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Developing a novel sinusoidal pulse width modulation (SPWM) technique to eliminate side band harmonics

Ilhami Colak [a,*], Ersan Kabalci [b]

[a] Department of Electrical & Electronics Engineering, Faculty of Technology, Gazi University, 06500 Ankara, Turkey
[b] Department of Electrical & Electronics Engineering, Faculty of Engineering and Architecture, Nevsehir University, 50300 Nevsehir, Turkey

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ABSTRACT

In this study, an enhanced SPWM modulation scheme is developed in order to minimize total harmonic ratio (THD) by eliminating the side band harmonics that are not paid attention in regular modulation schemes. Unlike the conventional SPWM, the developed modulation scheme considers the elimination of harmonics that are located at the carrier frequency and at the side bands of carrier frequencies. Therefore, the harmonic elimination feature of SPWM that eliminates the base harmonic orders but not considers the side band harmonics in frequency domain is improved with the developed analytical definition. The side band harmonic elimination feature of the proposed SPWM scheme eliminates higher order harmonics. The elimination of high-ordered attenuated harmonics decreases the harmonic contents seen in the THD spectrum. The simulation of inverter is carried out with Matlab/Simulink and experimental studies are performed utilizing TMS320F2812 DSP. The proposed SPWM schemes is tested according to various control strategies such as switching frequency (f_{sw}) and modulation index (m_i) terms by using a full bridge inverter. The analytical model improved to calculate and generate switching intervals is simultaneously operated in DSP instead of managing a look-up table. The experimental studies of the inverter verify that the developed SPWM modulation scheme mitigates the side band harmonics successfully. The higher order harmonics are eliminated and the THD ratios are decreased owing to proposed SPWM scheme.

1. Introduction

The static power converter based inverters are utilized in adjustable speed drives (ASDs), static VAR compensators, active filters, uninterruptible power sources (UPSs), and flexible AC transmission systems (FACTSs) which are only a few applications for industrial uses. The AC voltage generated at the output of inverter may be variable or constant depending to the requirements of the applications. The voltage source inverters (VSIs), where the independently controlled AC output is a voltage waveform, behave as voltage sources required by many industrial applications. The current source inverters (CSIs) are still widely used in medium-voltage industrial applications, where high-quality current waveforms are required. The VSI generates an AC output voltage waveform composed of discrete values (high dv/dt); therefore, the load should be inductive at the harmonic frequencies in order to produce a smooth current waveform.

A capacitive load in the VSIs will generate large current spikes, which can be prevented by an inductive filter between the AC side of VSI and the load. An inductive load in CSIs will generate large voltage spikes as on the contrary to VSI. If this is the case, a capacitive filter between the CSI AC side and the load should be used [1–4]. The efficiency parameters of an inverter such as switching losses and harmonic reduction are principally depended on the modulation strategies used to control the inverter [5–7]. As depicted in Fig. 1, inverter control techniques are based on fundamental frequency and high switching frequency.

The regular PWM modulation methods can be classified as an open loop and a closed loop owing to its control strategy. Open loop PWM techniques are the SPMW, the space vector PWM, the Sigma–Delta modulation, while closed loop current control methods are the Hysteresis, the Linear, and the Optimized current control techniques. The modulation methods developed to control the multilevel inverters are based on multi-carrier orders with PWM. Due to pre-defined calculations are required, the Selective Harmonic Elimination SHE–PWM is not an appropriate solution for closed loop implementation and dynamic operation in multilevel inverters. Among various control schemes, the sinusoidal PWM (SPWM) is the most commonly used control scheme for the control of multilevel inverters. In classical SPWM, a sinusoidal reference waveform is compared with a triangular carrier waveform to generate switching sequences for power semiconductor in inverter modules. The fundamental frequency SPWM control method was proposed to minimize the switching losses. The multi-carrier SPWM control methods are also implemented to increase the

* Corresponding author. Tel./fax: +90 312 212 13 38.
E-mail address: icolak@gazi.edu.tr (I. Colak).

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Nomenclature

CSI	current source inverter	VSI	voltage source inverter
DSP	digital signal processor	f_{sw}	switching frequency
FFT	fast Fourier transform	G	gain
IC	integrated circuit	m_i	modulation index
IGBT	insulated-gate bipolar transistor	V_d	DC supply voltage
SPWM	sinusoidal pulse width modulation	V_{ab}	line to line voltages
THD	total harmonic distortion		

performance of multilevel inverters and are classified according to vertical or horizontal arrangements of carrier signal [8–12]. There are several studies performed to evaluate control algorithms with DSPs in recent years owing to its robust processing capabilities of 32-bit, and fixed or floating-point calculations [13–15].

In this paper, classical SPWM control algorithm is developed by considering the side band harmonics and modulation bandwidth in Simulink during simulation. The experimental verification of the modeled system is analyzed by controlling the IGBT modules with developed SPWM algorithm generated by a TMS320F2812 DSP. The current and voltage waveforms generated by both simulation and experimental studies are compared under various conditions such as variable m_i and f_{sw} values. The THD ratios obtained and power factor of the implemented system are compared according to the similar studies in the literature. The performed studies were focused on DSP implementation instead of comparative analyzing in terms of harmonic contents or other factors in the generated line voltages and currents. The performance of the simulation is checked with DSP implementation. The THD ratios of both voltage and current of the implemented VSI provided better results according to previous studies [15–19].

2. System modeling

Modeling studies are performed by defining the inverter and control algorithm requirements. Full bridge inverter topology is selected due to its widespread application area. The circuit topology, the SPWM control scheme, and implementing the Simulink model of the inverter are analyzed in detail.

2.1. Circuit topology

While the single-phase VSIs cover low-range power applications, three-phase VSIs cover medium to high-power applications. The main purpose of these topologies is to provide a three-phase output voltage, where the amplitude, the phase, and the frequency of voltage should always be controllable. Three-phase bridge inverters are widely used in motor drives and general-purpose AC supplies. A typical three-phase VSI topology is shown in Fig. 2. As in single-phase VSIs, the switches of any leg in the inverter (S_1 and S_4, S_3 and S_6, or S_5 and S_2) cannot be switched on simultaneously to prevent a short circuit across the DC link voltage supply.

Similarly, in order to avoid undefined switching states and undefined AC output line voltages in the VSI, the switches of any leg in the inverter cannot be switched off simultaneously. The phase outputs are mutually phase shifted by 120° angles as seen in the Fourier expansions in Eqs. (1)–(3) where, V_d is the DC supply voltage. The line voltages can be defined as expressed for V_{ab} in Eq. (4).

$$V_{a0} = \frac{2V_d}{\pi}\left[\cos\omega t - \frac{1}{3}\cos 3\omega t + \frac{1}{5}\cos 5\omega t - \cdots\right] \quad (1)$$

$$V_{b0} = \frac{2V_d}{\pi}\left[\cos\left(\omega t - \frac{2\pi}{3}\right) - \frac{1}{3}\cos 3\left(\omega t - \frac{2\pi}{3}\right) + \frac{1}{5}\cos 5\left(\omega t - \frac{2\pi}{3}\right) - \cdots\right] \quad (2)$$

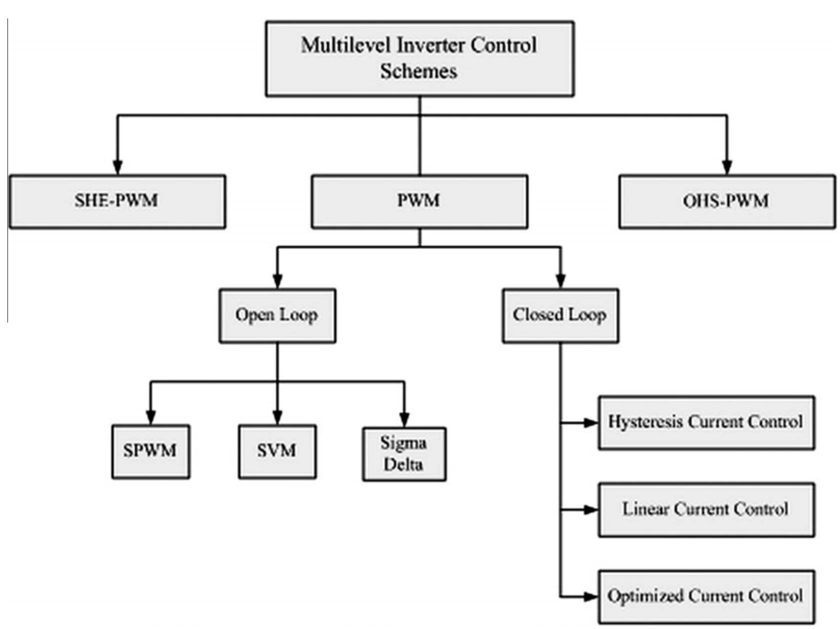

Fig. 1. Classification of multilevel inverter control schemes.