Active Harmonic Filtering using Current Controlled Grid Connected DG Units with Synchronous Reference Frame Algorithm

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Abstract: **The increasing application of nonlinear loads may cause distribution system power quality issues. In order to utilize distributed generation (DG) unit interfacing converters to actively compensate harmonics, this paper proposes an enhanced current control approach, which sealessly integrates system harmonic mitigation capabilities with the primary DG power generation function. It performs reactive power compensation and harmonic current suppression generated by nonlinear loads. The algorithm adopted to obtain the current reference of the DC/AC converter is based on the synchronous reference frame (SRF). Thus an accurate power control is realized even when the harmonic compensation functions are activated. Simulated and experimental results from a single-phase DG unit validate the correctness of the proposed methods**

Index Terms—Active power filter, distributed generation, harmonic compensation, harmonic extraction, phase-locked loop (PLL), SRF algorithm.

I. INTRODUCTION

Due to the growing importance of renewable-energy-based power generation, a large 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 issues. Moreover, the increasing presence of nonlinear loads, such as variable-speed drives, light-emitting diode (LED) lamps, compact fluorescent lamps (CFLS), etc will drain high contents harmonics from the utility grid, which contribute to PQ degradation in electrical power systems. When harmonic currents generated by nonlinear loads interact with the network line impedance, it results in voltage harmonic distortion that affects the PQ of all consumers connected to the same point of common coupling (PCC) in the electrical system. Additional, effects can be seen through the excessive heating of transformers and electrical equipment, increasing noise in the audible frequency, and electromagnetic torque oscillations in electric motors.

To compensate distribution system harmonic distortions, a number of active and passive filtering methods have been developed. However, installing additional filters is not very favorable due to cost concerns. Alternatively, distribution system power quality enhancement using flexible control of grid connected DG units is becoming an interesting topic where the ancillary harmonic compensation capability is integrated with the DG primary power generation function through modifying control references.

It is worth mentioning that the DG real and reactive power control performance shall not be affected during the harmonic compensation. To satisfy this requirement, the fundamental DG current reference shall be calculated according to power references. Conventionally, the fundamental current reference can be determined based on the assumption of ripple-free grid voltage with fixed magnitude, and the PLL is used to synchronize the fundamental current reference with the main grid. However,considering that PoC voltage magnitude often varies due to the distribution system power flow fluctuations, this method may cause nontrivial power control errors. Alternatively, the fundamental current reference can also be calculated through the "power–current transformation" in where only the detected PoC voltage fundamental component is used in the calculation. However, for a DG unit with the ancillary harmonic compensation capability, the interactions between distorted DG current and PoC harmonic voltages may contribute some DC real and reactive power bias. In order to ensure accurate power tracking performance, a closed-loop DG power
control is necessary.

To simplify the operation of DG units with ancillary harmonic compensation capabilities while maintaining accurate power control, this paper proposes an improved current controller which uses synchronous reference frame algorithm to produce the current reference.

II. DG UNITS WITH HARMONIC COMPENSATION

In this section, a DG unit using the compensation strategies in the conventional active power filters is briefly discussed. Afterward, a detailed discussion on the proposed control strategy is presented

A. Conventional Local Load Harmonic Current Compensation

Fig. 1 illustrates the configuration of a single-phase DG system, where the interfacing converter is connected to the distribution system with a coupling choke (*Lf* and *Rf*). There is a local load at PoC. In order to improve the power quality of grid current (*I*2), the harmonic components of local load current (*I*Local) shall be absorbed through DG current (*I*1) regulation.

The single-phase grid-tied DG (photovoltaic) and active filter (PV-AF) system discussed in this work is shown in Figure 1. It is connected to the utility grid by means of a full-bridge inverter to perform the following functions: active power injection into the grid, and, simultaneously, to perform active filtering and reactive compensation. The PWM converter is current controlled and it is grid-tie through a coupling inductor.

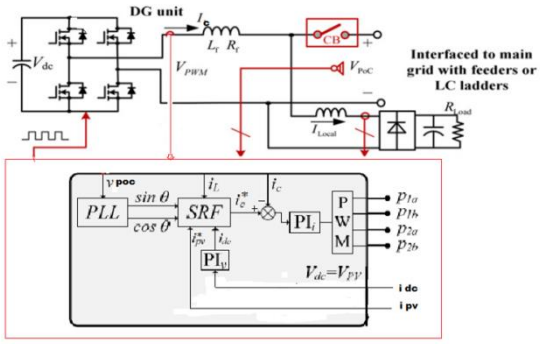

Fig. 1. DG unit with local load harmonic current compensation capability.

In order to obtain the reference current that is synthesized by the full-bridge converter, an algorithm based on synchronous reference frame (SRF) is adopted. Once the SRF is based originally on balanced three-phase loads, it must be adapted for using in single-phase systems. Therefore, a fictitious two-phase system must be created. A phase-locked loop (PLL) system is implemented for the utility grid phase-angle detection. It is also used to generate the coordinates of the synchronous unit vector *sin(θ)* and *cos(θ)* for the SRF algorithm

B.Reference Current Generation

Several methods and theories have been proposed in the literature to generate the compensation reference current for shunt-APF. In this work, for this purpose, it was used an algorithm based on synchronous reference frame. In the SRF-based algorithm the fundamental terms of voltage and/or current of the *abc*-phase stationary reference frame are transformed into continuous quantities into the *dq* synchronous axes, in which they spin at a synchronous speed in relation to the spatial vectors of voltage and/or current. In the *dq*-axes, the harmonic parcels of voltage and/or current can be represented by alternate parcels, which are superimposed to the continuous term. Therefore, the fundamental component can be easily obtained by means of low-pass filters (LPFs). A phase-locked loop (PLL) is used to estimate the utility grid phase- angle, allowing the generation of the coordinates, sinΘ and cosΘ that define the synchronous unit vector used in the SRF based algorithm, where θ is the estimated utility grid phase angle.

Once the SRF-based algorithm was conceived to be used in three-phase systems, some modifications should be made to allow its application in single-phase systems. Thereby, considering the modified SRF-based algorithm showed in Figure 2, the fictitious three-phase currents can be represented by the fictitious two-phase currents (iα=i_L ,iβ), Thus, is possible to adapt the SRF algorithm to be used in single-phase system.

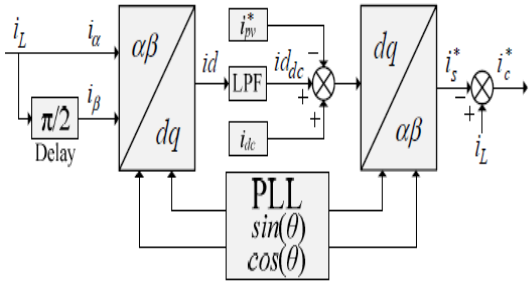

Fig:2 Block diagram of the single-phase SRF based algorithm

The algorithm shown in Figure consists in measuring of the load current Thus, the measured current is considered the fictitious current iα (axis-*α*). Subsequently, iα is delayed by π/2, producing the fictitious *β* coordinate iβ. Therefore, the fictitious two-phase stationary reference frame (*αβ*-axis) can be represented by

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{bmatrix} i_L(\omega t) \\ i_L(\omega t - \pi/2) \end{bmatrix}$$

After that, the currents i_α and i_β are transformed from the two-phase stationary reference frame into a two-phase synchronous rotating reference frame *dq*. The direct current *id* is obtained by means of equation given below. Now, it is possible to extract the DC component id_{dc} using a LPF, which represents the peak amplitude of the fundamental parcel of the load current.

Therefore, the fundamental reference current (*is**)can be obtained . Finally, the compensation current reference (*ic**)is given by.

$$id = i_\alpha.\cos(\theta) + i_\beta.\sin(\theta) \quad (4)$$

$$i_s^* = (id_{dc} + i_{dc} - i_{pv}^*).\cos(\theta) \quad (5)$$

$$i_c^* = i_L - i_s^* \quad (6)$$

The component i_{dc} is the output signal of the DC-bus controller (PI controller), which represents the compensation of the losses related to the inductances and switching devices. In other words, the PI output signal i_{dc} represents the total active power demanded by the PV-AF system to regulate the DC-link voltage. This quantity is

important mainly when the PV-AF system is working only as shunt-APF.

C.Current Control Loop

The block diagram of the current controller model used in the single-phase full-bridge converter is shown in the Figure 3, where the current reference ic^* is obtained by SRF algorithm showed in the Figure 2. In the block diagram of Figure 3 KP_i, and KI_i represent, respectively, the proportional and integral gains of the current PI controller KP_V; and KL_V represent, respectively, the proportional and integral gains of the DC-bus PI controller K_{PWM}; is the PWM gain; L_f and R_{Lf} are, respectively, the inductance and resistance of the output filter of PV-AF system.

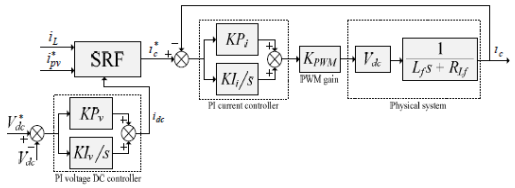

Fig 3: Block diagram of the current control loop

D.Phase lock loop (PLL)

A phase-locked loop or phase lock loop (PLL) is a control system that generates an output signal whose phase is related to the phase of an input signal. While there are several differing types, it is easy to initially visualize as an electronic circuit consisting of a variable frequency oscillator and a phase detector. The oscillator generates a periodic signal. The phase detector compares the phase of that signal with the phase of the input periodic signal and adjusts the oscillator to keep the phases matched. Bringing the output signal back toward the input signal for comparison is called a feed back loop since the output is 'fed back' toward the input forming a loop.

Keeping the input and output phase in lock step also implies keeping the input and output frequencies the same. Consequently, in addition to synchronizing signals, a phase-locked loop can track an input frequency, or it can generate a frequency that is a multiple of the input frequency. These properties are used for computer clock synchronization, demodulation and frequency synthesis.

Phase-locked loops are widely employed in radio, telecommunications, computers and other electronic applications. They can be used to demodulate a signal, recover a signal from a noisy communication channel, generate a stable frequency at multiples of an input frequency (frequency synthesis), or distribute precisely timed clock pulses in digital logic circuits such as microprocessors. Since a single integrated circuit can provide a complete phase-locked-loop building block, the technique is widely used in modern electronic devices, with output frequencies from a fraction of a hertz up to many gigahertz.

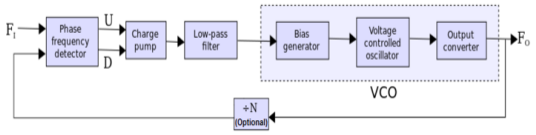

Fig:5 Block diagram of a phase-locked loop.

A phase detector compares two input signals and produces an error signal which is proportional to their phase difference. The error signal is then low-pass filtered and used to drive a VCO which creates an output phase. The output is fed through an optional divider back to the input of the system, producing a negative feedback loop. If the output phase drifts, the error signal will increase, driving the VCO phase in the opposite direction so as to reduce the error. Thus the output phase is locked to the phase at the other input. This input is called the reference

II.OVERALL SIMULATION DIAGRAM OF PROPOSED SYSTEM

The simulation diagram of the proposed system shown in figure 6. It illustrates the configuration of a single-phase DG system, where the interfacing converter is connected to the distribution System. There is a local non linear load at Poc. An improved closed loop current controller is designed in which the current reference of DC/AC converter is obtained through synchronous reference frame algorithm.

PWM reference input to the inverter circuitry is modified in order to get the required output.

V*PWM is modified in accordance with

1. DG current
2. I local
3. V poc

The DG unit is connected to the grid and nonlinear load with the help of dc/ac converters. The converter is pulse width modulated. The current reference in order to obtain the pulses for the converter action is from the synchronous frame algorithm and phase locked loop.

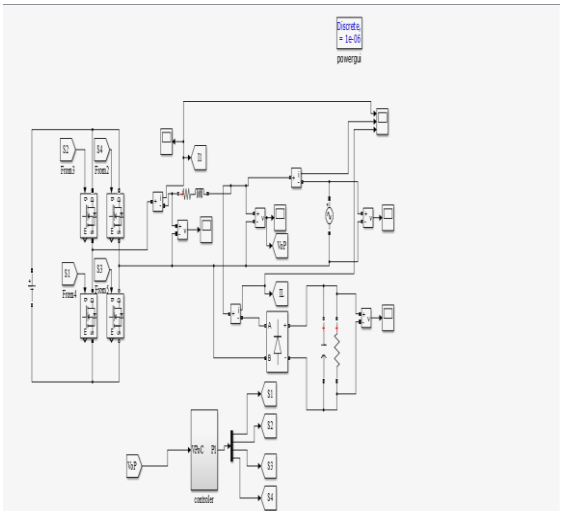

Fig 6:Simulation model of proposed system

Simulation Model of current controller

The poc voltage , local load current and DG currents can be used as the input of the proposed current controller, without affecting the harmonic compensation accuracy of the DG unit.Fig: 7 represents the simulation model of the current controller.In this current controller current reference is modelled using synchronous reference frame.

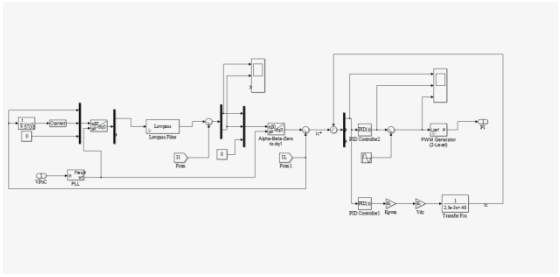

Fig:7 Simulation model of controller

III. SIMULATION RESULT

All the simulation results have been recorded accurately.

Wave form of DG current

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First the DG unit with a local diode rectifier load is tested in the simulation. The output current wave form of DG unit is given in the figure 8. The harmonic content not distorted the DG current wave form.

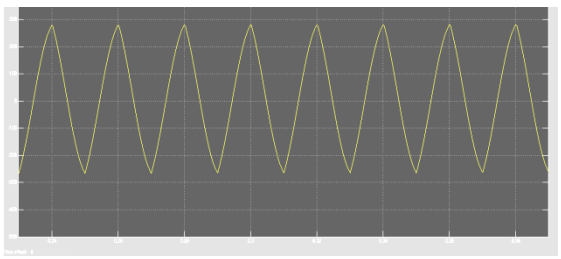
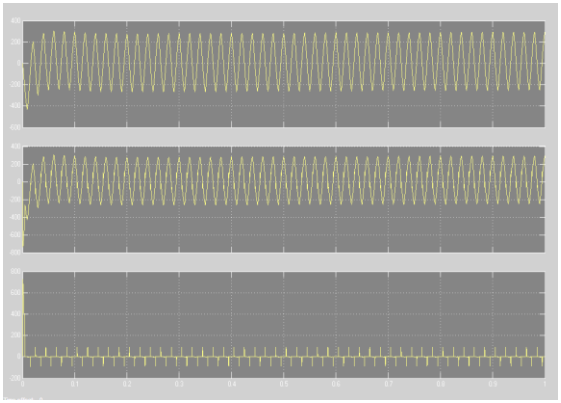


Fig 8 Wave form of DG current.

The wave forms of DG current, non linear load and grid current

The wave forms of DG current,non linear load cuttent,and grid current are given below (fig 9). From this we can detect the harmonic content in the non linear load. The harmonic content in the local load is much as is composed of nonlinear loads. After filtering the wave forms of DG current and grid current are becoming more sinusoidal.



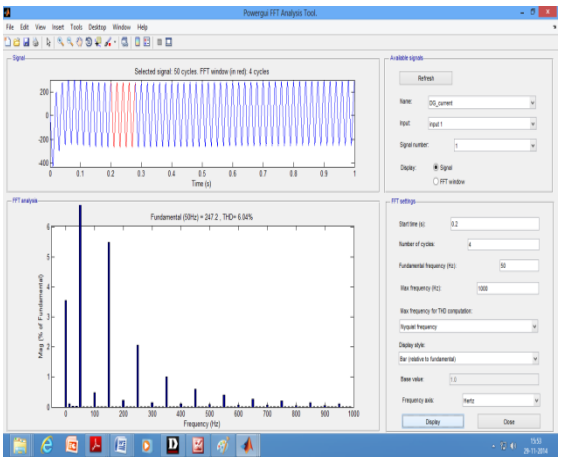
The FFT Analysis of DG current wave form .

Total Harmonic Distortion (THD), of a signal is a measurement of the harmonic distortion present and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency.

THD is used to characterize the linearity of audio systems and the power quality of electric power systems.

((sum of square of amplitude of all harmonics) / (square of amplitude of fundamental))^1/2 × 100% .

THD is the summation of all harmonic components of the voltage or current waveform compared against the fundamental component of the voltage or current wave. The Total Harmonics Distortion is much reduced. Total Harmonics Distortion of DG current is shown in Figure. The Total Harmonics distortion is obtained as 6.04%.



IV.CONCLUSION

A simple harmonic compensation is proposed for current controlled grid connected DG unit interfacing converters. The DG unit was connected to the utility grid by means of DC/AC converter.

The current reference synthesized by the converter was obtained by means of a SRF algorithm adapted for applications in single phase system.

The effectiveness of the system was verified considering the DG current and nonlinear load current wave forms and conducting FFT analysis to find THD.

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