

CLOSED LOOP POWER CONTROL OF GRID CONNECTED DG UNITS FOR REDUCING ACTIVE HARMONICS USING CURRENT CONTROL SCHEME

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Abstract: With an increase in non linear loads may raise power quality issues at the distribution side. In order to utilize distribution generation units in effective manner we have to reduce active harmonics. In this proposed method we used current control approach, which unlined integrated DG units in order to reduce harmonics by primary DG function. In this proposed current controller consists of two decouple control branches harmonic DG currents, load harmonic current detection, system harmonic voltage detection are not required. In this closed loop control is used is used to reduce difficulty it is directly fundamental current reference without phase locked loop(PLL) .This proposed control effectively reduces fundamental current in DG units. In this project we can know how we can reduce harmonic currents due to frequency deviation using current control technique to a DG unit connected with closed loop control simulation done in Matlab/Simulink.

Index Terms: Active power filter, distributed generation, resonant controller harmonic compensation, virtual impedance, Harmonic extraction, phase-locked loop (PLL).

I. INTRODUCTION

Now-a-days importance of renewable resources power generation is increasing; a large number of power electronic converters are used with DG units with low voltage power distribution systems. With the increase of non-linear loads like variable speed drives, LED (Light Emitting Diode) lamps will further decrease in power quality.

To reduce the harmonic distortion numbers of active and passive filters are used, By using filters cost will increases. Otherwise we use flexible control of grid connected DG units. Are reliable, where ancillary harmonic Compensation capability is integrated with primary power of DG units through control references.It is more important that DG unit's real and reactive power will not change in harmonic compensation.

It has to satisfy fundamental DG current with power reference. This current reference is taken from ripple free voltage with fixed magnitude and PLL used to synchronise fundamental current reference with main

grid. It can also be obtained from power-current transformation.

To make easier operation with DG units with ancillary harmonic compensation capability maintaining accurate power control. This proposed current control have two parallel branches First control branch is used to control fundamental current, second branch is to control load harmonic current or feeder resonance voltage. As in pi regulation in the outer power control loop, proposed DG unit also achieves zero steady state power tracking errors even fundamental current has some steady state errors. This result shows effectiveness of DG unit at the distribution side.

II. DG UNITS WITH HARMONIC COMPENSATION

In this we briefly know about how active filters acts in reducing harmonic distortion in DG units.After we can know about proposed control strategy.

A. Conventional Harmonic Current Compensation

In this interfacing converter is connected to distribution system with a coupling of choke (Lf and Rf), load at Poc.To improve power quality of grid current (I2), The harmonic load current (I local) will be absorbed through DG current (I1) regulation. As mentioned in above that current reference consists of two parts. One is current reference. (Iref) is synchronised with Poc voltage (VPoc) as

$$I_{ref-f} = \frac{\cos(\theta) \cdot P_{ref} + \sin(\theta) \cdot Q_{ref}}{E^*} \quad (1)$$

Where θ is the PoC voltage phase angle detected by PLL, Pref,Qref are the real and reactive power and E^* is the nominal voltage magnitude of the system. Therefore the current reference generator in (fig.1) is not accurate in controlling DG power, due to variations of the PoC voltage magnitude. To overcome this drawback, an improved power control method with consideration of PoC voltage magnitude fluctuations [11] was developed as shown in II-B. First, the fundamental PoC voltage $V_{PoC\alpha f}$ and its orthogonal component $V_{PoC\beta f}$ (quarter cycle delayed respect to $V_{PoC\alpha f}$) are obtained by using SOGI [15] as

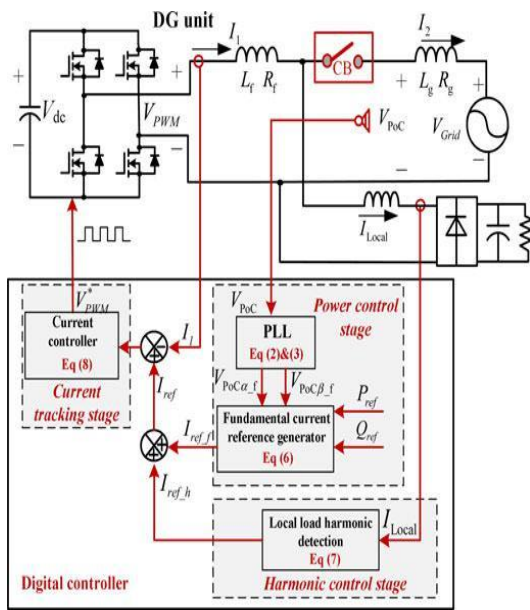


Fig-1. DG unit with local load harmonic current compensation capability.

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

Where ω_{D1} is the cut-off bandwidth of SOGI and ω_f is the fundamental angular frequency.

The relationships between the power reference and the fundamental reference current in a single-phase DG system can be formed in the artificial stationary $\alpha - \beta$ reference frame as given below:

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

$$Q_{ref} = \frac{1}{2} \cdot (V_{PoC\beta-f} \cdot I_{ref\alpha-f} - V_{PoC\alpha-f} \cdot I_{ref\beta-f}) \quad (5)$$

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.

The instantaneous fundamental current reference (I_{ref-f}) of a single-phase DG unit, DG harmonic current reference (I_{ref-h}) can be obtained as

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

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

Where $G_D(s)$ is the transfer function of the harmonic extractor

With the derived fundamental and harmonic current references, the DG current reference is written as

$$I_{ref} = I_{ref-f} + I_{ref-h}$$

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

Here V^*P is the reference voltage for pulse width modulation (PWM) processing, K_p the proportional gain of the current controller $G_{cur}(s)$, K_{ih} the resonant controller gain at the order h , ω_c the cut-off frequency of the resonant controller, and ω_h is the angular frequency at fundamental and selected harmonic frequencies.

B. Conventional Feeder Resonance Voltage Compensation

DG unit should not actively regulate the PoC voltage quality in this mode. As a result of this, PoC voltage can be distorted particularly when it is connected to the main grid through a long underground cable with nontrivial parasitic capacitance. The resonance issue associated with long underground cables, the R-APF concept can also be embedded in the DG unit current control, as shown in Fig. 2. Compared to Fig. 1, the DG harmonic current reference in this case is modified as

$$I_{ref-h} = \left(-\frac{1}{RV} \right) \cdot (G_D(s) \cdot V_{PoC}) \quad (9)$$

Where RV is the virtual damping resistance at harmonic frequencies. With this harmonic current reference (9), the DG unit essentially works as a small equivalent harmonic resistor at the end of the feeder, when it is viewed at power distribution system level. By providing sufficient damping effects to the long feeder, the voltage quality at different positions of the feeder can be improved.

C. Proposed Harmonic Compensation Method

The local load harmonic current compensation and the PoC harmonic voltage compensation, the harmonic current is absorbed by the DG unit

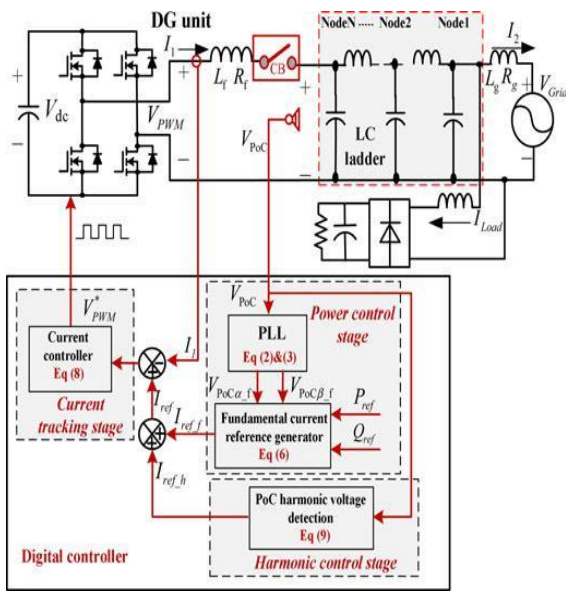


Fig-2.DG unit with PoC harmonic voltage mitigation capability.

The interactions between DG harmonic current and PoC harmonic voltage may cause some steady-state DG power offset. Nevertheless, the power control using fundamental current reference is still in an open-loop manner, which can not address the power offset introduced by harmonics interactions. In order to achieve accurate power control performance in current-controlled DG units, the instantaneous fundamental current reference (including both magnitude and phase angle information) can be determined by a simple closed-loop power control strategy as

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

Here $V_{PoC\alpha}$ is the nonfiltered PoC voltage expressed in the $\alpha - \beta$ reference frame ($V_{PoC\alpha} = V_{PoC}$) and $V_{PoC\beta}$ is its orthogonal component. The gains g_1 and g_2 are adjustable and they are used to control DG unit real and reactive power.

The detailed regulation law is given as

$$g_1 = \left(k_{p1} + \frac{k_{I1}}{s} \right) \cdot \left(\frac{1}{\tau s + 1} \cdot P_{ref} - P_{DG} \right) + \frac{P_{ref}}{(E^*)^2} \quad (11)$$

$$g_2 = \left(k_{p2} + \frac{k_{I2}}{s} \right) \cdot \left(\frac{1}{\tau s + 1} \cdot Q_{ref} - Q_{DG} \right) + \frac{Q_{ref}}{(E^*)^2} \quad (12)$$

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, E^* is the nominal voltage magnitude of the DG unit, τ is the time constant of first-order low-pass filters. P_{DG} and Q_{DG} are measured DG power with low-pass filtering as

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

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

Although the proposed closed-loop power control method eliminates power tracking errors, it can be seen that the fundamental current reference in (10) will be distorted if PoC voltage has some ripples. When it is applied to the current controller in (8), the distorted fundamental current reference will affect the performance of DG harmonic current tracking.

To overcome this drawback, an improved proportional and resonant controller with two control branches is proposed as

$$V_{PWM}^* = \frac{\overset{\text{Branch1:power control}}{2K_{if}\omega_c s}}{s^2 + 2\omega_c s + \omega_f^2} \cdot (I_{ref_f} - I_1) + \left(K_P + \sum_{h=3,5,\dots,15} \overset{\text{Branch 2:harmonic control}}{\frac{2K_{ih}\omega_c s}{s^2 + 2\omega_c s + \omega_h^2}} \right) \cdot (I_{ref_h} - I_1) = \overset{\text{Branch1:power control}}{G_f(s)} \cdot (I_{ref_f} - I_1) + \overset{\text{Branch2:harmonic control}}{G_h(s)} \cdot (I_{ref_h} - I_1) \quad (15)$$

As the fundamental resonant controller is not included in the harmonic control branch, it is possible to remove the harmonic extraction blocks in (7). Accordingly, the local load current or PoC voltage without any filtering is directly used as the input of the harmonic control branch. Note that when the harmonic current reference I_{ref_h} is set to zero, the harmonic control branch ensures that the DG current is ripple-free. This is very similar to the performance of conventional DG unit without any compensation, where the DG unit current is controlled to be sinusoidal.

$$I_{ref_h} = I_{local}, \quad \text{local non-linear load compensation} \\ -V_{PoC}/R_v \quad \text{feeder resonance voltage} \\ 0, \quad \text{DG harmonic current rejection.} \quad (16)$$

The grid voltage frequency variations often affect the power control accuracy and the harmonic compensation performance of the DG unit. As PI controllers are used in the closed loop power control, zero steady-state power control error can still be realized even when grid voltage frequency has variations. On the other, to alleviate the impact of frequency variation to DG harmonic current tracking accuracy, wide bandwidth (ω_c) harmonic resonant controllers should be considered. 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. In this case, the detected grid frequency is used as a parameter of resonant controllers and the DG current tracking accuracy can be improved accordingly. The frequency detector, the grid angle

calculation is not needed in the proposed DG power control loop.

III. Modelling of DG Unit with the Proposed Current Control Scheme

In this section, the harmonic compensation performance using the proposed current controller is investigated.

A. Modelling of the Proposed Current Control Method

It is well understood that the current-controlled inverter shall be described as a closed-loop Norton equivalent circuit

$$I_1 = H_c(s) \cdot I_{ref} - Y_c(s) \cdot V_{PoC} \tag{17}$$

Where the gain (Hc (s) and Yc (s)) can be derived based on the conventional current controller in (8) and the DG unit circuitry parameters [27]. The corresponding equivalent circuit is shown in Fig. 4. Note that for the DG unit with harmonic compensation capability, the current reference Iref in Fig. 4 has two components (Iref f and Iref h). For the DG unit using the proposed current control method, its equivalent circuit is derived as shown in the rest of this section. First, (18) describes the transfer function of DG unit filter plant GInd (s) a

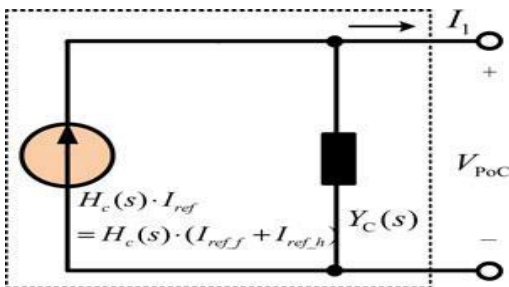
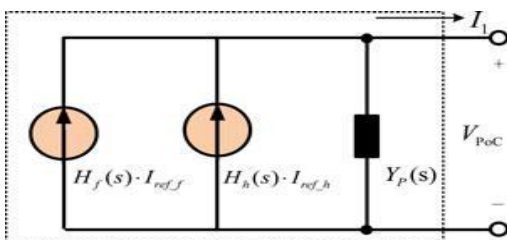


Fig. 3. Equivalent circuit of a DG unit using conventional current control method.

$$I_1 = G_{Ind}(s) \cdot (V_{PWM} - V_{PoC})$$

$$= \frac{1}{L_f s + R_f} \cdot (V_{PWM} - V_{PoC}) \tag{18}$$

Fig-4. proposed current control method



Where Lf is the inductance of the DG coupling choke and Rf is its stray resistance. VPWM is the average inverter output voltage. Additionally, the delay of DG control [28] is written as

$$V_{PWM} = e^{-1.5T_d \cdot s} \cdot V_{PWM}^* \tag{19}$$

Where Td is the sampling period of the system. Note that the delay here includes one sampling period processing delay and half sampling period voltage modulation delay.

By solving (15), (18), and (19), the closed-loop DG current response can be given as

$$I_1 = H_f(s) \cdot I_{ref_f} + H_h(s) \cdot I_{ref_h} - Y_P(s) \cdot V_{PoC} \tag{20}$$

Where Hf (s) and Hh (s) represent the closed-loop response of DG unit current to fundamental and harmonic current references, respectively. YP (s) demonstrates the sensitivity of DG line current tracking to PoC voltage disturbances [27]. The detailed expression of terms in (20) is listed as

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

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

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

For the DG unit with the proposed current control scheme, a modified Norton equivalent circuit with two controlled current sources can be applied to demonstrate the unique behaviour of the proposed controller. As illustrated in Fig. 5, the current source Hf (s) Iref f is responsible for regulating DG unit fundamental current. Additionally, the current source Hh (s) Iref h aims to compensate system harmonics at selected harmonic frequencies.

IV. SIMULATION DIAGRAM

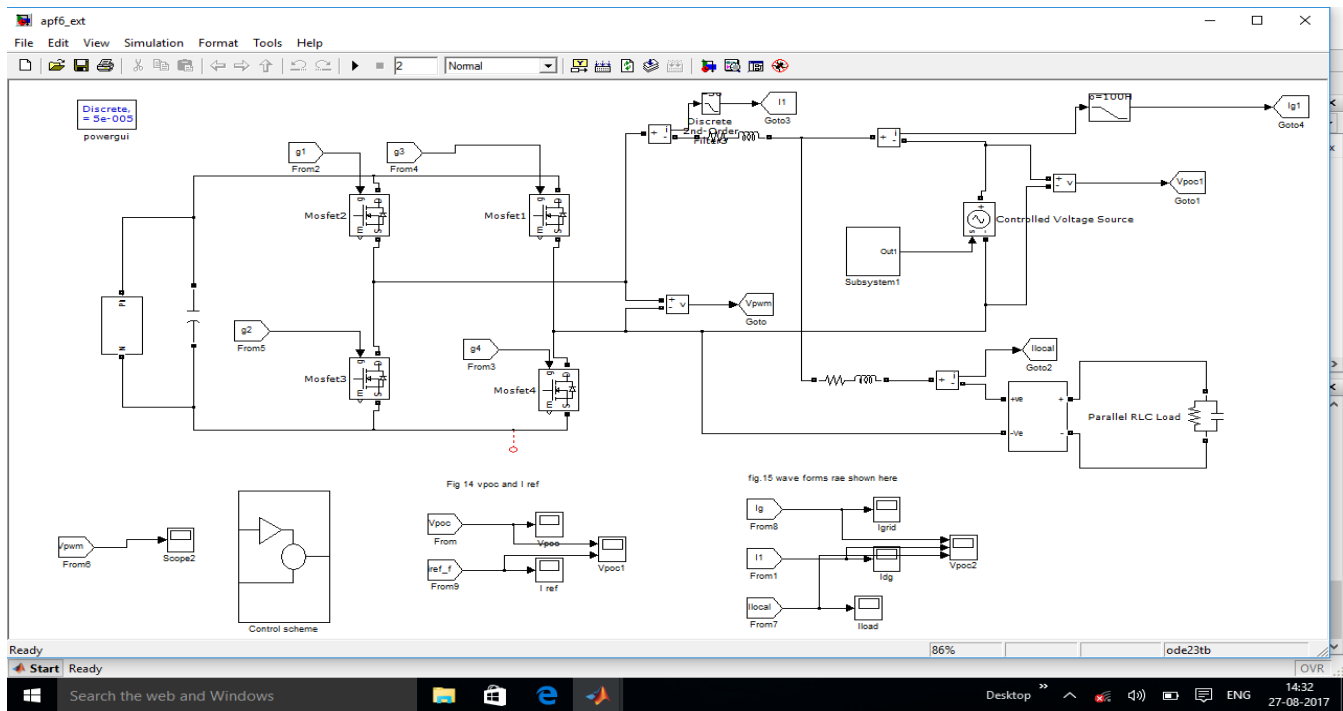


Fig 5.Simulation Diagram of Proposed System

SIMULATED RESULTS

In order to verify the correctness of the proposed control strategy, simulated results are obtained from a single-phase DG unit.

A. Simulated Results

The DG unit with a local diode rectifier load is tested in the simulation. The configuration of the system is the same as shown in Fig. 1, and PoC is connected to a stiff controlled voltage source (to emulate the main grid) with nominal 50 Hz frequency. The main grid voltage contains 2.8% third and 2.8% fifth harmonic voltages. In this simulation, the reference power is set to 600W and 200 var. The detailed parameters of the system are provided in Table 1. When the local load harmonic current is not compensated by the DG unit [corresponding to Iref h = 0 the performance of the DG unit is shown in Fig. 6. It can be seen from Fig. 7 that the DG current is sinusoidal with 5.57% total harmonic distortion (THD).

The proposed method can still realize satisfied local load harmonic current compensation, resulted in an enhanced grid current quality with 5.88% THD. Meanwhile, DG unit current is polluted with 201.5% THD.

System Parameter	Value
Grid voltage	Simulation 230V/50Hz Experiment 115V/50Hz
DG filter	$L_f=6.5\text{mH}$, $R_f=0.15\Omega$
Grid feeder	$L_g=3.4\text{mH}$, $R_g=0.15\Omega$
LC ladder with five identical LC filter	$L=1.0\text{mH}$, $C=25\mu\text{F}$ for each LC filter
Sampling/Switching frequency	20kHz/10kHz
DC link voltage	Simulation 550V Experiment 350V
Power Control Parameter	
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	
Proportional gain K_p	48
Resonant gains K_{rh}	$1500(h=f)$; $900(h=3, 5, 7, 9)$; $600(h=11, 13, 15)$
Resonant controller bandwidth ω_c	4.1rad/s
R_v (for PoC harmonic voltage compensation)	5Ω

Table-1.Simulation parameters.

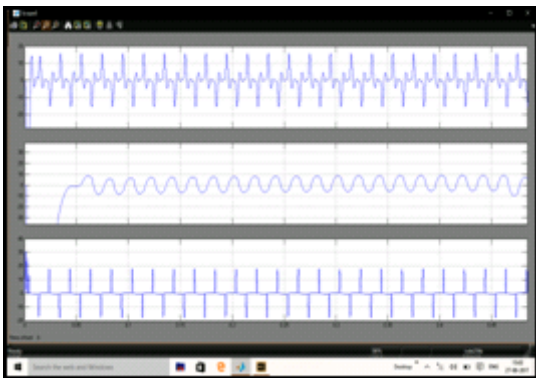


Fig.6. Performance of the DG unit during DG harmonic rejection: (a) grid current I_g (b) DG current I_{dg} (c) Local load current I_{Local} .

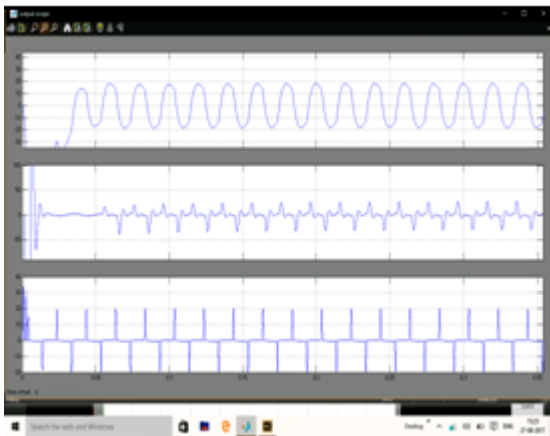


Fig.7. Performance of the DG unit during local load compensation: (a) grid current I_g , (b) DG current I_{dg} (c) Local load current I_{local} .

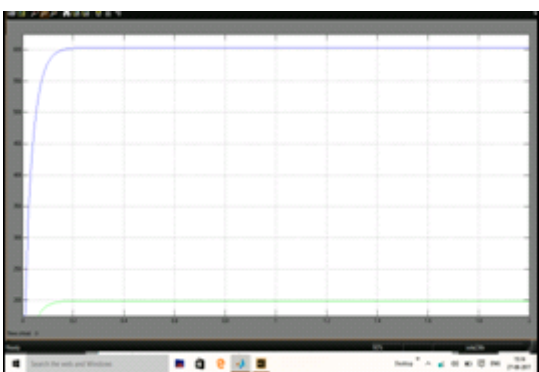


Fig-8. Power flow of the DG unit during local load harmonic current compensation ($P_{ref} = 600 \text{ W}$ and $Q_{ref} = 200 \text{ var}$).

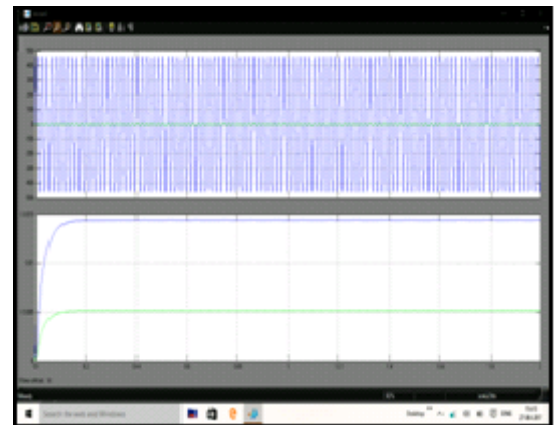


Fig-9. Power control reference during local load harmonic compensation: (a) PoC voltage and fundamental current reference I_{ref} ; (b) power control gains g_1 and g_2 .

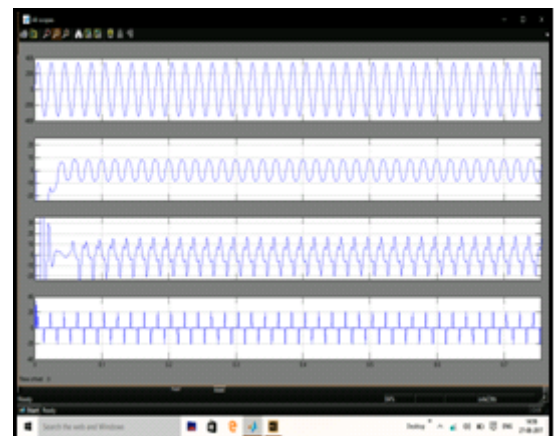


Fig-10 Performance of the DG unit under local harmonic compensation mode. (a) grid voltage V_{grid} , (b) grid current I_g (c) DG current I_{dg} (d) Local load current I_{local}

CONCLUSION

With the separation of conventional proportional and multiple resonant controllers into two parallel control branches, proposed technique realizes power control and harmonic compensation without using any local nonlinear load harmonic current extraction or PoC harmonic voltage detection. In proposed method the input of the fundamental power control branch is regulated by a closed-loop power control scheme, which avoids the adoption of PLLs. The main 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.

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