A Case Study On Voltage Control Strategy Of Standalone Microgrids

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Abstract -Rapidly increasing energy demand from the industrial and commercial sector, steadily reducing energy sources and at the same time increased concerns about environmental changes, have caused fast development of Distributed Power Generation Systems based on renewable energy. A recent concept is to group Distributed Power Generation Systems and the associated loads to a common local area forming a small power system called a microgrid. High penetration of renewable generation system which cause large voltage deviation in the system due to unpredictable output power fluctuations. This paper proposes a voltage control of microgrids. The aim of this control strategy is to maintain the system voltages at critical buses within safe operating limits. For stable voltage control, the Q/P droop control is added to the reactive power controller of the renewable generation systems. With this control, the voltage fluctuation induced by the output active power fluctuation is effectively prevented as if there is a voltage-damping effect in the renewable generation. This paper is the case study on voltage control strategy of standalone microgrids

Index Terms– MPPT and battery integrated voltage control method, Point of common coupling (PCC), Q/P droop control method, Voltage control

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1 INTRODUCTION

Restructuring of power system, environmental concerns regarding concentrated power plants, instantaneous changes of electrical energy price and fast technological development of distributed generation (DG) units have all made distributed generation ever increasing. A distribution network to which a distributed generation system is connected is called a microgrid. A microgrid appears when an electrical region can control its voltage and frequency and supply its load automatically and independently from the grid. Existing rules in electrical grids don't still let independent operation of microgrids due to several reasons such as safety of operators, stability, etc. The early power grids can be considered as the first distributed generation units as there were only DC networks and transmission of energy to long distances had therefore much energy loss. After appearance of power transformers, DC networks were gradually replaced by AC networks. Large power plants were founded at suitable places and energy was transferred long distances. The new trend towards DG has been due to several reasons as:

- Technological development in DG units
- Increased need to build new transmission lines
- Reliable energy demand
- Economical concerns
- Environmental concerns

More methods are available in voltage controls in microgrids, point of common coupling (PCC) voltage control method, Voltage control for Photo Voltaic Systems with MPPT and Battery Storage, Inverter Control method, And Q/P droop control. In point of common coupling (PCC) voltage control method, PV systems are mostly integrated to the power grid via voltage source converters (VSC) . A VSC is capable of operating in all four quadrants. Theoretically, the voltage at the point of common coupling (PCC) of a grid-connected VSC can be dynamically regulated by controlling the reactive power injected/absorbed by the VSC to/from the power grid. Therefore the capability of a PV system that is integrated to the grid via a VSC to regulate the network voltage would enable the PV system to be utilized as a dynamic voltage regulator in the network at all times. In Voltage control for Photo Voltaic Systems with Maximum power point tracking technique (MPPT) and Battery Storage, this method proposes several control algorithms through which the capability of PV generators for voltage control and to extract maximum power by MPPT control. Detailed models of PV, battery, inverter and converter are considered for the study. The major contribution and novelty of the proposed control methods lie in the coordination among individual proposed control methods: MPPT control at the PV side, battery control, and Voltage control algorithm at the inverter side. These three control algorithms at three stages are jointly linked through a power balance objective at the DC and AC side of the inverter so that the DC side voltage is indirectly controlled at the desired value in order to maintain the AC side voltage at the utility desired voltage. The first two methods are not beneficial economically, so the new method is Q/P droop control method is used. Q/P droop control, which has a damping effect on the voltage, is added to the renewable generation to prevent the voltage fluctuation induced by its own active output power fluctuations.

The remainder of this paper is organized as follows. Section II: point of common coupling (PCC) voltage control method. Section III: MPPT and battery integrated voltage control method. Section IV Q/P droop control method. Section V outlines the conclusion.

2. CASE STUDY 1: POINT OF COMMON COUPLING (PCC) VOLTAGE CONTROL METHOD

The sensitivity of the PCC voltage of a grid-connected PV system to active and reactive power is a function of the network impedance. The R=X ratio of a low voltage distribution grid is generally greater than 1. Therefore the PCC voltage of a PV system that is connected to the distribution grid is sensitive to both active and reactive power injected to the grid by the PV system. As a result, if a PCC voltage controller is designed for a PV system connected to the distribution grid, both network reactance and resistance should be taken into consideration. In order to regulate the PCC voltage of a PV system at a given reference voltage by controlling the amount of reactive power injected to the grid by the PV system, a closed-loop controller is needed. Further, to select a suitable compensator for the controller and tuning the controller to obtain the desired response, the dynamics of the control plant of the PCC voltage controller should also be known. Therefore, in the current research, a control plant model of the PCC voltage controller of a PV system, which is integrated to a single-phase power distribution grid via a VSC, is first derived. Both reactance and resistance of the power distribution grid are taken into consideration in deriving the plant model. A closed-loop controller is proposed to regulate the PCC voltage at a given reference voltage [2].

2.1. Control Of The PCC Voltage With A Dynamic Reactive Power Controller

The design of the PCC voltage controller is described in this section. Three different types of compensators are taken into consideration for designing the controller. The control plant model of the PCC voltage controller is used for designing and tuning compensators where applicable.

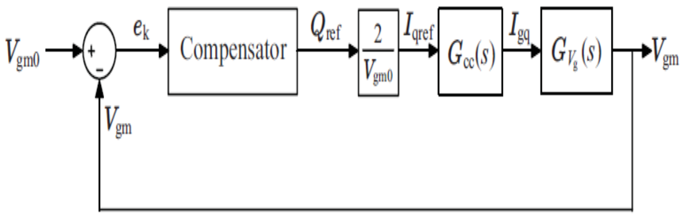


Fig.1.Control block diagram of the PCC voltage controller

The proposed closed-loop PCC voltage controller is shown in Fig. 1, where the error signal e_k is the difference in the magnitude of the reference PCC voltage V_{gm0} and the magnitude of the measured PCC voltage V_{gm} ,G_{cc}(s) is the closed-loop current controller of the PV system and finally G_{VG}(s) is the control plant model of the PCC voltage controller. Q_{ref},I_{qref} and $I_{gq}$are the reactive power reference, the magnitude of the reactive current reference and the magnitude of the reactive current injected to the grid respectively. The response time for the DC-link voltage controller of the PV system is longer than that of the current controller. Further, the PCC voltage controller should be made slower than the DC-link voltage controller to decouple the two controllers. Hence, the dynamics of the current controller can be disregarded assuming G_{cc}(s) = 1 when designing the PCC voltage controller. In Fig. 1, only the peak reactive current I_{gq} is shown as the output of G_{cc}(s) since the PCC voltage is controlled by regulating I_{gq} or the reactive power Q_g injected to the grid. But in the actual current controller of the PV system that is developed in the stationary reference frame with a proportional resonant (PR) regulator, both active and reactive current are controlled by one controller [2].

3. CASE STUDY 2: MPPT AND BATTERY INTEGRATED VOTAGE CONTROL METHOD

Proposed MPPT and Battery integrated voltage controlled solar PV system is presented in Fig.5. The control comprises of one loop for MPPT control, one loop for Voltage control at the inverter side and another loop for battery power management.

3.1. MPPT Control

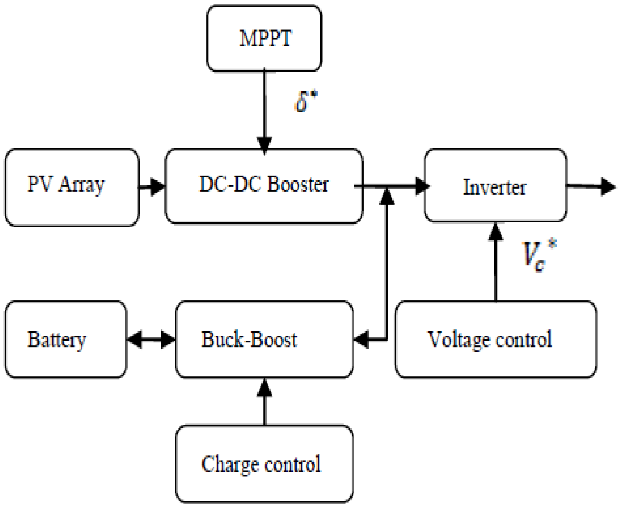


Fig.2. Proposed System Configuration

A typical solar panel converts only 30 to 40 percent of the incident solar irradiation into electrical energy. Maximum power point technique is used to improve the efficiency of the solar panel. According to Maximum Power Transfer theorem, the power output of a circuit is maximum when the Thevenin impedance of the circuit (Source impedance) matches with the load impedance. Hence our problem of tracking the maximum power point reduced to impedance matching problem. In the sources side we are using a boost converter connected to a solar panel in order to enhance the output voltage so that it can be used for different application like motor load. By changing the duty cycle of the boost converter appropriately we can match the source impedance with that of the load impedance. In recent years, a large number of techniques have been proposed for maximum power point tracking (MPPT).The majority of these methods are based on the perturbation and observation (P&O), which has the advantage of simple operation and easy to implement. The ''P&O'' method It is an iterative method of obtaining MPP. It measures the PV array characteristics, and then perturbs the operating point of PV generator to encounter the change direction. The maximum point is reached when

$$\frac{dP_{pv}}{dV_{PV}} = 0$$

Doing this method, the operating voltage of the PV generator is perturbed, by a small increment,ΔV_{PV} and the resulting change, ΔP_{PV}in power, is measured. If $\Delta P_{PV}$is positive, the perturbation of the operating voltage should be in the same direction of the increment. However, if it is negative, the system operating point obtained moves away from the MPPT and the operating voltage should be in the opposite direction of the increment. The logic of this algorithm is explained in Table 1 . True table associated with the operation for the Perturbation and Observe (P&O) method.

TABLE 1
OPERATION OF P&O ALGORITHM

ΔP_{PV}(t)	$\Delta V_{PV}(t)$
>0	+
<0	-

The ''+''sign refers to an increment and ''-'' sign to a decrease. In accordance with Table 2.1, if the PV power has increased, the operating point should be increased as well. However, if the PV power has decreased, the voltage should do the same.

3.2. Voltage Control

Second loop consists of Voltage control at AC side of the inverter. As shown in the control diagram in Fig. 3 (loop2), the PCC voltage is measured and the rms value of is calculated. Then, the rms value vtt is compared to a voltage reference $vt*(t)$ which could be a voltage specified by the utility, and the error is fed to a PI controller. The inverter output voltage $vc*(t)$ is controlled so that it is in phase with the PCC voltage, and the magnitude of the inverter output voltage is controlled so that the PCC voltage is regulated at a given level $vt*(t)$. The control scheme can be specifically expressed as [3].

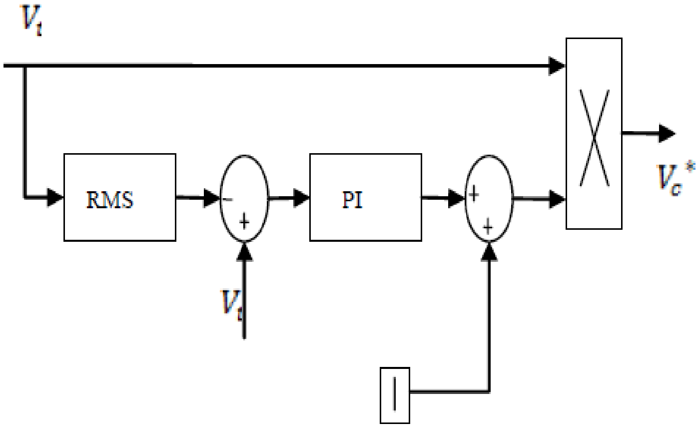


Fig.3. Integrated Solar PV MPPT and V-f control diagram

Where, $KP2$ and $KI2$ are the controller gains for this loop. In [3], 1 has been added to the right-hand side such that when there is no injection from the PV generator, the PV output voltage is exactly the same as the terminal voltage.

3.3. Battery Power Control

The controls shown in the diagram of Fig. 2 and described above are also integrated with the battery power control. The battery is incorporated in the PV system configuration in order to supply or absorb active power and support the frequency control objective with the PV generator. If there is abundant solar power and the active power required for frequency control is less than PV MPP, then the battery will be charged. If there is not enough solar power available and if the active power required for frequency control is more than PV MPP, then the battery will supply the deficit power in order to maintain the micro grid frequency at 50 Hz [4].

In this method differentiate the charging and discharging mode of the battery. This is undertaken by comparing PPV with $Pinverter$. If $PPV>Pinverte$, the battery is in charging mode, hence the switching signal which activates the Buck mode of the DC-DC converter. If $PPV<Pinverter$, the battery is in discharging mode. Hence the switching signal which activates Boost mode of the DC-DC converter. Hence, with this control logic, the converter is capable of operating in both directions and therefore, effectively charging and discharging the battery whenever required.

4. CASE STUDY 3: PROPOSED SCHEME

Here Q/P droop control method is used. In this study, the system nominal voltage is maintained by the excitation system [1]. To solve the local voltage fluctuations caused by the intermittent output power of renewable generation systems, we propose adding a Q/P droop control to the intermittent renewable generation systems, as shown in Fig. 4 where the subscript ref denotes the reference value, $\theta_s$is the angular position of the system voltage,V_{id} and $V_{iq}$are the inverter terminal voltage of the d- and q -components, respectively i_{id} and i_{iq} are the inverter terminal current of the d - and q-components, respectively, w_δ is the angular frequency of the system voltage, $L_f$is the filter inductance ,P and Q are the output active and reactive powers, respectively, K_{QP} and K_{QV} are the Q/P and Q/V droop coefficients, respectively,$P_0$and Q_0 are the operating points of the active and reactive power, respectively $Q_{max}$is the maximum reactive power, and V_{bus} is the voltage of the bus where the renewable generation is interconnected. P_{ref} is the maximum power from renewable generation that can be extracted from wind speed or solar irradiance. Q_0 is set to 0 so that the renewable generation systems operate as unity power factor when the voltage droop control is not activated [1].

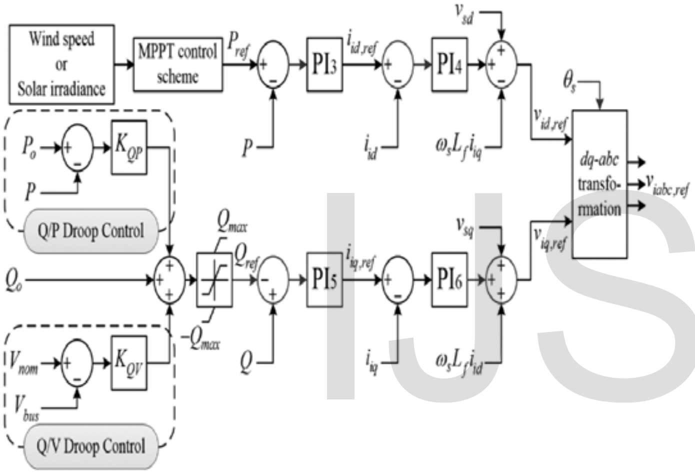


Fig.4. Control scheme of the grid-side inverter of the renewable Generation system.

As a conventional control, the Q/V droop control prevents the bus voltage from deviating far from the nominal value. As in K_{QV} has a value between 0 and 25 considering the rate capacity of power generation. The value of is based on the following equation,

$$K_{QV} = \frac{Q}{P_{rate}} \Big/ \frac{\Delta V_{bus}}{V_{bus}} \tag{1}$$

Where V_{base} and $P_{rate}$are the base voltage of the bus and the rate of active power of the generation system respectively. Here, K_{QV} of the PV and wind power is set to 25 and 5, respectively. Since K_{QV} is determined based on the rate capacity of power generation, adding the Q/P droop control might cause excessive reactive power output. To prevent this problemQ_{ref} is limited by the following equations [5].

$$Q_{MAX} = \sqrt{S_{rate}^2 - P^2} \tag{2}$$

Where, S_{rate} is the rate apparent power of the inverter which is considered to be same as the rate power of generation system. From (2), it can be noticed that the maximum reactive power is determined by the output active power which means that maximizing the active power is prioritized over compensating there active power. The voltage fluctuation cannot be effectively prevented by adopting the conventional Q/V droop control since it fundamentally triggered only after the voltage deviation is occurred as shown in Fig. 4. The focus of this paper is on the resolving of the fundamental problem that causes the voltage fluctuation. Thus, the role of the Q/P droop control of the renewable generation systems is to prevent voltage fluctuations induced by the system's own power fluctuations. By sensing the active power deviation from P_0, reactive power in proportion to K_{QP} is produced in compensation to prevent voltage fluctuation.

Day and night are considered separately to determine $P_0$and K_{QV} . for the PV and wind power is calculated by applying the average value of solar irradiance and wind speed, respectively. K_{QV} is obtained using a sensitivity matrix, which can be calculated from the Jacobian matrix equation [6].

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{P|V|} \\ J_{Q\theta} & J_{Q|V|} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} \tag{3}$$

Where, $\Delta P = [\,\Delta P_1, \Delta P_2, \dots\dots, \Delta P_{12}]^T$is the active power deviation at each bus, $\Delta Q = [\,\Delta Q_1, \Delta Q_2, \dots\dots, \Delta Q_{12}]^T$ is the reactive power deviation at each bus, $\Delta\theta = [\,\Delta\theta_1, \Delta\theta_2, \dots\dots, \Delta\theta_{12}]^T$is the voltage angular position deviation at each bus, $\Delta|V| = [\,\Delta|V|_1, \Delta|V|_2, \dots\dots, \Delta|V|_{12}]^T$is the voltage magnitude deviation at each bus, and $J_{P\theta}$, $J_{P|V|}$, $J_{Q\theta}$, and $J_{Q|V|}$are the Jacobian matrices. Note that the Jacobian matrix can become ill-conditioned or singular if the network voltage level is low. In this case, another method should be developed for acquiring Q/P droop coefficient. However, we focus on the medium or higher level of distribution network in this study. Taking the inverse transform of the Jacobian matrix given in (3), the sensitivity matrix equation can be expressed as

$$\begin{bmatrix} \Delta\theta \\ \Delta|V| \end{bmatrix} = \begin{bmatrix} S_{\theta P} & S_{\theta Q} \\ S_{|V|P} & S_{|V|Q} \end{bmatrix} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} \tag{4}$$

The voltage deviation occurring with the change in the active and reactive power is calculated as,

$$\Delta|V| = S_{|V|P}\,\Delta P + S_{|V|Q}\,\Delta Q \tag{5}$$

From (5), it can be noticed that the voltage fluctuation can be occurred by the active power fluctuation and can be reduced by compensation of the reactive power. The objective of the Q/P droop control is to mitigate the bus voltage fluctuation caused by the output power fluctuation of the renewable generation systems that are interconnected to that bus. Hence, to make the voltage deviation of bus equal 0, the following equation must be satisfied:

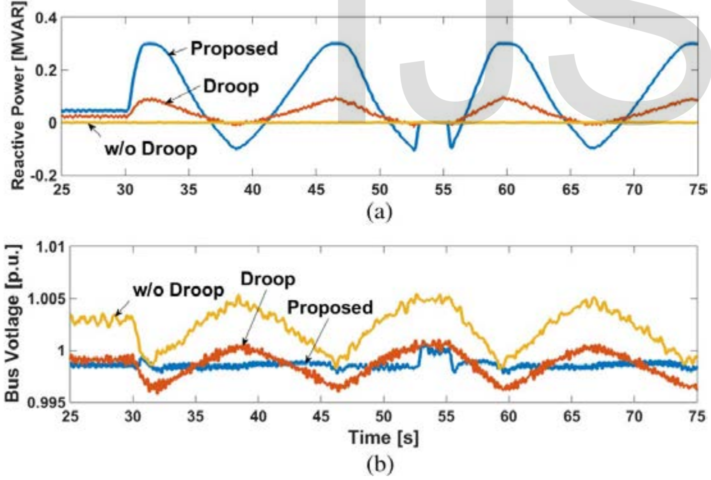
$$\begin{aligned}\Delta|V|_i &= S_{|V|P,i,i}\Delta P_i + S_{|V|Q,i,i}\Delta Q_i \\ &= 0 \qquad (6) \\ &= S_{|V|P,i,i}\left(P_{o,i} - P_i\right) + S_{|V|Q,i,i}\left(Q_{o,i} - Q_i\right)\end{aligned}$$

Since $Q_{0,i}$ is set to 0, (6) can be rearranged as

$$Q_i = \left(\frac{S_{|V|P,i,i}}{S_{|V|Q,i,i}}\right)\left(P_{o,i} - P_i\right) \qquad (7)$$

Where $S_{|V|P,i,i}/S_{|V|Q,i,i}$ is determined to be K_{Qp} of the renewable generation interconnected at bus. Determining proper P_0 is in the scope of the system scheduling.

We consider the active power fluctuation of the PV power system, the proposed voltage control strategy also positively affects the PV power system bus as shown in Fig. 5, and the proposed method performs well for the PV power system. However, if the reactive power is limited according to (2) as shown in Fig. 5(a) at around 53–56 s, the bus voltage became to have as similar value as that of the method adopting Q/V droop only.



(b)

Fig. 5. Simulation results for Case V. (a) Reactive power of PV power. (b) Bus voltage of PV power

5. CONCLUSIONS

First two methods uses voltage source converters without any damping effect on output voltage. Also in second method, there uses more number of control algorithm controlling the voltage limits of micro grid. So these factors make the control system were more complex and costlier. So the systems become uneconomical. The use of VSC will cause vulnerable to electromagnetic interference noise and the devices gets damaged in either open or short circuit conditions. But in Q/P droop control, which has a damping effect on the voltage, is added to the renewable generation to prevent the voltage fluctuation induced by its own active output power fluctuations. So to solve the local voltage fluctuations caused by the intermittent output power of renewable generation systems, the better method is Q/P droop control method. Besides, small-signal stability is not yet analyzed and a Q/P droop coefficient might not be acquired for a low voltage distribution network. Consequently, new load sharing method for the system of multi generators, small-signal stability analysis, and a method for acquiring Q/P droop coefficient for low voltage distribution network should be investigated for the future works.

REFERNCES

[1] Yun-Su Kim, Eung-Sang Kim, and Seung-Il Moon," Frequency and Voltage Control Strategy of Standalone Microgrids with High Penetration of Intermittent Renewable Generation Systems" *IEEETrans. Sustain.* On power systems, vol. 31, no. 1, January 2016.

[2] Brian k. Perera, philip ciufo and sarath perera," Point of common coupling (PCC) voltage control of a grid-connected solar photovoltaic (PV) system" in 39th Annual Conference of the IEEE Industrial Electronics Society (IECON 2013), 2013, pp. 7475-7480.

[3] M.R.Prasad, V.Sravan Kumar and P.Srihari," Voltage control for Photo Voltaic Systems with MPPT and Battery Storage in Micro grids", International Research Journal of Engineering and Technology (IRJET), Volume: 02 Issue: 02 | May-2015.

[4] L. Xu, Z. Miao and L. Fan, "Coordinated control of a solar battery system in amicrogrid," in *Proc. 2012 IEEE/PES* Transm. Distrib. Conf. Expo. *(T&D)*, pp. 1–7.

[5] J. MacDowell, "Installations connected to a power transmission system and generating equipment: Minimum design requirements, equipment, operations, commissioning and safety," NERC Corp., Atlanta, GA, USA, Nov. 2009.

[6] A. R. Bergen and V. Vittal, Power Systems Analysis, 2nd ed. Upper Saddle River, NJ, USA: Prentice-Hall, 2006.