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Two Level Voltage Source Grid Connected Inverter for Solar Photovoltaic System

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Abstract

In the recent years, the demand for the grid connected inverters has increased immensely as they act as an interface between the photo voltaic systems and the utility. The focus of this research article is to model and analyze the design characteristics of a two level, pulse width modulated, grid connected inverter using Matlab. The Proportional Integral and Proportional Resonant controller are being investigated and the performance of these controllers is being discussed. These simulation results show that the proportional resonant controller is able to mitigate the harmonics and perform satisfactory as compared to Proportional integral controller under the same harmonic conditions.

Keywords: *Control Design, Grid Connected Inverter, LCL filter, Pi Control, Proportional Control*

1. Introduction

In the modern world, the industrial development plays an important role in the development of every country. The industrial development in turn depends on a reliable electricity supply. The increasing worldwide demand for energy increased the concerns of the different countries regarding their energy security. Due to this, the focus is now shifting on the diversification, generation and efficient allocation of the energy sources. Solar Photo Voltaic (PV) has been a major portion in the energy mix of European nations for over a decade. Italy, Greece and Germany meets more than 5 percent of the annual electricity generated by solar PV but most of the European countries have reached their peaks for the production of the solar PV. Asian countries on the other hand have started investing in solar PV. A total of 36.9 GW of solar capacity of the whole world was added in 2013 in which china's share was 31 percent[1].

The current quality fed to the utility from the Photo Voltaic Systems (PVS) mainly depends upon the Current Controller employed in the Grid Connected Iinverters (GCIs). Therefore; it is essential that output current is free from any harmonics and distortions from the Current Controller. The two commonly used CCs that are used in PVS are Proportional Integral (PI) controller and Proportional Resonant (PR) controller. A comparison between the PI controllers and PR controllers has been done comprehensively in [2]**.** The aim of using all these control techniques and structures is to ensure better disturbance rejection and to raise outer loop gain. But drawback of using these controllers is that they offer low loop gain at the fundamental frequency and its harmonics. Furthermore, their disturbance rejection capability is also poor due to which THD of output current is also poor and contradicts with standards and limits. So

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there is a need of a suitable controller which is able to provide high gain at fundamental and other frequencies of choice. To gain high loop gain and better harmonic rejection at fundamental and other harmonics.

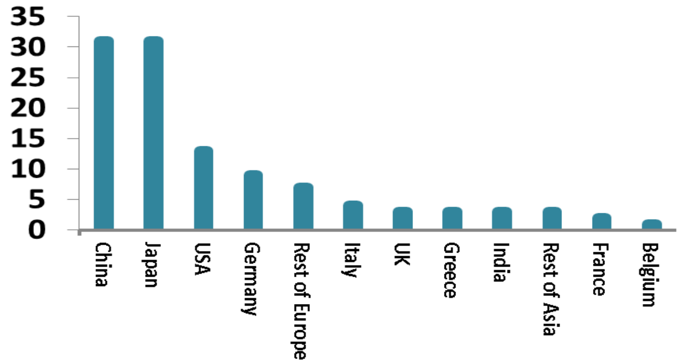

Figure 1. Percentage Share of PV Installations in 2013

The main objective of this article is to design a grid connected PVS and investigates the performance of PI Current Controller and PR Current Controller by simulating the linearized single phase system in Matlab. The performance of both Current Controllers is analyzed and compared using the axioms of control theory.

2. System Configuration and Mathematical Modeling of the Grid Connected System

The system values that are used for the *Matlab* simulation are given in the Table I. The control system forms an integral part of the PVS[3, 6]. The control of the renewable energy system has two main parts. The grid side control and the input power control. The grid side control mainly handles the power flow and its control from the grid side. It may include control of active and reactive power, synchronizing the grid and quality of the power. The input power control ensures that maximum power is extracted from the renewable energy systems, keeping in view the safety and reliability of the whole system.

The control scheme that is applied to control the converter of the grid side in the renewable energy systems has two interlinked control loop. The inner current loop has a faster response and it controls the grid current. It is the main loop for the quality of power that is fed to the utility. It also ensures the protection of the equipment by controlling the current. The external voltage loop is responsible for controlling the voltage across the capacitor that serves as the D.C. link.

Inherently system will be unstable if the output grid current of an LCL filter is directly feed backed, so to stabilize the system, there must be an additional feedback loop. Additional feedback can be provided either by the main inductor current or by capacitor current[7].

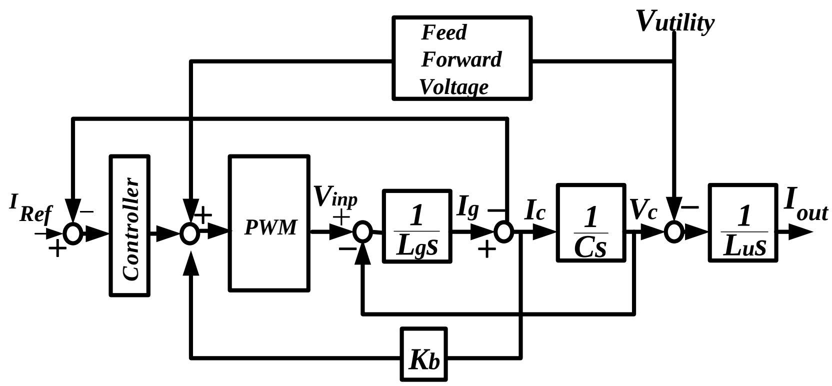

Figure 2. Control Structure of the Grid Connected Inverter

Table 1. Component Values of the Grid Connected System

Sr. No.	Electrical Parameter	Symbol	Value
1	Peak Voltage of the Grid	V_{peak}	230 V *(rms)*
2	DC link voltage	V_{dc}	800Vdc
3	Grid inductor	L_g	350μH
4	Utility inductor	L_u	50μH
5	Capacitor	C_s	22.5μF
6	Switching frequency	f_s	10kHz
7	Grid Frequency	f_g	50Hz
8	Output Current	I_{out}	50A

If gain for PWM block is assumed to be unity then the relationship between output current and reference input current is given by the following transfer function;

$$I_{out} = \frac{Gz(s)}{1+Gz(s)} I_{ref} - \frac{G_{plant}(s)}{1+Gz(s)} \text{Vutility} \tag{1}$$

$$Gz(s) = G_{plant}(s) * G_{controller}(s) \tag{2}$$

$$G_{plant}(s) = \frac{1}{(LgL_uCs)s^3 + (K_bL_uCs)s^2 + (L_g + L_u)s} \tag{3}$$

To make the system more realizable and closer to real time scenarios a disturbance function can be introduced which is given by the following equation as

$$\text{Disturbance}(s) = V_{utility}(L_g Cs^2 + K_c Cs + 0.5) \quad (4)$$

2.1. Filter Design

The main aim of the filter in GCI connected on the utility side is to protect the components of the inverter due to the disturbances coming from the utility. It also prevents unwanted harmonics and distortions from entering the utility.

There are different filters that can be used in GCI. The most common configurations are L type filter, LC type filter, LCL type filter and LCCL type filter [8, 13]. The selection criteria depends upon the topology configuration, the purpose of the inverter and the system performance requirements. Each type of filter has its own advantages and disadvantages associated with it for example, L type filters are bulky due to heavier inductor used in them and they are costly too.LC is another type of filter which is also commonly used. It is more compact in size as compared to the L filter. However, the impedance mismatching of LC filter causes degradation in its performance resulting in its inability to remove the harmonics along with the stability issues.

The LCL filter addresses the issues due to the LC filter and provides flexibility along with better results in robust conditions. It is therefore critically important to design and select the proper type of filter. The resonant frequency of the LCL filter is given by the following equation.

To reduce the resonance damping can be accomplished by either active means or passive means. Mostly, a resistor is connected in series with the capacitor that accomplishes the damping and also increases the stability of the system.

An active damping system is used for the control system as shown in Figure. 3. The current of the capacitor along with the loop gain (inner) K_b provides the necessary damping and stability to the system.

2.2. Controller Designs

Proportional integral controllers are used with the dq control as they have shown good performance in these systems. The transfer function of the proportional integral controllers for a three phase system is given by equation 6.

The implementation of Proportional Resonant controller becomes easier because it is in stationary frame and it could be implemented by three controllers. Only two controllers are required if the three phase circuit has an isolated neutral. The complexity of the controller is much less as compared to PI controllers. The transfer function of the Proportional Resonant controller for the three phase system is given by euation

$$G_{PI}(s) = \begin{pmatrix} K_p + \frac{K_i}{s} & 0 \\ 0 & K_p + \frac{K_i}{s} \end{pmatrix} \quad (6)$$

Where

K_p = Proportional Gain of the PI Controller

K_i =Integral Gain of the PI Controller

$$G_{PR}(s)=\begin{pmatrix} K_p+\frac{K_i s}{s^2+w^2} & 0 & 0 \\ 0 & K_p+\frac{K_i s}{s^2+w^2} & 0 \\ 0 & 0 & K_p+\frac{K_i s}{s^2+w^2} \end{pmatrix} \quad (7)$$

K_p = Proportional Gain of the PI Controller

K_i =Integral Gain of the PI Controller

w = Resonant frequency

The ideal resonant controller has no phase shift and gives an infinite gain at the resonant frequency as shown in the bode plot of ideal proportional resonant controller in Figure. 4. This gain helps to nullify the steady state error. The proportional gain determines the phase margin, gain margin and dynamics of the systems.

The infinite gain of the ideal Proportional Resonant (PR) controller gives rise to the stability problems. Also, it leads to an ideal quality of the GCI which is non-realizable in real time situations. For this purpose a modified PR controller is used whose gain is a finite value thus mitigating the stability problems.

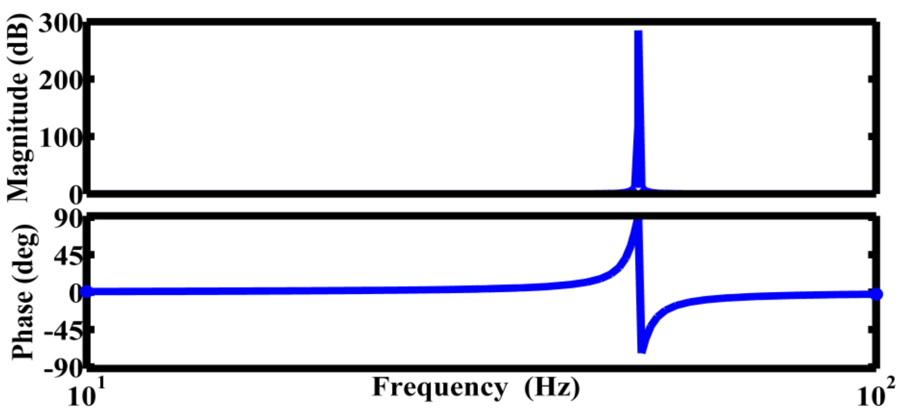

Figure 3. Bode diagram of the Ideal Proportional Resonant Controller with K_p=1 K_i=10 w=314 rad sec^{-1}

The modified PR controller can also be adjusted to make it less susceptible to the frequency changes in the utility. The transfer function of the modified PR controller is given by

$$G_{PR(modified)}(s)=K_p+\frac{K_i\, s}{s^2+2\zeta ws+w^2} \quad (8)$$

The inclusion of damping term has two benefits. It decreases the infinite gain at the fundamental frequency to a realizable finite value and also improves the bandwidth of the modified PR controller. The bode plot for the modified PR controller is shown in Figure 5.

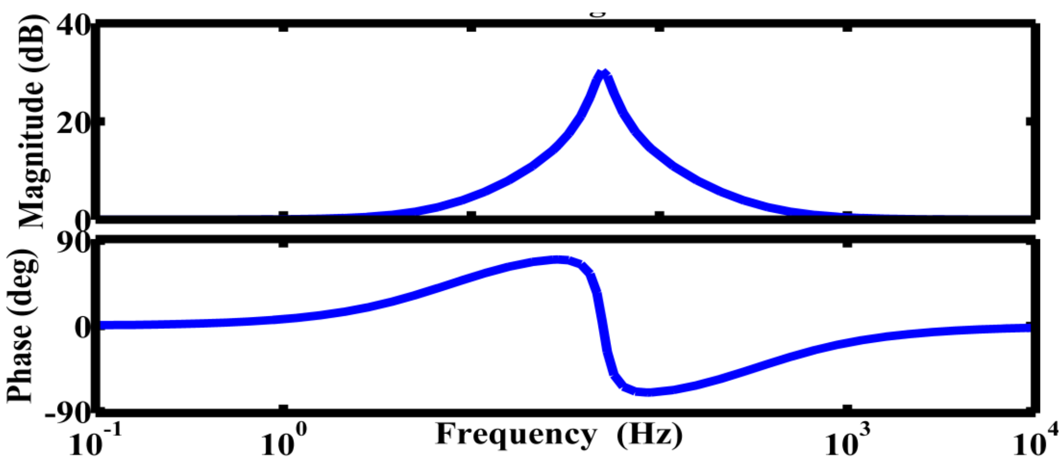

Figure 4. Bode diagram of the Modified Proportional Resonant Controller K_i =10 ζ =0.01 ws =10 rad sec^{-1} w =314 rad sec^{-1}

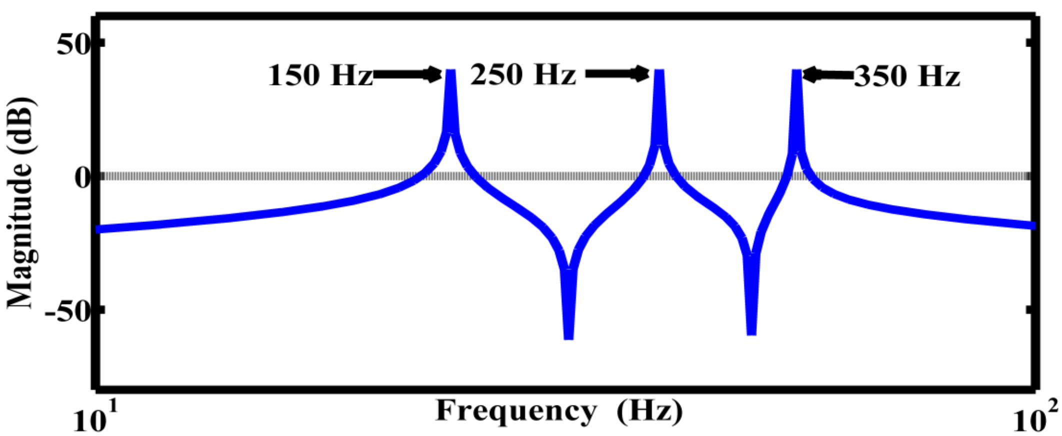

Figure 5. Proportional Resonant Controller Gains at Harmonic Frequencies K_i =10 ζ =0.01 ws =10 rad sec^{-1} w =314 rad sec^{1}

3. Simulation Results

Simulations were carried using Matlab/Simulink. The LCL filter was designed using the procedures of [14, 7] such that the maximum ripple current and the reactive power produced are within the acceptable limits.

The PI controller was designed using Matlab/Simulink. Figure. 7 shows the Fast Fourier Transform (FFT) analysis of the PI controller when the THD of 2.74% was introduced in the utility voltage. The THD values in the output were found to be 8.05%.

Though it was able to reduce the THD values, but it failed the ANSI-IEEE recommended THD values which is 5 %. The odd harmonic at 250 Hz was the highest harmonic that the PI controller failed to suppress. The THD value of the PI controller is 8.05 %. The odd harmonics of 3rd, 5th and 7th harmonic values were found to be 4.1 %, 4.8% and 1.58% respectively.

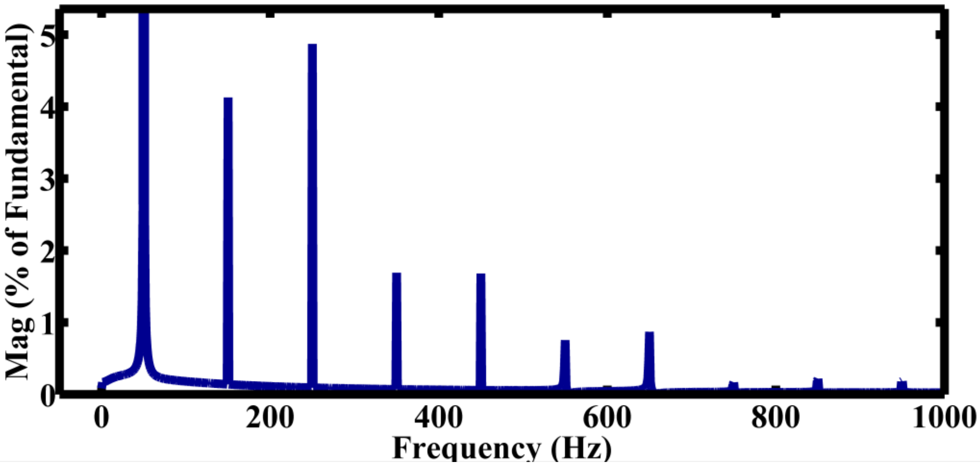

Figure 6. Fast Fourier Transform Analysis from PI Controller

The 3rd, 5th and 7th harmonics of a PR controller is less than the PI controller. The THD value of PR was 4.96%. The 3rd harmonic was 1.7 %, whereas 5th and 7th harmonic values were 3.5 % and 1.6 % respectively. These simulation results were encouraging and additional harmonic compensation could be used to produce better results.

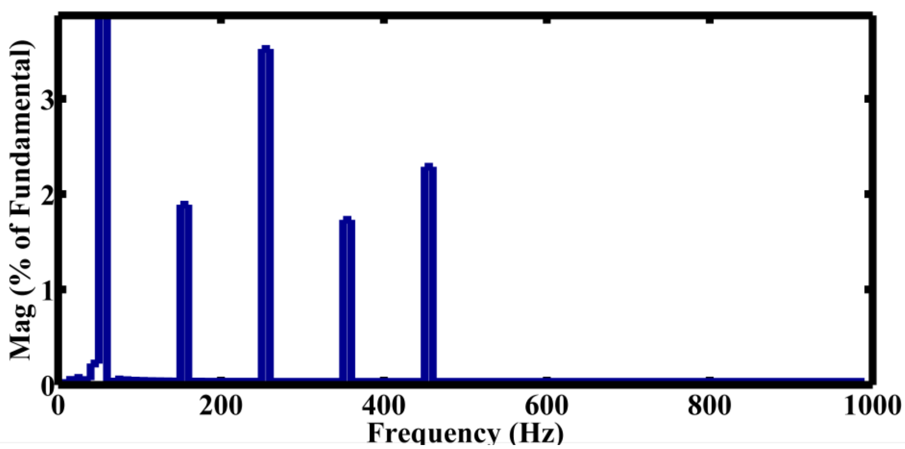

Figure 5. Fast Fourier Transform Analysis from Proportional Resonant Controller

4. Conclusion

This paper presents a comparison between PI controller and PR current controllers for Utility connected PV systems. These results show that the PR controller is able to meet the IEEE standards as compared to PI controller under harmonics. However, additional harmonic compensation can be used to produce more promising results with the PR controller. In the future, further investigation of both controllers on Real Time Digital Simulator (RTDS) would be done to verify the results obtained from Matlab

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