Harmonic Reduction in a Three-Phase Voltage Source Inverter Using RLC Filter and FFT

Vivek Pratap Singh, M. A. Ansari, and Nivedita Singh

Abstract With the increasing concern for the environment, attention is shifting toward solar energy in the power industry. But the power obtained from solar panels is in DC form; thus, we need to use an inverter to convert this power from DC to AC. During power, conversion harmonics are introduced in the system which affects the quality of power. Thus, it is necessary to reduce the harmonics present in the system for better power quality. This paper describes the implementation of a second-order RLC low-pass filter to a three-phase voltage source inverter with the 180° mode of conduction. Here, two systems have been simulated in the MATLAB/Simulink for harmonics analysis in fast Fourier transform (FFT). The level of harmonics present in the system is determined with the help of total harmonic distortion (THD). Results determine that the distortion in the output waveform is reduced with the implementation of a second-order RLC low-pass filter in the three-phase voltage source inverter.

Keywords Fast Fourier transform · RLC filter · Harmonics · Inverter · Total harmonic distortion

1 Introduction

Nowadays, renewable energy is getting more attention because of the increasing concern for the environment and to meet the increasing electricity demand. Photovoltaics plays an important role in renewable energy because it is considered a clean and ecological source of energy. The power obtained from solar photovoltaics is in DC form; thus, a converter device is needed. A three-phase voltage source inverter can be used to convert the power from DC to AC. While converting the power from one form to another, harmonics are introduced in the system which leads to losses and also affects the power quality [1]. Thus, it is necessary to reduce the harmonics present in the system in order to obtain a better power quality at the output.

V. P. Singh · M. A. Ansari (✉) · N. Singh (✉)
Department of Electrical Engineering, Gautam Buddha University, Greater Noida, India
e-mail: ma.ansari@gbu.ac.in

D. K. Sharma et al. (eds.), *Micro-Electronics and Telecommunication Engineering*, Lecture Notes in Networks and Systems 373,
https://doi.org/10.1007/978-981-16-8721-1_2

1.1 Inverter

Three-phase inverters have applications in variable frequency drives and HVDC transmission when we need to transfer high power [2]. Inverters can be broadly classified as:

Voltage source inverter (VSI): These types of inverters have stiff-type DC source voltage, and the inverter terminal of a VSI has zero or limited impedance.

Current source inverter (CSI): These types of inverters are supplied with variable current from the DC source having a high impedance.

1.2 Harmonics

Total harmonic distortion is the ratio of RMS value of total harmonics of the waveform to the RMS value of the fundamental wave that is the ratio of all harmonic components in the numerator and the fundamental component in the denominator. Total harmonic distortion is a unitless quantity. For a perfect sine wave, the value of total harmonic distortion should be equal to zero. So, we can say that total harmonic distortion determines the level of distortion present in the waveform.

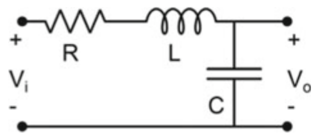
$$\mathrm{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\_\mathrm{rms}}^2}}{V_{\mathrm{fund\_rms}}} \tag{1}$$

The presence of harmonics causes heating problems in motors, and the value of torque is also reduced because of the presence of harmonics in the system. Harmonics also increase the voltage stress and heating problems for the generator [3]. Harmonics present in the system also cause mal-operation of electronics switchgear and relaying. So, we can say that the presence of harmonics will ultimately lead to a reduction in the equipment life; thus, it is necessary to consider these harmonics while designing the equipment that is their rating should be proper in order to limit the harmonics in the power system [4].

1.3 RLC Filter

RLC filter is designed for the three-phase VSI, which contains two reactive components that are inductor and capacitor. In the RLC circuit, capacitor and inductor are elements with storing capability, where the inductor initially opposes the change of current, while the capacitor initially opposes the change of voltage. The inductor successfully blocks high frequencies and passes low frequencies, while the capacitor passes high frequencies but blocks low frequencies.

Second-order RLC low-pass filter



After taking the Laplace transform of the R, L, and C in Fig. 1, the transfer function of the filter circuit is given by equation 2.

Comparing the above equation with the standard equation of the second-order system, we get

$$T(s) = \frac{Vo(s)}{Vi(s)} = \frac{1/Cs}{R + Ls + \left(\frac{1}{Cs}\right)} \tag{2}$$

$$T(s) = \frac{1}{LCs^2 + RCs + 1} \tag{3}$$

$$T(s) = \frac{1/LC}{s^2 + \frac{R}{L}s + \frac{1}{LC}} \tag{4}$$

$$T(s) = \frac{w_n^2}{s^2 + 2\varepsilon w_n s + w_n^2} \tag{5}$$

From the above equation, we will get the following values

$$w_n^2 = \frac{1}{LC} \tag{6}$$

Thus, we will get $w_n = \frac{1}{\sqrt{LC}}$

$$2\varepsilon w_n = \frac{R}{L} \tag{7}$$

Put the value of w_n thus we will get

$$\varepsilon = \frac{R}{2}\sqrt{\frac{C}{L}} \tag{8}$$

where ε = damping ratio of the system and w_n = frequency of oscillation.

2 System Description and Modeling

In this paper, a three-phase voltage source inverter for the 180° mode of conduction is modeled in MATLAB. Six IGBT two in each branch has been used as a switching device in the inverter. The pulse generator is used to provide a pulse to the switching devices. IGBT is utilized in the system since it has low power capacity and high switching speed.

2.1 Three-Phase Voltage Source Inverter with Resistive Load

A DC source voltage source is considered here with a value of 220 V. The type of load considered in the system is resistive, and the value of the resistance is 20 ohms. The internal resistance for all the six IGBT is taken as 0.001 Ω. The value of the amplitude taken in the pulse generator is 10, while the value of the pulse width is taken as 0.02. The Powergui block is taken as continuous in the system. Three-phase voltage waveforms have been obtained for the resistive-type load (Figs. 2 and 3 and Table 1).

2.2 Three-Phase VSI with RLC Filter

A second-order RLC low-pass filter is designed for a three-phase voltage source inverter with the 180° mode of conduction and with a frequency of oscillation of 50 Hz.

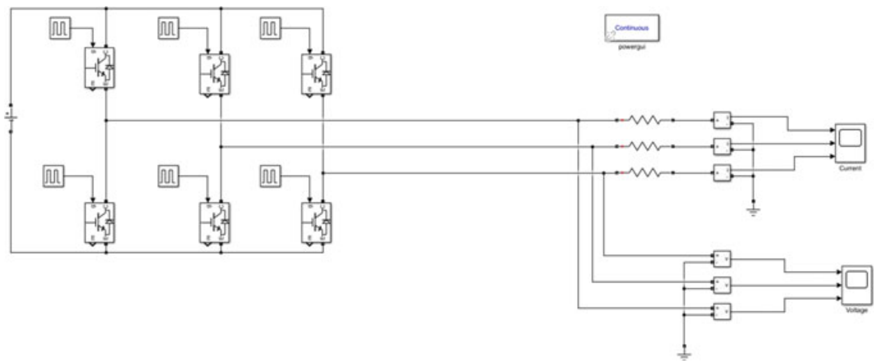


Fig. 2 Simulink model of three-phase VSI without filter

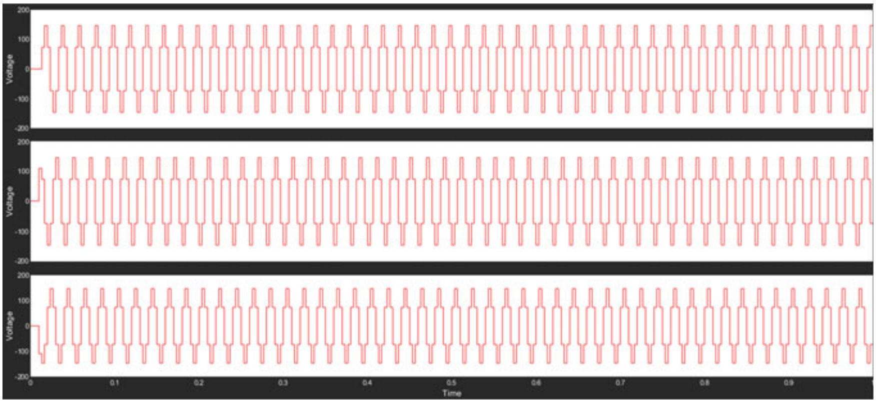


Fig. 3 Three-phase output current waveform of system without filter

Table 1 Parameters of three-phase voltage source inverter with resistive load

S. No.	Parameter name	Selected values
1	Source voltage	220 V
2	Load resistance	20 Ω
3	IGBT internal resistance	0.001 Ω
4	Powergui	Continuous
5	Pulse generator	Amplitude = 10 Pulse Width = 0.02

Filter designing: Cut off frequency (f_c) is given by, $f_c = \frac{1}{2\Pi\sqrt{LC}}$. f_c is taken as 50 Hz; in this case, we know that $\omega_o = 2\Pi f_c$

$$\omega_o = 2 \times \Pi \times 50 = 314 \text{rad/sec}.$$

Taking, $Q = 3.2$ and $C = 100$ uF

$$Q = \frac{wL}{R} \text{ also } Q = \frac{1}{\omega_0 CR}$$

Thus, the calculated values of resistance, inductance, and capacitance are 10 Ω, 100mH, and 100 uF, respectively. And the values of other parameters will remain the same that is source voltage is 220 V, the load resistance is 20 Ω, and IGBT internal resistance is 0.001 Ω (Figs. 4 and 5 and Table 2).

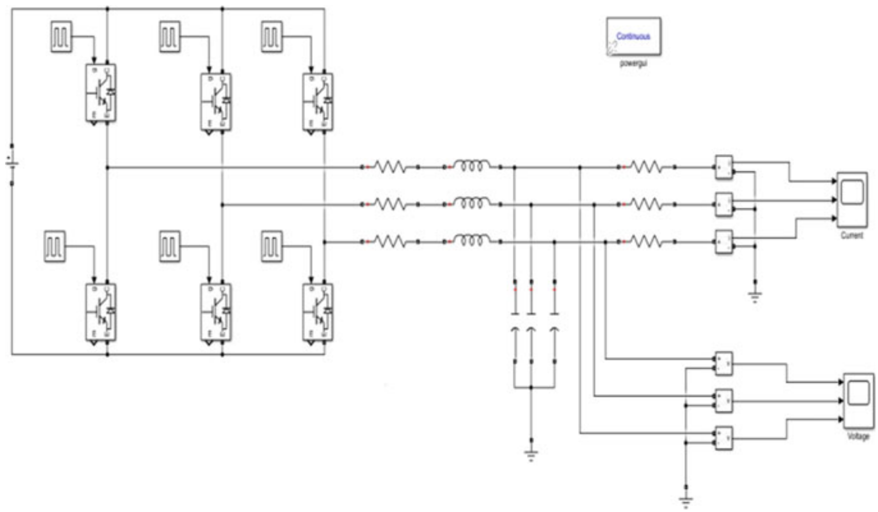


Fig. 4 Simulink model of three-phase VSI with filter

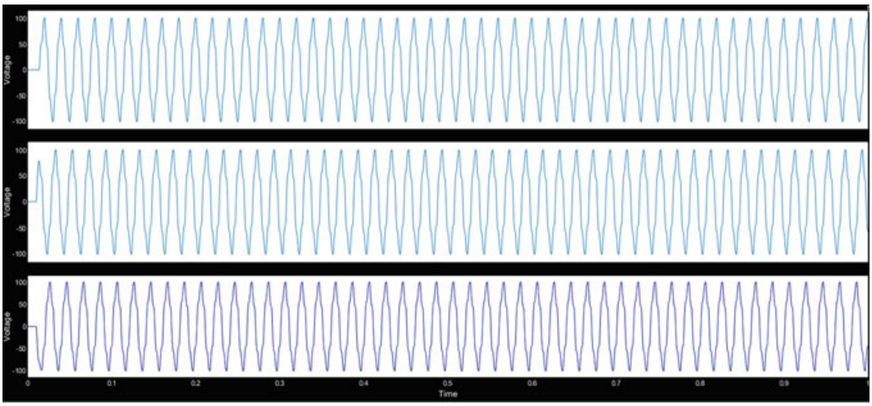


Fig. 5 Three-phase output current waveform of system with filter

Table 2 Comparison parameters of three-phase voltage source inverter with resistive load and RLC filter

S. No.	Parameter name	Selected values
1	Source voltage	220 V
2	Load resistance	20 Ω
3	IGBT internal resistance	0.001 Ω
4	Powergui	Continuous
5	Pulse generator	Amplitude = 10 Pulse Width = 0.02
	RLC Filter	Resistance = 10 Ω Inductance = 100 mH Capacitance = 100 uF

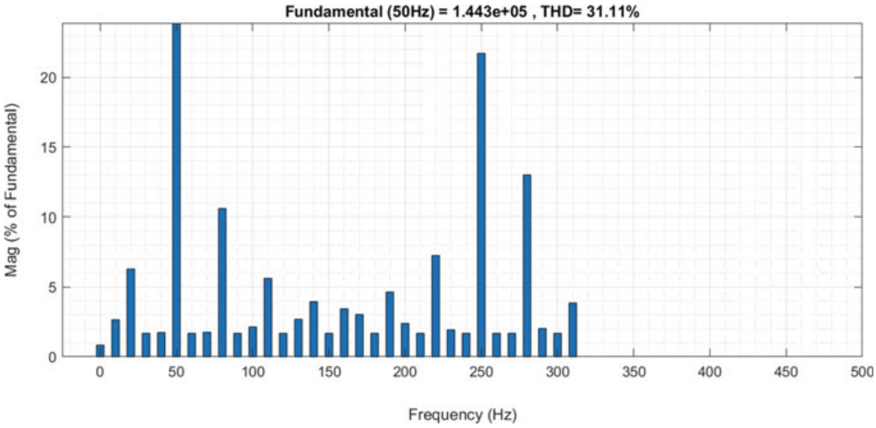


Fig. 6 FFT analysis of inverter without filter

3 Results and Discussion

Fast Fourier transform analysis of the three-phase output voltage waveform has been done in order to determine the value of total harmonic distortion present in the system.

3.1 Three-Phase VSI with R-Load

Figure 6 shows that the value of total harmonic distortion (THD) is 31.11% for the output three-phase voltage waveform.

3.2 Three-Phase VSI with RLC Filter and R-Load

The value of total harmonic distortion (THD) is 12.41% for the output three-phase voltage waveform of the inverter with RLC filter at the output side (Fig. 7).

4 Conclusion

A simulation model of three-phase voltage source inverter with resistive load and 180° mode of conduction has been developed in MATLAB/Simulink for a duration of 10 s. From the comparison table, it is seen that the value of total harmonic distortion is 31.11% for the output voltage waveform from three-phase VSI without any filter. While with the implementation of a second-order RLC low-pass filter, the value of

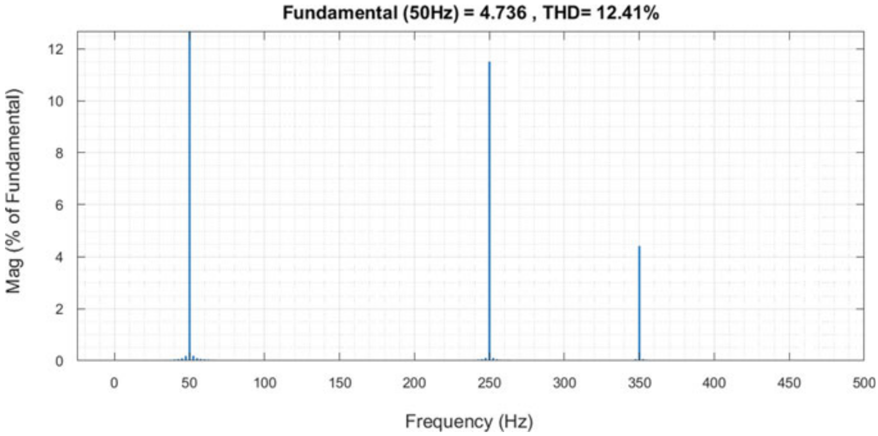


Fig. 7 FFT analysis of inverter with filter

Table 3 Comparison of total harmonic distortion

S. No.	Case studied	Total harmonic distortion (THD in %)
1	Three-phase voltage source inverter with R-load	31.11
2	Three-phase voltage source inverter with second-order RLC filter	12.41

total harmonic distortion obtained is 12.41% for the output voltage waveform. Thus, we can say that with the implementation of a second-order RLC low-pass filter to a basic circuit of three-phase voltage source inverter, the level of harmonics can be reduced which implies a better power quality (Table 3).

References

1. Mahajan V, Agarwal P, Gupta HO (2020) Power quality problems with renewable energy integration. In: Power quality in modern power systems. Academic Press, pp 105–131
2. Phukan R, Ohn S, Dong D, Burgos R, Mondal G, Nielebock S (2020) Evaluation of modular AC filter building blocks for full SiC based grid-tied three phase converters. In: 2020 IEEE energy conversion congress and exposition (ECCE). IEEE, pp 1835–1841
3. Ali AEMM, Mansy III, Ismael IM (2020) Improvement of power quality in electrical distribution system using shunt active power filter controlled by fuzzy logic controller (Dept E). MEJ. Mansoura Eng J 36(1):18–24
4. Onovakpuri O (2019) Investigation of power quality issues due to increased levels of distributed generation and possible solutions