Simulation and Harmonic Analysis of Three-Phase Diode-bridge Rectifier on MATLAB

Sakshi Chaudhary[1], Shreya Walade[2], Vedanti Mangalkar[3], Amit Bijewar[4], Kapil Shinde[5], Rajat Dhengre[6]

[1-6]Final year students, Dept. of Electrical Engineering, Yeshwantrao Chavan of college Engineering, Nagpur Maharashtra, India

---***---

Abstract - *Harmonics have become one of the most important issues in electrical power systems in recent years. In medium-power applications, harmonic reduction in inverters fed from a solo PV system is becoming increasingly significant. The goal of this research is to create and analyze several passive filters for improving power quality in standalone PV systems. To lower the total harmonic distortion of the proposed system, various passive filters are constructed and analyses. The design of passive filters for increasing power quality by reducing harmonic distortion induced by non-linear loads is presented in this thesis. The analysis of harmonics was carried out using the Fast Fourier Transform (FFT) to evaluate the system's Total Harmonic Distortion (THD) with and without filters, and MATLAB/SIMULINK was used to display the simulation findings because it is a well-known and acknowledged simulation software for power systems.*

1. INTRODUCTION

The ever-increasing usage of power electronic loads has brought important technical and economic questions about how power networks should be designed and operated. Despite the fact that they had a limited and localised impact on the harmonic voltage and current levels in these networks, the problem is anticipated to worsen in the future as penetration levels rise.

The investigation in this paper focuses on uncontrolled three-phase rectifiers and their compliance with IEEE 519-2014 standards.

The effects of eventually existing supply voltage harmonics on the response of three-phase filtered rectifiers is described in the reference. There is also a model for determining the current harmonics of these loads when they are energised by non-sinusoidal source voltages.

Using the MATLAB R2018a Simulink power system simulation model, the study investigates the simulation of regulated rectifier circuits. The waveforms are generated by the MATLAB simulation model. These waveforms are compared to the theoretical findings in order to validate this method.

1.1 Harmonics

Electrical energy is supplied at a single, constant frequency and at defined voltage levels of constant magnitude in an ideal power system. The presence of harmonic frequency frequencies is indicated by waveform distortion. The waveforms of real voltage and current are skewed. They're usually referred to as non-sinusoidal waveforms. A non-sinusoidal waveform is generated by combining many sine waves.

A non-sinusoidal waveform is generated by combining several sine waves of various frequencies. As a result, real-world power system signals have both fundamental and harmonic elements. The fundamental wave is the waveform in a non-sinusoidal wave with the frequency at which the device is constructed, intended to function, and/or is being controlled. Therefore, the fundamental frequency is know as fundamental frequency.

1.2 Mitigation of Harmonics

Harmonic distortion is present to some degree on all power systems. Fundamentally, one needs to control harmonics only when they become a problem.

When a problem occurs, the basic options for controlling harmonics are to mitigate the harmonic currents produced by the load by adding filters to the system, which block the currents from entering the system, or supply the harmonic currents locally. Thereafter, modify the frequency response of the system with the help filters, inductors, or capacitors.

When the electrical transmission and distribution system acts as a conduit for harmonics, any device connected to the grid could be responsible for generating them. In this case, identify sources of harmonics.

2. Power Passive Filter

In power systems Passive filter are used to suppress harmonic currents and decrease voltage distortions appearing in sensitive parts of the system. Passive filter work by exhibiting different impedance values at the resonant frequency. A filter connected in series should high impedance to the harmonic frequency that needs to be blocked.

Although a series configuration is possible, it is more common to connect filters in parallel. Such a shunt configuration diverts harmonic currents to ground, and simultaneously provides reactive power, which may be used to correct the power factor.

The topology of passive filters can be used to classify them. The topology can be categorized as shunt, series, or hybrid, with tuned and damped filters acting as low-pass and high-pass for shunt filters and low-block and high-block for series filters.

3. Model of Three-Phase Diode-Bridge Rectifier

A three-phase diode-bridge rectifier is widely used in high-power applications. It can be used with or without a transformer, and the output voltage has six-pulse ripples.

3.1. Circuit Description

Each diode conducts for 120 degrees and is numbered in order of conduction sequences. D1 - D2, D3 - D2, D3 - D4, D3 - D4, D5 - D4, D5 - D6, and D1 - D6 are the diode conduction sequences. The diodes connected to the supply lines with the maximum instantaneous line-to-line voltage can conduct.

Conduction always occurs in the most positive diode and the corresponding most negative diode in 3-phase power rectifiers. Conduction passes from diode to diode as the three phases rotate across the rectifier terminals. Then, in each supply cycle, each diode conducts for 120o (one-third), but only in pairs because it takes two diodes to conduct in pairs.

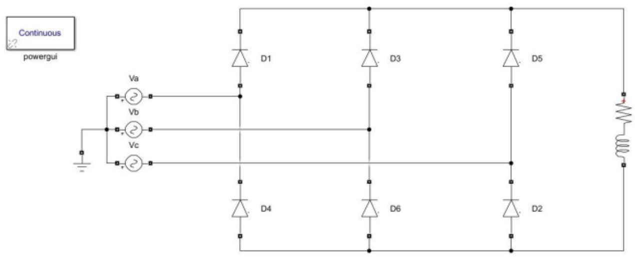

Fig -1: Three-Phase Diode Bridge Rectifier

RMS line to line voltage	400V RMS
Load (Resistive)	6ohms
Load (Inductive)	0.4mH

Table 1. Circuit Parameters

3.2 Harmonic Analysis

Considering the above circuit parameter, we get the following Fast Fourier Analysis of the following circuit:

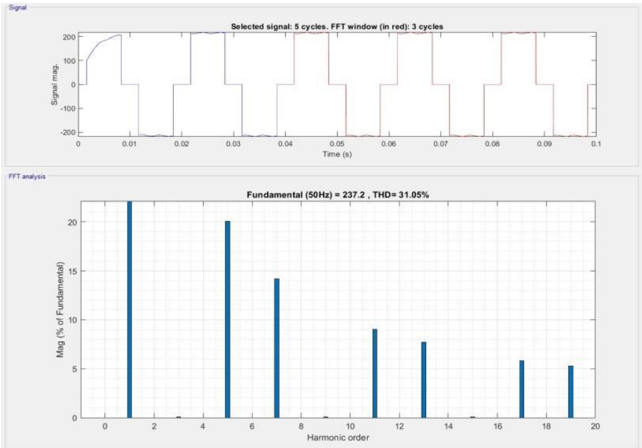

Fig -2: FFT Analysis without filter

From the above figure it is clear that THD of the input current of Three-Phase Diode Bridge Rectifier is **31.05%.**

The input current mainly injects prime order harmonics (i.e. 5, 7, 11..) into the supply system.

In this system, 3k (where k = 1, 2, 3..) order harmonics are not generated as three phase rectifier is used.

4. Proposed Model

The current harmonics on the AC side are considered in the above equivalent circuit of a rectifier. For an exact analysis, it is important to deal with the harmonics. For this reason, a new equivalent circuit model containing a Passive Power Filter for harmonic mitigation is suggested.

Let us consider the average output voltage of three phase diode bridge rectifier as

$$Vdc = \frac{3\sqrt{3}Vm}{\pi} = 1.654Vm = 540.179V$$

The average output current is

$$Idc = \frac{Vdc}{R} = \frac{540.179}{6} = 90.029A$$

Total rms value of supply current is

$$Is = \sqrt{\frac{2}{3}}Ia = 0.8165Ia = 73.529A$$

The rms value of the fundamental current is

$$Is1 = \frac{\sqrt{6}}{\pi}Ia = 0.7797Ia = 70.2156A$$

As the input current waveform is symmetrical in nature, angle between fundamental component of current and supply voltage will be zero.

International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 08 Issue: 05 | May 2021 www.irjet.net p-ISSN: 2395-0072

$$\emptyset_1 = 0$$

Active power (Ps) is

$Ps = 3V_S I_{S1} \cos(\emptyset_1)$ = 48.642kW

The Reactive power required is assumed to be 15% of active power.

$$Q_C = 15\%\ of\ P_S$$
$$= 7.2963KVAR$$

The capacitor's reactance is

$$X_C = \frac{kV^2}{Q_C} = \frac{400^2}{7.2963\times10^{-3}} = 21.923\Omega$$

Size of capacitor is

$$C = \frac{1}{2\pi f X_C} = 145.19\mu F$$

Reactive power supplied should be same by 5th, 7th and 11th harmonics.

Therefore,

$$C_5 = C_7 = C_{11} = \frac{C}{3} = 48.396\mu F$$

For 5th order harmonic,

Capacitor reactance is

$$X_{C5} = \frac{1}{2\pi f C_5} = 65.77\Omega$$

Size of reactor is

$$X_{L5} = \frac{X_{C5}}{n^2} = 2.6308\Omega$$

Inductance is

$$L_5 = \frac{X_{L5}}{2\pi f} = 8.374mH$$

The characteristic reactance is

$$X_5 = \sqrt{X_{L5} * X_{C5}} = 13.154\Omega$$

The series resistance for the inductor is

$$R_5 = \frac{X_5}{Q} = 0.263\Omega$$

Where quality factor(Q) is chosen to 50.

For 7th order harmonic,

Capacitor reactance is

$$X_{C7} = \frac{1}{2\pi f C_7} = 65.77\Omega$$

Size of reactor is

$$X_{L7} = \frac{X_{C7}}{n^2} = 1.3422\Omega$$

Inductance is

$$L_7 = \frac{X_{L7}}{2\pi f} = 4.272mH$$

The characteristic reactance is

$$X_7 = \sqrt{X_{L7} * X_{C7}} = 9.395\Omega$$

The series resistance for the inductor is

$$R_7 = \frac{X_7}{Q} = 0.1879\Omega$$

Where quality factor(Q) is chosen to 50.

For 11th order harmonic,

Capacitor reactance is

$$X_{C11} = \frac{1}{2\pi f C_{11}} = 65.77\Omega$$

Size of reactor is

$$X_{L11} = \frac{X_{C11}}{n^2} = 0.543\Omega$$

Inductance is

$$L_{11} = \frac{X_{L11}}{2\pi f} = 1.728mH$$

The characteristic reactance is

$$X_{11} = \sqrt{X_{L11} * X_{C11}} = 5.976\Omega$$

The series resistance for the inductor is

$$R_{11} = \frac{X_{11}}{Q} = 0.1195\Omega$$

Where quality factor(Q) is chosen to 50.

Harmonic order	Resistance (Ω)	Capacitance (µF)	Inductance(mH)
5th	0.263	48.396	8.374
7th	0.1879	48.396	4.272
11th	0.1195	48.396	1.728

Table 2. Filter Specifications

5. Simulated Result

In the rectified model we just added the filter in the input side of the three-phase diode bridge rectifier with the above calculated values.

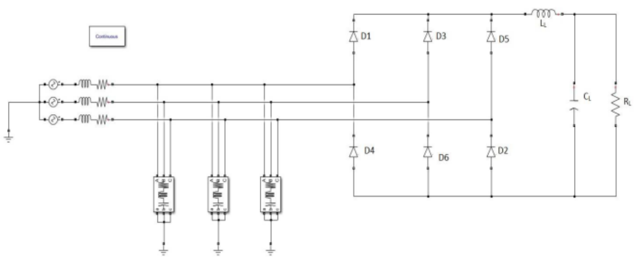

Fig. 3: Three-Phase Diode Bridge Rectifier with Shunt Passive Filter

5.1 Harmonics Analysis with filter

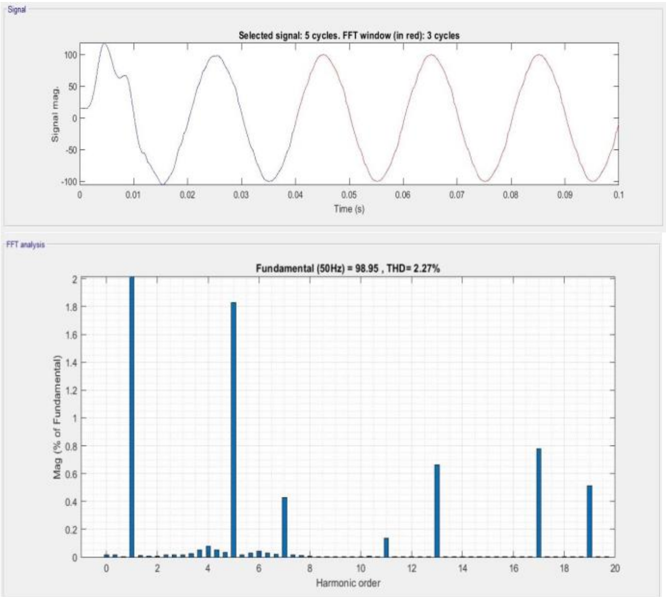

Fig. 4: FFT Analysis with Filter

From the above FFT analysis it is clear that THD of the input current of Three-Phase Diode Bridge Rectifier is **2.27%.**

Therefore, this circuit design satisfies **IEEE 519-2014** Standard of Total Harmonic Distortion which is less than 5%.

6. Conclusion

This journal focuses on the analysis and design of various passive filters. When a well-designed filter is connected, the THD is reduced to a very low value when compared to when there is no filter. Following the results, it can now be concluded that the proposed passive filter design produces the best results.

REFERENCES

1. Recommended Practice and Requirements for Harmonic Control in Electrical Systems, IEEE Std. 519-2014 (Rivision of IEEE std.519- 1992)

2. Anzalchi A., Moghaddami M., Moghadasi A., et al.Design and analysis of a higher order power filter for grid-connected renewable energy systems IEEE Trans. Ind. Appl., 53 (5) (2017), pp. 4149-4161

3. Beres R.N.A review of passive power filters for three-phase grid-connected voltage-source converters IEEE J. Emerg. Sel. Top. Power Electron., 4 (1) (2016), pp. 54-69

4. Jayalath S., Hanif M.An LCL-filter design with optimum total inductance and capacitanceIEEE Trans. Power Electron., 33 (8) (2018), pp. 6687-6698

5. Fang J., Li X., Yang X., et al.An integrated trap-LCL filter with reduced current harmonics for grid-connected converters under weak grid conditions IEEE Trans. Power Electron., 32 (11) (2017), pp. 8446-8457