried out in a way that improved voltage, reliability performance and quality of power, which meets customers' objectives. The DG implementation impacts both the consumers as well as the utilities in a numerous ways as listed below.

Diversification in Energy Resources

Several DG technologies like hydro technology,solar technology, wind turbines and geo-thermal technology do not use fossil fuels for energy generation, while gas turbines and micro turbines use natural gas. The investment in the DG technology promotes a country to enhance diversification in energy sources. This, ultimately, enhances the economy of the nation, fights fuel scarcity and disruptions, and makes it more energy self reliant.

Restrained investment in enhancement of facilities

The DGs can be used to fulfil local load increments by installing them near the load centres. This will reduce the need to build new transmission and distribution lines including up-gradation of existent framework. The DG also reduces land use by reducing right of way that would otherwise be needed to up-grade power stations and electric transmission and distribution lines. Futher, DGs are a profitable choice in rural electrification, where transmission and distribution costs are high.

Ease in installation and flexibility in operation

Some of the DGs can be assembled easily anywhere as modules. This means they can be installed anywhere in short time frame. Each module can be operated independent of other modules and immediately after installation. The total capacity can be raised or decreased by including or removing more modules. Additionally, if DGs are installed in proper location and with proper size, they relieve the overloads of feeders.

System protection costs

Due to bi-directional power flow in DG powered power systems, there is always a need to have better protection equipments. Tohave better control, techniques need to be developed that can notably curtail the system complexity encountered due to introduction of the DGs in the system. Such control strategy would essentially have to respond faster to avoid islanding operation during emergency.

Reduced fuel expenses

Many DG technologies are not dependent on fossil fuels for energy generation and their use as supplement to conventional energy generation techniques provides significant fuel savings. In addition, the DGs employing cogeneration are also capable of utilizing the waste heat produced, resulting in better efficiency for same fuel intake.

Optimising planning costs

Subject to the DG installation, the scheduled capacity can be met much prior to the actual construction period of the power plant. This mitigates the impact of market fluctuations, location market pricing and load growth in planning, thereby optimizing the planning costs and time.

Reduced operating costs

The DGs can lead to a variety of technical benefits such as reduced losses, improved efficiency, better reliability and improved voltage profile to reduce overall operating costs and energy cost.

IV. TECHNICAL IMPACTS OF THE DGS

Injection of the DG power is a challenging task. Extensive addition of DGs in electric distribution systems influences power quality both through their impact when connected on the grid and through their ability to provide reliable power during intentionally islanded from the grid. With improved technology and interconnection standards, it is likely that the DGs become an integral part of the distribution system. Researchers suggest that optimally and strategically placed DG units can reduce system losses. It also improves power quality, system reliability and stability [10]-[12]. However, the DGs are not placed at optimal locations and size; they may lead to stability problems. Problems of system frequency may result in islanding difficulties. Bidirectional power flow poses a threat to protection scheme of the system. Major technical impacts are discussed in detail below:

Power Losses

The DG technologies such as solar photo voltaic, fuel cells and micro turbine can contribute to active power requirement. Similarly, grid connected capacitors and other VAR compensators can provide reactive power. Synchronous generators can provide both active and reactive power. However, power losses can be minimised by ensuring optimal sizing and siting of the DGs. On feeders, where losses are high, even a small, strategically placed DG with output of just 10-20% of the feeder demand can result in significant loss reduction [13].

Voltage profile

Voltage profile depends on the DG technology employed, type of power converters and nature of load connected. A better voltage profile results in improved system performance. Properly placed and sized will address the issues of power quality whereas an unplanned placement might result in voltage flicker and voltage sag/swell [14].

Starting of motors or variations in DG output can raise considerable voltage fluctuations on the feeder. This flicker may be trivial as long as the frequency of fluctuations is low, beyond which certain mitigation efforts are taken. However, dynamic interactions of such machines with upstream voltage regulators cannot be dealt mildly. It is likely that these voltage fluctuations trigger hunting of upstream voltage regulator. The DG voltage flicker can be minor; hunting of regulator may create visible fluctuations. An extensive system analysis on dealing with these interactions needs to be carried out to avoid fluctuations for tuning of control equipments to reduce flicker [15].

Another problem with the DGs, which are connected through converters, is that they can introduce harmonics with restricted capacity to supply reactive power. The type of harmonics introduced and their severity is based on converter technology employed and interconnection configuration. An IGBT based pulse width modulated inverters are known to inject less harmonics. Permissible harmonic current injection for the DGs as per IEEE 519-1992 [16] is given in Table 2. The harmonics become a concern if level of distortion violates IEEE 519 standard, or if they cause resonance with condensers, or if it interferes with the functionality of harmonic-sensitive equipments. Heat produced by harmonics in the DGs may also violate the thermal limit of the system. Thus, before installing the DGs, it should be ensured that they follow IEEE 519 and harmonics that they generate are not injected into the system subject to fulfilling all other operating constraints [15].

Table 2
Permissible Harmonic Current Injection for Distributed Generation [16]

Harmonic Order	**Permissible Percentage Relative to Fundamental (Odd Harmonics)***
Less than 11th	4%
11th to 17th	2%
17th to 23th	1.5%
23rd to 35th	0.6%
35th or greater	0.3%
Total Harmonic Distortion	5%

*Even harmonics are limited to 25% of odd values

Voltage Support

Normally, DGs operate on power factor (PF) between 0.95 leading to 0.95 lagging and are not allowed to actively regulate the voltage at the point of coupling to the grid. This is done to prevent excessive voltages being generated and causing a safety hazard to persons and equipment [17-20]. However, it has been shown [15] that, with a high penetration of DGs, this practice of PF control of the DGs may actually lead to voltage regulation and instability problems. One such illustration is depicted in Fig. 3. In this case, DG unit is placed just downstream of a load tap changing (LTC)transformer uses line drop compensation to change taps. Here, the regulation controls will be unable to properly measure feeder demand resulting in lower voltage on the feeder. The voltage falls because the DG reduces the observed load at the line drop compensator control. This causes inadvertent operation of the regulator and voltage sags. Similarly, other network parameters are also negatively affected if the placement of DGs is not planned.

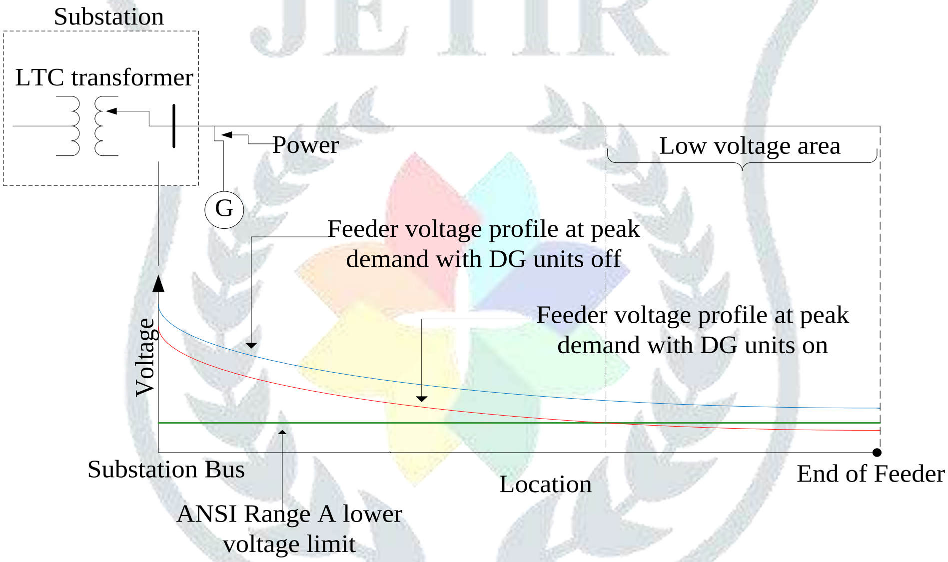

Fig. 3 An illustration detailing impact of inappropriately placed DGs on voltage support [15]

Reliability and system security

One of the key reasons to install the DG units in the distribution system is to improve reliability of the system. Use of the DG as a supplement or stand alone source is meant to ensure supply to customers at reduced costing. For example, stand-by generators have been used for a long time by customers as backing for their crucial loads in case of a long-term power outage. Such applications undoubtedly enhance the reliability of power dispensed to critical loads, an intrinsic benefit of DG. However, installation of the DG units in the distribution system may result in islanding and also adversely impact the short circuit levels of the existent system.

Figure 4 shows an illustration of fault contribution of 3 DG units connected in a typical distribution system. The lateral feeder has a fuse, as shown and fault selective relaying scheme/fuse saving is employed. A fuse saving scheme is utilized by utilities to detect temporary faults, de-energize the line and re-energize again using an auto-recloser. Faults are usually temporary in nature so this strategy avoids unnecessary permanent service interruption. In this case, if the DG units are engaged, the current in the lateral may become large enough that it may cause inadvertent operation of the fuse. This also suggests that the fuse might lose coordination with the feeder circuit breaker during the fault. Finally, the reliability and the safety of the distribution system are decreased. Here, it can also be concluded that the fault contribution of individual DG units may not large, however, cumulative input of many small units can transform the fault levels enough to cause fuse breaker miscoordination [15].

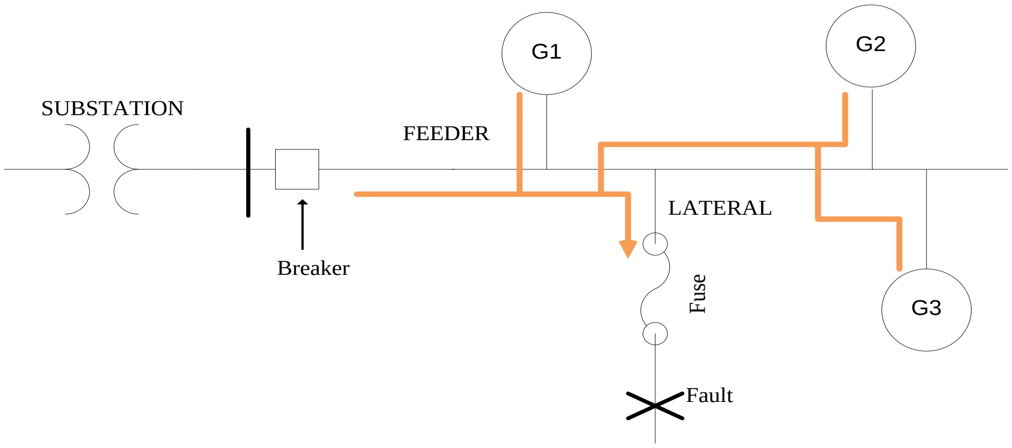

Fig. 4 An illustration of the fault contribution of 3 DG units connected in a distribution system [15]

Another major implication of addition of the DGs in distribution system is islanding. Islanding is a critical condition in which the DG or a group of the DGs continue to energize a portion of utility system even though grid power from the electric utility is no longer present. This disengagement could be due to action of anupstream breaker, fuse, automated sectionalizing switch or manual switching. Islanding occurs only if the generators can self excite and withstand the load in that portion of the utility system. In majority of cases, islanding is not desirable because it can cause severe reliability and voltage quality issues [21-22].

For example, as shown in Fig. 5, if an island occurs on a feeder during scheduled reclosing operations, the DG units will rapidly drift out of synchronism with the utility system. Thus, when a reclose occurs, the utility will connect out of phase with the island that can cause loss of utility equipment, the DG units and the customer loads. It is also probable that during islanding the DG sources supplying power do not adhere to standard permissible levels of voltage and frequency. It also causes serious safety risk during repair operations and line workers may be exposed to the supply directly. In addition, islanding may delay service recovery because some extra time would be consumed to disable island conditions [15], [21-22].

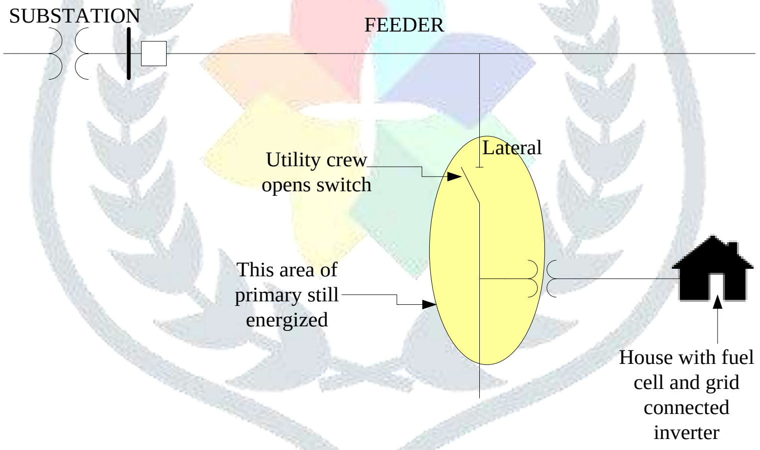

Fig. 5 An illustration depicting islanding in a distribution system [15]

Unbalancing

DGs sited remotely through long distance untransposed line frequently causes a critical unbalanced condition if the size of the DG is large compared to the feeder load. Such unbalance can cause serious stability and power quality issues. The maximum size of DG at a particular point is limited by permissible voltage drop during start-up of that induction generator-based DG [20].

V. IMPORTANCE OF OPTIMAL SIZING AND SITING OF DGs

DGs are only beneficial if their installations are accomplished strategically. Researches show that if the capacity and location of DGs are not prudently planned, the network parameters such as voltage profile, reliability index and stability will be deteriorated instead of improving. Incongruous placement of DGs can result in a rise in system losses and poor voltage profile whereas optimal sized DG units and types located appropriately provide system wide benefits.Clearly, the two of the most important factors of DG plans are determining the size and the location of these resources. The location and size of DGs can be selected according to the improvement of one or more network parameters. Technical studies largely consider the power loss, fault level, voltage profile, reliability and power quality issues as parameters to choose appropriate siting and sizing of DGs. The aggregate capacity of DGs on the system, the size of the DG unit, its intended mode of operation and expected voltage fluctuations size of generation relative load at the interconnection point, secondary configuration of the DG site including presence of adjacent customers along with protection and control constraints are some fundamental factors that govern profitable utilisation of DGs in distribution system [10],[23-24].

VI. CONCLUSIONS

Incorporation of the DGs in distribution networks impacts the flow of power and power quality conditions in the system. Though, these impacts can be positive as well as negative. This research attempts to review major impacts of the DG integration in the system. Many ecological, economic and technical benefits and hazards have been discussed. It is concluded that the positive impacts can only be harnessed subject to optimal planning of the DG units is ensured. A non-optimal planning can cause various issues, which impacts total losses, reliability, voltage regulation, voltage profile and security and stability of the system. The DG integration must be preceded by detailed analysis of the system security and protection schemes.

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