

# Realization of Harmonic Elimination on Grid Connected Power System with Closed Loop Current Control Technique

N.Nazzirudeen<sup>#1</sup>, G.Dineshkumar<sup>#2</sup>, Dr.M.Muruganandam<sup>#3</sup>PG Student, Department of EEE, Muthayammal Engineering College, Rasipuram, Tamilnadu, India<sup>1</sup>Assistant Professor, Department of EEE, Muthayammal Engineering College, Rasipuram, Tamilnadu, India<sup>2</sup>Professor and HOD, Department of EEE (PG), Muthayammal Engineering College, Rasipuram, Tamilnadu, India<sup>3</sup>.

**ABSTRACT:** More power quality issues are made in distribution system, due to increasing application of non-linear loads. Here converters are interfaced to compensate active harmonics to utilize distributed generation units. Current control approach is enhanced in this proposal; here current controller has two control branches to control harmonics to control DG current and fundamental current separately. The proposed harmonic compensation does not need harmonic current detection in local non-linear loads and harmonic voltage detection in distribution system. Fundamental reference current is derived directly by closed loop current control without using phase locked loop (PLL). The fundamental current tracking errors in steady state DG units are eliminated effectively by achieving this power scheme.

**KEYWORDS:** Active power filter, distributed generation, harmonic compensation, harmonic extraction, PI controller.

## I. INTRODUCTION

In traditional power systems, large power generation plants located at adequate geographical places produce most of the power, which is then transferred towards large consumption centres. Power quality can be ensured continuously by controlling the control centres monitor system. However, the power system is changed to large number of DG units including both renewable and non-renewable sources such as, Photovoltaic (PV) generators, wave generators, wind turbines, small hydro, fuel cells and Combined Heat and Power (CHP) stations [1]. Alternatively flexible control of grid connected DG units is becoming an interesting topic. Here control of parallel APF is a challenging task, due to generation of non-sinusoidal current [2]

Generally, APF control involves three stages, signal measurement, conditioning, harmonic detection and control. Many possible solutions have been made for APF control. Here, most of the methods employ filters with implemented current control in various reference frames, stationary fundamental (or) harmonic frame [3-5].

In harmonic reference frame, each harmonic was detected and controlled in its own frame, which seems to be the most performant method. But here computation time is expensive [6]. In stationary frames, generalized integrators (or) repetitive based control is developed using PI controllers. The current control techniques that are so far used to control active power filters are the linear control, the digital deadbeat control and hysteresis control [7].

In general, the analogue control techniques have the fast response and the control is not delayed by any conversion process or calculation time. Among the digital control, the deadbeat control algorithm gives the best dynamic responses; the fore mentioned analogue and digital control techniques are considered [8]. In order to compensate harmonic distortions at the distribution systems, a number of active and passive filtering techniques have been developed. But, due to the installation of additional filters, it adds cost to the system. Therefore, distribution system power quality enhancement using flexible control of grid connected DG units is considered [9]. In this method, the ancillary harmonics compensation capability is integrated with the DG primary power generation function through modifying control references [10].

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

On the other hand, the control of micro-grid can also be done by measuring local signals without communications among DG systems. In this method, the real (P) and reactive (Q) power can be regulated by controlling the frequency and voltage magnitude droop [11]. But in this method many DG units are considered and there are directly connected to Point of Common Coupling (PCC) with resistive feeder. So, this method may leads to several problems. Due to the presence of non-trivial feeder impedance, the PQ coupling and steady state reactive power error occurs. If the additional coupling inductor is not placed between the DG units and the PCC, the DG system stability and transient performance will be affected [12-14].

An accurate detection of local load harmonic current is necessary, so the various type of harmonic detection technique have been presented. The techniques are Fourier transformation based detection method, detection scheme using instantaneous real and reactive power theory, Second Order Generalised Integrator (SOGI) and the delayed signal commutation based detection [15]. The harmonic interaction process may increase the computing load of DG unit controllers in the steady state of DG output current to absorbed the local load harmonics, the main grid current can be directly controlled [16]. Due to this, the local load current is treated as a disturbance in the grid current regulation loop. This harmonic voltage detection control techniques cannot be used for shunt active harmonic filter in the point of connection [17].

So, this paper proposed an improved current control technique with two parallel control branch, here the first control branch is used for DG unit fundamental current control and the second branch is used to compensate local load harmonics current or feeder resonance voltage. In this proposed current controller, the PoC voltage of a local load current can be directly used as the input, without affecting the harmonic compensation accuracy [18]. The proposed DG unit achieves zero steady state power tracking error with simple PI regulation in the output power control loop.

## II. EXISTING HARMONIC COMPENSATION METHOD

### A. Local Load Harmonic Current.

Here, interfacing converters is connected to distribution system with coupling choke ( $L_f$  and  $R_f$ ). This is connected with single-phase DG system. Harmonic components of local load current ( $I_{Local}$ ) is absorbed using DG current ( $I_1$ ) regulation, to improves the power quality of grid current ( $I_2$ ).

Generally, current reference generators is not absolute in magnitude of PoC voltage to accomplish this problem, improved power control method is developed. First, the fundamental PoC voltage  $V_{PoC\alpha-f}$  and its orthogonal components  $V_{PoC\beta-f}$  are obtained by using SOGI as,

$$V_{PoC\alpha-f} = \frac{2\omega_{D1}s}{s^2 + 2\omega_{D1}s + \omega_f^2} \cdot V_{PoC} \quad (1)$$

$$V_{PoC\beta-f} = \frac{2\omega_{D1}s}{s^2 + 2\omega_{D1}s + \omega_f^2} \cdot V_{PoC} \quad (2)$$

Where,  $\omega_f$  is the fundamental angular frequency and  $\omega_{D1}$  is the cutoff bandwidth of SOGI. The relationships between fundamental references are considered using artificial stationary  $\alpha$ - $\beta$  reference frame as follows.

$$P_{ref} = \frac{1}{2} \cdot (V_{PoC\alpha-f} \cdot I_{ref\alpha-f} + V_{PoC\beta-f} \cdot I_{ref\beta-f}) \quad (3)$$

$$Q_{ref} = \frac{1}{2} \cdot (V_{PoC\beta-f} \cdot I_{ref\alpha-f} - V_{PoC\alpha-f} \cdot I_{ref\beta-f}) \quad (4)$$

Where,  $I_{ref\alpha-f}$  and  $I_{ref\beta-f}$  are the DG fundamental current reference and its orthogonal component in the artificial  $\alpha$ - $\beta$  reference frame. Similarly,  $V_{PoC\alpha-f}$  and  $V_{PoC\beta-f}$  are PoC fundamental voltage and its orthogonal component respectively. By using this equations, the fundamental current reference of single phase DG units can be obtained, which is synchronized with PoC voltage.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

The fundamental current reference and power reference are synchronized with PoC voltage as,

$$I_{ref\_f} = \frac{\cos(\delta).P_{ref} + \sin(\delta).Q_{ref}}{V^*} \quad (5)$$

Where,  $\delta$  is the PoC voltage phase angle detected by PLL,  $P_{ref}$  are  $Q_{ref}$  the real and reactive power references, and  $V^*$  the nominal voltage magnitude of the system. The instantaneous fundamental current references of single phase DG units are obtained by using equation (2) and (3) as follows.

$$I_{ref-f} = \frac{2(V_{PoC\alpha-f}.P_{ref} + V_{PoC\beta-f}.Q_{ref})}{V_{PoC\alpha-f}^2 + V_{PoC\beta-f}^2} \quad (6)$$

With the derived harmonic current and fundamental current reference is written as

$$I_{ref\_h} = G_B(s) \cdot I_{Local} = \sum_{h=3,5,7,9} \frac{2\omega_{D2}S}{S^2 + 2\omega_{D2}S + \omega_h^2} \cdot I_{Local} \quad (7)$$

Where,  $G_B(S)$  is the transfer function of the harmonic extractor. To realize selective harmonic compensation performance,  $G_B(s)$  is designed to have a set of bandpass filters with cut-off frequency  $\omega_{D1}$ .

Then, proportional and multiple resonant controllers are adopted to ensure rapid current tracking.

$$v_{PWM}^* = G_{cur}(s) \cdot (I_{ref} - I_1) \\ = \left( K_P + \sum_{h=f,3,5,\dots,15} \frac{2K_{ih}\omega_c S}{S^2 + 2\omega_c S + \omega_h^2} \right) \cdot (I_{ref-f} + I_{ref\_h} - I_1) \quad (8)$$

where  $v^*$  is the reference voltage for pulse width modulation (PWM) processing,  $K_P$  the proportional gain of the current controller  $G_{cur}(s)$ ,  $K_h$  the resonant controller gain at the order  $h$ ,  $\omega_c$  the cut-off frequency of the resonant controller, and  $\omega_h$  is the angular frequency at fundamental and selected harmonic frequencies.

### B. Feeder Resonance Voltage Compensation.

The PoC voltage can be distorted, when connected to main grid using long underground cable with non-trivial parasitic capacitance. To overcome this problem, feeder is modelled using LC Ladder. Here R-APF control concept is implemented in DG current control to reduce the resonance issues obtained in long underground cables. Then, DG harmonic current reference is modified as.

$$I_{ref\_h} = \left( -\frac{1}{R_d} \right) \cdot (G_B(s) \cdot V_{PoC}) \quad (9)$$

Where,  $R_d$  is the virtual damping resistance at harmonic frequencies. The voltage quality at different positions of the feeders can be improved by providing sufficient damping effects to the long feeder.

### C. Proposed Harmonic Compensation Method.

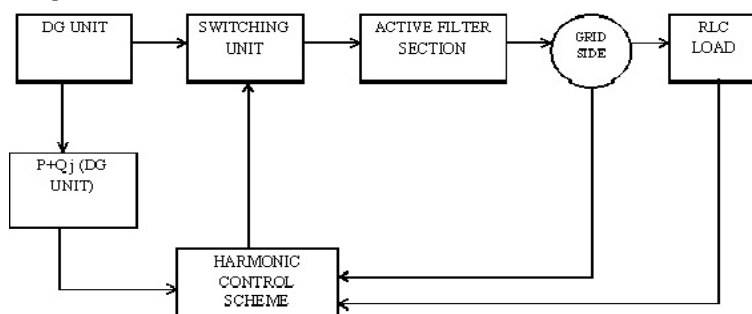


Fig.1. Block diagram of the proposed system

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

Interactions, between PoC harmonic voltage and DG harmonic current may cause some steady state DG power offset. In order to improve the accurate power control performance in current controlled DG units, Instantaneous fundamental current reference can be employed by using simple closed loop power control strategy as,

$$I_{ref\_f} = g_1 \cdot V_{PoC\alpha} + g_2 \cdot V_{PoC\beta} \quad (10)$$

Where,  $V_{PoC\alpha}$  is the non-filtered PoC voltage expressed in the  $\alpha - \beta$  reference frame ( $V_{PoC\alpha} = V_{PoC}$ ) and  $V_{PoC\beta}$  is its orthogonal component.

The real and reactive power control of DG is achieved by using adjustable gains  $g_1$  and  $g_2$  obtained from detailed regulation law as follows.

$$g_1 = \left( K_{P1} + \frac{K_{I1}}{s} \right) \cdot \left( \frac{1}{\tau s + 1} \cdot P_{ref} - P_{DG} \right) + \frac{P_{ref}}{(V^*)^2} \quad (11)$$

Then, DG power using low pass filters,

$$g_2 = \left( K_{P2} + \frac{K_{I2}}{s} \right) \cdot \left( \frac{1}{\tau s + 1} \cdot Q_{ref} - Q_{DG} \right) + \frac{Q_{ref}}{(V^*)^2} \quad (12)$$

where  $k_{P1}$ ,  $K_{I1}$ ,  $K_{P2}$ , and  $K_{I2}$  are proportional and integral control parameters,  $P_{ref}$  and  $Q_{ref}$  are the real and reactive power references,  $V^*$  is the nominal voltage magnitude of the DG unit,  $\tau$  is the time constant of first-order low-pass filters.

The proposed closed loop power control method eliminates power tracking errors, when the output power is given to current controller it produces some ripples,

$$P_{DG} = \frac{1}{2(\tau s + 1)} \cdot (V_{PoC\beta} \cdot I_{1\alpha} + V_{PoC\alpha} \cdot I_{1\beta}) \quad (13)$$

$$Q_{DG} = \frac{1}{2(\tau s + 1)} \cdot (V_{PoC\beta} \cdot I_{1\alpha} - V_{PoC\alpha} \cdot I_{1\beta}) \quad (14)$$

Where,  $I_{1\alpha}$  is the non-filtered DG current expressed in the stationary  $\alpha - \beta$  frame ( $I_1 = I_{1\alpha}$ ) and  $I_{1\beta}$  is its delayed orthogonal component.

To overcome this problem, the improved proportional and resonant controllers with two control branches are proposed as,

$$V_{PWM}^* = \frac{2K_{if}\omega_c S}{S^2 + 2\omega_c S + \omega_h^2} \cdot (I_{ref\_f} - I_1) + \left( K_P + \sum_{h=3,5,\dots,15} \frac{2K_{if}\omega_c S}{S^2 + 2\omega_c S + \omega_h^2} \right) \cdot (I_{ref\_h} - I_1) \quad (15)$$

$$= G_f(S) \cdot (I_{ref\_f} - I_1) + (G_h(S)) \cdot (I_{ref\_h} - I_1) \quad (16)$$

Here, fundamental current reference is regulated by “power control” branch. Only, fundamental resonant controller is adopted in this branch, the impacts that seen in harmonic components are automatically filtered out. Hereafter, harmonic disturbance will not introduce in the harmonic control branch.

Meanwhile, the harmonic current reference is regulated by “harmonic controller” branch. Here, superior harmonic current tracking is ensured using small proportional gain.

Here, PoC voltage (or) local load current can be directly used as input of harmonic control branch without achieving any filtering actions. The harmonic control branch ensures that DG current is ripple free, when harmonic current reference is set to zero. Then DG unit current is connected to be sinusoidal

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

$$I_{refh} = \begin{cases} I_{Local} , & \text{Local nonlinear load} \\ & \text{compensation} \\ -V_{POC}/R_d , & \text{Feeder resonance voltage} \\ & \text{compensation} \\ 0 , & \text{DG harmonic current rejection} \end{cases} \quad (17)$$

Here, steady state errors can be occurred due to presence of fundamental components in the output of harmonic control branch which is obtained from proportional gain when local load current is given as an input to the harmonic control branch. The proposed control method shows accurate real and reactive power control that guaranteed by two PI regulators in power control loop. As PI regulator (or) controller is used in closed-loop power control accuracy, zero steady state power control error can still realized even when grid voltage frequency variations are occurred.

In this case, Detected grid connected frequency is used as parameters of resonant controllers, and DG current tracking accuracy can be improved continuously. It is important to mention that grid voltage frequency variations often affect the power control accuracy and the harmonic compensation performance of the DG unit. Additionally, if the DG unit needs to be connected to a utility grid with nontrivial frequency variations, a frequency estimator can be adopted to detect the frequency of the grid.

### III. MODELLING OF DG UNIT WITH THE PROPOSED CURRENT CONTROL SCHEME

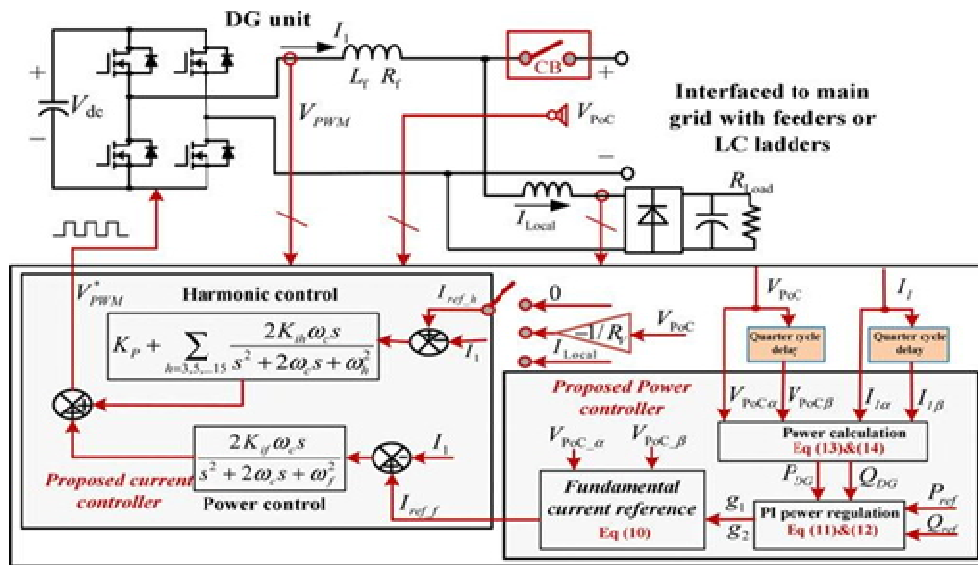


Fig.2. DG unit with proposed control scheme.

#### A. Modelling of Proposed Current Control Method.

The equivalent circuit of proposed current control method was derived in rest of this section .transfer function of DG unit filter plants as,

$$I_1 = H_C(s) \cdot I_{ref} - Y_C(s) \cdot V_{POC} \quad (18)$$

$$\begin{aligned} I_1 &= G_{1nD}(s) \cdot (V_{PWM} - V_{POC}) \\ &= \frac{1}{L_f s + R_f} \cdot (V_{PWM} - V_{POC}) \end{aligned} \quad (19)$$

Where,  $L_f$  is the inductance of the DG coupling choke and  $R_f$  is its stray resistance.  $V_{PWM}$  is the average inverter output voltage. Then delay of DG control is written as,

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

$$V_{PWM} = e^{-1.5T_d s} \cdot V_{PWM}^* \quad (20)$$

Where,  $T_d$  is the sampling period of the system. Here delay includes one sampling period processing delay and half sampling voltage modulation delay. By equating (15), (18) & (19), the closed loop DG current response can be given as,

$$I_1 = H_f(s) \cdot I_{ref_f} + H_h(s) \cdot I_{ref_h} - Y_p(s) \cdot V_{PoC} \quad (21)$$

Where,  $H_f(s)$  and  $H_h(s)$  represent the closed-loop response of DG unit current to fundamental and harmonic current references, respectively.  $Y_p(s)$  demonstrates the sensitivity of DG line current tracking to PoC voltage disturbances. By using this equation, response of DG units in closed loop can be achieved.

The detailed expressions of terms are listed as,

$$H_f(s) = \frac{e^{-1.5T_d s} \cdot G_f(s) \cdot G_{Ind}(s)}{1 + e^{-1.5T_d s} \cdot (G_f(s) + G_h(s)) \cdot G_{Ind}(s)}$$

$$H_h(s) = \frac{e^{-1.5T_d s} \cdot G_h(s) \cdot G_{Ind}(s)}{1 + e^{-1.5T_d s} \cdot (G_f(s) + G_h(s)) \cdot G_{Ind}(s)}$$

$$Y_p(s) = \frac{G_{Ind}(s)}{1 + e^{-1.5T_d s} \cdot (G_f(s) + G_h(s)) \cdot G_{Ind}(s)}$$

The unique behaviour of the proposed controller can be demonstrated using modified Norton equivalent circuit in proposed current control scheme with two controlled current sources.

## III. SIMULATED AND EXPERIMENTAL RESULTS

### A. Simulated Results.

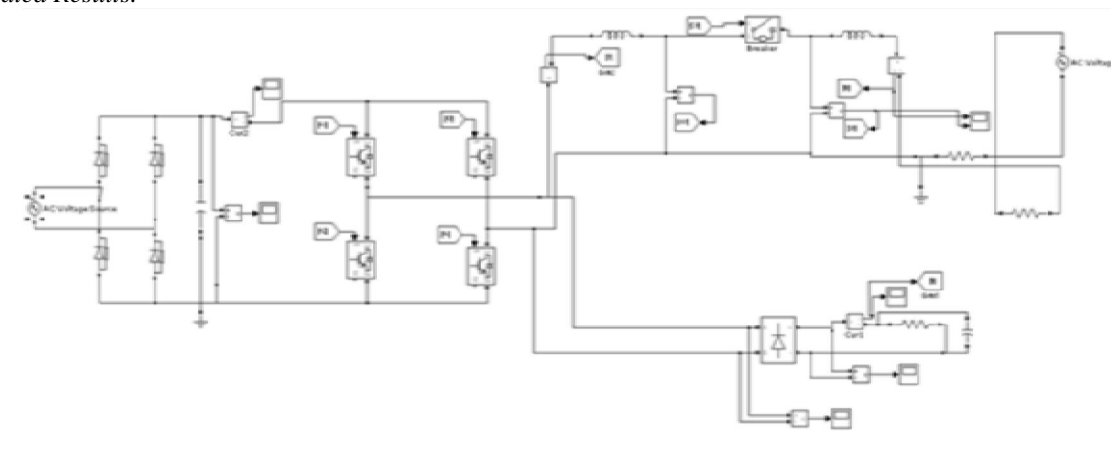


Fig.3. Simulation diagram for proposed control scheme.

#### 1. Compensation of Local Non-Linear Loads.

First, local diode rectifier load is tested with DG units using simulation. The main grid voltage contains 2.8% third and 2.8% fifth harmonics voltage.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

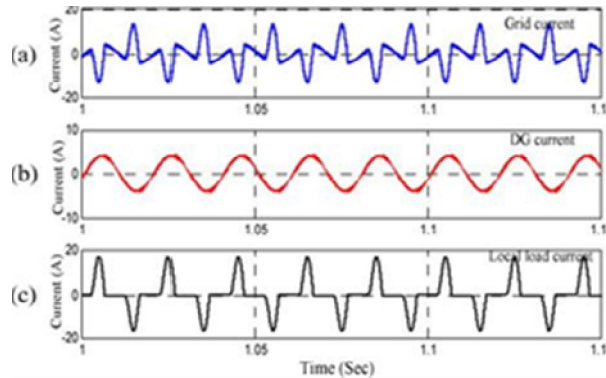


Fig. 4. Performance of the DG unit during DG harmonic rejection: (a) grid current  $I_2$  ; (b) DG current  $I_1$  ; (c) local load current  $I_{Local}$ .

In this simulation, the reference power is set to 600W to 200VAR. Here, DG current is sinusoidal with 5.57% THD; the proposed method still realizes current compensation in local load with enhanced grid current quality with 5.88% THD. Meanwhile, DG unit current is polluted with 201.5% THD.

The proposed closed loop control is effectively verified. Where real and reactive power calculated is regulates DG output power in closed loop manner, its guaranteed zero steady state power tracking errors.

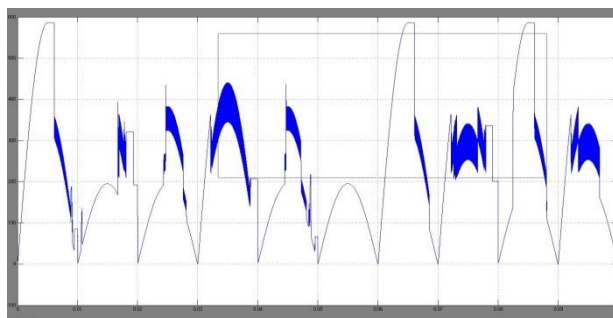


Fig.5. Performance of rectified input AC voltage with harmonics.

## 2. Compensation of Feeder Resonance Voltage.

To verify the feeder resonance voltage compensation, five cascaded LC filter is connected between DG units and stiff main grid. Performance of harmonic rejection mode of proposed controller is shown. Here, PoC voltage is distorted with 13.6% THD. On the same way fundamental current reference is distorted with DG current is sinusoidal with 5.61% THD and main grid current contains non-trivial harmonics with 24.2% THD.

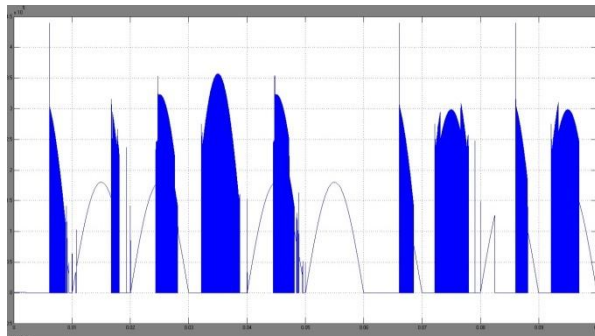


Fig.6. Performance of input current with harmonics.

# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

The associated current waveforms during feeder resonance voltage compensation are shown in Fig. 6. It is obvious that DG current has more distortions (with 35.09% THD), while the main grid current THD reduces to 8.12%.

## B. Experimental Results.

### 1. Local Non-linear Load Compensation.

Here, a small shunt capacitor is connected at PoC to absorb the switching ripples of the inverter. The real and reactive power control under harmonic compensation mode also tested by employing local load current directly as the input to the harmonic control branch

In this experiment, the measured local load current is compensated by DG units, resulted in improved main grid current is polluted with 51.08%thd. The effectiveness of proposed method, main grid voltage is reduced to 106V. In this method, it maintains an accurate power tracking even when main grid voltage varies. By varying the voltage steady state errors can be removed.

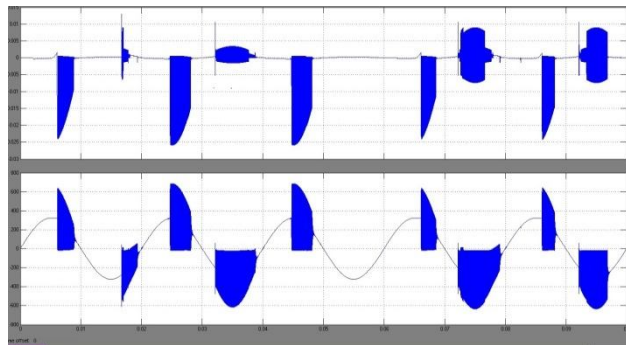


Fig.7. Output voltage and current with less harmonics

### 2. Compensation of Feeder Resonance Voltage.

Here, virtual harmonic resistance is used to measure the performance of feeder resonance voltage mitigation. In this case, 5ohm harmonic virtual resistance is used when compared to DG harmonic rejection control.

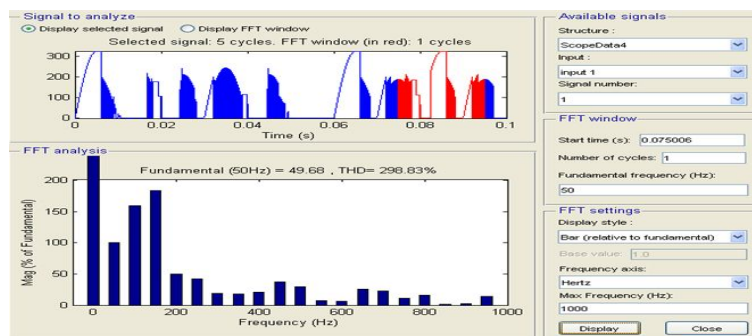


Fig.8.Simulated results that rejects the harmonic contents using FFT analysis.

The enhanced voltage quality is appeared from control of virtual damping resistance to effectively mitigate the voltage distortions.

## IV. CONCLUSION

In this paper, current controlled DG unit interfacing converters is proposed to compensate the harmonics. The proposed method realizes harmonic compensation and power control using closed loop current control scheme. Here the input of fundamental power control branch is regulated by closed loop power control. The harmonic voltage detection and local load harmonic current extraction does not required in this scheme. It ensures the accurate power control even when harmonic compensation tasks are activated in DG unit (or) PoC voltage changes. The experimental



# International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 4, Special Issue 6, May 2015

result and simulated result from a single phase DG unit is verified the feasibility of the proposed strategy. The achieving this proposed control method 28.9% THD of harmonic content can be removed. The simulated and experimental results of this proposed scheme is verified with its accurate operation.

## REFERENCES

- [1] M. Castilla, J. Miret, J. Matas, L. G. de Vicuna, and J. M. Guerrero, "Lin-ear current control scheme with series resonant harmonic compensator for single-phase grid-connected photovoltaic inverters," *IEEE Trans. Ind. Electron.*, vol. 55, no. 7, pp. 2724–2733, Jul. 2008.
- [2] C.Lascu, L.Asiminoaei, I.Boldea, and F. Blaabjerg, "High performance current controller for selective harmonic compensation in active power filters," *IEEE Trans. Power Electron.*, vol. 22, no. 5, pp. 1826–1835, May 2007.
- [3] J. He and Y. W. Li, "Analysis, design and implementation of virtual impedance for power electronics interfaced distributed generation," *IEEE Trans. Ind. Appl.*, vol. 47, no. 6, pp. 2525–2038, Nov./Dec. 2011.
- [4] L. Asiminoaei, F. Blaabjerg, and S. Hansen, "Detection is key Harmonic detection methods for active power filter applications," *IEEE. Ind. Appl. Mag.*, vol. 13, no. 4, pp. 22–33, Jul./Aug. 2007.
- [5] C. Lascu, L. Asiminoaei, I. Boldea, and F. Blaabjerg, "Frequency response analysis of current controllers for selective harmonic compensation in active power filters," *IEEE Trans. Power Electron.*, vol. 56, no. 2, pp. 337– 347, Feb. 2009.
- [6] J. He and Y. W. Li, "Hybrid voltage and current control approach for DG-Grid interfacing converters with LCL filters," *IEEE Trans. Ind. Electron.*, vol. 60, no. 5, pp. 1797–1809, May 2013
- [7] R. I. Bojoi, L. R. Limongi, D. Roiu, and A. Tenconi, "Enhanced power quality control strategy for single-phase inverters in distributed generation systems," *IEEE Trans. Power Electron.*, vol. 26, no. 3, pp. 798–806, Mar. 2011.
- [8] J. He, Y. W. Li, and S. Munir, "A flexible harmonic control approach through voltage controlled DG-Grid interfacing converters," *IEEE Trans. Ind. Electron.*, vol. 59, no. 1, pp. 444–455, Jan. 2012.
- [9] J. Miret, M. Castilla, J. Matas, J. M. Guerrero, and J. C. Vasquez, "Selec-tive harmonic-compensation control for single-phase active power filter with high harmonic rejection," *IEEE Trans. Ind. Electron.*, vol. 56, no. 8, pp. 3117–3127, Aug. 2009
- [10] D. A. Toerrey and A. M. A. M. Al-Zamel, "Single-phase active power filters for multiple nonlinear loads," *IEEE Trans. Power Electron.*, vol. 10, no. 3, pp. 263–272, May 1995.
- [11] Muruganandam, M. and Madheswaran, M. "Stability Analysis and Implementation of Chopper fed DC Series Motor with Hybrid PID-ANN Controller" Published in *International Journal of Control, Automation and Systems*, Springer, Volume 11, Issue 5, October 2013. ISSN: 1598-6446 (Print) 2005-4092 (Online)
- [12] M. Muruganandam, M. Madheswaran, "Experimental verification of chopper fed DC series motor with ANN controller" Published in *International Journal of Frontiers of Electrical and Electronic Engineering in China*, (Springer Publication) Volume 7, Issue 4, December 2012, pp 477-489. ISSN: 2095-2732 (print) 1673-3584 (Online)
- [13] M.Madheswaran and M.Muruganandam, "Simulation and Implementation of PID-ANN Controller for Chopper Fed Embedded PMDC Motor" Published in *ICTACT Journal On Soft Computing*, Volume 2, Issue 3, April 2012 pp 319-324. ISSN: 2229-6956(Online)
- [14] Muruganandam, M, Thangaraju I and Madheswaran, M. "Simulation and Implementation of an Embedded Hybrid Fuzzy Trained Artificial Neural Network Controller for Different DC Motor" Published in *International Journal of Engineering and Technology*, Vol. 6, Issue 1, pp. 315-332 February 2014. ISSN:0975-4024 (Online)
- [15] C Nagarajan, M Muruganandam, D Ramasubramanian, "Analysis and Design of CLL Resonant Converter for Solar Panel-battery Systems", *International Journal of Intelligent Systems and Applications (IJISA)*, Volume 1, December 2012 pp 52-58.
- [16] M.Saranya, S.Ramkumar and M.Muruganandam "Modelling and Simulation of High Step-Up DC/DC Converter for On-Site Generation System" *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol.4, pp.687-693, Feb.2015.
- [17] G.Maruthaipandian, S.Ramkumar and M.Muruganandam "Design and Implementation of BLDC Motor Using Regenerative Braking for Electric Vehicle" *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol.4, pp.694-701, Feb.2015.
- [18] I Thangaraju, M Muruganandam, M Madheswaran, "Performance Analysis and Experimental Verification of Buck Converter fed DC Series Motor using Hybrid Intelligent Controller with Stability Analysis and Parameter Variations", *Journal of Electrical Engineering & Technology*, Volume 10, Issue 2, March 2015 pp 518-528.