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Strategies for Eliminating Harmonics in an Inverter AC Power Supply

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Abstract: *An intensive effort has been made to articulate the strategies of eliminating or reducing harmonics in the output of an inverter circuit. An inverter is a circuit that converts direct current, dc to alternating current, ac which power most of domestic appliances. The output of this conversion is not free from harmonic distortion. Fourier series expression of the modulating output voltage waveform was analyzed. The amplitude of the fundamental frequency is controlled by adjusting α and its harmonic content can be controlled by adjusting the α, which makes the cosine(s) term of the output voltage to be zero. The elimination is important as it helps to safe guide our electronics devices from failure or burnout.*
Key words: *Harmonics, Inverter, direct current, non-sinusoidal, power system, distortion*

I. Introduction

Harmonics are produced by rapid rise of current, either in positive or negative direction. This results to non-sinusoidal nature of the waveform of the output of an inerter voltage source. Square waves and pulse wave produce a rapid and abrupt rise in this type of waveform [1,2,3,5].
Harmonics currents are the results of non-linear loads demanding a current waveform different from the shape of applied voltage wave. The non-linear load devices includes solid state power switching devices such as diodes, thyristors, SCRs or transistors that converts dc power by drawing the current in pulses. These semiconductor devices forms the majority of electronic component used in electronic devices.

Harmonics in power circuit are frequencies that are integer multiples of fundamental frequency generated by non-linear electrical and electronic equipments. The fundamental frequency (i.e. 50 or 60th) combines with the harmonic sine wave to form repetitive, non-sinusoidal distorted wave shapes [2,3,4].

Nature of Harmonics

Generally, in any facilities, the voltage supplied by a power system is not a pure sine wave. Rather, it usually possesses some amount of distortion, which has a fundamental frequency and harmonics at that frequency. Harmonics produced with even number (i.e. 2,4,6,8, etc) are referred to as even harmonics and those derived from odd numbers are referred to as odd harmonics. Also harmonics produced above the original frequency is called upper harmonics and that below the original frequency are called lowe harmonics.

Harmonic Current and Voltages

Harmonic current are as a result of non-linear loads demanding a current waveform different from the shape of applied voltage wave. Non-linear load devices are those that switch the current 'on' and 'off'. These devices includes solid state power switching devices such as diodes, thyristors, SCRs or transistors that convert direct current, dc power by drawing the current in pulses. Harmonics in power circuit are frequencies that are integer multiplies of a fundamental generated by non-linear electrical and electronics equipments. The fundamental frequency (i.e. 50 or 60th) combines with the harmonics sine wave to form repetitive, non-sinusoidal distorted wave shapes. However, contemporary electronic loads have different current and voltage wave shapes. For instance, the voltage may still appear to be sine wave, but the current waveform appears peaked, as if squeezes together. Such kind of load contains what is called switching power supply.

Total harmonic distortion (THD)

This is the measure of the amount of distortion produced as current flows from the power line. The THD value is the effective value of all harmonic currents added together, compared with the value of the fundamental current. The THD is used to qualify the non-sinusoidal property of a waveform. This can further be expressed as the ratio of the root mean square value of all the fundamental frequency terms to the root mean square value of the fundamental terms [2, 4].

Effect of harmonics in power systems

Harmonics in power systems can cause the following

(i) Heating Effect: Harmonics current flowing in machines causes heating effect both in the conductor and in the iron. It causes overheating of natural conduction and electrical distribution transformer.

(ii) Overvoltage: Harmonic voltage generated by harmonic current flowing against impedance led to significant over voltages. This cause the equipment failure. These over voltages can be enhanced by system resonance whereby a given harmonic current may generate a large harmonic voltage.

(iii) Resonance: When a harmonic current flows in an inductive-capacitive-resistive circuit, it can give rise to parallel resonance. This result to a high harmonic current of the appropriate frequency and this can cause increased harmonic voltage.

(iv) Interference: Power systems harmonics may cause interference with communication, signaling, metering control and protection system either by electromagnetic induction or by the flow of ground current.

(v) Other adverse effect of harmonics include overstressing and heating of insulation, machine vibration, destruction by heating of small auxiliary components of capacitor and motors and malfunctioning of electronics devices.

Hence, these harmonics levels are subject to elimination in order to safeguard consumer electronics devices [1, 2, 3, 4, 5]. Thus, this paper x-rays the strategies required to eliminate these harmonics, since its adverse effect to our machines, electronic devices and equipments cannot be over emphasized.

Harmonic Elimination by Attenuation method:

To attenuate harmonics for elimination, a shunt path for the harmonic current is provided and a series impedance across the harmonic voltage. Here, a harmonic passive filters and inductive reactance are used. In passive filters, tuned series L-C circuit that attenuate specific harmonic frequencies will be applied. The filter offers a low impedance path to ground for chosen frequencies. Also inductive reactance inform of line reactors or isolation transformers can help attenuate higher order harmonics and reduce overall harmonics content. Also inductive reactance in form of line reactors or isolation transformer can help to attenuate higher order harmonics and reduce overall harmonics content [2,3].

Harmonic Reduction by Transformer connection:

In this case, the output voltages of two or more inverter having similar waveforms shifted in phases from one another can be combined by means of transformer to produce a combination of voltage waveform with less harmonic content than that of the individual inverter waveforms [1,2,3].

Harmonic Minimization/Elimination using Pulse Width Modulation (PWM) Method

Harmonic minimization using PWM are designed with the objective of reducing the low order torque harmonics by the weighted minimization of stator current harmonics. The weighted functions or performance criteria, which are used for this minimization, are aimed towards improving the rotor motion. Because the weighted function places more emphasis on minimizing the low order current harmonics, the resulting low order torque harmonics are generally reduced to an acceptable low level.

Harmonic minimization using PMM strategies were designed to minimize the individual harmonic torque component. This in turn will reduce the variation of rotor speed ripple, $\Delta w_r(t)$ and rotor potential error, $\Delta p_e(t)$ respectively [1].

Where

$$\Delta w_r(t) = \frac{1}{j}\int_0^t T\rho(\tau)dt \quad (1)$$

And

$$\Delta p_e(t) = \int_0^t \Delta w_r(\tau)d\tau = \frac{1}{j}\iint_0^t T\rho(\tau)dtd\tau \quad (2)$$

Harmonic Elimination by Multiple Pulse Modulations

By turning the conducting thyristor off and on many times before the control is passed on the next thyristor, multiple pulses per half cycles are obtained. Hence, the number of pulses per half cycle, the less the harmonic output of the inverter.

Harmonic Elimination using Pulse Width Modulation, PWM Techniques

Harmonic elimination by Pulse width modulation switching strategies have been used for sometime in voltage fed inverters and this in more recent times are applied to current fed inverters drives. Harmonic elimination using Pulse width modulation strategies are used to eliminate mechanical resonance which results to harmonics. The objective of this application is avoidance of mechanical resonance. As these mechanical resonances tend to occur at low frequencies, typically in the frequency range below 100 Hz, it is desirable in practice to eliminate the low order stator current harmonics.

Also it is important to eliminate the higher numbers of current harmonics as the current fed inverter output decreases, as more torque harmonics occur within the resonant frequency band. This requires the pulse width modulating number to be progressively increases as the current fed inverter output frequency is reduced. In recent past, PWM switching strategies using three, five and seven pulses per half cycle have been used to eliminate 5^{th}, 7^{th} and 11^{th} current harmonics respectively. Hence, new current fed inverter modulation rules have been adopted which allows substantially higher number of harmonics to be eliminated using pulse width modulating pulse numbers [1, 2, 4].

High Pulse Number Harmonics Elimination using PWM techniques

Practically, it is impossible to eliminate the k lowest order current harmonics using pulse width modulation current waveform with k defined pulse width per quarter cycle $(2k + 1)$ pulses per half cycle. Then to generate a PWM current waveforms, which eliminate more than three harmonics requires numbers greater than seven to be used. [1]

Amplitude and harmonic control in power system

The amplitude of the fundamental frequency for a sequence full bridge inverter output is given by the direct current input voltage as shown in fig 1.

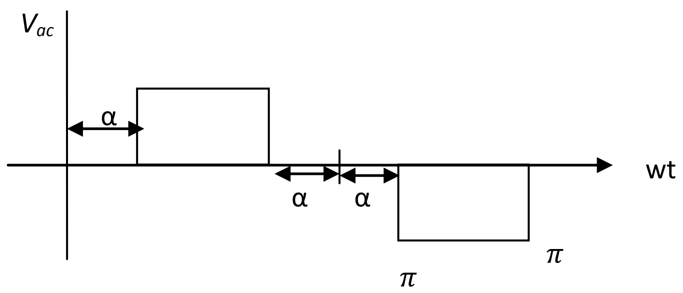

Fig 1: Inverter output for amplitude and harmonic control

$$V_{rms} = \sqrt{\frac{1}{\pi}\int_{\alpha}^{\pi-\alpha} V_{dc}^2 \, d(wt)} \qquad (1)$$

$$V_{\alpha n} = \sum_{n,\ odd} V_n \sin(nwt) \qquad (2)$$

Taking advantage of half wave symmetry, the amplitude is

$$V_n = \frac{2}{\pi}\int_{o}^{\pi-\alpha} \sin(nwt)\, d(wt)$$

$$= \frac{4V_{dc}}{n\pi}\cos(n\alpha) \qquad (3)$$

where α is the angle of zero voltage on each end of the pulse.

The amplitude of each frequency of the output is a function of α. In particular, the amplitude of the fundamental frequency is controlled by adjusting α.

$$\therefore\ V_1 = \frac{4V_{dc}}{\pi}\cos\alpha\,, n = 1 \qquad (4)$$

From eqn. (4), Harmonic content can also be controlled by adjusting α. If $\alpha = 30^o$, then $V_3 = 0$.
That is

$$V_3 = \frac{4V_{dc}}{\pi}\cos 3 \times 30^o$$

$$= \frac{4V_{dc}}{\pi}\cos 90^o = 0$$

This is significant because the third harmonics can be eliminated from the output voltage and current. Also, other harmonics can be eliminated by choosing a value of α, which makes the cosine term(s) go to zero.

II. Conclusion

Harmonics in power system is not healthy on the load that utilizes the system. Therefore efforts should be employed to see that this harmonics were eliminated in direct current power system to safe guide machines, equipments and electrical and electronics devices during its design.

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