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Single Phase Inverter System using Proportional Resonant Current Control

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ABSTRACT

This paper presents the harmonic reduction performance of proportional resonant (PR) current controller in single phase inverter system connected to nonlinear load. In the study, proportional resonant current controller and low pass filter is discussed to eliminate low order harmonics injection in single phase inverter system. The potential of nonlinear load in producing harmonics is showed and identified by developing a nonlinear load model using a full bridge rectifier circuit. The modelling and simulation is done in MATLAB Simulink while harmonic spectrum results are obtained using Fast Fourier Transfor. End result show PR current controller capability to overcome the injection of current harmonic problems thus improved the overall total harmonic distortion (THD).

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1. INTRODUCTION

Current harmonics can affect the power quality of power system including the performance of generation system and various applications. This power quality problem has existed since earliest days of industry. It can be found in application with non-linear magnetizing impedances and high switching frequency equipment. Single phase inverter is used when the main source is using direct current in order to generate AC electricity on the output power for some generation system [1]. The inverter is operate with pulse-width modulation at a high switching frequency and is either current or voltage controlled using a selected linear or nonlinear control algorithm [2]. This synthesis method of single phase inverter will produce current harmonic.

The current waveform with non-linear loads will not be the same as the voltage which is different from linear loads that current is proportional to the applied voltage [3]. Nonlinear loads have been a major source that produce large amount of harmonic in most of the power networks. Nonlinear loads can also cause resonance problems and degrade the power quality in power system [4]. Rectifiers are the main cause that degrades the power quality of power system because they are extensively used as interface circuits for power electronics system in industry. It is very commonly used in switched mode power supplies for many domestic appliances [5]. Furthermore, the low pass filter is a power electronic device that has superior in filtering performance and is capable to reduce harmonic distortion and can be used as a controlled current source or controlled voltage source [6].

Proportional resonant controller is function to eliminate the harmonic existed in power system. It has infinite gain at resonant frequency which ensures zero steady-state error in a stationary frame thus resulting in minimization of the load current distortion and harmonic content in the inverter [7]. This paper focus on the performance of proportional resonant current controller and verification to minimize the current ripples for single-phase inverter with low pass filter connected to nonlinear load as shown in Figure 1 below. The feed forward grid voltage compensation can effectively eliminate the output harmonics disturbance, and both fast dynamic response and high quality current output [8].

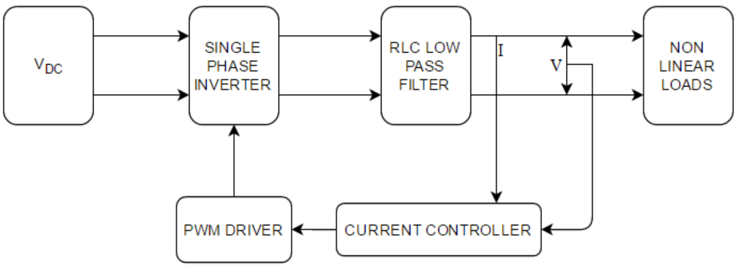

Figure 1. Block diagram for Inverter with PR current Controller

2. RESEARCH METHOD

In this section, discussions on each part of the Simulink model is explained.

2.1. DC Source and Bus Link

Voltage with 380V is used for the DC battery voltage rating to achieve the project scope. The DC source is the main supply to the single phase inverter and convert the electricity into AC. Bus link capacitor smoothen the AC power at the output of the inverter. The proper rating of the bus link capacitor can be calculated using;

$$C_{dc} = \frac{P}{2\omega V_{dc}\,\Delta V_{ripple}} \quad (1)$$

where C_{dc} is bus link capacitor, P is inverter power output, V_{dc} is the DC voltage used and ΔV_{ripple} is the ripple voltage. Here, power of the inverter system is assumed to be 3 kW with 2% ripple voltage. The value that calculated from the formula for the bus is 2.26 mF.

2.2. Single Phase Inverter

The inverter circuit design is using the H-bridge connection with four Mosfets as the switching devices and supplied by 380VDC. The output single phase inverter is in alternative current with square wave using pulse width modulator (PWM) input at the gate of Mosfet. The gate of Mosfet is supplied with 20 kHz of PWM switching frequency. The Mosfet is protected by protection diode with 0.8V.

2.3. RLC Low Pass Filter

In the single phase inverter system, low pass filter is designed to convert the square voltage waveform saturated with high switching frequency into a pure sinusoidal waveform. Cutoff frequency formula is given as below.

$$f_C = \frac{1}{2\pi\sqrt{L_F C_F}} \quad (2)$$

f_c is the cutoff frequency, L_F and C_F is the filter inductance and capacitance respectively. For the rating of filter inductance, the formula is given as below,

$$L_F = \frac{V_{DC}}{4 f_{SW} \Delta I_{pp}} \quad (3)$$

The ripple factor is decided to be 5 percent and the filter inductance for low pass filter has been calculated as 5mH. The rating of filter capacitor is lastly calculated using cutoff frequency formula and the value used is 4.7µF.

2.4. PWM Driver

Pulse width modulation (PWM) is a combination of carrier signal in saw tooth waveform and a reference waveform. The modulation for both of this signal can form the PWM waveform with proper duty cycle. This paper use a Unipolar PWM technique with modulation index, m_a set as 0.85 for the input signal. Carrier frequency is set to 20 kHz for this single phase inverter system.

2.5. Current Controller Design

The PR current controller $G_{PR}(s)$ is represented by:

$$G_{PR}(s) = K_P + K_I \frac{\omega_C s}{s^2+2\omega_C s+ \omega_0{}^2} \tag{4}$$

The Laplace transform in s-domain is suitable for continuous analysis. In order to get discrete equation, it has to be change to z-domain. It is changed to z-transform by inserting $s = \frac{2}{T_s}\frac{1-z^{-1}}{1+z^{-1}}$ using Tustin transform and resulted as below.

$$G_{PR}(z) = \frac{n_0+n_1 z^{-1}+n_2 z^{-2}}{1+d_1 z^{-1}+d_2 z^{-2}} \tag{5}$$

where,

$$n_0 = \frac{(4+4T_s\omega_c+\omega_0{}^2 T_s{}^2)K_p+4K_r T_s\omega_c}{4+4T_s\omega_c+\omega_0{}^2 T_s{}^2} \tag{6}$$

$$n_1 = \frac{(-8+2\omega_0{}^2 T_s{}^2)K_p}{4+4T_s\omega_c+\omega_0{}^2 T_s{}^2} \tag{7}$$

$$n_2 = \frac{(4-4T_s\omega_c+\omega_0{}^2 T_s{}^2)K_p-4K_r T_s\omega_c}{4+4T_s\omega_c+\omega_0{}^2 T_s{}^2} \tag{8}$$

$$d_1 = \frac{-8+2\omega_0{}^2 T_s{}^2}{4+4T_s\omega_c+\omega_0{}^2 T_s{}^2} \tag{9}$$

$$d_2 = \frac{4-4T_s\omega_c+\omega_0{}^2 T_s{}^2}{4+4T_s\omega_c+\omega_0{}^2 T_s{}^2} \tag{10}$$

The ω_c is set to be 5, ω_0 equal to 314.16 rad/s and T_s is 0.8 microseconds. The circuit is then designed in Simulink in discrete form.

2.6. Non Linear Load Model

In this project, transformer is used for isolation and step down purpose. 230/24V rated transformer is used. The full bridge rectifier was chosen for the nonlinear model and made up with four diodes. The output of the rectifier is in direct current waveform. The connection of the full bridge rectifier is shown in Figure 2 below. Where the V_{AC} is connected to the transformer output before the power is change to DC and the V_{DC} is the port after the rectification.

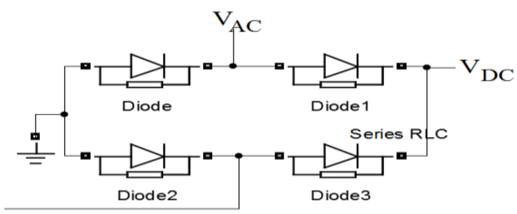

Figure 2. Full Bridge Rectifier Circuit

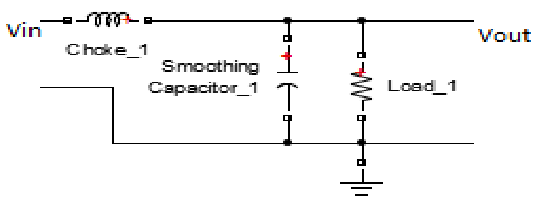

Figure 3. Capacitor Smoothing after Rectifier Circuit

A capacitor is designed after rectifier circuit to smoothen up the ripple voltage and choke as current limiter as shown in Figure 3. V_{IN} is the output from the full bridge rectifier circuit and V_{OUT} is output in the form of DC supply which are ready supply other DC loads.

Ripple factor can be determined using formula below,

$$RF = \frac{1}{\sqrt{2}(2f_r RC-1)} \tag{11}$$

Whereas the average voltage of the rectifier can be calculated using below formula.

$$V_{AVE} = 0.636\ x\ \sqrt{2}\ x\ V_{rms} \tag{12}$$

By using the ripple factor formula, the rating of the smoothing capacitor is calculated to be 17.6mF with resonant frequency of 100 Hz because of full wave bridge, ripple factor of 5 percent and resistive load with 4.3Ω. The choke can be calculated using formula below.

$$\frac{V_{rms}}{I_P} = 2\pi f_r L_R \tag{13}$$

Calculated inductor is 7.6mH to limit the current surge for the rectifier circuit. The overall single phase inverter circuit now can be constructed and designed in MATLAB Simulink as shown in Figure 4 below for further simulation and analysis.

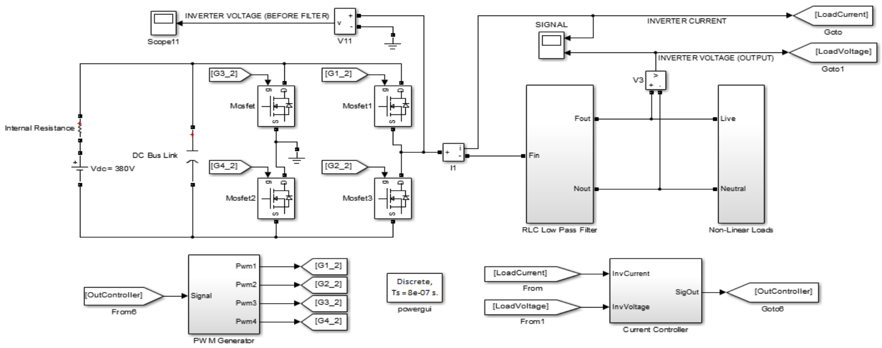

Figure 4. Overall inverter system with PR current controller connected

3. RESULTS AND ANALYSIS

In this section, results for the simulation is showed and explained in several sub sections. They are presented in figures and graphs.

3.1. Inverter System Analysis without Load

Circuit is modelled without load and the THD caused by the inverter itself was identified transafter simulate using Simulink. The low pass filter is function to change the square wave voltage waveform to sinusoidal waveform and also greatly reduce the current harmonic of the inverter using high switching frequency. Single phase inverter system without load parameter settings is shown in Table 1 below by following the results in modelling.

Table 1. List of parameters for inverter system with low pass filter

Parameter	Values
DC Voltage, V_{dc}	380V
Bus link Cap, C_{dc}	2mF
Switching freq, f_{sw}	20 kHz
Cutoff freq, f_c	1.124 kHz
Modulation index, m_a	0.85
Sampling time, T_s	0.8μs
Filter inductance, L_F	5mH
Filter Capacitance, C_F	4.7uF
Filter resistance, R_F	18 ohm

The FFT result of inverter system without load is done and analyze as shown in Figure 5. The result shows the inverter system has THD of 0.85% for this circuit without any load.

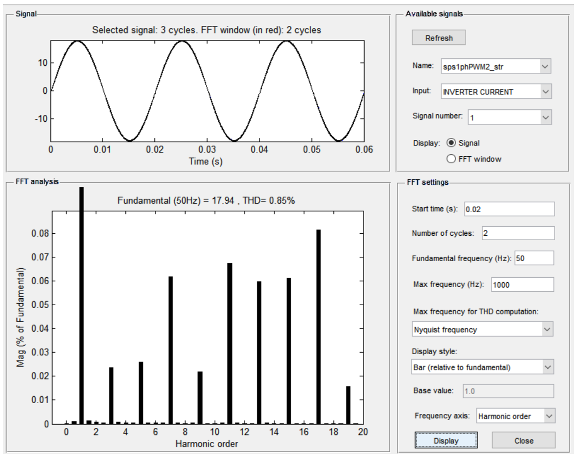

Figure 5. FFT analysis of inverter system without non-linear load and controller

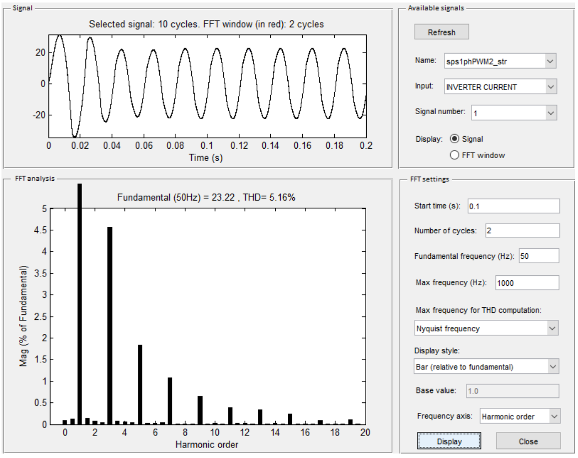

Figure 6. FFT analysis of inverter system with nonlinear loads

3.2. Analysis THD of Single Phase Inverter with Non Linear Load

The circuit is connected with nonlinear loads for this session and the project scope for the nonlinear model include both of the transformer and rectifier. The single phase inverter system with nonlinear models setting parameters is shown in Table 2 by following the result in modelling system. The PWM is generated with 20 kHz switching frequency with 20A peak current output waveform with nonlinear loads model. The FFT analysis is also done for inverter system connected to nonlinear loads. The result is shown in Figure 6. The result has proven in FFT analysis that the harmonics is 5.16% in total.

Table 2. List of parameters for inverter system with nonlinear model

Parameter	Values
DC voltage, V_{dc}	380V
Bus link cap, C_{dc}	2mF
Switching freq, f_{sw}	20 kHz
Cutoff freq, f_c	1.124 kHz
Modulation index, m_a	0.85
Sampling time, T_s	0.8μs
Filter inductance, L_F	5mH
Filter capacitance, C_F	4.7uF
Filter resistance, R_F	18Ω
Transformer rating, T_r	230V/24V
Load inductance, L_L	7.6mH
Load capacitance, C_L	17.6mF
Load resistance, R_L	4.3Ω

3.3. Analysis of inverter system with PR Controller

The inverter circuit with PR Controller is simulated and the value of K_p and K_r is tuned by trial and error method. The value of K_p and K_r is decide with 0.025 and 0.5 respectively. The FFT analysis is done for the inverter system connected with PR controller and Figure 7 shows the result with a total harmonic distortion of 2.07% and is decreased from before. PR current controller is capable to overcome the current harmonic problems in the odd frequency. This can be seen especially in the 3rd harmonic where it is improved from 4.5% to 1.7% thus improved the total harmonic distortion (THD).

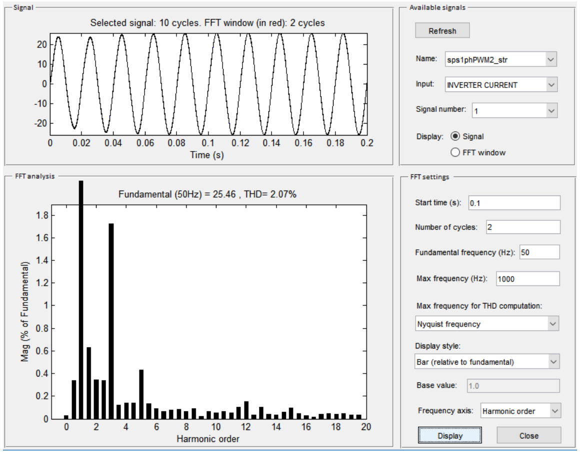

Figure 7. FFT analysis for inverter system with PR controller

4. CONCLUSION

In this paper the single phase inverter system with proportional resonant (PR) controller is proposed and the harmonic reduction performance for PR current control is presented. Single phase inverter system with conventional PI control can be replaced with PR control and it is showed by the better performance in terms of harmonic rejection. This paper has modelled and simulates to test the performance of PR control technique. PR control technique is very useful in terms of elimination of harmonics distortion, thus improving power quality in power system.

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