Energy Storage System and Multilevel Inverter for Electric Vehicles Application

[1]Dr. Shiv Kumar Sonkar, [2]Rishabh Kumar Sonkar
Associate Professor, Department of Electrical and Electronics Engineering, Madhyanchal Professional University, Bhopal[1]
Department of Electrical and Electronics Engineering, Sagar Institute of Research & Technology, Bhopal[2]

Abstract— A multilevel inverter is a power electronic device that is used for high voltage and high power application because of its characteristics of generating a sinusoidal voltage based on several DC voltage levels. They give good quality output resulting with lower harmonic distortion in the output. This topology is designed based on switched-capacitor voltage pump technique and the number of output levels is defined by the number of switched-capacitor cells cascaded. Only one dc voltage source is needed and the problem of voltage balancing across the capacitor is avoided as well. A small input voltage can be used to generate a boosted output voltage, by switching the capacitors in parallel and in series. The basic MLIs are cascaded H-bridge (CHB), neutral point clamped, and flying capacitor inverters. In addition, the inverters inherit various advantages of the original structure, such as a high boost factor of 6, self-balanced capacitor voltages and reduced voltage ripples. Circuit description, operation principle, hybrid PWM modulation and capacitor voltage ripples are analyzed. The capacitor voltages are self-balanced as they are connected in parallel with the input voltage source for several instances in every fundamental cycle.

Keywords— Multi-level Inverter, PWM, Boost Factor, Electric Vehicles

I. INTRODUCTION

Significant changes have occurred all over the world even over the past decade in the energy landscape. Globally, there's a big push towards a 100% incorporation of wind and solar power for electricity production, with synergistic support from Vehicleto-Grid (V2G) technology. Large-scale electric vehicles (EVs) can perform as new channels of source and energy storage mechanism in the smart grid via implementing V2G intended for power injection from EVs to the grid. V2G awards EV owners with numerous innovative roles in the smart grid such as mobile energy storage, renewable energy storage, backup supply. V2G has been intended as a means of lessening the grid potential operational delinquents and enhancing the opportunity for the proliferation of EVs. There are however a host of challenges, most of which are due to the intermittency and unpredictability of the mobility behaviour and renewable energy resources (RESs), along with market price volatility. Therefore, V2G scheduling becomes emerging research focus with a large-scale application of EVs. Present market regulations restrict fair participation in power markets for individual EVs' G2V scheduling [1, 2]. The complete financial value of EVs would be realized provided policy outlines, market rules and regulatory reforms allow EV Aggregator (EVA) to provide multiple services (energy and ancillary services) simultaneously, addressing congestion at the system level, paying attention to satisfying reserve requirements, and serving to accomplish energy management for single EV owner. It enables EVA to ensure that EVs can receive fair remuneration for unlocking their multi-valued streams and providing flexibility services in a cost-competitive manner. If aggregated and controlled, EVs can provide flexibility to the system operator (SO). This thesis will focus on some of the possible solutions for the V2G integration for providing ancillary services that are control-centric. This thesis will cover some of these challenges to V2G scheduling, highlights the current research in V2G optimization, and use-case studies that illustrate the role of EVA in power grids and electricity markets. Smart V2G scheduling can reshape the load profile and further decrease substantial investment costs and minimalize operative costs, by adopting G2V mode in off-peak duration and V2G mode when demand is high. EVA can maximize their flexibility provision from both the demand side (G2V) and supply-side (V2G) [3].

G2V mode: EVs are functioned as a demand-side managing alternative, forming a flexible electricity consumption supporting renewable power integration. 2) V2G mode: EVs are operated as dispersed generation resources. The batteries of EVs could inject power to the grid by discharging and forming large-scale distributed electricity storage regulated/controlled by the needs of an electric system. V2G control might offer an important revenue stream that would enhance the economics of grid integrated EVs and additionally motivate their adoption. It could also recuperate grid stability [4].

However, the downside of V2G operation is namely, reduced battery life, additional infrastructure cost, safety issues, etc. Utilizing a mobile energy storage system, EV batteries may store electric power which may assist as a grid source during peak periods. Employing distributed energy storage of EVs, EVAs could offer ancillary services viz. spinning reserves and frequency regulation. EV owners can be incentivized for motivation towards offering V2G services. In other words, their market participation can be facilitated to perform charging operation whenever the network experiences less demand and execute discharging at times when there is most demand on the network. Nevertheless, the V2G market entails strict regulations and integration of demand response prioritize are desired to enhance the market efficiency of V2G scheduling. The dynamics of mobility behaviour of EV owners elevates challenges to V2G scheduling of EVA. The EV batteries usage standards are very strict from their state of health aspect. Flexibility services use EV's manageable charging/discharging capability to adapt power rates at the network contact notch. Conventionally this servicing is all activities near elementary charging (whose intention is to upsurge the SOC to and to guarantee energy for driving) and they can be: Regulation-Up attained by decrease/increase of charging/ discharging power in charging G2V/ discharging V2G mode of operation, and start discharging if in idle mode. Regulation-Down realized by increase/decrease of charging/ discharging power, in charging G2V/ discharging V2G mode of operation, and start charging if in idle mode [5, 6].

II. LIITERATURE REVIEW

Y. Q. Wang et al. [1], a novel switched-capacitor-based T-type multilevel inverter (MLI) is proposed in this paper. In addition to achieving a lower maximum voltage stress on the switches than the input voltage, the proposed inverter also has the ability to boost voltage, making it suitable for high-voltage applications. It is important to point out that the proposed inverter has two topology extension schemes that help it get a higher voltage gain and output level. A seven-level inverter can be constructed with just two capacitors thanks to the advantages of low voltage stress and low power consumption. Additionally, capacitor voltage self-adjusting ability can improve on the intricacy of the circuit and control.

Ruijie Sun et al. [2], the inverter's capacitor topology, operating principle, modulation strategy, and analysis are presented. Comparing the proposed inverter to recently proposed hybrid MLIs and switched-capacitor MLIs reveals the inverter's advantages. In the end, a seven-level prototype is built to confirm the theoretical analysis's accuracy as well as the inverter's viability and efficiency.

Y. Q. Wang et al. [3], this paper proposes a novel single-phase boosting five-level inverter with fewer parts and simple control for use with electric vehicles (EVs) and renewable energy systems. The inverter has one diode, one capacitor, nine power transistors, and supplies power from a dc voltage source. To double the voltage gain, all you need are five independent control signals. The value of the input voltage matches the peak inverse voltages across each switch. The utilized capacitors have the capability of voltage self-balancing and have low ripples, and they operate alternately in charging and discharging states. In addition, the output levels of the proposed topology can be exponentially increased, making it very adaptable. The minimum capacitance is determined by calculating the maximum voltage ripple of the capacitor and analyzing the topology, operation principle, and modulation strategy. In conclusion, simulation validation is provided.

S. Habib et al. [4], the large number of devices and complicated expansion of conventional multilevel inverters cause issues. A modular expanded multilevel inverter that can effectively simplify expansion and reduce the number of devices is proposed in this paper. The voltage-dividing capacitors can be guaranteed to be voltage-balanced by the proposed inverter. The inverter is able to achieve high output voltage levels and voltage gain thanks to the cascading of the T-type switched capacitor module and the step-by-step charging method of the switched capacitors. Additionally, the inversion can be accomplished without the H-bridge, resulting in a significant decrease in the switches' total standing voltage. With only ten switches, the proposed topology's nine-level inverter achieves a voltage gain that is two times greater. Experiments and theoretical analysis confirmed the preceding advantages. In photovoltaic power generation at medium and low voltages, the proposed inverter has promising potential applications.

P. Wang et al. [5], in order to develop dependable and effective charging solutions for electric vehicles (EVs), the transportation sector needs new options for power electronics converters. The desire to reduce gasoline consumption and increase the battery capacity for greater electric range for EVs is feasible in the near future thanks to the ongoing development of power electronics converters. Since a power electronics converter serves as the primary interface between the power network and the EV battery system, new low-cost and high-reliability power converters are needed for the advanced charging mechanism of EVs. The expanding number of power converter topologies presents significant opportunities for the EV charging procedure. In light of this, the purpose of this paper is to suggest additional enhancements to EV charging systems by examining the significant aspects, current progress, and challenges of a number of power converters. In particular, both back-end and front-end converter configurations are thoroughly examined. In addition, the properties of resonant converter topologies and other DCDC converters are compared and contrasted in great detail. In addition, isolated and non-isolated soft switching topologies are categorized and thoroughly examined in light of their respective drawbacks and advantages. For researchers looking into power converter topologies for EV charging solutions, it is anticipated that this paper will be a useful addition and a worthy source of information.

J. Zeng et al. [6], due to the noise caused by fast switching power electronics, inverter-fed motors' partial discharge (PD) is more complicated than that of conventional sinusoidal voltage-operated motors. This is because impulsive voltages generated at a high frequency and with a short rise time are generated by inverters. At conditions of repeated impulsive voltage, the currently available PD sensors as well as related technology for sinusoidal and DC voltage cannot be utilized. In order to detect PD for impulsive voltage, the design of an antenna with optimized geometry and satisfied parameters will be reported in this work. The antenna is checked, and the test configuration and impulse voltage parameters' effects on PD features are talked about. To reduce the complexity and cost of PD test hardware under impulsive voltages with quick rise times, the envelope detection method in the frequency domain was proposed after the filter. The majority of the PD from motor insulation's frequency domain energy is distributed between 0.6 and 1.8 GHz. The PD energy spectrum expands to (1.5-1.8 GHz) by increasing the amplitude and frequency of the input impulsive voltage, while the PD signal strength abruptly decreases by decreasing the input amplitude. Besides, the high-recurrence dissemination of PD energy lessens all the more seriously with the distance and the electromagnetic energy of PD rots nonlinearly with the increment of proliferation distance. Consequently, in order to satisfy the safety test, selecting a test distance below 15 cm can guarantee a high signal-to-noise ratio and signal integrity in the results. Off-line PD measurements for insulation evaluations of inverter-fed motors could be developed based on the findings of this study.

W. J. Lin et al. [7], a single-source, multilevel inverter (MLI) based on the novel K-type unit (KTU) was proposed in this article. This article describes the 13-level topology's operation modes at various output levels, which include two KTUs and 1.5 voltage gain. Due to their symmetric operation during a cycle, the two capacitors connected in series with each KTU can achieve self-voltage balance, reducing control complexity in comparison to conventional MLIs. Both the calculation of capacitance and the analysis of self-balance are described in detail. Following that, the single-source generalized structure with additional KTUs for increasing output levels is presented. With more KTUs, the voltage gain rises as well as the output levels rise significantly. In addition, the advantages of the proposed KTU topology are highlighted in terms of reduced components, self-balance, voltage stress, and overall cost when compared to other MLI topologies proposed in recent years. At last, the 13-level reenactment and 1-kVA trial model with crucial recurrence regulation (FFM) are executed to confirm the achievability and transient execution of the proposed geography.

K. P. Panda et al. [8], multilevel inverters (MLIs) with self-balanced switched-capacitors (SC) have received wide recognition for increasing power capacity and power quality of the renewable energy and high-frequency power distribution systems. This brief presents a new SC MLI structure using a reduced number of switches and a single dc source. By suitable charging-discharging patterns, the SCs are self-balanced and high voltage boosting is achieved. Comparative analysis with state-of-art MLIs in terms of the number of components, standing voltage, boosting factor, and cost factor demonstrate the merit of presented topology. Further, experimental results confirm the workability of the proposed MLI under linear, non-linear loading and dynamic test conditions using both the 50 Hz and 2.5 kHz modulation.

III. MULTI LEVEL INVERTER

Figure 1 shows the multilevel converter modulation methods. The modulation control schemes for the multilevel inverter can be divided into two categories, fundamental switching frequency and high switching frequency PWM such as multilevel carrier-based PWM, selective harmonic elimination and multilevel space vector PWM Multilevel SPWM needs multiple carriers. Each DC source needs its own carrier. Several multi-carrier techniques have been developed to reduce the distortion in multilevel converters, based on the conventional SPWM with triangular carriers. Some methods use carrier disposition and others use phase shifting of multiple carrier signals. By generalizing, for an 'n' level multilevel inverter, (n-1) carriers are needed. The implementation of the various carrier PWM techniques that is possible for multi-level inverters are [5, 6]:

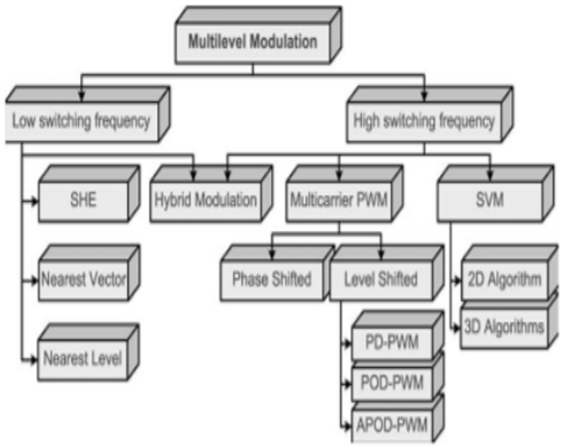

Figure 1: Multilevel converter modulation methods

Level Shifted PWM (LSPWM)

This modulation method is especially useful for NPC converters, since each carrier can be easily associated to two power switches of the converter. LSPWM leads to less distorted line voltages since all the carriers are in phase compared to PSPWM [7]. In addition, since it is based on the output voltage levels of an inverter, this principle can be adapted to any multilevel converter topology. However, this method is not preferred for CHB and FC, since it causes an uneven power distribution among the different cells. This generates input current distortion in the CHB and capacitor unbalance in the FC compared to PSPWM [8, 9]. Figure 2 shows the LS-PWM carrier arrangements.

Phase Shift Pulse Width Modulation

PWM signals are pulse trains which are applied to the gate of switches to perform the operation of converter. The pulse trains are fixed frequency and magnitude and variable pulse width [10]. There is one beat of settled extent in each PWM period. In any case, the width of the beats changes from period to period as indicated by a regulating signal.

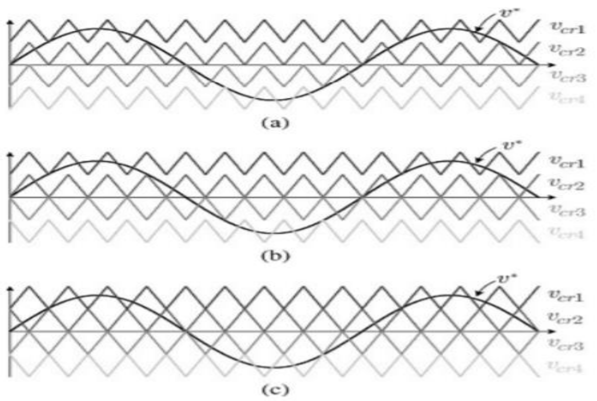

Figure 2: LS-PWM carrier arrangements: (a) PD, (b) POD, and (c) APOD.

At the point when a PWM flag is connected to the entryway of a power transistor, it causes the turn on and kills interims of the transistor to change starting with one PWM period then onto the next PWM period as indicated by the same regulating signal and thus working of converter begins. The recurrence of a PWM flag must be substantially higher than that of the regulating signal, the major recurrence, with the end goal that the vitality conveyed to the heap depends generally on the tweaking signal. The control of yield voltage is done utilizing beat width balance [11, 12].

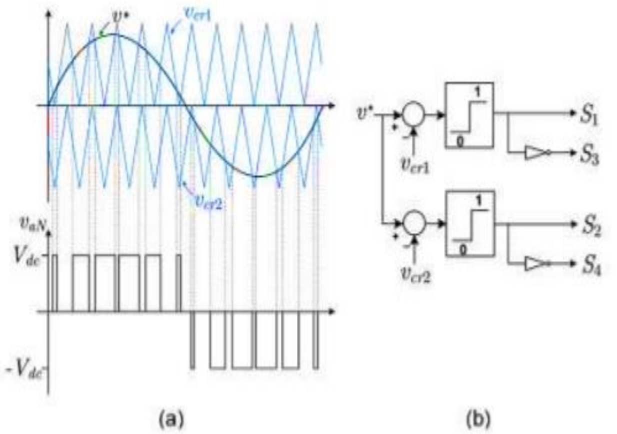

Figure 3: Phase Shift PWM

This technique uses a set of carriers that are all phase-shifted. The four triangular carriers are phase-shifted by 90º. Using the same sampling period, it has four times larger switching frequency than that of other techniques. This technique is specially conceived for FC and CHB converters. Since each FC cell is a two-level converter, and each CHB cell is a three-level inverter, the traditional bipolar and unipolar PWM techniques can be used, respectively. Due to the modularity of these topologies, each cell can be modulated independently using the same reference signal [13].

Total Harmonic Distortion

The total harmonic distortion (THD or THDi) is a measurement of the harmonic distortion present in a signal and is defined as the ratio of the sum of the powers of all harmonic components to the power of the fundamental frequency. Distortion factor, a closely related term, is sometimes used as a synonym.

In audio systems, lower distortion means the components in a loudspeaker, amplifier or microphone or other equipment produce a more accurate reproduction of an audio recording.

In radio communications, devices with lower THD tend to produce less unintentional interference with other electronic devices. Since harmonic distortion tends to widen the frequency spectrum of the output emissions from a device by adding signals at multiples of the input frequency, devices with high THD are less suitable in applications such as spectrum sharing and spectrum sensing [14, 15].

In power systems, lower THD implies lower peak currents, less heating, lower electromagnetic emissions, and less core loss in motors.

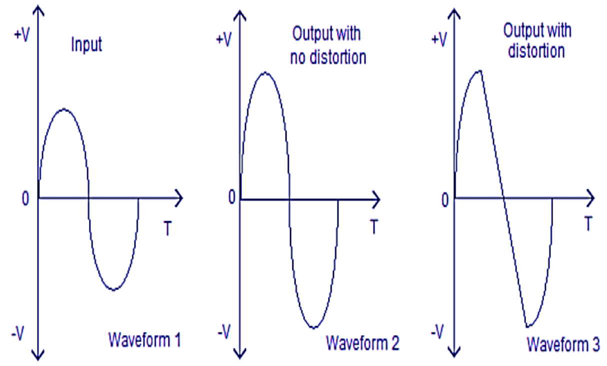

Figure 4: Output Waveform of Distortion

IV. ENERGY STORAGE SYSTEM FOR ELECTRIC VEHICLE

Various types of battery chemistry are available for electric vehicle applications. Li-ion battery is more suitable for EVs due to its battery property comparing to other battery options for an electric vehicle. Figure 1 presents a Battery power comparative market price comparison of multiple electric vehicles [11].

Battery energy storage topologies

Battery-based energy storage technology is divided into three topologies as with hybrid energy storage electric vehicles called as HEVs, external plug-based plug hybrid energy storage electric vehicles called PHEVs, and battery-based energy storage only called vehicles as EVs.

In Hybrid Electric Vehicles main power source is an IC engine combined with electric powered motors that use to store the energy in batteries. Gasoline-powered IC engine is the primary and batteries are the auxiliary parts for the energy source in HEV.

Figure: 5: Comparative assessment of different market costs for electric vehicles

Battery energy storage capacity is 1-3 kWh, by using this capacity vehicle can drive approximately 10 kilometers.

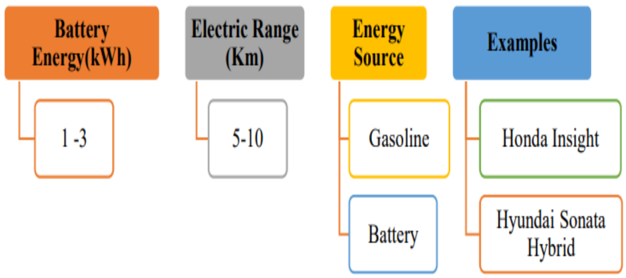

Figure 6: Hybrid Electric Vehicle specifications

Plug-in hybrid electric vehicles (PHEVs) use the battery and another fuel gauge for energy storage. batteries are used to power an electric motor and use another fuel, which is used to powered propulsion source. PHEV uses grid electricity to charge the battery which reduces the cost of the fuel. PHEVs have large battery packs compared to hybrid electric vehicles. This helps to travel more distances using only energy (about 30 to 60-plus kilometers in existing models), commonly referred to as the vehicle's "battery-powered range"[12].

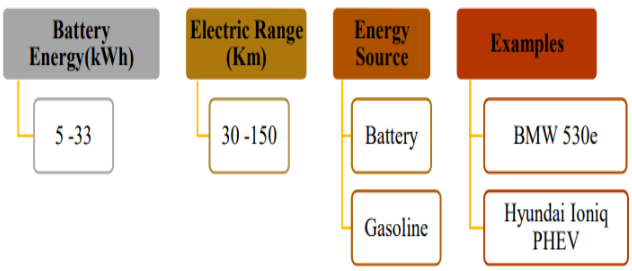

Figure 7: Plug-In Hybrid Electric Vehicle specifications

Vehicles including only battery-based energy storage are called BEV. These types of electric vehicles (EVs) use the battery bank to store the electrical energy that powers the motor. The battery bank is charged by using an external plug that extracts the energy from a charging station. Charging stations are power by electricity, BEV is considered as zero carbon emission vehicles because they do not produce direct exhaust or emissions comparatively other conventional vehicles [14]. For the electric cars, the energy storage is up to 100 kWh and the electric range is approximately 500 kilometers targets have been explored.

V. CONCLUSION

The presented research work has been focused on the construction of variable amplitude sinusoidal voltage using the different topologies. The first effort has been related to the development of new MLI topology using diodes and switching devices under symmetric and asymmetric mode. The advantage of the topology articulates any desired voltage level with a reduced total number of devices and sources over basic and similar topology. The voltages of the SC are naturally balanced owing to the self-balancing ability of the proposed topology. A simple series-parallel based technique is used to maintain the SC voltages without the need for any voltage/current sensors. The operating principle and the simple modulation method were discussed. The operability and feasibility of the proposed topology are validated through detailed experimental studies and the results are presented.

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