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Power Quality Features Improvement In Single -Phase Grid -Connected Inverter With Non-Linear Loads

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ABSTRACT: The increasing application of nonlinear loads may cause distribution system power quality issues. This work presents a control of Single-phase Grid Interactive Inverters with nonlinear loads and a technique for Harmonic compensation and power factor correction of nonlinear loads employing Current Controlled Voltage Source Inverter. This work will focus on the design methodology and the analysis of control strategy which allows the compensation of harmonics and phase displacement of the input current, for non-linear loads. The Utility-Connected Inverter should operate at both Stand-alone and Grid-Connected modes. However, the waveform qualities of the grid current in Grid-Connected mode and the output voltage in Stand-alone mode are poor under the nonlinear critical load with the conventional control. The impact of the nonlinear load on the grid current is analyzed. Harmonics problem in industrial power systems with non-linear loads are presented. By adding the load current into the filter inductor current loop, the influence of the nonlinear load on the grid current can be eliminated, and the waveform quality of the output voltage in stand-alone mode can be improved. The control method is simple and easy to be achieved. Simulation results from a Full-bridge Grid-Interactive Inverter with a Diode Rectifier load verify the theoretical analysis.

KEYWORDS: Power quality, Grid connected inverter, Maximum Power Point Tracking, Distributed generation System

I. INTRODUCTION

RECENTLY, due to the high price of oil and the concern for the environment, renewable energy is in the limelight. This scenario has stimulated the development of alternative power sources such as photovoltaic panels, wind turbines and fuel cells. The distributed generation (DG) concept emerged as a way to integrate different power plants, increasing the DG owner's reliability, reducing emissions, and providing additional power quality benefits.[1-5]. The energy sources used in DG systems usually have different output characteristics, and for this reason, power electronic converters are employed to connect these energy sources to the grid, as shown in Fig. 1.The power electronic front-end converter is an inverter whose dc link is fed by an ac/dc converter or by a dc/dc converter, according with the DG source type[6-7]. The commercial front-end inverters are designed to operate either as grid-connected or in island mode. In grid-connected mode, the voltage at the point of common coupling (PCC) is imposed by the grid; thus, the inverter must be current-controlled.[8-12]..

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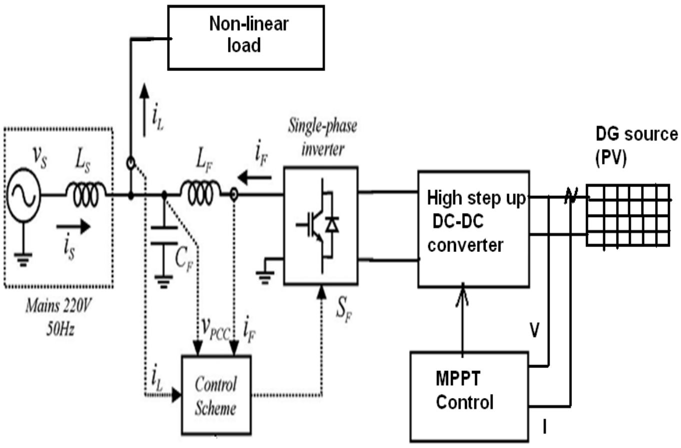

Fig. 1 General scheme of a DG unit connected to the Grid

Coming to the grid-connected mode, almost all the commercial single-phase inverters for DG systems inject only active power to the grid, i.e., the reference current is computed from the reference active power $p*$ that must be generated [18-20]. It is possible and can be convenient to integrate power quality functions by compensating the reactive power and the current harmonics drawn by specific nonlinear loads (see Fig. 1).The single-phase inverter can acquire active filtering features just adding to its control software some dedicated blocks that are specific to shunt active power filter (APF).

II. GRID INTEGRATED PV SYSTEM

This is the most important configuration and widely used in active filtering applications. A shunt APF consists of a controllable voltage or current source. The operation of shunt APF is based on injection of compensation current which is equivalent to the distorted current, thus eliminating the compensation current waveform (i_f), using the VSI switches. Suppose the nonlinear load current can be written as the sum of the fundamental current component ($i_{L, f}$) and the current harmonics ($i_{L, h}$) according to

$$iS=iL-if \quad (1)$$

$$iL = iLf + iLh \quad (2)$$

Then the injected compensation current by the shunt APF should be

$$if = iLh \quad (3)$$

The resulting source current is

$$iS = iL - iLf \quad (4)$$

This only contains the fundamental component of the nonlinear load current and thus free from harmonics. The injected shunt APF current completely cancels the current harmonics from the nonlinear load, resulting in a harmonic free source current. As a result, reduction in the voltage distortion occurs because the harmonic currents flowing through the source impedance are reduced. Shunt APFs have the advantage of carrying only the compensation current plus a small amount of active fundamental current supplied to compensate for system losses. It can also contribute to reactive power compensation.

A. Inverter control scheme

Harmonic and reactive current control is a critical technique in the conventional shunt Active Power Filter (APF) control. Recently years, another control scheme – the direct ac main current control is emerging, where the harmonic and reactive current detection module is no longer needed. [10],[11]. The proper conversion of the DC input power into an AC output current which has to be injected to the grid. This current has to exhibit low harmonic contents and must be in phase to the grid voltage in order to perform the power transfer at unity power factor. The maximum power

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extraction from the PV array by means of tracking the solar panels maximum power point (MPP) that varies with the solar irradiance and the PV panels' temperature.

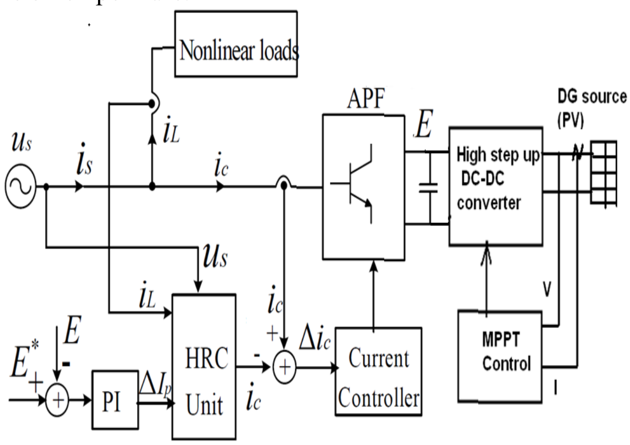

Fig.2 Proposed APF based on the Equivalence Principle

From Fig 2 an inverter is in parallel with a nonlinear load based on the direct current control scheme, where the dc capacitor's voltage E, is controlled by a PI regulator, the E* (E * > √| us |) is the preset of E, the *ΔIp* indicates the regulated quantity of the active current and *ic** indicates the APF current reference provided by the unit of calculating the harmonic and reactive currents (HRC) [8],[9].The APF current error, *Δic* , is used to control the PWM signals through a current controller. The mentioned control strategy above is the so-called conventional control scheme (CCS) of APF. In this paper, it is concluded that the two types of control schemes are equivalent for the current control for the shunt APF, and a new scheme based on the equivalent principle is presented and discussed. The inherent relations between the CCS and DCS are analyzed in details.[15],[16].A prototype was developed to demonstrate the performance of the proposed APF control scheme. Where *iL* , *is* and *ic* denotes the current of the nonlinear load, the ac main, and the APF respectively. The nonlinear load current, *iL* , consist of the fundamental frequency active current, *iLf* , and the harmonic and reactive current, *iLh* .These currents satisfy the equations as follows ,

$$isr = iL + icr \quad (5)$$
$$iL = iLf + iLh \quad (6)$$

$$icr = -iLh \quad (7)$$
$$isr = iLf \quad (8)$$

The harmonic and reactive currents of the nonlinear loads need to be detected and calculated firstly as the current reference of the APF in the conventional control scheme (CCS) mentioned above. If the order of Eqs.(7) and (8) are interchanged, however, that is, the ac main current *isr* is directly controlled to be equal to the *iLf* , then there are no need to detect and calculate the harmonic and reactive currents of the nonlinear loads. This is the so-called ac main current direct control scheme (DCS).

In the Equation (5)-(8), *icr* and *isr* are idealizations. In fact, however, the APF current also contains the switching current ripple which is inherent in the switch-mode converter—the actual APF. The actual currents can be expressed as

$$ic = icr + \Delta ic \quad (9)$$
$$is = isr + \Delta is \quad (10)$$

where *ic* is the actual output current of the APF, and Δ*ic* is the switching current ripple or error in *ic* , *is* is the actual main current, and Δ*is* is the switching current ripple or error in *is* . Fig.2 shows a shunt APF in parallel with a nonlinear load based on the CCS, where the dc capacitor's voltage, E, is controlled by a proportional–integral (PI) regulator, the *E** (* max *E* >| *us* |) is the preset of E, the Δ*Ip* indicates the regulated quantity of the active current to or from the APF, and * *ic* indicates the APF current reference provided by the unit of calculating the harmonic and reactive currents (HRC).
The APF current error, Δ*ic* , is used to control the PWM signals through a current controller.

$$\Delta ic = \Delta is \quad (11)$$

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If Eq. (11) is true, the current error, Δ*ic*, may be obtained by the use of Eq. (11), that is, Δ*is* can be used to replace the Δ*ic*.

III. MPPT SCHEME

MPPT or **Maximum Power Point Tracking** is algorithm that included in converter control used for extracting maximum available power from PV module under certain conditions. The voltage at which PV module can produce maximum power is called ‘maximum power point’ (or peak power voltage). Maximum power varies with solar radiation, ambient temperature and solar cell temperature. Typical PV module produces power with maximum power voltage of around 17 V when measured at a cell temperature of 25°C, it can drop to around 15 V on a very hot day and it can also rise to 18 V on a very cold day. The need for electrical tracking of the maximum power point in photovoltaic array, on their non linear I-v characteristics, is well known. Limited life span and high initial cost of the PV arrays make it all the more important to extract as much power from them as possible.

A. Constant voltage Method

Constant voltage method is based on the fact that the ratio of the MPP array voltage (Vmpp) to open circuit voltage (Voc) is nearly a constant (≈0.78), independent of any external conditions. The sensed PV array voltage is compared with a reference voltage to generate an error signal which, in turn, controls the modulation index, as shown in the flow chart Kobayashi et al have proposed a method on similar lines, where Voc is determined using a diode mounted at the back of the array (so that the same temperature as the array). A constant current fed into the diode and the resulting voltage across the diode is used as the array’s Voc which is then utilized in tracking Vmpp. This algorithm is the simplest MPPT control method. In some cases MPP fail means this method used to supplement an MPPT method and it does not require any computation process and the efficiency reach up to 95 %. The constant voltage method has simple implementation and will high tracking speed and reasonable accuracy. At low insulation conditions of PV panel the CV method is more efficient than other methods.

IV. SIMULATION DIAGRAMS

A. Simulation of Grid Connected Inverter

Simulation diagram of grid connected inverter with non linear load model is shown in Fig 4. The simulation results of grid current, load current, inverter output current and grid voltage is shown in Fig 5. From simulation results it is to be noted that the nature of source current becomes sinusoidal, which means the inverter is working in active filtering mode and simultaneously injects PV power to the grid. Hence the magnitude of the grid current is reduced to a considerable amount. Active power flow from the PV energy source to the grid and also performs the compensation of reactive power and the nonlinear load current harmonics. Keeping the grid current almost sinusoidal. The grid connected inverter can perform the functions of simultaneously Real power supplier and Active power filter or either one.

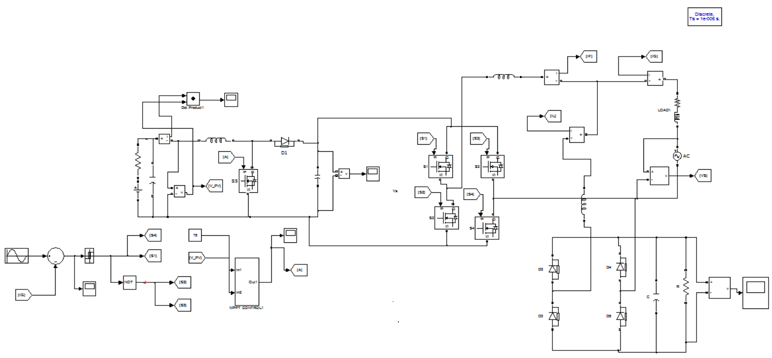

Fig. 3 Simulation Diagram of Grid connected Mode

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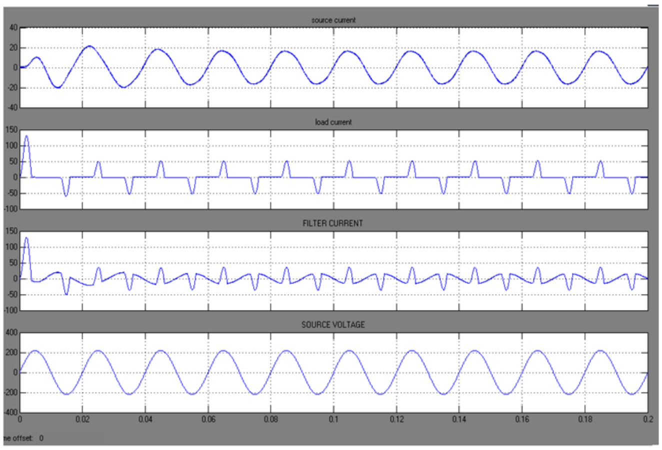

Fig.4 Inverter Simulation Result

The Utility Connected Inverter operate at grid connected mode in this mode the Total Harmonic Distortion of the grid current should be low ,and the Power Factor should be one. In this Fig. 6 shows the Total Harmonic Distortion Value at the time of connection of Nonlinear Load.

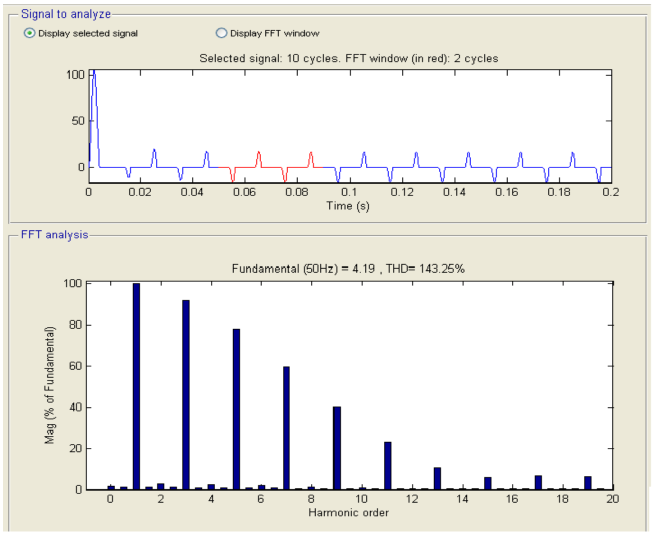

Fig .5 Harmonic Spectrum (Chart)

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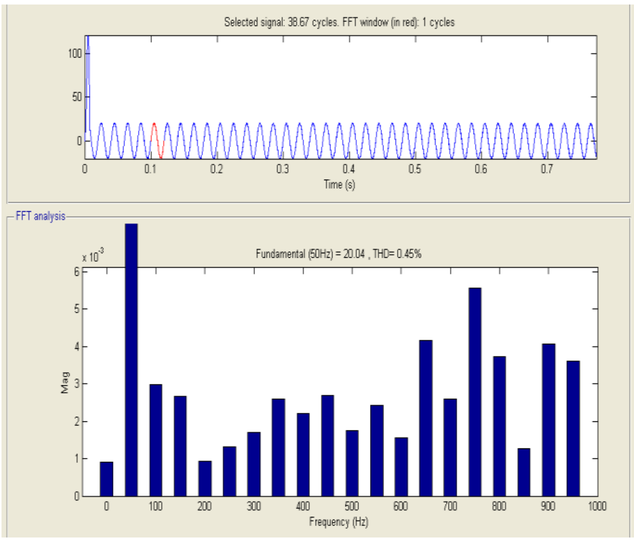

Fig .6 Harmonic Spectrum of Source Current

The simulation results of harmonic spectrum of source current after performing the inverter functioning as a filtering mode is shown **Fig 7**.It is to be noted that the inverter having better compensation characteristics in which harmonic contents is reduced from 143.25% without compensation to 0.47%.

B. Simulation of Mppt Converter

Simulation model of MPPT boost converter is represented in **Fig 8.** Simulation results of output current, output voltage and output power for 100 watts PV module specifications is shown in **Fig 9.**

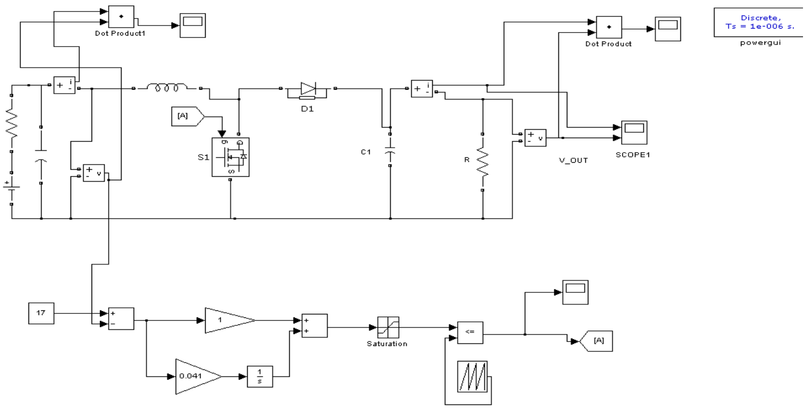

Fig. 7 Simulation Diagram of MPPT Converter

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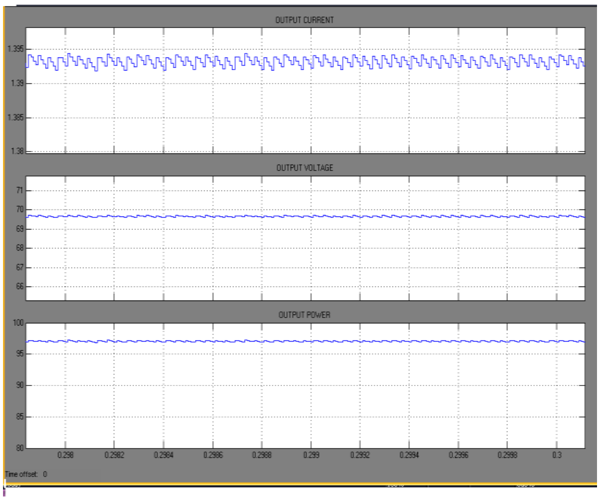

Fig.8 Simulation Output for MPPT Converter

V. CONCLUSION

This project has presented the development of a new variation of a single phase inverter topology controlled by DC bus voltage control. Firstly, the previous research works and related literatures are reviewed to give a better understanding of the related research area. This is followed by the theoretical analysis and design of the proposed grid connected inverter. Detailed description of the proposed current controlled inverter is provided to offer an overview of the operation principle and its overall control system. Computer aided simulations are carried out using MATLAB simulation package. Results obtained of with and without nonlinear loads are compared, analyzed and verified with the theoretical analysis. The harmonic filtering performance of the proposed grid connected inverter is validated by a detailed THD analysis. The analyzed results conclude that the proposed inverter improves the harmonic filtering performance of the grid system. The Total Harmonic Distortion obtained during operation of inverter functioning as filtering mode is 0.47%. It is to be noted that the inverter having better compensation characteristics in which harmonic contents is reduced from 143.25% without compensation to 0.47%. Furthermore, it is capable in handling the PV energy integration and harmonic filtering function simultaneously.

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