A Review of Experimental Study of Modular Multilevel Converter for Electric Vehicle Application

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Abstract- A power conversion system for plug-in hybrid electric vehicles based on "back-to-back" modular multilevel converter (BMMC) is proposed to solve the problem that traditional MMC-EV can only work with an engine. Specific A.C. current harmonics was introduced by operation of MMC-EV will speed up battery degradation and are harmful to battery lifetime. Electric vehicles are in great demand today due to rising fuel prices and environmental pollution concerns. As the backbone of EVs is an energy storage system, careful and efficient control of the energy storage system in terms of electricity, current, power and temperature is essential. This work addresses this problem by introducing a converter topology that allows a better use of battery cells and improves the efficiency of the energy conversion system.

Keywords-Modular Multilevel Converter, Electric Vehicle, Battery Lifetime, Circulating Current.

1 Introduction

The Modular Multilevel Converter (MMC) represents the emerging topology with scalable technology that enables advanced power and energy efficiency. The MMC is built on top of it, but each controls the submodule. Modular Multilevel Converter (MMC) is a new multilevel converter with medium and high power consumption.

Electric Power Supply (EVs) or plug-ins for free electric (PHEVs) is the best solution to replace the fuel in the transport component that helps to reduce greenhouse gas emissions and pollute the environment.

The use of vehicles is increasing every day. As vehicles are powered by fossil fuels such as gasoline and diesel, they cause air pollution, leading to global warming and related problems. More on fossil fuels are no longer a reliable source of energy as they are rapidly depleting. So here comes the role of the electric vehicles they use. Electric vehicles (EVs) are attractive alternatives to conventional gasoline and diesel internal combustion engines because they produce zero tailpipe emissions. The electric vehicle consists of a conventional internal combustion (IC) engine and an electric motor part. For the electrical part we use a converter, electric motor and a battery. However, they are limited by short range due to the limited amount of energy stored in electrochemical batteries. Electric vehicles are a less mature technology with still large scope for improvement, particularly in the area of energy storage devices and electric drives. The diffusion of EVs can be significantly improved with a better use of available energy, and this can be achieved by making the energy conversion system increasingly light, compact, flexible and reliable.

This work proposes a new modular multilevel converter (MMC) with embedded electrochemical cells that achieves very low cell unbalance without traditional balancing circuits and negligible harmonic content of the output currents. In this new topology, cells are connected in series through half-bridge converters, allowing high flexibility for battery discharging and recharging. The converter has a cell balance control that operates on each individual converter arm to equalize the state of charge of the cells.

Modular multilevel converters have been applied in the field of speed regulation, and there has been related research. They have better performance and unique advantages in speed regulation. Compared with two-level converter, its output voltage and current have lower harmonic distortion and electromagnetic interference rate. The battery pack is incorporated into the DC side of the modular multilevel converter (SM) submodule to form an energy storage type modular multilevel converter. This structure has been used in energy storage, new connection to the energy grid and regulation of the motor speed of electric vehicles.

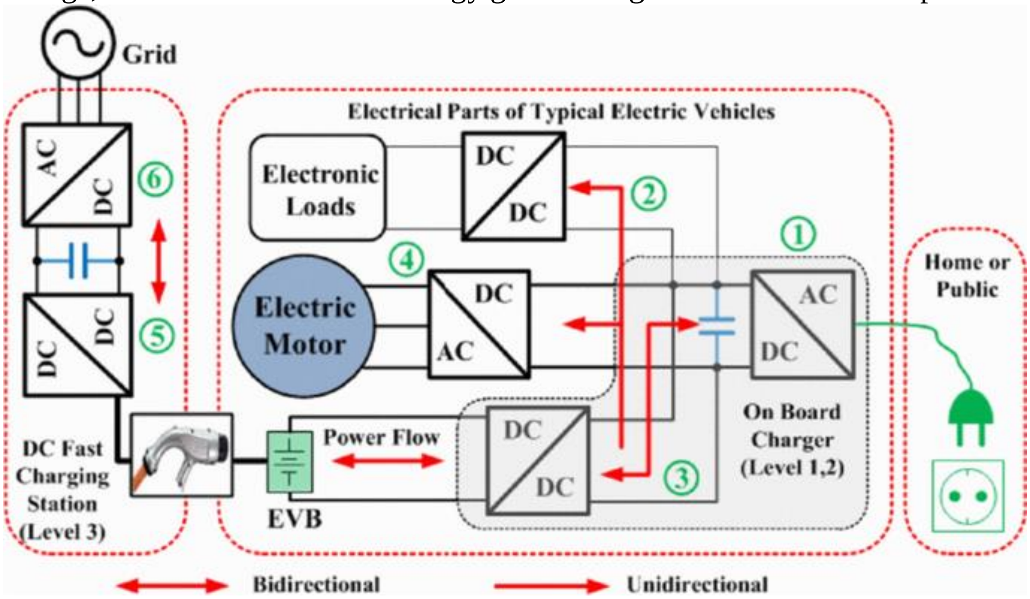

Figure 1 Modular Multilevel Converter with Electric Power Supply

This feature produces a mixed multilevel converter that can be used for low power electric motor applications. The topology uses energy storage to distribute electricity, including batteries. Batteries can be designed to charge or discharge depending on requirements. If the drive is expected to transfer power to the motor (assuming it is connected to the charging end of the drive), the batteries will be active in output mode. Once the combined load has come in, it adjusts the path at the converter's output, the batteries drain and charge.

2 Literature review

Nan Li et al. (2020), This paper proposes a multi-functional modular multi-level conversion system for electric vehicle, which can provide only the engine drive function as well as AC and DC battery charging functions. To illustrate the proposed system well, operational principles and control strategies are fully investigated, including state-of-charge (SOC) balance control strategy in conduction mode, DC or AC charging methods in charging mode.

Di Wang et al. (2019), The application of the multilevel modular converter (MMC) in the electric vehicle (EV) system is being studied in recent years as one of the emerging research topics, for its several advantages such as high modularity, tolerance failure capability, high-quality output and the ability to integrate the function of motor drive, on-board charger and cell equalizer. However, specific AC current harmonics introduced by MMC operation will accelerate battery degradation and are detrimental to battery life. In previous research on MMC in LV, there is no related study solving this problem. In this paper, an improved CMM v control method based on second-order circulating current injection is proposed, mitigating the negative influence of current harmonics on battery life, without increasing hardware cost.

Rahul Jaiswal et al. (2019), This paper presents the comparative analysis of the modular multilevel converter using a multicar modulation technique. Total harmonic distortion (THD) analysis was performed using the phase-array pulse-width modulation (PD-PWM) and phase-opposition-array pulse-width modulation (POD-PWM) technique at an index of variable modulation and fixed switching frequency. This analysis demonstrates that the POD-PWM v technique provides better harmonic performance and better response. The THD of MMC in a carrier variable v frequency and unit modulation index was also analyzed. This shows that the THD is enhanced beyond the carrier frequency.

The 20th century has seen an increase in energy demand and the like requires the development of new technologies and devices as a solution to meet these demands as well as conserving energy. Power generation from different sustainable sources (such as solar, wind, etc.) will account for the world's energy production in the coming years. Therefore, there is a need for reliable energy conversion and energy control techniques. To transmit high power over long distances, for example transporting wind energy from offshore areas to onshore areas, a high voltage direct current (HVDC) transmission system has been used. The reason for choosing HVDC systems over AC systems is that it limits short circuit current, lower losses, more economical and better controllability. However, the most essential advantage of HVDC systems is that the transmitted active power can be controlled.

Di Wang et al (2020), The multilevel modular converter (MMC) for electric vehicle applications has been studied in recent years, for its advantages such as high modularity, fault tolerance capability and multifunction capability (drive motor, equalizer cell and on-board charger) integration. However, during MMC operation, specific AC harmonics will be introduced into the battery cell currents, reducing battery life. A common mode multiple voltage injection control method, increasing the frequency of the 2nd order current harmonic and allowing filtering through smaller filters, is proposed in this work, to mitigate the negative influence of current harmonics on the life of the drums. To eliminate the effect of common mode components injected on the AC side, a hybrid MMC topology is also proposed. The simulation results verify the validity of the proposed method and topology.

The modular multilevel converter (MMC) has been continuously studied after being proposed and widely adopted for high voltage direct current (HVDC) and motor drive applications. As the electrification of transport develops, CMM research for electric vehicle (EV) applications regarding control strategies and efficiency evaluation has also been carried out. A number of MMC merits such as high modularity, fault tolerance capability and high quality output make it a promising candidate for EV applications. Furthermore, the ability to integrate engine drive, battery state of charge (SoC) equalizer and on-board charger functions makes the MMC even more competitive when used in EVs.

In the MMC, due to the interaction between the arm current and the switching operation, specific low-order harmonics are introduced into the currents flowing through the battery cells. These current harmonics cause additional losses with a consequent increase in the operating temperature of the battery cells, leading to an undesirable loss of capacity and ultimately accelerating the aging of the batteries. As the frequencies of the introduced harmonics are relatively low, the requirements for filter devices to filter out these harmonics will be demanding.

Xingxing Chen et al. (2020), Multiple insulated gate bipolar transistor (IGBT) open circuit faults severely affect the reliable operation of modular multilevel v-converters(MMCs). The existing literature does not provide an effective diagnostic algorithm for MMCs when multiple IGBT open circuit faults appear simultaneously on an arm. This paper presents a diagnostic strategy for dealing with this condition. Fault detection and estimation of the number of defective submodule (SM) are implemented by checking the arm voltage error value. Defective SMs are located by observing when the transition of their switching functions leads to an obvious change in arm voltage error. Meanwhile, errors between measured and predicted capacitor voltages are used to speed up localization. All faulty SMs can be quickly located one by one within several control cycles using the proposed localization method. Simulation and experimental results demonstrate the validity of the proposed diagnostic strategy.

Kaibalya Prasad Panda et al. (2019), multilevel inverters (MLIs) with switching self-balanced (SC) capacitors have received widespread recognition for increasing the power capacity and power quality of high-frequency and renewable energy distribution systems. This brief presents a new SC MLI structure using a reduced number of switches and a single DC source. By proper charging and discharging patterns, SCs are self-balanced and high voltage rise is achieved.

Comparative analyzes with state-of-the-art MLIs in terms of number of components, permanent stress, reinforcement factor and cost factor demonstrate the merit of the presented topology. Furthermore, the experimental results confirm the workability of the proposed MLI under linear, non-linear load and dynamic test conditions using 50 Hz and 2.5 kHz modulation.

Multilevel inverters (MLIs) have been researched extensively in the recent past for low, medium and high power applications. Improved power quality, low voltage stress, improved efficiency and high modularity are the main factors behind the tremendous growth and demand for MLIs in industries, electric vehicles, high frequency AC power distribution and renewable power generation.

R. Marquardt (2010), For demanding future applications in power transmission – such as grid connection of large offshore wind farms, solar thermal power generation or megacity power supply – there is a global need for advanced electronic power systems. The new concept of Modular Multilevel Converter (M2C) offers superior features for these applications. Its operations for HVDC systems are explained and investigated against new requirements – including fault management in multi-terminal HVDCN networks. Advanced voltage source converters (VSC) are a key component of future HVDC transmission systems. While bulk power transmission continues to be suitable for in-line switched thyristor converters, the most important future application fields share demanding requirements, which are best served by auto-switching converters. Examples of these applications are the integration of large solar thermal and wind farms into the grid, the upgrading of power supply to megacities, and the stabilization of existing AC grids.

The main requirements are fast and independent control of the flow of active and reactive power, operation without bulky passive filters, black start capability and the option to extend the DC network to more than two stations (multiterminal). Major fault conditions and disturbances – including short circuits on the DC side – must be managed quickly and safely.

Elisabeth N et al (2012), This characteristic complicates the modeling both mathematically and computationally. A mathematical model of the MMC is presented with the aim of developing a control system for the converter and the model is converted into the dq reference frame. Block diagrams for active power control and AC voltage magnitude are shown. With the new production of renewable energy, HVDC is more applicable than ever. Production requires solutions that can transport energy from areas of high generation to areas of lower generation. Offshore wind farms require HVDC transmission to shore and compact and reliable conversion technology with high power capacity. Connecting the drive to a DC network must be feasible and the drive must be able to handle fault situations. To gain compactness, the need for filters should be minimized. The emerging topology, the Modular Multilevel Converter (MMC), can meet these goals.

S. Rohner et.al (2019), the contents of each section can be provided for easy understanding of the paper. With the production of new renewable energy, HVDC is more viable than ever. More random power production requires solutions that can transfer power from high-generation areas to low-generation areas. Offshore wind farms require HVDC transmission to shore and compact and reliable inverter technology with large power capacity. The connection of the transformer to the DC network must be possible and the transformer must be capable of handling fault conditions.

S. Rohner et.al (2017), to achieve compactness, the need for filters should be reduced. An emerging architecture, the Modular Multilevel Converter (MMC) may address these goals. The latest generation of voltage source transformers (VSCs) is the main driver of the latest evolutionary step in the EMT software community due to their use of a very large number of power electronic devices. This technology, known as modular multi-level transformers (MMCs) or cascading two-level transformers (CTLCs), generates voltages with very low harmonic content and delivers loss levels much closer to those of "classical" thyristor line-switched transformers.

S. S. Gjerde and T. M. Undeland (2018), The MMC consists of several successive subunits (SM), whose internal structure can be half-bridge, full-bridge or double tongs SM. This work is devoted to a mathematical model that can be useful in the analysis and design of structures and control strategies for MMCs. This paper studies multi-level STATCOM modules using full-bridge SM. Due to its topology, MMC offers some unique advantages and features:

1. AC voltage and current have low harmonics. An idle filter becomes unnecessary.
2. The MMC arm currents are continuous, and there is no longer a single bulky capacitor in the DC connection.
3. The carrier frequency of the PWM is low, so the losses are reduced.
4. Short-circuiting of one of the sub-module (SM) capacitors has little effect on the others, and the system has a quick recovery.
5. The modular structure provides redundancy to withstand the breakdown of some SM temporarily.

S. Allebrod et.al (2019), In the MMC, there is a strong harmonic content in the arm current, although this is not reflected in the load current. This basically controls the dynamic behavior of the transformer. It is necessary to understand and predict the harmonic content of the arm current because the transient behavior of this system depends on the current harmonics. In addition, to evaluate the abnormal operation of the transformer; Like the failure of the module control system or the failure of the module itself, it is necessary to derive a well-defined model based on frequency domain methods. However, in the available literature, the analytical frequency domain description of the MMC cannot be found to focus on the harmonic interaction of the transformer.

J. K. Reed and G. Venkataramanan (2012), In general, transducers are non-linear and time-varying devices. It is well known that the frequency domain small signal model can be used to predict the dynamic performance and stability of MMC.

U. N. Gnanarathna et.al (2020), such a model is generally useful because it requires less computational time compared to a time domain simulation. It also provides further insight and understanding of the interaction between the AC and DC induced sides of the transformer. To some extent, the harmonic distortion difficulties encountered with previously used two- and three-level topologies are being replaced by the harmonic oscillation challenges in cell capacitors that require attention with respect to system dimensions and control. An analytical study was performed.

D. Soto-Sanchez and T. C. Green (2011), the effect of capacitive voltage ripple, under simplified assumptions regarding transformer control and modulation. However, to date, there has been no comprehensive frequency domain model for this structure, and the analysis has generally relied on extensive simulation studies. In this paper, a steady-state harmonic model is presented, which can explain the relationship between the operating point variables, the pulse pattern used in the cells, the cell capacitor harmonics and the circulating currents. It is now possible to get an average capacity of 1 gigawatt and above.

D. C. Ludois et.al (2010), discussion about control methods is sparse. This paper discusses the control methods and checks their performance using electromagnetic transients (EMT) simulation. The paper also looks at the control and performance of an HVDC transmission system feeding a weak AC system.

J. Reed (2011), The SM terminal voltage is determined by the states of the four switches. For SM, there are three operating modes, namely PWM mode, normal debug mode, and blocking mode. In PWM mode, four IGBT and T1 to T4 receive PWM gate signals. The T1 and T2 pair contains complementary signals, as well as the T3 and T4 pair. The terminal voltage SM is equal to either the capacitor voltage, negative capacitor voltage, or zero. When at least one IGBT pair is blocked, the SM is in normal correction mode. The terminal voltage is determined by the current direction which forces the conduction of some anti-parallel diodes. When there is no current, the SM has a high resistance and the terminal voltage is determined by the external circuit. Two IGBTs in one pair cannot have on-off signals at the same time. This mode will short circuit the capacitor and damage the device and is therefore prohibited.

S. Rohner et. al (2011), Rows and columns in this context refer to the position of the arm and it is a subunit of the circuit diagram in the MMC. Each arm has n subunits and x indicates the number of the subunit within the arm. Where the vNSB is defined as the neutral bridge voltage, which is nominally zero under balanced operating conditions. While this equivalent circuit model provides an honest representation of system behavior, it is still not particularly useful in studying the final behavior of a transformer, because it consists of 12 paired differential equations, even if all subunits are identical to each other. This section also reduces the complexity of the MMC analytical model to an equivalent buck converter circuit.

K. Ilves et.al (2012), to some extent, the harmonic distortion difficulties encountered with previously used two- and three-level topologies are being replaced by the harmonic oscillation challenges in cell capacitors that require attention with respect to system dimensions and control. An analytical study was performed. The effect of capacitive voltage ripples, under simplified assumptions regarding transformer control and modulation. However, to date, there has been no comprehensive frequency domain model for this structure, and the analysis has generally relied on extensive simulation studies. In this paper, a static harmonic model is presented that can explain the relationship between the operating point variables,

3. Components

Table 1 Detail of Components with Specifications

Sl. No.	Components	Specifications
1	Step-down Transformer	48 VA
2	Bridge Type Rectifier	IN4007, 3Amp
3	Blacking rectifier	5408, 3 Amp
4	Microcontroller. PIC 18F452	28 pin activated, 500 mA
5	Multilevel inverter	Two stage, SP1, SP2, By Thyristor (T1-T8)
6	Rectifier for linear coil	IN4007, 3Amp.
7	Linear coil	100 henry, 120 henry.
8	Linear coil with magnetic field	Two step
9	Resistance	1 watt, 100 kΩ
10	Capacitor	1000uF, 48 VDC
11	Filter	4700 µF
12	ON/OFF switch	5 Amp X 2
13	Two way switch	5 Amp., F/R
14	Gear head DC motor	1 Amp. X 2
15	LED Chamber	10 Watts
16	Regulator , LM7805	5 Amp

17	PV Cells	10 Watts
18	Connection Wire	1 mm
19	Selector switch	4 Points
20	MMC Power Consumption	10Watts

3.1 Photovoltaic cells

When light is shone on a photovoltaic cell (also called a solar cell) that light can be reflected, absorbed, or passed directly through the cell. A photovoltaic cell is made of a semiconducting material; "semi" means that it can conduct electricity better than an insulator but not it is also as good a conductor as metal.

3.2 Battery

Batteries are a group of one or more cells whose chemical reactions create a flow of electrons in a circuit. All batteries consist of three basic components: the anode (the "+" side), the cathode (the "-" side), and a type of electrolyte (a substance that reacts chemically with the anode and cathode)

3.3 DC Motor

A DC motor is an electric machine that converts electrical energy into mechanical energy. In a DC motor, the input electrical energy is the direct current which is converted into mechanical rotation.

3.4 Step-down Transformer

A step-down transformer is a type of transformer that converts high voltage (HV) and low current from the primary side of the transformer to the low voltage (LV) and high current value on the secondary side of the transformer. The opposite of this is known as a step-up transformer. A transformer is a type of static electrical equipment that converts electrical energy (from the primary side windings) into magnetic energy (at the core of the magnetic transformer) and back into electrical energy (on the transformer secondary side). The step-down transformer has a variety of applications in electrical systems and transmission lines.

3.5 Low pass filter

The Low Pass Filter (LPF) is designed to pass all frequencies below the cutoff frequency and reject all frequencies above the cutoff frequency. It is simply a parallel RC circuit across the input, with the output being output via the capacitor. At the cut-off frequency, the capacitive reactance of the capacitor C is equal to the resistance of the resistor R, which causes the output voltage to be 0.707 times the input voltage (-3 dB).

4 Harmonics

In an electrical power system, a harmonic is a voltage or current at a multiple of the fundamental frequency of the system, produced by the action of non-linear loads, such as rectifiers, discharge lighting, or saturated magnetic devices. Harmonic frequencies in the power grid are a frequent cause of power quality problems. Harmonics in power systems result in increased heating of equipment and conductors, misfire in variable speed drives, and torque pulsations in motors.

5 Current harmonics

In a normal AC power system, the current varies sinusoidally at a specific frequency, usually 50 Hz. When a linear electrical load is connected to the system, it draws a sinusoidal current at the same frequency as the voltage (although it is usually not in phase with the voltage).

Current harmonics are caused by non-linear loads. When a non-linear load, such as a rectifier, is connected to the system, it draws a current that is not necessarily sinusoidal. Current waveform distortion can be quite complex, depending on the type of load and its interaction with other system components. Regardless of how complex the current waveform becomes, the Fourier series transform makes it possible to deconstruct the complex waveform into a series of simple sinusoids, which start at the fundamental frequency of the power system and occur in integer multiples of the frequency.

Other examples of non-linear loads include common office equipment such as computers and printers, fluorescent lighting, battery chargers and also variable speed drives. In power systems, harmonics are defined as positive integer multiples of the fundamental frequency. Thus, the third harmonic is the third multiple of the fundamental frequency.

Harmonics in power systems are generated by non-linear loads. Semiconductor devices like transistors; IGBTs, MOSFETS, diodes etc are all non-linear loads. Other examples of non-linear loads include common office equipment such as computers and printers, fluorescent lighting, battery chargers and also variable speed drives. Electric motors do not normally contribute significantly to the generation of harmonics. Both motors and transformers, however, will create harmonics when overloaded or saturated.

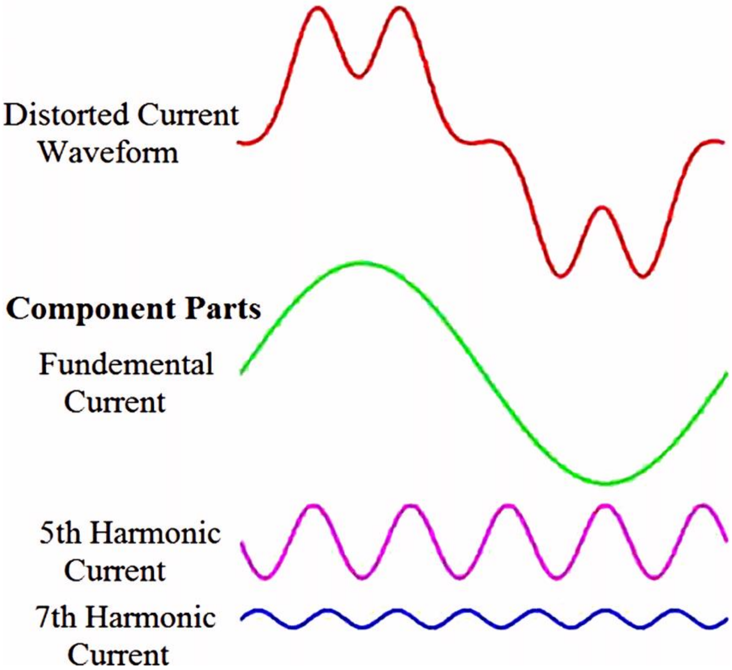

Figure 2 Current harmonics

Other examples of non-linear loads include common office equipment such as computers and printers, fluorescent lighting, battery chargers and also variable speed drives. In power systems, harmonics are defined as positive integer multiples of the fundamental frequency. Thus, the third harmonic is the third multiple of the fundamental frequency.

Harmonics in power systems are generated by non-linear loads. Nonlinear load currents create distortion in the pure sinusoidal voltage waveform provided by the utility, and this can result in resonance. Even harmonics normally do not exist in the power system due to the symmetry between the positive and negative halves of a cycle. Furthermore, if the three-phase waveforms are symmetrical, the multiple harmonics of three are suppressed by the delta (Δ) connection of transformers and motors as described below.

6 Voltage harmonics

Voltage harmonics are mainly caused by current harmonics. The voltage supplied by the voltage source will be distorted by current harmonics due to source impedance. If the voltage source impedance is small, current harmonics will cause only small voltage harmonics. Normally, voltage harmonics are very small compared to current harmonics. For this reason, the voltage waveform can usually be approximated by the fundamental frequency of the voltage. If this approximation is used, current harmonics have no effect on the actual power transferred to the load. An intuitive way to look at this is to sketch the voltage waveform at the fundamental frequency and superimpose a current harmonic without phase shift (to more easily observe the following phenomenon). What can be observed is that for each period of voltage, there is an equal area above the horizontal axis and below the harmonic current wave as there is below the axis and above the current harmonic wave. This means that the average real power contributed by current harmonics is equal to zero. However, if higher voltage harmonics are considered, current harmonics contribute to the actual power transferred to the load.

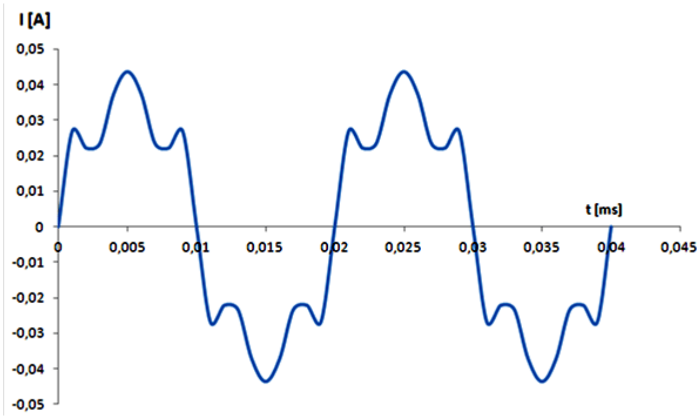

Figure 3 Voltage harmonics

7 Total harmonic distortion

Total harmonic distortion, or THD, is a common measure of the level of harmonic distortion present in power systems. THD can be related to current harmonics or voltage harmonics, and is defined as the ratio of total harmonics to the value at fundamental frequency times 100%.

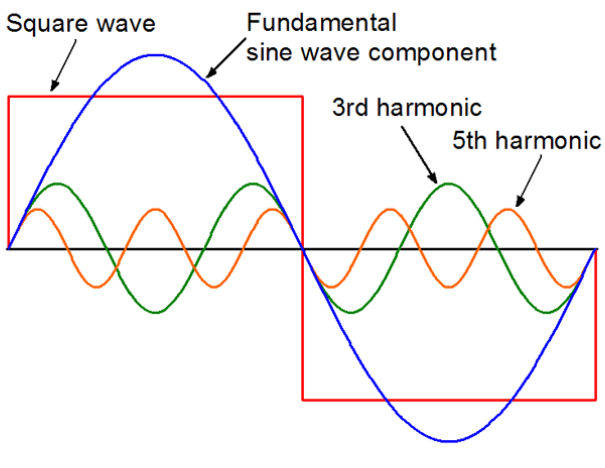

Figure 4 Fundamental pure sinewave

8 Conclusions

An improved MMC control system for EV application is proposed in this paper. A modular multilevel topology with embedded battery for BEVs was presented in this paper. Modular structured multilevel inverter is very attractive in battery vehicle applications. The proposed method can reduce current harmonics by using filter and mitigate the negative influence of harmonics on battery lifetime to improve its performance and found the low THD value of output motor current. The large number of submodules increases the number of output voltage levels and strongly reduces the THD of motor currents. The MMC is therefore a suitable candidate to eliminate battery balancing circuits from electric vehicles, as in the new concept the battery cells are directly incorporated into the energy converter.

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