Design of 2kW DC Charger for Two Wheelers

D. M. Chandwadkar, Azmina Gayasuddin Maniyar, S. P. Ugale

Abstract: The demand for Electric Vehicles is increasing day by day. EVs are silent, nonpolluting and produce zero emissions. This paper presents the design of a dc charger that performs the necessary functions for charging EV battery. An EV charger is a component in EV environment that supplies power for recharging the EV battery. Usually, charging an electric car seems to be very simple process, implying that one can plug one's car into a charger that is connected to the electric grid. However, it is not as that simple. It depends on the types of EVSE that one has deployed. Offboard DC Charger is connected to the premises wiring of the mains ac supply network .It is designed to be separate and operate entirely off the vehicle. In the offboard dc charger, direct current electrical power is delivered directly to the vehicle. The power module in a DC fast charger consists of an AC-to-DC rectifier converter and an isolated DC/DC converter. The AC-to-DC rectifier is power factor correction stage in which a Vienna Rectifier based PFC converter is used. The Isolated DC-DC Converter used here is the Phase Shift Full Bridge DC-DC converter. A 2 kW prototype of the offboard DC Charger is designed and simulated in MATLAB/Simulink R2018b.

***Index Terms*: charger , emissions, isolated, offboard.**

I. INTRODUCTION

The global Electric Vehicle market is amped up and is on the rise. EVs are slowly emerging as a viable alternative to the conventional gasoline vehicles. New battery technology is making EV more practical, but the real secret to its ultimate success is the charging system. EVs have a primary advantage, that they produce zero emissions. EVs are also quiet in operation and fast. The disadvantages of EVs are its cost , range, and issues for charging battery. Prices remain up due to small production volumes and the high battery cost. Range is one of the main limitations because of the battery capacity [1]. For public outlets feeding AC supply to the EV, the chargers are on board and these on-board chargers are supplied by vehicle manufacturer. If the public chargers, also known as off-board chargers are DC chargers, the batteries of the electric vehicles could be charged directly. An AC charger provides power for charging the electric vehicles battery through the vehicles onboard charger, while at the same time, a DC charger directly charges the electric vehicles battery.

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The Society of Automotive Engineers (SAE) further characterized the AC charging stations into standard levels as Level1 and Level 2. A Level 1 EVSE is typically a residential charger which uses commonly available 120 VAC/230 VAC power sources while Level 2 EVSE can be a residential or commercial charger used in public places such as malls, offices, etc. which uses poly-phase 240 VAC sources. There is an unofficial Level known as Level 3 DC for DC Charging Stations. This Level 3 DC charging station consists of an external charger to supply high-voltage DC directly to the vehicles battery and quickly charges it by reducing the charging time [2].The power subsystem (module) of an onboard charger and an off-board charger are differentiated on the basis of charging power levels. The power module of an off-board (DC) charger is generally designed for the purpose of transferring higher kilowatts of power on the EV and requires a more complex BMS which can increase overall efficiency of the electric vehicles. Similarly, an onboard charger is generally designed for lower kilowatts of power transfer on the EV and requires long charging time[3].

Power electronics converters play an important role in Electric Vehicles starting from the charging stations to driving of the electric motor drives [4]. In EVs, AC-DC Converters, DC-DC Converters and DC-AC Converters are the various types of converters present. The most important part in each EV is the battery that provides energy for the entire system. EV batteries needs to be charged up to a certain level to have sufficient amount of energy for the car user required during any travel. Different battery chargers have been introduced for EVs distinguished as fast or slow chargers in which charging depends on the power rating and the place of charge.

II. CLASSIFICATION OF CONVERTERS

The single-phase systems and passive three-phase diode rectifiers help to derive the three-phase PFC rectifier topologies. These single phase and three phase PFC topologies are basically classified mainly into three types such as passive, hybrid, and active PFC rectifier systems. The active PFC rectifier topologies are further divided into four types namely, the active six-switch boost-type PFC rectifier, the active six-switch buck-type PFC rectifier, Vienna rectifier, and the Swiss rectifier. The applications of high power, three-phase power factor correction are offboard electric vehicle (EV) chargers and telecom rectifiers in which Vienna Rectifier Topology is used. Control design of the rectifier can be complex. Three-phase power is used by equipment operating at high power in industrial applications.

To improve grid power quality and reduce the harmonic currents drawn, power factor correction is needed as many of the forward loads are DC. Applications such as regulated switch-mode dc power supplies and in dc-motor drive provides the significance of Dc-Dc Converters. Switch mode dc power supplies consists of dc-dc converters with an electrical isolation transformer, while dc-motor drives needs them without an isolation transformer. With all the different topologies discovered, dc-dc converters are categorized into two types, non-isolated and isolated converter. Buck converter, boost converter, buck-boost converter, Cúk converter, and full-bridge converter are the five topologies that are common non-isolated converter. The full-bridge is obtained from the buck converter whereas both the Cúk and buck-boost converters are a combination of the buck and boost converters. These converters are sometime used as unidirectional converters either to step up or step down the voltage. The electrical isolation in switching dc power supplies is provided by a high-frequency transformer where the input and output of the converter are electrically separated. Having isolation will assist in noise reduction, help in personnel safety, and provides protection to the system due to galvanic isolation. Various types of Isolated dc-dc converters can be classified into two basic categories like Unidirectional Core Excitation and Bidirectional Core Excitation on the way they utilize the transformer core. Some of the Non-isolated dc-dc converters can be modified to provide electrical isolation by means of unidirectional core excitation. Such modifications include Flyback Converter which is derived from the buck-boost converter and Forward Converter which is derived from the Step-down converter. To provide electrical isolation by means of bidirectional core excitation, the single-phase switch-mode inverter topologies can be used to produce an ac square-waveform at the input of the high-frequency isolation transformer. The inverter topologies which can constitute a switching dc power supply are Push-pull, Half-bridge and Full-bridge.

III. SYSTEM CONFIGURATION

The power circuit is composed of two different stages, AC/DC converter stage at the first followed by a DC/DC converter stage. A circuit configuration of the battery charger can be seen in fig. 3.1.The power-factor-correction (PFC) circuit conditions the three-phase AC filtered input. The AC is converted into a DC-voltage of about 560 V by active metal-oxide semiconductor field-effect transistor (MOSFET) rectifiers.

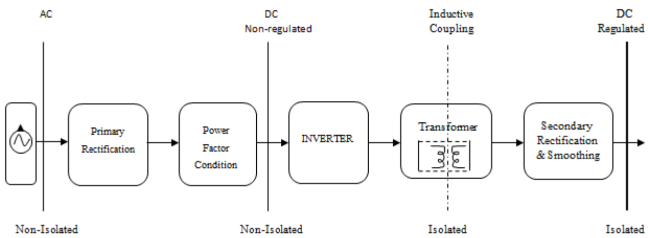

Fig. 3.1 System Diagram of DC Charger

This voltage is supplied to a DC/DC converter made up of insulated gate bipolar transistors (IGBTs) in order to generate the correct DC level voltage of about 48 VDC for charging of the battery. One or more MCUs like TI's C2000 Microcontroller series control the AC/DC and DC/DC power-conversions.

A. Vienna Rectifier

The AC/DC power circuit uses an input filter in order to reduce electromagnetic interferences to the grid and a three-phase power factor correction circuit. The PFC circuit regulates the output voltage (bus voltage) and also achieves the desired unity power factor in the point of connection to the grid. It comprises of a semiconductor switch, say, an IGBT in each phase leg of a 3-Phase diode bridge. The corresponding line current is forced to be sinusoidal and in phase with the Voltage by adjusting the width of the pulse that turns ON the IGBT.

When the IGBT is turned ON the corresponding phase is connected, by means of the line inductor, to the center point in between the two output capacitors. The phase current rises, through the IGBT charges the capacitor during that pulse period. When the IGBT is turned off, current tapers through the diode half bridge which can be upper or lower depending on direction of the current flow. In Vienna Rectifier configuration, as shown in fig. 3.2, the output capacitor is split in two parts as two equal value capacitors, C1 and C2, which are connected in series configuration. Across the output capacitors, the three Phase peak detected outputs are the –Vdc and +Vdc respectively.

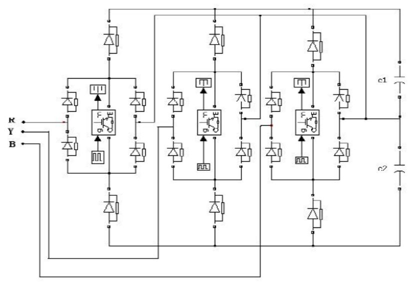

Fig. 3.2 Circuit Diagram of Vienna Rectifier

B. DC DC Converter

The phase shift isolated DC-DC Converter consists of an inverter, transformer and a secondary rectifier. There are two basic topologies that most of the isolated families fall into, voltage source converter and a current source converter with a high frequency transformer in between them.

The voltage source is paired with a current source to form a bidirectional flow to allow smooth power transfer. Each inverter or rectifier block can be in a form of voltage source or a current source converter. There are three basic structures that make a voltage source or a current source converter. These are the full-bridge, half-bridge and push-pull structure. The basic three topologies of the current source can be achieved by replacing the capacitor in parallel to the dc bus in a voltage source structure with an inductor that is placed in series with the dc bus. The phase shift full bridge DC-DC Converter is shown in fig. 3.3. The inverter consists of four IGBTs. When IGBTs Q1 and Q2 are turned on simultaneously, the supply voltage Vs appears across the load. If IGBTs Q3 and Q4 are turned on at the same time, the voltage across the load is of reversed

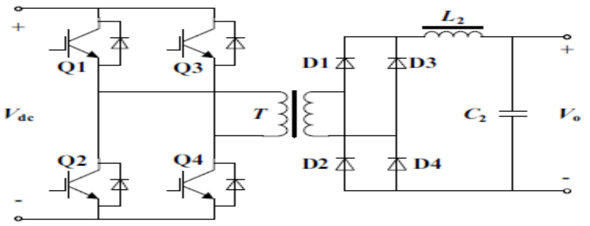

Fig. 3.3 Phase Shift Full Bridge DC-DC Converter

polarity and is –Vs. The table I shows the five states of the switches. IGBTs Q1,Q4 in fig. 3.3 act as the switching devices S1,S4, respectively. If two switches one upper and one lower conduct at the same time the output voltage can be ±Vs. The components conducting are shown in table.

Table I.

Switches				Vo	Components Conducting	
S1	S2	S3	S4		io > 0	io < 0
ON	ON	OFF	OFF	Vs	S1,S2	D1,D2
OFF	OFF	ON	ON	- Vs	D4,D3	S4,S3
ON	OFF	ON	OFF	0	S1,D3	D1,S3
OFF	ON	OFF	ON	0	D4,S2	S4,D2
OFF	OFF	OFF	OFF	- Vs Vs	D4,D3	D4,D2

The transformer turns ratio n which can be calculated from equation (1) is 8.4.

$$Ns/Np = (Vout / Vin\_min) * (1/\partial max) \quad (1)$$

$$n = Np/Ns = 8.4$$

The table II depicts the specifications of the phase shift full bridge DC-DC Converter. For the PSFB DC-DC Converter, the input voltage is 560V and the output voltage is 48V with the switching frequency of 100KHz. The IGBTs which can be selected are STGW60H65DFB with 650V, Ic = 60A.

Table II.

Parameter	Description	Typ.	Unit
Vin	Input Voltage	560	V
Vout	Output Voltage	48	V
Pout	Output Power	2	kW
Iout_max	Maximum Output Current	42	A
fsw	Switching Frequency	100	kHz

IV. MATLAB/SIMULINK MODEL

The simulation of the Vienna Rectifier has been performed in MATLAB R2018b software and the simulation model is shown in fig. 4.1. The simulation is performed in the Simscape Toolbox. In the Simscape Toolbox, each physical

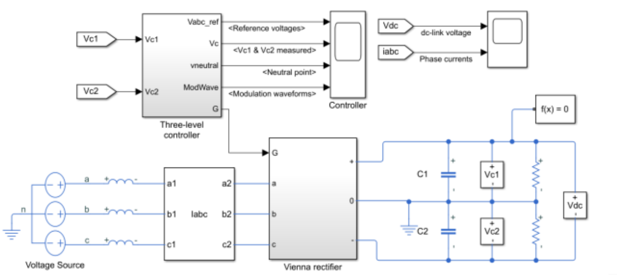

Fig. 4.1 Vienna Rectifier

network which is represented by a connected block diagram requires solver settings information for its simulation. The Solver Configuration block specifies the required solver parameters so that the model can be simulated correctly. Each distinct Simscape block diagram requires exactly one Solver Configuration block to be connected to it for its simulation. The simulation of Phase Shift full Bridge DC-DC Converter is carried out in Matlab Simulink R2018b as depicted in fig. 4.2. The toolbox used for performing the simulation is Simscape. The powergui block is needed to simulate any Simulink model containing Simscape Electrical and Specialized Power Systems blocks. It stores the equivalent Simulink circuit that represents the state-space equations of the model which are needed to derive the appropriate results.

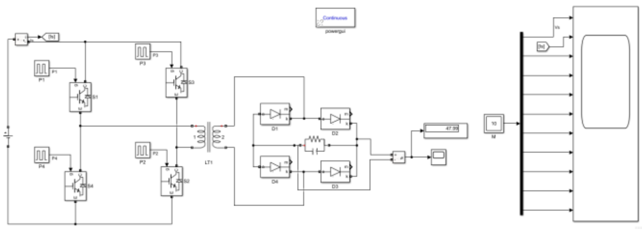

Fig. 4.2 Phase Shift Full Bridge DC-DC Converter

V. RESULTS

Sinusoidal PWM Method is used in the inverter. The diagnostics for the building of the ePWM model is shown in fig. 5.1. These pulses from the ePWM blocks are given for driving the IGBTs as shown in fig. 5.2. These are generated using the ePWM Block of the Texas Instruments C2000 TMS320F28027 MCU.

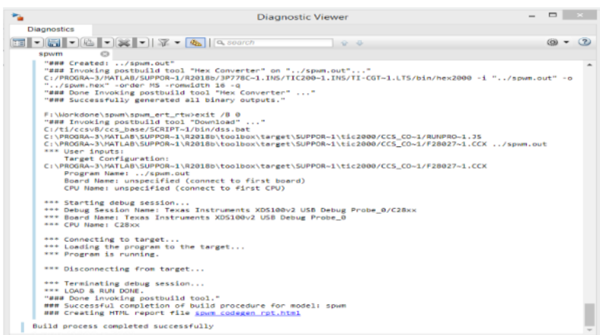

Fig. 5.1 Diagnostic viewer for building a Simulink Model

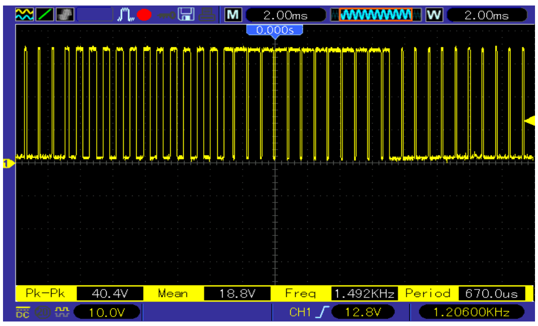

Fig. 5.2 SPWM for IGBTs

The Vienna rectifier has an input voltage of 3Ø 415 V, 50 Hz. Total Simulation time is 0.4 s, the modulation index changes from 0.3 to 0.8 at time 0.2 s. The waveforms of reference voltages, voltages across capacitors and modulation are depicted in fig. 5.3. The Vienna rectifier output voltage(dc-link voltage) and the phase currents are shown in fig. 5.4. The dc-link voltage varies according to the reference voltages and the modulation index.

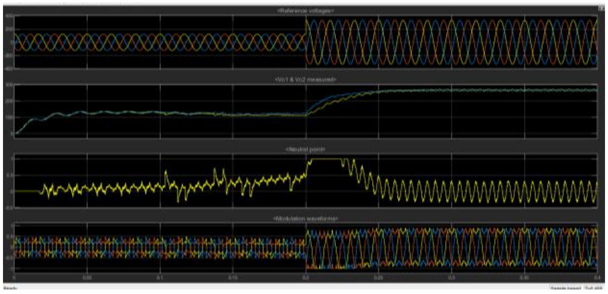

Fig. 5.3 The reference voltages,Vc1,Vc2 and Modulation Waveform

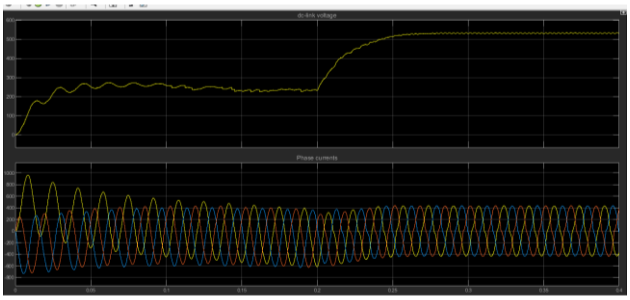

Fig. 5.4 The dc-link voltage and Phase currents.

The dc link voltage obtained from the output of the Vienna Rectifier(PFC) is the input for PSFB DC-DC Converter which is made up of IGBTs and the output voltage obtained is 48V. This 48V is required for charging of the electric vehicle battery. The input and output voltages of the DC DC Converter are plotted in the fig. 5.5.

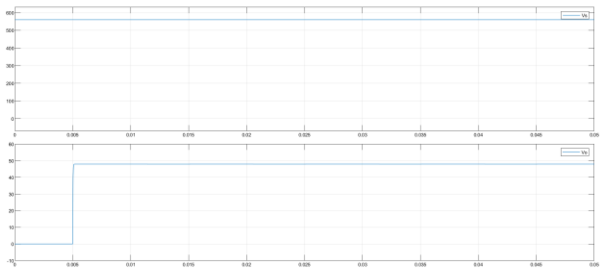

Fig. 5.5 The input and output voltages

VI. CONCLUSION

In this paper, 2 kW DC Charger is presented for Electric Vehicle Applications. The purpose of the PFC stage is to ensure that the input current is in phase with the grid voltage, thus improving the grids overall power factor. The dc link voltage obtained is 560V. The SPWM method is used in the inverter part. The output voltage of 48V is used for charging the electric vehicle's battery.

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