International Journal on Recent and Innovation Trends in Computing and Communication
Volume: 5 Issue: 7
ISSN: 2321-8169
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Enhancement of Power Quality in Grid Connected Photovoltaic System Using Predictive Current Control Technique

Neha Bhole,
SSBT'S COET Bhambhori, Jalgaon.
North Maharashtra University
bholeneha21@gmail.com

Dr. P. J. Shah
Professor of Electrical Engineering Dept.
SSBT'S COET Bhambhori, Jalgaon.
North Maharashtra University
pjshahj@yahoo.com

Abstract**—**Now- a days the increased use of power electronic devices has resulted in power quality problems such as voltage sag, swell, harmonics and voltage flicker. Non-linear loads affect system power quality. PV systems are grid connected via an interfacing converter. Single phase shunt active power filter (APF) can be used to develop the power quality in terms of current harmonic mitigation and reactive power compensation. In this paper a PV interfacing inverter which acts as a shunt an APF is controlled using predictive current control (PCC) technique for current harmonics mitigation. The MATLAB Simulink model is used to study the performance of system.

Keywords*-PV system, Power quality, Shunt APF, Predictive current control (PCC), Total harmonic distortion (THD).*

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1. Introduction

The power quality issues are obtained in power system and one of them is harmonics that influence to a great extent transformer overheating, rotary machine vibration, voltage quality degradation, damage of electric power components, and faulty medical facilities [1]. According to IEEE 519, harmonic voltage distortion on power system 69 kV and below is limited to 5.0% total harmonic distortion with each individual harmonic limited to 3%. The current harmonic limits vary based on the short circuit strength of the system they are being injected into. Essentially, the more the system is able to handle harmonic currents, the more the customer is allowed to inject. The goal of applying the harmonic limit specified in IEEE 519 is to prevent one customer. The intensive use of nonlinear loads, power quality improvement are important consideration and the limitations required by international standards according to IEEE519-1992[2].Those limitations were set to limit the disturbances and escape major problems in electrical power system. Since linear or non-linear single-phase loads are quickly increasing, zero sequence component and current harmonics are produced. This causes overheating of the associate distribution transformers that may lead to a system failure, especially in weak networks [3]-[5].

There is an increase in electric power demand in the world. The energy obtained from conventional sources such as coal is accompanied with environmental pollution. The fossil fuels are non-renewable. So the entire world is looking towards non-renewable sources of energy like solar PV systems, wind energy, tidal energy. These sources of energy are clean, free from environmental pollution and are renewable. These energy sources are used with distributed Generation (DG).There is also an increase in non-linear loads used in industrial and domestic applications. Non-linear loads affect system power quality such as voltage sag, voltage swell, current harmonics, and voltage flicker. Overheating of transformers, rotary machine vibrations, malfunctioning of electric power equipment's and medical facilities, saturations of distribution transformers are the effects of harmonics in system. In order to avoids these effects, the IEEE has imposed certain standards and limitations on the maximum allowable DC currents injected into the grid IEEE 519-1992. The harmonic current can be blocked by using a passive or APF [6]. Passive filter are used due to some advantages such as their simplicity, ease of maintenance and low cost. However, it has several drawbacks like the risk of series and parallel resonances, system impedance dependency and aging effect of the filter passive components. Generally, APFs sort out the classical problems of passive filters [7]. Shunt APF can be used to mitigate both of the line current harmonics and the neutral current in order to improve the system power quality and enhance the grid connection [8].The single-phase shunt APF uses a predictive current control technique to mitigate of the grid current harmonics as well as improve the power factor.

The suggested control strategy provides a multifunction with a simple controller incorporating phase locked loop independency, less sensors, ease of practical implementation, and reduced system size and cost. This paper discusses the predictive current control technique of inverter current control to mitigate current harmonics and improve power factor. The MATLAB SIMULINK modelis used to study the performance of the system.

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2. System Descriptions

There are two configurations to connect the PV system to the grid; two stage and single stage PV system. A conventional two stage system has a DC-DC converter directly coupled with PV array and grid connected inverter. A single stage PV system consists of a DC-AC inverter whose control is complex. In spite of having complex control a single stage system is more efficient and cheaper as compared to a two stage system.In this paper, a single stage system is used. In this system, the inverter is controlled using a predictive current control technique for current harmonics mitigation. For connection PV system to the grid, there are three commonly used grid interactive PV systems; the centralized inverter system, the string inverter system and the AC module / the Module Integrated Converter (MIC) system. Among these, the MIC system offers "plug and play" concept as well as significantly optimizes the energy yield. Also the MIC idea has become the trend for the future PV system development but challenges remain in terms of cost, reliability and stability for the grid connection. Usually single-phase shunt APF usages an inverter for harmonics elimination as well as reactivepower compensation [9]-[10].A grid connected PV systemwith active power filtering feature has been presented in [11]-[13].The single-phase shunt active power filter (APF) uses a predictive control technique to mitigate of the grid current harmonics and improve the power factor. However, measuring the load current is mandatory. Figure 1 shows general block diagram of grid connected PV unit.

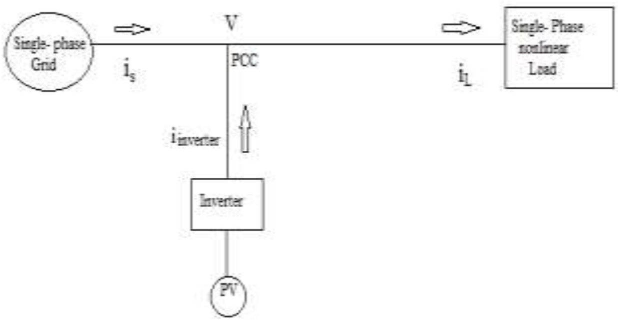

Figure 1 General block diagram of grid connected PV unit

Figure 2 shows the single phase single stage grid connected system with control signals. It consists of PV array, inverter, PWM, inverter control, nonlinear load and grid.

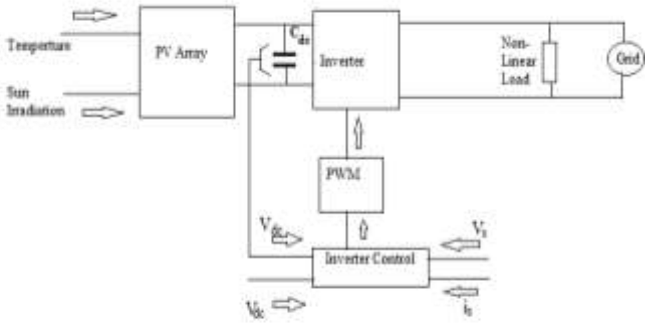

Figure 2 Overall systems modeling with control signal

3. Controller Design

The projected system shown in figure 3 consists of PV array, DC-link capacitor, and a multifunctional inverter connected at the point of common coupling to a single-phase grid through the interface inductances. The compensator reference current is calculated from the sensed grid current drawn by nonlinear and single-phase loads connected to the grid. The reference current is calculated by using capacitor voltage control. The compensation objective is to compensate for load current harmonics, reactive power compensation and to control the DC bus during bidirectional active power exchange between the DC side load or source and the power system grid. The controller is used to obtain the predicted voltage at the $(K+1)^{th}$instant. This predicted voltage is compared with repeating sequence to generate the gate pulses for the inverter. The proposed control system is shown in figure 3. The multifunctional inverter is controlled with a predictive control scheme. It needs the measurement of the grid voltage and grid current at PCC and the inverter DC-link voltage. The measurement of the load current and the injected inverter current are not essential. The inverter reference current is removed using DC-link capacitor voltage control method.The DC-link voltage, V_{dc} are subtracted from the reference voltage V_{dc}^{*}. A *PI*-controller acts on the resultant error. The DC-link voltage is maintained constant and the power balance between the grid, inverter, and the load is achieved as the capacitors compensate instantaneously the difference between the grid and the load power.

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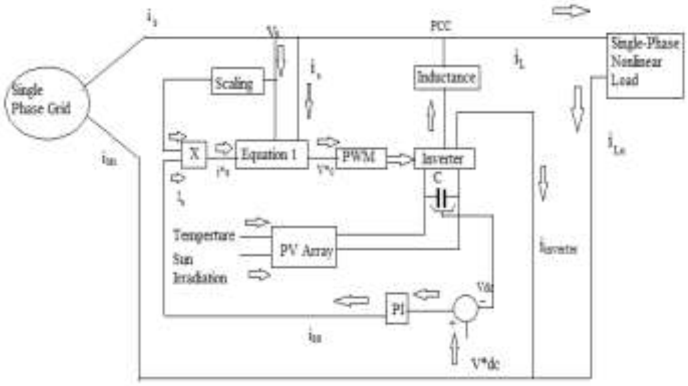

Figure 3 Block diagram of proposed control system

The predicted controller voltage in terms of reference current, measured grid current is given by

$$V_C^*(K+1) = L_i\left(\frac{i_s(K)-i_s^*(K)}{T_s}\right)V_g(K)\ (1)$$

Where, L_i is the interfacing inductance, T_s is sampling time, $i_s^*(K)$ and $i_s(K)$ are the sinusoidal reference and the measured grid current at sampling instant k and V_g is the grid voltage.

3.1 Input Voltage

For a single phase full bridge inverter output voltage is

given by,

$$v_o = \frac{2\sqrt{2}}{n\pi}v_{dc}\ (2)$$

Where, v_{dc} is inverter input voltage, n is order of harmonics and v_o is the *r.m.s* output voltage of inverter

3.2 Generation of Reference Current

The output of PV array is compared with reference of 420V. The reference signal is given to PI controller which reduces steady state error. The output of PI controller multiplied with sinusoidal signal gives the reference current for the controller i_r(k).The *p.u* sine wave is given by

$$V=1*\sin(w*t) \quad (3)$$

$$i_r(k) = e*V \quad (4)$$

Where, e is the output of PI controller.

3.3 Generation of Voltage

The reference current obtained is compared with current measured from the grid. The signal obtained is scaled by a factor $\frac{L_i}{T_s}$ and added to the measured grid voltage $v_g(k)$.The resulting signal is the predicted voltage which is compared with repeating sequence to obtain pulses for the gate circuit of inverter.

4. Performance Analysis of the Proposed System

The analysis of the proposed system shown in figure 2 is simulated using a MATLAB Simulink model. The system factors are listed in table 1.

Table1: The System Factors

Symbol	Quantity	Values
F	Line frequency	50Hz
V_{dc}^*	DC reference voltage	420V
V_s	Grid voltage in RMS	220V
C	PV module capacitor	4700μF
T_c	Atmospheric Temperature	25ºC
L_s	Grid tied inductor	3.2mH
C_{dc}	DC bus Capacitor	5 μF
R_i	Resistance of inverter	0.05 Ω
L_i	Inductance of inverter	3.2mH

The controller is modeled using MATLAB Simulink for inverter which is connected to grid and nonlinear loads.In this paper a single phase 50 Hz full bridge inverter is connected to grid and to nonlinear loads .For different nonlinear loads, the currents injected into the grid have THD less than 5% which is according to IEEE standards. The grid current THD is compared before and after compensation. The APF increases the THD from 3.1% to 3.2% which obey with the IEEE Std. 519-1992.The grid current THD is measured for different nonlinear loads. Table 2 shows grid current THD for different nonlinear loads.

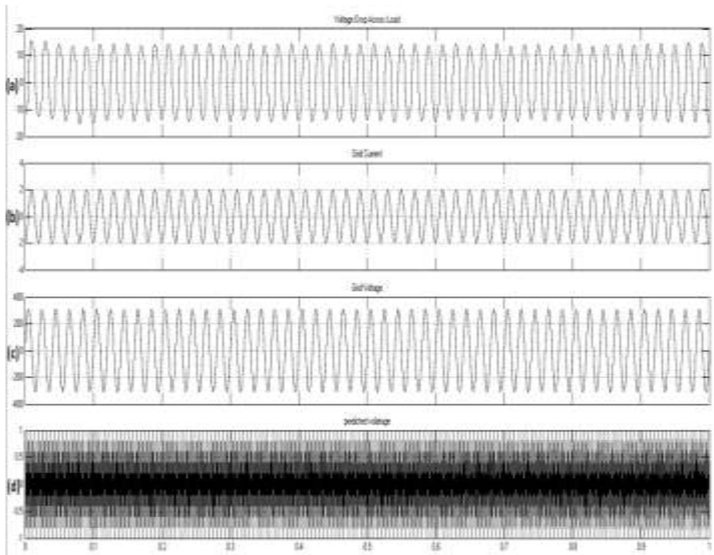

Figure 5 Simulation results: (a) Voltage drop across load, (b) Grid current, (c) Grid voltage, (d) Predicted voltage.

Fast Fourier Transform (FFT) Analysis:

The FFT analysis of grid current waveform for load of impedance is 5+j 3.14 Ω and having 0.45% THD. Figure 6 shows the FFT analysis of grid Current waveform.

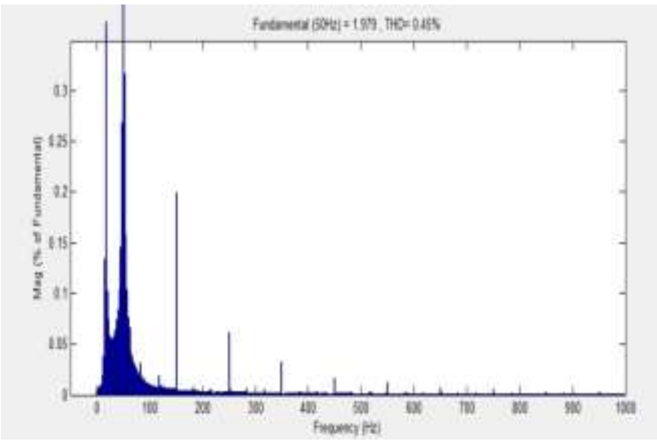

Figure 6 FFT analysis

Table 2: Grid current THD for different nonlinear load

Sr. No.	R(Ω)	L(mH)	THD (%)
1	90	50	4.451
2	80	60	4.262
3	70	40	4.033
4	25	30	3.877
5	50	30	3.918
6	30	13	3.731
7	20	5	3.742
8	10	10	3.768

5. Conclusion

In this paper, a PV system is interfaced to the grid via a multifunctional interfacing inverter. A simple Predictive current control method is used. Predictive controller gives better performance while the mathematical model is accurate, linear and time invariant. The system performance is investigated using MATLAB /Simulink model at different case of load variation. The inverter achieves function of supplying the available power from the PV unit into the loads in addition to improving the power quality in terms of grid current THD and power factor. Hence enhance power quality in grid connected PV system with current harmonic mitigation and reactive power compensation.

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