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DESIGN AND SIMULATION OF DC DC CONVERTER FOR FAST CHARGING EV APPLICATION

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ABSTRACT

In this paper, the DC fast charger module with its circuit topologies is studied detailed. The electric vehicle batteries are charged via DC fast chargers for quick charging. The electrical power goes through AC to DC and DC-DC power converters and reaches the battery. The first stage's responsibility is converting AC to DC, drawing low harmonic content and low reactive power from the grid, and providing fixed DC bus voltage. However, the latter task is charging the battery with a controlled current or voltage level. The common topology in the AC-DC converter is the Neutral Boost PFC in Vienna Rectifiers. However, Phase-shifted Full Bridge or LLC Resonant Converters are popular on the DC-DC side. The circuit models for those power stages are modeled in the PC platform and obtained the system efficiency of the DC Fast Charger. In the last part, the proposed idea is presented which involves sharing the charge of the electric vehicle battery between two power converters. The proposed study results show that the DC fast charging system efficiency increases remarkably on high output voltage levels.

Keywords: Chargers, Electric Vehicle Charge, Full Bridge DC-DC Converter, Power Electronics, Power Factor Correction.

1. INTRODUCTION

The popularity and the market of electric vehicles (EVs) are continuously growing over the last decade The market share of electric vehicles was 9% in 2021. Despite the pandemic and production shortage due to the chip crisis, it is expected to reach 13% in 2022 and 21.7% in 2030 Compared to traditional gasoline engine vehicles, there are many reasons to buy EVs. First of all, there is no CO2 emission in the power conversion. In addition, power source- electricity- is much less expensive than gasoline. As EVs include electric motors in traction and no need to use switch gear, they are much more efficient, comfortable, and quiet. The traction electric motor can provide high torque at a standstill which makes EVs highly dynamic and responsive. Moreover, EVs have fewer components than traditional vehicles which means less maintenance and long life. The last but not least feature is regenerative braking is always possible that make the EVs a fuel saver without adding any additional parts The increase in the market of EVs has led to an increase in the market of EV charging stations. The electric vehicle charger market size reached USD 8.8 billion and it is forecasted to grow to USD 23.4 billion by 2028 with a steady 15% CAGR. It is reported that the quantity of public EV charger stations is dramatically increasing compared to private chargers Moreover; R&D studies are mainly focused on increasing the power level of public EV Charger Stations as the people who drive electric vehicles mostly live in cities.

Public EV chargers are classified into two categories; AC Charger and DC Fast Charger Public AC chargers have usually three-phase input and provide up to 22 kW output power. AC chargers provide AC and need to use an onboard charger to convert AC into DC. Therefore, the charging power level is restricted by onboard charger capability On the other hand, DC fast chargers provide DC which directly charges the EV battery without using an onboard charger. Hence, its power level is only limited by charger power capacity and battery temperature during charging. Today, the battery charging power limit reaches about 350 kW Compared to AC charging, DC fast charging is more suitable for public areas as the charging time for each car is limited and many car users want to use charging stations

Electric vehicle chargers require high-power and high-frequency power converters to efficiently convert grid AC power to DC power for charging the vehicle's battery. DC fast chargers have two stages in power conversion; AC to DC and DC to DC conversion. In the first stage, the goal is to get fixed DC voltage by drawing low harmonic content AC current from a three-phase grid. These circuit types are named "power factor correction circuits Some applications use traditional

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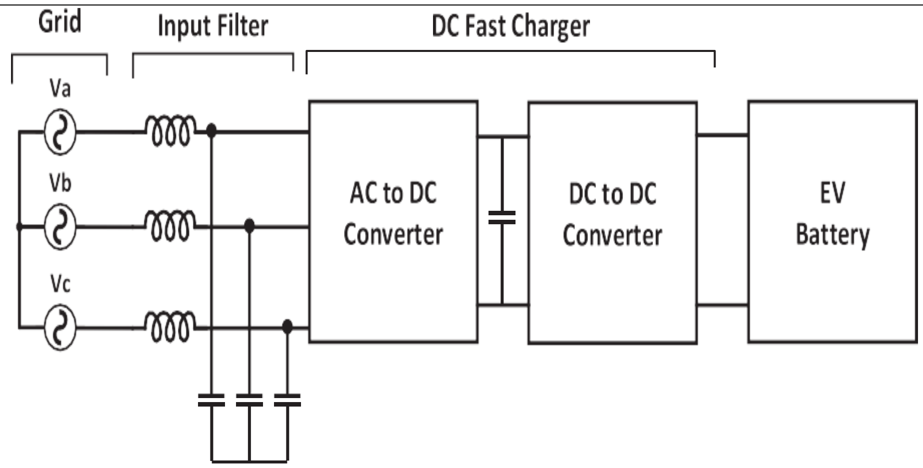

Transformer and rectifier circuits as an alternative method which may provide easy implementation. However, these systems are always large and cumbersome. However, the same goal can be implemented by using AC-DC and DC-DC converters

2. FUNCTIONALITIES NEEDED

A. Grid Support

To reduce the issues caused by fast charging's MW power demand, the charging station should be capable of injecting reactive power back into the grid in order to keep the Point of common coupling voltage and prevent voltage fluctuations.

Furthermore, grid supports such as peak demand reduction, Station-to-Grid (S2G), vehicle-to-grid (V2G), and active power filtering (APF) encourage utility owners to accept charging stations and attract more investors. Because grid support is based on trying to inject reactive and/or active power back into the grid, the charging station must have a bidirectional topology.

B. Integration of renewable energy sources

Renewable energy sources can help to energy the charging station least in part. As a result, the power drawn from the power grid is reduced, and some of the issues associated with EV charging, such as peak loading, overload, and voltage drop, may be mitigated. A renewable source, on the other hand, such as PV, has a low power generation density and cannot produce enough energy to mitigate the problems caused by fast charging.

C. Integration of battery energy storage

A few of the issues associated with fast charging can be mitigated by incorporating battery energy storage into the charging station, similar to RESs. Furthermore, by using BES with a proper control tactic, the processing variables of the RESs can be enhanced.

D. Power Density

The power density is defined as the ratio of total available power to charging station area. In urban areas with high land prices, the charging station's footprint must be kept small. However, in larger shopping malls, along highways, and in rural areas, this is not a major problem.

E. Reliability

A greater number of components, particularly Power Electronic (PE) components, reduces the overall system's reliability. A significant number of power electronic switches necessitates a large number of drive circuits, which adds to the system's complexity and reduces its reliability. The difficulty of control methods also contributes to decreased overall reliability.

3. CHARGING STATION DESIGN

3.1 AC TO DC FRONT END CONVERTER

Power electronics is expanding rapidly since it improves electricity in all aspects, from generation to end consumption. It was discovered in the investigation that preceded this work that a variety of approaches for limiting and mitigating disturbances and harmonic content at the point of common connection have been studied throughout the years. Among them are passive filters, passive components such as notch filters, and active filters. Active front end (AFE) is a technology that outperforms the previous solutions owing to its numerous advantages. The ability to decrease line current harmonics caused by high frequency switching, regenerative power flow capabilities, maintaining unity power

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factor, and DC-link voltage management are the important characteristics of AFE-based converters.

For AC to DC power conversion, conventional rectifiers are utilized. Its functioning determines the magnitude of harmonics injected into the linked distribution system. The typical converter's input current is non-sinusoidal, resulting in harmonic distortion. PWM converters appear to be a potential solution. Sinusoidal PWM [7] is a form of carrier-based PWM in which the modulating signal is sinusoidal and is compared to the carrier signal (triangular) to create gating pulses. The SPWM method [11] is severely limited by its small range of linearity. The linear range of SPWM control features is terminated at modulation index (ma)= 1. However, SVPWM has a linear range up to Max = 1.15. With varying loads, the resilience of the rectifier is critical. For control, PI regulators are utilized. The controllable variables are linked together. By decoupling the variables using the d-q transformation, a good voltage response with minimal harmonic distortion is created. The control system for a three-phase rectifier with fixed switching frequency SVPWM is provided, and the findings are confirmed using simulation.

In order to assure bidirectional power flow with increased power factor and THD, a single phase FEC using an IGBT as a switching device is employed in this study. Unipolar sine triangle PWM (pulse width modulation) approach is utilized to produce a pulse width modulated pole voltage, which is then used to create the proper gating pulse.

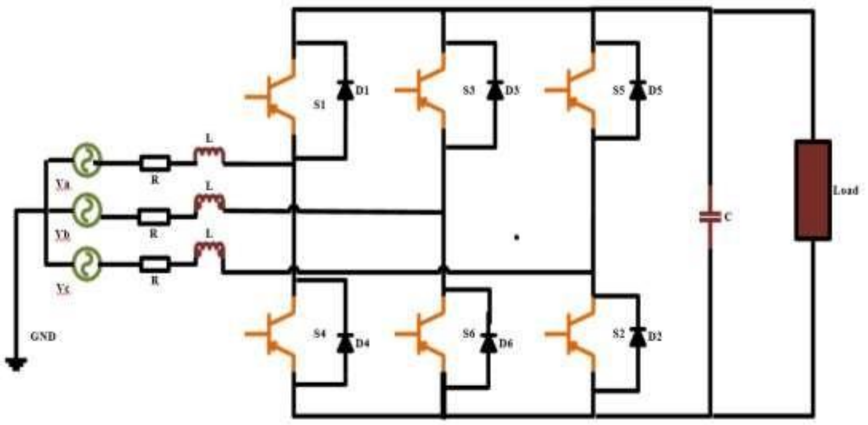

Fig 1: AC to DC Converter

3.2 ELECTRIC VEHICLE DC CHARGE TOPOLOGIES

3.2.1DC fast charging topologies

The EVs are intended to charge in a short time using DC fast chargers. Hence, 3-phase AC input is preferred to equally share the required electrical power. The block diagram of the DC fast charger is shown in Fig. 1. To minimize harmonic content usually, the input filter is used in a grid line. The first stage AC-DC power converter is assigned to obtain a constant DC voltage and to draw low harmonic content from the grid. The first stage is called “Power Factor Corrector-PFC”. However, the second stage DC-DC power converter is tasked with providing the required DC or voltage level needed by the load i.e. EV battery.

3.2.2 Power factor correction circuit topologies

There are two main goals in the power factor correction circuit; providing constant DC bus voltage from alternative grid voltage and drawing pure sinusoidal current from the grid. Moreover, the current should be synchronized with the grid voltage to reach the highest efficiency on the converter side by providing full active power.

There are four different rectifier topologies popular in DC EV chargers; conventional interleaved boost PFC rectifier bridgeless boost rectifier, totem pole PFC converter, and Vienna rectifier The most popular AC-DC power factor correction circuit in DC fast charger topologies is the Vienna Rectifier. This converter topology features high power density and efficiency with minimum power switches. Moreover, as the natural capability of the three-level switching boosts type, the PFC feature provides less voltage stress on the power switches. Hence, the losses and costs of the power semiconductor will be reduced significantly and this feature enables high switching frequency and results in making the converter highly compact. It should be noted here the Vienna Rectifier is the unidirectional PWM rectifier. So, it does not allow to push power to the grid. A vehicle-to-grid application is not possible with this topology. There are three different popular Vienna Rectifier types in the literature.

3.2.3 DC-DC converter circuit topologies

The high-power demand expected from DC fast charging stations allows only two types of DC-DC converter topologies; Phase Shifted Full Bridge Converter and Resonance Converter. The phase-shifted full bridge DC-DC converter is very similar to the conventional Full Bridge converter. Shifting the gate signal between the phase legs

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enables zero voltage switching (ZVS) which increases the efficiency, especially at high input voltage. Usually, this converter needs an extra commutating inductor which is serially connected to the primary winding of the transformer to ensure ZVS operation at light loads. The resonant converter is another alternative circuit topology to achieve very low switching loss and to operate at a high switching frequency in the circuit. There are three basic resonant converters; Series (SRC), Parallel (PRC), and Series-Parallel Resonant Converter (SPRC, or called LCC resonant converter)[30]. Moreover, there are two extra advanced Resonant converters; LLC resonant converter and CLLC resonant converter, as well. This study will not go into detail about the pros and cons of each converter. However, only some key features of LLC resonant converters will be mentioned as it is a trend in EV charging stations. In LCC resonant converters, the output regulation is performed with switching frequency variations. The ZVS capability for the whole load range is possible. The magnetic components i.e. magnetizing inductance and leakage inductance can be integrated into one magnetic core. LLC resonant converter is unidirectional and vehicle to the grid is not possible. Here, the pro- posed idea is mainly focused on the first stage of AC-DC conversion. So, only the phase-shifted full bridge converter will be modeled in the simulation study.

3.2.4 PHASE SHIFTED FULL BRIDGE DC/DC CONVETER (PSFB)

A phase shifted full bridge dc-dc converter (PSFB) [13], [14]is a full bridge dc-dc converter with a phase shifting control that is comparable to a standard full bridge dc-dc converter. The switches in a phase shifted full bridge dc-dc converter achieve zero voltage switching, which decrease switching losses. The converter can achieve high efficiency at high switching frequencies and has other advantages such as low Electromagnetic interference, low switching noise eliminates the need for additional snubber circuits to reduce losses. PSFB converters are used in medium to high power applications such as renewable energy systems, telecom rectifiers, battery charging systems, server power supplies, and so on to step down high dc voltages and provide isolation.

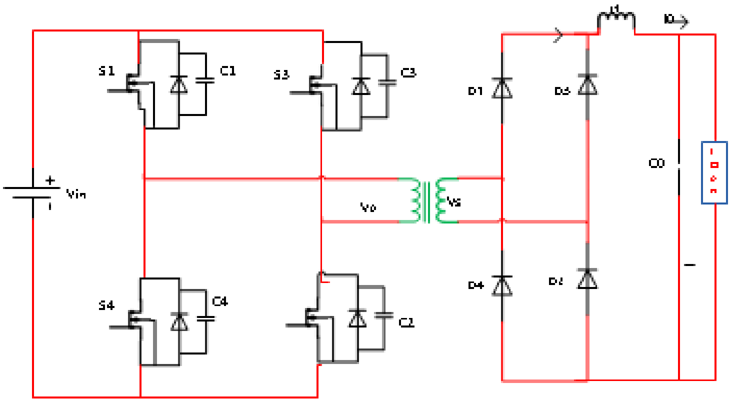

Fig 2: Phase Shifted Full Bridge

3.2.5. PHASE SHIFTED FULL BRIDGE DESIGN

A high frequency phase-shift full bridge converter [1] with the following specifications is designed and simulated.in MATLAB /Simulink.

Input Voltage Vin = 900 V

Required Maximum output Voltage Vo = 450 Volt

Turn Ratio of the transformer =0.5 Nominal Power P = 50 kW Output current I0 = 111.5 A

Switching frequency f = 25kHz Maximum duty cycle of D = 0.5 The voltage across the output filter inductor

$L0$=100 μH

The output voltage ripple is less than 1V then output Capacitor is

$C0$= 33μF

Specifications and Design parameters

Parameter	Symbol	Value
Input Voltage	Vin	900 V
Output Voltage	V0	450 V
Nominal Power	P	50 kW
Switching Frequency	fs	25 k HZ

Output inductor filter	L0	100 µH
Output Capacitor	C0	33µF

4. SIMULATION

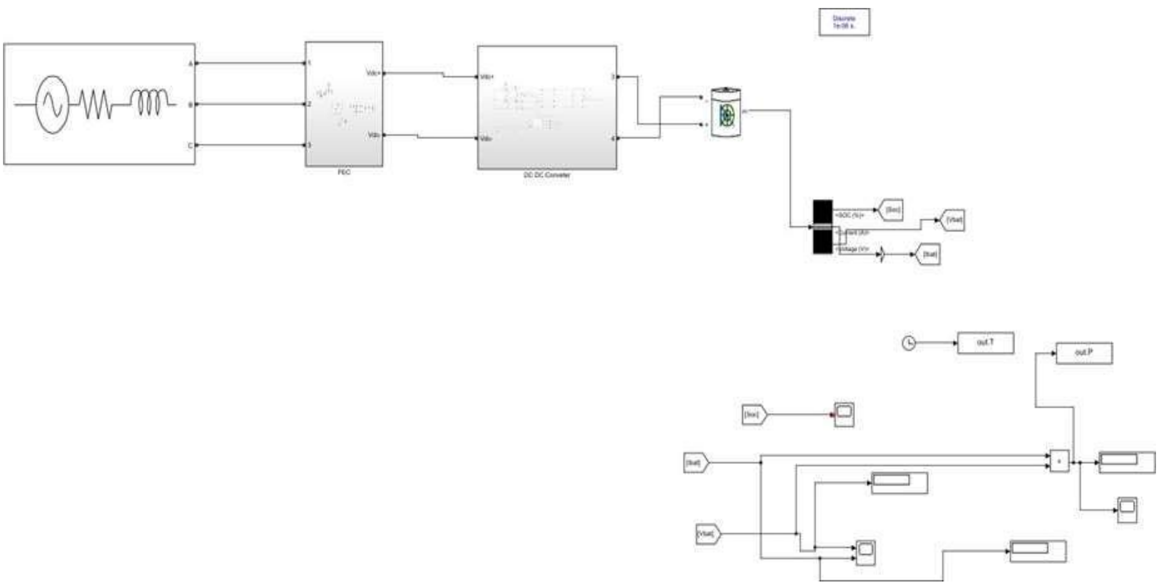

Fig 3: DC Fast Charging Station Simulation.

5. RESULTS

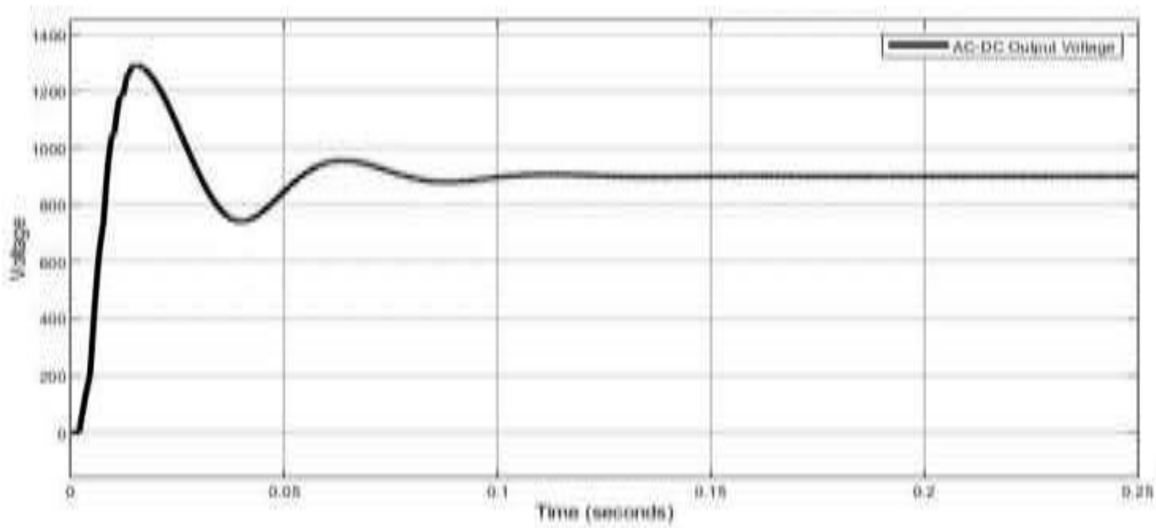

Fig 4: AC to DC Output Voltage

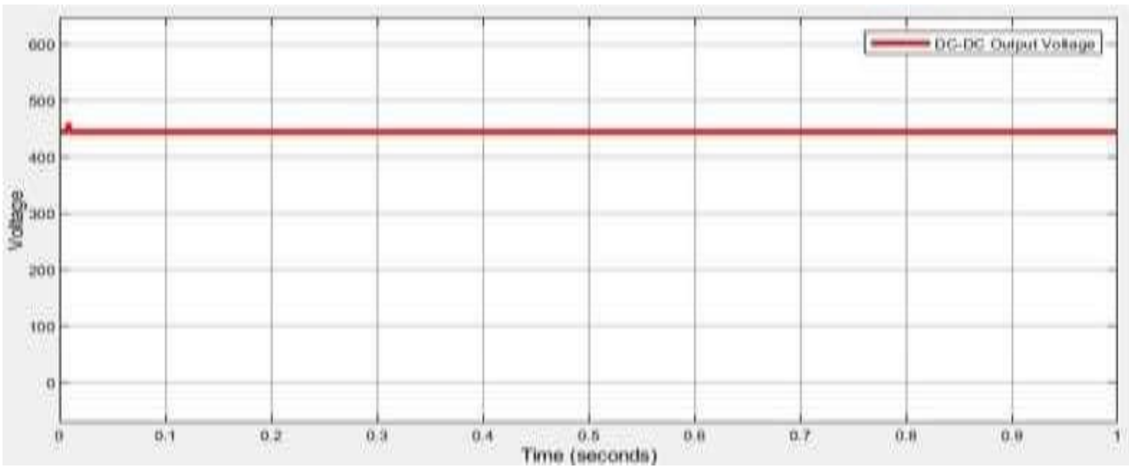

Fig 5: DC to DC output Voltage

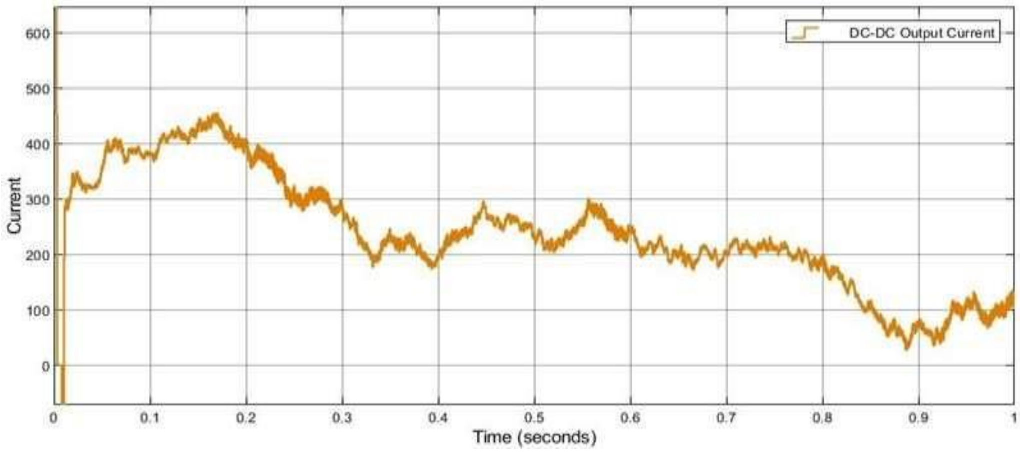

Fig 6: DC to DC Output Current

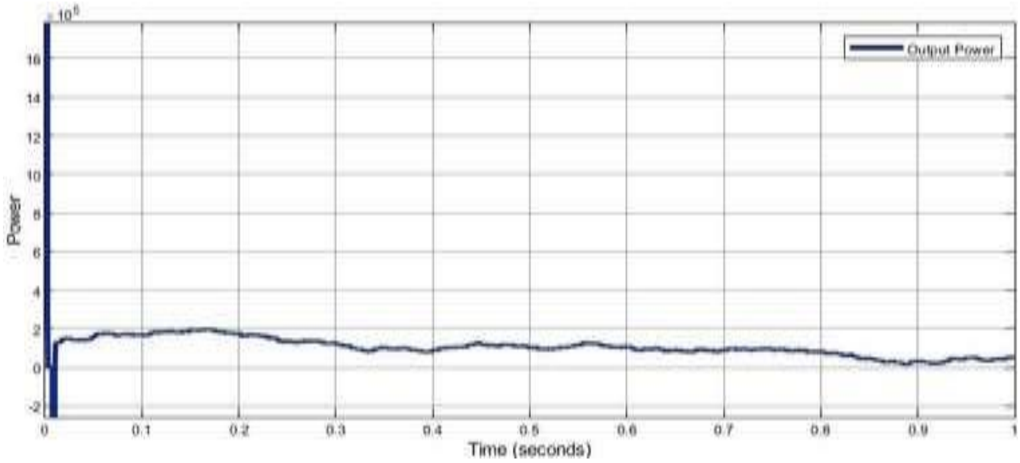

Fig 7: Output Power

AFC rectifier with SVPWM control is implemented. Closed loop control is accomplished by sensing phase voltages and currents. Three phase quantities are converted into d-q axis components using Clark's and Park's transformation. The PI regulation block includes current decoupling, and three PI controllers are required: one to regulate the DC link voltage, and the other two to regulate the d-q axis components. The pulse generator block consists of transforming d-q axis components into reference vectors and determining their amplitude and phase angle, as well as determining the angle of the vector in each sector, sector determination, and a seven-segment switching technique. The PSFB Converter Parameters are shown in table-2. The input value is taken from the output of AFC, the storage battery is connected to PSFB and getting output as in between 250V – 450V.

6. CONCLUSION

Despite the growing number of electric vehicles on the road, a lack of charging infrastructure and long charging times limit their use to daily commutes and short distance trips. To address this issue, a cost-effective and ubiquitous charging infrastructure that can compete with existing gasoline-powered vehicle refueling infrastructure is required. This paper examines cutting-edge XFC converter technology for EVs that can address the challenges and capitalize on the opportunities presented by the increasing penetration of EVs.

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