

# Independent Control of Active and Reactive Power in Microgrid

Denish A. Prajapat S<sup>1</sup> Bhavik N. Suthar<sup>2</sup> Vinod S Tejwani<sup>3</sup>

<sup>1,2</sup> Electrical Department <sup>3</sup>Ph.D. Research Scholar

<sup>1,2</sup> LDCE Ahmedabad <sup>3</sup> GTU, Ahmedabad

**Abstract**— Now a days the increasing demand of electrical energy, renewable energy based distribution generators (DGs) are increasingly play a dominant role in electricity production. In this paper it is shown that control of generated power is achieved from the microgrid (MG) to cater the sensitive and critical load during disturbances. The effect of RL load connection and disconnection is shown by MATLAB results. The converter used is a voltage source inverter (VSI) which is controlled using d-q reference frame to inject a controlled current into the grid. Phase lock loop (PLL) is used to generate the vectorized output.

**Keywords:** Voltage Source Inverter (VSI), Power Control, p-q control.

## I. INTRODUCTION

The need of reducing emissions in the electricity generation field, and recent technological developments in the microgeneration domain are the main factors responsible for the growing interest in the use of microgeneration. In [1], the feasibility of two microgrid control strategies, It was shown that both the master/slave approach and droop approach ensure stable microgrid operation subsequent to a fault condition. If there are no synchronous machines to balance demand and supply, through its frequency control scheme, the inverters should also be responsible for frequency control during islanded operation. In addition, a voltage regulation strategy is required; otherwise, the MG might experience voltage and/or reactive power oscillations [2].

Maintaining the voltage and frequency within the standard permissible levels is an important requirement in microgrid design procedures. Various microgrid control approaches have been developed to maintain the voltage and frequency of the microgrid within permissible levels. Examples of these control approaches are: 1) master/slave control [1]; 2) droop-based control [3], [4]. Under normal operation, each DG system in the microgrid usually works in a constant current control mode in order to provide a pre-set power to the main grid. When the microgrid is cut off from the main grid, each DG inverter system must detect this islanding situation and must switch to a voltage control mode. In this mode, the microgrid will provide a constant voltage to the local load [5].

Control strategy to control grid current using p-q theory and d-q (Synchronous reference frame) theory with phase lock loop (PLL) control has been discussed in this paper. The work presented here is about the simulation of a microgrid with RL load where the output current of inverter is controlled in d-q reference frame. PLL is used to generate the vectorized output. The design of the entire system, and results obtained are presented in the subsequent sections.

## II. BASIC STRUCTURE OF THE POWER CONTROL

Basic structure of the inverter connected to grid is shown in Fig. 1.

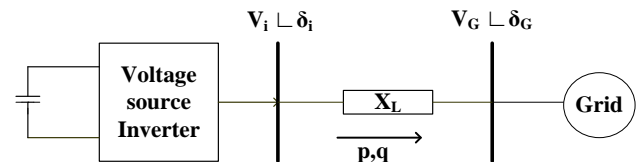


Fig. 1: Basic structure of the inverter connected to Grid

$$P = \frac{V_i V_G}{X} \sin(\delta_i - \delta_G) \tag{1}$$

and

$$Q = \frac{V_i^2 - V_i V_G \cos(\delta_i - \delta_G)}{X} \tag{2}$$

Where,

- $V_i$  = Inverter output voltage
- $V_G$  = Grid voltage
- $\delta_i$  = Phase angle of inverter output voltage
- $\delta_G$  = Phase angle of grid voltage
- $X$  = Line reactance

Let,

$$\delta_G = 0, \delta_i = \delta$$

Then,

$$P = \frac{V_i V_G}{X} \sin \delta \tag{3}$$

and

$$Q = \frac{V_i^2 - V_i V_G \cos \delta}{X} \tag{4}$$

Where,

$P$  = Real power

$Q$  = Reactive power

$X$  is the equivalent line reactance where the resistance is ignored. Since the DG unit output voltage control already exists, the task of the power controller is to generate voltage command ( $V_i \angle \delta_i$ ) for the voltage controller based on the desired power values  $P^*$  and  $Q^*$  and actual values  $P$  and  $Q$ . The desired DG output voltage  $V_i$  and the power angle  $\delta_i$  can be calculated from equation (3) and (4) given desired  $P$  and  $Q$  values and system parameter  $X$ .

### III. THEORETICAL CONSIDERATIONS ON P-Q CONTROL

The basic requirement of voltage source inverters is to control the flow of real and reactive powers between the microgrid and AC power system. Therefore, the first step in studying the subject of generation control is to see which variables influence the flow of real and reactive powers. The voltage source inverter controls both the magnitude and phase of its output voltage ( $V_i \angle \delta_i$  in Fig. 1). The vector relationship between the inverter voltage ( $V_i$ ) and the power system voltage ( $V_G$ ) along with the inductor's reactance determines the flow of real and reactive power from the microgrid to the power system. The flow of real and reactive powers can be controlled by generating the proper values for two variables of  $\delta_i^*$  and  $V_i^*$  from equation (3) and (4).

Concerning the above expressions, the following points can be raised [7] [8].

- As a consequence, the control of real and reactive power ( $P^* Q^*$ ) flow is reduced to the control of the power angle ( $\delta_i^*$ ) and the voltage level ( $V_i^*$ ) of the inverter. Therefore, power angle and voltage level would be the critical variables for real and reactive power flow control and can be controlled as shown in Fig.2.
- Although the flow of real and reactive power is not completely decoupled, they are fairly independent. In other words, the control of each one has only a minor impact on the other one.

It can be observed from equation (3) and (4) that both P and Q will be affected by only adjusting one of  $V_i$  and  $\delta_i$ , which is so called coupling between P and Q. However, variations of  $V_i$  and  $\delta$  have different levels of impact on P and Q as described in the following partial derivatives.

$$\frac{\partial P}{\partial \delta_i} = \frac{v_i v_G}{X} \cos \delta \quad (5)$$

$$\frac{\partial P}{\partial v_i} = \frac{v_G}{X} \sin \delta \quad (6)$$

$$\frac{\partial Q}{\partial \delta_i} = \frac{v_i v_G}{X} \sin \delta \quad (7)$$

$$\frac{\partial Q}{\partial v_i} = \frac{2v_i - v_G}{X} \cos \delta \quad (8)$$

When  $\delta$  is small which is true for large capacity power systems,  $\frac{\partial P}{\partial \delta_i}$  is close to  $\frac{v_i v_G}{X}$  and is  $\frac{\partial P}{\partial v_i}$  close to 0 and similarly  $\frac{\partial Q}{\partial \delta_i}$  is close to 0 and  $\frac{\partial Q}{\partial v_i}$  is close to  $\frac{2v_i - v_G}{X}$ .

This fact indicates that P is more sensitive to  $\delta$  and Q is more sensitive to  $V_i$  especially when the DG unit is connected to a large capacity system where the power angle  $\delta$  is usually small. The voltage and phase angle references can be generated as

$$\delta_i^* = \int K_p (P^* - P) dt \quad (9)$$

$$v_i^* = \int K_q (Q^* - Q) dt \quad (10)$$

In the proposed power regulation approach, P and Q controls are decoupled under steady state due to the integration of the errors. However, in the transient, the P and Q coupling cannot be eliminated. Both P and Q are nonlinear function of  $V_i$  and  $\delta_i$ .

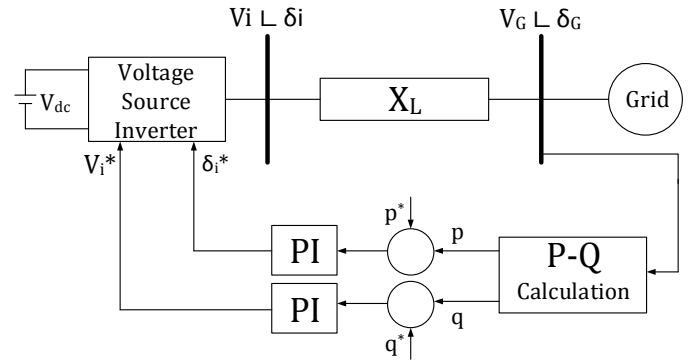


Fig. 2: Basic structure of the inverter control scheme.

The basic structure of the voltage source inverter (VSI) P-Q controller in the simplest way is shown in Fig.2 [9] [10]. Real and reactive powers ( $p, q$ ) can be controlled independently to a good extent. Two PI controllers would suffice to control the flow of real and reactive powers by generating the proper values for two variables of  $V_i^*$  and  $\delta_i^*$  as shown in Fig 2.

However, in practical systems, the above approach is not feasible. Practically, the value of X cannot be precisely known and may change due to the operation of the power system. Once an inaccurate value of X is used in the control, the error of X will lead to poor tracking and even instability. Therefore, power control solutions requiring knowledge of X cannot be practically used.

### IV. P-Q THEORY

In the case of the d-q frame, if the d-axis is aligned to the grid voltage, the reference current d-component  $i_d^*$  is controlled to manage the power angle ( $\delta^*$ ) and hence real power flow, while the reference current q-component  $i_q^*$  is controlled to manage the voltage level ( $V_i^*$ ) and hence reactive power flow of the inverter. The reference current q-component should be zero in order to have the grid currents in phase with the grid voltage. The p-q theory implements a transformation from a stationary reference system in a-b-c coordinates, to a system with coordinates  $\alpha$ - $\beta$ -0, where coordinates  $\alpha$ - $\beta$  are orthogonal to each other, and coordinate 0 corresponds to the zero-sequence component. [6]

$$\begin{bmatrix} v_\alpha \\ v_\beta \\ v_0 \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} \quad (11)$$

The  $\alpha$ - $\beta$  coordinates are transformed to the d-q coordinates that rotate at the angular fundamental frequency  $\omega$  of the grid voltage waveform. The state-vectors which express the inverter electrical quantities are projected on the d-axis and q-axis.

$$\begin{bmatrix} v_d \\ v_q \end{bmatrix} = R(-\omega t) \begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix}, R(\omega t) = \begin{bmatrix} \cos\omega t & -\sin\omega t \\ \sin\omega t & \cos\omega t \end{bmatrix} \quad (12)$$

If the inverter is connected to the grid through L-filter as shown in Fig. 1, then in the d-q frame rotating at the angular speed  $\omega$ ,

$$\frac{d}{dt} \left( R(\omega t) \begin{bmatrix} i_d \\ i_q \end{bmatrix} \right) = \frac{1}{L} R(\omega t) \begin{bmatrix} v_d \\ v_q \end{bmatrix} - \begin{bmatrix} e_d \\ e_q \end{bmatrix} \quad (13)$$

The above equation can be rewritten as follow:

$$\frac{d}{dt} \begin{bmatrix} i_d \\ i_q \end{bmatrix} = \frac{1}{L} \begin{bmatrix} v_d \\ v_q \end{bmatrix} + \omega \begin{bmatrix} i_q \\ -i_d \end{bmatrix} - \frac{1}{L} \begin{bmatrix} e_d \\ e_q \end{bmatrix}$$

The inverter is controlled using the time-integral of the d-q space vector. The resulting d-q components are time integrated, resulting in the flux vectors in PI controller inputs, for the inverter and AC system voltages.

The p-q power control is implemented through the current controller. The block diagram of the VSI p-q controller is shown in Fig 3. Synchronous reference frame control also called d-q control uses a reference frame transformation “abc to dq” which transforms the grid current and voltages into d-q frame. The transformed current controls the grid current [11]. For the simulation, battery is used as input of inverter.

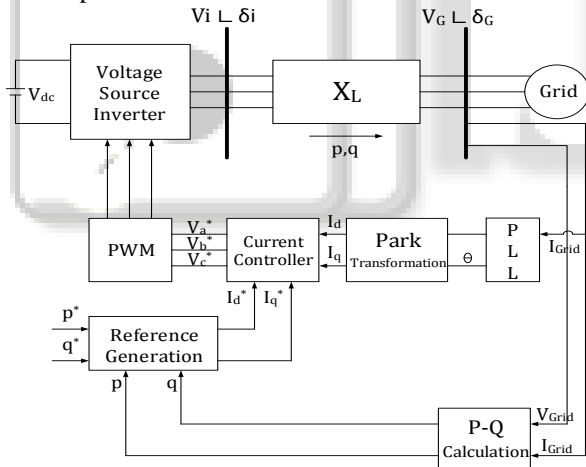


Fig. 3: Control schemes of the Inverter interface to the utility grid.

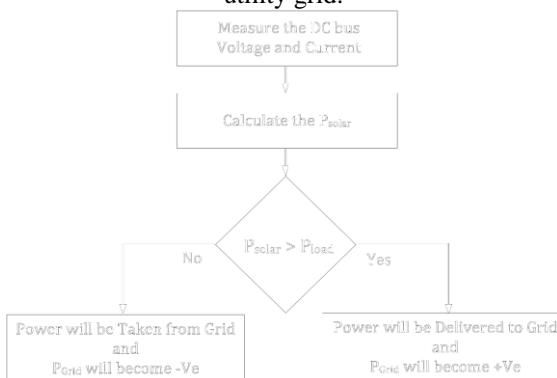


Fig. 4: Flow chart for Power Flow between Microgrid and Grid.

Initially measure the DC bus voltage and current, based on these values calculate the  $P_{solar}$ . If  $P_{solar}$  is greater than  $P_{load}$  then surplus power is delivered to grid and  $P_{grid}$  becomes positive. If  $P_{solar}$  is less than  $P_{load}$  then power is taken from grid and  $P_{grid}$  becomes negative. [12].

## V. RESULTS AND DISCUSSIONS

The Matlab/Simulink model of microgrid with RL load consist of following parameters

The desired P and Q values are set for two different cases. The reference d-q components of desired P and Q value are regulated with PI controllers. The gains of PI controllers are determined by trial and error for each case.

### A. Case 1: $P_{ref} = 1.0 \text{ p.u}$ , $Q_{ref} = 0.2 \text{ p.u}$

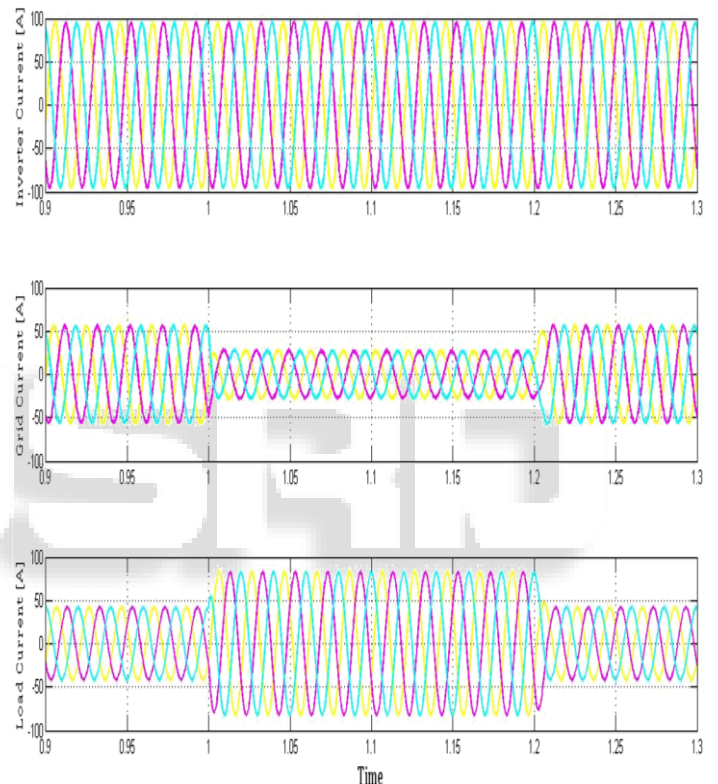


Fig. 5: Simulation results of Inverter, Grid and Load currents.

For the first case study, the reference real power is set to  $P_{ref} = 1.0 \text{ p.u}$  and the reference reactive power is set to  $Q_{ref} = 0.2 \text{ p.u}$ . In this case inverter based microgrid is capable of delivering the power for the RL load ( $P = 20 \text{ kW}$ ,  $Q = 10 \text{ kVAR}$ ). The amount of power generated is more so surplus power can be delivered to grid. At  $t = 1 \text{ sec}$  another RL load ( $P = 20 \text{ kW}$ ,  $Q = 10 \text{ kVAR}$ ) is connected to the microgrid. For that power generated by the inverter is given to the RL load and at  $t = 1.2 \text{ sec}$  the RL load is disconnected. This effect is shown in Fig. 5.

Fig. 6 shows the  $I_{d\_ref}$  and  $I_{q\_ref}$  which is generated based on actual and reference active and reactive power. The reference active power  $P_{ref}$  is set to  $1.0 \text{ p.u}$  and reference reactive power  $Q_{ref}$  is set to  $0.2 \text{ p.u}$ .

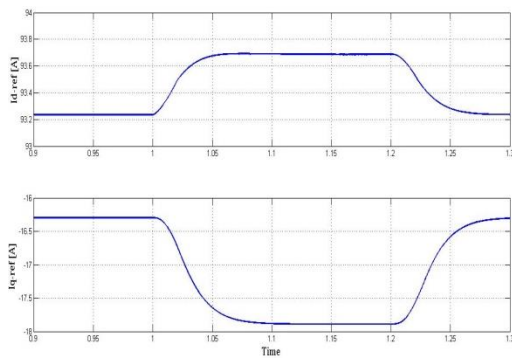


Fig. 6: Simulation Results of  $I_{d\_ref}$  and  $I_{q\_ref}$ .

B. Case 2:  $P_{ref} = P_{load}$ ,  $Q_{ref} = Q_{load}$

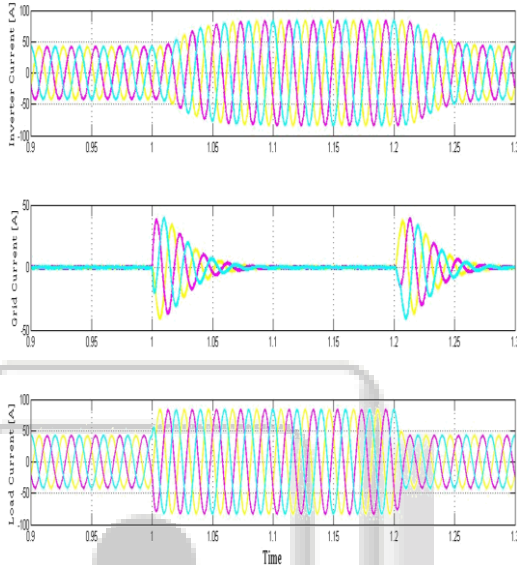


Fig. 7: Simulation results of Inverter, Grid and Load currents.

For the second case study, the reference real power is set to  $P_{ref} = P_{load}$  and the reference reactive power is set to  $Q_{ref} = Q_{load}$ . In this case inverter generate the power which is actually required for RL load ( $P = 20$  kW,  $Q = 10$  kVAr). The amount of power generated is equal to the power required for the load. At  $t = 1$  sec another RL load ( $P = 20$  kW,  $Q = 10$  kVAr) is connect to microgrid. For that inverter generate the required power for RL load. This effect is shown in Fig. 7 and also shown that the transient in grid current when load is connect and disconnect. Fig. 8 shows the  $I_{d\_ref}$  and  $I_{q\_ref}$  which is follow the reference power because reference power is change when there is a change in load.

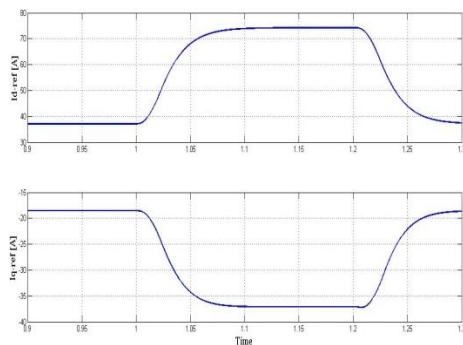


Fig. 8 Simulation Results of  $I_{d\_ref}$  and  $I_{q\_ref}$ .

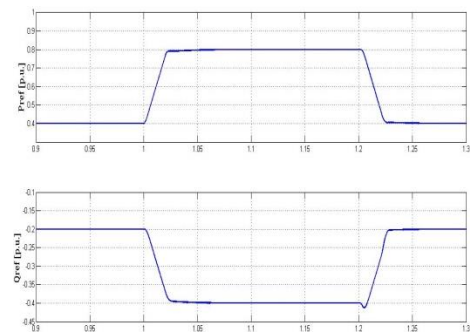


Fig. 9: Simulation Results of  $P_{ref}$  and  $Q_{ref}$ .

From Fig. 9 it is shown that the reference active and reactive power is changed when load is change at  $t = 1$  sec and  $t = 1.2$  sec.

## VI. CONCLUSION

From results of simulation it can be concluded that by controlling the inverter, the power exchanges between the grid, load and distributed generators can be done for various loading conditions. Power generated by the inverter can be controlled using synchronous d-q transformation.

## REFERENCES

- [1] J. A. Lopes, C. Moreira, and A. Madureira, "Defining control strategies for microgrids islanded operation," *IEEE Trans. Power Syst.*, vol. 21, no. 2, pp. 916–924, May 2006.
- [2] R. H. Lasseter and P. Piagi, "Microgrid: A conceptual solution," in *Proc. 35th PESC*, vol. 6, Aachen, Germany, Jun. 2004, pp. 4285–4290.
- [3] K. De Brabandere, B. Bolsens, J. Van den Keybus, A. Woyte, J. Driesen, and R. Belmans, "A voltage and frequency droop control method for parallel inverters," *IEEE Trans. Power Electron.*, vol. 22, no. 4, pp. 1107–1115, Jul. 2007.
- [4] C. K. Sao and P. W. Lehn, "Control and power management of converter fed microgrids," *IEEE Trans. Power Syst.*, vol. 23, no. 3, pp. 1088–1098, Aug. 2008.
- [5] I. J. Balaguer, L. Qin, Y. Shuitao, U. Supatti, and P. F. Zheng, "Control for grid-connected and intentional islanding operations of distributed power generation," *IEEE Trans. Ind. Electron.*, vol. 58, no. 1, pp. 147–157, Jan. 2011.
- [6] Hirofumi Akagi, Edson Hirokazu Watanabe, Mauricio Aredes, "Instantaneous Power Theory and Applications to Power Conditioning," IEEE Press series on Power engineering., A John Wiley & Sons, Publication. 2007
- [7] C. Wang, M. H. Nehrir, and S. R. Shaw, "Dynamic models and model validation for PEM fuel cells using electrical circuits," *IEEE Trans. on Energy Conversion*, vol. 20, No. 2, pp. 442–451, June, 2005.
- [8] Koen J. P. Macken, Jeroen Van den Keybus, and Ronnie J. M. Belmans, "Distributed Control of Renewable Generation Units With Integrated Active Filter," *IEEE Transactions on Power Electronics*, vol. 19, No. 5, pp. 1353–1360, Sep., 2004.
- [9] R. Lasseter and P. Piagi, "Providing Premium Power through Distributed Resources," *Proceedings of the*

33rd Hawaii International Conference on System Sciences, 2000.

- [10] P. Giroux, G. Sybille, and H. Le -Huy, —Modeling and Simulation of a Distribution STATCOM using Simulink’s Power System Blockset!, IECON’01: 27th Annual Conference of the IEEE Industrial Electronics Society, pp. 990-994, 2001.
- [11] Sangita R Nandurkar, Mini Rajeev, “Design and Simulation of three phase Inverter for grid connected Photovoltaic systems” Proceedings of Third Biennial National Conference, NCNTE- 2012, Feb 24-25.
- [12] V. S. Tejwani, B. N. Suthar, “Novel Control Strategy for Grid- connected PVES for Smart Distribution System” Fifth International Conference on Power and Energy Systems, Kathmandu, Nepal 28 - 30 October, 2013.

