International Journal of Recent Technology and Engineering (IJRTE)
ISSN: 2277-3878 (Online), Volume-1 Issue-1, April 2012

Definitions and benefits of Distributed Generation Technologies

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Abstract*: *The application of deregulation in the electric power sector and as a result of that, a new identity appeared in the electric power system map known as "distributed generation" (DG). Consistent with new technology, the electric power generation trend uses disbursed generator sized from kW to MW at load sits in preference to using traditional centralized generation units sized from 100MW to GW and situated far from the loads where the natural recourses are accessible. This paper introduces an appraisal of this revolutionary approach of DGs, which will change the way of electric power systems operate along with their types and operating technologies. Some important definitions of DGs and their operational constraints are discussed to help in understanding the concepts and regulations related to DGs. Furthermore, we will review the operational and economical benefits of implementing DGs in the distribution network. Most DG literatures are based on studying the definitions, constructions or benefits of DGs separately. Conversely, in our paper we aim to give a comprehensive review by adding new classifications to relate the DG types, technologies and applications to each other.

Index Terms: Distributed generation (DG), Fuel cell (FC), Micro-turbine (MT), Photovoltaic (PV), Wind turbine (WT)

I. INTRODUCTION

Distributed generation (DG) is not a new concept but it is an emerging approach for providing electric power in the heart of the power system. It mainly depends upon the installation and operation of a portfolio of small size, compact, and clean electric power generating units at or near an electrical load (customer). Till now, not all DG technologies and types are economic, clean or reliable. Some literature studies delineating the future growth of DGs are: • The Public Services Electric and Gas Company (PSE&G), New Jersey, started to participate in fuel cells (FCs) and photovoltaics (PVs) from 1970 and micro-turbines (MTs) from 1995 till now. PSE&G becomes the distributor of Honeywell's 75kW MTs in USA and Canada. Fuel cells are now available in units range 3–250kW size [1]. • The Electric Power Research Institutes (EPRI) study shows that by 2010, DGs will take nearly 25% of the new future electric generation, while a National Gas Foundation study indicated that it would be around 30% [2]. PV industries and companies expect about one million rooftops equipped by PV modules within the coming decade [3]. The largest commercial 1MW FC (five 200kW units) installed by the US Postal Service at the Anchorage Mail Processing Centre, Alaska and is connected to the utility grid [4]. In the year 2000, new wind farms of 3000MW capacities were installed [3]. Surveying DG concepts may include DG definitions, technologies, applications, sizes, locations, DG practical and operational limitations, and their impact on system operation and the existing protective devices. This paper focuses on surveying different DG types, technologies, definitions, their operational constraints and operational and economical benefits. Furthermore, we aim to present a critical survey by proposing new DG classifications.

Revised Manuscript Received on 30 April 2013.
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II. TYPES OF DISTRIBUTED GENERATION

There are different types of DGs from the constructional and technological points of view as shown in Fig. 1. These types of DGs must be compared to each other to help in taking the decision with regard to which kind is more suitable to be chosen in different situations. However, in our paper we are concerned with the technologies and types of the new emerging DGs: micro-turbines and fuel cells. The different kinds of distributed generation are discussed below.

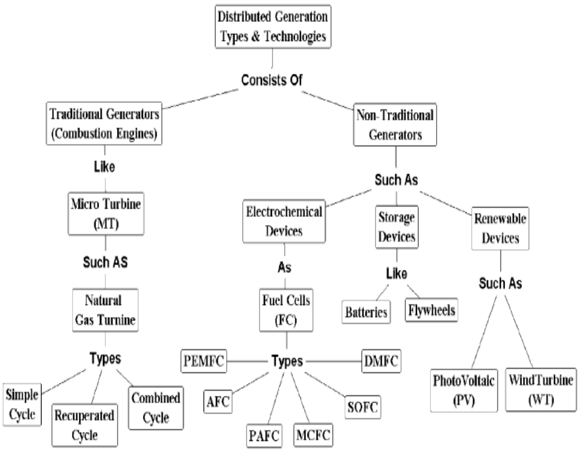

Fig. 1. Distributed generation types and technologies.

A. *Traditional combustion generators*

Micro-turbine (MT)

Micro-turbine technologies are expected to have a bright future. They are small capacity combustion turbines, which can operate using natural gas, propane, and fuel oil. In a simple form, it consists of a compressor, combustor, recuperator, small turbine, and generator. Sometimes, it has only one moving shaft, and use air or oil for lubrication. MTs are small scale of 0.4–1 m^3 in volume and 20–500kW in size. Unlike the traditional combustion turbines, MTs run at less temperature and pressure and faster speed (100,000 rpm), which sometimes require no gearbox [5]. Some existing commercial examples have low costs, good reliability, fast speed with air foil bearings ratings range of 30–75kW are installed in North-eastern US and Eastern Canada and Argentina by Honeywell Company [1] and 30–50kW for Capstone and Allison/GE companies, respectively [6]. Another example is ABB MT: of size 100kW, which runs at maximum power with a speed of 70,000 rpm and has one shaft with no gearbox where the turbine, compressor, and a special designed high speed generator are on the same shaft [5].

Advantages of MTs.

- They can be installed on-site especially if there are space limitations. Also they are compact in size and light in weight with respect to traditional combustion engines.
- They are very efficient (more than 80%) and have lower emissions (less than 10 ppm NO*x*) with respect to large scale ones.
- They have well-known technology and they can start-up easily, have good load tracking characteristics and require less maintenance due their simple design [5].
- They have lower electricity costs and lower capital costs than any other DG technology costs [1].
- They have a small number of moving parts with small inertia not like a large gas turbine with large inertia.
- Modern power electronic interface between the MT and the load or grid increases its flexibility to be controlled efficiently [6]. There are different types of MTs according to their operation such as gas turbines and combustion turbines. Gas turbines are combustion turbines that produce high temperature and pressure gas. This high-pressure gas is used to rotate turbine shaft, which drives a compressor, an electric alternator and generator. Gas turbines are always used above 1MW, but nowadays we can generate electricity through small modulars with a micro-gas turbine of 200kW size [5]. The produced heat can be used as a waste heat recovery to generate steam for compound heat and power (CHP) as shown in Fig. 2, combined cycle application and fuel cell/turbine hybrids applications. MT types are different according to their operating cycle configurations [7]:

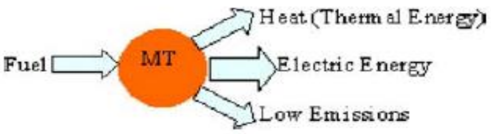

Fig. 2. Typical micro-turbine operation.

Simple-cycle gas turbines: Simple gas turbines can be either a single-shaft machine (with air compressor and power turbine (PT) on the same shaft) or a split-shaft machine. Also, they have a burner or combustor, and an electric generator rotated by power turbine.

Recuperated gas turbines: They are similar to simple-cycle gas turbines, but with a special heat exchanger (a recuperator). This recuperator uses the output exhaust thermal energy to preheat compressed air in its pass to the burner to increase the turbine electrical efficiency.

Combined cycle gas turbine: They use the exhaust energy in a heat recovery steam generator (HRSG) based on the concept of heat recovery, which may include a burner to increase the steam output. Steam from the HRSG drives a steam turbine, which generates power in addition to the main power turbine as shown in Fig. 3 to increase the total electric efficiency.

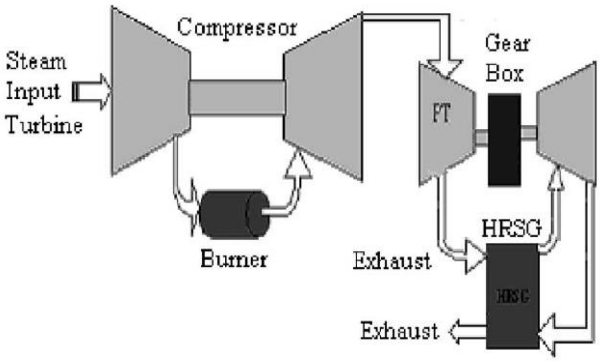

Fig. 3. Combined cycle gas turbine.

B. *Non-traditional generators*

Electrochemical devices: fuel cell (FC)

The fuel cell is a device used to generate electric power and provide thermal energy from chemical energy through electrochemical processes. It can be considered as a battery supplying electric energy as long as its fuels are continued to supply. Unlike batteries, FC does not need to be charged for the consumed materials during the electrochemical process since these materials are continuously supplied [8]. FC is a well-known technology from the early 1960s when they were used in the Modulated States Space Program and many automobile industry companies. Later in 1997, the US Department of Energy tested gasoline fuel for FC to study its availability for generating electric power [6]. FC capacities vary from kW to MW for portable and stationary units, respectively. It provides clean power and heat for several applications by using gaseous and liquid fuels [9]. FCs can use a variety of hydrogen-rich fuels such as natural gas, gasoline, biogas or propane [10]. FCs operates at different pressures and temperatures which vary from atmospheric to hundreds of atmospheric pressure and from 20 to 200 °C, respectively [10]. As shown in Fig. 4, a typical FC consists of two oxidant electrodes separated by an electrolyte member. Oxygen, as an oxidant, passes through one electrode (cathode) either at low pressure (using a blower) or at high pressure (using air compressor) [8]. Hydrogen, as a fuel, passes through the other electrode (anode). FC technology is based on an electrochemical process in which hydrogen and oxygen are combined to produce electricity without combustion. The catalyst splits the hydrogen atom into a proton and an electron. The proton passes through the electrolyte; however, electrons create a separate current that can be utilized before they return to the cathode, to be demodulated with the hydrogen and oxygen in a molecule of water [8, 9].

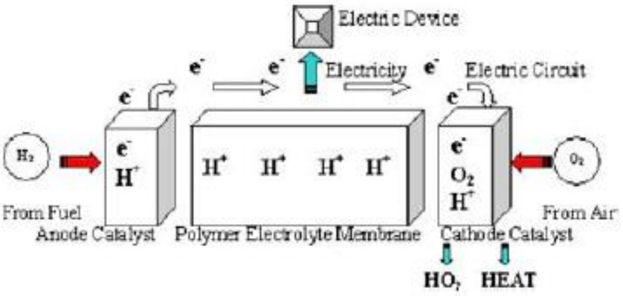

Fig. 4. Polymer electrolyte membrane FC.

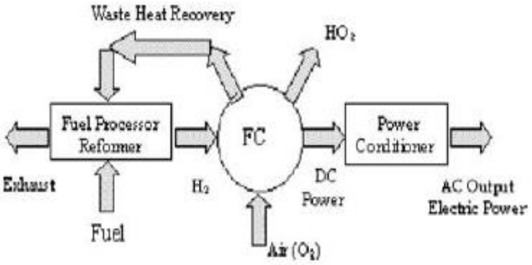

Fig. 5. FC construction, operation, and products.

The operating stages and products of this electrochemical process, as shown in Fig. 5, are direct current electric power, water, heat, and some low emitted gases (like NO*x* and CO2) with respect to traditional generators and hence is considered an environmentally safe electric power generation [9]. A fuel processor is used to convert the source fuel to a hydrogen-rich fuel stream, which is needed for the electrochemical reaction. A power electronic device (a power conditioner) has to be used to convert the output direct current to the alternating one to be connected to the grid and control its voltage level according to the required application [8, 9]. The hydrogen used can be obtained either by reformation of hydrocarbons or by means of chemical and electrolysis operations from water [10]. The most commonly used method is reformation of hydrocarbons such as natural gas because it is already commercially available as it can be transmitted by means of pipelines. Producing hydrogen can be done chemically by using steam on heated carbon. The output products of this process are H_2 and CO_2. This chemical operation requires heating for the steam and the carbon, which is considered a waste of energy. Another means of producing H2, and storing the energy in it, is from electrolysis of water. This process is not economic as it uses electric energy to do the process and cover its losses [10]. Usually the reforming process, which is known as “steam catalytic reforming process” to get a hydrogen-rich fuel [11], occurs at high temperature around 800 ◦ C. Therefore, we need an external reformer device for low temperature operating FC as shown in Fig. 5 [8, 9].

Advantages of FCs.

- FCs transforms the fuel chemical energy to electric power with a 60% efficiency, which is considered to be twice of that of the traditional generating stations [11].
- The absence of moving parts in FCs operation, except for air blowers (for O2) and fuel (for H2) and/or water pumps, results in very low noise levels, relatively higher efficiencies and emits lower air pollutants [9,11].
- No combustion is involved in the FC operation make it environmental friendly generation with approximately negligible emissions (low CO2) [9].
- Also, due to the output bi-product (electricity and heat as a result of high fuel conversion efficiency) and their prices, small size FCs in the coming recent years are expected to be implemented in commercial and residential buildings for both purposes of lighting and heating at the same time [9,10].
- Today, FCs consists of staking cells, which give it the flexibility to be built to match specific power needed with less capital cost. FC power plants are commercially available for use by electric power producers and industrial applications [10].

Disadvantages of FCs. From the electrical point of view, as a result of aging the FC internal impedance slowly increases, therefore, we need a power electronic interface to regulate the output voltage [9].

FC types and technologies. There are different types and operating technologies of fuel cells depending on the electrolyte used such as: proton exchange membrane or polymer electrolyte membrane fuel cell (PEMFC), alkaline fuel cell (AFC), direct methanol fuel cell (DMFC), phosphoric acid fuel cell (PAFC), molten carbonate fuel cell (MCFC) and solid oxide fuel cell (SOFC) as shown in Table A.1 (Appendix A) [8–10]. The electrochemical process is based on the electrolyte media used, which determines the FC operating temperature [9, 11].

B Storage devices

It consists of batteries, flywheels, and other devices, which are charged during low load demand and used when required. It is usually combined with other kinds of DG types to supply the required peak load demand [6]. These batteries are called “deep cycle”. Unlike car batteries, “shallow cycle” which will be damaged if they have several times of deep discharging, deep cycle batteries can be charged and discharged a large number of times without any failure or damage. These batteries have a charging controller for protection from overcharge and over discharge as it disconnects the charging process when the batteries have full charge. The sizes of these batteries determine the battery discharge period. However, flywheels systems can charge and provide 700kW in 5 s [6].

C. *Renewable devices*

Green power is a new clean energy from renewable resources like; sun, wind, and water. Its electricity price is still higher than that of power generated from conventional oil sources. Some types of renewable resources are discussed below:

Photovoltaic (PV).

1. *Construction*: The basic unit of PV is a cell that may be square or round in shape, made of doped silicon crystal. Cells are connected to form a module or panel and modules are connected to form an array to generate the required power.

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2. *Operation and ratings*: Cells absorb solar energy from the sunlight, where the light photons force cell electrons to flow, and convert it to dc electricity. Practically, each cell provides 2–4A according to its size with an output voltage of 0.5V. Normally an array, cells connected in series, provides 12V to charge batteries.

3. *Restrictions*: PVs consist of modulars which can be connected to provide a variety of power ranges but on the other hand there are many restrictions:

- It provides low output power.
- The cost of land where PVs installed is expensive (1 acre of land produces 150 kW) [1].
- It is restricted to certain geographic and weather features [1].

Some applications of PV.

- Space programs as it provides power to satellites equipments and transmitters in space. Remote communications, lighting road signs, roof projects for home lighting and heating and road lighting. Also, PV provides "load direct application" such as solar water pumping for use or storage that operates only while sunlight exists. PV is cost efficient especially if the nearest line of power is far from the application's place.

- Solar energy can be used during the peak loads to fit with load curve peaks. For example during summer days PV is used to provide the necessary excess power required due to air conditioning and cooling processes and the rest of the power is supplied to the grid so there is no need to be "dispatchable".

There are different types of PV applications such as:

- PV–diesel hybrid power system, which uses supervisory control and data acquisition (SCADA) for control purposes.

- Standalone PV direct-coupled system supplies the output dc power directly to a dc load, which operates only when there is solar energy. However, standalone PV can be combined with storage "deep cycle" batteries to maintain supplying loads even during nights, cloudy and bad weather.

- Also, in some applications PV systems can have an inverter to operate ac loads as well.

Wind-turbines (WT). Wind energy is not a new form it has been used for decades. A WT consists of a rotor, turbine blades, generator, drive or coupling device, shaft, and the nacelle (the turbine head) that contains the gearbox and the generator drive. Modern wind turbines can provide clean electricity as individuals or as wind farms. Wind turbine blades usually are two or three blades each nearly 10–30m long.

Operation. The wind rotates the windmill-like blades, which in turn rotate their attached shaft. This shaft operates a pump or a generator that produces electricity. Although, the energy characteristics of larger wind turbine farms are closer to the centralized energy sources, small wind turbines (working as modules) can be combined with PV and battery systems to serve area of 25–100kW.

The advantages of wind turbines are.

- Contribute to clean air (no pollution) unlike the traditional oil fuel that contributes acid rain (from sulphur dioxide or nitrogen oxides) and global warming (from carbon dioxide) to the environment.

- Contribute to global safety (non-hazardous or radioactive wastes) unlike nuclear power.

- Future sustainable (It has no input fuel, just the wind which will not run out by time).

- Traditional fuel costs increase with time but wind energy costs decrease with time.

III. Different DG classifications

Usually DGs are classified according to their different types and operating technologies. However, it is more convenient to classify them from the electric point of view to study their impact on the electric system. Different classifications can be obtained to differentiate between DG types according to their electrical applications, supply duration, generated power types, electric ratings and renewable and non-renewable technologies. Several proposed DG classification will be discussed as follows.

Applications

Different DG technologies are implemented to fulfil the requirements of a wide range of applications. These applications differ according to the load requirements. As a result they affect the types of DGs used. Some of these applications are discussed below:

Standby: DG can be used as a standby to supply the required power for sensitive loads, such as process industries and hospitals, during grid outages.

Stand alone: Usually, isolated areas use DGs as a power provider instead of connecting to the grid. These areas have geographical obstacles, which make it expensive to be connected to the grid.

Peak load shaving: The electric power cost varies according to the load demand curves and the corresponding available generation at the same time. Hence, DGs can be used to supply some loads at peak periods, which reduce the electricity cost for large industrial customers who used to pay time-of-use rates (TOU).

Rural and remote applications: DG can provide the stand-alone remote applications with the required power. These applications include lighting, heating, cooling, communication, and small industrial processes. Even more, DGs can support and regulate the system voltage at rural applications (sensitive loads) connected to the grid.

Providing combined heat and power (CHP): DGs providing CHP as a cogeneration has a high overall energy utilization efficiency. The produced heat, from converting fuel into electric power process, is used onsite for a wide range of applications in hospitals, large commercial areas and process industries.

Base load: Utility owned-DGs are usually used as a base load to provide part of the main required power and support the grid by enhancing the system voltage profile, reducing the power losses and improving the system power quality.

A classification can be concluded by relating most candidates of DG types and also the traditional centralized generation stations to different wide range applications as shown in Table I.

Table I Comparison between common energy types

Energy type	Main applications
Micro-turbines	Help for peak load shaving, co-generation, and as a base load. Commercially available in small units with sizes 30–75kW [1].
Fuel cells	Suitable for providing CHP for air-conditioning, cooling, and heating purposes. Large stations are suitable for base load applications. Commercially available in small units with sizes 3–250kW and connected as modular to serve large loads [1].
Photovoltaic	Stand alone and base load in some rural applications if combined with batteries. It can be considered as a maintenance free supply for telecommunication and road lighting and advertising.
Wind turbines	Remote homes and farms and process industry applications.
Traditional internal combustion engines (diesel engines)	Already in use for several years, but they have high emissions and operation and maintenance costs in addition to diesel's hazardous during transportation to remote consumers [1]. Most of them are used for peak load shaving and backup operation (for reliability purposes) not for continuous operation
Central power generation (fossil fuel)	Main electricity generation as the main base load. Used for peak load shaving and backup operation.

Supply duration and power type: DG output power duration varies significantly according to the DG size, type and application used. Its duration can be a long period of supply mainly for base load applications, unsteady supply that is generated from renewable resources and short period of supply, which is used to support the grid supply. A comparison can be done according to the amount of power supplied, its duration and its type (either active power, reactive power or both) as shown in Table II.

Table II. Comparison between common energy types for power and time duration

Power supplied period	DG type	Remarks
Long period supply	Gas turbine and FC stations	Provide P and Q except FC provides P only. Used as base load provider.
Unsteady supply	Renewable energy systems; PV arrays, WT Depend on weather conditions.	Provide P only and need a source of Q in the network. Used in remote places. Need control on their operation in some applications.
Short period supply	FC storage units, batteries, PV cells	Used for supply continuity. Store energy to use it in need times for a short period.

DG capacities: DG capacities are not restrictedly defined as they depend on the user type (utility or customer) and/or the used applications. The most common classification used is shown in Fig. 6. These levels of capacities vary widely from one unit to a large number of units connected in a modular form.

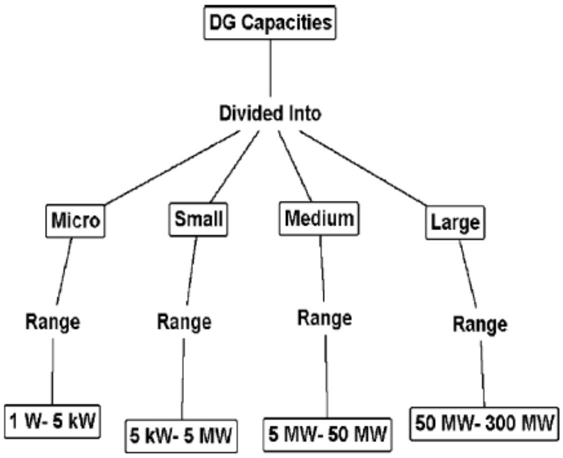

Fig. 6. Distributed generation capacities [2].

Generated power type: The output electric current can be either direct or alternating.

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FC, PV and batteries produce direct current, which is suitable for dc loads. However, we can convert this current to an alternating one for ac loads and for grid connections. This conversion can be done through a power electronic interface between the DG device and the grid. Other types of DGs like MT and WT provide an alternating current, which for some applications must be controlled using modern power electronic equipments to get regulated voltage.

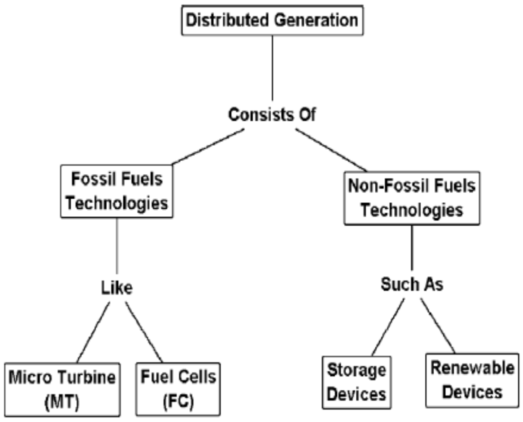

Fig. 7. Distributed generation technologies.

Technology: Another attempt for DG classification can be done according to the type of the fuel used. It can be either fossil or non-fossil fuel as shown in Fig. 7. This classification is not commonly used like that of Fig. 1, as our concern is the emerging DG technologies not their fuel used. It can be either fossil or non-fossil fuel as shown in Fig. 7. This classification is not commonly used like that of Fig. 1, as our concern is the emerging DG technologies not their fuel.

IV. Distributed generation definitions

DG is a fairly new trend in the electricity industry, market and deregulated systems. Till now, there are no consistent definitions that can describe DG terminologies. However, there are some definitions that can be considered common for most literatures. Some of these definitions are discussed below.

DG names

There are several terms used to refer to distributed generation, for example:

- "Dispersed generation" used in North America.
- "Embedded generation" used in South American countries.
- "Decentralized generation" used in Europe and some Asian countries. However, literature survey recommended the name of "Distributed generation" to be used all over the world [2].

DG purpose

Basically, it is used to provide part or all of a customer's real power demand and/or as a standby supply. Therefore, according to this definition, there is no need to supply reactive power from DG as in the case of FC for example [1, 2].

DG location

A definition: "The location of distributed generation is defined as the installation and operation of electric power generation modulars connected directly to the distribution network or connected to the network on the customer site of the meter" [2]. This definition under the deregulation trend encourages us suggest addition to the transmission and distribution systems definition. A transmission system can be defined as: "The system, which is operated by an independent company and not providing power generation or involved in distribution or retail service" [2]. A distribution system can be defined as: "The system, which is operated by a distribution company, can provide power generation through an electric utility or customers and involved in distribution or retail service". The proposed addition to the transmission system, distribution system and DG location definitions are helpful for many exceptional cases as follows [2]:

- If a large industrial customer site is connected directly on the transmission network and has a CHP system. In this situation CHP can be considered as a DG because it is connected directly on the customer side of the meter.
- If a distribution network capacity is limited, a medium size wind farm can be connected directly to a transmission system. In this case the wind farm cannot be considered as a DG. As a special case not following the location definition, DGs can be implemented by the utility itself by placing them into certain predetermined substations to help in reducing the peak load capacity and delaying the need for substation capacity expansion [1]. This idea can be extended in implementing DG as a new alternative for distribution system planning.

DG rating

There are different definitions for generation size range according to some institutes and literatures as shown in Fig. 6. However, these definitions are dependent on the government regulations as discussed below.

In the Swedish market

The DG capacity is up to 1.5MW. This value is not enough for deciding that this generation rating is for DGs or not, due to the cases below:

- In case of wind energy, Sweden plans offshore wind farms having a maximum capacity of 1000MW. Each wind turbine rating is 1.5MW, which can be considered as a DG based on the modular rating not the total wind farm capacity.
- In the case of hydro modulars the capacity is calculated as the total rating of the power station not for each individual modular. So in most cases they are not considered to be as a DG.

In Germany (Berlin)

The local utility BEWAG built a power generation station in the city centre.

This power station, which feeds into 110, 33 kV distribution lines, provides electricity and heat (300MW each, respectively). The generated electricity and heat are consumed locally so that this power station can be considered as a DG. According to the above discussion there is no common DG rating definition because the maximum capacity of a DG connected to the distribution network depends on the distribution system's capacity and its voltage level. However, most literatures use small and medium DG sizes.

DG power delivery area

There is no specific definition for DG power delivery area, but usually the DG produced energy is supposed to be consumed within the distribution network. However, DGs can feed back some of their generated electric power to the transmission system if it exceeds the distribution network load demand where DGs are installed.

DG operational constraints

To study the effect of implementing DGs in the distribution network, we have to discuss the DG operational constraints. Like any electric device, DGs have both steady state and dynamic models. In our paper, we are concerned with the steady state model as we are studying the impact and benefits of implementing DGs as a source of steady active power. Steady state operation is usually used in normal operation and in case of small disturbance existing in the system while DGs are still connected to the grid and supplying power with a constant frequency. The operational constraints differ according to the DG type as follows [12]:

- *Gas turbine, combustion engines, and hydro generation*

DGs: These types of DG generations can be considered alike, though not identical to, the traditional central generation, which has the ability to be dispatched. But they have two additional constraints.

(a) *The output generated power*: The DG output power (Pg) has minimum and maximum power limits. The minimum output generated power of some DG is essential in the case of co-generation required for some applications, like heating purposes. The maximum power generation limit is for thermal and overloading capabilities.

$$Pg \min \leq Pg \leq Pg \max \qquad (1)$$

(b) *The ramp rate*: This ramp is due to the natural delay taken by DGs to increase the amount of output generated power in a certain defined duration.

$$\Delta Pg\ t \leq \Delta Pg \text{ limit} \qquad (2)$$

where ΔPgt is the amount of the increased output generated power from moment $t - 1$ to moment t.

- *Renewable energy DGs*: This kind of energy resource includes WTs and PV arrays. The main characteristic of this generation is that it cannot be dispatched in emergency situations as its outputs are mainly affected by environmental conditions such as wind speed and sunlight, respectively. In some kinds of this generation, the output power generated is related to the system frequency (f) and voltage at the bus where DGs are connected (Vg).

$$Pg = f\,(f,\ Vg) \qquad (3)$$

- *Storage devices*: Some kinds like batteries can be dispatched to control the output power and their period of duration. However, each kind has different characteristics.

$$\sum_{t=1:\,j} pg\ tT \leq E \qquad (4)$$

where Pgt is the released output power at time t; E, the total available storage energy; and T is the time elapsed.

- *FCs, renewable, and storage devices*: They produce active power only. Therefore, the required reactive power can be obtained from the system by one of the following methods: a fixed capacitor, a controllable capacitor with a fixed power factor or interfacing with the network through power electronic devices. The three possibilities can be described as follows:

$Qg = Q$fix (fixed)

$Qg = f(Pg)$ (fixed power factor)

$Qg = Q$ System Interfacing (5)

V. Benefits of distributed generation

DG implementation in the distribution system has many benefits. These benefits enface the advantages that will be gained. Some DGs benefits are discussed below:

1. *From the economical point of view*:

- DGs can provide the required local load increases by installing them in certain locations so they can reduce or avoid the need for building new T&D lines, upgrade the existing power systems and reduce T&D networks capacity during planning phase [3, 12, and 18].
- DGs can be assembled easily anywhere as modules (FC-MT and MT-batteries) which have many advantages as [2]:

(a) They can be installed in a very short period at any location. Each modular can be operated immediately and separately after its installation independent of other modules arrival and not affected by other modular operation failure.

(b) The total capacity can be increased or decreased by adding or removing more modules, respectively.

- DGs are not restricted by the centralization of the power as they can be placed anywhere. Thus, DG location flexibility has a great effect on energy prices [13]. However, renewable DGs technology such as hydro, wind, and solar units require certain geographical conditions.
- DGs are well sized to be installed in small increments to provide the exact required customer load demand.
- Remote or stand-alone CHP DGs can be more economical [14]. CHP DGs can use their waste heat for heating, cooling or improving their efficiency by generating more power, which is not applicable in the situation of centralized generation alone [13].
- DGs can reduce the wholesale power price by supplying power to the grid, which leads to reduction of the demand required [15].

- Due to deregulation DGs will be of great importance in generating power locally especially if the location margin pricing (LMP) is applied for independent transmission operators (ISO's) and regional transmission organizations (RTO's). LMP can give an indication of where DGs should be installed [15].
- DGs increase the system equipments, transformers, lifetimes, and provide fuel savings.
- Installing DGs reduce the construction schedules of developing plants. Hence, the system can track and follow the market's fluctuations and/or the peak-load demand growth [16].
- According to different DGs technologies, the types of energy resources and fuels used are diversified. Therefore, there is no need for certain type of fuels more than others [16].

2. *From the operational point of view*: DGs have a positive impact on the distribution system voltage profile [3, 17, 18] and power quality problems [3, 12].

- DGs can reduce the distribution network power losses [3, 15, 17, 18], distribution loads requirements by supplying some of the distribution load demand, reduce power flow inside the transmission network to fit certain constraints and improve its voltage profile [15].
- DGs can help in "peak load shaving" and load management programs [13].
- They can help in system continuity and reliability, as there are many generation spots not only one centralized large generation. Especially in the case of end-user customers with low reliability since when combined with DGs there will be new customer classifications between high need for reliability with high service cost and others with less service cost and relatively lower reliability [13].
- DGs can be used as on-site standby to supply electricity in case of emergency and system outages (provide local reliability [15]).
- DGs maintain system stability, supply the spinning reserve required [12].
- DG's capacities vary from micro to large size so they can be installed on medium and/or low voltage distribution network which give flexibility for sizing and siting of DGs into the distribution network [16].
- They provide transmission capacity release.
- With regard to, environment and society, renewable DGs eliminate or reduce the output process emission [12].

VI. Conclusions

This paper analyses the types of distributed generation, technologies, definitions and operational constraints. Some novel DG classifications are established to emphasize DG concepts. DGs economical and operational reimbursement have been commenced to support the execution of DG in the distribution network.

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