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Effects of Harmonics in Power Systems and Improvements to Increase Power Quality

Dinesh Tiwari
PG student, Electronics, Pillai, Institute of Information Technology, New Panvel, India

Abstract:
A circuit converting d.c. power to a.c. power at desired voltage and frequency is called an inverter. The output voltage waveform of ideal inverter should be sine wave in nature. However the waveform of practical inverter is non-sinusoidal (or rectangular) and contains harmonics which reduces the power quality a lot. Thus the principle of the paper is to know the effects of harmonics in power system and improvements to increase the power quality using a technique is explained in detail.

Keywords*: Inverters, Harmonic Reduction, PWM inverter, Power quality, Power systems*

1. Introduction

Harmonics have existed in power systems over years. In the past, most electrical equipment used balance linear load. A linear load in a power system distribution is a component in which the current and voltage are perfect sinusoidal. Examples of linear loads are induction motor, heaters and incandescent lamps etc. But the rapid increase in the electronics device technology such as diode, thyristors and more caused industrial loads to become non-linear. These components are called solid state electronic or non-linear load. The non-linear load connected to the power system distribution is responsible to generate harmonics current and voltage. Harmonics in power distribution system are current or voltage that are integer multiples of fundamental frequency. For example if the fundamental frequency is of 50 Hz, then the 2-nd harmonics is 100Hz, the 3-rd is 150Hz and so on. A pure voltage or current sine wave has no distortion and no harmonics but non sinusoidal wave has distortion and harmonics. To quantify the distortion, the term total harmonics distortion (THD) is used. The THD value is the effective value of all the harmonics current added together, compared with the value of the fundamental current and these Waveform distortion can be analyzed using Fourier analysis as a periodical oscillation at different frequency. The harmonics current injected on power distribution system caused by nonlinear load, can damage equipment overtime by sustained overheating or cause sudden failures due to resonant conditions. In order to control harmonics, IEEE Standard 519, “Recommended Practices and Requirement for Harmonic Control in Electrical Power Systems,” was adopted. IEEE Standard 519 limitations on voltage and current harmonics in order to ensure that harmonic distortion levels throughout the Entire electrical distribution system, from utility to consumer, will remain low enough for the system to function properly.

2. Filters Used in Power System

Presence of harmonics has been a lot since the 1990’s and has led to deterioration in the quality of power. Also, some nonlinear loads and electronics equipment are such that instead of drawing current sinusoidally they tend to draw current in short pulses thus creating harmonics. Some of the examples of nonlinear loads would be rectifiers, inverters, etc. Some of the major issues concerned with harmonics in nonlinear loads are overheating, temperature increase in generators, etc. These effects may result into permanent damage of the devices. [3] One of the ways to resolve the issue of harmonics would be using filters in the power system. Installing a filter for nonlinear loads connected in power system would help in reducing the harmonic effect. The filters are widely used in power system for reduction of harmonics.

2.1. Role of Filters in Power System

There are two types of filters – Active Filters and Passive Filters. Capacitors are frequently used in the Active and Passive filters both for harmonics reduction. The Passive filters are used in order to protect the power system by restricting the harmonic current to enter the power system by providing a low impedance path. Passive filters consist of resistors, inductors and capacitors. The Active filters are mostly used in distribution networks for sagging in voltage, flickering, where there are harmonics in current and voltages, etc. Using these filter would result into a better quality of power. There is also a third type of filter which is used i.e. The Hybrid Filter. Hybrid filters are composed of the passive and active filters both. [3]

2.2. Passive Filters

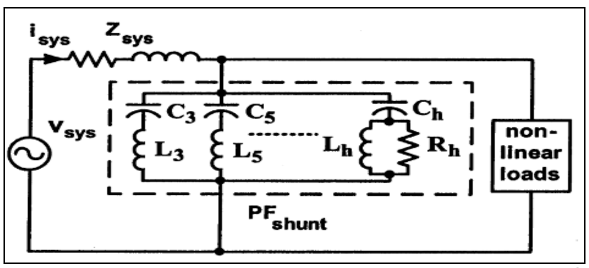
Passive filters consist of resistors, inductors and capacitors. They are not expensive and are often used to restrict the harmonic currents from entering the power system there by minimizing the effect of harmonics due to nonlinear loads. Also, the passive filters are kept close to the source of harmonic generation i.e. the nonlinear loads. Doing so, the passive filters produce better results in reducing the harmonic effect. One of the most important aspects in installing the passive filters in the power system are that they should be installed based on the order of the harmonics that are supposed to be filtered. For example, in order to install a filter for the 3rd order of harmonics, it is required that the filter of 1st order of harmonics is already installed. In order to reduce the harmonic effect; the passive filters create a resonance frequency. This resonance frequency is kept away from the nonlinear load's harmonic distortion. Also, the passive filters are calibrated at a point which is a bit lower than the point at which the harmonics is supposed to be reduced so that, if there is any change in the parameters there is still margin for improvement. If this is not done, then there might be a condition in power system due to capacitance and inductance of filter that the resonance is shifted causing unfavorable conditions in the power system. There are two types of Passive filters

- Shunt Passive Filter.
- Series Passive Filter.

These filters are used for single phase and three phase power system. One important thing to note is that, more than one shunt and series passive filters can be used with and without each other in a system. Some of the basic differences between the shunt passive and series passive filters are as follows.

- The shunt passive filters carry only part of the total load current while the series passive filter carries full load current.
- The shunt passive filters are cheaper compared to the series passive filters so they are used more often than the series passive filters.

Figure 1 and 2 shows the single phase passive filter with shunt and series configuration respectively.



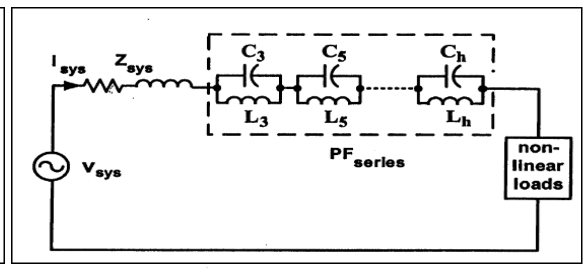


Figure 1: Single Phase Passive filter with Shunt Configuration [3]
Figure 2: Single Phase Passive Filter with Series Configuration [3]

2.3. Active Filters

Active filters are a perfect alternative to the passive filters. The active filters are used in a condition where the harmonic order changes in terms of magnitudes and the phase angles. In such conditions it is feasible to use the active elements instead of passive ones in order to provide dynamic compensation. The active filters are used in nonlinear load conditions where the harmonics are dependent on the time. Just like the passive filters, active filters can be connected in either series or parallel depending on the type of sources which create harmonics in the power system. The active filters minimize the effect of harmonic current by using the active power conditions to produce equal amplitudes of opposite phase there by cancelling the harmonics that are caused in the nonlinear components and replace the current wave from the nonlinear load.

3. Harmonic Reduction in Inverter

3.1. DC- AC Inverter

There are three types of inverter- Single Phase, Three Phase and Multi-Level inverter, used for DC to AC conversion. DC to AC inverters are those devices which are used to produce inversion by converting a direct current into an alternating current. In case of DC to AC inverters the output AC voltage can be either single phase or three phase. Also, the magnitude of the AC voltage is from the range of 110-380 Volts AC while the frequencies are 50 Hz, 60Hz or 400Hz. As explained in earlier, the harmonics can be present in any system. Similarly, the harmonics are present in a system where inverters are used as well. Ideally, the main aim of using an inverter is to produce an ac output from the dc source. Theoretically the output voltage waveform is expected to be sinusoidal, but in practical terms there is definitely going to be distortions due to harmonics present in the system which results into distorted output waveforms. As a result of this, inverters are used in a system in order to produce output waveforms which are purely sinusoidal and distortion free. Figure 3 shows a circuit showing DC-AC inverter along with filters which are used to reduce the effect of harmonics to provide distortion free output ac signal. The front part of the circuit consists of AC to DC converters. These AC to DC converters has one ac frequency i.e. the line frequency and it relies on line communication for switching. The system also consists of DC to AC inverters which are used to turn on or off the power switches. Unlike AC to DC converters in DC to AC inverters, the ac frequency is not the line frequency. The figure also shows a voltage control where variable frequency drives are used to control the speed of motors and provide variable output voltage. Due to this complex structure, the inverter circuits require proper control signals to produce the expected ac output voltage. The figure also shows a filter circuit which is used to reduce the harmonics in the system to produce clean sinusoidal output ac voltage. A comparator circuit is also employed which compares the output ac voltage with the reference ac voltage. If he output ac voltage is more distorted as compared to the reference ac voltage then filter circuits are used again to produce the desired clean sinusoidal AC voltage.[6][7]

3.2. Methods for Harmonic Reduction in Inverters

As explained earlier, one of the most important aspects of a system is the reduction of harmonics that are present in the system. In case of an inverter, it is very important to remove the harmonics from the ac output. The harmonics present in a dc to ac inverter are very much obvious compared to the harmonics that can be present in an ac to dc converter. This is because of the output of dc to ac inverter being ac. Thus, the filters that are used in dc to ac inverter have different designs compared to the filters used in ac to dc converters. In case of ac to dc converters, the main objective is to improve the output voltage ripple. Thus, passive filters can be easily used in order to improve the output of an ac to dc converter. While, in case of dc to ac inverter, the harmonic reduction is harder and it also includes the use of active filters. As the output of dc to ac inverters is alternating, it is very important to produce sinusoidal output waveforms. In order to produce such sinusoidal waveforms, filters are implemented which reduce the harmonic effect by removing the third and higher harmonics from the system. The filters used to remove the harmonics from the inverters are more complex and consists of large number of inductors and capacitors to remove the harmonics of higher order. This also results into more costly filters to remove harmonics from the inverter. Thus, in order to avoid the cost of such expensive and complex filters controlling the width or reducing the number of pulses may result into reduction of harmonics. One such technique is explained below. [6][7]

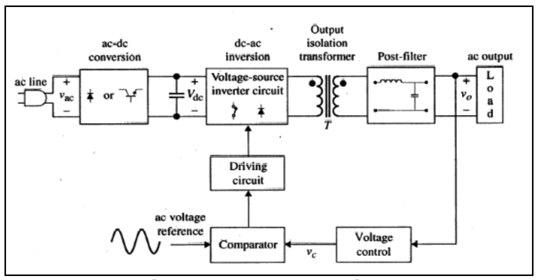


Figure 3: Power Electronic Circuit with DC-AC inverter. [6]

3.3. Pulse Width Modulation Technique

Figure 4 shows a single phase inverter block diagram with a high frequency filter that is used in order to remove the harmonics from the output waveform. Here, vo is the ac output while vin is the input dc voltage.

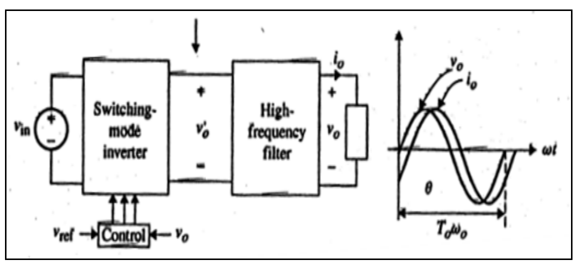
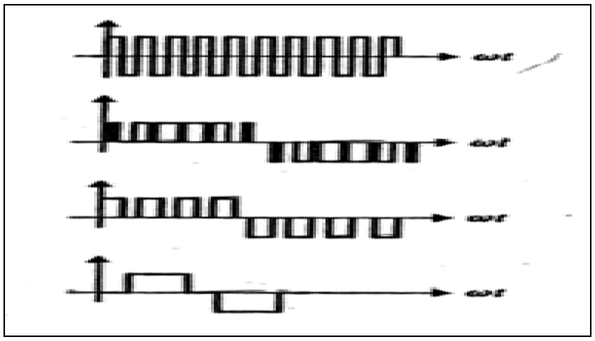


Figure 4: Single Phase Inverter with Filter [6]

Figure 5 shows output waveforms that gets produced based on the Pulse width modulation technique when it is employed. In a single phase inverter, the varying width of the output pulse is used to control the output voltage. Thus, this process of controlling the output voltage of inverter in order to reduce the harmonics is known as Pulse Width Modulation. The Pulse Width Modulation is classified into two techniques. [6]

- Non- Sinusoidal Pulse Width.
- Sinusoidal Pulse Width Modulation

In case of Non sinusoidal pulse width modulation, all the pulses that have same pulse width are modulated together. The pulse widths of pulses are adjusted together in same proportion on order to remove the harmonics from the system. A typical representation of Non sinusoidal pulse width modulation is shown in figure 6 shown below. [6]



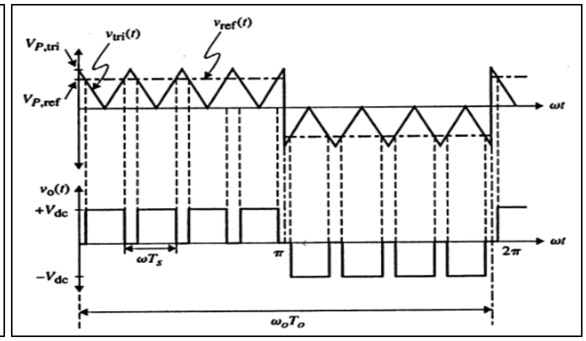


Figure 5: Output waveforms Produced Based on PWM Technique [6]
Figure 6: Representation of Non Sinusoidal Pulse Width Modulation [6]

Sinusoidal Pulse Width Modulation is a bit different compared to Non Sinusoidal Pulse Width Modulation. In case of sinusoidal pulse width modulation, all the pulses are modulated individually. Each and every pulse is compared to a reference sinusoidal pulse and then they are modulated accordingly to produce a waveform which is equal to the reference sinusoidal waveform. Thus, sinusoidal pulse width modulation modulates the pulse width sinusoidally. [6] Figure7 shows a representation of Sinusoidal Pulse Width Modulation.

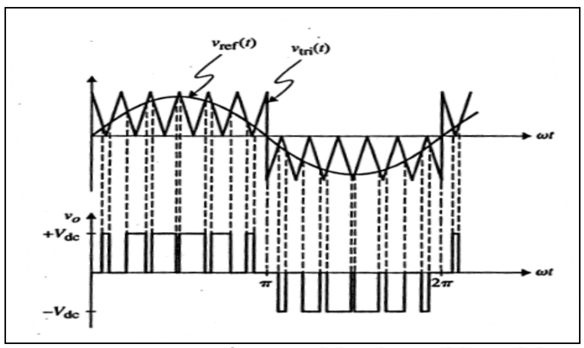


Figure 7: Representation of Sinusoidal Pulse Width Modulation [6]

For figures 6 and 7,

ts	Time of the triangular waveform
fs	frequency of the triangular waveform
Vref	Reference voltage of the square or sinusoidal waveform
Vpref	Peak value of the reference voltage
to	Time of the output waveform of the Inverter which is desired
fo	Frequency of the output waveform of the Inverter which is desired
ma	Amplitude modulation index of Inverter
mf	Frequency modulation index of Inverter
k	Number of pulses per half cycle

4. Conclusion

Thus this paper explains the effects of Harmonics in the Power System and steps to reduce the effects of Harmonics. This paper also explains how Harmonic distortion is one of the most important problems associated with power quality and creates several disturbances to the Power System. It includes the Harmonic reduction techniques to improve the power quality.

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6. Refrences

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