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An overview of distributed generation in power systems

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Abstract

The need for smart electrical systems with minimal technological error and environmental impact is driving interest in Distributed Generations (DGs), which can have a number of additional benefits such as decreased transmission and distribution system resources, enhanced stability, and improved power efficiency, among others. Nonetheless, these benefits may or may not be valid depending on the system design and management. Furthermore, the role of small generation distributed in the low/medium voltage network has gained significance as a result of technological and administrative improvements in the electricity supply industry motivated by the advent of completion. This paper seek to address distributed generation in power systems.

Keywords: System; Generation; Environment; Stability; Electricity

1. Introduction

This essay examines the effect of distributed power generation technologies on the future power grid. There is a list of the various DG solutions built into the Indian power grid, as well as possible potential and options. Due to raising fossil fuel prices and environmental issues, the penetration of distributed generation from renewable energy sources is increasing and is expected to increase more in the future.

This growing penetration brings with it a slew of technological and economic difficulties in incorporating distributed generation into established power networks, many of which are thoroughly discussed. Several researchers have suggested ways to boost the grid by using Distributed Generation (DG). The recommendations for DG were focused on taking electricity closer to customers, reducing transmission losses, and thereby lowering maintenance and delivery costs. DG also lowers emissions, provides renewable electricity, and lowers installation costs. These factors have given DG a significant advantage over other forms of power generation in recent years, especially when considering cost. These variables have given DG a competitive edge over other forms of power generation in recent years, especially in rural areas. The global energy market for renewable energy has suggested that DG is the perfect alternative, as it accounts for more than 70% of global energy demand. Germany uses DGs to meet more than 55 percent of its electricity generation, while the United States uses DGs to meet more than 45 percent of its electricity consumption [1].

The addition of DGs to a network does not guarantee system stability or 100 percent reliability, particularly when a failure occurs due to a lack of load or generation. These faults can cause system adjustments, resulting in voltage breaches, increased actual and reactive power losses, and a reduction in potential excess power as more load is considered, among other things. Knowledge of these factors would assist in proper network management for optimum utilization; however, failure to consider these factors could result in system instability, which could lead to system collapse.

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Most analysts have focused on system stability, using indexes that are dependent on future behavior predictions that do not fully represent the system's actual future behavior in the near future [2]. As a result, the current system's stability in response to potential behaviour was included in this study. The job deemed a fraction of the Nigeria Network for successful analysis in PortHarcourt Network. The reliability analysis can be seen from a variety of perspectives, including system stability, line losses, generation failure and soon.

When it comes to determining a system's durability and stability, several experts have suggested a plethora of methods based on the activities under consideration. The research used in this dissertation would reveal the system's state by looking at voltage stability, actual and reactive power losses, system loadability, and related indices. Power flow analysis, continuation power flow analysis, and measured indices can be used to do this. The machine will be investigated using power flow analysis, which will display the state of the network under a constant load. Continuation power flow analysis will further investigate the system under load increment and its behavior at maximum loading. This will show at what point the system will tend to collapse, while the reliability indices will investigate the behavior of the network when fault leading to loss of DG is encountered. This will reveal which area to give more attention to avoid system outage or collapse.

1.1 Power System Stability

Power System Stability can be classified as rotor angle and voltage stability [3]. It can also classification based on Time Scale and Driving Forces as shown in Table 1. Time scale is sub-divided as short term, and long term.

Rotor angle is further divided into small signal and transient stability. Small signal stability is related to small disturbance akin to undamped oscillations as the name implies. Transient stability is the quality of power system to return to its normal condition after large disturbance. The time frame typically lasts for a couple of seconds, hence, the name short term time frame. Rotor angle and short term voltage stability are hard to distinguish in terms of time scale because they are typically the same. In long-term time scale where the short-term dynamics have already died out, frequency and voltage stability problems emerge. Frequency instability relates to the active power imbalance between generators and loads. The long term voltage stability typically is defined by the condition of the device such as load shedding and slowed corrective actions [4].

Power System Stability can also be defined as that quality of power system to come to normalcy after a disturbance [5]. It can also be seen as that knowledge of power system, to come to an operational equilibrium after being susceptible to a disruption for a given initial operating condition, with majority of the network variables remaining intact [6]. Disturbance can come in various forms like sudden change in load, sudden short circuit between the line and the ground, line to line fault, three phase fault, etc.

Table 1 Power System Stability Classification

Time scale	Generator- driven		Load-driven	
Short term	Rotor angle stability		Short term voltage stability	
	Transient	small signal		
Long term	Frequency stability		Long term voltage stability	
			Small disturbance	Large disturbance

Table 2 Power system component and load classifications

Time Scale	System Component	Type of Load
Instantaneous	Network	Static loads
Short term	Generator, switching capacity/ Reactors, FACTS and SVC	Induction motors
Long term	OLTC, and OXL	Regulator controlled loads

Power system comprises of some synchronous machines working in synchronism. For power system continuity, it is important that they remain in perfect synchronism under steady state condition. When the system encounters a disturbance, it will result to a force which will either make the system to be normal or abnormal. Retaining its normalcy can be seen as stability. To maintain a reliability source, it is necessary to design a power system in such a manner that it can retain stability under several contingencies to avoid loss of load, unless if connected to a faulty element. This can guarantee costumers' satisfaction and system efficacy [7].

Power system stability can be classified into steady-state, dynamic, transient and static stability [8]. Small-signal stability and transient stability can be classified under rotor angle stability. Rotor angle stability involves the study of the electromechanical oscillation inherent in a power system. It has the ability to return balance for each one of the synchronous machine in the system between the electromagnetic and mechanical torque. The problem is always associated to the power output in the system which depends on the rotor angle change. Instability can occur if the system cannot absorb the kinetic energy corresponding to the rotor speed difference.

Small signal stability is associated to a system regaining synchronism under small disturbance, which depends on the initial operating state of the system. Linearization of the system equation can be permitted when the disturbance is considered sufficiently small, which can also be associated to insufficient damping of oscillations [9].

Rotor angle large disturbance stability can be seen as transient stability. It depends on that quality of power system after being susceptible to intense disruption like short circuit on transmission line regain synchronism [10]. Transient stability could occur considering the extent of the disturbance and initial condition of the system. Dynamic voltage stability by most literature is been classified as a form of rotor angle stability, though it has been used to denote several things by most authors.

2. Different Voltage Stability Analysis Method

Voltage stability has its origin ranging from the effort of load variability to return power usage above the capability of the transmission and generation systems. Under normal situation the voltage can be maintained within the physical limits of the controllers. But when very large outages or demands occurs the controllers may get to their limits. With the more loading and utilization of the power transmission systems, the issue of voltage stability attracts more attention. Voltage collapse can occur in the systems and subsystems abruptly. Continuous monitoring of the condition of the system is therefore required. Voltage instability occurs because of the insufficient reactive power support at the weak buses. The voltage instability problem can be alleviated by providing additional reactive power support through fixed or switched capacitors [11].

[12] outlined a method that can identify the regions experiencing voltage collapse and equipment outages that cause voltage collapse in each of these regions. This method seeks to identify whether voltage collapse caused by a contingency is because of obstructive voltage instability. The advantage of this method is that it demands petite calculation and broad in attempting to find all regions with voltage collapse problems and all single and double equipment outages that cause voltage collapse in each region.

However, the graphs of P-V and Q-V are highly non-linear around the maximum allowable power point, and the slope of the curve changes sign at the maximal tolerable power point. Thus to estimate critical load using data at a specific operational point may not provide the accurate result without practically producing the entire curves. A simple method based on V-I characteristics is proposed to compute the critical load at the verge of voltage collapse [13]

This method needs present and several past operating points of bus voltage and current data. This information required for preparing the V-I characteristics are readily available in all power system. To produce the V-I characteristics, voltage and current data are analyzed using the least square method. The extrapolated component of the characteristics is then utilized to calculate the critical load at the point of voltage collapse. Initial knowledge of other system variables is not demanded in this method.

A stability factor method to identify the critical lines of critical buses of power system was proposed by [14]. The method was then compared with three established methods; Firstly is Lee's stability method margins that makes use of boundary line as voltage stability reference for determining if there is a stable system and the critical bus is that which has a stability margin near to zero. The Second method which is the Kessel's stability indices approach generates the stability indices for each of the buses in the system and those with higher value index is known as the critical ones. While the third method is referred to as the stability indicators method formulated based on the modification in the Jacobian load flow.

The stability indicator which is a point of reference of the closeness to voltage collapse is then ascertained from the eigenvalue of the Jacobian load flow. Eigenvalues computation for all load buses are done and certified voltage control area buses should have greater eigenvalue. Voltage collapse point originates when eigenvalue for critical bus decreases to less than unity.

Over the last few years, it is possible to synchronize the sampling process in distant substation economically by using the global positioning system (GPS). Phasor measuring units (PMUs) have evolved into mature tools that makes use of synchronization signals from the GPS satellite systems [14].

When a major disturbance occurs, protection and control systems have to reduce the effect, stop the degradation and return the system to normalcy using proper corrective measures. Broad area measurement and protection systems reduce severity of the disturbances by early recognition, proposition and execution of coordinated stabilizing actions. A system designed to encourage system protection schemes for frequency, angle and voltage instabilities and synchronize phasor measurement units [15]

The position of the transmission line and critical node cannot be identified in a simple way. Most methods determined the critical nodes by checking the system's closeness to singularity through either sensitivity or eigenvalue behaviour of the Jacobian matrix. Voltage phasor contains enough information to compute the voltage stability margin of a power system however, this causes computational burden for the stability of the voltage real-time estimation.

[16] proposed a voltage collapse proximity index for identifying critical transmission path with respect to the real and reactive power loading based on the voltage phasor approach. In this method, transmission path stability index is the variation between the halved voltage phasor magnitude of the generator in question and the voltage drops along the transmission path. Two types of transmission paths; the active power transmission path (a serial connected buses with decrease in phase angles occurring from a generator bus) and reactive power transmission path (a series of connected buses with decrease in voltage magnitude again occurring from a generator bus) were proposed. Here, if the value of transmission line stability index reaches zero then the power transfer on the transmission path becomes unstable due to voltage collapse.

3. Distributed Generation

The global population of about 7.7 billion people is increasing by 90 million per year which makes the global demand for energy to increase [17]. Most of the countries have embraced DG as the best form of energy supply to substitute the traditional ones like coal, large turbine, etc. Most of the European Unions have embraced DGs of which an example is Germany which has its energy supply to be about 47% DGs. In US energy market, natural gas continue to dominate the generation mix which provides 44% of the energy with solar and wind which follow suit to nearly 12% of the capacity which is driven by cooperate commitment, declining prizes, supportive policies such as renewable portfolio standards (RPS), and improved performance [18]. The world is experiencing an energy transition which will change the way energy is produced, transported and distributed and it will be affected in order to optimize energy usage and minimize cost. This can only be possible with the use of DGs especially as off-grid supply. A total shift in energy structure which could promote renewable usage is highly needed [19]

Global concerns for climate change continues to affect modern standard of living which have pushed for a transition towards sustainable energy system. Due to this, energy policies have been designed, evaluated, implemented and redesigned with the hope to reduce our anthropogenic green house gas emission, of which the energy sector contributes so much to it [20]. The implementation policies and recent technologies are changing the way energy is produced and distributed. It is twitting towards smarter and dynamic energy generation due to integration of monitoring, automation and control technologies that facilitates the collection and use of data for a more efficient use of resources. These changes could be achieved by:

- Increasing the penetration of DG, mostly renewable, such as wind and solar
- Increase in the importance of maintaining energy efficiency and demand response action.
- Increasing the power quality expectation, driven by consumers demand and regulatory actions.
- To include energy incentive for better utilization of electricity infrastructures.
- Reviewing aged energy equipment or infrastructures that are in line with the changes in electricity usage pattern.
- Proffering regulation that can adjust to the recent trend of energy demand and technology.

DG can be defined as a small scale electricity generation. It appears to be a fairly new concept in the energy market, but the idea is not new. The first grid was a DC base, which limited it to a low supply voltage and could only supply a neighborhood [21]. The ideas that led to DG consideration are the electricity market liberalization and environmental concerns. Though DG have the capacity to sustain supply to an area, the grid can be seen as alternative when there is little supply from the DGs. [22] proposed that DGs need to scale up to six times its performance now in order to meet the global demand in suggesting a better road-map to 2050.

Though DGs could be seen as a replacement for traditional supplies, the low power capacity limits it to grid integration where it may play less impact and obstruct the grid design. This is some of the disadvantages attached to DG installation. It is suggested that better performance could be achieved if viewed from off-grid [23]. This will also proffer great performance as it is closer to consumers, limiting losses due to power transmission and a higher efficiency, thereby supplying to more consumers and reducing the cost of power. Though most researchers have considered a higher penetration of DGs considering the emerging technologies which could enable DGs supply above the former rated values, still much implementation have not been considered in that due to ongoing study on grid behaviour after the introduction of DGs [24].

4. Power System Reliability

The electric power system is made up of complex interrelated system which could distort the reliability of the network. This makes it expedient to study the critical parameters that contributes to the network reliability [5]. Reliability improvement could be achieved using recommended components or provision of redundancy, which could be achieved by increasing the generation capability.

Reliability can be seen as the ease of an equipment to work efficiently and effectively over a time period, under certain conditions. It can also be seen as the likelihood that an equipment will work under certain state for a given time period [25]. In power system, the reliability considered are the measure of power interrupted, load connected, frequency of interruption, amount of customers and duration of interruption. All reliability study facts within these indices [26].

In recent times, most reliability studies have complex numeric time series analysis for the equipment deterioration and its impact on the performance of the equipment. Study have shown that equipment depreciate on usage which could aid to determine the life span of that equipment [27]. Factor(s) that could aid performance increase could be servicing and maintenance of the equipment [28].

5. Conclusion

The effect of distributed power generation systems on the future power grid is the subject of this article. The numerous DG options integrated in the Indian power system, as well as future potential and options are listed. The penetration of distributed generation from renewable energy sources is growing and projected to rise more in the future due to rising fossil fuel prices and environmental concerns. This growing penetration brings with it a slew of technological and economic difficulties in incorporating distributed generation into current power networks, many of which are discussed in depth.

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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