INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & MANAGEMENT

INTEGRATION OF MICROGRIDFOR VOLTAGE CONTROL IN A SMART DISTRIBUTION GRID

J.O.Petinrin*, J.O. Agbolade, I.A. Bamikefa, and M.A. Sanusi
*Electrical/Electronic Engineering Department, School of Engineering Technology, Federal Polytechnic Ede, Ede, Osun State, Nigeria

ABSTRACT

Voltage regulation for stability and reliability is required during the connection of large number of Distributed generation (DG) to the microgrid to avoid reactive power and or voltage oscillations. The energy demand must be equal to energy consumed in a balanced system, if not; it will cause frequency deviation from its set point value. Open Distribution System Simulator (OpenDSS) simulation software is used to estimate the degree of involvement of battery energy storage (BES) unit in a distributiongrid voltage level management and the ability of microgrid involvement in active voltage control of medium voltage feeder in this paper. The study revealed that the coordination of VAr control devices such as OnLoad Tap Changer (OLTC) transformer and shunt capacitors (SC) with battery energy storageat the distribution network is more efficient and more accurate means of voltage regulation/control than the application of VAr control devices only. In addition, the activities of microgrids in voltage control of smart distribution network showed that voltage level can be affected in medium voltage and in low voltage network by active and reactive absorbing and feeding of a battery energy storage that is connected to distribution network substation.

Keywords: *Battery Energy storage, Distributed Energy Resources,Microgrid, Smart Grid,Voltage control*

I. INTRODUCTION

Cold-formed steel (CFS) sections applications are widely used in the construction of modern steel The concerns of reducing reliance on energy demand will continue to grow globally at an ever increasing rate. There have been many researches on how this demand could be met while simultaneously addressing critical issues such as energy security, reliability, stability and sustainability. It has been recognized that distributedenergy resources (DERs) within a microgrid (MG) have the tendency to address most of these issues [1].

The deployment of distributed generation(DG) such as wind energy and solar photovoltaic (PV) have gained significant interest recently, due to continued advancement in renewable energy (RE) technologies, their effectiveness as a local power source; where generation is in close proximity to loads or consumers,increasing reliability and positive impact on operation planning and expansion its potential for GreenHouseGas (GHG) emissions[2]. There is a serious change now in power system in the area of power flow direction,structure, security and responsibility. This could be achieved through the deployment of DERs in microgrids integrated into the smart distribution grid at different voltage levels and at many spread connection points [3]. This results in a vision for smart grid (SG) for the future network to be decentralized, distributed and shared in the operation of the power system with the help of DERs [4].

The future grid system known as SG will integrate DER in a coordinated manner through Intelligent Management System (IMS) ensuring at the same time reliable operation and increased power quality [5]. It will also give opportunity for the realization of the potentials of DER for different interest groups such as Distributed generation producers and consumersDistribution System Operators (DSOs), and Service providers [6]. Microgrid is part of a power system which consist of one or multiple DER units (in electrical closeness to one another) capable of operating either in parallel with or autonomous from a power utility grid as shown in figure 1,while providing reliable power to multiple loads and consumers [7]. A MG can be connected to/or disconnected from the grid to enable operation in both grid-connected mode or autonomous mode [8]. It should be also capable of riding through between the two modes if necessary.

A MG can be strategically placed at any site in a power system, most especially at the grid system for grid reinforcement, thereby deferring or eliminating the need for system upgrades and improving system reliability, efficiency and integrity[9]. In autonomous mode, the MG management system (MMS) takes over the responsibility of economic and efficient operation of the MG, taking into consideration the technical boundary conditions both in grid connected and autonomous operation. However, when MG operates in the grid-connected mode, it balances its loads by purchasing or importing power from the main grid it is connected to.

This paper discusses the integration of Microgrid for voltage control in a smart distribution grid. Open distribution system simulator (OpenDSS) simulation software comMatlab is used to estimate the degree of involvement of BES unit in low voltage network voltage level management and the ability of MGs involvement in active voltage control in a smart distribution system. Section II of the paper discusses the impact of MG voltage control in a smart distribution grid, section III explains voltage and frequency control within MG and the active participation of MG in smart grid voltage control is presented in section IV, while section V discusses the coordination of VAr control devices such as On load tap changer (OLTC) transformer and shunt capacitor (SC) with battery energy storage (BES) in a MG feeder and finally section VI states the conclusion.

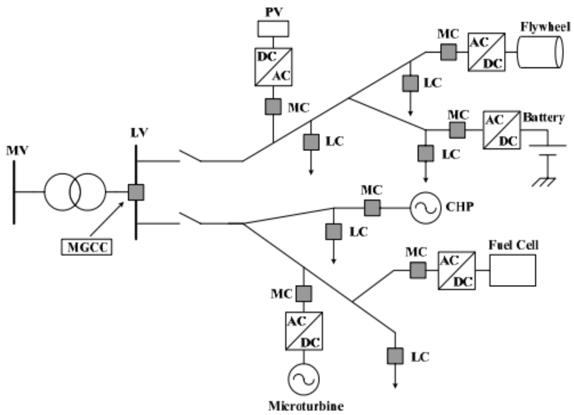

Fig. 1 Microgrid architecture [10].

II. VOLTAGE CONTROL IN A DISTRIBUTION NETWORK THROUGH MICROGRID

On-load transformer tap changer (OLTC) transformers at high voltage/medium voltage (HV/MV) substations and with fixed off-load transformer tap changers at medium voltage/low voltage (MV/LV) distribution substation has been the practice for voltage regulation on distribution system[11]. It is expected that voltage variation increases with the increase penetration of DGs and electric vehicles in LV network. There is need for more intelligent way of handling voltage variation in LV network for better application of LV network [6] than the active power curtailment of DGs or large amount of reactive power produced or consumed by the DGs.

As a result of increased generation and demand changes in future distribution network, it has been presented in [12], to change fixed off-load tap changers at MV/LV distribution transformer to OLTCs to control LV network voltage level as part of active distribution management. Likewise, from the MG concept, the BES based master unit at MV/LV distribution substation should have some functions during normal operation of LV network in order to be economically feasible [6]. This means that it should not only enable possible momentary island operation for protection purpose. The best approach is to include controllable OLTCs to distribution transformers; the BES at MV/LV distribution substation would actively manage the voltage level of MG during the normal grid connected operation [12]. Also, the MG could as well take part in the MV feeder voltage control through coordinated management of the BES, controllable DERs and dispatchable loads by MMS.

The utilization of BES to actively control voltage provides more flexibility and allows more DGs to be integrated to MGs[13]. In addition, it will facilitate better capacity operation of existing LV lines and improves the energy efficiency of the LV distribution network. In the future smart grids, the local technical service markets are one possibility to implement these functions as discussed by [14]. During the grid connected MG operation, the BES function as voltage level control in LV network so that rise of voltage level is controlled by charging the BES when there is high generation and low loading, theBES discharges to the network so as to increase the voltage level during low generation and high loading. The BES equally functions as power flow management from MG to MV network at the point of common coupling (PCC) of MG. At this point active power P=0, reactive power Q=0 or based on control command from Distribution Management System (DMS) of Distribution System Operator (DSO) about the allowable power flow limits for active and reactive power in PCC of MG.

The involvement of MG to actively participate in active management of MV feeder voltage control is restricted by technical boundaries and limits which determine the amount of active and reactive power enable to flow in PCC of MG between the main grid and MG without affecting the possibility of islanding operation.

III. VOLTAGE AND FREQUENCY CONTROL WITHIN MICROGRID

Voltage control for stability and reliability is required during the connection of large numbers of DG to the MG to avoid voltage and or reactive power oscillations. Adequate care need to be taken in the voltage control/regulation to prevent large circulating reactive currents between sources. The active and reactive power generated must be equal to active and reactive power consumed in a balanced system, if not; it will cause frequency deviation from its set point value. To prevent this occurrence, both voltage and frequency needs to be controlled so as to remain within predefined limit around the set point value. This can be done through the adjustment of active and reactive power generated and consumed. Active and reactive power control is not possible in MG but voltage can be regulated applying voltage versus reactive power droop controller for reliability and stability [15] and each DG must be connected with power VS frequency droop controller during islanding. These droop controller provides decentralized operation of MG without communication between the DGs. The successful islanding of MG depends on quick and accurate voltage and frequency control [16].

The control of storage units in MG is not adequate to manage/restore voltage and frequency closer to the sets values. Apart from this, controllable loads and DGs such as PV, fuel cells, micro turbines can take part in voltage and frequency control according to their voltage and frequency droops. This is to provide plug-and-play method of connection for DGs in distribution system[17]. Master slave method was used by [18] to determine the performance of MG comprising two types DGs. In the method, the output power of inverter based DGs are modified to compensate the new change in the MG system when islanding takes place. The MG setting is adjusted so as to minimize the transient accruing during transition from grid connected mode to islanded mode. Inverter based DGs can supply adequate amount of reactive power to enhance the voltage quality and damping of oscillation taking place in the frequency efficiently. Small signal state space approach is presented by [19]. Each DG inverter have an outer power loop base using droop control to share the active and reactive powers with other DGs. Voltage and current control is applied in inverter internal controls to reject high frequency disturbances and damp output filter to mitigate any resonance with external network.

Voltage versus reactive power droop
Connection of large micro-source to MG is difficult if not impossible with basic unity power factor controls. For local reliability and stability, there must be local voltage regulation/control without which system with high penetrations of micro-sources could experience voltage and reactive power oscillations. With this voltage control, large circulating reactive current between sources will be eliminated. Small error in voltage set points causes circulating current to exceed the rating of the micro-sources. It is necessary to apply voltage versus reactive current droop controller to avoid circulating current exceeding the rating of the micro-source even when there is only small error in voltage set points. As the reactive power generated by the micro-source becomes capacitive, the local voltage set point is reduced but if inductive, it increases.

Power versus Frequency Droop
With static switch devices MG can island smoothly and reintegrate automatically to the utility grid like UPS system. To avoid frequency generation error at each converter and power operating point matching load changes when MG moves from dispatched power mode to islanding mode, it is required to apply power versus frequency controller at each micro-source. This requires no communication network. MG loads receive power from both the utility grid and micro-sources in dispatched mode depending on the customer demand. If the MG islanded because of faults or

system disturbances, the voltage phase angles at each micro-source in the MG change, causing a serious reduction coupled with power increase which make each micro-source to make available its proportional share of power.

IV. COORDINATION OF VARCONTROL DEVICES AND BATTERY ENERGY STORAGE

Coordination of VAr control devices and battery energy storage (BES) is tested on a modified standalone IEEE 123 bus feeder of an actual 115 kV/4.16 kV 50-Hz distribution circuit. The total load is 6.5 MW and is distributed among commercial and residential energy consumers. The IEEE 123 bus feeder, shown in Fig. 2, consists of three-phase overhead or underground primary feeders and double-phase or single-phase line sections near the end of the feeder laterals. Loads with different types including constant current, constant impedance and constant power are modeled at the system buses. The power injections of the variable RGs have been represented by voltage-independent active injections with zero reactive power.

The Renewable generation (RG), a hybrid PV/wind energy system integrated in the feeder is as shown in Fig. 3. Each RG is represented by its supply. Inverter power controllers regulate the power outputs, by providing reference values for the output voltage magnitude and phase. The real power drop of particular interest here is characterized by a frequency set-point and a droop gain while the generator rating limits the extent to which the droop is applicable [9, 20].In this paper, the MGs (PV and wind generators) are deployed in buses 251, 300, 450,79 and 95 of the feeder to share real power demand according to their combined droops, and to suppress rapid changes in the output power. An energy management system, in real time, can adjust the PV and wind generators droop settings relative to each other to implement a particular droop operating point with a certain power sharing at a chosen frequency.

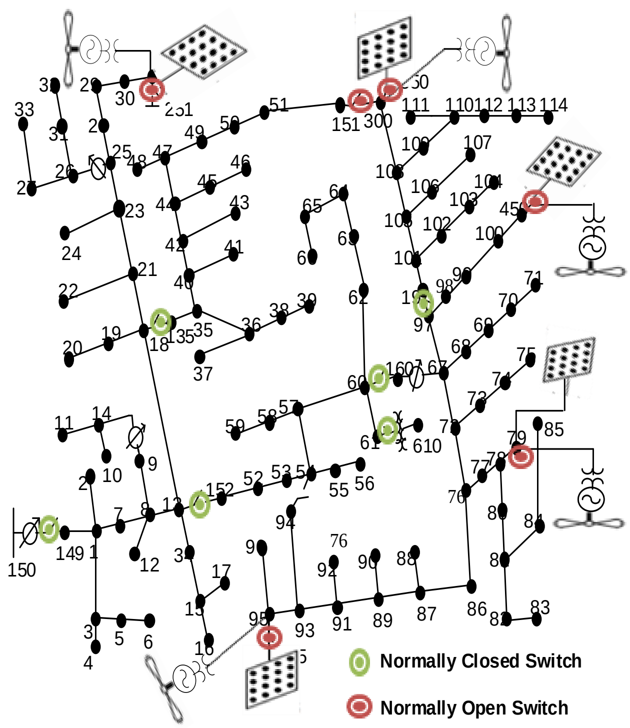

Fig. 2 Modified 123 bus Feeder

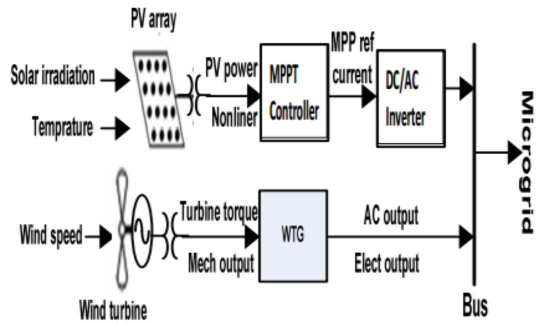

Fig. 3 Block diagram of hybrid PV/Wind energy system[9].

The VAr control devices such as LTCs and the capacitor banks (SCs) are coordinated with the BES for smooth operation to achieve the desired objectives of this paper. The BES is integrated in the MG to decouple the timing of generation production (or absorb the variability of the RG) from the consumption of electric energy. The LTC are coordinated with the 2.5 MW battery energy storage co-located with the MG at the buses to make sure the voltage profile as a result of the RG penetration is within the permissible limits.

The per unit voltage of the chronological 24-hourly simulation of the system with 6.5 MW peak load, 30% RG penetration using Open distribution system simulator (OpenDSS) com Matlab is carried out. Four scenarios are involved in the simulation. In the first scenario, the regulator devices are disabled and the voltage profile is monitored and recorded. The voltage output is as shown with dashed-dotted-dashed line in Fig. 4. It falls below the accepted voltage limits. The voltage is regulated within the limits in some hours of the day (dashed line) when the OLTC only is enabled in the second scenario. However, the voltage is below the boundary limit in the night hour due to no power injection from the PV in the night.

In the third scenario, switching ON the capacitor banks increases the voltage profile (dotted line) as depicted in Fig. 4. This maintains the distribution system security as the voltage profile gets flattened off. The capacitors, expectedly, have great influence on the reactive power flow. Line current is drastically reduced, thereby reducing the line voltage drop. The more the capacitor banks connected, the more the losses get reduced and the more the voltage profile is improved. The capacitors, therefore, have compensated for the line voltage drop and kept the voltage close to 1.0 pu.

Finally, a total BES of 2.5 MW is distributed in the feeder at buses. The dispatch operation of the BES integrated with the RG in the MG feeder is to charge and discharge as the need arises. The voltage profile is as shown in the figure with solid line. The integration of the BES has warranted voltage profile improvement, voltage leveling and smoothening of intermittency from the RG. The voltage deviation is substantially reduced to 0.0027 as shown in Table 1. This illustrates the effect of energy storage along with RG.

Results consistently indicate that the coordinated operation of the VAr control devices causes reduction in system losses and enhances system capability to maintain voltages within the permissible bounds. The use of BES effectively assists to harness intermittent renewable energy resources, accommodate higher proportion of them, mitigate the voltage rise as well as voltage drop and provide additional flexibility to the system to hedge against the fluctuations of variable RG output. The integration of BES in the feeder was able to absorb and inject power into the buses as deem fit, thereby demonstrated the benefits of peak load shaving, mitigation of peak-valley difference. It improves the voltage profile quality and offers active power adjustment capacity to the MG in the smart distribution system.

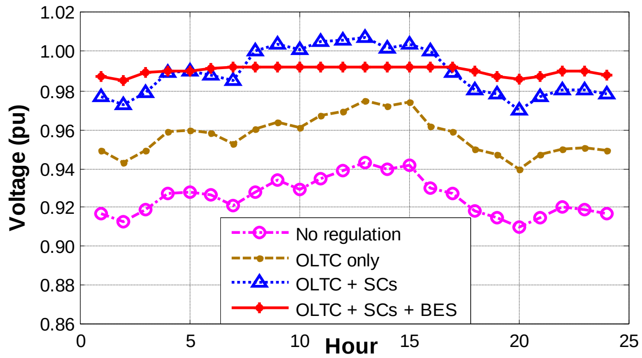

Fig. 4 Application of control devices at 30% RG penetration at bus 450

Table 1 Voltage deviation with control devices

Description	Max Voltage (pu)	Min Voltage (pu)	Voltage Deviation
No Regulation	0.9430	0.9130	0.0300
OLTC only	0.9750	0.9430	0.0320
OLTC + SCs	1.007	0.9700	0.0370
OLTC + SCs + BES	0. 9922	0.9850	0.0072

V. CONCLUSION

Voltage regulation for reliability and stability is required during the connection of large numbers of distributed generation to the microgrid to avoid voltage and or reactive power oscillations. Adequate care need to be taken in the voltage control/regulation to prevent large circulating reactive currents between sources. The active and reactive power generated must be equal to active and reactive power consumed in a balanced system, if not; it will cause voltage/frequency deviation from its set point value. To prevent this occurrence, both voltage and frequency needs to be controlled so as to remain within predefined limit around the set point value.

This paper discusses the active participation of MG in smart grid voltage control. Open distribution system simulator (OpenDSS) simulation software is used to estimate the degree of involvement of BES unit in low voltage network voltage level management and the ability of LV microgrid involvement in active voltage control of medium voltage feeder in this paper.

Results consistently indicate that the coordinated operation of the VAr control devices causes reduction in system losses and enhances system capability to maintain voltages within the permissible bounds. The use of energy storage effectively assists to harness intermittent renewable energy resources, mitigate the voltage rise as well as voltage drop and provide additional flexibility to the system to hedge against the fluctuations of variable renewable generation output. The coordinated capability improves the voltage profile quality and offers active power adjustment capacity to the MG.

REFERENCES

[1] D. F. Menicucci and J. Ortiz-Moyet, "Advanced concepts for controlling energy surety microgrids," Sandia National Laboratories2011.
[2] J. Petintin and M. Shaaban, "Voltage regulation in a smart distribution system incorporating variable renewable generation," in Innovative Smart Grid Technologies-Asia (ISGT Asia), 2014 IEEE, 2014, pp. 583-588.

[3] P. M. S. Carvalho, P. F. Correia, and L. Ferreira, "Distributed reactive power generation control for voltage rise mitigation in distribution networks," Power Systems, IEEE Transactions on, vol. 23, pp. 766-772, 2008.
[4] E. Ortjohann, P. Wirasanti, M. Lingemann, W. Sinsukthavorn, S. Jaloudi, and D. Morton, "Multi-level hierarchical control strategy for smart grid using clustering concept," in Clean Electrical Power (ICCEP), 2011 International Conference on, 2011, pp. 648-653.
[5] K. E. Antoniadou-Plytaria, I. N. Kouveliotis-Lysikatos, P. S. Georgilakis, and N. D. Hatziargyriou, "Distributed and decentralized voltage control of smart distribution networks: models, methods, and future research," IEEE Transactions on Smart Grid, 2017.
[6] H. Laaksonen, K. Kauhaniemi, and S. Voima, "Microgrid voltage level management and role as part of smart grid voltage control," in PowerTech, 2011 IEEE Trondheim, 2011, pp. 1-8.
[7] F. Z. Peng, Y. W. Li, and L. M. Tolbert, "Control and protection of power electronics interfaced distributed generation systems in a customer-driven microgrid," in Power & Energy Society General Meeting, 2009. PES'09. IEEE, 2009, pp. 1-8.
[8] M. Shahidehpour and M. Khodayar, "Cutting Campus Energy Costs with Hierarchical Control: The Economical and Reliable Operation of a Microgrid," Electrification Magazine, IEEE, vol. 1, pp. 40-56, 2013.
[9] J.O. Petinrin and M. Shaaban, "A hybrid solar PV/wind energy system for voltage regulation in a microgrid," in Research and Development (SCOReD), 2013 IEEE Student Conference on, 2013, pp. 545-549.
[10]A. Madureira, C. Moreira, and J. P. Lopes, "Secondary load-frequency control for MicroGrids in islanded operation," in Proc. International Conference on Renewable Energy and Power Quality ICREPQ '05, Spain, 2005.
[11]J.O. Petinrin and M. Shaaban, "The Impact of Renewable Generations on Voltage Stability in the Distribution Systems," Renewable and Sustainable Energy Reviews, 2016.
[12]C. Oates, A. Barlow, and V. Levi, "Tap changer for distributed power," in Power Electronics and Applications, 2007 European Conference on, 2007, pp. 1-9.
[13]M. Shaaban and J.O Petinrin, "Integration of Energy Storage for Voltage Support in Distribution Systems with PV Generation," Journal of Electrical Engineering & Technology, vol. 11, pp. 1077-1083, 2016.
[14]S. Chatzivasiliadis, N. Hatziargyriou, and A. Dimeas, "Development of an agent based intelligent control system for microgrids," in Power and Energy Society General Meeting-Conversion and Delivery of Electrical Energy in the 21st Century, 2008 IEEE, 2008, pp. 1-6.
[15]R. H. Lasseter, "Microgrids and distributed generation," Journal of Energy Engineering, vol. 133, pp. 144-149, 2007.
[16]G. Venkataramanan and M. Illindala, "Small signal dynamics of inverter interfaced distributed generation in a chain-microgrid," in Power Engineering Society General Meeting, 2007. IEEE, 2007, pp. 1-6.
[17]A. Salam, A. Mohamed, and M. Hannan, "Technical challenges on microgrids," ARPN Journal of Engineering and Applied Sciences, vol. 3, pp. 64-69, 2008.
[18]F. Katiraei, M. R. Iravani, and P. Lehn, "Micro-grid autonomous operation during and subsequent to islanding process," Power Delivery, IEEE Transactions on, vol. 20, pp. 248-257, 2005.
[19]N. Pogaku, M. Prodanovic, and T. C. Green, "Modeling, analysis and testing of autonomous operation of an inverter-based microgrid," Power Electronics, IEEE Transactions on, vol. 22, pp. 613-625, 2007.
[20]C.-M. Hong and C.-H. Chen, "Intelligent control of a grid-connected wind-photovoltaic hybrid power systems," International Journal of Electrical Power & Energy Systems, vol. 55, pp. 554-561, 2014.