

Voltage Stability Improvement of Bauchi 33 kV Distribution Network with Distributed Generation Using PSAT

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ABSTRACT

Distributed generations (DGs) play a key role in power distribution networks. Integration of DGs in distribution systems require optimal placement and sizing of distributed generators to yield minimum power losses and improve voltage profile. Optimal location of DG in power distribution is very important. This paper presents voltage stability analysis of Bauchi distribution network with distributed generation (DG) using power system analysis tools (PSAT) software. The proposed continuous power flow method (CPF) is done in two stages. First stage; CPF was run without distributed generation to find the weak bus of the network. The second stage was run with distribution generation connected at the weak bus. Particle swarm optimization algorithm was used to locate the DG optimally and obtained optimal active power injection of DG. The distributed generation considered here is Waya Dam power plant Bauchi and is successfully done which improved the voltage profile of the weak buses in the network. From the results obtained, there is a reduction of power losses in the network after DG connection. The total real power loss reduction with DG is 92.5% whereas; the total reactive power loss reduction is 94.5% respectively.

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INTRODUCTION

Voltage stability analysis has become a major research area in the field of power systems after a number of voltage instability incidents were experienced around the world. Voltage instability has been responsible for several network collapse and blackout; it is now receiving special attention in many systems. Voltage stability is therefore defined as the ability of power system to maintain steady voltages at all buses in the system after being subjected to a disturbance from a given initial operating conditions [1]. It depends on the ability to maintain equilibrium between load demand and the supply from the power system. Instability that may results appears in the form of a progressive fall or rise of voltage of some buses. With the development of economy, load demands in distribution networks increase sharply [2]. Hence, the distribution networks are operating closer to the voltage instability boundaries.

It is necessary to consider voltage stability with the integration of DG units in

distribution systems. Distributed generation is therefore defined as a small-scale electricity generation fueled by renewable energy sources, such as solar and wind, or by low-emission energy sources, such as fuel cells and micro-turbines [3]. The essence of the distributed generations is not only to improve the voltage stability, but at the same time can be used to expand the network [4]. There are several numbers of techniques for studying voltage stability. The saddle node bifurcation theory, static and dynamic techniques modal analysis [5]. Continuation power flow method gives the reformulated set of equations and is achieved using local parameterization. The proposed methodology in [6] is based on CPF. The effectiveness of the presented methodology is demonstrated in a test network with integration of different penetration levels of DG.

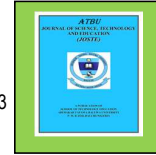
The proposed method yields efficiency in obtaining more benefits from the same amount of DG power, decreasing the losses and improving the voltage profiles. In [7] the authors also considered the issue of in-situ

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decentralized testing of microgrid controllers. Time-synchronization techniques such as the GPS timing signal and the PTP are very likely to play a significant role in both, microgrid control and controller testing. Similarly, advances in numerical techniques that assess conventional power system stability are also likely to play a role in micro-grids and as well more industrial applications will push the research in this area after the recent final approval of the Standard IEEE 1547.4, which allows microgrids to operate in island. [8] has reviewed an extensively discussed several issues related to distributed cooperative control, including consensus protocol algorithms such as linear consensus, heterogeneous consensus, finite-time consensus, non-linear consensus, etc. This paper has also presented an overview of current developments on distributed control systems applied to isolated AC, DC and hybrid MGs. For each type of MG, the main distributed control schemes proposed in the literature have been reported and discussed in detail. Those were classified according to the hierarchical control of MGs, i.e., primary, secondary and tertiary control layers.

Regarding the primary control level methods such as virtual impedance, droop-free control, virtual generators, and synthetic inertia have been thoroughly reviewed, highlighting the advantages of applying these strategies in a distributed scheme for the regulation of harmonic distortion, imbalances, reactive power and to improve the inertia of the MG, among others issues. Distributed cooperative control for economic dispatch of electrical energy in DC, AC and Hybrid microgrids has also been thoroughly discussed and reviewed in this paper, highlighting two methodologies: those methods based on an incremental cost consensus approach and those based on distributed gradient algorithms. Distributed secondary control strategies have also been extensively reviewed; consensus-based strategies and power quality issues were addressed in detail. Distributed tertiary control schemes applied to the economic dispatch of MGs were also reviewed.

[9] studies that microgrids have many attractive features that make its research promising and boost its competitiveness in penetrating renewable energy. Microgrid

architecture and classifications have been reviewed here, along with the control techniques and strategies for islanded operation mode. Challenges to microgrids during this mode include maintaining the voltage amplitude and frequency, and optimal power sharing which ensures minimum power losses, high power quality hence low harmonic distortion, and operating the DERs on their preset values after any disturbance occurs. A robustly controlled microgrid ensures seamless import/export of active and reactive powers by the main grid and continuous supply of the critical load during islanded mode. These lead to a flexible and smart power system.

In [10], a method of DG unit allocation is proposed. This method targets to utilize the DG units to improve the voltage stability margin. This research work focuses on analyzing voltage stability, voltage profile, power flow and the P-V curve of a system with integrate wind turbine or photovoltaic in the distribution system. The candidate buses for the DG units' installation are selected based on the sensitivity to the voltage stability. Simulation results indicate that DG size and location can have a positive impact on the voltage stability margin. Therefore, an optimization method can be used to design the locations and sizes of the DG units, to achieve the target of improving the voltage stability margin. The simulation results indicate the highest penetration level of the wind turbine units are recommended to be placed in the most sensitive voltage buses in order to improve the voltage stability margin. The simulation results indicate optimum penetration level of the photovoltaic are recommended to be placed in the most sensitive voltage buses in order to improve the voltage stability margin. [11] focused on the analysis of voltage stability, power angle stability and frequency stability. The whole theoretical system of the study of power system stability has not been established, so the research of stability power system is a long way to go. With the development of voltage stability research, the important role of dynamic characteristics of composite load in voltage instability has become a common consensus. Composite load, due to complex, random variable, geographical dispersion and nonlinear characteristics, often adopts approximate simplified model in the actual simulation, which

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greatly affects the reliability of voltage stability analysis results. Therefore, established accurate and practical load model will greatly promote the development of voltage stability analysis.

CONTINUOUS POWER FLOW METHOD

Continuous power flow (CPF) is a mathematical path following methodology used to solve systems of nonlinear equations [12]. Using the continuation method, a solution branch can be tracked around the turning point without difficulty. This makes the continuous method quite attractive in approximations of the critical point in a power system. The CPF captures the path-following feature by means of a predictor-corrector scheme [13]. Moreover, CPF can be used to determine generator reactive power limits, voltage limits and flow limits of transmission lines [14]. Basically, the predictor starts from a known solution and forecasts the next equilibrium point. Then, a corrector algorithm based on Newton-Raphson method, makes successively adjustments to state variables until correct load flow solution is reached [15]. Figure 1 illustrates the load flow predictor-corrector step.

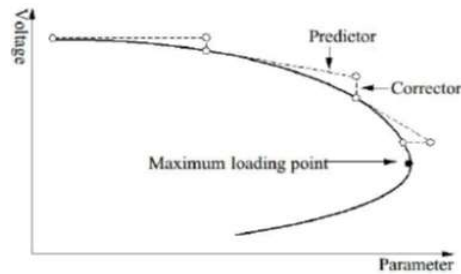


Figure 1: An illustration of Predictor-corrector Step

MATHEMATICAL REFORMULATION OF POWER FLOW EQUATION

To determine the successive load flow solution using continuation power flow. The load flow equations are reformulated by inserting load parameter λ [16]. That can be obtained either by means of a local parameterization or a perpendicular intersection.

$$P_d = \sum_{j=1}^n VV_j Y_{ij} \sin(\theta_i - \theta_j - \theta_{ij}) \dots(1)$$

$$Q_d = \sum_{j=1}^n VV_j Y_{ij} \cos(\theta_i - \theta_j - \theta_{ij}) \dots(2)$$

Subject to the following constraints;

$$P_{gi} - P_{di} - P_{ci} = 0 \dots(3)$$

Where, η is an appropriate value for the k^{th} element of x . Once a suitable index k and the

$$Q_{gi} - Q_{di} - Q_{ci} = 0 \dots(4)$$

Where, the subscript g and d are the generation and load demand respectively. The load parameter is inserted into power demand (P_d and Q_d), so as to run the simulation. The reformulated equations become;

$$P_{gi} - P_{di} - P_{ci} - \lambda = 0 \dots(4)$$

$$Q_{gi} - Q_{di} - Q_{ci} - \lambda = 0 \dots(5)$$

Where, the value of λ will be varied from 0 to maximum variation and state as follows;

$$0 \leq \lambda \leq \lambda_{critical} \dots(6)$$

The basic equations correspond to the standard power equations except that load is added as a parameter. The reformulated power flow equation with provision of increase generation as load increase is as follows;

$$f(\theta, V) - \lambda K = 0 \dots(7)$$

Where, λ is the load parameter, Θ is the vector of bus voltage angle; V is the vector of bus voltage magnitude. The equation above is solved by specifying the value of λ .

A. Predictor Steps

The first task in the predictor step is to calculate the tangent vector which is obtained from;

$$[F_\delta, F_v, F_\lambda] \begin{bmatrix} d\delta \\ dV \\ d\lambda \end{bmatrix} = 0 \dots(8)$$

On the left side of the equation is a matrix of partial derivatives multiplied by the vectors of differentials. The former is the conventional power flow Jacobian augmented by one column (F^λ), this is satisfied by setting one of the components of the tangent vector to +1 or -1.

A. Corrector Step

After the prediction is made, the next step is to correct the predicted solution, the technique used here is local parameterization, where by the original set of equations is augmented by one equation specifying the value of one of the state variables. In equation form, this relation is expressed as;

$$\begin{bmatrix} F(x) \\ x_k - \eta \end{bmatrix} = 0, \quad x = \begin{bmatrix} \delta/v \\ \delta/\lambda \end{bmatrix} \dots(9)$$

value of η are specified, a slightly modified NR Power flow method (altered only by one

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additions equation and one additional state variable) can be used to solve the set of equations. This procedure provides the corrector needed to modify the predicted solution found.

APPLICATION OF CONTINUATION POWER FLOW TO 9-BUS SYSTEM

Continuation power flow method is applied to the modeled Bauchi 33 kV distribution network in PSAT software, which consists of nine buses among which there is one swing bus (reference bus), two PV buses and six PQ buses [17]. The developed model was simulated in two scenarios; with and without DG connected. Particle swan optimization was employed and best location was determined for distributed generation connection. Both dynamic and static voltage stability analyses were carried out using P-V curves and maximum system loadability. The network was modeled in PSAT environment as shown in Figure 3.

Case 1: Results of continuation power without DG

In this case, the network was modeled without DG in order to determine the base case results.

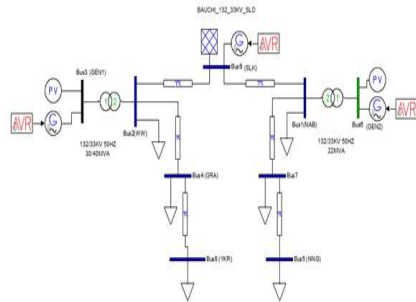


Figure 3: Developed Bauchi 33 kV Network in PSAT

The CPF is achieved using perpendicular intersection method and converged at maximum of 50 iterations in 11.53seconds and maximum loading $\lambda = 1.8$. The real and reactive powers injected to the network at maximum loading condition are 4.5128p.u and 1.8546p.u respectively, whereas the real and reactive powers consumed by the load are 4.5p.u and 1.5p.u. This shows that the network is overloaded. If demand is increase beyond its limit, then more reactive power is drawn and losses increase.

Figure 4 depicts both the PV curves of all buses as obtained from the reports of the CPF. Except the three buses, all the others present a sharp nose curve, or a straight line, that is, their voltage magnitudes remain fixed at the specified values. Figure 6 shows the voltage profile of all buses of the 9-Bus system.

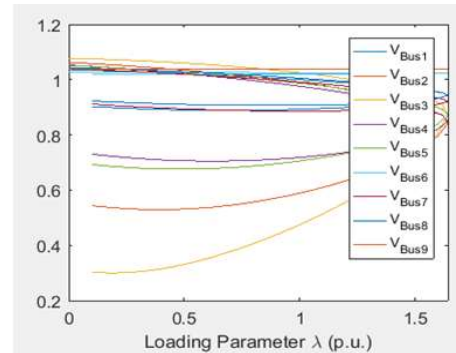


Figure 4: V-λ Curves for 9-Bus System

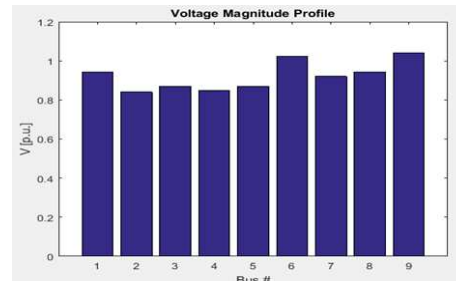


Figure 5: Voltage Magnitude of the 9-Bus System

From Figure 5, it can be realized that bus 2, 4 and 5 are the most loading and are the candidate buses for DG installation. Their voltage magnitudes are 0.84078pu, 0.84855pu and 0.87010p.u respectively. Bus 9 is slack bus its voltage magnitude is 1.0 p.u. and angle is zero. Particles swan optimization was employed to the 9-bus system which signifies bus 4 as the global best location for the installation of DG.

Case II: Results of continuation power flow with DG

From case one, it can be seen that bus 2, 4 and 5 has the lowest voltage magnitudes, which indicate the weak buses. Particle swan optimization (PSO) was run and the optimal location obtained, bus 4 revealed to

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be the lowest. Hence, the distributed generator is connected to this bus and continuous power flow (CPF) was rerun and the new result of voltage magnitudes obtained can be seen in Figure 6.

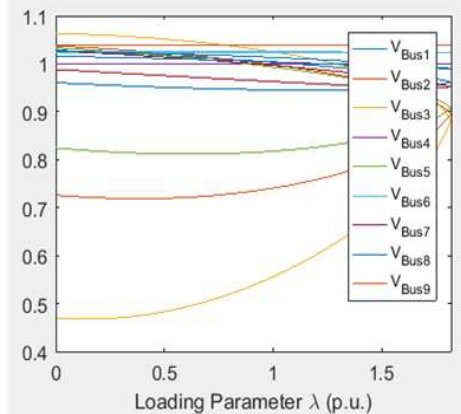


Figure 6: V-λ Curves of all Buses with DG

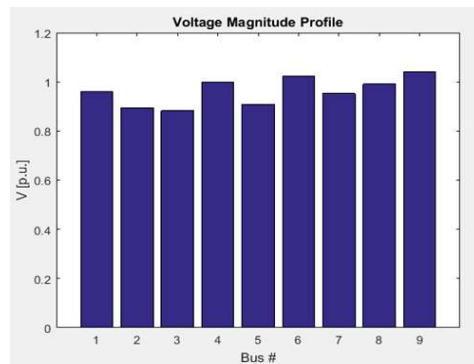


Figure 7: Voltage Magnitude of all Buses with DG

Table 1: Comparison of Voltage Magnitude of the Weak Buses

Bus No.	Bus Name	V(m) with DG (pu)	V(m) without DG (pu)	V(m) Improvement	% Increase in Voltage Magnitude
2	Water Works	0.89519	0.84078	0.05441	94
4	GRA	1.00000	0.84055	0.15945	85
5	Yankari	0.90833	0.87011	0.03822	96

In table 1, the comparative aspect of voltage magnitudes with and without DG. It can be seen that there is a remarkable change in the voltage magnitude before and after DG connected. Bus 2 has the voltage magnitude of 0.84078p.u and change directly to 0.89519p.u after DG connection in bus 4. This changed the

The PV curves of Figure 6, bus 4 shows a straight line from the graph and a voltage magnitude of 1.0pu. This signifies that, bus 4 is now stable, and there is no voltage stability issue. Bus 2 and 5 also show a remarkable change in their PV curves, as their voltage magnitude profile increased to 0.8958pu and 0.9083pu respectively. This also shows that the two buses are stable since their voltage magnitude is greater than 0.84pu which is regarded as weak voltage level. Bus 4 is an optimal location as it improved the voltage level of bus 2, 4 and 5 and minimizes losses in the respective buses.

A. Comparison of Voltage Magnitude Profile With and Without DG

Power flow simulations carried out in PSAT software with and without DG installed in the system was conducted. Table 1 shows compares of results for voltage magnitude of some selected buses.

bus from weak bus to a stable bus. Bus 4 changed tremendously to a well stable bus with voltage level of 1.0p.u after DG connected at the bus. This shows that DG can improve voltage stability of a given network and reduce losses.

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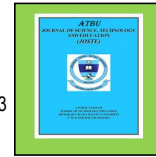


Table 2 shows the complete power flow simulation results for the base case that is without DG considered during the modeling,

whilst Table 3 is the power flow simulation results not considering DG in the modeling of the network.

Table 2: Base Case Voltage Profile (PF)

Bus No.	Bus Name	Base kV	Voltage (p.u)	Phase (p.u)
1.	Nabordo	33	1.0001	-0.18201
2.	W/Works	33	0.9899	-0.17810
3.	Gen. 1	33	1.0250	-0.07753
4.	GRA	33	0.9761	-0.18962
5.	Yankari	33	0.9871	-0.20067
6.	Gen. 2	33	1.0250	-0.1334
7.	Dass	33	0.9910	-0.1764
8.	Ningi	33	1.0053	-0.1122
9.	Gen. 3	33	1.0400	0

Table 3: Power Flow Results without DG

From Bus	To Bus	Line	Power Flow (p.u)	Q Flow (p.u)	P Loss (p.u)	Q Loss (p.u)
Bus 2	Bus 5	1	0.30936	0.02723	0.00097	0.00598
Bus 5	Bus 1	2	-0.19161	-0.07875	0.00043	0.00334
Bus 2	Bus 4	3	0.12064	-0.03007	0.00015	0.00055
Bus 1	Bus 7	4	-0.04204	0.06897	7.0E-05	-0.00035
Bus 4	Bus 8	5	-0.77552	-0.02626	0.000602	0.05920
Bus 7	Bus 6	6	-0.64211	-0.08068	0.00421	0.04113
Bus 9	Bus 8	7	2.02790	0.59512	0	0.23785
Bus 3	Bus 2	8	1.63000	0.52138	0	0.17423
Bus 6	Bus 1	9	0.85000	0.40030	0	0.04924

Table 4 presented the simulation result of the distribution network when DG was included in the modeling.

Table 4: Power Flow Results with DG

From Bus	To Bus	Line	Power Flow (p.u)	Q Flow (p.u)	P Loss (p.u)	Q Loss (p.u)
Bus 2	Bus 5	1	-0.30839	-0.02125	0.00097	0.00598
Bus 5	Bus 1	2	0.19204	0.08209	0.00043	0.00334
Bus 2	Bus 4	3	-0.12048	0.03062	0.00015	0.00055
Bus 1	Bus 7	4	0.04211	-0.06992	7.0E-05	-0.00035
Bus 4	Bus 8	5	0.78154	0.08545	0.00602	0.05920
Bus 7	Bus 6	6	0.64632	0.12182	0.00421	0.04113
Bus 9	Bus 8	7	-2.02790	-0.35727	0	0.23785
Bus 3	Bus 2	8	-1.63000	-0.34716	0	0.17423
Bus 6	Bus 1	9	-0.85000	-0.35107	0	0.04924

Table 3 and 4 shows the basic power flow results with the voltage magnitudes which is in limit with different phase angles. The total real and reactive power losses of the network before and after DG connection are also deduced. The total real power loss in p.u before DG

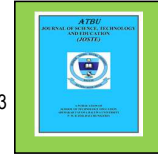
connection is 0.01282p.u and 0.01186p.u after DG connection. Likewise, the total reactive power loss of 0.60455p.u is observed in the network before DG connection and 0.57117p.u after DG connection. This shows that there is a reduction of power losses in the network after

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DG connection. Total real power loss reduction with DG in percent is 92.5% whereas; the total reactive power loss reduction is 94.5% respectively.

CONCLUSION

The 33 kV feeder of Bauchi distribution network was modeled in MATLAB/PSAT environment. The model network is simulated and the power flow was run. In the process critical feeders are identified for the installation of the distributed generations. Particle Swarm Optimization techniques (PSO) was employed and optimal location is determined, CPF is a powerful tool for identifying the weakest bus in the network, the critical and most vulnerable line with respect to a particular load bus. This will eventually help to locate the maximum load-ability of the load buses. This also gives a guide to the system operator to take quick action to avert the voltage collapse when a particular bus is being overloaded and where to place the DG in the network to enhance voltage stability and minimize losses.

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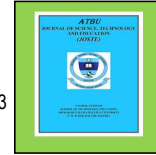
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