

Grid Current Compensator for Grid-Connected Distributed Generation under Nonlinear Loads by Using DQ-SRF Technique

Bhutendra Gour. A¹, Mr.Prasad.D²

P.G. Student, Department of EEE, Sona College of Technology, Salem, Tamilnadu, India¹

Assistant Professor, Department of EEE, Sona College of Technology, Salem, Tamilnadu, India²

ABSTRACT: In distributed generation, the harmonics are high due to converter switching and non linear loads used by the consumers. This highly distorted current cannot be fed directly to the utility grid as it will imbalances the whole power system operations. In order to avoid this problem filters are used with some strategies. This paper deals with the current control strategy for grid connected operations of distributed generations under non-linear loads using dq-srf technique. The proposed method has current controller which is designed in dq-synchronous reference frame (dq-srf) and composed of PI controller. More over the proposed technique does not need any sensors for measurement harmonic analysis of grid voltage and as well as harmonics are removed to the maximum extent. Hence this can be easily adopted at any distributed generation which adds as an advantage. The operation principle of proposed current controller is validated through MATLAB SIMULINK.

KEYWORDS: Distributed generation (DG), Inverter, Non-linear load, dq-srf technique, harmonic compensation.

I.INTRODUCTION

In traditional methods for reducing the harmonics due to switching in the converter when power obtained through various power generation techniques like solar, wind etc. are reduced by the filters and facts devices. But these are used at the high power generations. In case of distributed generation which generated few megawatts, the power is directly consumed by the non-linear loads then the surplus power is fed to the utility grid if deficient power is consumed from the utility grid. Due to this non-linear loads, the current is highly distorted which cannot be fed directly to utility grid. In both configurations, i.e., with and without the local load, the prime objective of the DG system is to transfer a high quality current (grid current) into the utility grid with the limited total harmonic distortion (THD) of the grid current at 5% as recommended in the IEEE 1547 standards [15].

To produce a high quality grid current, various current control strategies have been introduced, such as hysteresis, predictive, proportional-integral (PI), and proportional-resonant (PR) controllers. However, these current controllers are only effective when the grid voltage is ideally balanced and sinusoidal. Unfortunately, due to the popular use of nonlinear loads such as diode rectifiers and adjustable-speed AC motor drives in power systems, the grid voltage at the point of common coupling (PCC) is typically not pure sinusoidal, but instead can be unbalanced or distorted. These abnormal grid voltage conditions can strongly deteriorate the performance of the regulating grid current [17]. Instead of using this technique, the harmonics cannot completely removed due to the limited efficiency of the devices. More over it need current measuring devices to manipulate the harmonics. But the method proposed in this paper i.e. dq-srf does not need any measuring instruments or harmonic analysis of grid voltage and as well as harmonics are removed to the maximum extent. This technique is followed to control the current which is highly modified due to the non-linear loads that are used by the consumers.

A repetitive controller (RC) serves as a bank of resonant controllers to compensate a large number of harmonic components with a simple delay structure. However, despite the effectiveness of the RC in harmonic compensation, the traditional RC has a long delay time, which regularly limits the dynamic response of the current controller. Along with grid voltage distortion, the presence of nonlinear loads in the local load of the DG also causes a

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

negative impact on the grid current quality [13]. To overcome the limitations of aforementioned studies, this paper proposes an advanced current control strategy for the grid connected DG, which makes the grid current sinusoidal by simultaneously eliminating the effect of nonlinear local load and grid voltage distortions. First, the influence of the grid voltage distortions and nonlinear local load on the grid current is determined. Then, an advanced control strategy is introduced to address those aforementioned issues. The proposed current controller is designed in the dq -srf reference frame and is composed of a PI and a RC.

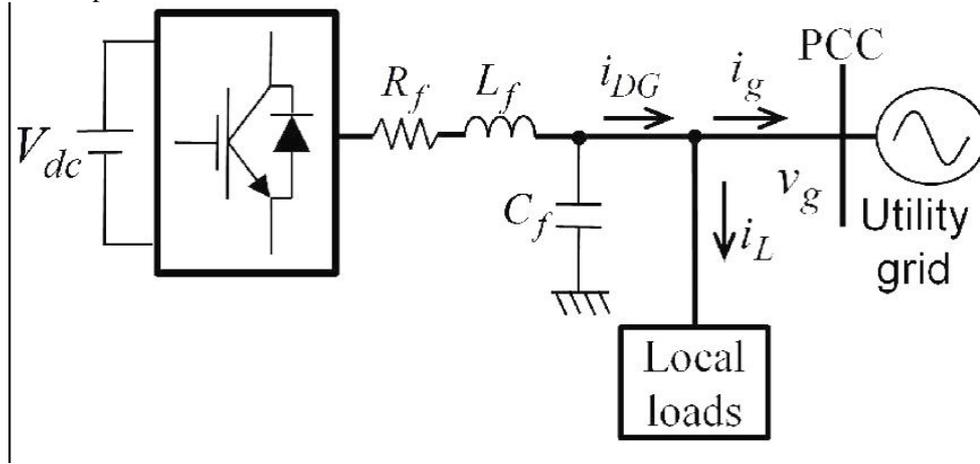


Fig.1 System configuration of grid-connected DG system with local load.

II. SYSTEM CONFIGURATION AND ANALYSIS OF GRID VOLTAGE DISTORTION AND NONLINEAR LOCAL LOAD

Fig. 1 shows the system configuration of a three-phase DG operating in grid-connected mode. The system consists of a DC power source, a voltage source inverter (VSI), an output LC filter, local loads, and the utility grid. The purpose of the DG system is to supply power to its local load and to transfer surplus power to the utility grid at the point of common coupling (PCC). To guarantee high quality power, the current that the DG transfers to grid (i_g) should be balanced, sinusoidal, and have a low THD value. However, because of the distorted grid voltage and nonlinear local loads that typically exist in the power system, it is not easy to satisfy these requirements.

A. Effect of Grid Voltage Distortion

To know the influence of grid voltage distortion on the grid current performance of the DG, a model of the grid connected DG system is developed as shown in Fig. 2. In this model, the VSI of the DG is simplified as voltage source (v_i). The inverter transfers a grid current (i_g) to the utility grid (v_g). For simplification purpose, it is assumed that the local load is not connected into the system. From Fig. 2(a), the voltage equation of the system is given as

$$V_i - V_g - L_f \frac{di}{dt} - R_f i_g = 0 \quad (1)$$

Where R_f and L_f are the equivalent resistance and inductance of the inductor respectively.

If both the inverter voltage and the grid voltage are composed of the fundamental and harmonic components as (2), the voltage equation of (1) can be decomposed into (3) and (4), and the system model shown in Fig. 2(a) can be expressed as Figs. 2(b) and (c), respectively.

$$V_i = V_{i1} + \sum_{h \neq 1} V_{ih}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

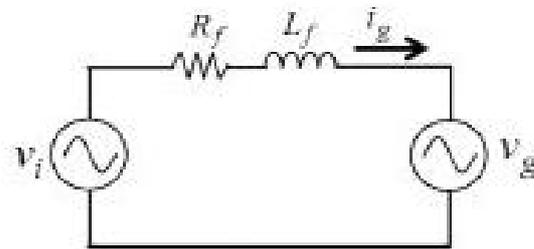
Vol. 4, Special Issue 6, May 2015

(2)

$$V_g = V_{g1} + \sum_{h \neq 1} V_{gh}$$

$$V_{i1} - V_{g1} - L_f \frac{di_{g1}}{dt} - R_f i_{g1} = 0 \tag{3}$$

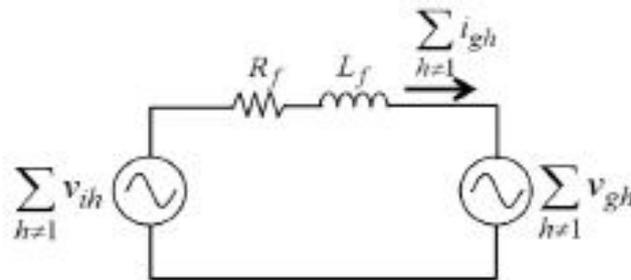
$$\sum_{h \neq 1} V_{ih} - \sum_{h \neq 1} V_{gh} - L_f \frac{d(\sum_{h \neq 1} i_{gh})}{dt} - R_f \sum_{h \neq 1} i_{gh} = 0 \tag{4}$$



(a)



(b)



(c)

Fig.2 Model of grid-connected DG system under distorted grid voltage condition.

From (4), due to the existence of the harmonic components $\sum_{h \neq 1} V_{gh}$ in the grid voltage, the harmonic currents $\sum_{h \neq 1} i_{gh}$ are induced into the grid current if the DG cannot generate harmonic voltages $\sum_{h \neq 1} V_{ih}$ that are exactly the same as $\sum_{h \neq 1} V_{gh}$. As a result, the distorted grid voltage at the PCC causes non-sinusoidal grid current i_g , if the current controller cannot handle harmonic grid voltage $\sum_{h \neq 1} V_{gh}$.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

B. Effect of Nonlinear Local Load

Fig. 3 shows the model of a grid-connected DG system with a local load, whereby the local load is represented as a current source i_L , and the DG is represented as a controlled current Source i_{DG} . According to Fig. 3, the relationship of DG current i_{DG} , load current i_L , and grid current i_g is described as

$$i_{DG} = i_L + i_g \quad (5)$$

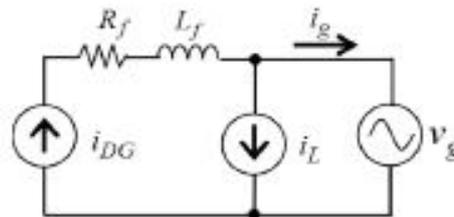


Fig.3 Model of grid-connected DG system with nonlinear local load

Assuming that the local load is nonlinear e.g., a three-phase diode rectifier—the load current is composed of the fundamental and harmonic components as

$$i_L = i_{L1} + \sum_{h \neq 1} i_{Lh} \quad (6)$$

where i_{L1} and i_{Lh} are the fundamental and harmonic components of the load current, respectively. Substituting (6) into (5), we have

$$i_g = i_{DG} - (i_{L1} + \sum_{h \neq 1} i_{Lh}) \quad (7)$$

From (7), it is obvious that to transfer sinusoidal grid current i_g into the grid, DG current i_{DG} should include the harmonic components that can compensate the load current harmonics $\sum_{h \neq 1} i_{Lh}$. Therefore, it is important to design an effective and low-cost current controller that can generate the specific harmonic components to compensate the load current harmonics. Generally, traditional current controllers, such as the PI or PR controllers, cannot realize this demand because they lack the capability to regulate harmonic components.

III. PROPOSED CONTROL SCHEME

To enhance grid current quality, an advanced current control strategy, as shown in Fig. 4, is introduced. Even though there are several approaches to avoid the grid voltage sensors and a PLL [19], Fig. 4 contains the grid-voltage sensor and a PLL for simple and effective implementing of the proposed algorithm, which is developed in the d-q reference frame.

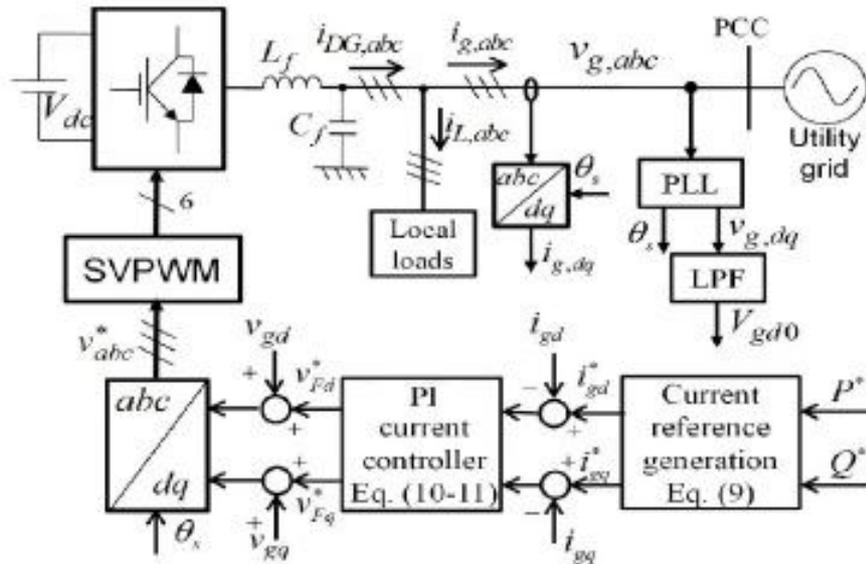


Fig. 4. Overall block diagram of the proposed control strategy.

The proposed control scheme is composed of three main parts: the phase-locked loop (PLL), current reference generation scheme, and current controller. The operation of the PLL under distorted grid voltage has been investigated in detail in [20]; therefore, it will not be addressed in this study. As shown in Fig. 4, the control strategy operates without the local load current measurement and harmonic voltage analysis on the grid voltage. Therefore, it can be developed without requiring additional hardware. Moreover, it can simultaneously address the effect of non linear local load and distorted grid voltage on the grid current quality.

A. Current Reference Generation

As shown in Fig. 4, the current references for the current controller can be generated in the $d-q$ reference frame based on the desired power and grid voltage as follows [14]:

$$i_{gd}^* = \frac{2 P^*}{3 V_{gd}} \quad (8)$$

$$i_{gq}^* = -\frac{2 Q^*}{3 V_{gd}}$$

Where P^* and Q^* are the reference active and reactive power, respectively; V_{gd} represents the instantaneous grid voltage in the $d-q$ frame; and i_{gd}^* and i_{gq}^* denote the direct and quadrature components of the grid current, respectively. Under ideal conditions, the magnitude of V_{gd} has a constant value in the $d-q$ reference frame because the grid voltage is pure sinusoidal. However, if the grid voltage is distorted, the magnitude of V_{gd} no longer can be a constant value. As a consequence, reference current i_{gd}^* and i_{gq}^* cannot be constant in (8). To overcome this problem, a low-pass filter is used to obtain the average value of V_{gd} , and the $d-q$ reference currents are modified as follows:

$$i_{gd}^* = \frac{2 P^*}{3 V_{gd0}} \quad (9)$$

$$i_{gq}^* = -\frac{2 Q^*}{3 V_{gd0}}$$

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Where V_{gd0} is the average value of V_{gd} , which is obtained through the low-pass filter (LPF) in Fig. 4.

B. Current Controller

An advanced current controller is proposed by using a PI and RC in the d-q reference frame. The block diagram of the current controller is shown in Fig. 5. The open-loop transfer function of the PI and RC in a discrete time domain is given in (10) and (11), respectively.

$$G_{PI}(z) = K_p + \frac{K_i}{z-1} z \quad (10)$$

$$G_{RC}(z) = \frac{K_r z^k z^{-N/6}}{1-Q(z)z^{-N/6}} \quad (11)$$

Where K_p and K_i are proportional and integral gains of the PI controller, $z^{-N/6}$ is the time delay unit, z^k is the phase lead term, $Q(z)$ is a filter transfer function, and K_r is the RC gain.

In Fig. 5, the RC is used to eliminate the harmonic components in the grid current caused by the nonlinear local load and/or distorted grid voltage. Meanwhile, the role of the PI controller is to enhance the dynamic response of the grid current and to stabilize the whole control system.

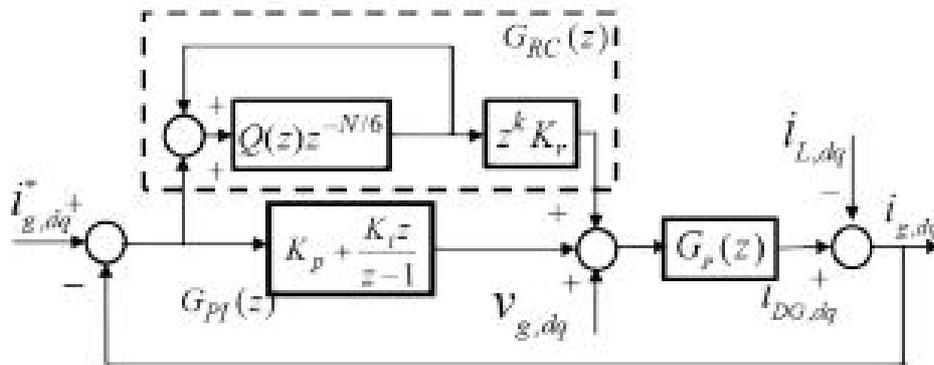


Fig. 5 Block diagram of the current controller

IV. DESIGN OF REPETITIVE CONTROLLER

The RC has three main components that must be determined: the filter $Q(z)$, the phase lead term z^k , and the RC controller gain K_r . Selection of the filter $Q(z)$ is used to improve the system stability by reducing the peak gain of the RC at a high frequency range. There are two methods that have been commonly used to select $Q(z)$: a closed unity gain $Q(z) = 0.95$, and a zero phase-shift LPF $Q(z) = (z + 2 + z^{-1}) / 4$ [21]. In this study, we use $Q(z) = (z + 2 + z^{-1}) / 4$ because it provide the high peak gain of the PI-RC at the low frequency range and low peak gain (less than 0 dB) at the high frequency range (higher than 2 kHz) as shown in Fig. 8. It is well-known that a low peak gain at the high frequency range can effectively prevent the system unstable.

V. EXPERIMENTAL RESULTS

Fig.11 shows the waveform of the voltages that are obtained in the distributed generation which never changes before and after the connection of the current compensator to the distribution generation grid. The compensator which

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

is designed only to the maintenance of current. Thus it compensates only the current of the source. Load current also does not varies after the mounting of the compensator because load is non-linear, it will be same as the before and is shown in the Fig. 12.

Fig. 13 shows the current waveform of the source before the mounting of the current compensator with non-linear load. And the compensator designed will modifies this current only. The modified current is shown in the Fig.14.

Comparing Fig.13 and Fig.14 it is obvious that the harmonic distortion is reduced to the maximum extent. Certainly it brings the harmonic distortion less than 5% as mentioned in IEEE 1547 standard.

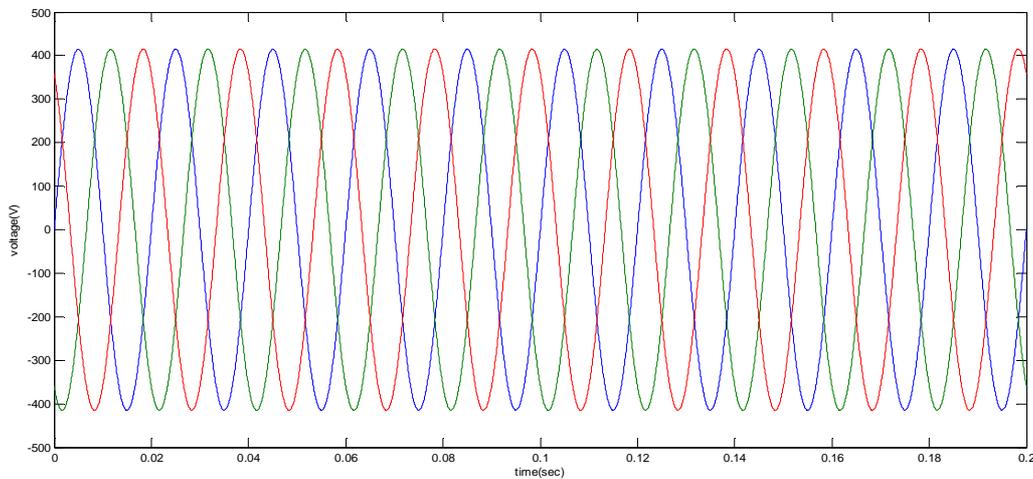


Fig. 11 Showing the voltage of the distributed generation grid before attaching the current compensator.

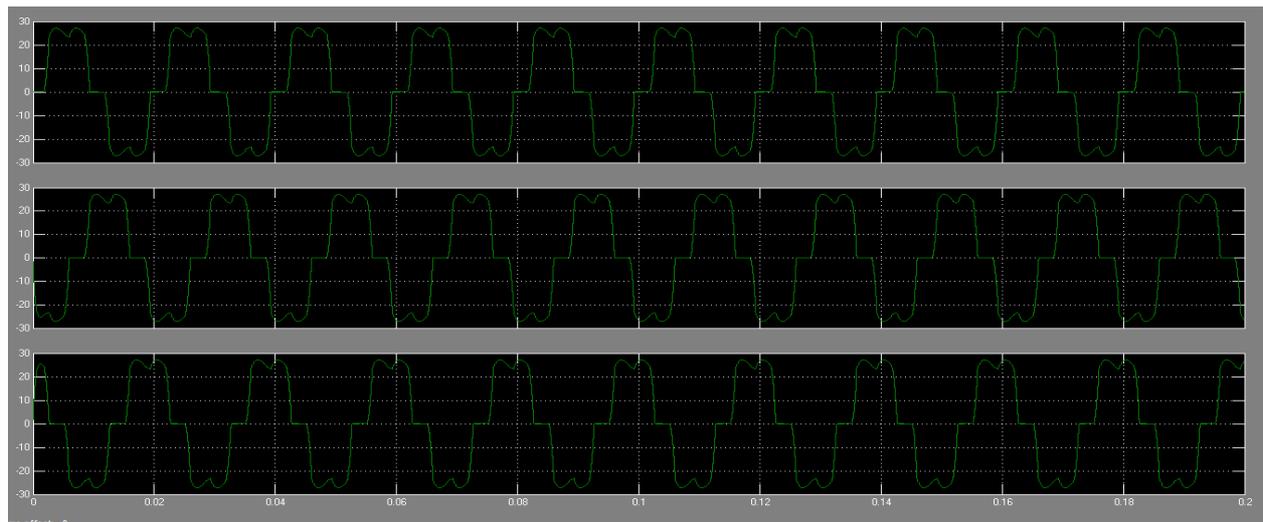


Fig.12 showing the load current waveforms of the distributed generation before connecting the current compensator.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

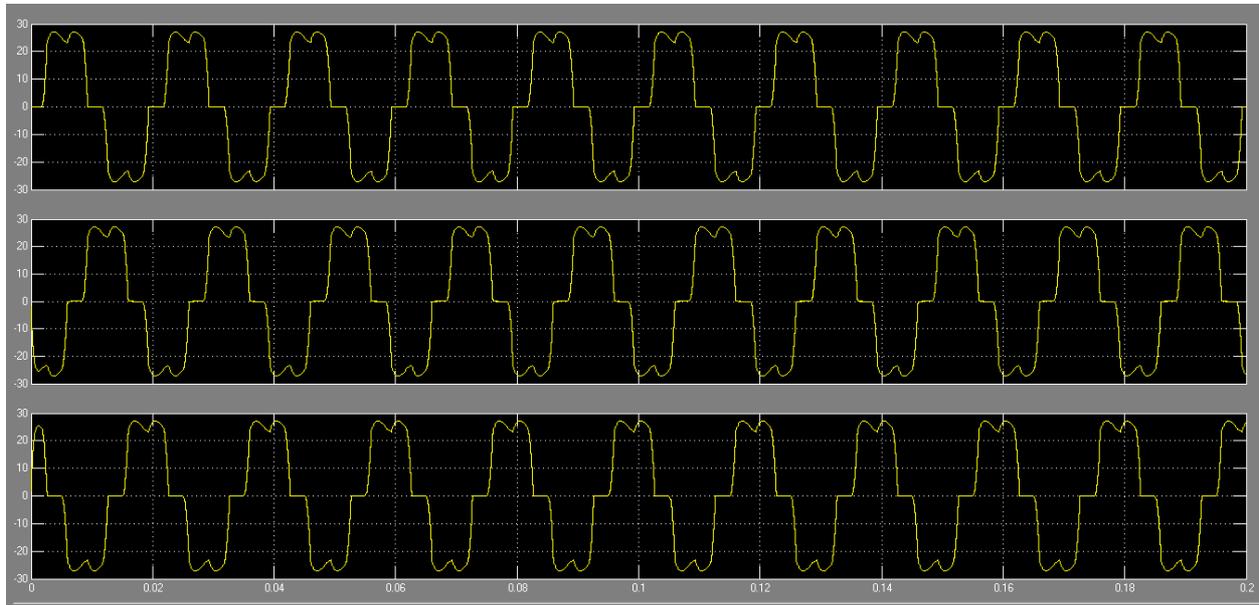


Fig.13 showing the source current waveforms of distributed generation before connecting the current compensator

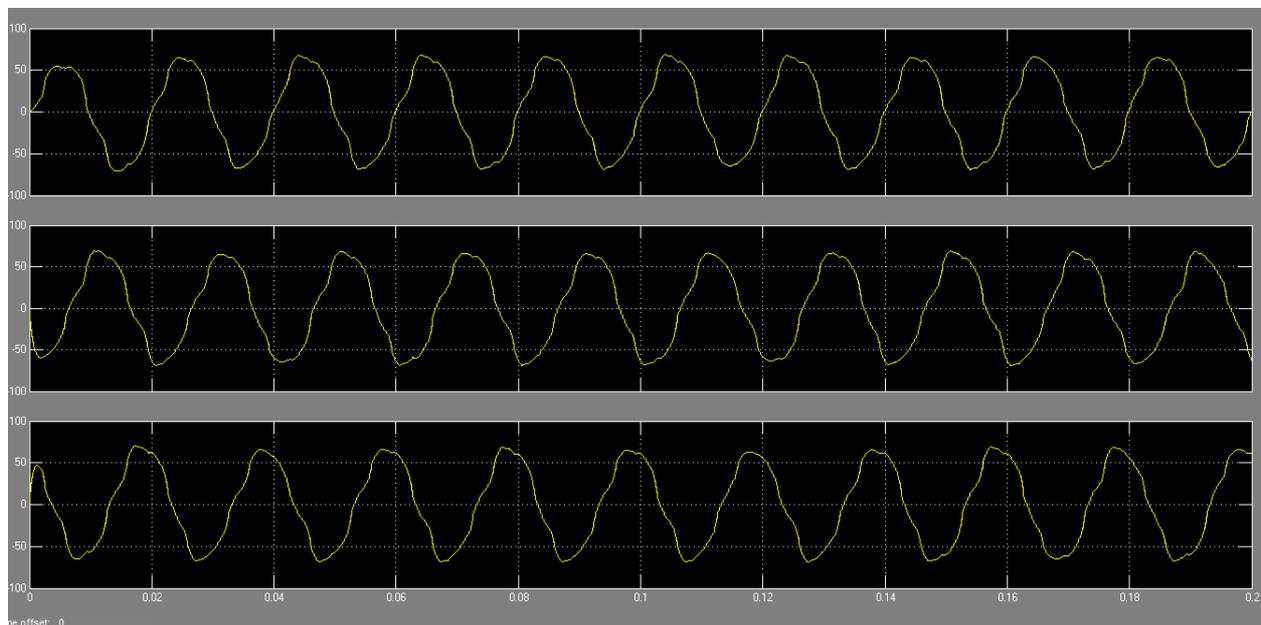


Fig.14 showing the waveforms source current in distributed generation after connecting the current compensator

Thus the designed current controller will remove the harmonics due to the voltage distortion and non-linear loads used in the distributed generation.

International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

VI. CONCLUSION

In this paper the new technique for the current compensation has been discussed in which THD is below 5%. And the mounting of current compensator is also easier as it does not need any measuring instruments. For future enhancing some other new technique can be found which can reduce than this technique. At present dq-srf technique is the best for the current compensation in the distributed generation.

REFERENCES

- [1] R. C. Dugan and T. E. McDermott, "Distributed generation," *IEEE Ind. Appl. Mag.*, vol. 8, no. 2, pp. 19-25, Mar./Apr. 2002.
- [2] F. Blaabjerg, R. Teodorescu, M. Liserre, and A.V. Timbus, "Overview of Control and Grid Synchronization for Distributed Power Generation Systems" *IEEE Trans. Ind. Electron.*, vol. 53, no. 5, pp.1398-1409, 2006.
- [3] Suul, J.A.; Ljokelsoy, K.; Midtsund, T.; Undeland, T., "Synchronous Reference Frame Hysteresis Current Control for Grid Converter Applications," *IEEE Trans. Industry Applications*, vol.47, no.5, pp.2183-2194, Sept.-Oct. 2011.
- [4] Qingrong Zeng; Liuchen Chang, "An Advanced SVPWM-Based Predictive Current Controller for Three-Phase Inverters in Distributed Generation Systems," *IEEE Trans. Ind. Electron.*, vol.55, no.3, pp.1235-1246, March 2008.
- [5] Buso, Simone; Mattavelli, Paolo, "Digital Control in Power Electronics," *Synthesis Lectures on Power Electronics*, Vol.1, Iss.1, pp.1, 2006.
- [6] Busada, C.A.; Gomez Jorge, S.; Leon, A.E.; Solsona, J.A., "Current Controller Based on Reduced Order Generalized Integrators for Distributed Generation Systems," *IEEE Trans. Ind. Electron.*, vol.59, no.7, pp.2898-2909, July 2012.
- [7] M. Liserre, R. Teodorescu and F. Blaabjerg, "Multiple harmonics control for three-phase grid converter systems with the use of PI-RES current controller in a rotating frame," *IEEE Trans. Power Electron.*, vol.21, no.3, pp.836-841, May 2006.
- [8] Castilla, M.; Miret, J.; Camacho, A.; Matas, J.; de Vicuna, L.G., "Reduction of Current Harmonic Distortion in Three-Phase Grid-Connected Photovoltaic Inverters via Resonant Current Control," *IEEE Trans. Ind. Electron.*, vol.60, no.4, pp.1464,1472, April 2013.
- [9] Rong-Jong Wai; Chih-Ying Lin; Yu-Chih Huang; Yung-Ruei Chang, "Design of High-Performance Stand-Alone and Grid-Connected Inverter for Distributed Generation Applications," *IEEE Trans. Ind. Electron.*, vol.60, no.4, pp.1542-1555, April 2013.
- [10] Balaguer, I.J.; Qin Lei; Shuitao Yang; Supatti, U.; Fang Zheng Peng, "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.
- [11] Pozzebon, G.G.; Goncalves, A.F.Q.; Pena, G.G.; Mocambique, N.E.M.; Machado, R.Q., "Operation of a Three-Phase Power Converter Connected to a Distribution System," *IEEE Trans. Ind. Electron.*, vol.60, no.5, pp.1810-1818, May 2013.
- [12] Qing-Chang Zhong; Hornik, T., "Cascaded Current-Voltage Control to Improve the Power Quality for a Grid-Connected Inverter with a Local Load," *IEEE Trans. Ind. Electron.*, vol.60, no.4, pp.1344-1355, April 2013.
- [13] Zhilei Yao; Lan Xiao, "Control of Single-Phase Grid-Connected Inverters with Nonlinear Loads," *IEEE Trans. Ind. Electron.*, vol.60, no.4, pp.1384-1389, April 2013.
- [14] Liu, Z.; Liu, J.; Zhao, Y., "A Unified Control Strategy for Three-Phase Inverter in Distributed Generation," *IEEE Trans. Power Electron.*, vol.29, no.3, pp.1176-1191, Mar. 2014.
- [15] IEEE Application Guide for IEEE Std 1547, IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems, IEEE Std 1547.2-2008
- [16] Teodorescu, R. Blaabjerg, F. Liserre, M. Loh, P.C., "Proportional-resonant controllers and filters for grid-connected voltage-source converters," *IEEE Proceedings - Electric Power Applications*, Vol.153, Iss.5, pp.750, 2006.
- [17] T.-V. Tran, T.-W. Chun, H.-H. Lee, H.-G. Kim, and E.-C. Nho, "Control Method for Reducing the THD of Grid Current of Three-Phase Grid-Connected Inverters under Distorted Grid Voltages," *J. Power Electronics*, vol.13, no.4, pp.712-718, July 2013.
- [18] Q.-N., Trinh; H.-H. Lee, "Improvement of current performance for grid connected converter under distorted grid condition," in *Proc. IET Conference on Renewable Power Generation (RPG 2011)*, pp.1-6, 6-8 Sept. 2011.
- [19] Mohamed, Y.A.-R.; El-Saadany, E.F., "Adaptive Discrete-Time Grid-Voltage Sensorless Interfacing Scheme for Grid-Connected DG-Inverters Based on Neural-Network Identification and Dead beat Current Regulation," *IEEE Trans. Power Electron.*, vol.23, no.1, pp.308-321, Jan. 2008.
- [20] V.Blasko, V.Kaura, "Operation of a Phase Locked Loop System under Distorted Utility Conditions", *IEEE Trans. Ind. Electron.*, vol.33, no.1, p.58-63, January/February 1997.
- [21] Q.-N. Trinh and H.-H. Lee, "Advanced Repetitive Controller to Improve the Voltage Characteristics of Distributed Generation with Nonlinear Loads," *J. Power Electronics*, vol.13, no.3, pp.409-418, May 2013.
- [22] IEC1727, "Characteristic of the utility interface for photovoltaic (PV) systems," November 2002.
- [23] Gomez Jorge, S.; Busada, C.A.; Solsona, J.A., "Frequency-Adaptive Current Controller for Three-Phase Grid-Connected Converters," *IEEE Trans. Ind. Electron.*, vol.60, no.10, pp.4169-4177, Oct. 2013.
- [24] Bin Zhang; Danwei Wang; Keliang Zhou; Yigang Wang, "Linear Phase Lead Compensation Repetitive Control of a CVCF PWM Inverter," *IEEE Trans. Ind. Electron.*, vol.55, no.4, pp.1595-1602, April 2008.
- [25] *IEEE Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems*, IEEE Standard 519-1992, 1992.
- [26] Roger C. Dugan, Mark F. McGranaghan, Surya Santoso, H. Wayne Beaty "Electrical Power System Quality" Third edition, pp.197-323