A Review on Distributed Generation Definitions and DG Impacts on Distribution System

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Abstract: Rapidly growing the power consumption and decrease in generating and transmission capacities have set the trend towards the Distributed Generation (DG) sources. Still there is not a univer sal definition of DG. This paper discusses the different definitions proposed in the literature. For DG system to become a major part of the current power scenario it needs to be connected with the existing grid system. This integration will cause some technical, operational and economic impacts on distribution systems. This paper also summarizes these different impacts of DG on distribution system.

Keywords: Distributed Generation, Impacts of DG, Islanding, Economic Impacts of DG, Power Quality, Voltage Regulation, Islanding, Dispatched Operation

I. INTRODUCTION

Existing electrical energy distribution system in most of the countries is mainly dependent on the centralized generating plants. These plants are installed at distant locations from the load centers. Although these plants are able to fulfill the demand of the consumers but in some cases, during peak hours, generation of centralized power plant may be insufficient to fulfill the whole demand. A DG can fulfill the extra demand during peak hours. Distributed resources can either be grid connected or independent of the grid [1]. Distributed systems include biomass-based generators, combustion turbines, thermal solar power and photovoltaic systems, fuel cells, wind turbines, micro turbines, engines/generator sets, and storage and control technologies [1].

The inclusion of Distributed Generation (DG) in power systems is suggested by several research reports related to DG. Due to this reason, some countries promoted the installation of DG systems at large scale to make it competitive with the existing power system. Although integration of DG in distribution system is advantageous but improper installation may cause several adverse effects on the existing system. Since power systems are not designed to incorporate power generation sources into distribution levels hence integration of DG in existing system leads to a certain impacts on distribution networks. These can be categorized into: technical, economical and operation impacts. Such impacts should be carefully estimated and studied before integration of DG. The paper is organized as follows: in section 2, an overview of different definitions of DG is presented; In section 3, different technical, economical and operation impacts of DG are explained and finally section 4 and 5 list the conclusions of the work and the references used.

II. DEFINITIONS OF DISTRIBUTED GENERATION

Generally the basis of defining DG is its size and location but some countries define distributed generation as having some basic characteristic (for example, using renewable, cogeneration, being non dispatchable, etc.). In literature definitions for distributed generation (DG) are not same but different terms and definitions are used for distributed generation. Nevertheless, the following definition is generally agreed in the literature for DG: "A generating plant connected directly to the grid at distribution level voltage or on the customer side of the meter" [2]. Further-more, in the literature, terms such as embedded generation, dispersed generation, distributed energy resources (DER) and decentralized generation, have also been used in the context of DG. The term dispersed generation is usually referred to a distributed power generation unit regardless of the technology, and whether it is connected to the grid or completely independent of the grid [3]. The above definitions do not specify any criterion or classification of DG based on their capacity. Although, there is no generally accepted rule or standard, the following definitions are used in different countries and situations:

The Department of Energy (DOE) considers distributed power systems to typically range from less than a kilowatt (kW) to tens of megawatts (MW) in size as DG unit [1].

In New Zealand, generating units of capacity less than 5 MW are usually considered DG [3]. According to the Gas Research Institute, typically between 25 kW to 25 MW generation units are considered as DG [4]. In [5] DG size is defined as the as ranging "from a few kilowatts to over 100 MW" and according to [6] DG is defined as generation between "500 kW and 1 MW". The Electric Power Research Institute (EPRI) considers small generation units from a few kW up to 50 MW and/or energy storage devices typically sited near customer loads or distribution and sub - transmission substations as distributed energy resources [7]. Swedish legislation treats generating units under 1500 kW differently from those unit capacities higher than 1500 kW. Then, it can be considered that DG capacity in Sweden is defined as those units under 1500 kW [8]. In the English and Welsh power markets, a power plant with capacity less than 100 MW is not centrally dispatched. Therefore, in this market DG is referred to any generating unit under 100 MW [8]. In Australia, generating units under 30 MW are considered as DG [8].

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Several International Organizations also tried to define the distributed generation. According to International Council on Large Electric Systems or Conseil International des Grands Réseaux Électriques (CIGRE), [9] distributed generation can be defined as all generation units with a maximum capacity of 50MW to 100MW, that are usually connected to the distribution network and that are neither centrally planned nor dispatched.

The IEEE [10] on the other hand, defines distributed generation as the generation of electricity by facilities that are sufficiently smaller than central generating plants so as to allow interconnection at nearly any point in a power system. According to the International Energy Agency (IEA), Distributed Generation is a generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution level voltages. The technologies include engines, small (and micro) turbines, fuel cells, and photovoltaic systems. [11]. Distributed Generation (DG) is the strategic placement of small power generating units (5 kW to 25 MW) at or near customer loads [12]. Distributed energy resources are small-scale power generation technologies (typically in the range of 3 to 10,000 kW) located close to where electricity is used (e.g., a home or business) to provide an alternative to or an enhancement of the traditional electric power system [13]. In [14, 15] distributed generation is defined as a small source of electric power generation or storage (typically ranging from less than a kW to tens of MW) that is not a part of a large central power system and is located close to the load, to meet specific customer needs, to support economic operation of the distribution grid, or both.

In [16, 17] authors conclude that the distributed generation can be defined in terms of connection and location rather than in terms of generation capacity. Distributed generation is the integrated or stand-alone use of small, modular electricity generation resources by utilities, utility customers, and/or third parties in applications that benefit the electric system, specific end-user customers, or both [18]. Considering the different definitions of DG [19] concluded that the distributed generation is a source of electric power connected to the distribution network or to the customer site which is sufficiently smaller than central generating plants.

III. IMPACTS OF DG

A DG system may use renewable or non-renewable source of generation and can be grid connected or stand alone system. Due to low investment cost and small size Distributed Generation plays an important role in power system planning. The DG in distribution system can significantly affect the flow of power and voltage conditions at customers and utility equipment. These impacts may be either positive or negative depending on the distribution system operating characteristics and the DG characteristics [20-22].Positive impacts are generally called "system support benefits," and include [21, 23, and 24]:

- Reduction in Losses
- Improved system reliability
- Voltage support and improved power quality
- Transmission and distribution capacity release
- Deferments of new or upgraded transmission and distribution infrastructure.
- Lowering of cost by avoiding long distance high voltage transmission.
- Environment friendly where renewable sources are used.

As the number of distributed generation systems increases in the system these also raises the new maintenance and security issues. These issues may be technical, operational and economical [25-27], discussed as follows:

3.1. Technical Impacts:

The main objective of DG integration is to solve technical problems associated with integration to ensure high system reliability with distributed generation. The following section gives an overview of the technical issues caused by distributed generation.

A. Capacity

Adding distributed generators at the distribution level can significantly pose a problem to the amount of power to be handled by the equipment (cables, lines, and transformers)[28]. According to [26] transformers will be most affected when power generation increases as compared to power consumption. In this case reverse power flow may occur and transformer capacity should be able to handle this reverse flow. Generally this problem arises at peak hours because at that time both continuous and peaking distributed generators will operate to cash in the price premium.

B. Effect on Power Quality

Distributed generation can either contribute to or deteriorate power quality [16]. Frequency is one of the most important parameter of the power quality. Installation and connection of DG to existing grid will definitely affect the system frequency of the system as DG can serve as source of harmonics to the network. Harmonics produced can be either from the generation unit itself (synchronous generator) or from the power electronics equipment such as inverters [27]. Now days, inverters are designed with IGBT (Insulated Gate Bipolar Transistor) technology that use pulse width modulation to generate the injected "pure" sinusoidal wave. This new technology produces a cleaner output with fewer harmonic that must satisfy the IEEE 1547-2003 standards [29]. The standards primary motive is to ensure that DG units do not have negative impacts on other customers or equipment connected to the grid; it applies to the inter connection of all generation with aggregate capacity of 10 megavolt amperes (10 MVA, approximately 10 MW) or less to the distribution system [30]. Normally, comparing harmonic contribution from DG with the other impacts that DG may have on the power system, it is concluded that they are not as much of a problem [22]. Flicker is also an important power quality issue.

"Flicker" refers to rapid variations of voltage that can cause noticeable variations in lighting and interrupt the operations of electronics.

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Flicker can occur, for example, when clouds pass by photovoltaic cells, rapidly changing their power output [31]. For a standalone DG system the disturbances of loads cause sudden load current changes to the DG inverter and due to this voltage drops due to the output impedance of the inverter, and there will be fluctuation in output voltage which will cause flickering. In grid parallel mode, flicker is less of a problem since the grid supports the AC voltage. In standalone mode, the key to reducing voltage flicker is to reduce the output impedance of the Power Conditioning System (PCS) [32].

C. Effect on Protection System

In radial network without presence of DG, power flow is unidirectional but in parallel connection of DG with the existing grid the possibility of the bidirectional power flow increases, this may cause unbalance in the existing system.

Distribution networks today are typically designed using a "fit and forget" approach in which settings for protection equipment remain static. DG units can increase current at a fault and reduce it at the protection device for the period before the DG senses the fault and disconnects, making it harder to detect a fault and complicating the coordination among protection devices [31]. For DG to have a positive effect, it should be suitably synchronized with the system operating conditions and feeder design. DG is connected to the network through an interconnection point called the point of common coupling (PCC). The PCC has to be properly protected to avoid any damage to the DG equipment and the utility equipment, during fault conditions [33].The extent at which protection coordination is affected depends on the size, type and location of DG [28]. For avoiding major modification on the existing feeder [34] suggests that capacity of the DG should be 5% of the existing capacity of the line. Hence new protection system is required for the modified system. According to [35] new protection requirements can be grouped as generating unit protection, distributed network protection and interface protection. Reclosing of the switch is another issue with the distributed generation. If speed of reclosing of switch is slower than this may increase the duration of fault and may lead to other serious faults. On the other hand if reclosing speed is higher than it may be reclosed before complete disconnection of DG and may damage the DG. Therefore there is need to find a balance between degraded supply quality due to longer off times and potential damage to DG [36].

D. Effect on the Reliability

Reliability is one of the important characteristics of power system that consists of security and adequacy assessment. Both of them are affected by implementation of distributed generation in electrical distribution system [37]. The time necessary to start-up the DG should be taken into account for the reliability evaluation of the distribution system including DG. If this time is sufficiently short, the customers suffer a momentary interruption, while, if not, they suffer a sustained interruption [38].

E. Effect on Voltage Regulation

Distribution system voltage regulation is designed on the basis of forecasted daily and seasonal changes in loading. Power injections from DG change the direction of flow of power. In case of minimum demand and maximum generation at the DG system voltage level at the load centers may increase above the permissible limits. Due to this distribution system voltage regulation devices, such as step voltage regulators, load tap changers, and switched capacitor banks may respond inappropriately [32].

F. Power Conditioning Issues

Some distributed generation technologies produces the DC power and for connecting the DG with existing grid this DC power is need to be converted into the AC power. This conversion from DC to AC may introduce the harmonics in the supply although this concern with modern technology inverters is less[39]

G. Effect on Power Loss

Line losses are directly related with the efficiency of the system. Higher losses will cause the poor efficiency of the system. Line losses can be decreased by reducing either line current or resistance or both. When DG is used to provide energy locally to the load, line loss can be reduced because of the decrease in current flow in some part of the network. However, DG may increase or reduce losses, depending on the location, capacity of DG and the relative size of load quantity, as well as the network topology and other factors [40].

Recent research has shown that above a threshold (at very high penetration rate and with generators concentrated in a specific area and all of them feeding the distribution grid), the size of the transmission and distribution losses goes up [41]. Locating the DG units is an important criterion that has to be analyzed to be able to achieve a better reliability of the system with reduced losses [22]. Locating DG units to minimize losses is similar to locating capacitor banks to reduce losses. The main difference between both situations is that DG contributes active power and reactive power (P and Q) but capacitor banks contribute only reactive power flow (Q) [22]. Mainly, generators in the system operate with a power factor range between 0.85 lagging and unity, but the presence of inverters and synchronous generators provides a contribution to reactive power compensation (leading current) [42].

H. Islanding:

It occurs when distributed generator (DG) continues to power a location even though electrical grid power from the electric utility is disconnected. Islanding can be dangerous to utility workers, who may not realize that a circuit is still powered, and it may prevent automatic reconnection of devices. Islands are not inherently harmful to distribution systems and in some cases intentional islanding is done for the maintenance purpose.

One of the major problems with islanding is that it is often caused by faults that occur between the DG and the substation, which often results in relays opening at different times to remove fault current and results in a loss of phase and voltage synchronization.

The loss of synchronization can result in large transients when a recloser operates to reconnect the island and can then result in false tripping [43],[44]

I. Voltage and Current Transients:

Short term abnormal voltage or current oscillation may occur as distributed generators are switched ON or OFF. The result of these oscillations can have a destabilizing effect on the network [28].

J. Short Circuit Levels of Network:

The presence of DG in a network affects the short circuit levels of the network. It creates an increase in the fault currents when compared to normal conditions at which no DG is installed in the network [27].

The influence of DG to faults depends on some factors such as the generating size of the DG, the distance of the DG from the fault location and the type of DG. This could affect the reliability and safety of the distribution system [22].

K. Voltage Unbalance:

When a single phase DG (such as Photovoltaic based DG) is integrated in Distribution Network (DN) then this may results in the voltage unbalance in DN. This unbalance depends in the number of DG units introduced into DN.

3.2 Economic Impacts:

One key barrier in growth of DG is the cost competitiveness of distributed generation. Cost of DG system varies, however, a lot from one technology to the other. This section discusses the financial aspects of DG integration on the electric utility and its customers. Some major points are as follows:

A. High Investment cost:

Distributed generation is less competitive to other conventional technologies in terms of cost. According to [45] one of the major remaining issues is the relatively high capital costs per kW installed power compared to large central plants.

B. Low Transmission Losses:

The amount of energy lost in transmitting electricity is reduced because the electricity is generated near to where it is used, sometimes even in the same building. This also reduces the size and number of power lines that need to be constructed.

C. Regulating Power Markets:

The purpose of the regulating power market is the correction of deviations from the schedule, i.e., the provision of additional electricity if frequency decreases, and reduction of electricity generation if the frequency increases. It depends on national market design when actors have the last possibility to correct their schedules on other markets – day ahead or as close as 15 minutes ahead. In general, it is assumed that variable supply sources as most DG increase the demand for regulating power due to meteorological forecast errors [38].

The participation of DG could be positive to overcome assertions of non-competitive markets [46].

D. Impact on Electricity Price:

Distribution companies and large customers, who buy electricity directly from the markets, may install their own DG systems to fulfill their electricity demand partially.

Due to this they will purchase less power from the grid and this will reduce their costs. By installing more DG units, market participants can cope with the variation in the price during peak demand hours. The market price is affected by the ability of customers to choose between power from the grid or from their own DG units, resulting in a reduction of market power by generation companies [47].

E. Deferred Investment:

In distribution system planning and expansion, especially where demand growth is low and the system is operating at its marginal resources, DG installations can be a practicable solution to defer upgrades [47].

3.3 Operational Impacts:

In this category those issues are mentioned which are needed to be considered during operation of DG system. Following are the some important points:

A. Regulatory:

In the absence of a clear policy and associated regulatory instruments on the treatment of DG, it is very unlikely that this type of generation is going to thrive. In order to foster the required changes, there is a clear need to develop and articulate appropriate policies that support the integration of DG into distribution networks [48].

B. Output Power Uncertainty:

Distributed Generation units using renewable sources of energy are supply dependent. This issue becomes serious if contribution of DG is higher in overall capacity. In such condition if there is any wrong forecast then balance energy need to be purchased for compensating the difference between agreed and actual production.

Today lack of prediction exactness can be compensated by combining the renewable DG with storage facility [49].

C. Storage Needs:

Due to forecasting problems associated with the renewable energy sources need of storage system rises in DG system. Storage system may use Batteries, Flywheels, Super capacitors, and Super Conducting Magnetic Energy Storage Systems etc.

D. Operational Mode:

Many DG systems are flexible in nature and hence they can be operated in Standby or Peak Shaving mode. Making use of DG allows a flexible reaction to electricity price evolutions. DG then serves as a hedge against these price fluctuations [50]. Operating mode of DG should be monitored continuously so that it can be changed according to the demand.

E. Dispatched Operation:

In context of renewable sources of energy dispatched operation means whether a generator can be shut off or not.

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In case if forecasting is not accurate and storage devices are not working then it should be possible to turn on or off the generator as per the demand of the network. Thermal or hydro generator are well controlled hence are dispatched and on the other hand renewable generator depends on the inflow of the driving energy [25].

F. Active Network [25, 28]:

Generally distribution networks passively distribute energy from the transmission networks to the customers. The synchronization between the generators and the regulations in outputs are made directly at the transmission level. The integration of distributed generation on a large scale will imposes the changes in the distribution network. In this case distribution network has to be active because they will have to manage the incoming power from the grid through the transmission lines, forecast the levels of output from distributed generators (and especially peak generators), collect information, device start-up procedures in case of system failures, automation. This increased level of complexity will require the development of management and control procedures necessary to ensure quick and safe operation [28]. [51] suggests to subdivide the distribution network into single cells, containing a certain amount of DG and loads, managing protection, power flow and voltage control autonomously. Thus, distributed intelligence and control would be added to DG.
These control possibilities would also allow connecting more DG onto the distribution network [52].

G. Virtual Power Plant [25, 28]:

A virtual power plant is the coordination of several distributed generators in order to act as an integrated plant [28]. The plant is virtual; as it is not in one place but made of the aggregation of several units. In other words, different power generation and storage devices with diverse weaknesses and strengths are combined so they cleverly complement [25].The operation of such a plant required a strong integration of information, communication and management systems

IV. CONCLUSION

This paper has presented an overview of definitions of DG and the parameters need to be considered while integrating the DG to the electric power systems for the benefit of utility and consumers. Properly installed DG will be advantageous to environment, installed system and will be economically beneficial to utility and consumers. Although Distributed Generation has the potential to play an important role in fulfilling the future energy demand but still there are some technical, economical and operation barriers that are limiting the introduction and use of DG. From a monetary viewpoint, distributed generators technology needs improvement to lower the cost per kWh while specializing in end-use where they can prove more competitive than centralized generators.

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