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A Review of Multilevel Selective Harmonic Elimination Techniques

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Abstract – Selective harmonic elimination (SHE-PWM) offers tight control of the harmonic spectrum of a given voltage and/or current waveform generated by a power electronics converter. Due to its formulation and focus on elimination of low-order harmonics, it is highly beneficial for high-power converters operating with low switching frequencies. Over the last decade, the application of SHE-PWM has been extended to multilevel converters. This paper provides a comprehensive review of the SHE-PWM modulation technique, aimed at its application to multilevel converters.

Index Terms – pulse width modulation (PWM), selective harmonic elimination (SHE).

1. INTRODUCTION

The performance characteristics of inverter/rectifier conversion systems largely depend on the choice of the particular PWM technique [1], [2].PWM techniques can be broadly classified as carrier-based sinusoidal PWM(SPWM), space vector modulation (SVM) or SHE-PWM. Historically, SHE was proposed in the early 1960s, when it was found that low-order harmonics could be suppressed by adding several switching angles in a square wave voltage [3]. Years later [4], [5], the idea was extended using Fourier series to mathematically express the harmonic contents of a PWM waveform by a group of nonlinear and transcendental equations. Transitions were then calculated in such a way that the low-order harmonics are set to zero while keeping the fundamental at a predefined value. SHE-PWM demonstrates several characteristics including [1]:

1) High performance with low ratio of switching frequency to fundamental frequency;

2) High voltage gain and wide converter bandwidth;

3) Smaller filtering requirements;

4) Elimination of low-order harmonics, resulting in no harmonic interference such as resonance with external line filtering networks, typically employed in inverter power supplies;

5) Low switching losses with tight control of harmonics and ability to leave triplen harmonics uncontrolled to take advantage of circuit topology in a three-phase system;

6) Performance indices that can also be optimized for different quality aspects, such as voltage/current THD.

2. CLASSIFICATION OF SHE - PWM FORMULATIONS

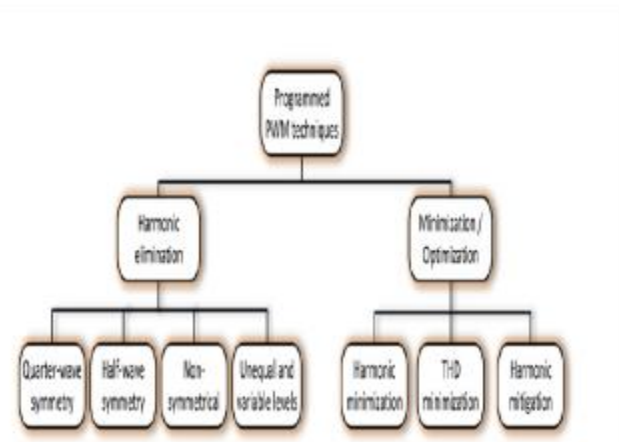

Figure 1. Classification of SHE – PWM

SHE-PWM is based on the Fourier series decomposition of the periodic PWM voltage waveform generated by a power electronics converter, as given by (1), and calculation of the switching angles (αi) that eliminate/control the selected low order harmonics.

$$f_N(t) = \frac{a_0}{2} + \sum_{n=1}^{N} \left(a_n \cos\left(\frac{2\pi nt}{T}\right) + b_n \sin\left(\frac{2\pi nt}{T}\right) \right).$$

There are several ways to define a given SHE-PWM problem, as illustrated in Figure. 1. The simplest formulation of the SHE-

PWM problem for both two-level and multilevel waveforms assumes QW symmetrical waveforms. This greatly simplifies the formulation and solution process, since the dc component, even harmonics and the sine coefficients of odd harmonics are all equal to zero, resulting in the least number of equations requiring solution.

3. MULTILEVEL INVERTER TOPOLOGIES

Owing to the recent popularity and immense industrial usage of multilevel inverters, a lot of research is going on in the field of multilevel inverter topologies. All these topologies have various applications along with their inherent limitations.

There are two methods of controlling multilevel inverters:

- PWM Control (allows variations in output voltage)
- Line Frequency Control (does not allow variation in output voltage)

3.1 Cascaded H-Bridge Multilevel Inverters

- They consist of switching devices and diodes arranged in an H-bridge configuration.
- Changing the pattern of switches give different voltage levels.
- The usual inverter uses separate DC sources but another topology using only single DC source is also available.

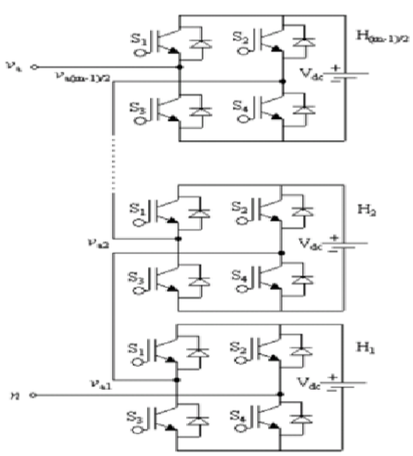

Figure 2. Cascaded H-Bridge Multilevel Inverters

Advantages:

- We get same switching frequencies for all the switches.
- Modular structure is easier to analyze.

Disadvantages:

- Separate DC sources are required.

3.2 Diode Clamped Inverters

- Diode clamped inverters are also known as neutral point inverters.
- They aim at converting the DC source voltage into capacitor voltage.
- For n levels, n-1 consecutive switches from a single phase must be turned on.
- For n levels, n-1 capacitors are required.

Advantages:

- Low cost and less components due to less number of capacitors.
- Can be operated on SDCS.

Disadvantages:

- For more than three levels, the charge balance gets disturbed.
- Output voltage gets limited.

3.3 Capacitor Clamped Inverters

- Also known as flying capacitor inverters (because they float with respect to earth's potential), they use capacitors as clamping devices instead of diodes.
- The clamping capacitors have to be pre-charged before using them in the inverter.
- Only one switch out of each pair has to be in the on state necessarily to ensure the balanced configuration.
- There are redundant states of switches to guarantee balanced voltages in floating capacitors.

Advantages:

- Each branch can be analyzed independently.

Disadvantages:

Pre-charging capacitors is difficult.

4. OTHER TOPOLOGIES

Numerous other topologies have been proposed which aim at combining the benefits of these basic topologies or removing their disadvantages. Few of the relatively popular ones are mentioned:

- Generalized P2-cell Multilevel Inverter

Abbreviated as GMLI, this cell has the capability to self-balance, which the previous topologies lacked. This comes really handy while delivering active power. GMLI has two voltage level cells. Each contains two pairs of diodes and switches and one capacitor in each cell. All these cells are connected in a triangle.

- Reversing Voltage Multilevel Inverter

RVMLI is a relatively less popular topology. It first gives only half wave by sending only positive value and then by using a converter, it changes it into negative value half way through to give out a complete sine wave.

- Modular Multilevel Inverter

Modular multilevel is a new topology and as its name suggests, its design strategy involves modules. Modular approach has been accepted as an easier and better approach by many schools. Every module consists of half bridge.

Which of the topologies is the best depends, upon place where you use it and you requirements. There are many types of multi-level inverters, designed according to different applications and their uses.

5. CLASSIFICATION OF SHE - PWM ALGORITHMS AND SOLVING TECHNIQUES

The various algorithms and solving techniques for obtaining the optimal and/or multiple sets of solutions for a range of SHE-PWM is shown in the figure 3.

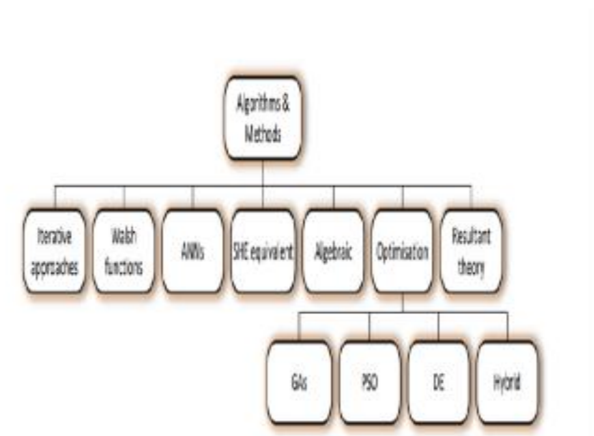

Figure 3. Classification of SHE-PWM algorithms and solving techniques.

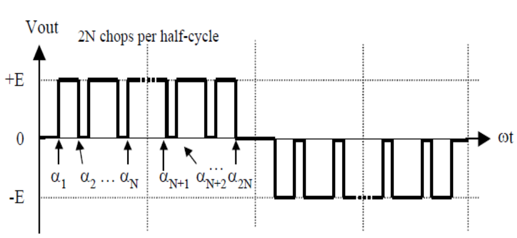

Figure 4 Generalized three-level SHE PWM waveform

6. CONCLUSION

The selective harmonic eliminated PWM technique is reviewed. SHE-PWM is a very promising approach for future advanced power conversion systems, and there is a wide range of research opportunities across different aspects that should be investigated to improve its features and practicality.

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