



LOW ORDER HARMONICS IMPROVEMENT OF A SINGLE GRID CONNECTED INVERTER SYSTEM UNDER PR CONTROL TECHNIQUE

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ABSTRACT

Distributed generation technologies or embedded generation is rapidly becoming a significant and important matter worldwide. It is important that the current harmonics current produced at the output of the inverter do not exceed the standards. In this paper, simulation of grid connected inverter system with PI and PR current controller are done and the results show improvements in the low order harmonics spectrum when using the PR control technique in the inverter system.

Keywords: harmonics, controller, inverter.

INTRODUCTION

Power quality is defined as the voltage and current provided by the grid that can be successfully utilized by the user without interference or interruption (G. T. Heydt, 1998). Distributed generation technologies or embedded generation is rapidly becoming a significant and important matter worldwide. Typically, these generation systems are connected at strategic places within the power distribution network and much closer to the end users than conventional power stations. Based on (P. Chiradeja and Y. Ma, *et al*, 2005), the key advantages of this type of electricity generation are as follows:

- i- It can reduce transmission losses as the plant is installed near its application.
- ii- It has satisfying power supply demand where the energy can always be utilized whenever needed by users. For instance in the event of line outage or scheduled interruption.

For good power quality operation, it is important that the current harmonics current produced at the output of the inverter do not exceed the national Point of Common Coupling standards (IEEE Std 929-2000, 2000). The impact of these harmonics includes variation in root mean square (RMS) voltage, disturbance of electronic components and stress on insulation materials (E. Caamano *et al*, 2007). Other impacts are discussed in Chapter 2. Therefore, it is vital to reduce the harmonic level to be under the limit specified by national standards, such as the IEEE 929 Standard in the US (IEEE Std 929-2000, 2000).

REVIEW ON HARMONIC PERFORMANCE TECHNIQUES

To date, a considerable amount of literature has been published to improve the harmonic performance of grid connected inverters, all with their associated merits and disadvantages. It is always possible to make the improvements by improving the power electronic converter hardware; inverter topology, PWM switching schemes, filter arrangements, and so on. Alternatively, it is also possible to enhance the performance and robustness of the inverter current controller.

A generalized technique of harmonic elimination in the half bridge and full bridge output waveforms was proposed by Patel and Hoft (H. S. Patel and R. G. Hoft, 1973). In this work, output waveforms for both the half bridge and full bridge are 'chopped' M times per half cycle. An equation is then obtained through several steps of derivation which can best be solved by computational techniques. Whilst complex, solutions for eliminating the 5th, 7th, 11th, 13th, and 17th can be obtained. In another study by Su *et al* (S. Xiu'e *et al*, 2010) a proportional resonant (PR) controller scheme is also used to achieve a high quality sinusoidal output current waveform in a single phase PV inverter. By simulation, it is shown that the THD obtained for the output current is 2.72%, which is clearly acceptable.

A different research study on the proportional resonant (PR) control system has also been carried out by Guoqiao *et al* (S. Guoqiao *et al*, 2008 and 2009). In his papers, a new current feedback method for the PR controller is proposed. In the first paper, instead of taking the inverter output current or the grid current as the feedback, he suggests to use the weighted average value (WAC) of the inverter output current and the grid current as the current feedback method. In the second paper, he



recommends splitting the capacitor of the LCL filter into two parts (C_1 and C_2) and to take the current flowing between the two capacitors as the feedback current for the PR controller. From the experimental results for both proposed methods, two conclusions are drawn. Firstly, the control system is reduced from a third order system to a first order system; this can be proved by deriving the transfer function solution for the system. Secondly, less phase error and lower current THD are achieved when compared to using the inverter output current feedback.

The most recent research was presented by Jevraj and Nasrudin (J. Selvaraj and N. A. Rahim, 2009). The paper claimed that there is a limitation in harmonic reduction when using a typical single phase three level inverter. The idea behind this topology is to generate five level of output voltage; $+V_{PV}$, $+1/2V_{PV}$, 0 , $-1/2V_{PV}$, $-V_{PV}$; where V_{PV} is the voltage across the DC-DC boost converter. Furthermore, the proposed topology uses an auxiliary circuit between the DC-DC boost converter and the inverter. The lower THD measurement for the proposed inverter proved that harmonic content can be reduced as the number of output levels increases. However, the measured PV system efficiency is low because of the auxiliary circuit.

In this paper, a comparison is made based on the low order harmonic performance of the inverter current between the grid inverter system when using PI and PR current controller.

SIMULATION MODEL AND RESULTS

Model of a single grid connected inverter system

A single grid connected system is modelled initially using Matlab as the simulation tool (Figure-1). It comprises of PWM circuit, an H bridge inverter that consists of 4 mosfets with internal diodes, a low pass filter, current controller and the supply grid with grid impedance. The low pass filter consists of an inductance and a capacitor with values as listed in Table-1. It is designed so that the magnitude of frequencies lower than an approximate of 1 kHz can pass through and magnitude of the frequencies higher than an approximate of 1 kHz is filtered. This is to prevent the unwanted switching frequency harmonics being injected to the grid. Figure-1 shows a single inverter system model. The parameters are listed in Table-1.

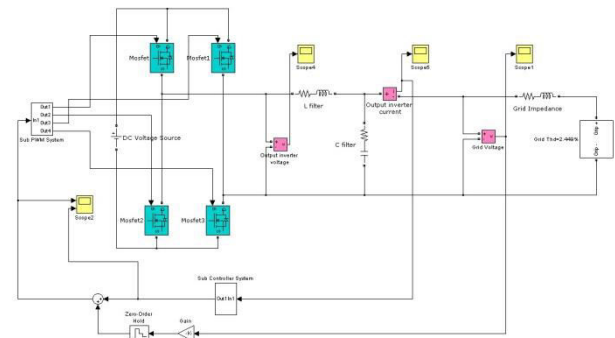


Figure-1. System model.

Table-1. System parameters.

DC voltage source	400 V
Frequency	50 Hz
Filter Inductance and Resistance	$L=2 \text{ mH}$, $R=0.15 \Omega$
Filter Capacitance and Resistance	$C=12 \mu\text{F}$, $R=0.0566 \Omega$
Filter cut off Frequency	1027 Hz
Grid Voltage	240 V _{RMS}
Grid Impedance	$R=0.1 \Omega$, $L=0.1 \text{ mH}$

The grid model used is of 240 V_{RMS} which contains different magnitude and phase angle for each particular frequency of up to the 50th. In total, this will create an approximate background THD of 2.45% in the grid supply voltage. The harmonic data is based on experimental data acquired by a previous student in the Power Electronics, Drives and Machines laboratory at Newcastle University (G. Hong Soo, et al 2009). This data is readily available for simulation use by the research group.

The reference current is chosen to be 20 A peak as the system is assumed to work in a perfect sunny day with 3 kW output power. The simulation model samples the currents and voltages every 50 μs . In addition, the PWM output is updated at the same rate. This simulates the basic operation of a real digital control system.

Conventional PI control technique

Figure-3 shows the PI controller model used in the simulation. The measured inverter output current will be I_{n1} . It is then compared with the I_{ref} , resulting an error which is used in the control process. The output of the current controller is then compared with a 20 kHz triangular wave signal to generate the PWM switching pattern to control the state of the H-Bridge power converter. Both gains; proportional gain and integral gain are tuned using a simple a manual tuning method until the



output current matches the reference signal. Further fine tuning is then carried out to achieve an optimised current output, with good power quality (low harmonics). In this simulation, the gains used are 0.03 for K_p and 0.03 for K_i . The model is run for 1.0 sec. Following this, FFT analysis is performed and the harmonic content of the output current waveform is recorded, up to the 20th harmonic (1 kHz). Above this, the harmonics are significantly attenuated by the low pass filter. However, the overall THD of the current waveform is also recorded as an additional measure of power quality.

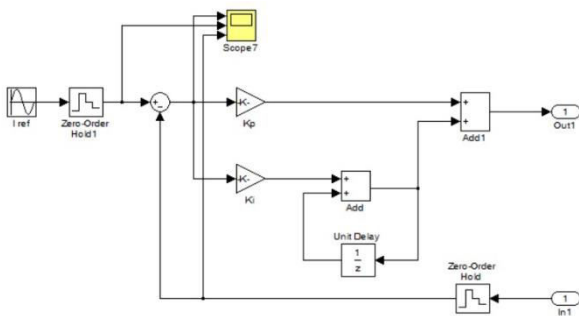
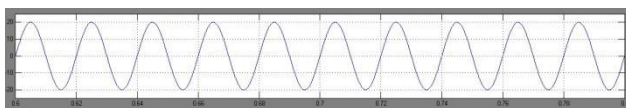


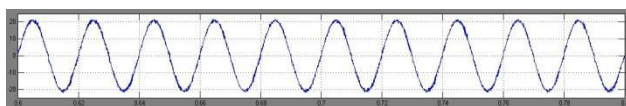
Figure-2. Conventional PI current control digital model.

Simulation results on PI control technique.

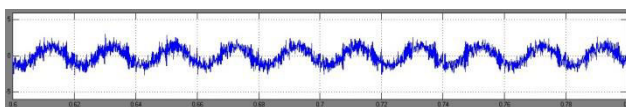
Figure-3 shows the screen shot of the reference current signal, the inverter output current signal, and the observed current error signal applied to the PI controller.



(a) Reference current (20 A peak).



(b) Inverter output current.



(c) Error between reference current and inverter output current.

Figure-3. Screen shot of the reference, output and error signal (PI).

With the chosen K_p and K_i value, when the model is run, the error between both the inverter output current and reference current is the smallest which is approximately 1.5 A peak. The harmonic spectrum for the

inverter output current is measured using FFT Analysis. The sample taken for the analysis is 10 cycles starting from 0.6 sec to 0.8 sec. The low order harmonic data is then exported to Excel and post processed to produce the result illustrated in Figure-4.

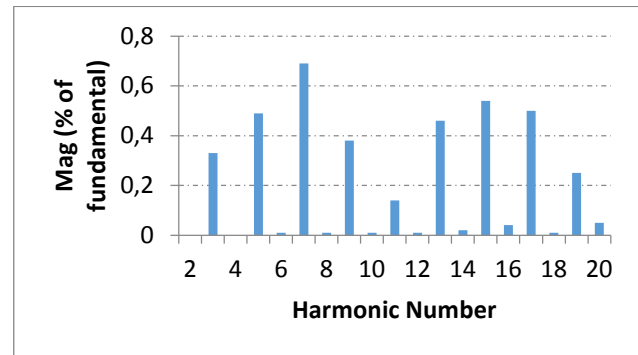


Figure-4. Low order harmonic spectrum of inverter output current with PI control. ($K_p = 0.03$, $K_i = 0.03$).

The inverter output current shows a THD of 2.06 %, with high harmonics appear between the 3rd and 17th order. These low order harmonics are the prominent harmonics which are the focus to be eliminated or reduced in this research work. As mentioned previously, higher order harmonics beyond the 20th are less severe due to the 1 kHz cut off frequency of the low pass filter.

Proportional resonance (PR) control technique

Next, the same simulation model of a single inverter grid connected system is once this time, instead of using the PI current control technique, the proportional resonance (PR) current control technique is implemented. Figure 5 shows the controller model of the PR technique. In2 is the measured inverter output current whilst Out2 is the output signal after the controlling process that will be used for PWM switching purposes. Based on Figure 6, several coefficients need to be determined carefully in targeting a reduction or elimination of the low order harmonics thus achieving a low THD value of the inverter output current. For ease of simulation, the denominator from the equation is strategically replaced with a constant value for the controller, $const$. This leaves the b_0 , b_1 , b_2 , a_1 and a_2 as one single value with only the proportional gain, K_p and the resonance gain, K_R to be tuned (R. Teodorescu *et al*, 2004). Therefore;

$$const = \frac{1}{4 + T^2 \omega_o^2}$$

$$b_0 = (4 + T^2 \omega_o^2) K_p + 2TK_R$$

$$b_1 = (2T^2 \omega_o^2 + 8) K_p$$

$$b_2 = (4 + T^2 \omega_o^2) K_p - 2TK_R$$



$$a_1 = \frac{2T^2\omega_o^2 - 8}{4 + T^2\omega_o^2}$$

$$a_2 = 1$$

By inserting $50 \mu s$ into T (sampling time) and 2π times the fundamental frequency (50 Hz) into ω_o , all values, with the exception of K_P and K_R are obtained. Then, K_P and K_R need to be tuned so that the lowest inverter output current THD is achieved. Following a manual tuning method, the optimum output result is achieved when K_P is 0.04 and K_R is 700.

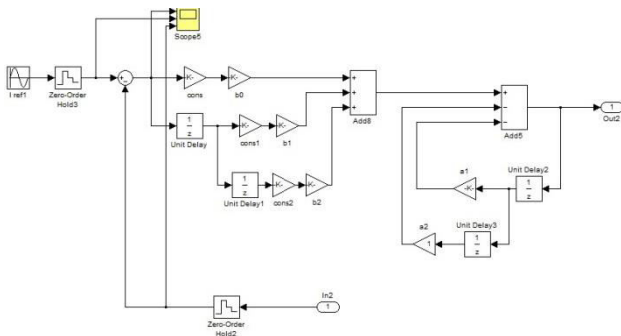
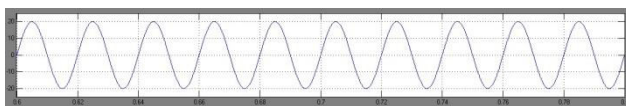


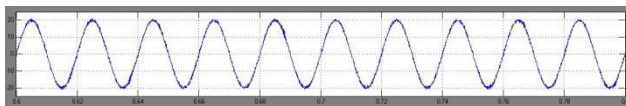
Figure-5. Simulation model of current controller using PR technique.

Simulation results on PR control technique

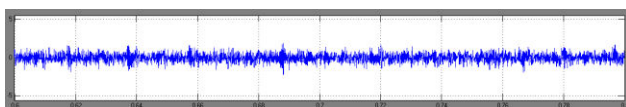
The reference current, measured inverter output current and the error can be seen in Figure-6. Based on the figure, the error current for the system using the PR control technique is minimised when compared with the error current for the system using the PI control technique (Figure-4). This shows an advantage of the PR control system.



(a) Reference current (20 A peak)



(b) Inverter output current



(c) Error between reference current and inverter output current

Figure-6. Screen shot of the reference, output and error signal (PR).

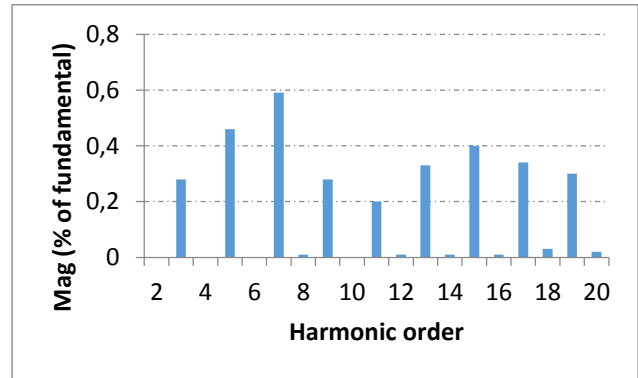


Figure-7. Low order harmonic spectrum of inverter output current with PR current controller.

Figure-7 shows the low order harmonic spectrum of the inverter output current after the data from FFT analysis in Simulink has been transferred to Excel. When run in the same length time as the system using PI current controller and sample time taken for the analysis made is also the same as the system using PI current controller, the THD achieved is 1.80% which is a reduction of approximately 13% from using the conventional PI control technique.

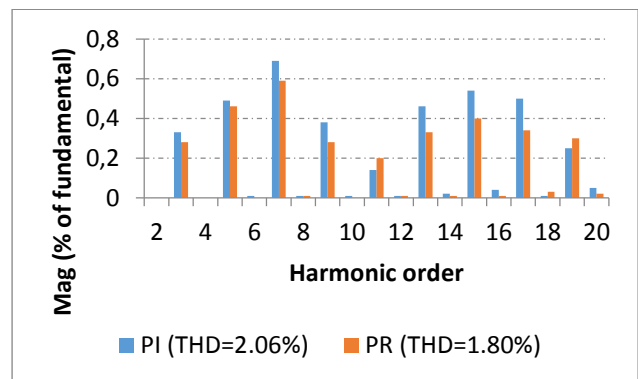


Figure-8. Comparison of PI and PR current controllers.

Figure-8 illustrates the spectrums of Figure-4 and Figure-7 when they are set in a single bar graph. Besides the improvement in the THD, it clearly shows that the harmonics magnitude between the 3rd and the 17th harmonic orders have also been reduced and improved.

CONCLUSIONS

In grid connected system, it is vital to inject a unity power factor current into the grid. This can be achieved with an appropriate current controller scheme of the inverters. For this research project, two methods or techniques have been simulated and tested. They are the conventional PI control technique and the proportional resonant (PR) control technique. From the simulation results, it is shown that by using the proportional resonant



controller technique, performance of the low order harmonics spectrum is improved.

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