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HBCC WITH FUZZY LOGIC TECHNIQUE FOR THREE–PHASE PWM AC CHOPPER FED INDUCTION MOTOR DRIVE SYSTEM FOR POWER FACTOR CORRECTION

[*1]Dr. P. Chandra Sekhar, [2]M. Deepthi

[1]Associate Professor, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India.

[2]Student, PEED, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India.

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***Corresponding Author: Dr. P. Chandra Sekhar**
Associate Professor, Department of EEE, Mahatma Gandhi Institute of Technology, Hyderabad, Telangana, India.
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ABSTRACT

Switched Capacitor Multi Level Inverter (SCMLI) with reduced components is attractive for higher number of voltage levels due to less implementation complexity and low cost. In this study, a new family of hybrid SCMLI for high frequency power distribution system is presented to eliminate the intermediate power conversion. Firstly, a five-level SCMLI employing a single voltage source is proposed, which is further extended to nine-level (9L) with its operation. Further extension/enhancement of the proposed 9L-SCMLI for generating a higher number of voltage levels with reduced number of components is achieved on the basis of structural modification. The mathematical analysis for determination of capacitance, power loss analysis and comparative analysis has been provided in detail. A comprehensive comparison with other similar topologies is also provided to highlight the merits of the proposed topology. Simulation and experimental results are discussed for various dynamic load conditions with different output frequencies to validate the suitability of the proposed SCMLI for various high-frequency AC applications, such as renewable energy systems, microgrids, electric vehicles and so on.

KEYWORDS: Fuzzy Logic, PWM Chopper, Hysteresis Band Current Control, Power Factor Correction.

1. INTRODUCTION

NASA has introduced the high-frequency AC (HFAC) power distribution system (PDS) for space applications, as it offers several merits over the conventional DC power distribution [1, 2]. HFAC PDS is also an attractive solution to other applications like telecom, electric vehicles and renewable energy microgrids. The high-frequency inverters have advantages like reduced high- order harmonics and low current ripple harmonics in induction motor drives. Power converters play a major role in microgrids due to their advantages like being efficient, reliable, managed heat distribution and high power density[3] . Multilevel inverters (MLIs) are one of the emerging converters owing to their several structural benefits in terms of easy extension, reduced voltage stress (dv/dt) and having equal load sharing and efficient energy harvesting making them highly suitable for various renewable energy applications. Among several MLIs, switched capacitor MLIs (SCMLIs) are the most widely used because of the features of voltage boosting over conventional ones with reduced number of DC sources. To generate a higher number of voltage levels, cascaded MLIs are taken into consideration aiming for reduced number of devices but it ends up having high blocking voltage and does not ensure the voltage boosting feature[4].

There are several power and signal transmission methods that have been applied in various areas. For example, the general method for transmitting data through a power line is to modulate the data onto a high-frequency carrier, and then couple the data to the power line through a coupling circuit after power amplification [5]. Since the power line itself is not designed to transmit communication data, adding signals on it can increase the complexity of the power line channel. Additionally, the electromagnetic interference should be considered while designing a broadband power line communication (PLC) model as its 2 MHz to 32 MHz carrier frequency may coincide with the frequency of short-wave radios [6]. Power over Ethernet (PoE) is the technology that uses twisted-pair Ethernet cabling to pass data along with electric power to some IP-based terminals such as voice-over-Internet telephones and IP camera. However, because the maximum output power of power sourcing equipment of PoE is larger than 15.4W in the standard IPEED802.3af, such technique is not suitable for pan–tilt–zoom camera and other high power required applications [7].

2. CASCADED H-BRIDGE MULTI LEVEL INVERTER

Cascaded H-Bridge (CHB) configuration has recently become very popular in high-power AC supplies. A cascade multilevel inverter consists of a series of H-bridge (single-phase full bridge) inverter units in each of its three phases. The ac terminal voltages of different level inverters are connected in series. Through different combinations of the four switches, S1-S4, each converter level can generate three different voltage outputs, +*Vdc*, -*Vdc*and zero. The AC outputs of different full-bridge converters in the same phase are connected in series such that the synthesized voltage waveform is the sum of the individual converter outputs. Note that the number of output-phase voltage levels is defined in a different way from those of the two previous converters (i.e. diode clamped and flying capacitor). In this topology, the number of output-phase voltage levels is defined by $m= 2N+1$, where N is the number of DC sources. A seven-level cascaded converter, for example, consists of three DC sources and three full bridge converters. Minimum harmonic distortion can be obtained by controlling the conducting angles at different converter levels. Each H-bridge unit generates a quasi-square waveform by phase shifting its positive and negative phase legs‟ switching timings. Each switching device always conducts for 180° (or half cycle) regardless of the pulse width of the quasi-square wave. This switching method makes all of the switching devices current stress equal. In the charging mode, the cascade converters act as rectifiers, and power flows from the charger (ac source) to the batteries. The cascade converters can also act as rectifiers to help recover the kinetic energy of the vehicle if regenerative braking is used. The cascade inverter can also be used in parallel HEV configurations. This new converter can avoid extra clamping diodes or voltage balancing capacitors.

The combination of the 180° conducting method and the pattern-swapping scheme make the cascade inverters voltage and current stresses the same and battery voltage balanced Identical H- bridge inverter units can be utilized, thus improving modularity and manufacturability and greatly reducing production costs.

3. CASCADED H-BRIDGE INVERTER

The conducting angles, θ1, θ2, ...,θs, can be chosen such that the voltage total harmonic distortion is a minimum. Generally, these angles are chosen so that predominant lower frequency harmonics, 5th, 7th, 11th, and 13th, harmonics are eliminated. More detail on harmonic elimination techniques will be presented in the next section. Multilevel cascaded inverters have been proposed for such applications as static var generation, an interface with renewable energy sources, and for battery-based applications. Three-phase cascaded inverters can be connected in wye, as shown in Figure 4.3, or in delta. Peng has demonstrated a prototype multilevel cascaded static var generator connected in parallel with the electrical system that could supply or draw reactive current from an electrical system. The inverter could be controlled to either regulate the power factor of the current drawn from the source or the bus voltage of the electrical system where the inverter was connected.

Peng and Joos have also shown that a cascade inverter can be directly connected in series with the electrical system for static var compensation. Cascaded inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaic's or fuel cells. Cascaded inverters have also been proposed for use as the main traction drive in electric vehicles, where several batteries or ultra capacitors are well suited to serve as SDCSs. The cascaded inverter could also serve as a rectifier/charger for the batteries of an electric vehicle while the vehicle was connected to anac supply as shown in Figure 1. Additionally, the cascade inverter can act as a rectifier in a vehicle that uses regenerative braking.

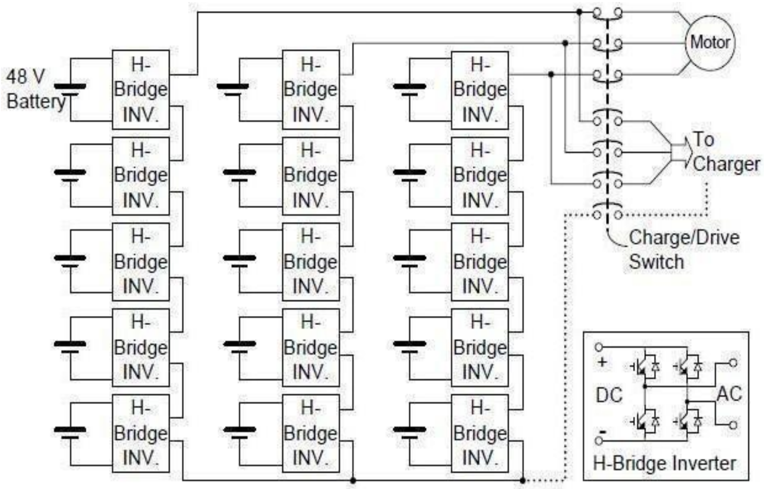

Figure1: Three-phase wye-connection structure for electric vehicle motor drive and battery charging.

4. PROPOSED POWER AND SIGNAL MULTIPLEX TRANSMISSION

This paper elaborates the principle of the proposed P&SMT method by using the transmitted battery state of charge (SOC) signal and motor speed control signal as an example. The proposed system structure of an EV using the P&SMT method is shown in Fig. 2.

The communication between the battery and BMS, and that between the MCU and motor are realized by transmitting signals through a three-phase multilevel inverter circuit. The proposed topology of a three-phase P&SMT system is indicated in Fig. 3. Specifically, each phase of the inverter topology contains four series connected H-bridge cells, where the cell powered by a DC voltage source is used for signal transmission, and the rest three cells powered by batteries are applied for energy transmission. The motor speed adjustment signal and the SOC signal are transmitted through the phase A and phase B branch respectively. In this model, a permanent magnet synchronous motor (PMSM) is applied as a load of the inverter topology.

The signals are modulated by the FSK method in the proposed system and the signal transmission scheme is presented in Fig. 2. If the transmitted 4-bit signal SI is '1010', then two carriers with different frequencies shown in SC can be applied for modulating digital '1' and digital '0' respectively. Since the signal is designed to be transmitted through an H-bridge cell in each phase, such the signal can be modulated by controlling the fast switching process of the four switches in the cell. Specifically, a switch will turn on if a digital '1' is applied as a gate signal and it will turn off when digital '0' is used. In Fig. 3, the switches Q1 Besides, the switches Q1 and Q2 operate with the opposite state to that of the switches Q3 and Q4 to avoid short circuit. Because the H-bridge cell used for signal transmission is series connected with the other three cells applied for energy transmission, the transmitted signal can be considered as superimposed on the output current waveform.

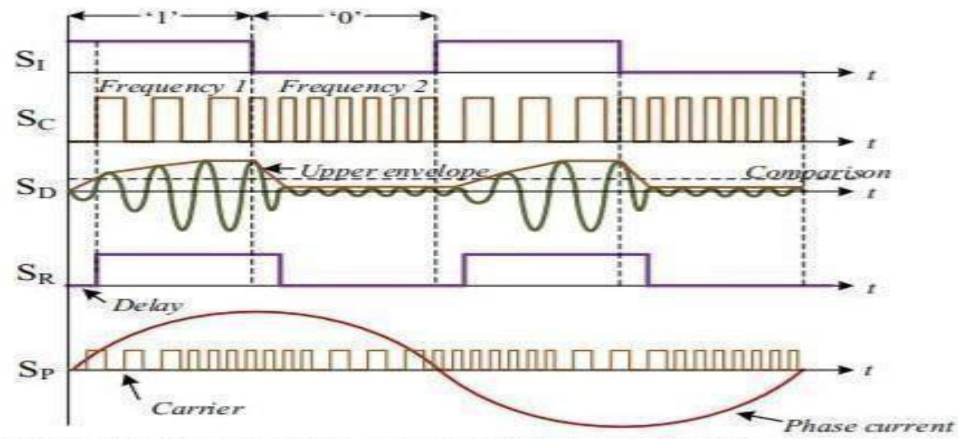

Figure 2: The signal transmission scheme of the proposed system.

Then a band-pass filter is employed to extract the transmitted signal from the output current waveform at receiver. For any signal f(x) with period T and angular frequency ω=2π/T, its Fourier series expansion can be expressed as:

$$F(x) = \frac{1}{2}a_0 + \sum_{n=1}^{\infty}(a_n \cos n\omega x + b_n \sin n\omega x) \qquad (1)$$

where the coefficients in this series are defined by

$$\begin{cases} a_0 = \dfrac{2}{T}\displaystyle\int_{-T/2}^{T/2} f(x)\,dx \\ a_n = \dfrac{2}{T}\displaystyle\int_{-T/2}^{T/2} f(x)\cos n\omega x dx \\ b_n = \dfrac{2}{T}\displaystyle\int_{-T/2}^{T/2} f(x)\sin n\omega x dx \end{cases} \qquad (2)$$

Similarly, if a square wave f(t) with period T is applied as a carrier for digital '1', it can be expressed as:

$$f(t) = \begin{cases} 0 & -\dfrac{T}{2} \le t < 0 \\ 1 & 0 \le t \le \dfrac{T}{2} \end{cases} \qquad (3)$$

The Fourier series expansion of f (t) is derived as:

$$F(t) = \frac{1}{2} + \frac{2}{\pi}\sin x + \frac{2}{3\pi}\sin 3x + \frac{2}{5\pi}\sin 5x + \frac{2}{7\pi}\sin 7x + \ldots + \frac{2}{n\pi}\sin nx \qquad (4)$$

where n is an odd number. Because the Fourier series expansion of f(t) only contains the odd harmonic components, and the first-order harmonic has the largest amplitude, the first-order harmonic can be utilized for restoring the communication signals. For instance, the curve SD in Figure 2 represents the

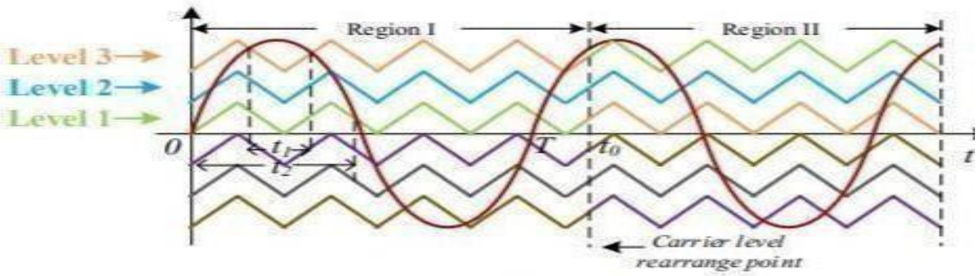

Figure 3: Carrier level reaarangement in the PMW process.

Demodulated carrier for digital '1', then its upper envelope can be acquired using an envelope detector. With an appropriate comparison value, the upper envelope can be recovered to digital '1' when its amplitude larger than the comparison value. Otherwise, it will be recovered to digital '0'. Finally, the restored SR is obtained after sampling the recovered digital signal using the initial bit rate of SI.

Motor Speed Regulation and Battery Balance Discharging

In the proposed system, the motor speed is managed by setting the power frequency different values with the transmitted signal. Expressly, the relationship among the motor speed n, pole-pair p, and power frequency f for a PMSM is indicated as:

$$n = \frac{60f}{p} \qquad (5)$$

where the constant 60 refers to 60 s/min. Theoretically, the speed of a 2-pole pair motor should change between 1200 r/min and 1800 r/min if its power frequency varies between 40 Hz and 60 Hz. With the transmitted signal s, the power frequency f is then calculated by

$$f = 20 \times s + 40 \qquad (6)$$

The power frequency will be 40 Hz and 60 Hz if the digital '0' and digital '1' occur in the transmitted signal s respectively. Next, the three-phase reference sinusoidal waves are obtained from

$$\begin{cases} P_a = A\sin(2\pi f) \\ P_b = A\sin\left(2\pi f - \frac{2}{3}\pi\right) \\ P_c = A\sin\left(2\pi f - \frac{4}{3}\pi\right) \end{cases} \qquad (7)$$

where Pa, Pb, and Pc represent the reference wave in phase A, phase B, and phase C respectively, and A is amplitude. The phase B and phase C reference waves lag the phase A reference wave by 2π/3 and 4π/3 radians respectively. Finally, the modulated variable frequency sine waves are used to drive the motor to achieve motor speed adjustment.

In the conventional sinusoidal PWM method, the gating signal of a switch is generated by comparing the reference wave with a triangular carrier. Because various carriers and the reference wave intersect at different positions, the duty cycle of each switch is different. For instance, in a single period from 0 to T as displayed, the duty cycle of a switch controlled by 'Level 3' carrier is smaller than that of the other switch modulated by 'Level 1' carrier (t1<t2) . Since the input power comes from batteries, the switch operating with a smaller duty cycle consumes less power than the switch operating with a larger duty cycle. This will further lead to the case of batteries' remaining capacity being unbalanced after the system running for a while. Therefore, the battery balance discharging can be realised by periodically rearranging the carrier levels within the PWM process. To achieve this target,

firstly, the battery SOC values at the periodical sampling point are combined to form a data stream and transmitted through the DC voltage source powered full-bridge cell using FSK method. After demodulating the signal from the phase current, the SOC values are separated into different decimal numbers. Finally, the carrier levels of PWM are rearranged according to the transmitted SOC and the battery balance discharging is realized.

5. CONCLUSION

The proposed power and signal multiplex transmission system enables simultaneous transfer of electrical power and communication signals over a single medium, enhancing efficiency and reducing wiring complexity. It supports improved space utilization and cost-effectiveness, particularly in compact or remote systems. This integration can lead to more reliable and streamlined operations in various industrial and technological applications.

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