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RESEARCH ARTICLE OPEN ACCESS

Design and Implementation of Proportional Resonant Controller for Power Inverters

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ABSTRACT.
This paper provides a design procedure of single-phase inverter with LC filter and the inverter load current is regulated by Proportional-resonant controller. The Proportional-resonant controller provides an effective control of single-phase inverter suitable for various Distributed Generation systems i.e grid connected and stand-alone systems. The performance study is based on frequency response and the model is simulated in MATLAB/ SIMULINK environment which provides better stability, improved load current regulation with low THD value prescribed in the IEEE standards. The prototype model is also fabricated with Atmega328 processor and performance are satisfied.

Keywords: PV inverter, LC filter, PR controller, APF,THD.

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I. INTRODUCTION

Inverter is one of the main power conditioning devices in the integration of renewable energy, other distributed energy sources. Voltage source converter is the basic component in power quality improvement to filter out the harmonics i.e Active Power filters and Facts devices. The power conversion from DC to AC with good power quality is from an Inverter. As a consequence, power converters for renewable energy sources are becoming increasingly common. It's vital to produce clean and green energy. It is important to sustain the inverter output and the proposed system is designed with an LC filter to filter out high frequency components. [1] The various control techniques to control the PV inverters to provide high quality of output current and voltage connected to a linear or non-linear load are hysteresis current controller, Predictive Current controller, Proportional Integral (PI) controller and Proportional Resonant (PR) controller [2]. The effect of harmonics such as power losses, decay of quality power reduces the equipment life and failure of components. In a grid-connected application, for example, the power converter must follow many typical grid parameters, including voltage, current, frequency, harmonics, power factor, and flicker.

Based on literature the hysteresis controller is simple, unconditional stability and good accuracy with comprehensive band harmonic spectrum. The predictive controller force the measured current to track the reference current . The famous conventional controller PI controller produces steady state error while tracking the sinusoidal reference due to dynamic integral term[3]. The proposed PR controller provides zero steady state error, high gain in wide range of frequency response with fast tracking of specified references and with low value of %THD. The block diagram of single-phase inverter with PR controller is shown in Fig:1.

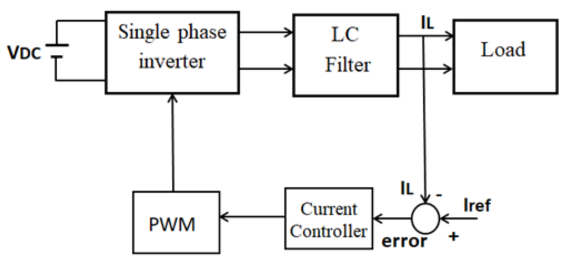

Fig.1 Closed loop Block diagram of single-phase inverter

II. DESIGN PROCEDURE OF THE SYSTEM

From Fig:1 the system input is 400V DC and it is converted to 230V AC by a single phase inverter circuit. DC components are filtered out by LC filter and the ripple free signal is fed to the load.The filter output is maintained by developing a closed loop system with a current controller. The controller compares the actual load current and the reference current and the error signal is modulated [10] with the help of proposed PR controller. From the PR controller output unipolar PWM pulses are generated to trigger the power semiconductor switches of the inverter. The step by step design procedure of each block is as follows:

Step 1: Design of single-phase Inverter

The design parameters of 2KW, 230V, 50Hz single-phase inverter is charted in Table:1.Four IGBT switches with a switching frequency of 10KHz.

Table:1 Design parameters of the proposed model

Description	Parameters	Values
Input DC Voltage	V_{in}	400V
Output AC Voltage	V_o	230V
Supply Frequency	f_o	50Hz
Output Power	P_o	2KW
Switching Frequency	F_s	10KHz
Voltage THD	THD_V in %	<5%
Ripple Current	I_{rip} in %	<20%

Step 2: Design of LC filter

a) Inductor L:

The voltage across the inductor is given by eq.1 and the potential difference between the inductor is defined by eq.2 and shown in Fig.2.Inductor ripple current is calculated by using eq.3 [7] and the maximum ripple current is derived by differentiating ΔI_{pp} with respect to time and equate it to zero , the obtained result is eq.4.

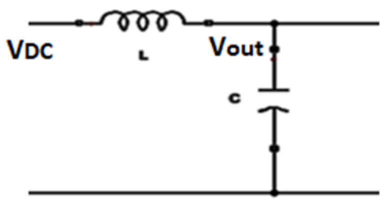

Fig.2 LC filter

$$V = Li\frac{di}{dt} \quad (1)$$

$$Vdc - Vout = Li\,\frac{\Delta Ipp}{DT_s} \quad (2)$$

$$\Delta I_{pp} = \frac{DT_{s(\,Vdc-Vout)}}{L_i} \quad (3)$$

$$\Delta I_{pp} = \frac{Vdc*T_s}{4*L_i} \quad (4)$$

The duty cycle is calculated by eq.5 where ma is the modulation Index and output voltage is calculated as per eq.6 and eq.7. Inductor current is calculated as per eq.9.

$$D(\omega t) = ma * \sin(\omega t) \quad (5)$$

$$Vo = Vdc * D \quad (6)$$

$$Vo = Vdc * m_a * \sin(\omega t) \quad (7)$$

$$L_i = \frac{Vdc}{4*f_{sw}*\Delta I_{pp\,max}} \quad (8)$$

Therefore by substituting the values in eq.8

$$L_i = \frac{400}{4*10000*8.7*\sqrt{2}*0.2} \quad (9)$$

$$L_i = 4.06mH \quad (10)$$

$$Iout = \frac{KW}{Vout} = \frac{2000}{230} = 8.7A \quad (11)$$

From the above design the value of inductor is calculated as 4.06mH shown in eq.9 and the current through the inductor is 8.7A given in eq.11.

b) Capacitor C:

The cut-off frequency is calculated using eq.10 and it is 10% of switching frequency as shown eq.11. The capacitor value is found out using eq.12, the values are substituted in eq.13 and as per the design the value of capacitor is calculated as 6.23 µF.

$$Fc = \frac{1}{2\Pi\sqrt{LC}} \quad (10)$$

$$Fc <= \frac{f_{sw}}{10} \quad (11)$$

$$C = \left(\frac{10}{2\Pi f_{sw}}\right)^{\wedge} 2 * \left(\frac{1}{L_i}\right) \quad (12)$$

$$C = \left(\frac{10}{2*\Pi*1000}\right)^{\wedge} 2 * \left(\frac{1}{4{,}06*10^{-3}}\right) \quad (13)$$

$$C = 6.23\mu F$$

Step 3: Design of PR controller:

The general block diagram of PR controller is shown in Fig:3 The ideal and non-ideal PR controller in s-domain is represented in eq.14 and eq.15 respectively . The ideal PR controller suffers from stability problem and sudden phase shift and these are eliminated by non-ideal PR controller [3].

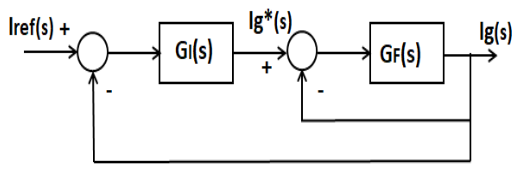

Fig.3 Block diagram of non-ideal PR controller

where Kp = Proportional Gain
Ki = Integral Gain
$\omega_0 = 2\Pi fo$ = Resonant frequency
ωc = Cut-off frequency

The performance of system dynamic can be improved by proper tuning of gain .By including the harmonic compensator the selected harmonics i.e lower order harmonics are eliminated.

a) Voltage controller:

The voltage controller is designed by considering the Controller time constant as 200µs, filter capacitance of 6.23µF and Capacitor ESR =0.0042 ohm. The proportiona

gain value is estimated as 0.003115 given by eq.15

$$Kp = \frac{\text{Capacitance}}{\text{Time Constant}} \quad (15)$$

$$Kp = 0.03115 \quad (16)$$

b) Current Controller:

For current controller design, let us consider the controller time constant as 150µs, filter Inductor as 4.06mH and Inductor series resistance as

a) Resonant gain Kr:

The general transfer function of resonant gain is given by eq.18

$$Gn = \frac{K_r \omega_n}{\omega_n 2 - \omega^2} \quad (18)$$

Where $\omega_n = \frac{1}{\sqrt{LC}}$ and $\omega = 2 * \Pi * f$,
let the value of Gn is 0.1 and Kr for voltage controller is 100

$$\frac{\omega^2}{K_r} = \frac{2*\Pi*50^2}{100} \quad (19)$$

$$\frac{\omega^2}{K_r} = 986.83 \quad (20)$$

Let Kr for current controller is 400

$$\frac{\omega^2}{K_r} = \frac{2*\Pi*50^2}{400} \quad (21)$$

$$\frac{\omega^2}{K_r} = 246.7$$

Thus the inverter, filter and controller parameters are calculated as per the specifications.

III. SIMULATION AND RESULT

The single-phase inverter with PR controller is modeled and simulated as per the design calculation. The inverter power switches are triggered by unipolar PWM pulses generated by the PR controller block. The system is demonstrated in MATLAB Simulink as per the proposed design shown in Fig.4. and the various

system parameters are observed as shown below. The Unipolar PWM pulses are generated to operate the four switches i.e SW1, SW2, SW3 and SW4 by comparing the actual inverter output voltage and reference voltage shown in Fig.5.

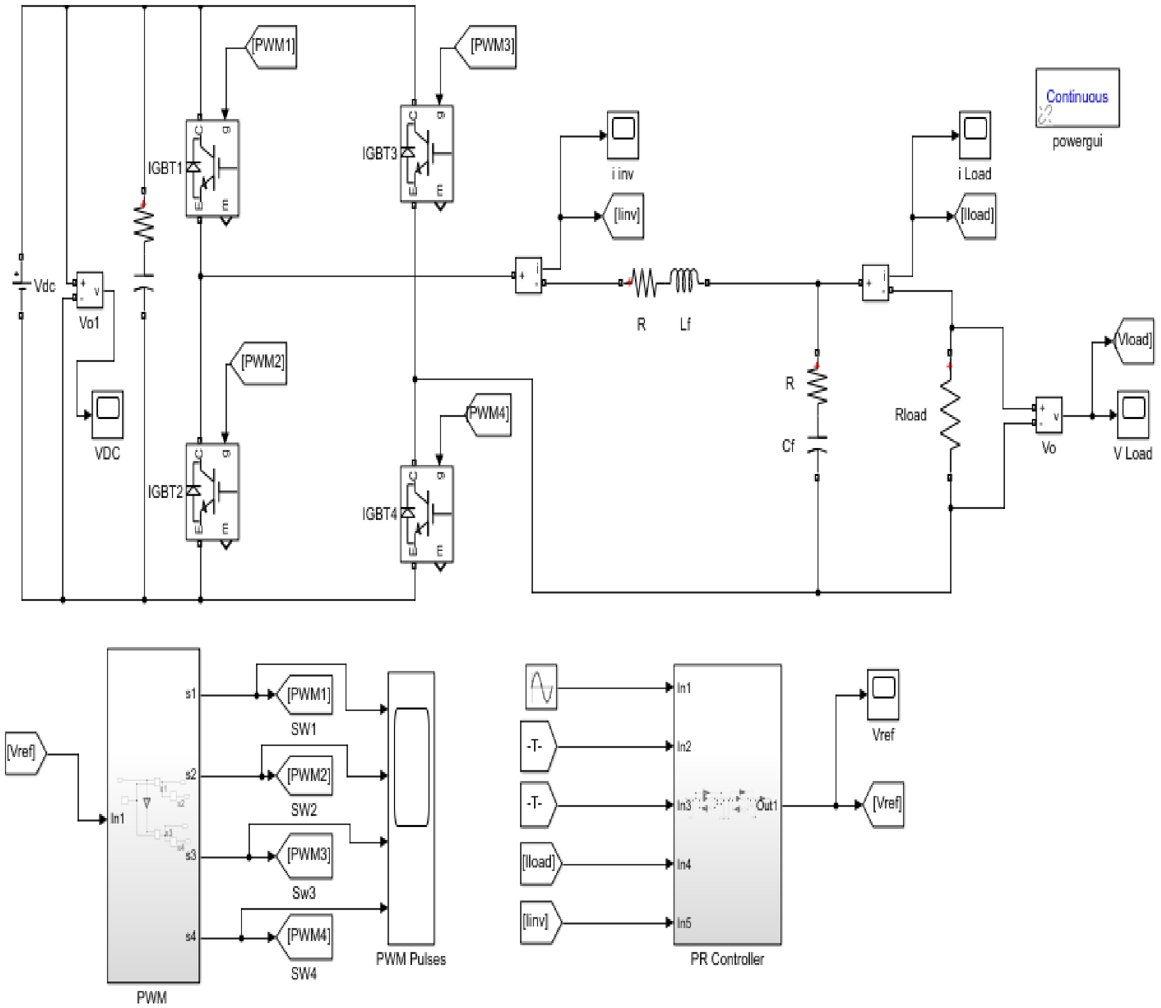

Fig:4 simulation model of power inverter with PR controller

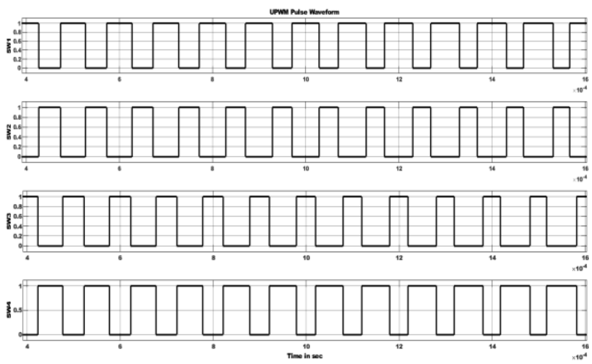

Fig.5. UPWM pulse of inverter

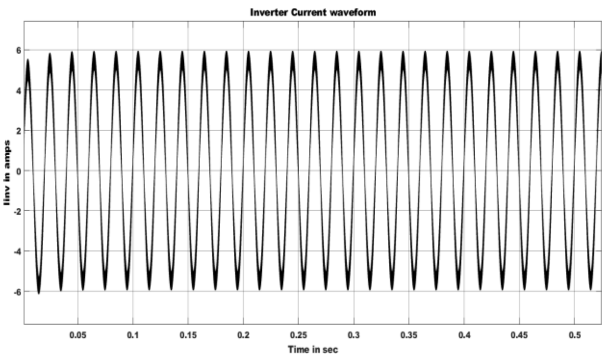

Fig.6. Inverter current waveform of inverter

The inverter current waveform and the load current waveform as per design are traced as shown in Fig.6 and Fig.7 respectively.

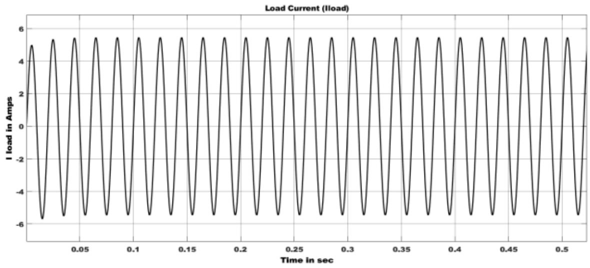

Fig.7 Load current waveform of inverter

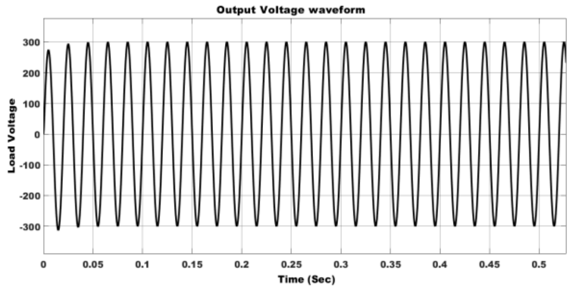

Fig.8. Output Voltage waveform of Inverter

The output voltage is witnessed across the load resistance as shown in Fig.8.By proper design of PR controller the specified output load voltage of 230V is maintained for variation input and as well as variation in load .The input,output waveforms are traced for V_{DC} = 400V & 380Vas shown below in Fig.9 and Fig.10.

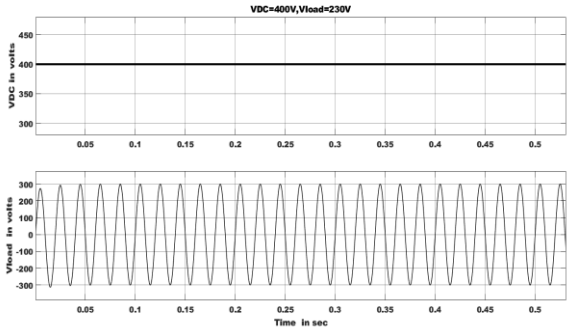

Fig.9. Output Voltage waveform of Inverter V_{DC} = 400V

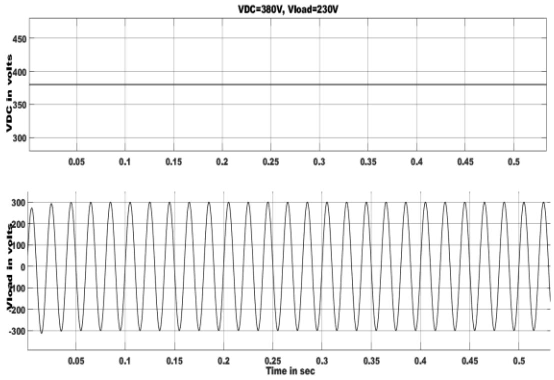

Fig.10. Output Voltage waveform of Inverter V_{DC}=380V

The Fig:11 shows the Frequency spectrum of load voltage for the rated supply frequency 50HZ is 300 and the Total Harmonic Distortion is very much reduced to

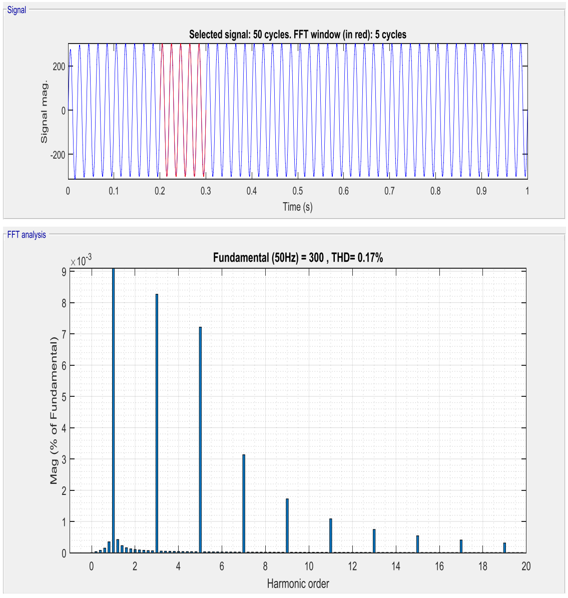

Fig.11. Frequency Spectrum of load voltage

0.17% compared to the conventional PI controller [4][[5].

IV. EXPERIMENTAL RESULTS

Fig:12 Prototype model of single phase inverter with arduino-ATMEGA 328 based PR controller

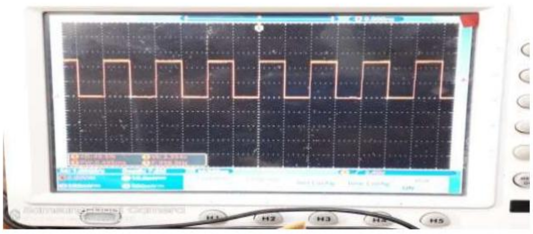

Fig:13 UPWM pulse waveform

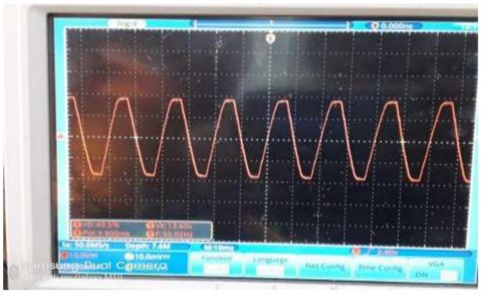

Fig 14: Output Voltage Waveform of Inverter with PR controller

The Fig:12 shows the experimental proto type model of single phase inverter with ardunio based PR controller. In the experimental setup the PR controller is implemented using Arduino IDE wit ATMEGA-328 microcontroller with to generate the pulse signal to the power inverter switches. Fig:13 and Fig:14 shows the UPWM pulse waveform and Inverter output voltage for load variations measured from experimental setup. The performance is verified using the design values and it is satisfied.

V. CONCLUSION

Thus the single-phase inverter is designed and implemented with proportional-Resonant controller. The performance of inverter is improved compared with the PI controller. The designed inverter topology is suitable for a PV based generation with grid connected system and stand-alone applications. This Power inverter with PR controller design is suitable for Active Power Filter to mitigation of harmonics generated by a non-linear load. It is concluded that from FFT analysis of load voltage, the THD value is 0.17% .This shows the performance of PR controller is better than the PI controller[6]-[8]. Based on the design procedure the experimental set is fabricated and the triggering pulses are generated using ATega328 and the performance is satisfied.

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