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# Potential of Renewable Energy Sources for Distributed Generations: An Overview

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## ABSTRACT

The universal energy predicament and the exhaustion of fossil fuel reserves necessitate the requirement for green and dependable source of energy. Renewable energies are produced from the natural processes that are replenished such as sunlight, wind, rain, tides, and geothermal heat. Furthermore, transmission of electricity which is tantamount to high cost and energy losses resulted to the integration technology of distributed generator (DG) during the past decade to supplements centralized generation. DGs are sustainable solution to provide electricity to customers at reliable and affordable price. This paper is an overview of renewable energy sources as used in distributed generation by presenting an updated data of the status of renewable energy resources. It also discusses impact of DG in distribution system, benefits of DG and its classification. Renewable DG technologies and factor hindering establishment of Distributed Generation were also highlighted.

***Keywords:*** renewable energy; distributed generator; fossil fuel; source of energy; power

## (1) INTRODUCTION

The requisite for energy can never be over-stressed in the present-day world; it is indeed necessary to the self-actualization of basic private and community desires in our contemporary society [1]. Energy consumption is speedily growing in developing nations, which affects overall climate change and universal and local energy management. Amid the several categories of energy transporters, electricity has a distinct role in assisting to accomplish social and financial growth [2]. According to United Nation, 789 million people across the world have no access to electricity [3]. Provision of electricity to consumers is mostly based on having centralized generation which involves the use of conventional generators. Thus, the generated electricity is transmitted via a transmission line to substations where the voltage is step down before the electricity is distributed for energy consumption [4].

The customary power generation sources are centrally operated which are not ecofriendly in addition to cost issues in the current liberalized electricity market [5]. It is asserted that Over 13% of the total power generation is dissipated in the distribution system as I2R copper loss [6]. The demand for flexible and independent power network has been increasing [7]. There have been changes in electrical power systems from the present's centralized bulk systems, with generation plants coupled to the transmission network to more decentralized systems, with smaller generating units attached to distribution networks near the point of consumption. These types of generating units are denoted to as distributed generation (DG) [8].

Even though the traditional sources of fossil fuel burning was able to produce excess amount of energy, its limited nature is a worry for the future. Engaging ecologically friendly sources identified as renewable energy for creation of energy has grew extensive reception across the world [9].

## (2) RENEWABLE ENERGY

The climate change and exhaustion of non-renewable energy sources has created a growing concern. Increased communal consciousness has called for reduction in one of the main sources of climate change which is carbon emissions [10] – [12]. This necessitates gradual yet steady substitution of conventional coal-based power plants with eco-friendly renewable energy sources [13]. Contrary to fossil fuel, the renewable-energy-based technologies that can offer safe and clean electricity are currently inexpensive and more available than ever to the population [14].

The renewable energy (green energy) technologies are rising rapidly in recent years, which will soon reach aspiring targets because they have the capability to minimize energy crisis in addition to been environmentally friendly [15]. The portion of renewable energy in electricity generation at the end of 2021 is around 28.3% with 15% coming from hydropower, 10% from solar and wind are 3.3% from other new renewable sources [16]. As shown in Figure 1, there was a reduction in percentage of fossil fuel consumption.

It is estimated that by 2030 the investment required for worldwide energy access will cost more than $48 billion each year [17]. It has become vital for the power and energy engineers to look out for the renewable energy sources such as sun, wind, geothermal, ocean and biomass as maintainable, economical and eco-friendly alternatives for conventional energy sources [17].

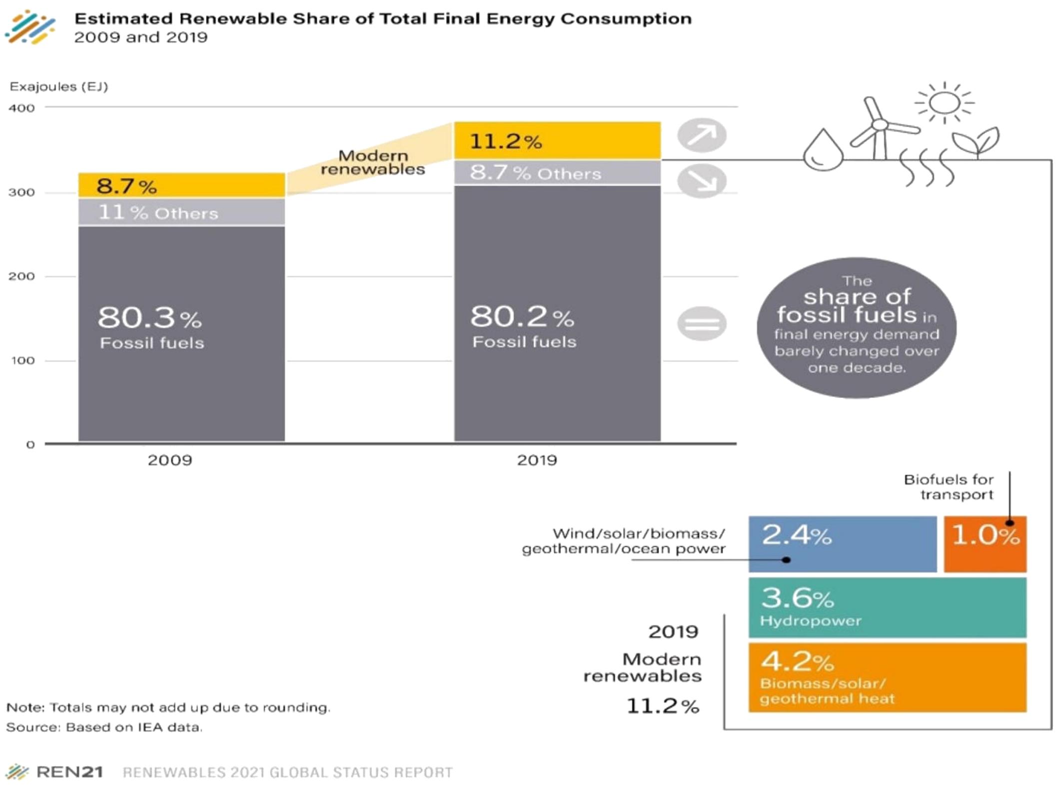


**FIGURE 1:** Estimated Renewable Energy of Total Final Energy Consumption 2009 and 2019 [16].

Solar and wind energy are amongst the several technologies for green energy generation in the literature that are frequently used because they are viable options both technically and environmentally [18]. The quantity of solar energy getting to the Earth's surface is about 100,000TW [19]. The total global primary energy consumption in 2022 is 12,476.6 million tons of oil equivalents [20].

Solar energy is predicted to play a very vital role in the future global energy requirements and particularly in developing countries [21].

Amongst all renewable energy technologies, solar photovoltaic (PV) grew fastest with a yearly increment of 58% during the period of late 2006 to 2011 [22]. As shown in Figure 2, PV also increases from 29% in 2014 to 58% in 2020.

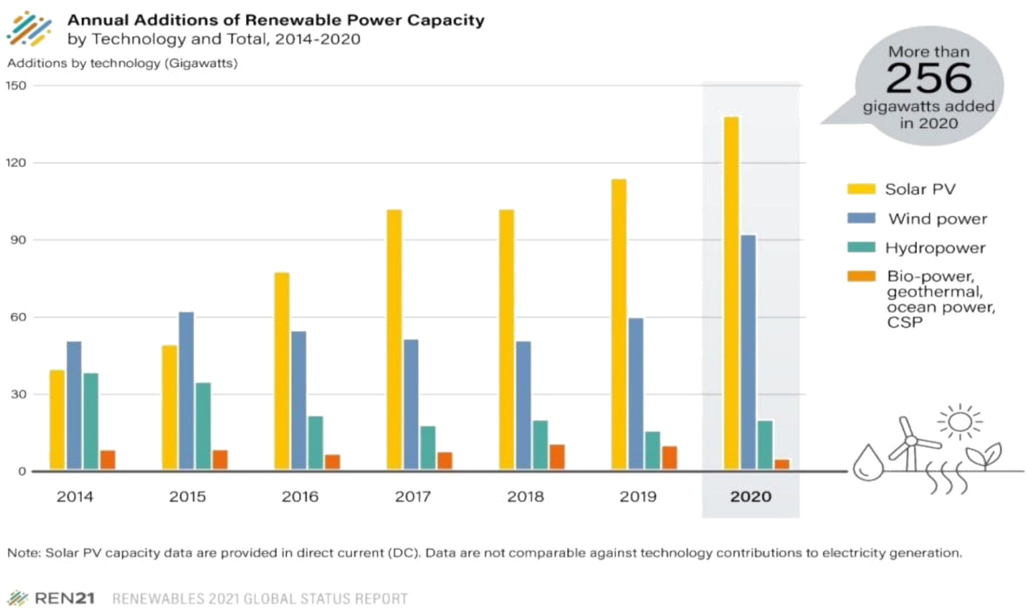


**FIGURE 2:** Annual Addition of Renewable Power Capacity by Technology and Total, 2014 – 2020 [23].

Wind is a usual manifestation linked to the movement of air masses triggered primarily by the differential solar heating of the earth's surface [24]. Electrical energy can be produced from wind energy when wind blow over a wind turbine. The kinetic energy of the wind at rated wind speed is converted into mechanical power by turning the turbine blade, thus producing electricity through the shaft connected to the alternator [25], [26]. Wind power utilization in the world is currently at the scale-up development [27]. Globally there was an increase of 38.475GW to wind power generated in 2009, 39.062GW (from159.1GW to 198GW) in 2010 and up to 60.4 GW (from591.1GW to 651GW) in 2019 as shown in Table 1.

**TABLE 1:** Wind Power Global Capacity and Annual Additions, 2009-2019 [28].

| Year | Annual Additions (GW) | Year-end Total (GW) |
|---|---|---|
| 2009 | 38.475 | 159.1 |
| 2010 | 39.062 | 198 |
| 2011 | 40.635 | 238.1 |
| 2012 | 45.03 | 282.9 |
| 2013 | 36.023 | 318.7 |
| 2014 | 51.7 | 369.9 |
| 2015 | 63.8 | 432.7 |
| 2016 | 54.9 | 488 |
| 2017 | 53.5 | 540 |
| 2018 | 50.7 | 591 |
| 2019 | 60.4 | 651 |

**(2.1) Renewable Energy Potential in Nigeria**

In 2019, 46% of Sub-Saharan Africa representing 570 million remains the region with the lowest electricity access rate [29]. Nigeria which is the Africa's largest economy has about 10% of the un-electrified population of Sub-Saharan Africa [30]. In 2019, her electricity demand is estimated to be 144.5 TWh/yr [31].

A country with a population of over one hundred and seventy million barely generates meager 6000MW of electricity which by international standard the produced power is not enough to sustain healthy living let alone to support infrastructure and industrial development [32]. In 2017, about 40% of the population had no access to reliable, affordable and sustainable electricity [30]. Industrial and economic development has been hindered by Inadequate power supply resulting in the underperformance of agro-allied industries, wastage of perishable farm produce, reduced efficiency in manufacturing and service industries [33]. Surprisingly there are huge nonrenewable energy sources such as natural gas, crude oil, coal and lignite available: natural gas reserves and crude oil are estimated to be 5,000 billion and 36.2 billion barrels $m^3$ respectively [34] [35]. The deficit from conventional energy is attributed to poor supply of infrastructure [36]. Renewable energy sources such as: solar, wind, geothermal, hydro and biomass are readily available in the country [37].

Nigeria with her location on the equator is within a high sunshine belt where solar radiation is fairly well distributed [21]. The amount of electricity generated by a solar PV is a function the solar insolation and ambient conditions such as: spectral distribution of incident radiation, temperature, dust and cloud cover, angle of incidence of solar radiation, wind speed, and operational efficiencies of system components [38]. Since this is a comparative analysis, the ambient conditions will be ignored. As shown in the Table 2, to determine the solar potential, a town is selected from each of the six geopolitical zone of the country viz: Gombe from North East (NE), Katsina from North West (NW), Abuja from North Central (NC), Osogbo from South West (SW), Owerri from South East (SE) and Port Harcourt from South South (SS).The value of average of thirty-eight years (1984 to 2021) daily global solar radiation was obtained from website National Aeronautics and Space Administration (NASA), an independent agency of the US federal government responsible for the civil space program, aeronautics research, and space research [39] as shown (Table 2). The accuracy of data provided by NASA is sufficiently high accuracies for all locations on the globe [40] [41].

**TABLE 2:** Solar Insolation of selected town in Nigeria.

| Zone | Lon. | Lat. | Monthly Solar Insolation ($kW/m^2/day$) | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | J | F | M | A | M | J | J | A | S | O | N | D | **AN** |
| Gombe (NE) | 11.17 | 10.28 | 5.6 | 6.0 | 6.4 | 6.3 | 6.1 | 5.8 | 5.3 | 5.0 | 5.5 | 5.9 | 5.8 | 5.5 | **5.8** |
| Katsina (NW) | 7.62 | 12.98 | 5.5 | 5.8 | 6.4 | 6.7 | 6.4 | 6.0 | 5.8 | 5.4 | 5.9 | 5.8 | 5.5 | 5.3 | **5.9** |
| Abuja (NC) | 7.40 | 9.08 | 5.4 | 5.7 | 6.1 | 6.0 | 5.6 | 5.1 | 4.6 | 4.2 | 4.8 | 5.4 | 5.8 | 5.3 | **5.3** |
| Osogbo (SW) | 4.54 | 7.78 | 5.0 | 5.2 | 5.3 | 5.2 | 5.1 | 4.5 | 3.9 | 3.7 | 4.1 | 4.6 | 5.1 | 4.9 | **4.7** |
| Owerri (SE) | 7.04 | 5.51 | 5.1 | 5.2 | 5.0 | 5.0 | 4.8 | 4.3 | 3.9 | 3.9 | 4.1 | 4.4 | 4.8 | 4.9 | **4.6** |
| Port Harcourt (SS) | 6.98 | 4.85 | 4.9 | 4.9 | 4.6 | 4.6 | 4.3 | 3.6 | 3.4 | 3.7 | 3.6 | 4.0 | 4.4 | 4.8 | **4.2** |

The annual average solar insolation for NE, NW, NC, SW, SE and SS were 5.8 kW/m2/day, 5.9 kW/m2/day, 5.3 kW/m2/day, 4.7 kW/m2/day, 4.6 kW/m2/day and 4.2 kW/m2/day respectively. The minimum solar insolation was in August for NE, NW, NC, SW, SE and July for SS with solar insolation of 5.0 kW/m2/day, 5.4kW/m2/day, 4.2kW/m2/day, 3.7kW/m2/day, 3.9kW/m2/day and 3.4kW/m2/day respectively.

Similarly, the maximum solar insolation was for NE, NW, NC, SW, SE and SS were 6.4kW/m2/day, 6.7kW/m2/day, 6.1 kW/m2/day, 5.3kW/m2/day, 5.2kW/m2/day and 4.9kW/m2/day respectively

As shown in Figure 3, for most month the solar insolation is highest in NW then NE, NC, SW, SE and SS in that order.

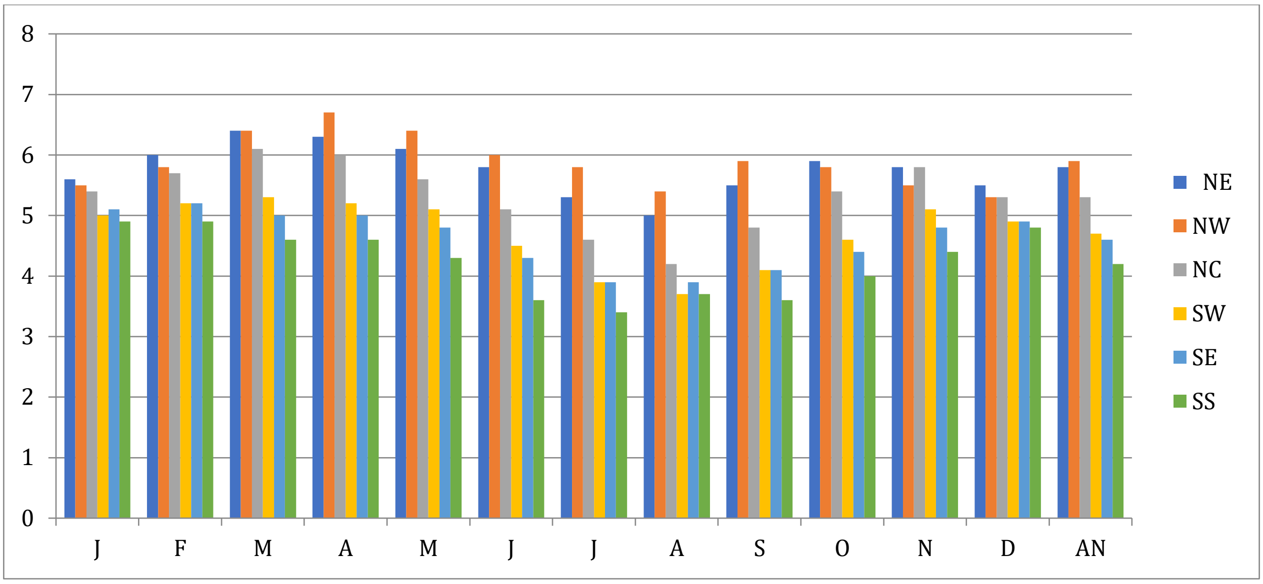


**FIGURE 1:** Solar Insolation of selected town in Nigeria.

From the figure, yearly average daily solar insolation in Nigeria is between 5.9 kW/m²/day in the North and 4.2 kW/m²/day in the South equivalent to annual solar insolation of 2.155 MW/m² and 1.534MW/m²respectively.

There were several researchers who assessed wind potential in several part of Nigeria: [42] assessed selected sites from three major geopolitical zones. [43] studied three selected sites within Lagos metropolis. [44] investigated three locations in south-south Nigeria while [32] covers six selected locations in the same zone, [45] investigated Kastina state, [9] assessed local meteorological site in Sokoto State, [46] assessed Edo state, [47] evaluated the vast Nigerian onshore and offshore and [48] investigate Aliero, Kebbi state. [49] analyzed the sustainable and economic benefits for deploying and integrating wind energy into Nigeria energy mix. Their research reveals that and offshore and onshore wind speed lies between 1.9 m/s to 8 m/s depending on the location.

From the wind map (Figure 4) it is clear that there is location such as Kastina, zamfara etc with very good wind potential having speed above 6m/s which is suitable for electricity generation. The wind potential in state like Kogi, Ekiti, Edo etc are only appropriate for water pumping.


**FIGURE 2:** Wind Map of Nigeria [50].

Several Indigenous researchers revealed that Hydro Potential in Nigerian is high with they estimated to accounts for over 32% of the total installed commercial electric power capacity, in fact the overall large-scale potential exceeds 11,000 MW [51]. Additionally, there are about 37.0 MW aggregate capacities of small hydropower stations installed by government and non-governmental company [52]. There are also about thirty geothermal potential spots in the country. From available waste and other sources, the country produces about 2.10 x 109 GJ of biomass energy yearly [53] [54].

## (3) DISTRIBUTED GENERATION

DGs are also called; dispersed generation, on-site generation, decentralized generation, embedded generation (EG), situ generation, decentralized energy or distributed energy, generates electricity from many small energy sources [55]. In literatures there are several definitions attributed to DG [56]. DG is defined as an electric power source connected directly to the distribution network or on the customer site of the meter [55], [57], [58]. The International Energy Agency defines distributed generation (DG) as an electricity source that is connected directly to the distribution network to supply a local consumer and support the distribution network [59]. [60] defined DG as small scale generators connecting at the distribution level. [61], define DG as small-scale power generations technologies of low voltage type that provide electrical power at a site closer to consumption centers than central station generation.

DG has numerous advantages of which includes: Low cost (no transmission line), Easy to maintain and operate, Lessens the complexity, Eco-friendly (especially renewable), Reduced lines and power losses, better power quality and reliability, mitigate the impact of massive grid failure, ‘congestions’ mitigation at distribution and transmission level, effective reactive power control, shorter power outages and mutual backup with the large power grid [62]-[67]. With the worldwide exhaustion of fossil fuels and deregulation of power industry, the integration technology of distributed generator (DG) has attracted rapidly increased attention during the past decade [68]. The past era has seen a global movement toward the utilization of distributed and renewable resources [69]. The reason is obvious: it provides clean, dependable and profitable power supply [70]. It usually provides a valuable substitute to traditional sources of electric power for commercial, industrial and residential applications.

It is a veritable alternative that utility planners should explore in their quest for the finest solution to electric supply problems [71].

The DGs are of relatively small sizes ranging from a few kW to around100MW [72]-[74]. They entail of electric power generator sources link to an electric distribution network which are used for generating electricity on-site. They are designed at the customer load site which can be utilized to achieve the energy obligation of a specific geographical distribution area in the following ways [75]:

i. Peak shaving: where they are used to generate a portion of customer's electricity onsite to reduce the amount of electricity purchased during peak price periods.

ii. Standby generation, where they serve as a backup to power supply and as wholly a green power source using renewable technology for improved reliability.

The difference between distributed generation and power plants operating in the modern transmission system is at least partly semantic. Although both types of generators operate in an interconnected system, power plants on transmission systems are generally located far from the loads they serve and are operated by utilities, whereas distributed generators are typically located on-site close to the loads they serve and could be operated independently by a customer or independent power producer instead of a utility company [76].

**(3.1) DG Technologies and Types**

Base on the link to the grid, it can be categorized as either Grid connected or autonomous DG [77]. These are further sub-divided into two groups considering the availability: firm and intermittent power. It is termed as firm power generation when the power control of the DG is a function of energy demand. In this scenario it is often designated as supporters; during the periods of high consumption. The intermittent (irregular) power generation is not dependable for accomplishing all load requirements due to its erratic nature [62]. Based on capacity, DG can be classified as depicted in Table 2.

**TABLE 2:** Classification of DG Based on Capacity [56].

| Classes | Capacity |
|---|---|
| Micro-DG | 1 W < 5 kW |
| Small DG | 5 kW < 5000 KW |
| Medium DG | 5 MW <50 MW |
| Large DG | 50 MW<300 MW |

**(3.2) Optimal DG Allocation Methods**

Proper location of DGs in power systems is important for obtaining their maximum potential benefits [78]. The optimal siting and sizing of DG in the distribution system decreases the losses, improves the voltage profile and improve the economics of the system [75][79]. For optimal allocation of DG in distribution networks, different objectives such as power loss minimization, improvement of voltage profile, network investment cost minimization, reduction of environmental impact, etc. were proposed by researchers using single or multi objective problem formulation [80]. Normally, the positioning of distributed generation resources would be close the load centers to attain the optimal benefits [81]. However, if there are several options for the positioning of micro-grid with different costs, it may be economical to resolve the DG best location and sizes with prominence on deployment cost over the sizes of closer loads [69]. The optimal siting and sizing of DGs in distribution systems have been scrutinized in several literatures from different view point. The techniques can be summarized into four: Analytical approach, Classical approach, Meta-heuristic Optimization approach, Hybrid approach and others approaches [82], [83].

Analytical methods though not appropriate for a system with bulky and composite networks are performing well for simple and small systems [84]. Several analytical algorithms have been deployed to solve optimization problem of which includes: 2/3 rule or Golden rule, Exhaustive Search with sensitivity factor, Linear differential, Loss Sensitivity Factor (LSF), power stability index (PSI), voltage sensitive index (VSI) etc.

Various classical optimization methods are doing better than analytical approaches for determining a near-optimal solution with improved precision [85]. Classical optimization methods include: Gradient Search (GS), Non-Linear and Mixed Integer Non-Linear Programming (NLP and MINLP), Dynamic Programming (DP), Exhaustive Search (ES), ordinal optimization Continuation Power Flow (CPF) etc.

A metaheuristic algorithm is a reiteration-based technique that inspects and manipulates the candidate solutions by combining several concepts so as to control a subservient heuristic [86]. These algorithms are capable of considering several types of single or multiple objectives [59] However, their performance in terms of optimality and efficiency firmly depends on the adjustment of optimization parameters. Particularly, these algorithms may not be able to obtain global optimality in the case of large-scale DG placement due to premature convergence [87]. An example of metaheuristic algorithms includes: Genetic algorithms, Particle swarm optimization, Tabu search, Simulated annealing, Ant colony optimization, harmony search, artificial bee colony, cuckoo search algorithm, ant lion optimization algorithm, shuffled bat algorithm, shuffled frog leaping algorithm, firefly algorithm, hybrid TS-PSO algorithm, hybrid ACO-artificial bee colony algorithm, hybrid particle artificial bee colony-harmony search algorithm, hybrid big bang-big crunch (BB-BC) algorithm etc. for example, [88] solved optimization problem using a new ant lion optimizer (ALO) considering different objectives. [65], applied three step procedures, based on Genetic Algorithms and Decision Theory to establish the best distributed generation siting and sizing on an MV distribution network.

According to [85], several other optimization methods have been efficiently used to solve optimization problem in several literatures such as: a backtracking search optimization algorithm, Pareto Frontier Differential Evolution (PFDE), Symbiotic Organisms Search (SOS) algorithm, Quasi –Oppositional Swine Influenza Model-based Optimization with Quarantine (QOSIMBO-Q), Quasi-Oppositional Teaching Learning based Optimization, Supervised Big Bang - Big Crunch (BB-BC), Modified Honey Bee Mating Optimization (MHBMO), Modified Bacterial Foraging Optimization (MBFO), Modified Teaching Learning Based Optimization (MTLBO) and improved harmony search algorithm. The choice of optimization technique depends on the objective function as summarized in Table 4.

**TABLE 3:** Optimizing techniques, merits and demerits [81] [89].

| S.No. | Objective(s) | Technique(s) | Merit(s) | Demerit(s) |
|---|---|---|---|---|
| 1. | Reduction of the system losses as single objective | Artificial bee colony (ABC) based optimization algorithm | For global optimization an multi modal and multi variable results are excellent | Low efficiency, very much dependent on the control parameters associated to the algorithm |
| 2. | Losses minimization and voltage profile improvement | Backtracking Search Optimization Algorithm (BSOA) for DG placement | Excellent property for global optimization solution | Followed non-uniform crossover strategy, a random mutation strategy that is only one direction for each individual target |
| 3 | Improvement of voltage profile as single objective | Harmony search algorithm | Able to handle continuous and discontinuous function, free from disparity, able to conquered of GA and good global search. | Local convergence speed is lethargic |
| 4. | Reduction of cost and system losses | Meta heuristic approach Shuffled frog leaping (SFLA) algorithm | Highly efficient and good computing performance and global search capability | Suffer from uneven initial population, lethargic searching speed and catching local maxima easily |
| 5. | Reduction of system losses, cost, improvement of voltage profile and system loadability | Improved Particle Swarm Optimization (IPSO) and MCS based algorithm | High degree of accuracy and net saving was more as compare to other techniques and capable to handle all types of loads as DG penetration level increases | Difficulty faced to select the inertia weight |
| 6. | Minimization of the (losses, cost), load growth and improvement of voltage profile, system reliability | Multi-objective Tabu Search (MTS) based approached proposed | Capability to have an adaptive memory that produce most flexible behavior | The method is efficient for local optimization only and time consuming |
| 7 | Minimization of costs, emission and system losses and improvement of voltage profile | Improved honey bee mating optimization (HBMO) algorithm | Provides better and accurate result in shorter time and have excellent computational capacity | Become slower and inefficient when number of iteration increases |

### (3.3) Impact of DG in Distribution System

DGs are a dependable way out to provide profitable and reliable energy to consumers [4]. It can offer numerous gains to the system [90]. As a complement to centralized generation, the employment of DGs has many positive effects on power systems, especially on distribution systems with long power-supply distance and weak network structure, such as shifting the peak loads, reducing the network losses, improving the voltage profiles, enhancing the system reliability and so on [91] – [93].

## (4) RENEWABLE DG TECHNOLOGY

DG technologies include photovoltaic, wind turbines, internal combustion engines, combustion turbines, micro-turbines and fuel cells, among others [58], [94]. The DG technologies can be classified into renewable and non-renewable. DG is not synonym for Renewable sources [95], though most DG uses renewable energy due to its benefits. There is a significant desirability for Renewable DG units due to their capability to increase the distribution system efficiency [96]. Table 2 depicts the renewable energy sources use in DG, its electric power generation range, merit and demerits.

**TABLE 4:** Major DG Technologies and their Merits and Demerits [5], [55], [74].

| S/N | DG Technology(ies) | Electric Power Generation Range(s) | Merit (s) | Demerit (s) |
|---|---|---|---|---|
| **1.** | Solar Technology.<br>Solar Photo-Voltaic (SPV).<br>Solar Thermal Power Plant.<br>Solar Thermal (Lutz System) | 200W–3000kW<br><br>1MW–80 MW<br><br>10–10 MW | Easiest and cleanest<br>Maintenance cost is very less.<br>Fuel free<br><br>Over all environmentally friendly | Require large solar collector<br>Solar thermal systems are health hazard<br>Need battery bank for storage<br>SPV module pose disposal problem<br>Initial cost is very high |
| **2.** | Small Hydro<br><br>Micro Hydro | 5kW–100MW<br><br>1kW–1MW | Free and renewable energy source, Less installation cost Eco-friendly.<br><br>Small size, light weight Emission free, Less noise | Generation depends on water. Affected in flood time. Load demand cannot be meet out, Initial cost is more, and Cost is more.<br>Low working temperature, less efficiency, and Initial cost is more. |
| **3.** | Ocean Energy | 100kW–1000kW | Carbon free. It is a renewable based energy source. | Difficult to harness, very less efficiency, and Initial cost is high |
| **4.** | Wind Turbine | 200W–3MW | Generation cost is very less, No adverse effect on global environment.<br>Fuel free, and Saving of land use. | Wind generators are hazards. Noise pollution, Wind speed affects the output, and Variable power production highly dependent on wind speed. |
| **5.** | Biomass Energy | 100kW–20 MW | Renewable energy source.<br>Reduce Green House Gas (GHG) emission.<br>Lessen dependency on upon conventional fuel.<br>Stops desertification. | Combustion of biomass produces air pollution.<br>Source limitation.<br>Maintenances are expensive.<br>Soil erosion. |

## (5) FACTOR HINDERING ESTABLISHMENT OF DISTRIBUTED GENERATION

Regardless of the numerous advantages offered by renewable distributed generation technologies, there could be numerous economic and technical challenges if the DG is inappropriately integrated with the existing distribution networks [59]. Aside the technical challenges, its integration in distribution networks may also create safety problems [97], [98]. Undesired effects such as increased fault current, readjustment of the control and protection systems, fluctuations in the voltage profile, inversion in the flow direction etc. may arise if the integration of DG is not properly planned [99]. Unlike conventional generation, DG is not dis-patchable and does not deliver any supplementary service to the system; for that reason, a huge amount of DG pressures the power system operation, drawing it near to the stability margin [100]. DG technology is presently encountering the following difficulties [66]:

i. High access cost and is hard to control; and

ii. Intermittent and fluctuating nature of DG (such as photovoltaic generation and wind power) may endanger large power grid.

## (6) SUMMARY

In this paper the latest data of the status of renewable energy technology in comparison with fossil fuel was presented as well as its merits. Impact of DG in distribution system, its classification, renewable DG technologies and factor hindering establishment of Distributed Generation were also discussed. The DG installation reduces the installation of new lines and uses the peak load period.

Distributed generators (DGs) are reliable solution to provide power which accommodate the load increase and relieve network overload in addition to offer technical and economic benefit.

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