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Modeling and Simulation of DC Fast Charging Station for Electric Vehicles

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ABSTRACT

Owing to the increasing 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 widespread charging infrastructure that can compete with existing gasoline-powered vehicle refueling infrastructure is required. This can be accomplished by using DC (Direct Current) extreme fast charging stations. Extreme fast charging station consists of cascaded H-bridge (CHB) converter which is used to directly interface with the medium voltage (MV) grid and Phase Shifted Full Bridge (PSFB) based soft-switched solid-state transformer (SST) to achieve galvanic isolation. Based on battery capacity, a conventional charging station with a level 2 charger takes about 6 to 8 hours to charge EVs from 0 %to 100%. Whereas an Extreme fast charging station takes about 15 to 20 minutes to charge EVs from 0% to 100%. In this project we present an extreme fast charging simulation model based on bidirectional isolated dc/dc converter by using which we can charge the vehicle. This work emphasis on reducing this charging time to a much lower as compared to existing methods by using Front end converter, PSFB, solid state transformer. Extreme fast charging station simultaneously charges multiple EV's at a time thus thereby reducing the overall cost, area required for installing the charging station and also the charging time. Because this process reduces charging time, vendors can earn more profits by charging a greater number of vehicles, and customers can save time.

Keywords: Extreme Fast Charging, Solid State Transformer, Phase Shifted Full Bridge.

1. INTRODUCTION

The widely use of electric vehicles (EV) can benefit the environment, the economy, and society as a whole. In comparison to Gasoline Powered Engine (ICE) vehicles, EVs have several advantages. The first advantage stems from the structural applications of electric vehicles and ICE vehicles, which differ in terms of energy efficiency and maintenance and fuel consumption costs. Because the first group has an electric motor, braking energy can be saved, whereas the latter group has inefficient energy consumption in the same situation. Furthermore, because EVs use electricity as their primary fuel rather than gasoline, they can save significant fuel costs per year. Furthermore, unlike ICE vehicles, electric vehicles do not have many machineries. The second benefit is that by utilizing locally electricity produced, the reliance on imported gasoline will be greatly decreased. As a result, the risk associated with oil price fluctuations will be reduced, and national energy security will be enhanced. The third advantage stems from EVs' environmental friendliness and public health benefits. Automobiles emit hazardous pollutants such as particulate matter and carbon emissions. EV charging eliminates these harmful emissions from urban areas, resulting in reducing pollution for the society. The generation of required power in remote power plants is usually cleaner because air pollution and environmental is more achievable in a few power plants rather than a large number of vehicles.

As a result, many countries have developed targets for widespread adoption of EVs, and the replacement of ICE vehicles with EVs is expected to rise in the coming years. Regardless of the fact that there are some advantages to widespread adoption of

EVs, there are some significant barriers that prevent widespread adoption. From the point of view of an EV owner, there are two major issues: long charging times and a lack of charging stations. These have reduced the driving range of EVs to the point where approximately 40% of EV owners' daily trips exceed the available electric range of their EVs.

As a result, getting fast charging architecture appears to be necessary in order to make EVs more appealing and, as a result, increase their accumulation. 50 kW [13],14] quick chargers are available today for installation in public parking lots such as universities, medical facilities, and shopping malls. Despite the fact that these chargers are faster than lower power chargers used at home, a full charge may take an hour, which is far from normal. Furthermore, they are unable to alleviate the associated issues with EV charging, so their use is restricted, subject to good preparation and devoted facilities. As a result, there is a scarcity of fast charging infrastructure that can be fed from the existing power grid without requiring a deeply committed power system and complex communication and metering infrastructure. Fast charging stations appear to be a viable option for mitigating the associated problems with EVs[1]–[10].

Fast charging stations appear to be an appealing option for both power system administrators and possible future EV owners due to the integration of Battery Energy Storage Systems (BESs) and Renewable Energy Sources (RESs) into the charging station, as well as having greater autonomy over the

EV chargers, ES, and RES. In this scenario, charging stations must be designed with the intention of addressing the aforementioned issues, with a particular focus on fast charging, which is a particularly appealing feature for end users of electric vehicles. taking into account the aforementioned issues, with special emphasis on the fast-charging operating condition, which is a particularly appealing feature for electric vehicle end users.

2. FUNCTIONALITIES NEEDED

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.

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.

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.

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.

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 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.

3.1.1 MATHEMATICAL MODEL

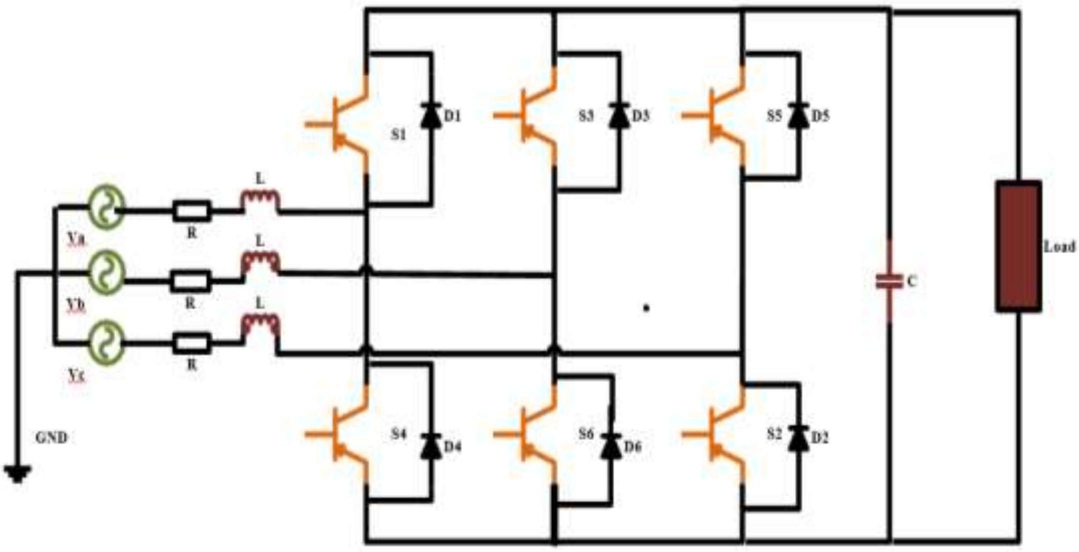


Fig 1. AC to DC Converter

Figure depicts the comparable circuit schematic of a three-phase active front-end converter (AFC). For the sake of simplicity, the supply from the mains is considered to be balanced. V_a, V_b and V_c are phase voltages. i_a, i_b and i_c are phase currents. R and L are equivalent resistance and boost inductor, respectively, and their values are supposed to be identical for all three phases. D.C. link capacitor (C) to smooth the AFC output voltage by minimizing ripple. V_{ar}, V_{br} and V_{cr} are the rectifier's input voltages, whereas i_l represents the load current.

The equations for voltage are given by

$$V_a = L\frac{di_a}{dt} + Ri_a + V_{ar}$$

$$V_b = L\frac{di_b}{dt} + Ri_b + V_{br}$$

$$V_c = L\frac{di_c}{dt} + Ri_c + V_{cr}$$

Source voltage is given by:

$$V_a = V_m \sin\theta$$

$$V_b = V_m \, \mathrm{Sin}(\theta - \tfrac{2\pi}{3})$$

$$V_c = V_m \sin(\theta - \tfrac{4\pi}{3})$$

Input voltage to the rectifier can be expressed as:

$$V_{ar} = [S_a - \tfrac{1}{3}(S_a + S_b + S_c)]\, V_{dc}$$

$$V_{br} = [S_b - \tfrac{1}{3}(S_a + S_b + S_c)]\, V_{dc}$$

$$V_{cr} = [S_c - \tfrac{1}{3}(S_a + S_b + S_c)]\, V_{dc}$$

Where Sa, Sb, and Sc are switching functions, and the top switch is on Si =1and the bottom switch is on Si = 0 I = a, b, c). The current flowing through the D.C link capacitor is

$$C\frac{dV_{dc}}{dt} = S_a i_a + S_b i_b + S_c i_c - i_L$$

the mathematical model of three phase rectifier in stationary abc coordinate system as below:

$$L\frac{di_a}{dt}=V_a- Ri_a+(S_a+S_b+S_C)/3\ V_{dc}$$

$$L\frac{di_b}{dt}=V_b- Ri_b+(S_a+S_b+S_C)/3\ V_{dc}$$

$$L\frac{di_c}{dt}=V_c-Ri_c+(S_a+S_b+S_C)/3\ V_{dc}$$

$$C\frac{dV_{dc}}{dt}=S_a i_a+S_b i_b+S_c i_c-\frac{V_{dc}}{R_L}$$

Where

$$U_{rd}=S_d.V_{dc}$$

$$U_{rq}=S_q.V_{dc}$$

The rectifier's input voltages are U_{rd} and U_{rq} are switching functions in a synchronously rotating d-q coordinate. U_d, U_q and i_d, i_q are voltage sources and currents in synchronously rotating d-q coordinates, respectively.

The equation shows that i_d and $i_q$are connected to both the coupling voltages Li_d and Li_q. To enable high performance functioning of the current control loop, the current must be decoupled. U_{rd} and U_{rq} must be managed to decouple i_d and i_q.

$$U_{rd}=-U'_{rd}+\omega Li_q+U_d$$

$$U_{rq}=-U'_{rq}+\omega Li_d+U_q$$

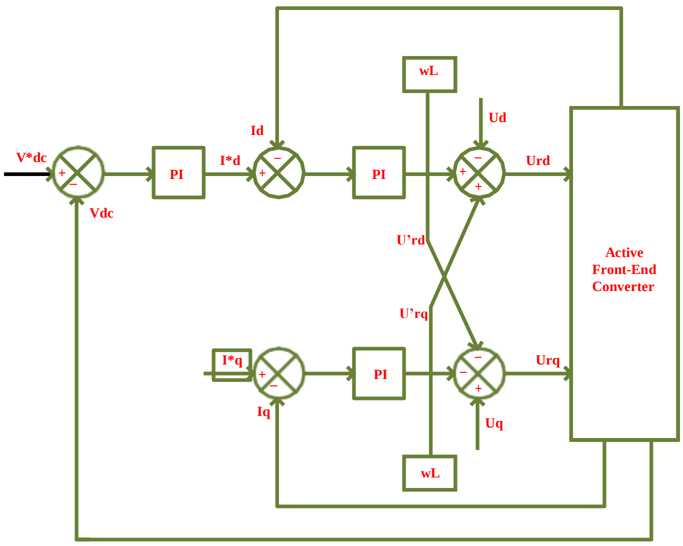
By inserting it into equation

$$L\frac{di_d}{dt}=-Ri_d+U'_{rd}$$

$$L\frac{di_q}{dt}=-Ri_q+U'_{rq}$$

Because U'_{rd} and U'_{rq} are exclusively connected to i_d and i_q, respectively, they are dissociated from the current's i_d and i_q. PI controllers are used to control the voltage and current.

3.1.2 SVPWM CONTROL STRATRGY



The rectifiers should make sure power factor correction is achieved and current harmonics are kept to a minimum in accordance with international standards like IEC1000-3-2, EN61000-3-2, and IEEE519 SVPWM [11] is becoming more popular because it is simpler to implement digitally, maintains regenerative action, injects harmonics at the input side of the rectifier owing to switching, and provides unity power factor at the point of common coupling. By rotating a reference vector across the state space diagram, which is made up of six non-zero vectors creating a hexagon, SVPWM is achieved. The vector diagram is displayed in fig 2. The three-leg, two-switch configuration of a three-phase rectifier results in a total of six switches, which suggests that there are eight different operating states for the converter, which is represented as a voltage vector from V0 to V7 in the alpha-beta coordinate system. While V0 and V7 are zero vectors, voltage vectors V1 to V6 are non-zero vectors. $\boldsymbol{Vref}$ is a sector I reference voltage vector with an angle of S.

Two switches in the same leg, one of which is turned on and the other off, are all that are needed to transition from one switching state to the next. It takes no more than a minimal amount of switching for a $\boldsymbol{Vref}$ to go from one sector to the next.

Table – 1

Specifications of FEC

Parameters	**Symbol**	**Value**
Grid Voltage	*VSource*	415 volts (rms)
Grid Frequency	*fsource*	50
Filter Capacitance	*Lf*	100 µF
Filter Inductance	*C f*	500µH
DC Reference Voltage	*Vdc*	900 volts

4. DC TO DC CONVERTER

DC-DC converters are devices that convert direct current voltage from one voltage level to another. They can be step up or down. Power electronic converters are typically made up of semiconductor switches such as MOSFETS and IGBTs. Non isolated and isolated DC-DC converters [12]are the two types. In the isolated topology, a transformer provides isolation between the input and the output. Boost converter, Interleaved boost converter, Unidirectional three-level, Bidirectional three-level boost converter, Three-level flying capacitor converter are examples of non-isolated converters. Phase shifted full bridge converter, Dual Active Bridge converter, Double inductor and Capacitor Converter, CLLC converter are examples of isolated converters.

High power isolated DC-DC converters have emerged in the market in latest decades of their use in applications such as Fuel cell applications, Battery-based storage systems, and Telecommunications systems, among others. The transformer is used in most applications to provide isolation as part of the circuit. The advantages of using isolated are that the isolated topology's transformer can provide a large step up or step-down conversion ratio, multiple dc outputs can be obtained by providing multiple secondary windings, and voltage and current stress in the transistors can be reduced by proper turn ratio design.

4.1 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.

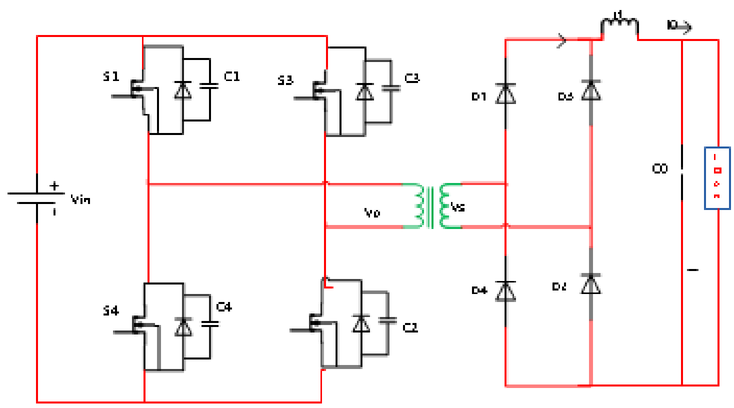


Fig 4. Phase Shifted Full Bridge

4.2 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

Table -2

Specifications and Design parameters

Parameter	**Symbol**	**Value**
Input Voltage	*Vin*	900 V
Output Voltage	*V*0	450 V
Nominal Power	P	50 kW
Switching Frequency	*fs*	25 k *HZ*
Output inductor filter	*L*0	100 µH
Output Capacitor	*C*0	33µF

5. SIMULATION

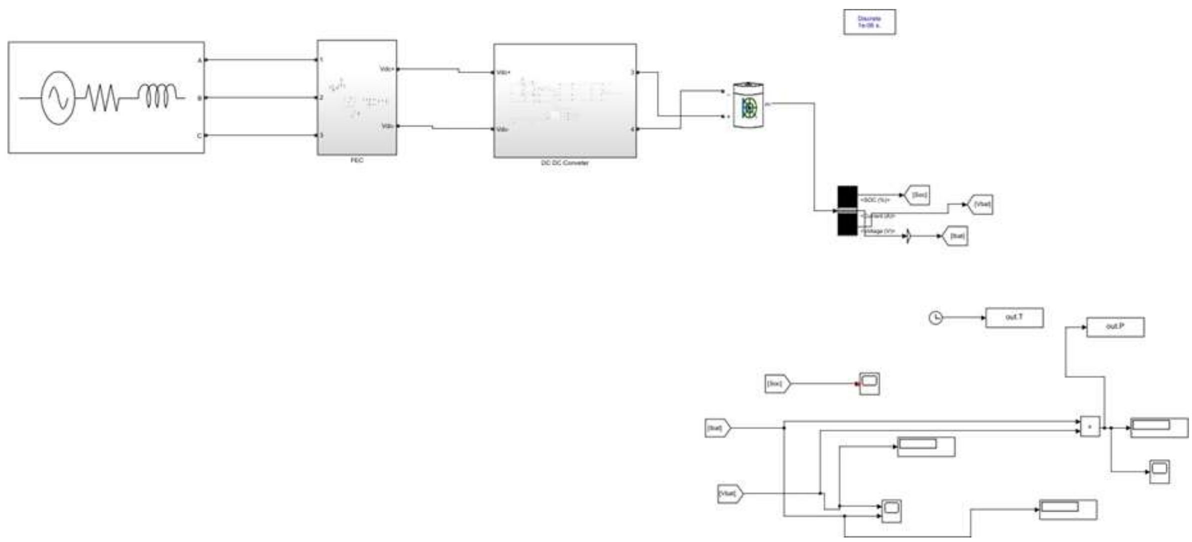


Fig 5. DC Fast Charging Station Simulation.

6. Results

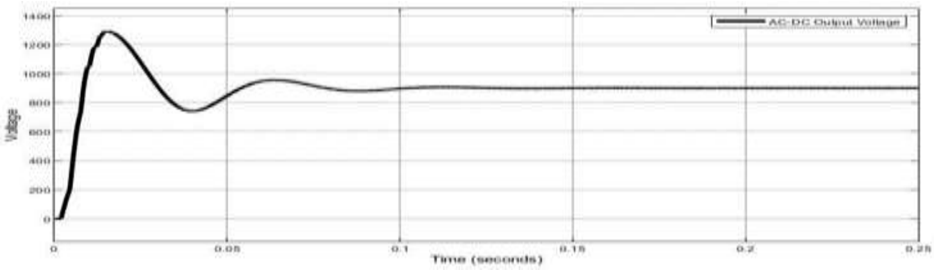


Fig 6. AC to DC Output Voltage

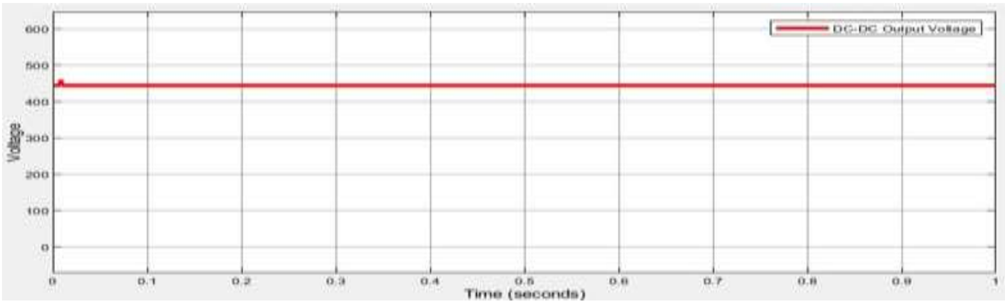


Fig 7. DC to DC output Voltage

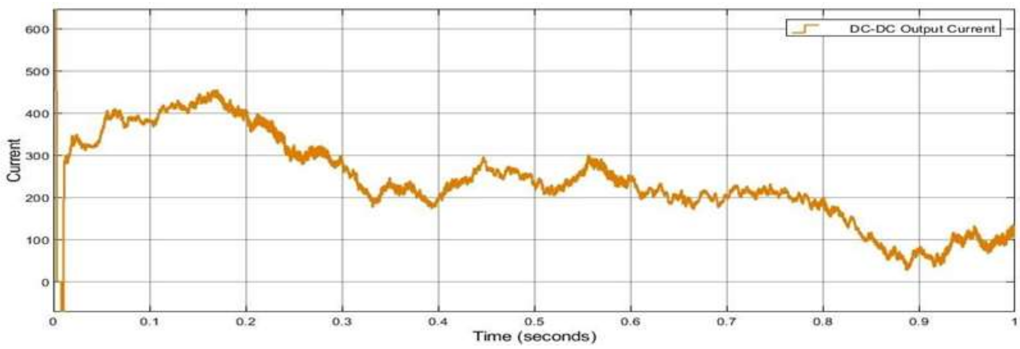


Fig 8. DC to DC Output Current

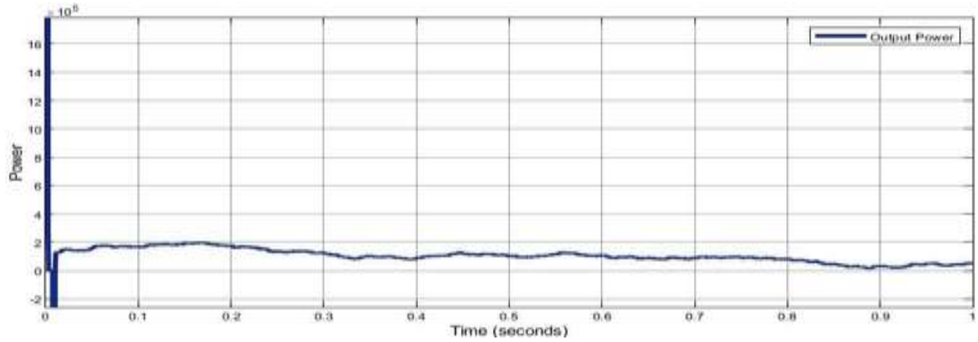


Fig 9. Output Power

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.

7. 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 refuelling 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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