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Review of Grid Integration with Conventional & Distributed Generation Sources

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ABSTRACT

The growing need of environmental protection, energy savings, reducing mismatch between supply and demand is putting pressure on replacing distributed generation (DG) sources. It is because the DG technologies usually empower distributed Generators for their operation. And, various conventional and non Conventional distributed energy sources (generators) have different integration issues when connected with grid. This paper reviews the state of art of different technologies used in Distributed Generation along with their integration issues and optimization necessities from different aspects. Distributed Generation sources introduced in modern power system in integration issues with conventional energy sources resulting in non uniform voltage profile, frequency stability which need to be optimized with various algorithms.

Index Terms: Grid Integration, Distributed Energy Resources, DG Optimization Techniques, Electric Power System.

I. INTRODUCTION

Most of the Traditional/conventional electric power systems are based on central power generation [1]. Conventionally in these system (s), a series of high power generators feed power through transformers to high voltage transmission network; aiming to transport power/energy over notable distances of several kilometres. This power is then taken through transformers at distribution side available for end users. However around the globe, Distributed Generation is gaining popularity due to less transmission system capacities with reliability in existing system. [2, 3]. Generally, the term Dispersed or Distributed Generation refers to any electric power production technology that is integrated within distribution systems, close to the point of use [2-4]. In early nineteenth century, industry gained interest in installing dispersed resources in a utility [2-5]. It is because of the invention and development of various resources such as photovoltaic cells, wind generation, battery storage, fuel cells and/or demand-side management solicitations [4-10]. However, these units are of smaller sizes and can only be connected directly to the low voltage network or on the low power consumption consumer end. These resources in addition with conventional energy sources can follow the load variations flexibly. It is done methodically as when load changes it matches up due to large transmission availability. It is also beneficial in limiting the frequency of accidents spread out as this type of system is not too large and complex which exists in orthodox systems. Due to these advantages, DG concept and sources are being in research, development and use worldwide for last many years [3-18] various studies have been made and/or in progress to investigate the performance of Distributed Generators in Power system both, quantitatively and qualitatively [4-25]. This paper reviews the classification of Distributed Generation along with their benefits and challenges, various analytical studies performed for their optimization and their outcome in mitigation the stability of power system. The rest of the paper is organised as follows. Section 2 presents a discussion on classification of distribution generation systems. Section 3 highlighted the key challenges of distribution generation systems and the associated work done

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over last several years. A discussion on integration of distributed generation systems in grid is presented in Section 4; with finally Section 5 highlights the stability issues and challenges with future directions.

II. CLASSIFICATION OF DISTRIBUTED GENERATION

Distributed generation primarily focuses on integrating various sources with same or different power capacities to the grid. It can be broadly defined any source of electric power which have capacity confined in limits, directly or indirectly connected to the low power network where its power can be consumed by end users. In an another definition, IEEE defined it as the generation of electricity by facilities that are sufficiently smaller than central generating plants to allow interconnection at nearly any point in a power system [25-32].

In addition, the parameters such as voltage profile improvement index; line loss reduction index; environmental impact reduction index; and DG benefit index are primarily taken into consideration for their efficient use [34].

Therefore, several studies have been made over the recent years for monitoring and optimising these parameters to obtain the best possible efficiency of these sources. Some typical examples include: [1-4], [11-44], [57-76], & [76-85].The most mature and cost effective resource among different renewable energy technologies is Wind. It was initially introduced as a source for stability investigation for deregulated power system. Several studies have been made on wind source. For example, Jeff [22], mentioned that, the power resource in form of wind is intermittent and involves asynchronous generator and various excitation issues when used in interconnected systems. The key distributed generated sources and their capabilities are mentioned in Table 1.

For an efficient integration of various sources mentioned in Table 1, the location of DGs in power systems is very important for obtaining their maximum potential benefits [33-36].

Table 1
Capabilities and system interfaces of Distributed Generation

Technology	*Capability Ranges*	*Utility Interface*
Fuel cells	A few tens of kW to a few tens of MW	dc to ac converter
Micro turbines	A few tens of kW to a few MW	ac to ac converter
Combustion turbine	A few MW to hundreds of MW	Synchronous generator
Combined cycle	A few tens of MW to several hundred MW	Power generator
Internal Combustion Engine	A few hundred kW to tens of MW	Synchronous. generator or ac to ac converter
Oceanic	A few hundred kW to a few MW	Four-quadrant. synchronous machine
Geothermal	A few hundred kW to a few MW	Synchronous generator
Wind	A few hundred W to a few MW	Asynchronous generator
Solar, photovoltaic	A few hundred W to a few MW	dc to ac converter

The interconnected system comprises of mainly mini hydro and wind (operate as peak and base power plant) in connection with available conventional source. In decentralized power system, new concept is introduced [19-32], [36-42], [49-63], with various challenges to incorporate advanced technologies in a conventional system.

III. DISTRIBUTED GENERATION TECHNOLOGIES & CHALLENGES

(A) Fuel Cells

Fuel Cells (FC) are electrochemical devices converting the chemical energy content of a fuel directly to electrical energy [23]. Fuel cells, are initially introduced by Narayan in 1994 [1] and can broadly characterized by the material of electrolyte used. FC is primarily used as standalone systems depending upon availability and type of load required [39]. There are several different FC technologies have been developed; with power ranging up to 5 kW [44], up to 250 kW [46]. Fuel cells are low noise, clean, efficient, and easy to install in compact units. Several studies have been made in the development of FCs. Some key studies include in [1- 15], [25-35], [40-56]. Despite of several advancements such as loading electrodes, high power density, high specific power and energy, there are several challenges related to FC. Some typical challenges include Power quality, response to load changes and low efficiencies. Therefore, an analysis of storage capacity and cost effectiveness of fuel cells still need to be addressed as it fulfil the basic requirement to be operated as DG source.

(B) Photovoltaic Systems

Photovoltaic (PV) cells are devices that convert sunlight to electricity, bypassing thermodynamic cycles and mechanical generators. Several researchers, such as Kanellos [51], have claimed that these systems are suitable for interaction with power system having multiple resources connected together. PV solar panels normally consist of discrete multiple cells, connected together either in series or parallel, that convert light radiation into electricity. In general, the power of a single module varies between 50 and 100W and its efficiency are near about 15%. It is expensive on basis of technology and installation [38]. The main concern using the photovoltaic technology is stability mainly voltage stability, as integration and output are dependent. These are generally low power (50 and 100W per module), so a high number of PVs needs to be integrated to generate adequate level of power suitable for power grids. Several theoretical and experimental studies have been made in this area. For example, [42] from their Experimental results suggested that the maximum power point tracking part of the control system of the PV generator dominated the dynamic behaviour of the system, down-scaling the conventional grid control concept to the low voltage grid [32]. Photo voltaic systems provide supply for intermittent type of load (peak type subjected to voltage variations). The type of load offers voltage and frequency instability and when connected with grid, leads to non sequence currents. Different types of voltage control techniques were used to mitigate the negative effects of rapid changes in irradiance were presented in literature [57- 64]. Therefore, various methods have also been proposed for stability of micro grid with power electronic converters and control strategies [66- 70], in addition to faulty and natural condition of grid under synchronism [56 - 60]. The output of photovoltaic also depend on weather conditions [74].To overcome this drawback, various techniques like MPPT and P & O have been presented in literature [71 -76], [76 -92]. The key issues on integrating PV sources with power grid are bus voltage fluctuation, active power variation, reactive power flow and poor system dynamics [92].

(C) Wind Energy

Wind energy uses various types of wind turbines and for convert ting mechanical energy to electrical energy using induction generators like SEIG, SCIG and DFIG [79]. There are many small wind turbines available that produce less than 5kW and some large utility-scale units produce over 1 MW [74]. Wind power generator normally operated at variable speeds due to wide dynamic fluctuations in wind speed [92]. Normally there are two trends concerning wind power. The first one is the introduction of permanent magnetized direct driven machines and the second one is wind farm with DC interconnections. In case of permanent magnet direct driven machines the construction gets simplified while reducing rotor losses [37]. In permanent magnet, when used in distribution network, the wind power technology also has challenge of reactive power control. The other trend concerns wind farm configurations with low cost profile and high efficiency. According to the interconnection requirement, these reactive sources have to be adjusted regularly to maintain power factor within the desirable range when wind fluctuates. In practice, however, most wind farms install fixed-capacitor banks to meet the reactive power compensation requirement at their maximum output level [41]. There are several solutions existing for wind power technology and some key research studies are presented in literature [93 - 96]. Power control techniques like PPET, SVC compensation have also been proposed with off grid and on grid applications [97 -99]. But the other major drawback of this technology is that the turbine only produces electricity when the wind is blowing at good value which is not frequent.

(D) Small Hydro-Turbines

The terms small hydro defines installations for the production of hydroelectricity at low power levels. Usually, the power from such installations can be in the range of 5–100 kW for ‘‘micro hydroelectric’’ power stations, and between 500 kW and 10MW for mini hydro-power stations [40]. Small hydro turbines employ mini hydro generation with small capacity and used for peak power plants, integrated with wind or photovoltaic systems [44]. The hydroelectric potential is normally used as conventional energy source and employed in Centralized Power system. In centralized power system, various faults occurs which leads to failure of Grid. Normally, the interconnected system is disconnected without fault to check stability and reliability of a system. Islanding operation also been discussed in literature pertaining to Hydro Electric and other DG sources [85]. The intentional Islanding operation also performed to find the constraints of stability under faulty conditions [91]. Non Linear Voltage stabilizer also proposed in integration of power system to overcome oscillations under faulty conditions and in integration mode [92].

(E) Micro turbine Based Energy

There are some distributed power schemes based on the micro turbines as the prime mover for the generator [70]. In these schemes, the generator connected to the micro turbine is a synchronous machine whose output voltage has a frequency directly proportional to the angular speed of the micro turbines shaft [70]. Micro turbines are one of the most promising DG products currently on the market [24]. Their key technical features are high efficiency (as high as 85%), and low emissions (< 15ppm No_x and CO). These can also provide fuel flexibility, e.g., oil, diesel, natural gas, biogas, methanol, hydrogen, etc. The key challenges for these DG sources are intermittent power, small load factor.

(F) Reciprocating Engines

This DG technology was developed more than a century ago, and is still widely utilized in a broad array of applications [1]. The engines range in size from less than 5 to over 5,000 kW, and use diesel, natural gas, or waste gas as their fuel source. The fuels of reciprocating engines have relatively higher emission. Current efficiencies are in the range of 30-40%. The key challenges for these DG sources are: low load factor, low response towards variation in load.

(G) Industrial Combustion Turbines

A combustion turbine is a mature technology and range from 1 MW to over 5 MW. Various studies also performed to study transient analysis for Combustion turbines [61]. They have low capital cost, low emission levels, but also usually low electric efficiency ratings. For last several years, development efforts on these turbines are focused on increasing efficiency levels for this widely available technology [71].Industrial combustion turbines are being used primarily for peaking power and in cogeneration applications.

These technologies provide deployment and integration of distributed resources and generation including renewable energy resources.

In summary, the distributed generations’ technologies include wind generators, photovoltaic, and biomass generators with their sizes varying between several kW to a few MW. For economic analysis, the costs of the system with different DG technologies and energy storage devices can be compared using the software tool “hybrid optimization model for electric renewable (HOMER)” [131].

The next section discusses the integration of these sources in the grid.

IV. GRID INTEGRATION & BENEFITS

In Renewable Energy and Distributed Generation Task Force (REDGTF) Action Plan [9], renewable energy projects developed and policies advocated have been presented. The integration of sources with Grid (DG only) [100- 103], (DG and Conventional) are presented in literature to increase reliability and capacity of existing system to meet the demand [92]. There are many benefits with use of Distributed Generation introduced in conventional power system with use of power electronic converters for stability [70], reliability for enhancement [63], and power control [103- 115]. A discussion on these is presented as follows.

(A) Reliable

The electric power system is able to deliver electric power without interruption is termed 100% reliable. The reliability is justified through various factors. For example, the frequency and power control is done on the basis of the characteristics of these generation units for providing customers with quality power with maximum power output [48]. Power and frequency control through compensation techniques, which empower (DG) sources at a customer level to provide flexibility in operation and also increases reliability of a system [65].

(a) Congestion Factor

With sudden increase in load, transmission lines become overloaded, this leads to high tension among the lines, and frequency of breakdown also increases [21]. With introduction of (DG) the availability of Generation and Available transfer capability (ATC) also improves which further reduce the value of congestion factor [68].

(b) Independent Operation

DGs are independent in operation as they are capable of managing load variation efficiently. Thus, they are not prone to interconnected systems, if connected they are immune to black outs or severe faults which spread out very fast in large interconnected system which doesn’t fulfil the condition of reliability [116-123]. The installations of DGs are like that they are connected as back up of one another such as near the feeders, near the end and at pie line which increases the reliability of system.

(B) Ancillary Services

(a) Load Frequency Control [65]

In large power system, there is large gap between demand and generation which leads to load mismatching [78]. DGs have main feature of load follower which allow DGs to compensate load effect keeping frequency constant. DGs also help to maintain security of a system [80].

(b) Spinning Reserves

DGs normally operate at reduced load and able to pick up a load instantly without leading to outage or taking additional support. This helps in maintaining synchronization among different units and leads to reliability [17]. IC or Reciprocating technology can be used to bridge a gap between load compensation when load suddenly shoots up.

(c) Voltage Profile [34]

DGs also provide an additional feature of reactive power compensation by injecting or absorbing reactive power to maintain voltage profile [34]. It also improves power quality by minimizing the problem of Voltage sag and swell as compared to centralized generation scheme [44].

(C) Loss

The main losses occur during transmission and distribution of power in grid. The major reason for losses is high value of current and line resistance. To reduce heavy current and resistance, source should be near the load. With the penetration of DGs in distribution systems, it usually locates near the load. As a result, it reduces the line current through the power line of transmission and distribution systems. On the other hand, it also reduces the distance between power supply and load, contributes to reduction in line resistance. This helps in reducing considerable amount of line losses and several studies in this area have been reported in [123-, 127].

(D) Environment Friendly

The major contribution to energy sector in terms of generation is from thermal, hydro and nuclear power plants which are not friendly to environment where as DGs penetration alleviate the use of renewable energy sources as well as promote the concept of clean energy. (DG) sources also reduce the gestation period and installation cost. With the introduction of DG, Carbon footprints are also reduced [46].

(a) Energy Utilization

DGs penetration alleviates the use of renewable energy sources and increases energy utilization efficiency. Various algorithms [124- 132] have been presented power saving of Combined heat and Power (CHP) is put forward and compared to the separate conventional generation. Energy Utilization also improves Load Factor, Diversity factor of a system.

(D) Economical

(a) Accessibility

In some remote locations such as remote hilly areas or islands, power system cannot reach due to poor geographical positions, inaccessible transportation condition, or enormous construction cost. However, with penetration of DGs, those problems can be solved. Among the technologies of DGs, reciprocating engines and gas turbines, wind turbines and PV exploring solar energy can be used to supply power for remote locations [71].

(b) Consumers' Profits

DGs can allow customers to choose the most suitable power supply from different energy such as PV, wind farms, thermal plants, hydropower stations, and nuclear power plants depending upon availability, reliability and customer satisfaction. DGs can provide higher quality power needed by customers, especially industries [21]. DGs can offer higher energy utilization efficiency and reduce the cost of consumers spending in line loss, and waste energy by encouraging combined heat and power (CHP) [57] over a large commercial scale. DGs also provide reliability to consumers on their electrical part to increase their services and production.

V. OPTIMIZATION FOR STABILITY IN INTERCONNECTED SYSTEM

Distributed Generation plays an important role in enhancing the capability of power system. However, there are certain challenges in obtaining reliable desired output from a hybrid system (comprising of various sources like DPGS and conventional Energy sources). This is why various optimization techniques have been developed [16] are being used to achieve stability (transient [27], steady state [64] and dynamic [74]) and reduce losses and obtain an optimum response.

An optimization technique, by definition is a tool or an algorithm to select sensitive parameters which can be affected in environment when disturbance occurs [81-84]. Several optimisation techniques and algorithms were being developed to enhance the performance and reduce the complexity of a system [96]. A concept for the optimization of nonlinear functions using particle swarm methodology along with relationship between artificial life and genetic algorithms is most highlighted in various research studies, such as [134-142]. The Particle Swarm optimization (PSO) is mainly used for optimal design of multi-machine Power System Stabilizers (PSSS) [16]. In multi machine system, the generators using conventional (Synchronous) or distributed (asynchronous) approach can be used and optimization equations can be framed. PSO based PSS (PSOPSS) under different disturbances and loading conditions have been tested and examined [128-138]. The Small Population based PSO (SPPSO) is also used to determine the optimal parameters of several PSSs simultaneously in a multi-machine power system after a long disturbance [58]. The tuning problem of PSSs parameters is partially solved by PSO with the Eigen value-based multi objective function (MOPSO), considering robustness of a system and self examining for dynamic stability. [69].PSO has also been reported to be applied to economic dispatch problems and Power system restoration (PSR) considering DPGS and UDCP parameters [125-132].

Some other optimisation algorithm includes the particle swarm-based-simulated annealing (PSO-B-SA) optimization algorithm, which was proposed to optimizing micro-source output for the MG problem [85]. The Ant colony optimization was also proposed to investigate effectiveness in cost and safety of micro Grid is discussed [88].

Hybrid particle swarm optimization (HPSO) considered the nonlinear characteristics of the practical distribution systems. In this study [27] on HPSO, the actual measurements and practical equipment used in a system was considered.

Adaptive Neuro-Fuzzy Inference Systems (ANFIS) was incurred by instability parameters to provide better interconnection to MG to enhance power capacity of MG and then PSO algorithm was applied to find the optimum bus for connecting MG in the system to maintain voltage profile and reduction in power loss [103].

Hybrid systems exhibit both discrete state and continuous state dynamics which interact to such a significant extent that they cannot be decoupled and must be analysed simultaneously [20]. A parameterization approach to the open loop dynamic optimization of hybrid systems has therefore been proposed [20]. Parametric approach leads to new optimization analysis which leads to specific parameter analysis known as Sensitivity Analysis. Eigen value analysis and nonlinear simulation results showed that inter area modes of oscillation can be damped out effectively for wide range of loading and system configurations [24]. Eigen values primarily depend upon system and loading configurations.

In an interconnected system, along with parametric analysis, dynamic security is also important. While taking into consideration, [Zhang] [150] developed a technique using Lyapunov function to compute critical values of any parameter that induces stability in the system, independent of complexity of a system. This technique already applied to adaptive control leading to Trajectory Sensitivity Analysis (TSA) [6,].Short term voltage stability poses a significant threat to system stability and reliability [136-143]. Therefore, a dynamic optimization approach, control vector parameterization (CVP) was introduced using basics from trajectory sensitivity analysis, singular value decomposition and linear programming optimization [149].

DAIS model is a realization of the hybrid automaton. In this approach, each component is modelled autonomously and the interconnection is established by simple algebraic equations. This approach addressed large disturbances in power systems often initiate complex interactions between continuous dynamics and discrete events [31].

Another DCAM model as proposed, based on an OPF approach, was for Distribution network considering voltage and reactive power limits [145-154].

Another approach using a combination of the fuzzy logic and the particle swarm optimization (PSO) techniques for optimal tuning of (PI) based controllers for maintain frequency limits in the AC MG systems is discussed in [82].

In summary, optimization Techniques used in DG power system depend upon kind of stability like small signal, large signal, transient, or steady state stability and parameters tested for stability. The optimization involves analysing the performance indices for a system and techno-economic indices of a system.

VI. CONCLUSION

Electric Power system is one of the most complex systems of the world. In present scenario, there is a huge gap in demand and supply. To reduce the gap between demand and supply, new generation technologies such as DPGS are being introduced which have less Gestation period and less investment in terms of installation and commissioning. The hybrid DPGS have many issues while connecting these resources with conventional sources, connected with Grid.

Therefore, this paper has reviewed the Distributed Generation technologies; their challenges, benefits and key issues pertaining to their stability in interconnected power system.

The power quality and stability are major concerns for future power system, if they are on grid, or off grid configuration. To optimize the power output, various optimization techniques from evolutionary algorithm [8, 10] to Neuro-fuzzy interaction system or Particle Swarm Optimization to Genetic or Parametric Approach for Dynamic stability are reviewed.

For demand side management, DPGS can be used as stand alone, but on centralized power system, it can only be used ON Grid comprising of multiple Energy sources which have different generators, provide inter area oscillations and intermittent power loss.

The recent research [103,104] on power system is practical implementation of sources together connected with Grid to act as base and peak power plants so that reliability increases and quality of life improves. This research also leads towards the Smart Grid, which make intelligent control of Resources for their optimum use keeping their key issues intact.

In summary, DPGS offers the potential solution to provide smart way of providing power to customers. However, it has several challenges which need to be addressed. The review through this paper has provided a detailed knowledge in this area and further work will focus on providing solutions to these challenges, in order to make DPGS fully and reliably used with high efficiency.

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