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Improved Active Power Filter Performance for Renewable Power Generation Systems

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Abstract: An active power filter implemented with a four-leg voltage-source inverter using a predictive control scheme is presented. The use of a four-leg voltage-source inverter allows the compensation of current harmonic components, as well as unbalanced current generated by single-phase nonlinear loads. Now a day's due to increase in the power demand, generation has to be increased. Due to which the fossil fuels are using out which creates the pollution too. Hence we are using the Renewable energy sources which neither creates pollution problems nor energy conservation problems. Renewable energy resources (RES) are being increasingly connected in distribution systems utilizing power electronic converters. Among the Renewable energy resources most abundantly available throughout the earth is Sun radiation. In order to convert the solar radiation to Electrical energy we use PV Cell. Hence designed PV Cell is applied to the converter and given to the grid. Even many techniques proposed the Modeling and designing of the PV Cell and its interface to the grid, it suffers from many controlling problems due the Non linear characteristics of the Load. This paper presents a novel control strategy for achieving maximum benefits from these grid-interfacing inverters when installed in 3-phase 4-wire distribution systems. The inverter is controlled to perform as a multi-function device by incorporating active power filter functionality. The inverter can thus be utilized as: 1) power converter to inject power generated from RES to the grid, and 2) shunt APF to compensate current unbalance, load current harmonics, load reactive power demand and load neutral current. All of these functions may be accomplished either individually or simultaneously.

Keywords: Fuzzy Logic Controller, Active power filter, current control, four-leg converters, predictive control Harmonics.

I. INTRODUCTION

Increasing global energy consumption and noticeable environmental pollution are making renewable energy more important. Today, a small percentage of total global energy comes from renewable sources, mainly hydro and wind power. As more countries try to reduce greenhouse gas (GHG) emissions, new power generation capacity can no longer be met by traditional methods such as burning coal, oil, natural gas, etc. However, these DG units produce a wide range of voltages [1] due to the fluctuation of energy resources and impose stringent requirements for the inverter topologies and controls. To have sustainable growth and social progress, it is necessary to meet the energy need by utilizing the renewable energy resources like wind, biomass, hydro, co-generation, etc. In sustainable energy system, energy conservation and the use of renewable source are the key paradigm. The need to integrate the renewable energy like wind energy/PV into power system is to make it possible to minimize the environmental impact on conventional plant [1]. The integration of wind energy into existing power system presents technical challenges and that requires consideration of voltage regulation, stability, power quality problems. The power quality is an essential customer-focused measure and is greatly affected by the operation of a distribution and transmission network. The issue of power quality is of great importance to the wind turbine [2].

There has been an extensive growth and quick development in the exploitation of wind energy in recent years. Although active power filters implemented with three-phase four-leg voltage-source inverters (4L-VSI) have already been presented in the technical literature [2]–[6], the primary contribution of this paper is a predictive control algorithm designed and implemented specifically for this application. Traditionally, active power filters have been controlled using pre-tuned controllers, such as PI-type or adaptive, for the current as well as for the dc-voltage loops [7], [8]. PI controllers must be designed based on the equivalent linear model, while predictive controllers use the nonlinear model, which is closer to real operating conditions. An accurate model obtained using predictive controllers improves the performance of the active power filter, especially during transient operating conditions, because it can quickly follow the current-reference signal while maintaining a constant dc-voltage. So far, implementations of predictive control in power converters have been used mainly in induction motor drives [9]–[16]. Conventionally, PI, PD and PID controller are most popular controllers and widely used in most power electronic appliances.

However recently there are many researchers reported successfully adopted Fuzzy Logic Controller (FLC) to become one of intelligent controllers to their appliances [3]. With respect to their successful methodology implementation, this kind of methodology implemented in this paper is using fuzzy logic controller with feed back by introduction of voltage respectively. The introduction of change in voltage in the circuit will be fed to fuzzy controller to give appropriate measure on steady state signal. The fuzzy logic controller serves as intelligent controller for this propose. This paper presents the mathematical model of the 4L-VSI and the principles of operation of the proposed predictive control scheme, including the design procedure. The complete description of the selected current reference generator implemented in the active power filter is also presented. Finally, the proposed active power filter and the effectiveness of the associated control scheme compensation, power quality improvement is simulated using Matlab/ Simulink.

II. FOUR-LEG CONVERTER MODEL

It consists of various types of power generation units and different types of loads. Renewable sources, such as wind and sunlight, are typically used to generate electricity for residential users and small industries. Both types of power generation use ac/ac and dc/ac static PWM converters for voltage conversion and battery banks for long term energy storage. These converters perform maximum power point tracking to extract the maximum energy possible from wind and sun. The electrical energy consumption behavior is random and unpredictable, and therefore, it may be single- or three-phase, balanced or unbalanced, and linear or nonlinear. An active power filter is connected in parallel at the point of common coupling to compensate current harmonics, current unbalance, and reactive power. It is composed by an electrolytic capacitor, a four-leg PWM converter, and a first-order output ripple filter, as shown in Fig. 1. This circuit considers the power system equivalent impedance Zs , the converter output ripple filter impedance Zf , and the load impedance ZL.

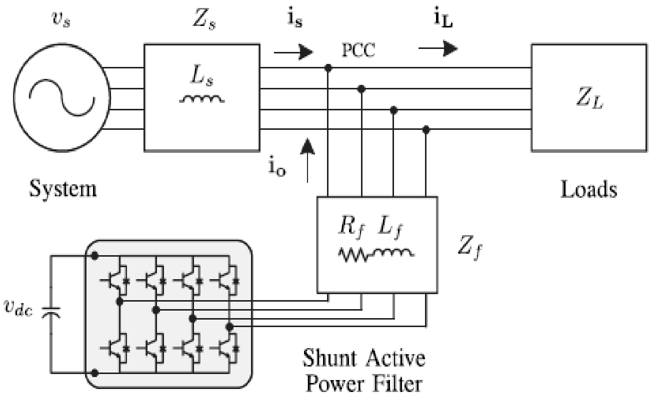

Fig.1.Three-phase equivalent circuit of the proposed shunt active power filter.

The four-leg PWM converter topology is shown in Fig. 2. This converter topology is similar to the conventional three-phase converter with the fourth leg connected to the neutral bus of the system. The fourth leg increases switching states from improving control flexibility and output voltage quality, and is suitable for current unbalanced compensation. The voltage in any leg x of the converter, measured from the neutral point (n), can be expressed in terms of switching states, as follows:

$$v_{xn} = S_x - S_n \, v_{\mathrm{dc}}, \quad x = u,\ v,\ w,\ n. \tag{1}$$

The mathematical model of the filter derived from the equivalent circuit shown in Fig. 1 is

$$\mathbf{v_o} = v_{xn} - R_{\mathrm{eq}}\,\mathbf{i_o} - L_{\mathrm{eq}}\frac{d\,\mathbf{i_o}}{dt} \tag{2}$$

Where Req and Leq are the 4L-VSI output parameters expressed as Thevenin's impedances at the converter output terminals Zeq. Therefore, the Thevenin's equivalent impedance is determined by a series connection of the ripple filter impedance Zf and a parallel arrangement between the system equivalent impedance Zs and the load impedance ZL.

$$Z_{\mathrm{eq}} = \frac{Z_s Z_L}{Z_s + Z_L} + Z_f \approx Z_s + Z_f \tag{3}$$

For this model, it is assumed that ZL _ Zs , that the resistive part of the system's equivalent impedance is neglected, and that the series reactance is in the range of 3–7% p.u., which is an acceptable approximation of the real system. Finally,

Req = Rf and Leq = Ls + Lf . (4)

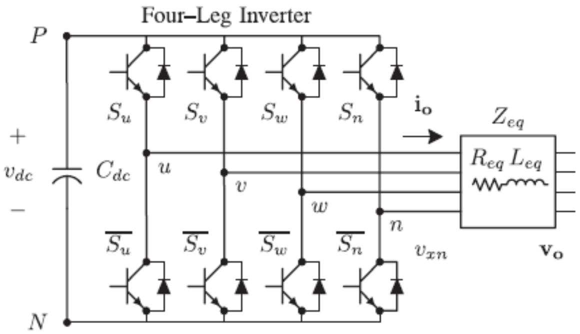

Fig.2. Two-level four-leg PWM-VSI topology

III. REFERENCE CURRENT GENERATION SCHEME

A dq-based current reference generator scheme is used to obtain the active power filter current reference signals. This scheme presents a fast and accurate signal tracking capability. This characteristic avoids voltage fluctuations that deteriorate the current reference signal affecting compensation performance. The current reference signals are obtained from the corresponding load currents as shown in Fig. 4. This module calculates the reference signal currents required by the converter to compensate reactive power, current harmonic and current imbalance. The displacement power factor (sin φ(L)) and the maximum total harmonic distortion of the load (THD(L)) defines the relationships between the apparent power required by the active power filter, with respect to the load, as shown

$$\frac{S_{\mathrm{APF}}}{S_L} = \frac{\sqrt{\sin\phi_{(L)} + \mathrm{THD}_{(L)}{}^2}}{\sqrt{1 + \mathrm{THD}_{(L)}{}^2}} \tag{5}$$

Where the value of THD(L) includes the maximum compensable harmonic current, defined as double the sampling frequency fs. The frequency of the maximum current harmonic component that can be compensated is equal to one half of the converter switching frequency. The dq-based scheme operates in a rotating reference frame; therefore, the measured currents must be multiplied by the sin(wt) and cos (wt) signals. By using dq-transformation, the d current component is synchronized with the corresponding phase-to-neutral system voltage, and the q current component is phase-shifted by 90◦. The sin(wt) and cos (wt) synchronized reference signals are obtained from a synchronous reference frame (SRF) PLL. The SRF-PLL generates a pure sinusoidal waveform even when the system voltage is severely distorted. Tracking errors are eliminated, since SRF-PLLs are designed to avoid phase voltage unbalancing, harmonics (i.e., less than 5% and 3% in fifth and seventh, respectively), and offset caused by the nonlinear load conditions and measurement errors [3], the relationship between the real currents iLx(t) (x = u, v,w) and the associated dq components (id and iq).

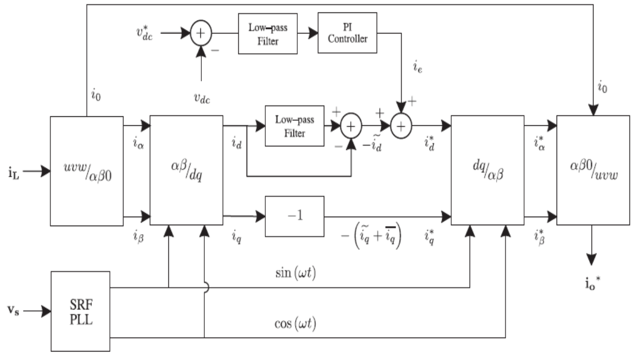

Fig.3. dq-based current reference generator block diagram.

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \sin\omega t & \cos\omega t \\ -\cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_{Lu} \\ i_{Lv} \\ i_{Lw} \end{bmatrix} \tag{6}$$

A low-pass filter (LFP) extracts the dc component of the phase currents id to generate the harmonic reference components id . The reactive reference components of the phase-currents are obtained by phase-shifting the corresponding ac and dc components of iq by 180◦. In order to keep the dc-voltage constant, the amplitude of the converter reference current must be modified by adding an active power reference signal ie with the d-component. The resulting signals i*d and i*q are transformed back to a three-phase system by applying the inverse Park and Clark transformation, The cut off frequency of the LPF used in this paper is 20 Hz.

$$\begin{bmatrix} i_{ou}^* \\ i_{ov}^* \\ i_{ow}^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} \frac{1}{\sqrt{2}} & 1 & 0 \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ \frac{1}{\sqrt{2}} & -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} 1 & 0 & 0 \\ 0 & \sin\omega t & -\cos\omega t \\ 0 & \cos\omega t & \sin\omega t \end{bmatrix} \begin{bmatrix} i_0 \\ i_d^* \\ i_q^* \end{bmatrix} \tag{7}$$

The current that flows through the neutral of the load is compensated by injecting the same instantaneous value obtained from the phase-currents, phase-shifted by 180◦, as shown next.

$$i_{on}^* = -\left(i_{Lu} + i_{Lv} + i_{Lw}\right) \tag{8}$$

One of the major advantages of the dq-based current reference generator scheme is that it allows the implementation of a linear controller in the dc-voltage control loop. However, one important disadvantage of the dq-based current reference frame algorithm used to generate the current reference is that a second order harmonic component is generated in id and iq under unbalanced operating conditions. The amplitude of this harmonic depends on the percent of unbalanced load current (expressed as the relationship between the negative sequence current iL,2 and the positive sequence current iL,1). The second-order harmonic cannot be removed from id and iq , and therefore generates a third harmonic in the reference current when it is converted back to abc frame [17]. Since the load current does not have a third harmonic, the one generated by the active power filter flows to the power system.

A. DC Link Voltage Control

The dc-voltage converter is controlled with a traditional PI controller. This is an important issue in the evaluation, since the cost function is designed using only current references, in order to avoid the use of weighting factors. Generally, these weighting factors are obtained experimentally, and they are not well defined when different operating conditions are required. Additionally, the slow dynamic response of the voltage across the electrolytic capacitor does not affect the current transient response. For this reason, the PI controller represents a simple and effective alternative for the dc-voltage control. The dc-voltage remains constant (with a minimum value of sqrt of 6vs(rms)) until the active power absorbed by the converter decreases to a level where it is unable to compensate for its losses. The active power absorbed by the converter is controlled by adjusting the amplitude of the active power reference signal ie , which is in phase with each phase voltage. In the block diagram shown in Fig. 4, the dc-voltage vdc is measured and then compared with a constant reference value v*dc. The error (e) is processed by a PI controller, with two gains, Kp and Ti . Both gains are calculated according to the dynamic response requirement. Fig. 4 shows that the output of the PI controller is fed to the dc-voltage transfer function Gs which is represented by a first-order system.

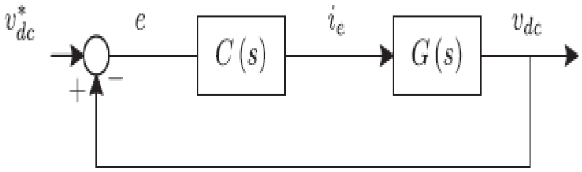

Fig.4. DC-voltage control block diagram.

The equivalent closed-loop transfer function of the given system with a PI controller

$$C(s) = K_p\left(1 + \frac{1}{T_i \cdot s}\right)$$

$$\frac{v_{\mathrm{dc}}}{i_e} = \frac{\frac{\omega_n^2}{a} \cdot (s + a)}{s^2 + 2\zeta\omega_n \cdot s + \omega_n^2} \tag{10}$$

Since the time response of the dc-voltage control loop does not need to be fast, a damping factor ζ = 1and a natural angular speed ωn = 2π·100rad/s are used to obtain a critically damped response with minimal voltage oscillation. The corresponding integral time Ti=1/a (13) and proportional gain Kp can be calculated as

$$\zeta = \sqrt{\frac{3}{8}\frac{K_p v_s \sqrt{2} T_i}{C_{\mathrm{dc}} v_{\mathrm{dc}}^*}}$$

$$\omega_n = \sqrt{\frac{3}{2}\frac{K_p v_s \sqrt{2}}{C_{\mathrm{dc}} v_{\mathrm{dc}}^* T_i}}. \tag{11}$$

IV. ABOUT HYBRID GENERATION SCHEME

The photovoltaic (PV) power generation systems are renewable energy sources that expected to play a promising role in fulfilling the future electricity requirements. The PV systems principally classified into stand-alone, grid connected or hybrid systems. The grid-connected PV systems generally shape the grid current to follow a predetermined sinusoidal reference using hysteresis-band current controller, which has the advantages of inherent peak current limiting and fast dynamic performance. The model of grid connected photovoltaic system to control active and reactive power injected in the grid is presented. The proposed multilevel power converter uses two single-phase voltage source inverters and a four wire voltage source inverter. The structural design of this new power converter allows a seven level shaped output voltage wave at the output of multilevel inverter.

A. Photovoltaic Array Modeling

Numerous PV cells are connected in series and parallel circuits on a panel for obtaining high power, which is a PV module. A PV array is defined as group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction that directly converts solar radiation into dc current using photovoltaic effect. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode, shown in Fig. 6. The series resistance RS represents the internal losses due to the current flow. Shunt resistance Rsh, in parallel with diode, this corresponds to the leakage current to the ground. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behavior of the PV cell. The grid integration of RES applications based on photovoltaic systems is becoming today the most important application of PV systems, gaining interest over traditional stand-alone systems. This trend is being increased because of the many benefits of using RES in distributed (aka dispersed, embedded or decentralized) generation (DG) power systems.

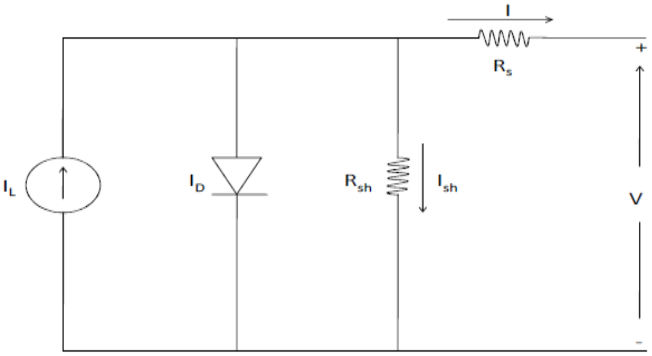

Fig6. Circuit Diagram of a Solar Cell.

B. Wind Energy System

Wind turbines transform wind energy into electricity. The wind is a highly variable source, which cannot be stored, thus, it must be handled according to this characteristic. The principle of operation of a wind turbine is characterized by two conversion steps. First the rotor extract the kinetic energy of the wind, changing it into mechanical torque in the shaft; and in the second step the generation system converts this torque into electricity. In the most common system, the generator system gives an AC output voltage that is dependent on the wind speed. As wind speed is variable, the voltage generated has to be transferred to DC and back again to AC with the aid of inverters. However, fixed speed wind turbines are directly connected to grid.

V. MATLAB MODELEING AND SIMULATION RESULTS

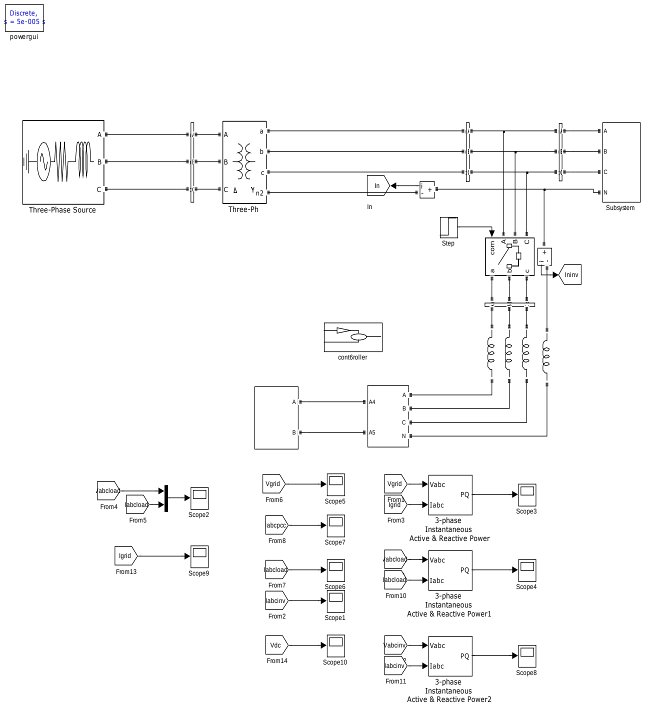

Fig7. Simulink Model .

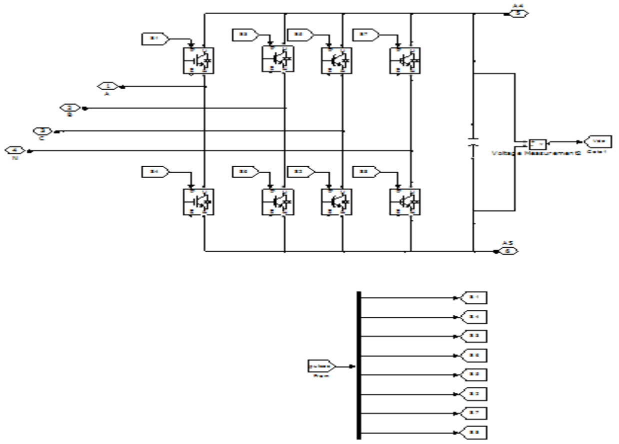

Fig8. 4-Leg Converter.

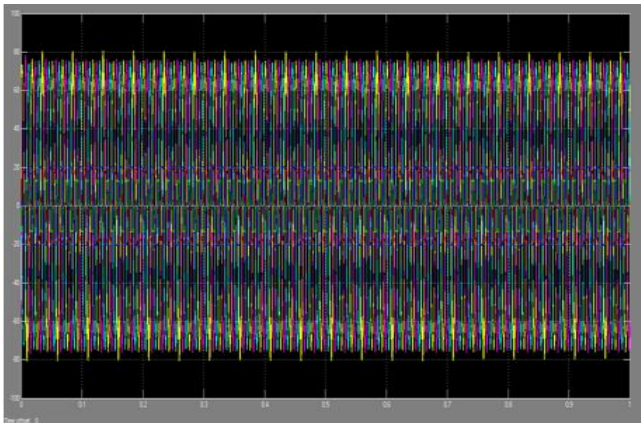

Fig9. Load Voltage & Current.

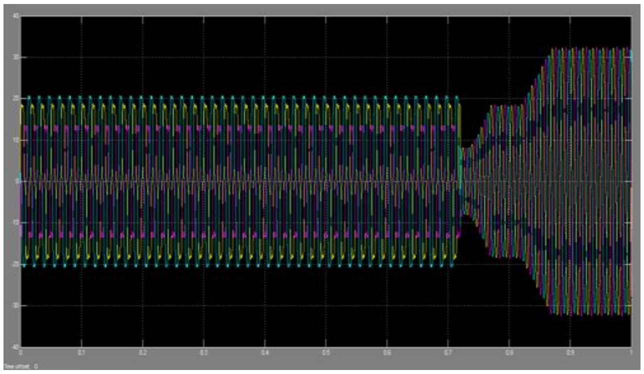

Fig10. Grid Current.

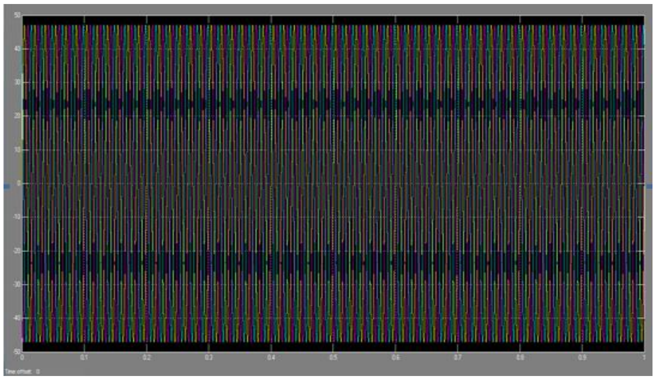

Fig11. Grid Voltage.

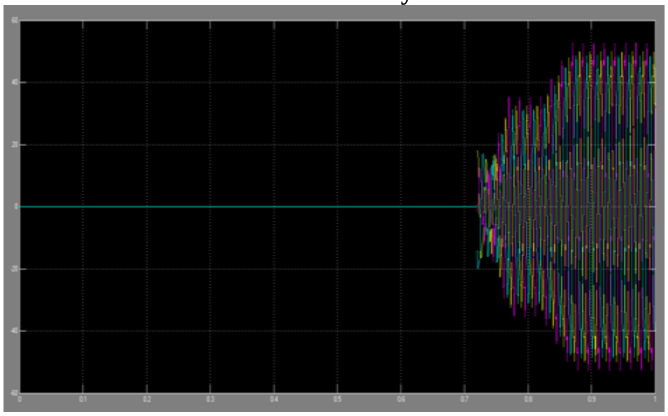

Fig12. Converter Current.

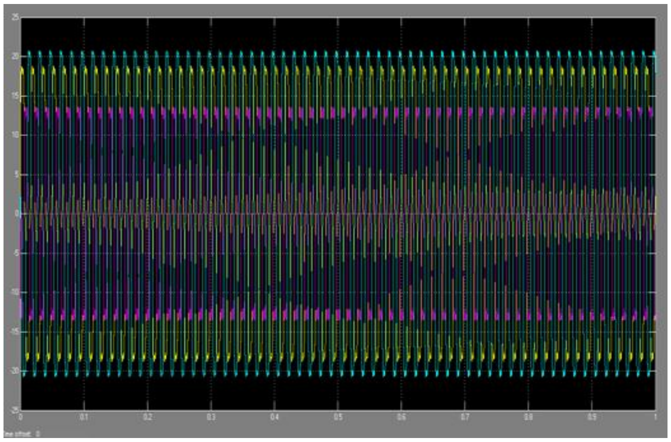

Fig13. Load Voltage.

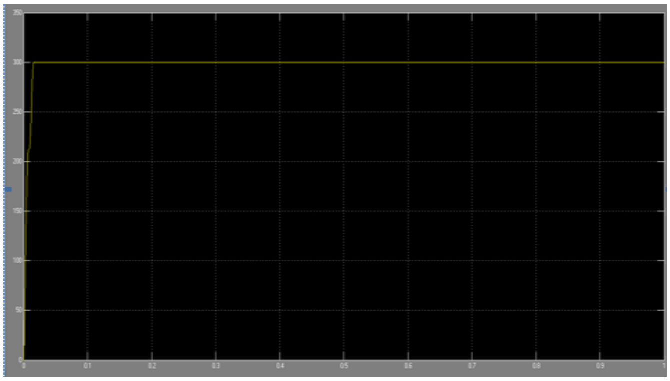

Fig14. DC Voltage.

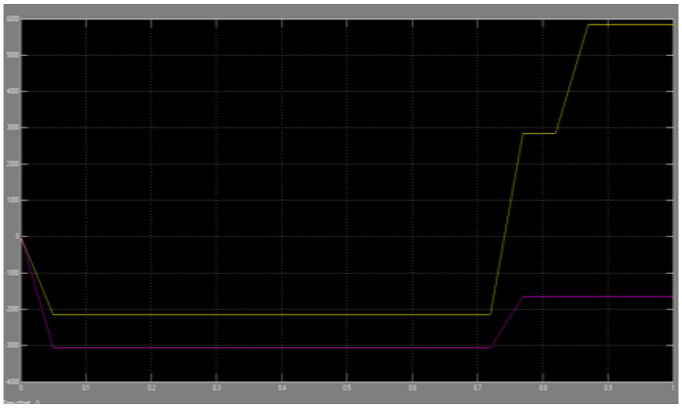

Fig8. Active Power & Reactive Power.

V. CONCLUSION

Improved dynamic current harmonics and a reactive power compensation scheme for power distribution systems with generation from renewable sources has been proposed to improve the current quality of the distribution system. Advantages of the proposed scheme are related to its simplicity, modeling, and implementation. The use of a predictive control algorithm for the converter current loop proved to be an effective solution for active power filter applications, improving current tracking capability, and transient response. Simulated and experimental results have proved that the proposed predictive control algorithm is a good alternative to classical linear control methods. The predictive current control algorithm is a stable and robust solution. Simulated and experimental results have shown the compensation effectiveness of the proposed active power filter.

VI. REFERENCES

[1] J. Rocabert, A. Luna, F. Blaabjerg, and P. Rodriguez, “Control of power converters in AC microgrids,” IEEE Trans. Power Electron., vol. 27, no. 11, pp. 4734–4749, Nov. 2012.

[2] M. Aredes, J. Hafner, and K. Heumann, “Three-phase four-wire shunt active filter control strategies,” IEEE Trans. Power Electron., vol. 12, no. 2, pp. 311–318, Mar. 1997.

[3] S. Naidu and D. Fernandes, “Dynamic voltage restorer based on a fourleg voltage source converter,” Gener. Transm. Distrib., IET, vol. 3, no. 5, pp. 437–447, May 2009.

[4] N. Prabhakar and M. Mishra, “Dynamic hysteresis current control to minimize switching for three-phase four-leg VSI topology to compensate nonlinear load,” IEEE Trans. Power Electron., vol. 25, no. 8, pp. 1935–1942, Aug. 2010.

[5] V. Khadkikar, A. Chandra, and B. Singh, “Digital signal processor implementation and performance evaluation of split capacitor, four-leg and three h-bridge-based three-phase four-wire shunt active filters,” Power Electron., IET, vol. 4, no. 4, pp. 463–470, Apr. 2011.

[6] F. Wang, J. Duarte, and M. Hendrix, “Grid-interfacing converter systems with enhanced voltage quality for microgrid application;concept and implementation,” IEEE Trans. Power Electron., vol. 26, no. 12, pp. 3501–3513, Dec. 2011.

[6] F. Wang, J. Duarte, and M. Hendrix, “Grid-interfacing converter systems with enhanced voltage quality for microgrid application;concept and implementation,” IEEE Trans. Power Electron., vol. 26, no. 12, pp. 3501– 3513, Dec. 2011.

[7] X.Wei, “Study on digital pi control of current loop in active power filter,” in Proc. 2010 Int. Conf. Electr. Control Eng., Jun. 2010, pp. 4287–4290.

[8] R. de Araujo Ribeiro, C. de Azevedo, and R. de Sousa, “A robust adaptive control strategy of active power filters for power-factor correction, harmonic compensation, and balancing of nonlinear loads,” IEEE Trans. Power Electron., vol. 27, no. 2, pp. 718–730, Feb. 2012.

[9] J. Rodriguez, J. Pontt, C. Silva, P. Correa, P. Lezana, P. Cortes, and U. Ammann, “Predictive current control of a voltage source inverter,” IEEE Trans. Ind. Electron., vol. 54, no. 1, pp. 495–503, Feb. 2007.

[10] Satyanarayana, G.; Ganesh, K.Lakshmi; Kumar, Ch. Narendra; Krishna, M.Vijaya, "A critical evaluation of power quality features using Hybrid Multi-Filter Conditioner topology," Green Computing, Communication and Conservation of Energy (ICGCE), 2013 International Conference on , vol., no., pp.731,736, 12-14 Dec. 2013.

[11] R. Vargas, P. Cortes, U. Ammann, J. Rodriguez, and J. Pontt, “Predictive control of a three-phase neutral-point-clamped inverter,” IEEE Trans. Ind. Electron., vol. 54, no. 5, pp. 2697–2705, Oct. 2007.

[12] P. Cortes, A. Wilson, S. Kouro, J. Rodriguez, and H. Abu-Rub, “Model predictive control ofmultilevel cascaded H-bridge inverters,” IEEE Trans. Ind. Electron., vol. 57, no. 8, pp. 2691–2699, Aug. 2010.

[13] P. Lezana, R. Aguilera, and D. Quevedo, “Model predictive control of an asymmetric flying capacitor converter,” IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 1839–1846, Jun. 2009.

[14] P. Correa, J. Rodriguez, I. Lizama, and D. Andler, “A predictive control scheme for current-source rectifiers,” IEEE Trans. Ind. Electron., vol. 56, no. 5, pp. 1813–1815, May 2009.

[15] M. Rivera, J. Rodriguez, B. Wu, J. Espinoza, and C. Rojas, “Current control for an indirect matrix converter with filter resonance mitigation,” IEEE Trans. Ind. Electron., vol. 59, no. 1, pp. 71–79, Jan. 2012.

[16] P. Correa, M. Pacas, and J. Rodriguez, “Predictive torque control for inverter-fed induction machines,” IEEE Trans. Ind. Electron., vol. 54, no. 2, pp. 1073–1079, Apr. 2007.

[17] M. Odavic, V. Biagini, P. Zanchetta, M. Sumner, and M. Degano, “Onesample- period-ahead predictive current control for high-performance active shunt power filters,” Power Electronics, IET, vol. 4, no. 4, pp. 414–423, Apr. 2011.

[18] IEEE Recommended Practice for Electric Power Distribution for Industrial Plants, IEEE Standard 141-1993, 1994

[19] R. de Araujo Ribeiro, C. de Azevedo, and R. de Sousa, “A robust adaptive control strategy of active power filters for power-factor correction, harmonic compensation, and balancing of nonlinear loads,” IEEE Trans. Power Electron., vol. 27, no. 2, pp. 718–730, Feb. 2012.

[20] M. Sumner, B. Palethorpe, D. Thomas, P. Zanchetta, and M. Di Piazza, “A technique for power supply harmonic impedance estimation using a controlled voltage disturbance,” IEEE Trans. Power Electron., vol. 17, no. 2, pp. 207–215, Mar. 2002.

[21] S. Ali, M. Kazmierkowski, “PWM voltage and current control of four-leg VSI,” presented at the ISIE, Pretoria, South Africa, vol. 1, pp. 196–201, Jul. 1998

[22] S. Kouro, P. Cortes, R. Vargas, U. Ammann, and J. Rodriguez, “Model predictive control—A simple and powerful method to control power converters,” IEEE Trans. Ind. Electron., vol. 56, no. 6, pp. 1826–1838, Jun. 2009.

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