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Total Harmonics Distortion of 5 Level and 3 Level Inverter using Proportional Resonant Controller

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Abstract: Total harmonics distortion (THD) is the main problem of an inverters. Most of the harmonic currents and voltages flow in the load are frequencies that are higher than the fundamental supply frequencies, where it then generates more heat and increases the possibility of equipment malfunction. Harmonics are the additional current and voltages doesn't contribute any mechanical force to the motors, instead, it is simply dissipated as heat in the load, thus may cause premature equipment failure and can cause equipment malfunction. In order to mitigate these harmonic problems, a proportional resonant (PR) is used in this work. The cascaded 5 level inverter topology is incorporated to suppress the harmonics produced by the inverter at its output. Results of the THD current are then compared between the 3 level and 5 level inverters.

Keywords: Total Harmonics Distortion, Inverter, Proportional Resonant Controller

1. Introduction

As science and technology are growing rapidly day by day, people are now living in the world where its hunger for more power consumptions. The interest for power keeps on rising all around the world and the market for small distributed power generation systems like photovoltaic (PV) systems connected to the domestic grid is increasing rapidly [1]. Solar Photovoltaic (SPV)-based power generation systems are popular among various renewable energy sources due to their flexibility in capacity addition and low maintenance cost [2]. This is due to they offer improved output waveforms, smaller filter size, lower EMI, lower total harmonic distortion (THD), and others [3].

However, harmonics level is still a controversial issue for inverters. The harmonic problem could be further complicated by the harmonic resonance introduced by other system components [4]. New power quality standards for distributed generation in the low voltage grid like IEEE-1547 in US and IEC61727 in Europe impose some limits for the current harmonics [5]. Traditionally, a typical single-phase three-level inverter adopts full-bridge configuration by using approximate sinusoidal modulation

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technique as the power circuits. The output voltage then has the following three values: zero, positive (+Vdc), and negative (−Vdc) supply dc voltage (if Vdc is the supply voltage). The carrier frequency and switching functions will resulting the harmonic components of the output voltage. Therefore, their harmonic reduction is limited to a certain degree [3].

Next, current feedback Proportional Integrate (PI) control with grid voltage feed-forward is commonly used in stationary reference frame for current-controlled inverters. But PI controller main problem is poor disturbance rejection capability and incompetence to track a sinusoidal reference without steady-state error [6]. For common filters a high switching frequency must be used to obtain high dynamic performance and enough attenuation of harmonics caused by the pulse width modulation (PWM) method. This is a big drawback in higher power applications [6].

These issues can be solved by using appropriate controllers in the inverter system. Hence, this paper proposes a current control technique for a single phase grid-connected 5 level inverter and compare with 3 level inverter system. A Proportional- Resonant (PR) controller is used for replacing the conventional Proportional - Integral (PI) controller in this system as PR current controller capability to overcome the injection of current harmonic problems [7]-[8].

2. Methodology

The component that is needed for this work are DC supply, cascaded H-bridge multilevel inverter, LCL filter meanwhile a PR controller will be used as its control systems. Figure 1 below shows the block diagram of the project.

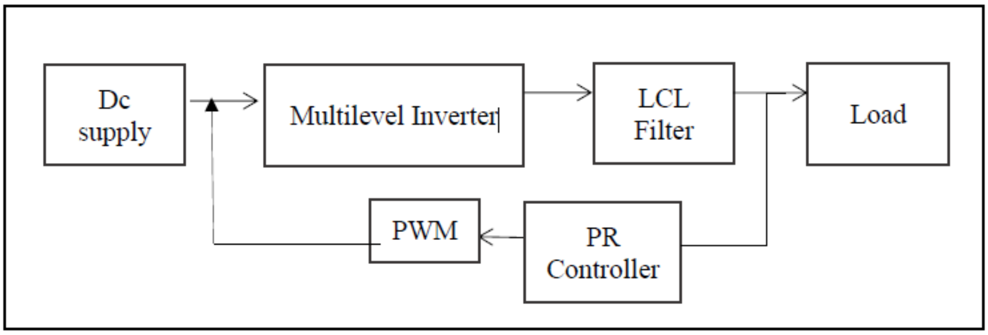


Figure 1: Block diagram of inverter system with PR controller

2.1 Cascaded H-bridge multilevel inverter

Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge inverter. Each inverter level can generate three different voltage outputs, +Vdc, 0, and –Vdc by connecting the dc source to the ac output by different combinations of the four switches, S1, S2, S3, and S4. To obtain +Vdc, switches S1 and S4 are turned on, whereas –Vdc can be obtained by turning on switches S2 and S3. By turning on S1 and S2 or S3 and S4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources [9].

2.2 LCL Filter

The LCL-filter is mainly used to achieve decreased switching ripple with only a small increase in filter hardware compared with the L-filter. It has the following components.

$$Z_1 = R_1 + L_1 s \qquad Eq,1$$

$$Z_g = (R_2 + R_g) + (L_2 + L_g) \qquad Eq,2$$

$$Z_g = \frac{1}{C_s} \qquad Eq,3$$

Here, L_1 is the inverter side inductance, L_2 is the grid side inductance of the filter, L_g is the line inductance of the grid, and their equivalent series resistors (ESR) are R_1 , R_2 and R_g respectively. C is the capacitance of the LCL-filter. For the purpose of current control, three transfer functions are given as

$$G_{Vi\to I1}(s) = \frac{I_1(s)}{V_i(s)} = \frac{Z_g+Z_0}{Z_1Z_g+Z_iZ_0+Z_gZ_0} \qquad Eq,4$$

$$G_{Vi\to I2}(s) = \frac{I_2(s)}{V_i(s)} = \frac{Z_0}{Z_1Z_g+Z_iZ_0+Z_gZ_0} \qquad Eq,5$$

$$G_{I1\to I2}(s) = \frac{I_2(s)}{I_1(s)} = \frac{Z_0}{Z_g+Z_0} \qquad Eq,6$$

Where $I_1(s)$ is the inverter output current, $I_2(s)$ is the grid side current, and $V_i(s)$ is the inverter output voltage. For comparing with an L-filter (with inductance L), we assume, $L = L1 + L2 +$, $\alpha = L1/L$, and neglect ESR of the inductor. Figure 2 below shows a LCL filter.

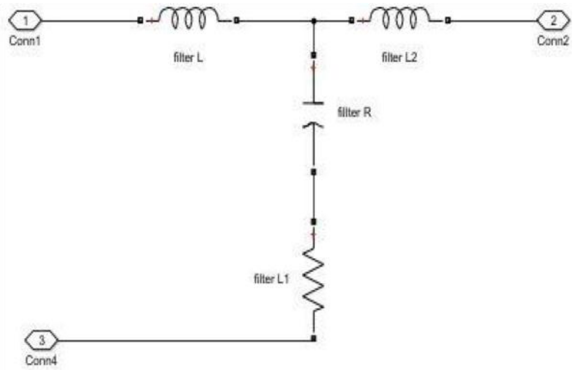


Figure 2: LCL Filter

2.3 PWM (Pulse Width Modulation)

A Pulse Width Modulation (PWM) Signal is a method for generating an analog signal using a digital source. A PWM signal consists of two main components that define its behavior: a duty cycle and a frequency. The output will appear to behave like a constant voltage analog signal when providing power to devices [10].

2.4 PR controller

The PR regulator can be expressed as (8), where Kp is the proportional gain tuned in the same way as that for a PI controller, and it basically determines the dynamics of the system in terms of bandwidth, phase, and gain margin [11]. With the resonance part, K_R added to the proportional controller, the steady state error of the system is nearly eliminated.

$$K_P + \frac{2K_Rs}{s^2+\omega_o^2} \qquad Eq,7$$

3. Results and Discussion

The results for this project were the simulation of the 3 level and 5 level inverter with PR controller and the comparison of the corresponding output voltage THD. Figure 3 below shows the circuit modelling of PR controller circuit in Matlab Simulink while Figure 4 and 5 illustrates the modelling circuit of 3 level and 5 level inverter system.

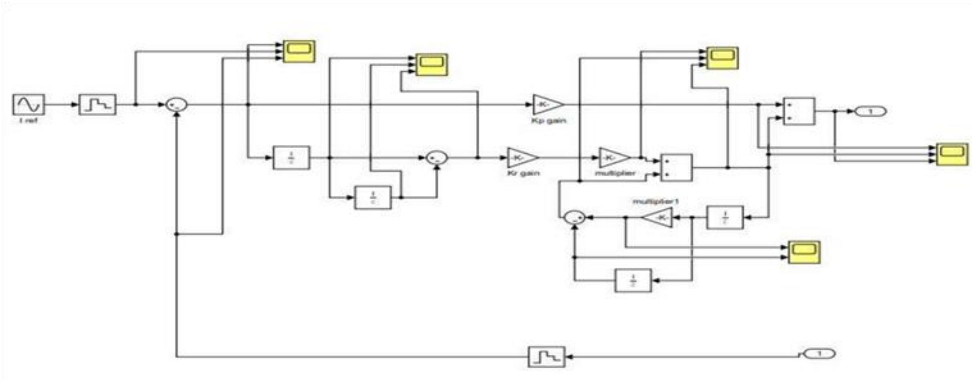


Figure 3: Model of PR controller in Simulink

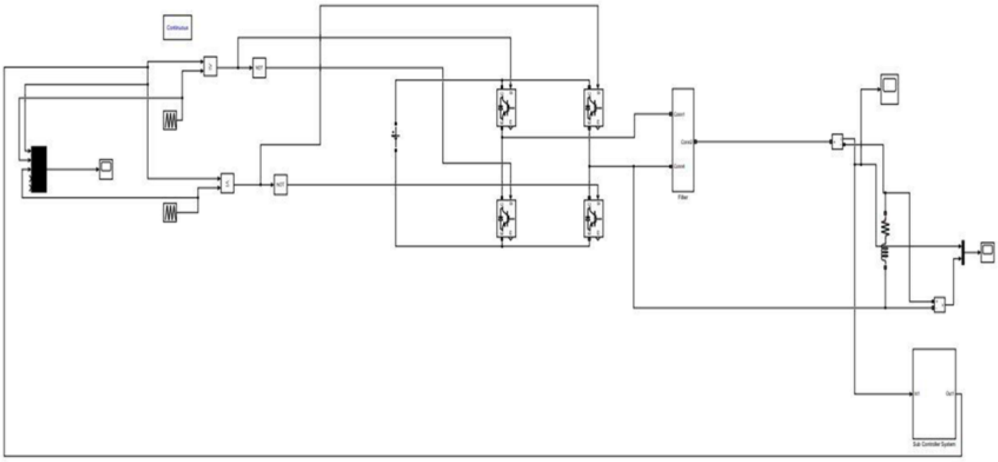


Figure 4: Level inverter circuit in Simulink

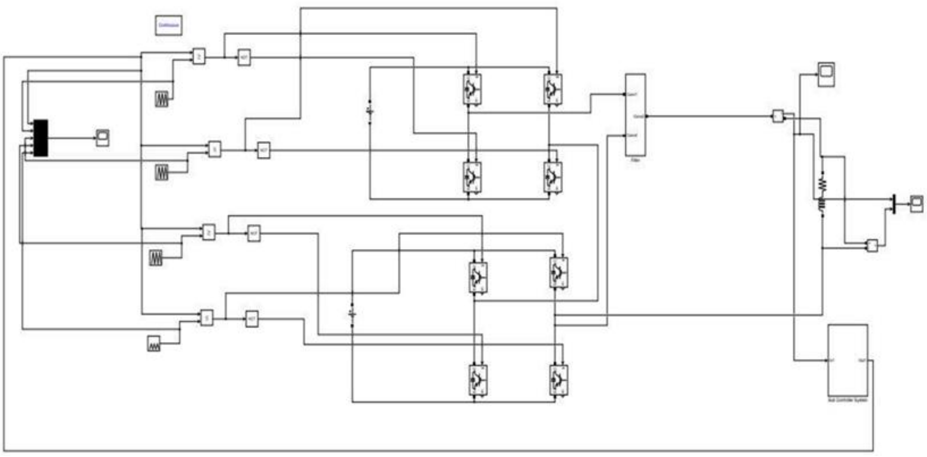
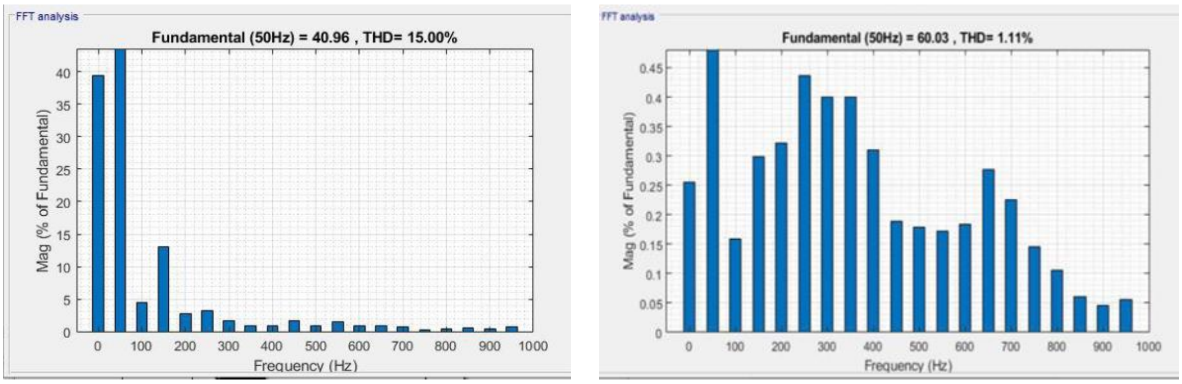


Figure 5: Level inverter circuit in Simulink

Figure 6 shows the waveforms of the inverter output. These waveforms are then analysed for the THD using FFT analysis in Matlab. The results of the output voltage THD is illustrates in Table 1.



(a) 3 level inverter (b) 5 level inverter

Figure 6: FFT analysis of both inverters

Table 1. Comparison of THD 3 level and 5 level inverter

Inverter	Output Voltage THD
3 level	15%
5 level	1.11%

From the table, it clearly shows the THD of 5 level inverter circuit is far more reduced than the 3 level inverter circuit. This can be seen in Figure 6 where harmonics are occurred at higher value at more than 10% of fundamental at the 3rd harmonic. Moreover, at other harmonic levels such as the 5th and 7th, they also show higher percentage around 2-3%. Whereas for the FFT analysis in Figure 6(b) that is for the 5 level inverter, the harmonics level at the 3rd, 5th, 7th and so on are far less than 0.5% which shows better value in terms of its total THD.

4. Conclusion

Harmonics seriously can affect electrical appliance. The result of this simulation of five level inverter were shown in this project. Some of the advantages are that the output waveform was improved since 5 level inverter produced nearly sinusoidal output voltage waveforms, hence the total harmonic distortion also low. In general, higher level inverter is better than lower level inverter when it comes to THD.

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