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Active harmonic filtering using current-controlled, grid-connected DG units with closed-loop power control

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ABSTRACT

Renewable energy sources such as solar, wind are becoming more popular to generate power. These renewable energy based power generation systems generate DC power output. An inverter is needed to convert DC power from renewable energy sources into AC power. These renewable energy sources are connected to the grid through interfacing converters which supply active and reactive powers to the main grid. Inverters are either be connected in standalone or in grid-connected mode. In the case of grid-connected mode, the output voltage and frequency of inverter should be same as grid voltage and frequency. If loads connected to the grid are non-linear in nature, then it can introduce power quality problems such as harmonic distortions in grid voltage.

Keywords*— Harmonic, Current-controlled, Grid-connected, DG units, Closed-loop power control*

1. INTRODUCTION

Renewable energy sources such as solar, wind are becoming more popular to generate power. This renewable energy based power generation systems generate DC power output. An inverter is needed to convert DC power from renewable energy sources into AC power. These renewable energy sources are connected to the grid through interfacing converters which supply active and reactive powers to the main grid. Inverters are either be connected in standalone or in grid connected mode. In the case of grid connected mode, the output voltage and frequency of inverter should be same as grid voltage and frequency. If loads connected to the grid are non-linear in nature, then it can introduce power quality problems such as harmonic distortions in grid voltage [1].

Due to the growing importance of renewable energy based power generation, a number of power electronics interfaced DG units have been installed in the low-voltage power distribution systems. It has been reported that the control of interfacing converters can introduce system resonance problem. Moreover, the increasing presence of nonlinear loads, such as variable-speed drives, electronic equipment, electronic and electric discharge lightning, etc., will further increase the system power quality problems [1].

To compensate grid harmonic distortions, a number of active and passive filtering methods have been developed. However, installing additional filters is costly. Alternatively, distribution system power quality enhancement using control of grid connected DG units reduces the voltage distortion, where the harmonic compensation capability is integrated with the DG primary power generation function through modifying control references. This project considering that the available power from backstage renewable energy resources is often lower than the power rating of DG interfacing converter [2]

1.1 Objective of the proposed system

The objective of the project is to develop a simulation model of PIC Controller for a PWM Inverter and hardware model using PIC 16F8877A controller

- Design Simulation model of dc-ac converter using MOSFET IRF840
- Design of control technique such as PWM, PI
- Design Hardware model of power supply 5vdc
- Design Hardware model of the driver circuit
- Programming PIC 16F8877A controller
- Result analysis using CRO and Power analyser.

2. LITERATURE REVIEW

The increasing use of distributed generation with renewable energy sources is advantageous due to the elimination of harmful emission and the inexhaustible resource of primary energy. The distribution system interfacing with the gird is challenging due to its generation variation. The power electronics play a very important role to match the characteristics of distribution generation unit with the grid. The battery is used as the distribution generation, which is charged using the solar PV panel. The DC output of the battery is converted into AC using inverter [1].

An inverter is a device which converts DC output into AC at desired voltage and frequency. This conversion can be achieved by controlled turn on and turn off devices that is BJT, MOSFETs, IGBTs, GTOs and Thyristor or SCR depend on the application. Generally, inverters are classified as a Voltage Source Inverter (VSI) and Current Source Inverter (CSI) [2].

The difference between VSI and CSI is that the Voltage Source Inverter (VSI) is fed by constant DC voltage source with small impedance and Current Source Inverter (CSI) is fed by adjustable current from DC voltage source of high impedance. The VSI becomes more dominant over CSI because of its high efficiency, lightweight and low cost [2]. The active harmonic filter proposed for the location near to the major nonlinear loads to provide harmonic compensation in a power network. The current controller force the actual compensating current to track the reference compensating current, hence the selection of controller significantly affect the performance of active power filter. There are different types of current controller used in shunt active filter such as 1) hysteresis current controller, 2) Fourier transformation based current controller and 3) conventional current controller. This three harmonic compensator explained respectively as bellow.

The hysteresis current controller keeps the actual compensating current within hysteresis band by switching action of shunt active harmonic filter. If hysteresis current controller used for three-phase system, the active harmonic filter requires three independent hysteresis controllers, one for each phase. The output signal of these three hysteresis controllers is used to trigger individually the switches of 3-phase inverter. This scheme faces the problem of coordination between three individual hysteresis current controllers' results in random switching [2].

Fourier transformation based harmonic compensation method the voltage and current signal of PCC are sensed, the Fourier transformation is then applied to the captured voltage/current signal. The harmonic component of the captured voltage /current signal is firstly separated by eliminating the fundamental component. The inverse Fourier transform is then applied to find the compensated reference signal. The main drawback of this system is a time delay in a sampling of system variables and computation of Fourier coefficients. This makes the system impractical for real-time applications [5].

Active Harmonic Filter (AHF) designed for development of control including more features in terms of power quality regulation such as compensation of voltage unbalance, sag, swell, network resonances. The design of the active harmonic filter is based on the currently regulated voltage controlled strategy, which is used to control grid interfaced voltage source inverter. In which the capacitor voltage feedback compensator Kv is used to force the capacitor voltages to track their reference sinusoidal waveform, The output of this voltage compensator is then fed to capacitor current compensator Ki, it stabilizes the system and improves the system dynamic response [5].

3. SYSTEM DEVELOPMENT

Simulation Model of Proposed Control Scheme:

In compensation of nonlinear load, 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 figure 1, and PoC is connected to a controlled voltage source (to emulate the main grid) with a nominal 50 Hz frequency. In this simulation, the reference power is set to 600W and 200 var. When $I_{ref_h} = 0$, the load harmonic current is not compensated by the DG unit shown in equation (16). The performance of the grid connected DG unit is shown in figure. 2 In open loop system simulation, the voltage and current THD are 44.53% and 66.74% respectively. Whereas in closed loop active harmonic compensation system we get reduced THD of voltage and current which are 4.46% and 19.02% respectively.

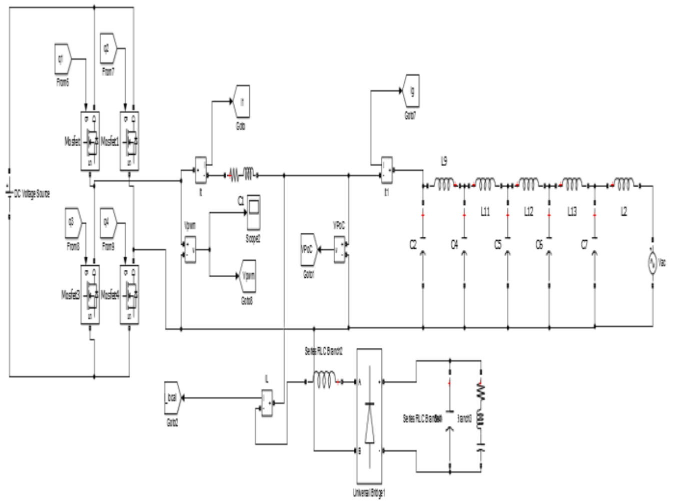

Fig. 1: MATLAB simulation of the proposed control scheme

At the same time, the harmonic load currents flow to the main grid is illustrated in figure 1. Once the nonlinear load harmonic current compensation is activated by setting $I_{ref_h} = I_{Load}$ in equation (16). The proposed method can still realize satisfied nonlinear load harmonic current compensation, results in an enhanced grid current quality with 5.88% THD.

The Table shows parameters used in MATLAB simulation of the proposed control scheme shown in figure 1.

Table 1: Simulation Parameters

System Component	Values
Grid voltage	230V/50Hz
DG filter	Lf=6.5mH,Rf=0.15Ω
LC Ladder	L=1.0mH,C=25µF
DC link voltage	550V
Power references	P_{ref}=600W, Q_{ref}=200VAR

For the DG unit operating under nonlinear load harmonic compensation mode, its fundamental current reference adjusted by equation (10). The effectiveness of the proposed closed loop power control strategy is shown in the figure, where the real and reactive power is calculated by equation (13) and (14). When the conventional open-loop power control in figure .1 is applied, it can be noticed that the DG output real and reactive power control is not accurate. On the other hand, as the proposed control strategy regulates DG output power in a closed loop manner, it guarantees zero steady-state power tracking error [14], [15], [16].

The series filter Rf and Lf are used as a filter to block the inverter harmonics. If an inverter output is directly given to the LCL filter on the grid side, there will be an occurrence of voltage resonances problem at the PoC. The PLL produces the overshoot error because of the defined locking frequency range. So PI controller used in the proposed method to avoid overshoot [14].

In the simulation model labelled as figure4.1 describes the DG unit interface with the grid through interfacing converters and the diode rectifier as a nonlinear load connected at the point of coupling. The real and reactive power references are considered to be 600W and 200VAR respectively from maximum power point tracking or from a central control station.

2 Results of Simulation figure 2 (a) shows the point of coupling voltage and figure 2(b) shows fundamental current reference.

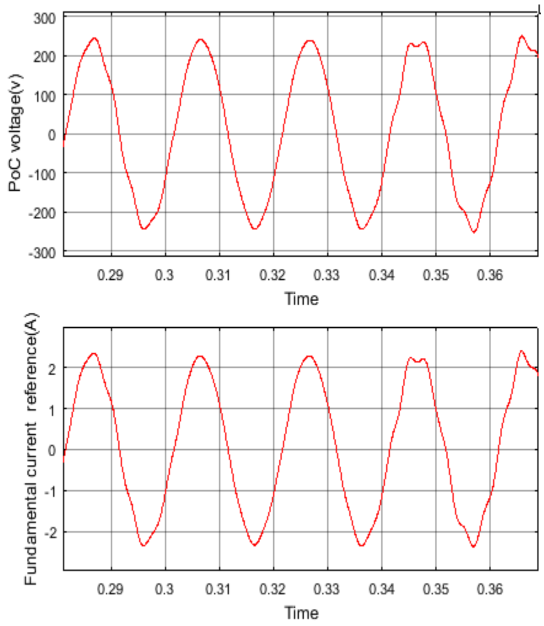

Fig. 2: The voltage at PoC and fundamental current reference for DG during load harmonic compensation (a) Point of coupling voltage and (b) Fundamental current reference

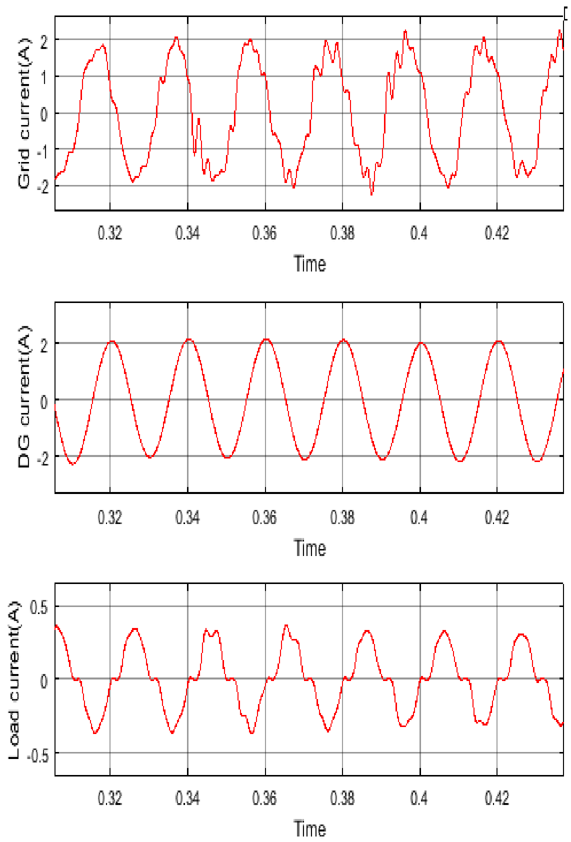

Fig. 3: The DG unit performance during harmonic compensation of load (a) Grid current, (b) DG current, (c) Nonlinear load current

The DG unit performance during harmonic compensation of load is shown in figure 3 (a), 3 (b) and 3(c) for grid current, DG current and nonlinear load current respectively. From figure 3 (a), it is noted that the grid current is distorted due to nonlinear load and the nonlinear load current also has distorted waveform.

The point of Coupling voltage and fundamental reference current during grid voltage resonance compensation are shown in figure 4 (a) and 4 (b) respectively.

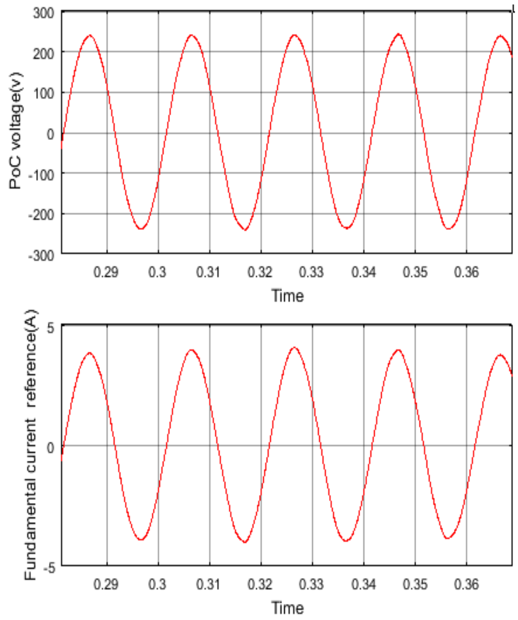

Fig. 4: Point of Coupling voltage and fundamental reference current during grid voltage resonance compensation (a) PoC voltage and (b) Fundamental current reference

The figure 4.11(a), 4.11 (b), 4.11 (c) shows the DG unit performance during voltage resonance compensation with Grid current, DG current and load current respectively. Figure 5(a) shows the grid current is sinusoidal due to closed loop active harmonic compensation.

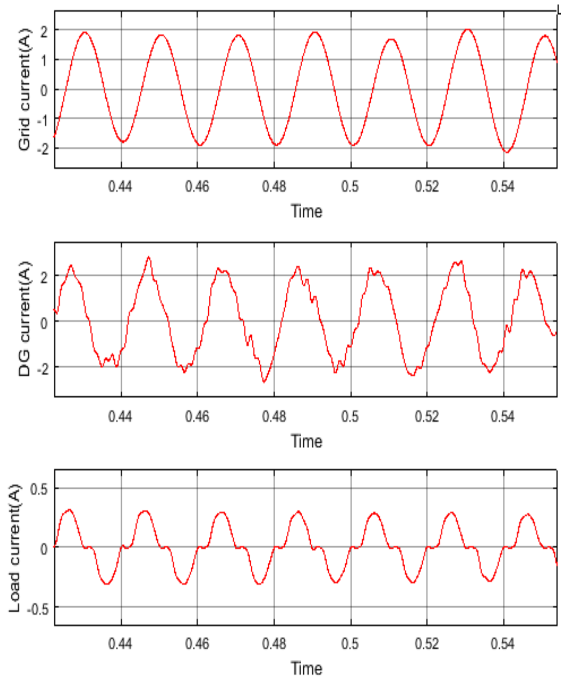

Fig. 5: DG unit performance during voltage resonance compensation with (a) Grid current, (b) DG current and (c) Load current

4. HARDWARE IMPLEMENTATION OF SYSTEM

The hardware set up of the proposed compensation method is shown in bellow picture 6.

The results of the system are checked by using Digital Storage Oscillator (DSO) and power quality analyzer to measure THD. Actually, the concept of implementation of hardware setup of proposed harmonic compensation is by using dSPACE, that can interface with simulation and experimental results are tested, but here we used PIC controller for hardware implementation and tried to reduce the harmonic in the system.

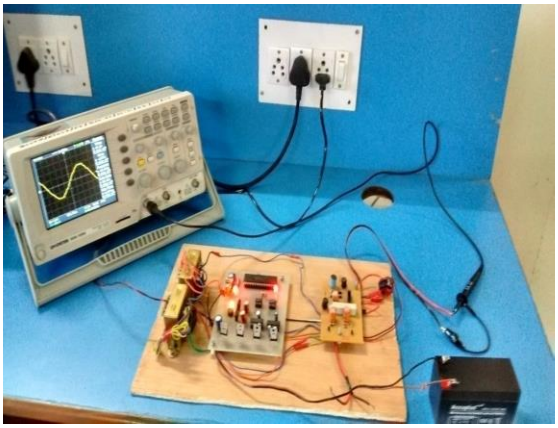

Fig. 6: Hardware setup of the proposed system.

The output results of the hardware setup are shown below figure 7 and figure 8. The figure 7 shows the result of a system without harmonic compensation which represents the grid voltage waveform with fluctuation and figure 8 shows the result after system with harmonic compensation which represents the grid voltage waveform which is almost sinusoidal.
Conclusion

Effective utilization of renewable energy is important than a generation. This project realizes harmonic compensation without using any separate harmonic detection of 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 PLL.

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.

6. FUTURE SCOPE

The proposed control scheme, can also implement using three-phase inverter, to compensate the harmonics produced due to the nonlinear loads.

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