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Closed Loop Power Control of Grid Connected Dg Units for Active Harmonic Flitering Using Current Control Method

[1] A.Varunkumar, [2] B.Mothiram
[1] PG Scholar, SRKR Engineering College, Bhimavaram.
[2] Asst. Professor, SRKR Engineering College, Bhimavaram.

Abstract: **Increase in application of non-linear loads will cause power quality issues. In utilizing Distribution generation unit interfacing converters to actively compensate harmonics so paper enhanced a current control approach. The current controllers has two well coupled control branches to independently control the fundamental harmonics DG currents and local non-linear load harmonic current detection, so distribution system harmonic voltage detection are not necessary for proposed method. So closed loop power control scheme is employed to directly derive fundamental current reference without using PLL. The power control eliminates impact of steady state fundamental current tracking errors in DG unit. Harmonic compensation function is active which means accurate power control is realized. This paper is simulated and results are shown below..**

Keywords:-- Active power filters, distribution generation, current control, PR controller, harmonic compensation

I. INTRODUCTION

Control of interfacing converters can cause distribution system resonance issues, the presence of non-linear loads will further degrade distribution system power quality. To compensate distribution system harmonic distortion a number of active and passive filters methods are developed. For local load harmonic current compensation accurate detection of harmonic current is very important. Several methods are adopted such as Fourier transformation based detection using real and reactive power theory, Second order generalized integrator and delayed signal cancellation based detection. Recent hybrid voltage and current control method allows compensation of local load harmonics without using any harmonic detection process where droop control scheme adopted to regulate output power of DG unit, so DG real and reactive power control performance will not effected during harmonic compensation. Fundamental current reference calculated according to power reference it can be determined based on assumption of ripple free grid voltage with fixed magnitude and can be calculated by power-current transformation. To simplify DG unit operation with harmonic compensation while maintaining accurate power the paper proposes current controller with two parallel control branches one is responsible for DG fundamental current control the other is employed to compensate local load harmonic current or feeder resonance voltage. In this inputs for current controller are point of connection voltage and local load current, these will not affect harmonic compensation accuracy. With PI regulation in outer power control loop DG achieves fundamental errors while fundamental current tracking have steady state errors.

DG UNITS WITH HARMONIC COMPENSATION

A detailed discussion on the proposed control strategy is done

1. Conventional local load harmonic current compensation:
   In this single-phase DG system is configured and interfacing converter is connected to distribution system with coupling choke (L_f & R_f) local load at point of connection to improve power quality of grid current (I_2), harmonic component of local load current (I_{local}) shall absorbed through DG current regulation (I_1)

From below figure current reference consists of two parts first one is fundamental current reference (I_{ref-f}) that synchronizes with point if connection voltage (V_{PoC})

$$I_{ref-f} = \frac{P_{ref} \times \cos(\theta) + Q_{ref} \times \sin(\theta)}{E^*}$$

Current reference generator is not accurate in controlling DG power as PoC voltage magnitude varies. To overcome this improved power control i.e. Feeder resonance voltage compensation is proposed. So PoC voltage $V_{poc\alpha-f}$ and its orthogonal component $V_{poc\beta-f}$, both are employed

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from second order generalized integrator.

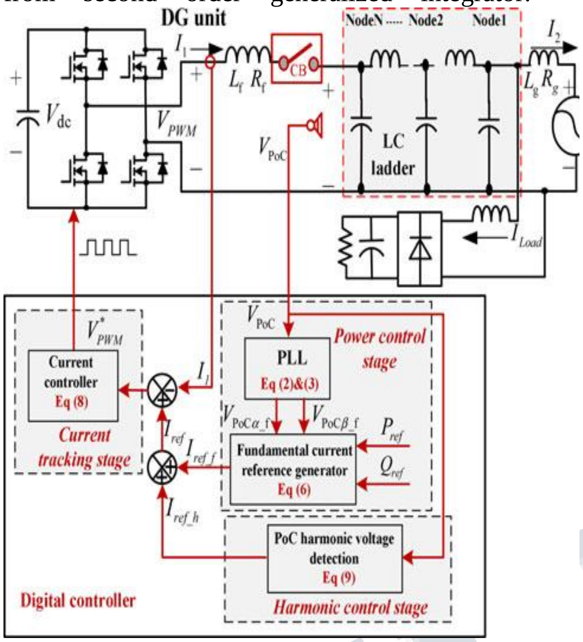

Fig. 1. DG unit with local harmonic current compensation capability.

In DG system power and fundamental reference current can be established in artificial stationary α-β reference frame, from P_{ref} and Q_{ref} we get fundamental current reference. For harmonic current of local non-linear load DG harmonic current reference (I_{ref}) is produced. So DG current reference $I_{ref} = I_{ref-f} + I_{ref-h}$

After that proportional and resonant controller are adopted to ensure rapid current tracking.

1. **Conventional feeder resonance voltage compensation:**

   In previous figure in control mode DG unit should not actively regulate POC voltage quality. So POC voltage can be distorted especially when connected to main grid through underground cable with parasitic capacitance. Feeder is modeled by an LC ladder. In this resistive active power filter concept can also embedded in DG unit current control let see in below figure.

   DG harmonic current reference

$$I_{ref-h} = \frac{-1}{R_v}\left(G_d(s) \times V_{poc}\right)$$

   Where R_v = virtual damping resistance

Providing sufficient damping effects to long feeder voltage quality at different position can be improved.

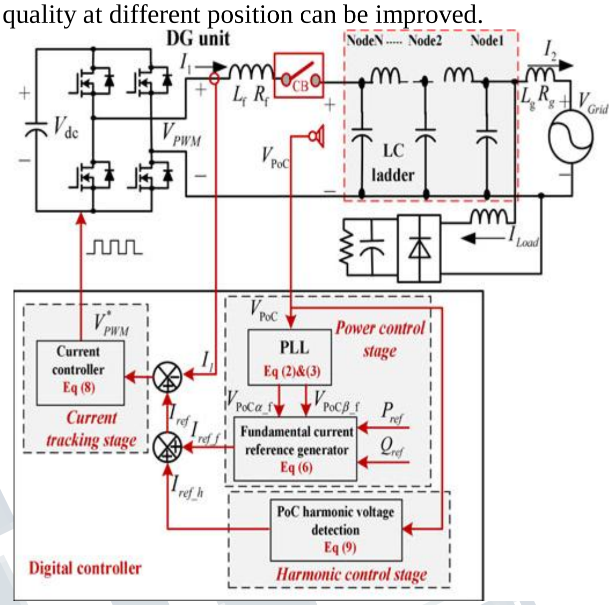

Fig. 2. DG unit with PoC harmonic voltage mitigation capability.

2. Harmonic compensation method:

   Interaction between DG harmonic current and POC harmonic voltage may cause some steady state DG power offset. The power control in fundamental reference is open loop which can't address power offset introduced by harmonics to achieve it is determined by closed loop power control strategy

$$I_{ref-f} = g_1 . V_{poc\alpha} + g_2 . V_{poc\beta}$$

Where g_1, g_2 are adjustable gains to control DG unit real and reactive power

$$g_1 = \left(K_{p1} + \frac{K_{I1}}{s}\right)\left(\frac{1}{\tau s + 1} \times P_{ref} - P_{dg}\right) + \frac{P_{ref}}{\left(E^*\right)^2}$$

$$g_2 = \left(K_{p2} + \frac{K_{I2}}{s}\right)\left(\frac{1}{\tau s + 1} \times Q_{ref} - Q_{dg}\right) + \frac{Q_{ref}}{\left(E^*\right)^2}$$

$K_{p1,2}$ and $K_{I1,2}$ are proportional and integral control parameters, τ is the time constant of first-order low-pass filters

P_{DG} and Q_{DG} are measured DG power with low-pass filtering. In $\alpha - \beta$ frame ($I1 = I1\alpha$), although in closed

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loop power control power tracking errors are eliminated but fundamental current reference frame will be distorted if V_{PoC} has ripples so it will affect dg harmonic current tracking. To overcome this resonant controller is adopted, the impact on harmonics components ($I_{ref\text{-}f}$) automatically filtered out and meanwhile $I_{ref\text{-}h}$ is regulated by resonant controller

$$I_{ref\text{-}h} = \begin{cases} I_{local} & \ldots\text{. Local nonlinear load compensation} \\ -V_{PoC}/R_v & \ldots\text{. Feeder resonance voltage compensation} \\ 0 & \ldots\text{. DG harmonic current rejection} \end{cases}$$

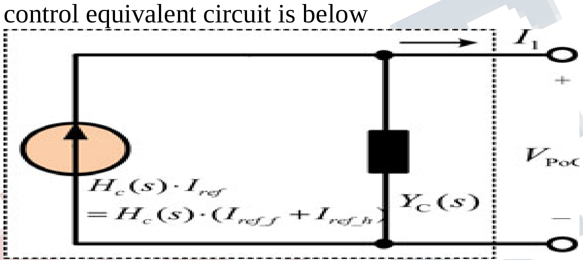
MODELING OF DG UNIT WITH THE PROPOSED CURRENT CONTROL SCHEME:

1. Modeling of the Proposed Current Control Method*:*

The current controlled inverter shall be described as a closed loop Norton equivalent circuit

$$I_1 = H_c(s) \times I_{ref} - Y_c(s) \times V_{poc}$$

Here gains are derived from conventional current control equivalent circuit is below



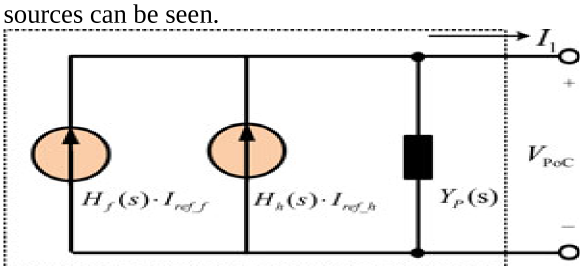
DG unit with proposed control scheme

So $I1 = G_{Ind}(s) \cdot (V_{pwm} - V_{PoC})$ and delay if dg control is written as $V_{pwm} = e^{-1.5Td.s} \times V_{pwm}^{*}$

By solving I_1, V_{pwm} we get closed loop dg current response

$$I_1 = H_f(s) \times I_{ref-f} + H_h(s) \times I_{ref-h} - Y_p(s) \times V_{poc}$$

Behavior of proposed current controller in Norton equivalent circuit with two current sources can be seen.



The current source $H_h(s)$, $I_{ref\text{-}h}$ aims to compensate system harmonics at selected harmonic frequencies.

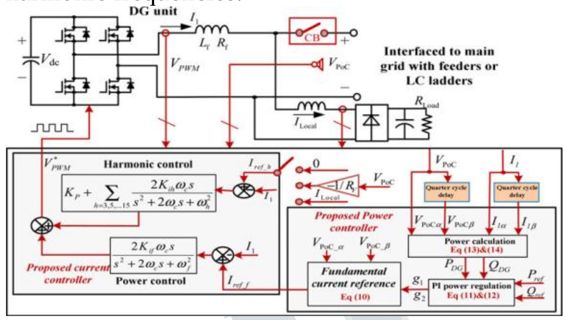


Fig. 3. DG unit with proposed control scheme.

SIMULTION RESULTS

Simulation on DG unit with Diode rectifier load is tested. System configuration shown in Fig.1, where PoC is connected to controlled voltage source with frequency of 50 Hz , main grid voltage contains 2.8% third and 2.8% fifth harmonic voltages. In simulation reference power is set to 600W and 200 var.

Table.1 Parameters In Simulation

System parameters	value
Grid voltage	Simulation 230V/50Hz Experimental 115V/50Hz
DG filter	L_1=605,H, R_1=0.15Ω
Grid feeder	L_g=3.4mH, R_g=0.15Ω
LC ladder with five identical LC filter	L=0.1mH, C=25µF, for each LC filter
Sampling/Switching frequency	20kHz/10kHz
DC link voltage	Simulation 550V Experiment 350V
Power control parameters	Value
Real power control K_{p1}, K_{i1}	K_{p1}=0.00001, K_{i1}=0.001
Reactive power control K_{p2}, K_{i2}	K_{p2} =0.00001, K_{i2} =0.001
LPF time constant τ	0.0322 sec
Current control parameter	Value
Proportional gain K_p	48
Resonant gain K_{Ih}	1500(h=f); 900(h=3, 5, 7, 9);600(h=11, 13, 15)
Resonant controller bandwidth ω_c	4.1 rad/s
R_v(PoC harmonic voltage compensation)	5Ω

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The parameters of the system are shown in Table 1. When the local load harmonic current is not compensated by the DG unit [if Iref-h = 0 the performance of the DG unit is shown in Fig. 1,3&5. It can be seen from Fig. 7,9&11. that the DG current is sinusoidal with 6.96% total harmonic distortion (THD). The proposed method can still realize local load harmonic current compensation, resulted in an enhanced grid current quality with 6.95% THD. Meanwhile, DG unit current is polluted with 62.63% THD.

Performance of DG unit during harmonic rejection.

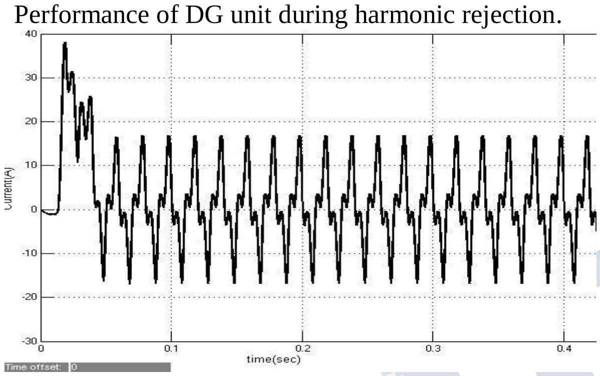

Figure 1. Grid current I_2

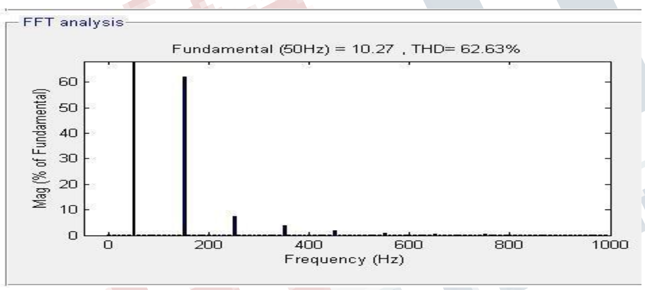

Figure 2. FFT analysis for grid current I_2

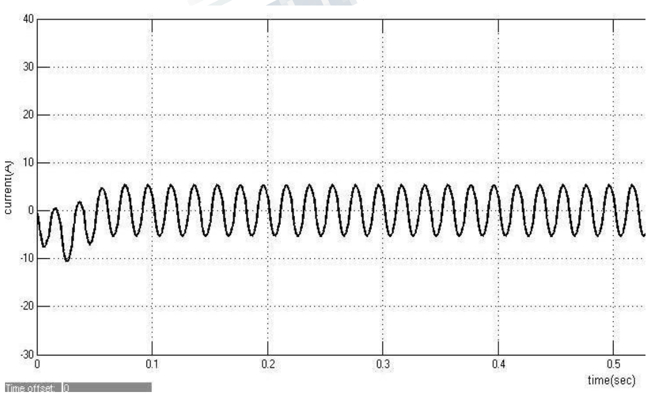

Figure 3. DG current I1

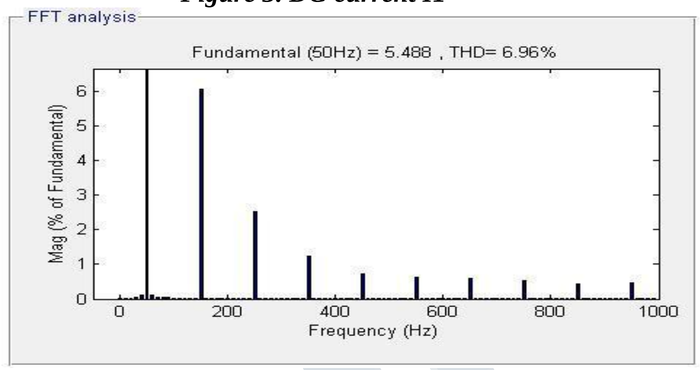

Figure 3. FFT analysis for DG current I_1

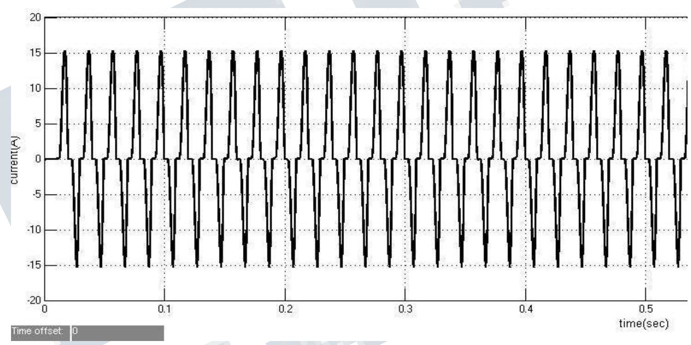

Figure 5.Local load current I_{local}

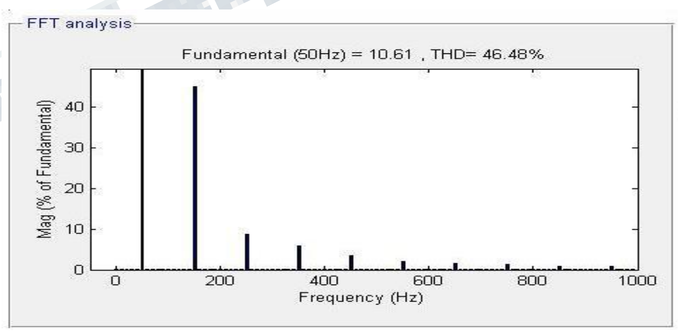

Figure 6. FFT analysis of local load current Ilocal

Performance of DG unit during local load compensation:

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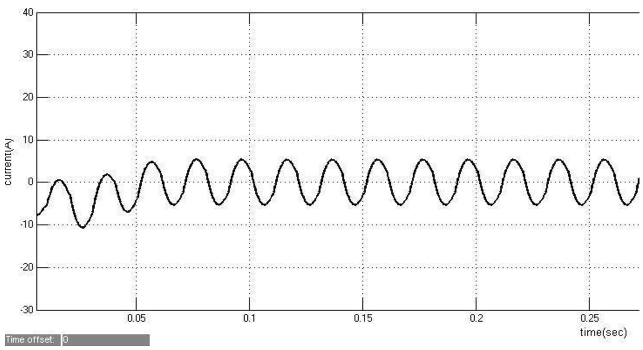

Figure 7. Grid current I2

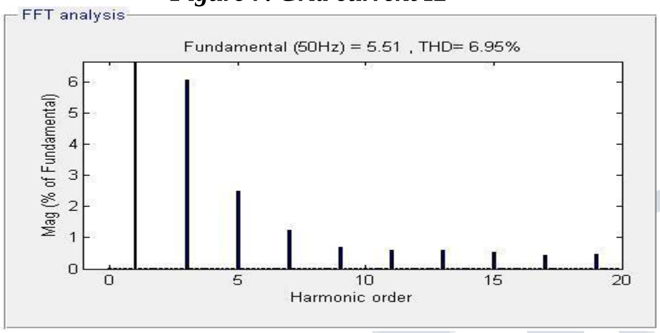

Figure 8. FFT analysis for grid current I2

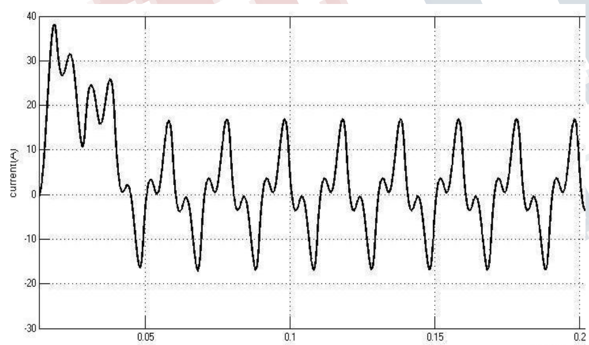

Figure 9. DG current I1

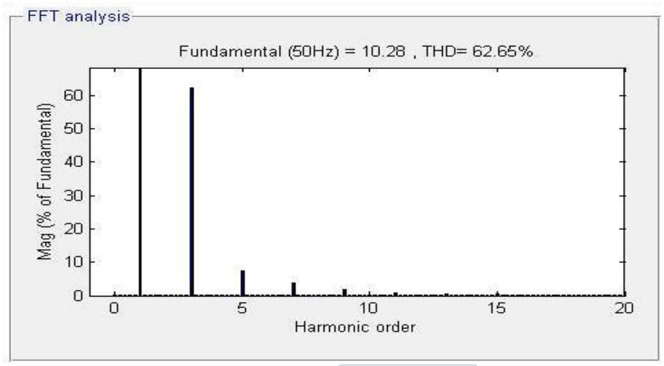

Figure 10 FFT analysis for DG current I1

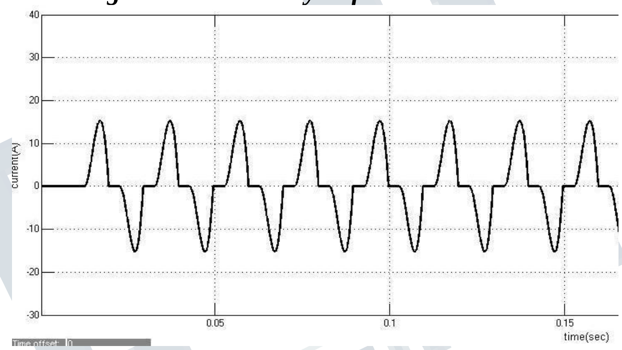

Figure 11. Local load current Ilocal

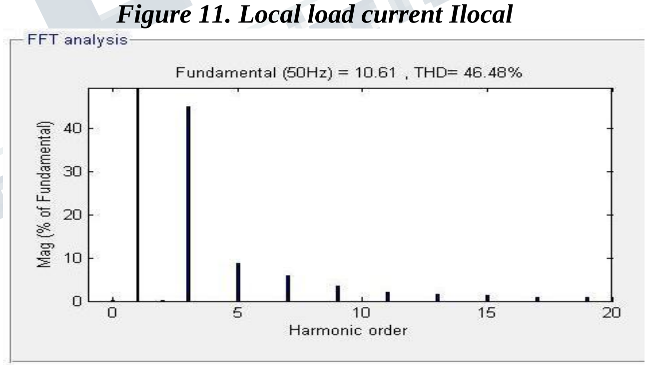

Figure 12.FFT analysis for local load current Ilocal

Power control reference during local harmonic compensation

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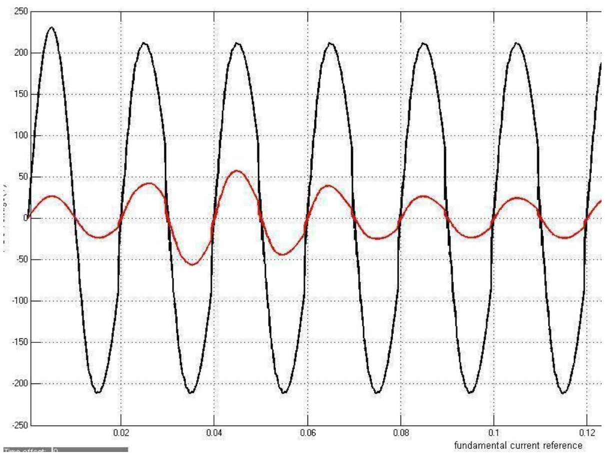

Figure 13. PoC voltage and fundamental current reference Iref-f

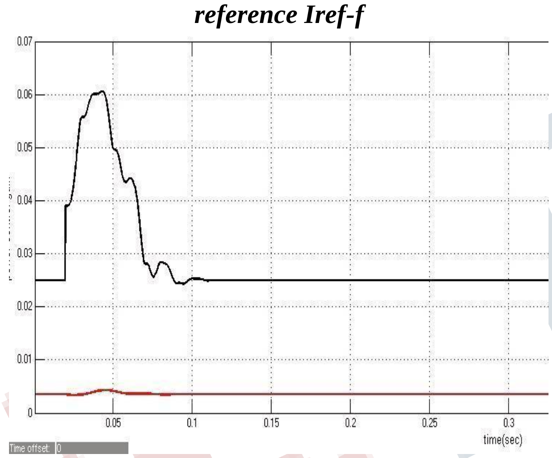

Figure 14. Power control gains g1 and g2

` Power flow of DG unit during local load harmonic current compensation(Pref, Qref)

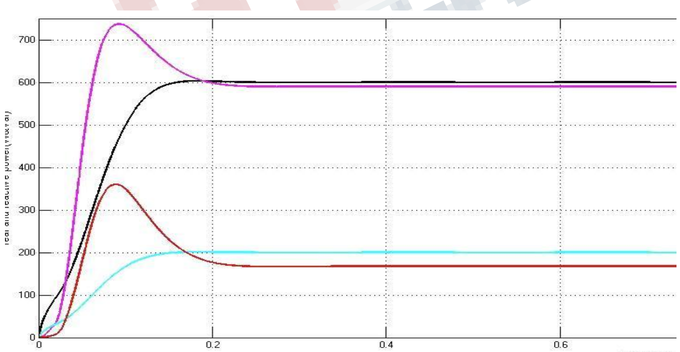

Figure 15. Real and reactive power in closed (pink &green) and open (black & red) loop power control

Performance of DG unit during feeder resonance voltage compensation

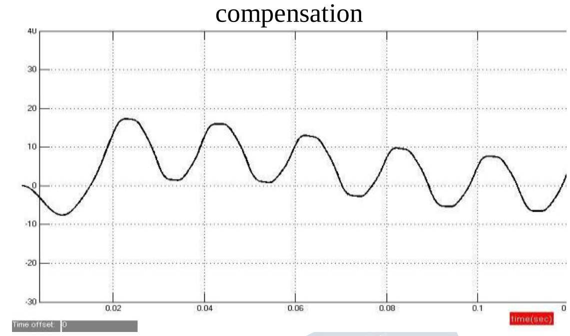

Figure 16.Grid current I2

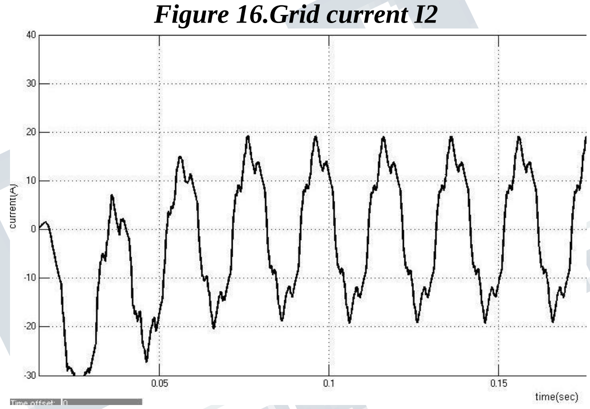

Figure17. DG current I1

THD values of both grid and DG current are 6.18% and 25.22%.

II. CONCLUSION

In this paper simple harmonic compensation strategy is proposed for current controlled DG unit interfacing converters. By separating the conventional proportional and multiple resonant controllers into two parallel control branches, the proposed method realizes power control and harmonic compensation without using any local nonlinear load harmonic current extraction or PoC harmonic voltage detection. The input of the fundamental power control branch is regulated by a closed-loop power control scheme, which avoids the adoption of PLLs. The proposed power control method ensures accurate power control even when harmonic compensation tasks are activated in the DG unit or the POC voltage changes. By these results we can reduce active harmonics in DG unit systems. We can reduce cost of usage of filters, which increases cost not economical. Simulated results are kept above.

