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# Survey Paper on PFC Rectifier based Charging and Discharge Mode of Electric Vehicle

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**ABSTRACT:** Electric vehicles (EVs) are proving to be economically and sustainable alternative to the conventional ICE vehicles and the advancements in battery charging technology will definitely help in transitioning towards cleaner and more efficient transportation system. EVs are also expected to last longer than gasoline vehicles due to reduced operating and maintenance costs. However, a well-managed network with charging infrastructure is essential to ensure a smooth rollout of electric mobility requiring efficient EV chargers. The battery packs that drive the EVs are typically charged from utility grid by using a power electronics conversion system (PECS) that conditions the grid-power to suit the battery requirements. These EV chargers are usually classified as on-board chargers and off-board chargers. The on-board chargers are placed inside the vehicle facilitating the user to easily charge the vehicle in home or at garage. Since these chargers interface with the external EV supply equipment (EVSE), their general architecture comprises of an input electromagnetic interference (EMI) filter followed by the AC-DC stage, DC-DC stages, and output filter. The off-board chargers, on the other hand, are not mounted on the vehicle and can be seen as public charging stations or at office parking. These have the preliminary DC-DC stage external to the vehicle and provide DC power to charge the vehicle battery.

**KEYWORDS:** Electric Vehicles (EVs), DC-DC Stage, AC-DC Stage

## I. INTRODUCTION

Over the past decade, developments in technology related to EVs have seen a rapid growth in reaction to the anticipated market demand for such vehicles. The high-density rechargeable battery packs of EVs are one of the most important components that directly impact the acceptance of electric mobility [1–3]. EVs are typically charged from the utility power grid through battery charging systems however other charging methods like charging directly from solar PV plants or wireless inductive charging also exist. Battery swapping is also a method for charging EVs wherein depleted vehicle batteries are replaced by pre-charged ones.

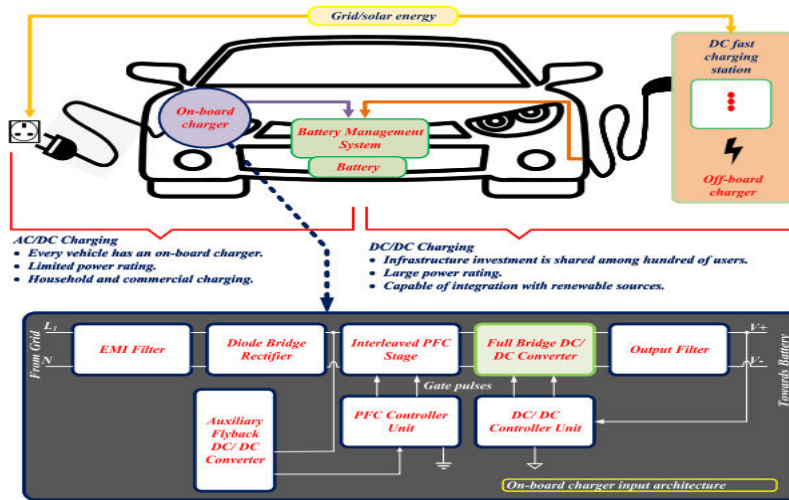


Figure 1: On-board vehicle charger and its single-phase input architecture

This conductive battery charging systems are further classified as on-board and off-board chargers as shown in Fig. 1 [4], according to the standards defined by the SAE, USA as shown in Fig 2 [5]. In general, on-board chargers are mounted on the vehicle chassis whereas off-board chargers are kept external to the vehicle. Each power unit type has its own merits and demerits. Among all these power units, the DC-DC converter stage is more popular since it plays the important role of matching the charger rating with the required battery power requirement [6–8]. The internal architecture comprises of two power conversion stages: AC-DC and DC-DC. The AC stage is responsible for improving the input power factor while the DC stage provides the suitable voltage and current in accordance with the battery profile [9]. Nowadays, the development of highly efficient and economic EV battery chargers is of high interest. Many EV charger configurations have been developed in the past decade in which the development of DC-DC converter stands out as a prominent development. This power conversion stage has made the converter capable to deliver power according to battery rating [10, 11].

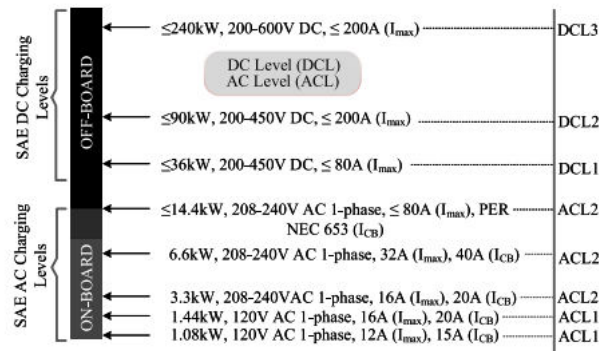


Figure 2: SAE standards for AC charging and DC charging of EVs

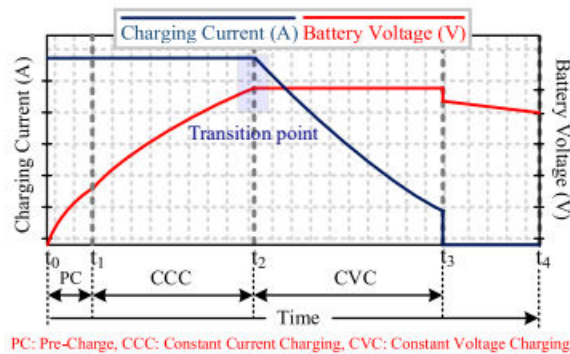


Figure 3: Lithium-ion battery charging characteristics and converter testing zone

## II. LITERATURE REVIEW

**Jain et al. [1]**, the two-stage charging interface of electric vehicle (EV) batteries includes AC-to-DC conversion. Using multilevel rectifiers (MLRs) reduces power switch voltage ratings while producing a high-quality input voltage waveform for these chargers. However, balancing the capacitors in MLRs is a significant challenge. A self-balanced switched capacitor power factor correction (PFC) five-level rectifier is proposed in this work. The presented topology has five power switches and one switched capacitor for each leg, with power switch voltage ratings equal to the dc output voltage. Because the load always appears in parallel with a switched capacitor of one of the legs, it does not require an additional filter capacitor on the dc side. The capacitive filter on the ac side and the inductive filter on the dc side are eliminated by the five-level operation with continuous conduction. The proposed rectifier's design, modulation strategy, operating principle, and closed-loop control are all discussed in this article. Experiment results validate the proposed topology, and other topologies are compared to it. Buck operation with a wide output regulation, the possibility of bidirectional power flow required for vehicle-to-grid systems, and the straightforward realization of its three-phase version by simply adding one more leg make the proposed topology suitable for EV battery charging applications. Experiments have also demonstrated these characteristics.

**Ebrahimi et al. [2]**, presents another three-stage five-level converter geography with a solitary dc source. The conventional flying capacitor multicell and diode-clamped multilevel topologies are combined in the proposed topology. The structure's reduced volt-ampere and, as a result, volume of flying capacitors while maintaining the same voltage blocking capability for semiconductor switches is a significant advantage of the proposed topology. The flying capacitor voltage balancing method and the appropriate modulation strategy are presented. Different performance criteria, including switch count and rating, flying capacitor volt-ampere, component cost, losses, and switching frequency, are compared to some existing five-level topologies with a single dc source and the same voltage rating of switches to demonstrate the advantages of the proposed converter. From a variety of performance criterion perspectives, the findings demonstrate that the proposed structure is superior to other five-level converters. To confirm the converter's operation and performance, simulation results are presented. Experimentation on a smaller prototype system confirms the theoretical analysis's validity.

**Lee et al. [3]**, in low-power boost power factor correction (PFC) control, critical conduction mode (CRM) and discontinuous conduction mode (DCM) have dominated. Two-level DCM and CRM typically have variable frequency and a high peak current at several hundred kilohertz, respectively. Secondary effects like high electromagnetic interference, current stresses, challenging input filter design, and switching losses may result from the two factors. This article makes use of the three-level boost (TLB) and its three-level current-slope options solely to take advantage of the fixed frequency and lower peak current advantages of DCM and CRM. To achieve fixed-frequency quadrangular CRM operation, this article proposes a hybrid conduction mode (HCM) control with adaptive single-switch on-time. Low inductor current enters DCM

at lower input voltage, allowing TLB PFC to operate in hybrid modes with varying ac input. This article's analyses and experiments show that the proposed HCM control can significantly reduce switching losses and peak current stress, increasing efficiency across a wide range of input voltages and loads while maintaining an acceptable PF drop. In addition, the proposed control is implemented with a straightforward voltage-balancing scheme that has been demonstrated to be effective in resolving the inherent topology issue.

**Zhang et al. [4]**, under unbalanced dc-link voltages, the mechanism of current distortions in a five-level flying capacitor rectifier is examined in depth in this article. A phase-shifted pulsewidth modulation-based multizero-sequence component injection algorithm is proposed. More specifically, the fundamental period is broken up into clamping and continuous intervals by the proposed modulation algorithm. Clamping compensation is added to three-phase reference signals for clamping a one-phase reference signal to zero in order to reduce current distortions at zero-crossing points during the clamping interval in light of the inherent topological constraint that the terminal voltage is related to the polarity of the phase current. In order to avoid affecting the average terminal voltage, the voltage of each flying capacitor is controlled by adjusting two switching modulation waves and injecting independent compensation components. Optimized compensation is simultaneously injected into three-phase modulation waves to improve the quality of dual dc voltages by reducing the average neutral-point current ripple during the continuous interval. The theoretical ranges that are permissible for both the unbalanced voltage degree and the unbalanced power degree are also deduced. Finally, the proposed algorithm's efficacy is tested through simulations and experiments.

**De Souza Kohler et al. [5]**, a flying-capacitor topology-based, five-level, unidirectional single-phase PWM rectifier operating as PFC is proposed in this paper. The main thing is that the proposed converter only has three active switches, which means it costs less than the more common five-level topology. The magnetic devices are lighter and less bulky thanks to the multilevel voltage operation. Additionally, the DC output voltage of 82% of semiconductors permits the use of low-voltage semiconductor devices. To demonstrate the structure's viability, extensive mathematical analysis, control-oriented modeling, and experimental findings are presented.

**Lee et al. [6]**, customary basic conduction mode (CRM) control for some lift inferred power factor remedy (PFC) circuits structures three-sided inductor current. When compared to other topologies, the conventional method is unappealing for a three-level boost (TLB) converter because it increases losses while maintaining the same waveform quality. This article focuses on the unique structure of TLB and its inherent degree-of-freedom (DOF) in current-slope shaping in order to improve waveform quality and efficiency. A new CRM control for TLB PFC is proposed and analyzed on the basis of the DOF. The digital implementation method and detailed design are also provided. The proposed CRM control, in contrast to conventional approaches, breaks down each switching cycle into three parts: the common on-time of two switches, the additional on-time of one switch, and the common off-time. As a result, the current synthesized by TLB inductor is quadrangular. The analyses and experiments show that the proposed control can reduce TLB's switching frequency and peak input current. With virtually no change in power factor, efficiency, total harmonic distortion, and input current quality are improved.

**Zhang et al. [7]**, examines an innovative model predictive control method for neutral-point-clamped (NPC) single-phase three-level pulsewidth modulation (PWM) rectifiers called optimized switching finite control set model predictive control. The ac-side current error of the single-phase PWM rectifier and the neutral point voltage of the converter are both converged to the bounded invariant set in order to guarantee the power converter's actual stability. Setting the bounded invariant set allows for the adjustment of system performance. The ac-side current, the neutral point voltage, and the current error can all be predicted in advance using the NPC single-phase three-level PWM rectifier model. The above goals are accomplished by improving the determination of switch mixes. When the ac-side current error and the neutral point voltage of the converter are controlled within a certain range, the proposed method has the advantage of being able to reduce the average switching frequency of the converter, making it suitable for the use of a high-power single-phase PWM rectifier.

**X. He et al. [8]**, to equalize the dc-link voltages of the cascaded rectifier, a fixed and smooth-switch-sequence modulation strategy is proposed in this article. The structure of a neutral-point-clamped cascaded rectifier with three levels and a single

phase is investigated. The calculation of the carrier wave disposition, the fixed pulse generator, and the voltage rank function are the three fundamental components of this strategy that are analyzed in turn. To measure the voltage balancing boundary of the presented method, a criterion for the degree of load imbalance is also established. The smooth switch sequence, the strong voltage balance capability, and the fixed switch sequence are among the advantages of the proposed control strategy. When the number of cascaded modules is large, the cascaded rectifier can effectively reduce the switching frequency, achieve voltage balancing, and lessen the controller's calculation burden due to these benefits. Simulation and experiment results confirm the proposed strategy's effectiveness.

### III. POWER FACTOR

Power factor is a vitality idea that is identified with control stream in electrical frameworks. To comprehend control factor, it is useful to comprehend three unique kinds of energy in electrical frameworks. Real Power (Genuine Power) is the power that is really changed over into valuable work for making warmth, light and movement. Genuine power is estimated in kilowatts (kW) and is totalized by the electric charging meter in kilowatt-hours (kWh). Reactive Power (Responsive Power) is the power used to maintain the electromagnetic field in inductive and capacitive gear. It is the non-working force part. Responsive power is estimated in kilovolt-amperes receptive (kVAR). Responsive power does not show up on the client charging articulation. Apparent power is the mix of genuine power and responsive power. Apparent power is estimated in kilovolt-amperes (kVA) and is totalized by the electric charging meter in kilovolt-ampere-hours (kVAh). Power factor (PF) is characterized as the proportion of genuine energy to apparent power.

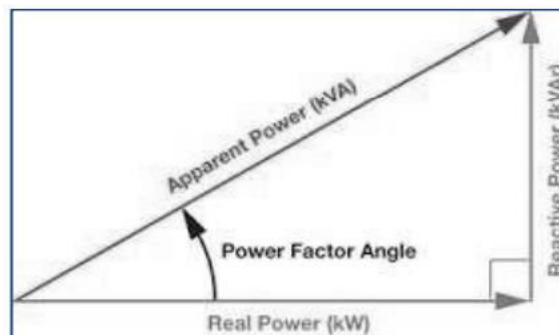


Figure 4:  $PF = \text{Real Power} / \text{Apparent Power}$

**POWER FACTOR CORRECTION:** Power factor amendment is the way toward making up for the slacking current by making a main current by interfacing capacitors to the supply. An adequate capacitance can be associated with the goal that the power factor is acclimated to be as near solidarity as would be prudent. Power factor correction (PFC) is an arrangement of checking the unwanted impacts of electric loads that make a power factor that is short of what one (1). Power factor redress might be connected either by an electrical power transmission utility to enhance the solidness and effectiveness of the transmission system or, adjustment might be introduced by individual electrical clients to diminish the costs charged to them by their power specialist co-op. There are two kinds of PFCs:

1. Passive
2. Active

**PASSIVE PFC:** The least difficult approach to control the symphonious current is to utilize a channel: it is conceivable to outline a channel that passes current just at line recurrence 50Hz. This channel lessens the symphonious current, which implies that the non-direct gadget now resembles a straight stack. Now the power factor can be brought to close solidarity, utilizing capacitors or inductors as required. This channel requires vast esteem high-current inductors, in any case, which are cumbersome and costly. A latent PFC requires an inductor bigger than the inductor in a dynamic PFC, yet costs less.

This is a basic method for amending the nonlinearity of a heap is by utilizing capacitor banks. It isn't as viable as dynamic PFC. Uninvolved PFCs are regularly more control proficient than dynamic PFC.

ACTIVE PFC: A "dynamic power factor corrector" (dynamic PFC) is a power electronic framework that Controls the measure of energy drawn by a heap so as to acquire a power factor as close as conceivable to solidarity. In many applications, the dynamic PFC controls the info current of the heap with the goal that the present waveform is relative to the mains voltage waveform (a sine wave). The reason for influencing the ability to factor as near solidarity (1) as conceivable is to make the heap hardware that is control factor redressed show up simply resistive (clear power equivalent to genuine power). For this situation, the voltage and current are in stage and the responsive power utilization is zero. This empowers the most proficient conveyance of electrical power from the power organization to the shopper. A few sorts of dynamic PFC are: Boost, Buck and Buck-support. Power factor corrector can be single-organize or multi-arrange. Dynamic PFC is the best.

**THE ADVANTAGES OF AN IMPROVED POWER FACTOR:** Higher power factors result in: (1) Reduction in framework misfortunes and the misfortunes in the links, lines, and feeder circuits and in this way bring down link sizes could be decided on. (2)Improved framework voltages, along these lines empower keeping up appraised voltage to engines, pumps and other gear. The voltage drop in supply conductors is a resistive misfortune, and squanders influence warming the conductors. Enhancing the power factor, particularly at the engine terminals, can enhance the effectiveness by decreasing the line current and the line misfortunes. (3) Improved voltage control. Expanded framework limit, by arrival of KVA limit of transformers and links for a similar KW, consequently allowing extra stacking without quick development. APPLICATION: 1. Automated Power factor Correction can be used for the industries purpose in the future. 2. It can be used in household purpose for higher efficiency.

#### IV. CONCLUSION

Continuous growth of sophisticated electronic equipments in the distribution system needs utility interface improvement. Dynamic control of current harmonics and reactive power management improves the reliability and efficiency of the distribution system. The series and shunt connected active filters play a major role in improving the distribution system power quality. The VSI topology is widely used in most of the power electronic converters especially in custom power devices. This research provides the applications of two-leg, three-leg, and four-leg inverter topologies in shunt and series connected active filters. It also provides a solution for optimized control methods for series and shunt connected active filter topologies. The work also highlights the cost effective sensorless PWM rectifier control techniques suitable for EV system.

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