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A Study on PWM Rectifier for Battery Charging Applications – A Review

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Abstract: ***Electric Vehicles (EV) are becoming more popular in present scenario because it can be easily charged using charger. Thus, the chargers play a vital role in EV vehicle. Hence, many distinct types of EV charging technologies have been developed so far. This paper reviews an effective and quick charging approach which extends the life cycle of a battery with high charging efficiency. This article also presents about characteristics of charger in terms of converter topologies, modulation schemes and control algorithms.***

Keywords: Electric Vehicles, Converter, Modulation Schemes, Battery Charger.

I. INTRODUCTION

Exhaust gas from vehicles due to fossil fuels is a major source of pollution in the environment. In response to the growing battery market and environmental pollution concerns, various battery operated technologies such as EV, ESS and LEV have been recently developed. This emission free vehicles can alleviate the air pollution problem. It also requires less maintenance and less noise is produced when compared to a standard car. The charging of the EVs batteries is one of the most important aspects of the vehicle. EV battery chargers can be built within the vehicle or used separately as an off-board charger. The energy flowing between grids and EV batteries are made possible with unidirectional or bidirectional converter. Grid-vehicle and vehicle-grid charger applications utilize unidirectional power flow chargers, while grid-vehicle and vehicle-grid charger applications encourage the design of bidirectional charger. Thus, this study provides an overview of modern battery charging infrastructure for EVs.

II. BATTERY CHARGING CONVERTER

For the quick charging of batteries, a variety of converter topologies are available. In this paper, some viable choices are highlighted. They are as follows:

2.1 Single Phase Current Source PWM Rectifier

Figure 1 shows the power circuit for the single phase PWM rectifiers. From the figure 1 (a) it is observed that while the neutral leg is switched, intermediate voltage levels of each capacitor at the input filter contributes the output voltage (e.g., Vcl or Vc2). But it will results in additional switching states and hence there will be a reduction in output voltage. Similarly, due to higher number of switching sequences, the output voltage gets distorted. Hence, its efficiency gets reduced.

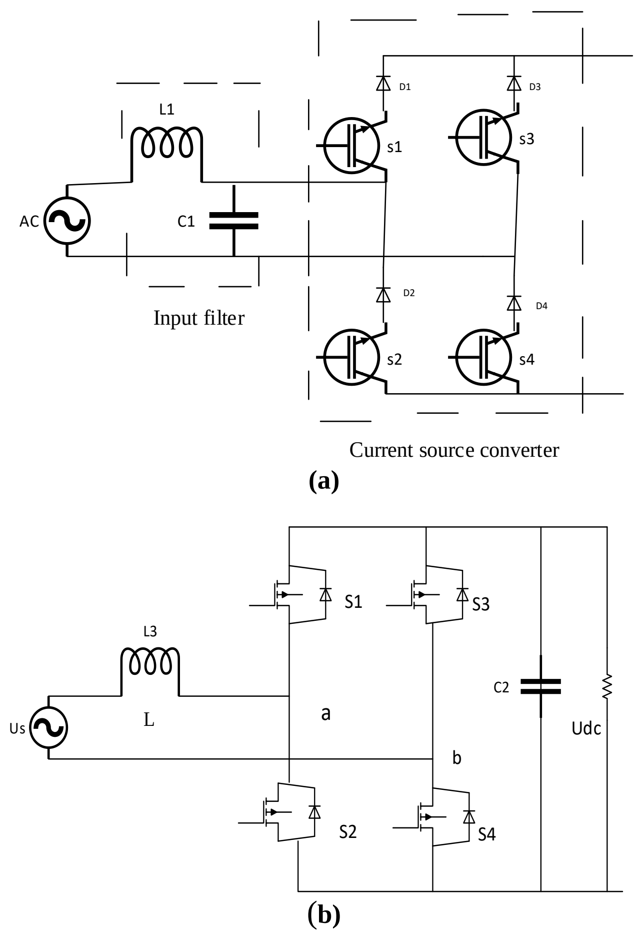

Figure 1. (a) Single Phase current source rectifier. (b) Single Phase voltage source rectifier.

Current ripples presented in the Single phase onboard charging systems of EVs have an impact on battery life. Isolated multifunctional charger architecture [1] was proposed to solve this problem. The proposed architecture serves as a battery charger and also as an active filter (AF) for the battery charger. Thus, results in minimized current ripple. Similarly, the pulsating power delivered by the AC at the line frequency causes 2nd harmonic ripple voltage on the DC link.

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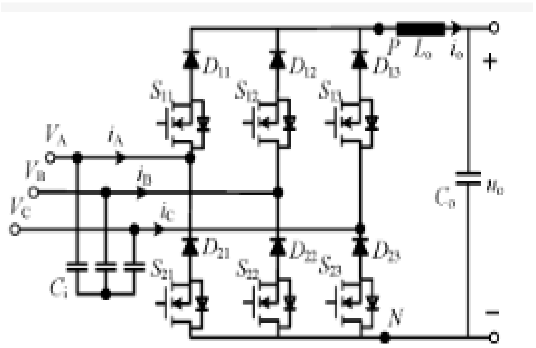
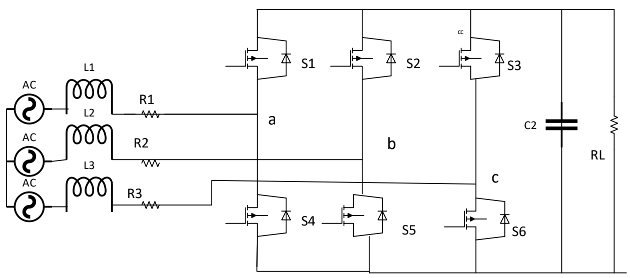
To eliminate this, an inductance based AF utilizing machine windings leakage inductance and a current compensation control approach has been developed [2].

Although the bridge rectifiers (diode) are inexpensive, durable and simple to install, their operation is not smooth. The diode bridge has a higher loss rate. So, 3 phase rectifiers were introduced to address issues of diode bridge rectifiers.

2. 2 Three Phase Current Source PWM Rectifier



(a)



(b)

Fig 2 (a) Three Phase current source rectifier. (b) Three Phase voltage source rectifier.

Due to its higher electromagnetic compatibility (EMC), 3 Phase current source rectifiers are becoming more common as the front end converter in power electronic systems. The circuit of this rectifier is shown in Fig. 2. The proposed rectifier comprises 6 controllable switches.In this illustration, antiparallel diodes of IGBTs in commercial power modules are depicted [5]. Additional diodes are connected in series with the transistors because of low reverse voltage blocking capacity of IGBT. The DC side of the circuit is coupled with a smoothing inductor to obtain smoothened output. 3Phase voltage source rectifier is the most viable topology for battery charging circuit utilized in EV. It has simple structure, with compact inductor. It also exhibits low THD at the output current. An improved DPC for a 3phase rectifier has been developed. Duty cycle control has been formulated to control the period to the voltage vector [8]. To reduce the odd order harmonics in supply line side currents, a digital plugin frequency domain based repeated control system was devised [9]. To achieve voltage regulation under dynamic load condition, 3phase Voltage Source Rectifiers (VSRs) controlled using a DC bus voltage switched control mechanism is formulated [10]. For fast charging, rectifier with SPWM based topology was designed [18-20]. Even though a variety of battery charger topologies for electric vehicles have been devised, they are vulnerable to input side fluctuations. As a result, there will be reduction in PF and higher harmonics. As a result, controllers must be incorporated to ensure the charger's stability.

III. CONTROL STRATEGIES OF ENERGY EFFICIENT CONVERTERS

To increase the dynamic response of single phase rectifiers, various control methods have been devised. PID controllers are a common closed loop control technique in many industrial control systems. Figure 3 depicts the schematic diagram of a PID controller.

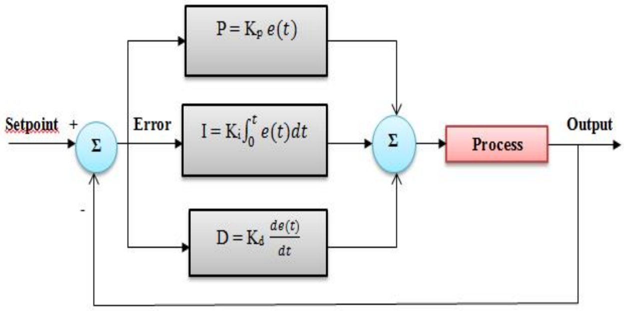


Figure 3. Block diagram of a PID controller.

To improve the dynamic response of a 1phase PWM rectifier, deadbeat predictive current control (DPCC) have been introduced [3].

The effectiveness of the proposed deadbeat control method's are confirmed by simulation and empirical findings. However, PID controllers developed for rectifiers have certain limitations. In nonlinear applications, its performance is variable and noise in the process causes changes in the system's output. Fuzzy controllers have been used to solve this problem and can able to enhance the dynamic response of the converters. FLCs are intelligent control systems which can make decisions based on expert knowledge or experience. The block diagram of FLC is presented in Figure 4.

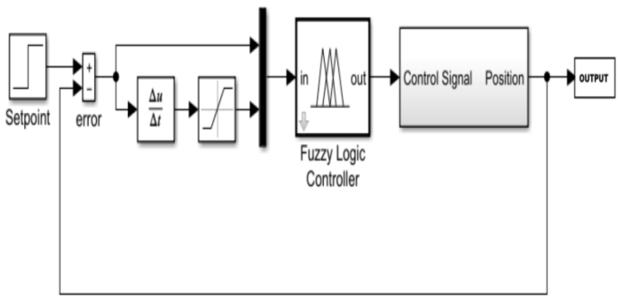


Figure 4 Schematic representation of FLC.

The dead band controller for a 3phase rectifier system was devised [4]. FL is incorporated in this architecture to predict the parameter in the deadbeat controller.

The experimental results validated the proposed control strategy. To achieve high performance control, controller design for 6 switch PWM VSRs was carried out with rotating d-q frame coordinates. Lee et al. (2011) proposed a simplified Park Transformation topology that was tested using 6 switch PWM VSR [6]. The results showed that the d-q frame controllers are superior to conventional controllers.

A unique and simple DPC technique for a 3phase PWM rectifier was developed without any predefined

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switching table. In this, FL rules are utilized to decide the switching state and the instantaneous active and reactive power tracking error serves as a FL variables. The results have demonstrated good performance and suggested that proposed DPC scheme is significantly superior to classical DPC [7]. As a result, a greater variety of topologies for battery charging applications in EV systems have been created to date.

IV. PWM TOPOLOGY

In commercial AC motor drives, a 3phase VSI is widely for controlling. In this, the gating signals should be pulled ahead or delayed by 120° to provide 3phase balanced voltages. Two alternative PWM topologies, notably SVM and SVPWM have been frequently employed to achieve these switching signals. In order to produce converter gate signals, SPWM compares a sinusoidal reference voltage with a triangular carrier signal. SVPWM topology has become a common PWMtechnique in applications like control of AC induction motor etc. It's a more advanced technique which generates a higher voltage with lower THD at its output.

Table 1. Comparison of development of battery charging topologies for EV applications in terms of their configuration and switching topology.

Author	Configuration	Modulation techniques
Yun Zhang , 2020	Single phase	
Yun Zhang, 2019	Single phase	Current compensation
Ping Wang, 2019	Single phase	Dead beat control
Lijun Hang, 2010	Three phase	Deadbeat
Yongchang Zhang, 2012	Three phase	Direct power control
Tzann-Shin Lee, 2011	Three phase	sinusoidal PWM
Abdelouahab Bouafia, 2009	Three phase	Direct power control
X. H. Wu, 2010	Three phase	Digital repetative control
X. H. Wu, 2008	Three phase	Frequency domain based repetative control
Wei Zhang, 2012	Three phase	d-q
Bor-Ren Lin 2000 [11]	Three phase	Inverter based diode clamp
Rajesh Ghosh, 2008 [12]	Three phase	CSPWM
Bor-Ren Lin, 1999 [13]	Single phase	Hysterises current control
X. H. Wu, 2008 [14]	Three phase	Instantaneous power flow
Hidenori Tanaka, 2015 [15]	Single phase	Reactive power control
Toshihiko Tanaka, 2013 [16]	Single phase	Power quality compensator
Shu-Zu Dai, 1992 [17]	Single phase	SPWM
Junjie Ge, 2014	Three phase	Direct power control
Flabio Alberto Bardemaker Batista, 2006	Three phase	Space vector modulation
Amirhossein Moeini, 2016	Single phase	SHCM-PWM
Toshihisa Shimizu, 1997 [21]	Single phase	Conventional PWM
Chien-Ming Wang, 2004 [22]	Single phase	Zcs-PWM
Sheng-Yuan Ou, 2011 [23]	Single phase	Voltage balance control
Zhiyong Zeng, 2015 [24]	Single phase	SVM
Ruxi Wang, 2010 [25]	Single phase	Energy storage capacitor
Jinhui Xia, 2017 [26]	Single phase	Sliding mode observer
Feng Wu, 2016 [27]	Three phase	Open circuit fault diagnosis
Guan-Chyun Hsieh ,1999 [28]	Single phase	FWBR
Adel Rahoui, 2020 [29]	Three phase	VF-PDPC
Feng Wu, 2017 [30]	Three phase	Primary inductances energy analysis

Table 2. Comparsion of development of battery charging topologies for EV applications in terms of their efficiency.

Author	Efficiency (%)
Yongchang Zhang, 2013	90
Tzann-Shin Lee, 2011	88
Bor-Ren Lin 2000	88
Bor-Ren Lin, 1999	90
Toshihisa Shimizu, 1997	88
Chien-Ming Wang, 2006	98.3
Sheng-Yuan Ou, 2012	95
Guan-Chyun Hsieh, 1999	95

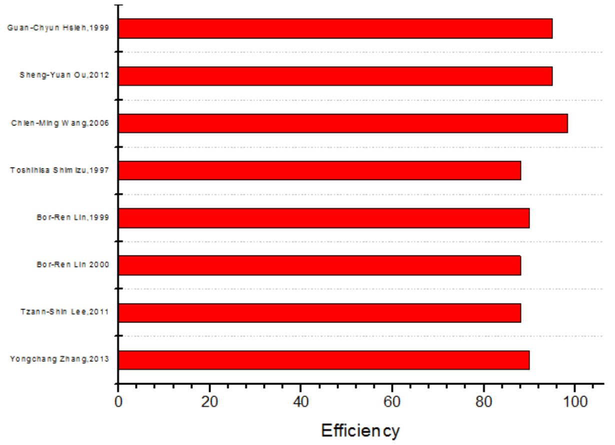

Figure 5. Comparison of development of battery charging topologies for EV applications in terms of their efficiency.

V. CONCLUSION

The first section of this paper analyses the various charging topologies adopted for EV. The controllers developed for the improvement of their performance are discussed in the next section. Based on this study, it can be inferred that the controller's performance is more important for enhancement of the battery charging system. It can also be inferred that adopting AI-based controllers will increase the performance of battery charging unit in terms of power factor and efficiency.

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