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Electric Vehicle Charging Station by Using Multiport Converter at Constant Current & Constant Voltage

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***Abstract*-Due to constant increasing voice against carbon emission, Electric Vehicle has become very popular across all over the world. However, there are some challenges like high vehicle costs, lower travel range, and lack of charging infrastructure which needs to be addressed. Though, Range concern of users can be resolved by establishing DC fast charging (DCFC) station across all over the places but fast charger puts a huge amount of load on the grid which is not designed for this scenario and needs to be reinforced which results in high upgrading cost. However, there are various DCFC topologies with battery energy storage system (BESS) are given in the literature which can resolved these issues. This dissertation closely reviews and presents pros and cons of various DCFC topologies with BESS given in the literature. In this work, the multi-port converter is proposed for the DC fast charging station. It uses the multiple-port of AC and DC sources to charge the battery. Due to ease of control and availability of resources, only three ports are considered in this work to charge the battery. The two ports uses Grid and solar panel as the source while third port is the energy storage system which will supply the deficit of energy when load demand is high on charging station. The ports of multi-port converter is controlled using different converter in order to charge the battery in constant current (CC) and constant voltage (CV) mode. The control strategy and detailed mathematical modelling along with in depth analysis of AC-DC and DCDC Converter is presented in the thesis and experimental and simulation results attached to verify the claims proposed in this work.**

***Index Terms*- Direct Current (DC), Direct Current Fast Charging (DCFC), Battery Energy Storage System(BESS),Alternating Current (AC),Constant Current (CC), Constant Voltage (CV).**

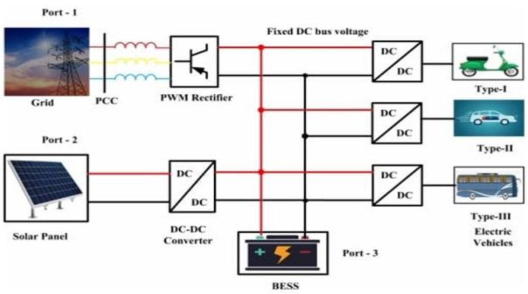
INTRODUCTION

The urge to reduce greenhouse gases and the advance research in the battery technology attracted attention of the world towards electric vehicle (EV) to replace the internal combustion (IC) engines. However, EV sales contribute a small portion of total vehicle sales in most of the country due to travel range concerns of users & lack of charging infrastructure. Though travel range can be improved by using large and more energy-dense batteries but mass and cost of vehicles will also be increased. Specifically, the battery can have cost up to 50% of the total vehicle price which limits the option of using large and high energy-dense batteries beyond certain level. The installation of DC fast charging (DCFC) networks can reduce range and charging concerns of users on long drives without requiring very costly EVs with large batteries.Though typical home chargers of AC Level 1 or Level 2 are best suitable for night charging for driving within a city, the need for recharge on long drive can cause inconvenience and uncertainty for drivers.To reduce some of these issues, most manufacturer offer EVs with fast charging, as shown in Table 1.1 & 1.2. Fast charging depends on the C-rate of a battery, if a battery is being charged at greater than or equal to 1 C, we call it as fast charging. For example, a battery of 1 KWh is being charged at 1 KW or 2 KW or 3 KW is fast charging. Fast charging draws huge amount of power from the grid. For example, if 10 cars of battery size 40 KWh is being charged at a same time at a charging station, more than 400 KW power will be drawn from the grid. 1 In India, most of the places presently grid supply is usually: 1-phase, 230 V, 15 A (3.3 KW) or 3-phase, 415 V, 125 A (50 KW). Our present grid will not support fast/ultra-fast charging. Also, it is not certain that this huge amount of power will be drawn from the grid continuously but it depends on the no. of EVs connected to the grid. If we draw power versus time curve, it may have very high slope and it leads to stability problem to the grid. Therefore, the installation of fast charging station is not possible at such locations without upgrading the present electrical services, which usually results in high installation cost.

MULTI-PORT CONVERTER

Fig represents proposed topology of multi-port converter for fast charging station

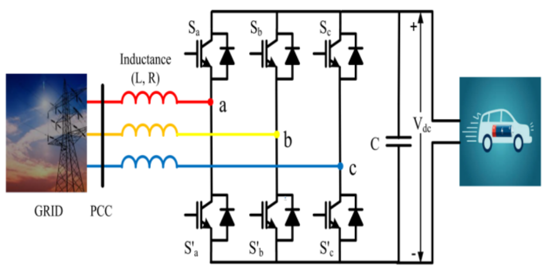
Port-1 consist of three phase grid along with the PWM rectifier. When PWM rectifier operates, it will insert the lower order harmonics into the grid. In order to suppress the lower order harmonics and to make the current sinusoidal, three phase inductor is connected between the grid and the PWM rectifier. But even 7 after connecting the inductor between the grid and the PWM rectifier, the voltage and current at the grid terminal are not in phase. In order to keep the grid voltage and grid current in phase, PWM rectifier is operated in closed loop manner with inner current control loop which will keep the grid voltage and current in phase while outer voltage loop will generate the required DC bus voltage. By using inner current loop, the current flowing at the DC bus is also controlled which will operate the battery charger in constant current mode. Initially when the battery voltage is very low and if the converter is operating in constant voltage mode, the difference between battery voltage and converter output voltage is higher which will allow battery to take large current from the converter. But the converter is designed for some current rating and if that current is exceed beyond the certain value then there is chances that converter get damaged. So it is necessary to charge the battery in constant current mode at its initial charging time.



Port-2 consist of solar panel with the boost converter. The voltage of the solar panel is lower than the voltage required to charge the battery. The reason behind to keep the voltage less is that potential induced degradation (PID) effect is higher in case of higher solar panel voltages. The boost converter is used to elevate the solar panel voltage till battery voltage in order to charge the battery. The boost converter is also controlled in closed loop fashion in order to maintain the voltage at the battery terminal. The boost converter is operating in constant current and constant voltage mode to protect the life of battery.

Port-3 consist of Battery energy storage system (BESS). When the availability of the source power is greater than the power required by the load, then BESS will charge to store the available energy. When the peak load demand is higher and the power available at the source terminal is lower than the load demand then BESS will supply the power to the load. Also in the night time the availability of power at the solar panel is lower, in this condition the BESS will supply the required power along with the grid. It is necessary to keep the track to tariff applied by the grid. consider the condition when the load on the charging station is higher and the tariff rate of the grid is also higher then it is necessary to see the availability of the power from the other source like solar panel and BESS. If the availability of power is also less at the solar panel, then it is necessary to extract maximum power from the 8 BESS and minimum power from the grid. In case of midnight, the power available at the solar panel terminal is lower and the grid power tariff rate is also lower then it is economical to take the maximum power from the grid and charge the BESS. In day time from 11pm-4pm, the load on the charging station is lower and the power availability at the solar panel terminal is higher due to higher radiance, then it is necessary to supply the load of EV through solar panel and store the available power into the BESS.

3-phase Active Front End Rectifier



The circuit configuration of the active front end rectifier (AFER) is shown in Fig.3.2. The AFER is supplied with three phase voltage source through the filter inductor (L) and parasitic resistance of inductor (R). Sa, Sb and Sc are the inverter top switch switching function corresponds to leg-A, leg-B and leg-C. While S 0 a , S 0 b and S 0 c are the inverter down switch switching function corresponds to leg-A, leg-B and leg-C. Both top and down switching function of corresponding leg are complementary to each other. C is the DC link capacitor used to filter out the high frequency ripple voltage from the output DC voltage. Then the output port is available to charge the battery.

CALCULATION OF INDUCTANCE & CAPACITANCE

When the any switch of the particular leg is turned on, the inductor will charge through the available AC voltage as shown in Fig.3.3. The corresponding design procedure of filter inductor is as follows. From Fig.3.3, the instantaneous voltage

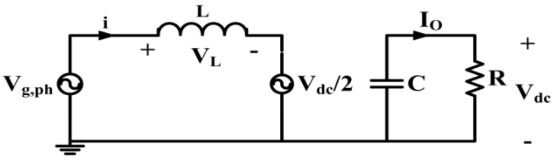


Fig . On state circuit of a particular leg of AFER

appearing across the inductor can be written as

VL = L × di dt

The voltage appearing across the inductor is the difference between the available AC source voltage and DC bus voltage. Then the above expression is modified as

Vgph + Vdc / 2 = L × ΔI / DT

In order the design the inductor for worst case scenario, the duty of the switch should be equal to 0.5 which is given as

Vg,ph → P eak, D = 0.5

⇒Vgph(peak) = 17 × √ 2 / √ 3 = 13.88 V

⇒ I = 100 / √ 3 × 17 = 3.4 A

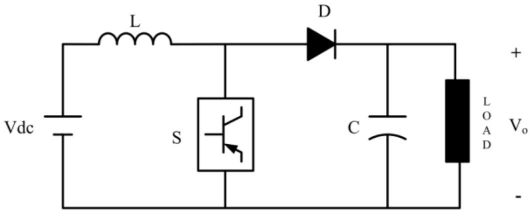
⇒ L = (13.88 + 24) × 0.5 / 0.03 × 3.4 × 10^4 = 18.56 mH

⇒ IO = 100 / 48 = 2 A

⇒ C = 2 × 0.5 / 0.03 × 48 × 10^4 = 70 µF

At DC power of 100W and the DC voltage of 48V, the requirement of DC link capacitor is equal to 70 µF .

Boost Converter



In boost converter as shown in Fig 3.13 Vdc is input DC voltage, Vo is output voltage, L is inductance which is used to suppress the ripple current and to make the current continuous as this boost converter operates in continuous current mode, C is filter capacitor which is used to suppress the output voltage ripple, ’s’ represents the switch and D represents the diode. When switch ’s’ is ON inductor will be charged and stores energy and when ’s’ is OFF inductor current will be flowing through diode and load, means inductor will be discharged through load, thereby output voltage Vo will be more than Vdc, it can be also verified by applying KVL.

Calculation of L & C

Average current flowing through inductor is given by

IL = 100 / 30 = 3.34

A Since desired output voltage is 48 V and corresponding duty cycle (D) required will be less than 0.5. However, I have considered D = 0.5 for calculating L & C to provide some cushion to the L & C.

L = Vdc × DT / ΔIL = 30 × 0.5 / 0.03 × 3.34 × 10^4 = 15 mH

Average output current is given by

IO = 100 / 48 = 2.1 A

Value of ’C’ is given by

C = Io × DT / ΔVo = 2.1 × 0.5 / 0.03 × 48 × 10^4 = 73 µF

SIMULATION RESULT OF AFER

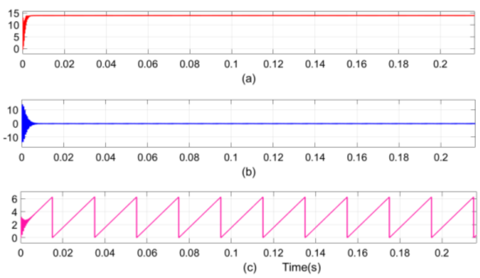


Figure (1): (a) Vd, (b) Vq, (c) θ = ωt

Fig 1&2 shows the vd, vq, θ = ωt & id, iq, θ = ωt respectively. We can see that magnitude of vq &

iq is zero which leads to AFER operates on unity power factor and therefore, total reactive power flowing between grid and the AFER will be zero.

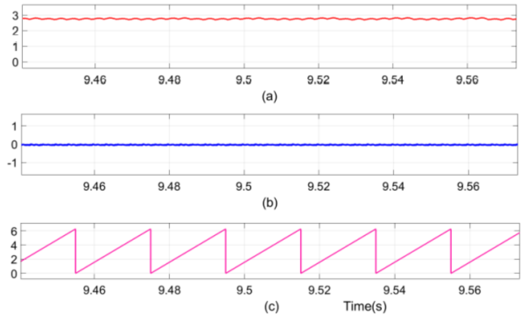


Figure (2): (a) id, (b) iq, (c) θ = ωt

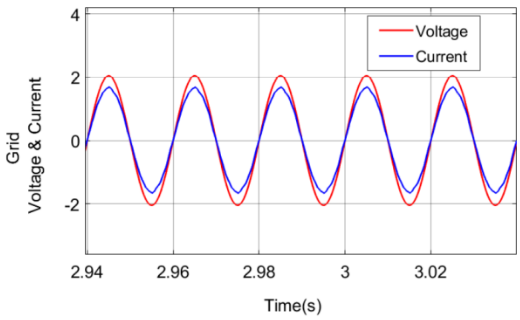


Figure (3): Grid voltage & current

Fig 3 shows the grid voltage and grid current drawn which are in phase and hence power is being drawn from the grid is at unity power factor.

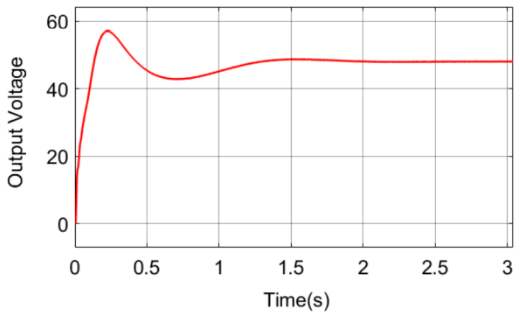


Figure (4): Output DC voltage

Fig 4 shows the output DC voltage of AFER and output voltage reaches in steady state around 1.5 seconds, we can say that system has good dynamic response.

Simulation results of boost converter

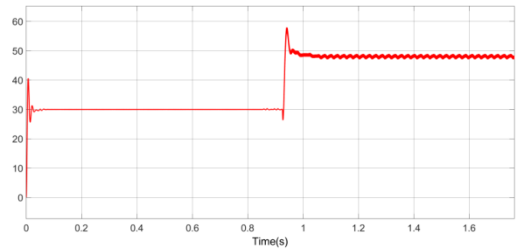


Figure (1) : Output Voltage

Fig1 represents the output voltage of boost converter and we can see that at t = 0.92 s, reference is changed from 30 volts to 48 volts and the converter output voltage becomes from 30 volts to 48 volts very quickly because system has very fast dynamic response and corresponding variation in duty ratio is shown in Fig 2 .

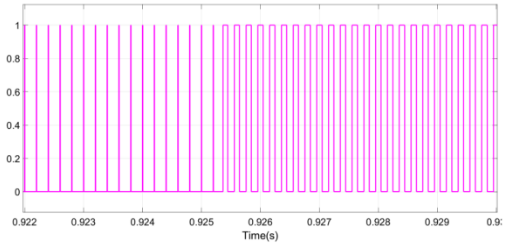


Figure (2) Duty ratio corresponding to output voltage

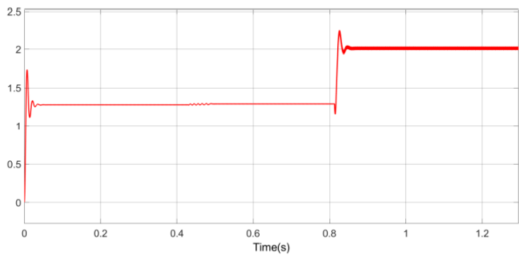


Figure (3): Output Current

Fig 3 represents the controlled output current of boost converter, at t = 0.81 s current reference is changed from 1.3 A to 2 A and converter response is very quick to achieve 2 A of output current because the system has very fast transient response and their corresponding variation in duty ratio is shown in the Fig 4.

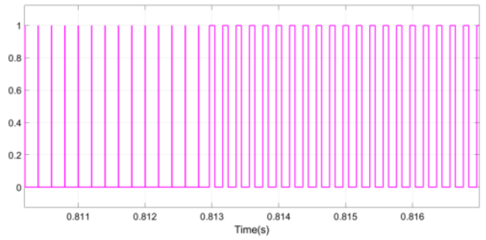


Figure (4): Duty ratio corresponding to output current

CONCLUSION

In this work, the multi port converter is proposed for battery DC fast charging station. The multi port converter is designed using two port consist of Grid along with active front end rectifier and another port consist of the solar panel and DC-DC boost converter. Active front end rectifier is used to keep power factor unity at the grid terminal by keeping the grid current in phase with the grid voltage. Also AFER is operating in constant current (CC) and constant voltage (CV) mode to charge the battery in both the modes. Along with this, the DC-DC boost converter is also operating in CC and CV mode to make the ease of control in charging of EVs. From the analysis it is concluded that the CC mode of charging is suitable for the initial charging of the battery, while the CV mode is suitable for the later stage of battery charging. From the analysis, it is also concluded that CC mode is always prefer over the CV mode as the current going into the battery is always in control. As per the discussion and analysis, The multi-port converter employed battery charging station should always be located outside the cities as it has to supply the lump-sum amount of load which will not be feasible to provide by the normal distribution grid. While to established such a charging station requires big land in order to keep the solar panel and other sources which will include the overall initial investment of the system.

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