Power quality Enhancement in Islanded Microgrid

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Abstract — **In recent years, the penetration of distribution generations (DGs) has increased. Also the role of distributed generation has significantly increased not only as power generator, but also as an important factor in power quality improvement. In this paper, a method is proposed for reducing the voltage unbalance while the DG is not connected to the grid. Control loops pertaining to voltage and frequency powers are provided in order to control the voltage and frequency of local load. Besides, the virtual impedance loop and proportional-resonant controller are also utilized in the control loop. The simulation results confirm the functionality of the control strategy and the controllers in eliminating the imbalance**.

Keywords-Unbalance Voltage; Proportional-resonant controller; Virtual Impedance; Droop control

I. INTRODUCTION

Distributed generation systems usually have a DC link and a converter for connecting them to the power grid or ac load. The converter's function is to control the injection of active and reactive power to the grid or voltage and frequency of load. Moreover, the converter can used as imbalance and harmonic compensation through generating the appropriate output. The control method introduced in [1, 2] is performed by series and parallel connection of two inverters like an active filter. The function of parallel inverter is to control the injected active and reactive powers to the grid and the series inverter's task is to compensate the imbalance of grid's current.

Injection of appropriate current to the grid is another compensation method [3]. Imbalance compensation is limited because it causes an increase in voltage regulation and makes the voltage controller ineffective. Many strategy address voltage unbalance compensation (VUC) of point of common coupling (PCC) or DG terminal by proper control of DGs interface inverters [4]-[10]. To compensate unbalanced voltage of Sensitive Load Bus (SLB), an extra control loop is devised in [6] as secondary control. In [9], satisfactory voltage quality of multi-area MG is obtained. In [10], DGs inverters rated power is considered in the coordinated control . In this paper, the compensation is done by changing reference voltage and hence sending the right commands to the switches. The control system's structure includes the following items:

PR controller related to voltage and current

Virtual impedance loop

Droop control for active and reactive power

Voltage imbalance compensator

II. DG CONTROL STRATEGY

The system's overall diagram is shown in fig. 1. It includes the inverter, the LCL filter and the distribution lines. A single phase R-L load is used as the unbalanced load. System's variables are stated in stationary reference frame. Clarke transform is used to state the variables.

$$X_{\alpha\beta} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} . X_{abc} \tag{1}$$

$$X_{abc} = \sqrt{\frac{2}{3}}\begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} . X_{\alpha\beta} \tag{2}$$

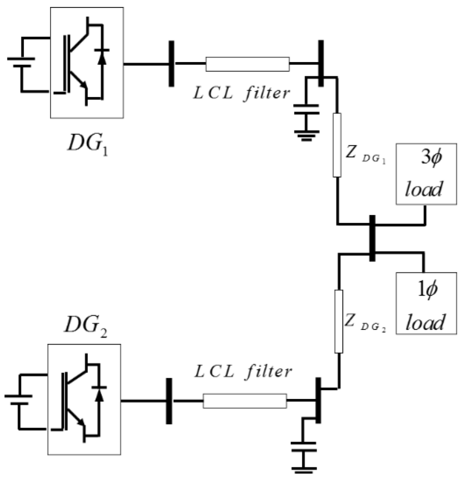

Figure 1. Overall diagram of the studied micro grid

A. Active and Reactive Power Control

Considering a DG with impedance $Z\measuredangle\theta$ which is connected to the grid, active and reactive powers are calculated as follows [4]:

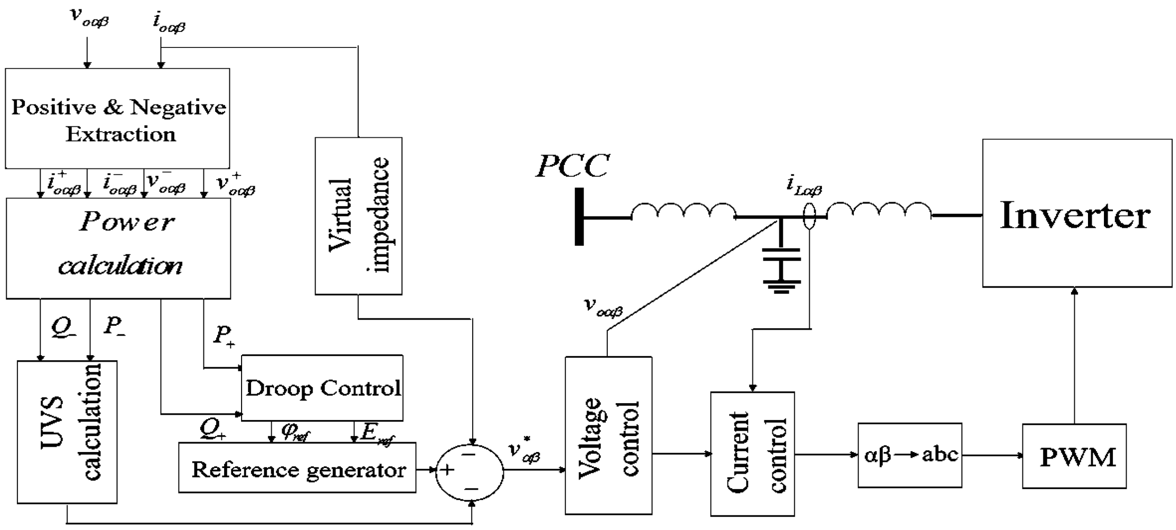

Figure 2. Control diagram of each distributed generation unit

$$P = \left[\frac{EV}{Z}\cos\varphi - \frac{V^2}{Z}\right]\cos\theta + \frac{EV}{Z}\sin\varphi\sin\theta \quad (3)$$

$$Q = \left[\frac{EV}{Z}\cos\varphi - \frac{V^2}{Z}\right]\sin\theta - \frac{EV}{Z}\sin\varphi\cos\theta \quad (4)$$

Where E is inverter's output voltage, V is grid voltage, φ is the load angle (the angle between E and V) and Z and θ are impedance magnitude and angle, respectively. Assuming the phase angle of grid voltage to be zero, the phase angle of inverter's output voltage is φ. If we assume the impedance between the inverter and the grid to be inductive (Z=X), consequently we have $\theta = 90°$ and we have:

$$P = \frac{EV}{Z}\sin\varphi \quad (5)$$

$$Q = \left[\frac{EV\cos\varphi}{x} - \frac{V^2}{x}\right] \quad (6)$$

In practical applications, φ is small. Hence, active and reactive powers will become as follows:

$$P \approx \frac{EV\varphi}{Z} \quad (7)$$

$$Q \approx \frac{V}{x}(E - V) \quad (8)$$

Therefore, we can control the active and reactive powers through the phase angle and the magnitude of DG's output voltage, respectively. Based upon this, we use the following droop characteristics in order to control active and reactive powers.

$$\varphi^* = \varphi_0 + m_P(P_{ref} - P) \quad (9)$$

$$E^* = E_0 + n_P(Q_{ref} - Q) \quad (10)$$

Where s is Laplace variable, E_0 is rated voltage's peak, φ_0 is rated phase angle, P is active power, P_{ref} is reference active power, Q is reactive power, Q_{ref} is reference reactive power, m_p is proportional gain of active power , n_p is proportional gain of reactive power, E^* is magnitude of reference voltage and φ^* is reference voltage's phase angle.

As seen in fig. 2, E^* and φ^* are used to generate the three-phase balanced signals. This voltage has only the positive sequence, so we use positive sequence in droop characteristics.

B. Power Caculation

Based upon the theory of instantaneous power, the instantaneous values of active and reactive powers are calculated as follows:

$$p = v_{0\alpha}i_{0\alpha} + v_{0\beta}i_{0\beta} \quad (11)$$

$$q = v_{0\beta}i_{0\alpha} - v_{0\alpha}i_{0\beta} \quad (12)$$

Because the voltage and current both have positive as well as negative sequences, the instantaneous power can be separated into positive and negative terms.

$$P = P_+ + P_- \quad (13)$$

$$Q = Q_+ + Q_- \quad (14)$$

$$\begin{bmatrix} P_+ \\ Q_+ \end{bmatrix} = \frac{3}{2} \begin{bmatrix} V_{+\alpha}^{pcc} & V_{+\beta}^{pcc} \\ V_{+\beta}^{pcc} & -V_{+\alpha}^{pcc} \end{bmatrix} \begin{bmatrix} I_{+\alpha}^{o} \\ I_{+\beta}^{o} \end{bmatrix} \quad (15)$$

$$\begin{bmatrix} P_- \\ Q_- \end{bmatrix} = \frac{3}{2} \begin{bmatrix} V_{-\alpha}^{pcc} & V_{-\beta}^{pcc} \\ V_{-\beta}^{pcc} & -V_{-\alpha}^{pcc} \end{bmatrix} \begin{bmatrix} I_{-\alpha}^{o} \\ I_{-\beta}^{o} \end{bmatrix} \quad (16)$$

In order for the system to be stable against sudden changes and power disturbances, we use a low-pass filter to obtain the DC constituent of each power.

C. Voltage and current Controler

Concerning the insufficiency of PI controller in tracking the sinusoidal signals, the proportional-resonant controller in stationary reference frame would be preferred for voltage and current control. Proportional-resonant voltage and current controllers are as:

$$G_v(s) = k_{pv} + \frac{k_{rv}\omega_c s}{s^2+\omega_c s+\omega_0^2} \quad (17)$$

$$G_i(s) = k_{pi} + \frac{k_{ri} s}{s^2+\omega_0^2} \quad (18)$$

Where k_{pV} (k_{pI}) and k_{rV} (k_{rI}) are the proportional and resonance gains of voltage (current) controllers, respectively and ω_{CV} is cut-off frequency of voltage controller.

According to fig. 2, the voltage controller follows the reference voltage generated by the virtual impedance loop and the imbalance compensator and the droop controller; and will generate the reference current of the current controller. The current controller's output current is transformed into abc frame and will generate the required reference voltage for PWM modulator. The PWM modulator then generates appropriate inverter command pulses.

D. Vitual Impedence Loop

Virtual Resistance will increase the system oscillation's damping. Unlike the actual resistors, virtual ones have no power loss, so virtual resistance can be implemented without any efficiency reduction [5]. The virtual impedance also eliminates the coupling between active and reactive powers, thus causes the droop based controller to become more stable.

Virtual Impedance in stationary reference frame can be obtained as shown in fig. 3 where R_v and L_v are virtual resistance and inductance, respectively [6]. According to fig. 3 we have:

$$u_{V_\alpha} = R_v . i_{0\alpha}^{+} - L_v . \omega . i_{0\beta}^{+} \quad (19)$$

$$u_{V_\beta} = R_v . i_{0\beta}^{+} + L_v . \omega . i_{0\alpha}^{+} \quad (20)$$

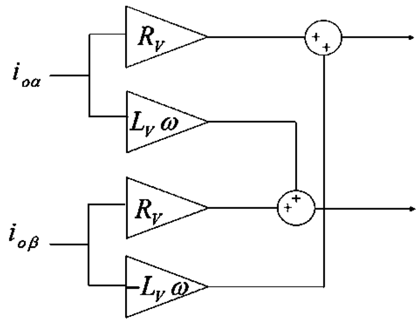

Figure 3. Virtual impedance block diagram

III. CONTROL STRATEGY FOR UNBALANCE COMPENSATION

In This section unbalance compensation are used and in the next section the effect of negative sequence generation is determined and stability of system is analyzed.

A. VUF Calculation

According to fig. 4, we use the positive and negative sequences of α- component of the DG's output voltage in order to calculate the VUF. Actually, the RMS values of $v_{0\alpha}^{-}$ and $v_{0\alpha}^{+}$ are obtained by applying the rms and low-pass filter functions. The low-pass filter's transfer function is as follows:

$$LPF(s) = \frac{s}{s+\omega} \quad (19)$$

Where ω_c is 2 rad/s. Finally, the VUF will be determined by dividing $v_{0\alpha}^{-}$ by $v_{0\alpha}^{+}$.

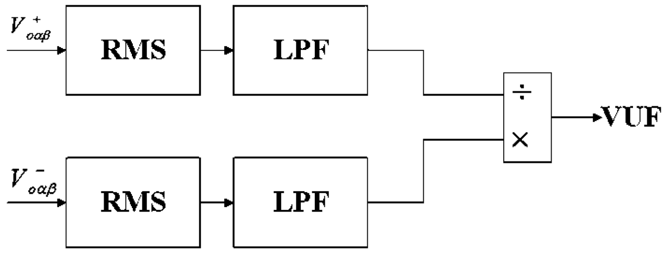

Figure 4. VUF calculation diagram

B. Detrminig the Effect of Negative Sequence Voltage Generator

According to fig. 5, the injected negative sequence voltage to the system is calculated as:

$$UVC = S^{-} V_o^{-} G_c \quad (20)$$

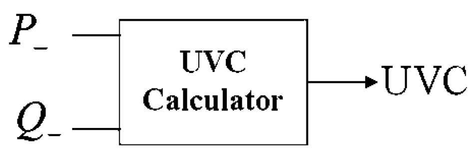

Figure 5. Function of UVC

Besides, the DG's output impedance for the negative sequence is:

$$Z_o^-(s) = R_l + R_v - (L_l + L_v)s \quad (21)$$

Hence, the magnitudes of the active and reactive and apparent powers can be formulated as:

$$P_- = 3(R_1 + R_v)I_{o-}^2 \quad (22)$$

$$Q_- = 3(L_1 + L_v)I_{o-}^2 \quad (23)$$

$$|S_-| = 3|Z_o^-|I_{o-}^2 \quad (24)$$

Based on small signal representation we have:

$$U\grave{V}C = [3|Z_o^-|(I_{o-}^2)V_o^- + 6|Z_o^-|(\hat{I_{o-}})(I_{o-})].G_c.LPF \quad (25)$$

From the other side, considering

$$I_{o-} \approx \frac{E^*}{Z_{UL}} \quad (25)$$

$$V_{o-} \approx -Z_o^-(s)I_{o-} \quad (26)$$

We have

$$UVC = [(\frac{3|Z_o^-|(E^*)^2}{Z_{UL}^2(j\omega)}\hat{v_{o-}} - \frac{6|Z_o^-|(E^*)^2 Z_o^-(j\omega)}{Z_{UL}^2(j\omega)})\hat{I_{o-}}]G_c \quad (24)$$

After applying the compensator we will have:

$$\hat{V_{o-}} = H\hat{I_{o-}} \quad (27)$$

Where

$$H = \frac{6G_-(j\omega).X_v.|Z_o^-|(E^*)^2 Z_o^-(s).G_c.LPF}{Z_{UL}^2(j\omega)+3G_-(j\omega).X_v.|Z_o^-|(E^*)^2 G_c.LPF} - \frac{Z_o^-(j\omega).Z_{UL}^2(j\omega)}{Z_{UL}^2(j\omega)+3G_-(j\omega).X_v.|Z_o^-|(E^*)^2 G_c.LPF}$$

It is obvious that, by the increase of Gc, unbalance compensation is increased but stability of control system is decreased. Therefore a value of Gc is selected that satisfy both unbalance compensation and system stability.

The poles of H(jω) for UCG = (0.6,0.8 ,1.2,1.4 and 1.6) are shown in Fig. 6. As shown, for UCG = 1.6, one poles are located in the right half of the s-plane, and thus, the control system becomes unstable. Therefore,Gc= 1.4 is selected .

IV. Simulation Result

The system shown in fig. 1 has been simulated using MATLAB/Simulink. The parameters of the system are shown in table 1 to table 3. At t=0.8s the imbalance compensator is applied to the system and as a result, voltage imbalance will decrease. As seen in fig. 6, it will reduce from $UVC_1 = 7.5\%$ (before the compensation) to $UVC_2 = 0.7\%$ (after the compensation).

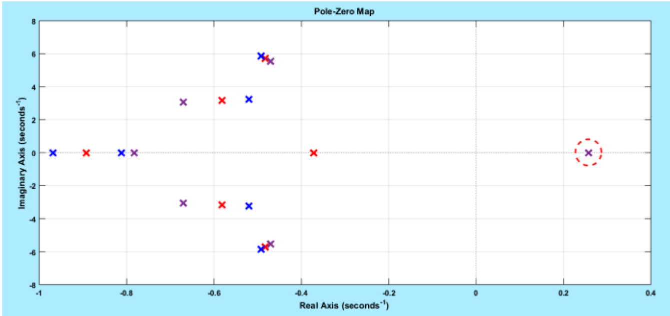

Figure 6. Poles of H(jω)

Negative sequences of active and reactive powers are shown in fig. 7. After applying the UVC, the imbalance has been reduced, so the negative sequence power is decreased. Positive sequences of active and reactive powers are also shown in fig. 8 and fig. 9. They are increased due to the function of UVC. The DG1's terminal voltage is shown in fig. 10. As seen, as a result of compensation, PCC voltage unbalance is decreased

TABLE I. THE PARAMETERS PERTAINING TO POWER LEVELS

$R_g[\Omega]$	L_g[mH]	$C[\mu F]$	L_o[mH]	$L[mH]$	$V_{dc}[V]$
0.3	3	25	2	2	700

TABLE II. THE CONTROLLER PARAMETERS

ω_C	K_{RV}	K_{RI}	K_{PV}	K_{PI}
1.5π	20	500	1	2

TABLE III. THE PARAMETERS PERTAINING TO POWER CONTROL

Q_{ref}^+	$P_{ref}^+[w]$	n_I	n_P	m_I	m_P	ω_0	E_0
350	1300	0.15	0.005	0.002	0.00003	100π	312

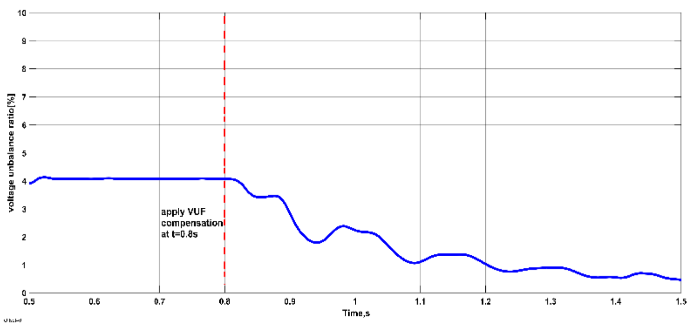

Figure 7. Imbalance of PCC voltage

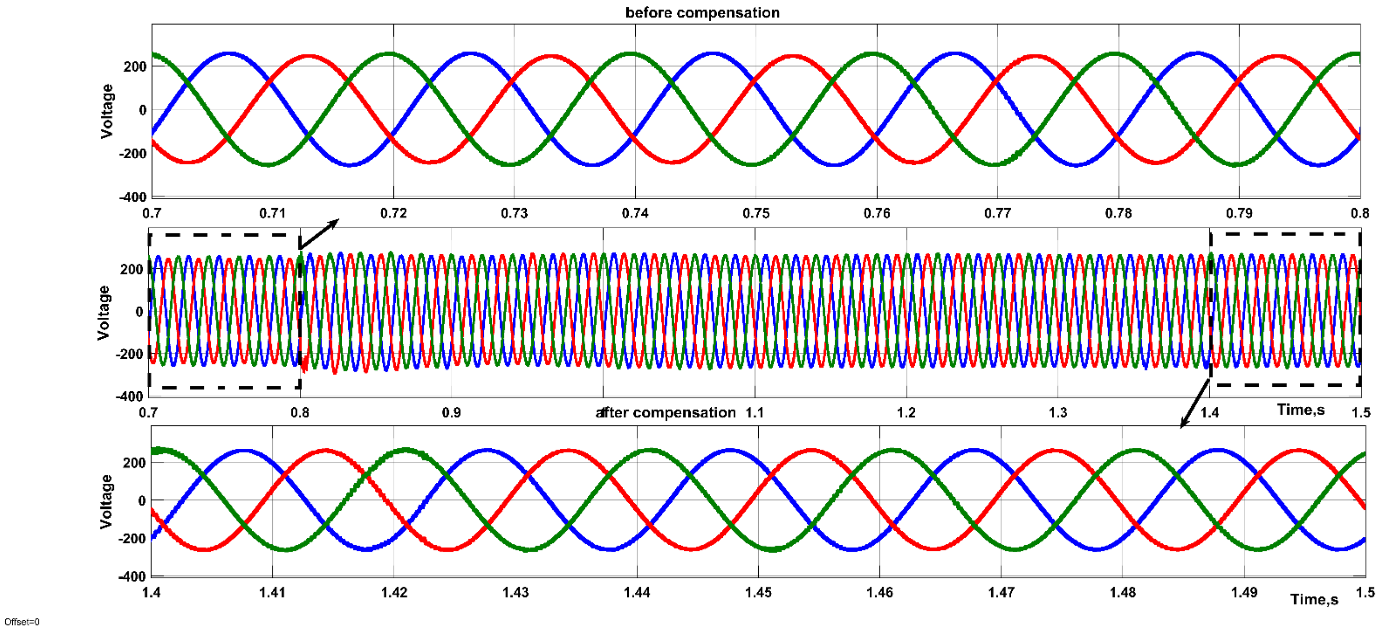

Figure 8. Figure8. Three phase PCC voltage

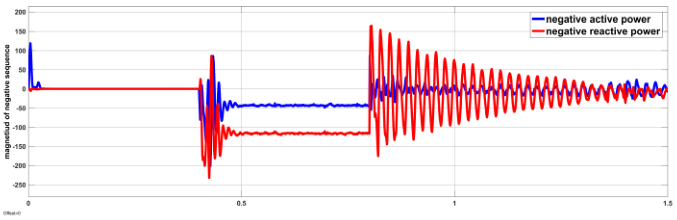

Figure 9. Magnitudes of negative sequence active power (blue) and reactive power (orange) of DG1 and DG2

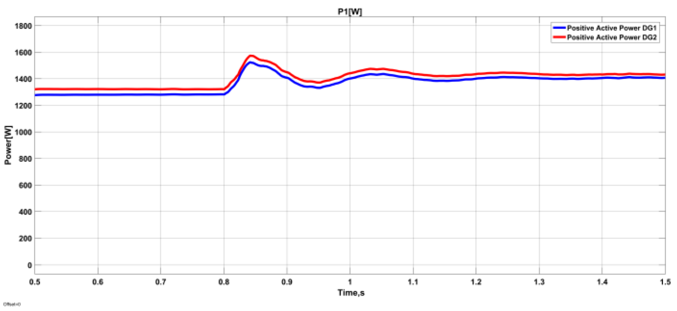

Figure 10. Positive sequence active powers of DG1 and DG2

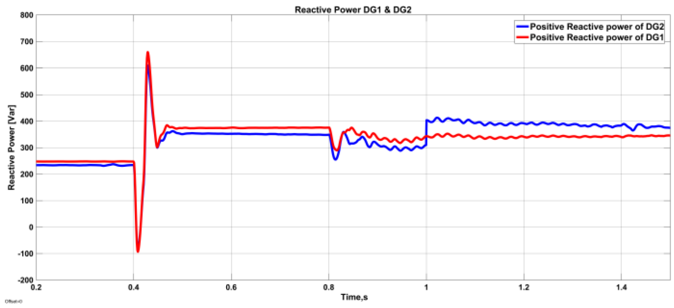

Figure 11. Positive sequence reactive powers of DG1

V. Conclusion

In this paper, a new approach is proposed in order to decrease the voltage imbalance using the distributed generation. The method of determining negative sequence of apparent power was explained. Positive sequence of apparent power is given to the power controller to determine the magnitude and phase angle of the output reference voltage. Each DG unit can eliminate the imbalance using the designed control loop in addition to injection of active and reactive powers. The control system injects the negative sequence of the voltage, which is a multiple of negative apparent power, to the reference voltage and will decrease the voltage imbalance. The simulation results confirm the control system's functionality.

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