An Improved Control Method for the DC-DC Converter in Vehicle to Grid Charging System

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***Abstract*—This paper presents the charging station of an electric vehicle (EV) battery in smart grid system for compensating of active power. By injection of the active power from the bidirectional vehicle to grid (V2G)charger, there is a reduction of overloading of transformer and voltage profile improvement. A new control strategy is used for bidirectional electric vehicle charger. The charger consists of a two stage bidirectional power converter is designed for the grid to vehicle(G2V) charging and vehicle to grid(V2G) discharging. The switching of bidirectional DC-DC converter modules of charging station control the charging of the EV battery with constant current and discharging with variable current. The performance of the bidirectional controller prototype with current control strategy is validated through simulation in MATLAB/simulink environment under different load condition. The control strategy incorporates both dynamic charging and discharging.**

Keywords*—-Battery charger, bidirectional power flow, electric vehicle, G2V, V2G, power management.

I. Introduction

The electric vehicle (EV) has been used in the transportation sector in order to reduce environment pollution [1], instead of conventional internal combustion (ICE) vehicle.These days the EV is utilized in the low voltage distribution network for smart grid in oder to avoid peak load condition [2], [3]. The batteries of the EV are one of the latest innovative energy storage system which is charged from the grid (i.e. Grid to vehicle mode) and energy feed back towards the power grid (i.e. vehicle to grid mode) V2G [4].The bidirectional battery charger of the electric vehicle system will increase the grid security and decrease the power loss in the power system.

The electric vehicle battery can be charged using various topologies in the single phase and the three phase system such as unidirectional and bidirectional system. The front end AC-DC converter topologies considered are the diode bridge rectifier,matrix rectifier [5], [6], [7]. Several literature have reported the merits of [8].The bidirectional chargers of EV charging system in voltage drop,harmonic filtering,active power and reactive power compensation.In [9], it has been shown that when large number of EV are interconnected in power grid,it creates negative impact on the grid. The impact is manifested through harmonics variation of the power demand,system losses,variation of the voltage and the load profile,transformer overloading. [10], [11], [12], [13]. This impact is caused as there is lack of coordination among the EV charging at peak load demand periods.Hence the safe operating limits of the power grid are crossed. Many have reported the bidirectional charger with different control strategies for solving EV charging problem [14], [15].The charging problem has been smoothly modeled under normal operation, where the EV charger batteries are connected to a power grid in a constant load G2V/V2G mode. There is hardly any literature showing the design of the power grid for sudden load variation in the distribution side. Due to the sudden load variation power quality improvement and the power grid stability are the challenging issues for the uncontrolled battery charging process [16], [17].

In this paper, a new control strategy is proposed for the vehicle to grid battery charger by controlling the current between the electric vehicle battery charger and the power grid. The control strategy has the advantage that charging system is not affected by the sudden load variation under abnormal circumstances.

Section II of the paper has presented the configuration and adopted control strategies of a V2G charger. The proposed methodology along with equation for charging and discharging under abnormal load conditions are described in Section III. The results and discussion are given in Section IV. Section V has concluded the paper.

II. Proposed Bidirectional Vehicle to Grid Charger

The topology of modeling two stage bi-directional converter is shown in Fig. 1. Three phase AC-DC converter is mainly used as rectifier and inverter during charring and discharge operation. The DC-DC converter determines the power outage of the grid and generates the reference current of battery for the charging and the discharging, otherwise known as buck and boost operation. Again to limit the battery degradation while V2G operation, consider the minimum state of charge (SOC) for charging and minimum SOC for discharging as shown in Fig. 4. In oder to minimize the grid impact, the EV charger is operated under variable charging and discharging rate due to to sudden change in load condition at distribution system. In the variation of load, the maximum current flow from the power grid to the load demand and EV charger which is the maximum current rating of grid side transformer. So during off load period, both the battery and the load absorb the surplus power of the grid in oder to avoid the waste of excess energy produced by generation unit through the bidirectional EV charger topology. This acts as a distributed storage unit. At peak period V2G function provides the backup power to the electrical appliance of the power grid in order to prevent

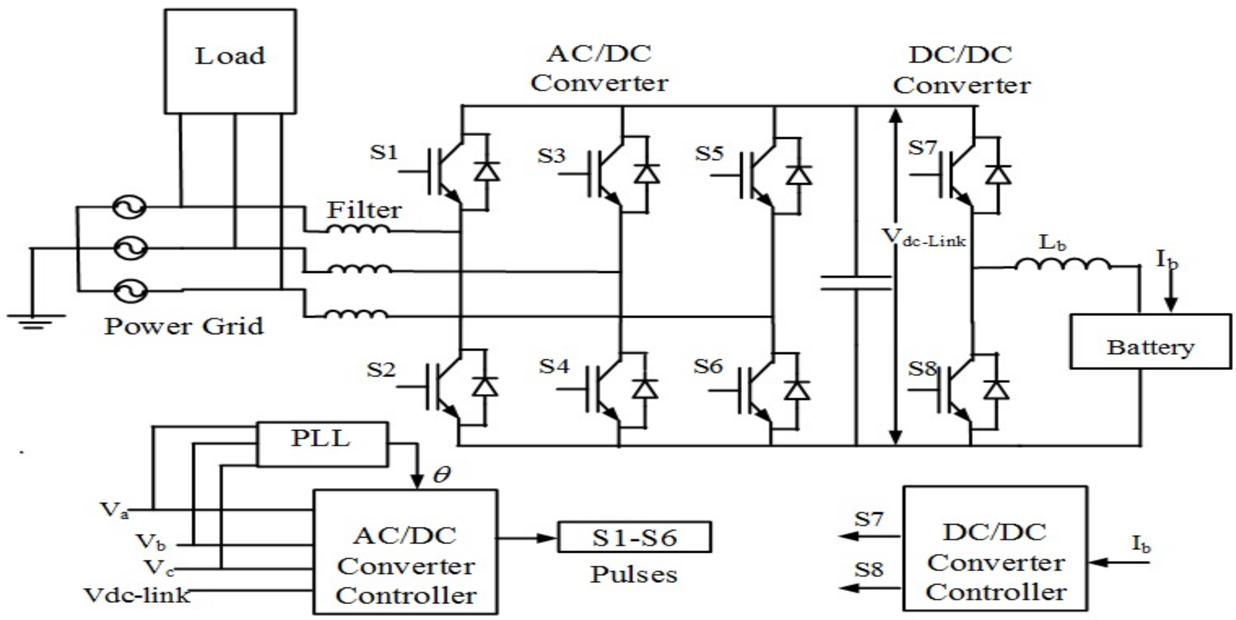

Fig. 1. Structure of the proposed bi-directional charging system.

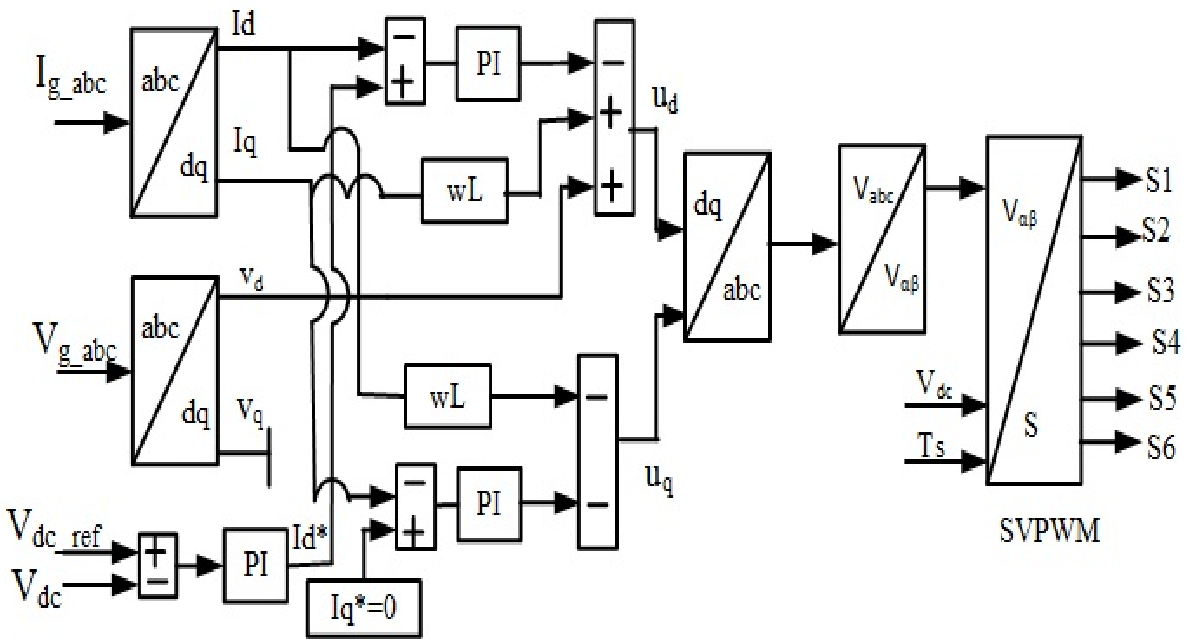

Fig. 2. Vector decoupling control of AC/DC converter.

the power outages, improve the reliability and the security of power grid against the failure. Therefore without smart charging strategy, it is unable to implement the EV battery charger is a dynamic load and distribution generation unit (DG).

The charging station control system shown in Fig. 2 is a two stage control in dq frame. It is designed for the outer voltage loop and the inner current loop. For synchronization purpose, a PLL block is used in order to track the grid voltage magnitude and the phase. The d- axis the outer loop controls the DC link voltage, and inner loop controls the active AC in order to allow bi-directional power flow in the converter. The q-axis inner current loop adjusts the reactive current at unit power factor, lagging and leading the power factor operation. Further the dq vector decoupling and the feed- forward voltage signal is added in order to improve the performance during transients. Application of dq fram,we get DC signals output of PI controller which helps eliminates the steady state error.The decoupling term wLi_d and wLi_q has been considere to enhance the performance of current control loop and calculating the rectifiers input voltage for u_d^{con} and u_q^{con}.These voltage are the modulation signal for the SVPWM techcnique.A novel SVPWM scheme generates the

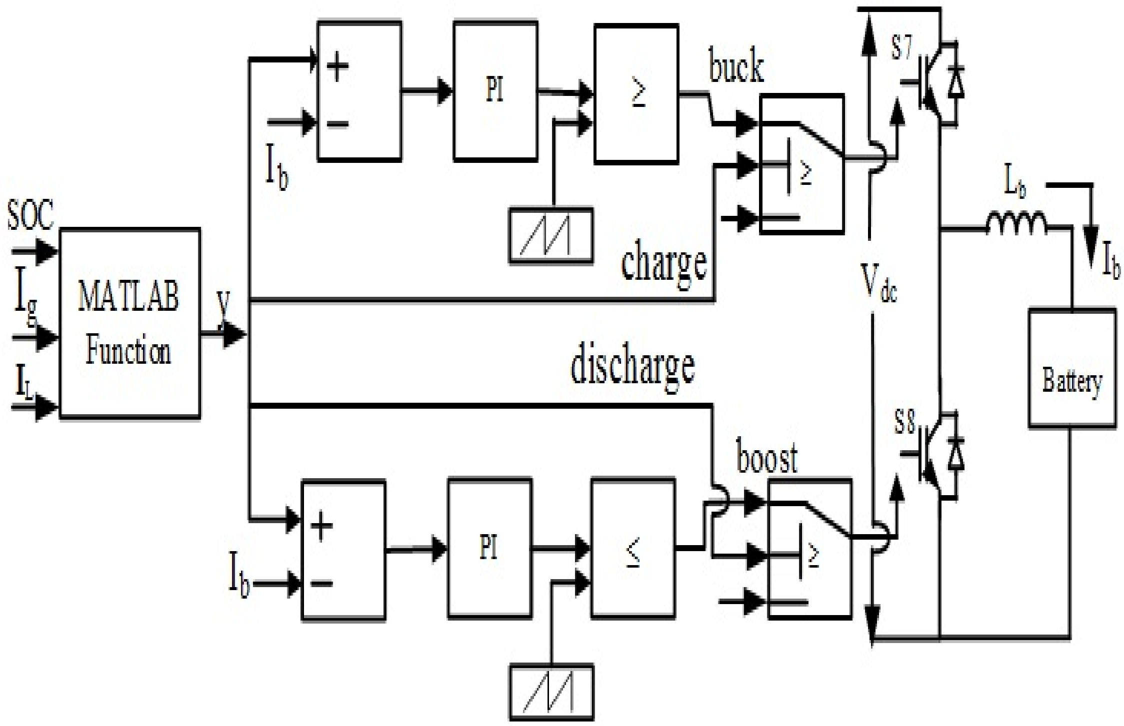

Fig. 3. Bidirectional buck-boost DC-DC converter.

voltage source inverter switch pulses according to modulating functions.This technique helps to controlof the active and reactive power drawn from the grid sepatetly.If we consider the $I_q^{ref} = 0$,then it work at unit power factor.

$$u_d = i_q\,.wL + v_d + K_p(i_d^{ref} - i_d) + k_i \int (i_d^{ref} - i_d)dt$$

$$v_q = -\,i_d\,.wL + K_p(i_q^{ref} - i_q) + K \int (i_q^{ref} - i_q)dt$$

The Fig. 3 shows the control technique of the DC/DC converter; this controller compares the reference battery current with the measured battery current by choosing the charging or discharging mode.The current reference battery is calculated by considering the maximum grid current limit and the variable load current given in (1).

$$I_b^* = \frac{(i_{g\,\lim it} - i_l)}{K} \tag{1}$$

K is the converter proportionality factor. The EV charging and the discharging process has been accomplished by the use of the IGBT switches S7 and S8, respectively. The IGBT switch S7 will perform the buck operation under the charging mode. The switch S8 will will perform the boost operation under discharging mode. The pulses required for the proper functioning of the switches has been generated with the help of the PWM operation with the output of the PI controller.

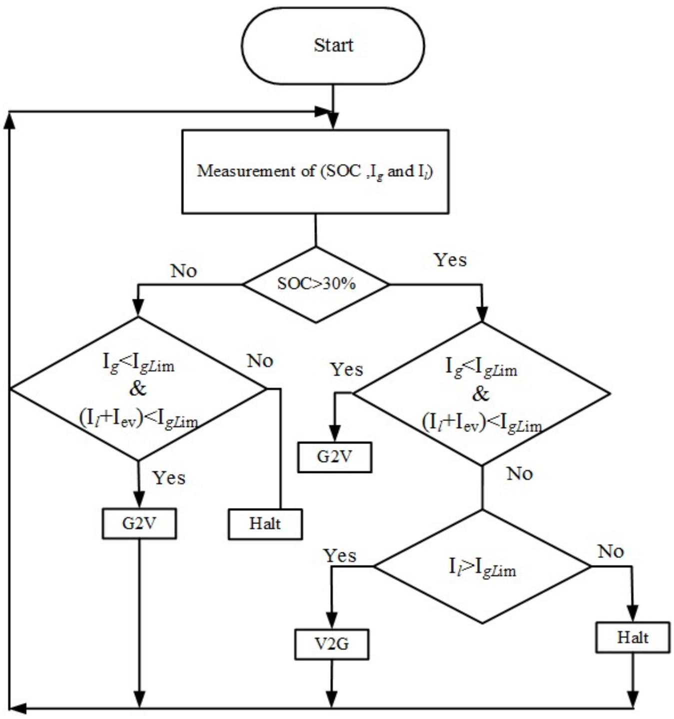

Fig. 4. Flow chart of proposed methodology.

III. Proposed Charging Discharging Sequence.

Fig. 4 The proposed current flow determination algorithm for the EV charger system including G2V and V2G mode.

Charging mode(G2V): The charging mode of the EV charger prevails under normal load condition. under such condition, the SOC of the battery is less than 30% and the grid current is more than the demand of load current.

Standing mode(Halt): When the peak load condition is about to start, the SOC of the battery as found by the system controller to be less 30%,As far as the EV charger operation is concerned,it is under halt condition. Both the charging and the discharging mode do not operate simultaneously.

Discharging mode(V2G): In this mode the SOC of the battery is found to be greater than 30% and EV charger operates in V2G mode under peak load condition.

As per the requirement of load power, the relationship between the grid power and the battery power is established.

When the power generated from the grid exceeds the load consumption, the battery is charged from the grid .But at the peak load condition the grid is also connected to extra load .Under such circumstances the generated power is less than the load demand. The system instability is prevented by utilizing bidirectional EV charger to transfer the energy stored the battery for the extra load demand. During the peak-load condition, the relationship between the load current,I_{Load} , and the grid current, I_{grid} , can be given by (2)

$$I_{Load} > I_{grid} \tag{2}$$

Under peak load conditions, the maximum current and the power capacity are given by equations(3) and (4) respectively.The battery power and peak time help in calculating P_{V2G} .

$$I_{V2G} = I_{Load} - I_{grid} \tag{3}$$

$$P_{V2G} = \frac{P_{batt}}{t_{pk}} \tag{4}$$

The charging mode operation of the bidirectional charger is obtained, when the load current is less than the grid current. as expressed in (5), The possible charging current, I_{Charge} , can be written as (6).

$$I_{grid} > I_{Load} \tag{5}$$

$$I_{Charge} \leq (I_{grid} - I_{Load}) \tag{6}$$

$$I_{ev} = \int_{t1}^{t2} (I_{g\lim} - I_{load}) + \int_{t2}^{t3} (I_{g\lim} - I_{load}) + \int_{t3}^{t4} (I_{g\lim} - I_{load})$$

$$I_{grid} = I_{load} \pm I_{ev} \tag{7}$$

Equation (7) is expressed that the grid current is always fixed according to EV battery charging and discharging. The plus sign indicates the charging and minus sign is for discharging condition.

IV. Simulation Results and Discussion

The EV station parameters are shown in Table I. The equation (1) to (7) have been used to arrive at the results in the Fig. 5, 6, 7 the simulation for a change in the load presented and is given in the Table II. As it can be seen, from t=0.0s to 0.3s the percentage of SOC is increased means of the battery charged. From t=0.3s to 0.6s, another 1000 W is connected, the grid side transformer (1 KVA, 230/230 V) is overloaded. Therefore the battery will be discharged. This battery supply to the grid avoids the overloading of transformer. Again at t=0.9s, the previous load of 1500 W is disconnected, and the battery once again is charged. So we can find from simulation that the charger is designed to charge in constant current mode and discharge in variable current mode. During G2V operation the battery current is $i_{bat} < 0$ and V2G operation the battery current is $i_{bat} > 0$.

TABLE I. EV station parameter

Grid voltage	230 V
1 KVA transformer	230/50 V
Passive L filter	3 mH
Switching frequency	20 kHz
DC link voltage	100 V
DC link capacitance	2200 mu F
Lithium-ion battery	12 V/ 7 Ah

TABLE II. Dynamic load

Sl.No	Time	Load
1	0.0s to 0.3s	1000W
2	0.3s to 0.6s	2000W
3	0.6s to 0.9s	2500W
4	0.9s to 1.2s	1000W

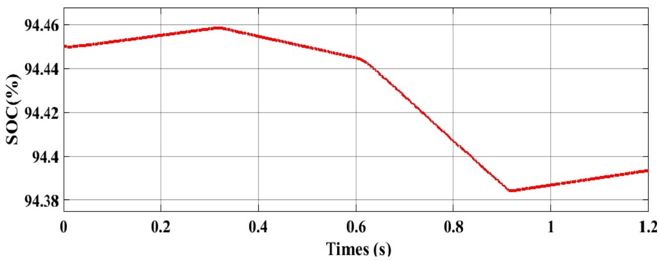

Fig. 5. SOC during charging and discharging mode.

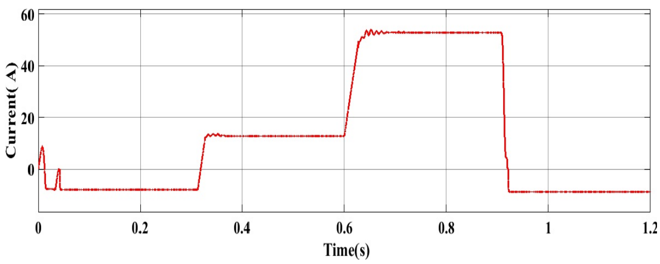

Fig. 6. Current during charging and discharging mode.

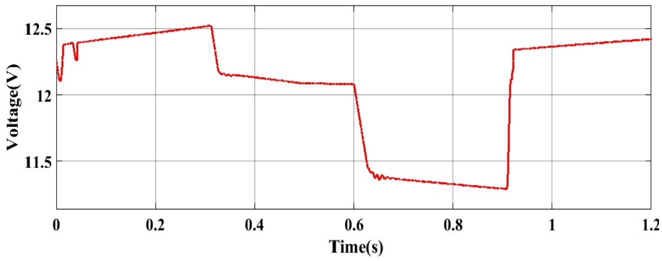

Fig. 7. Voltage of battery during charging and discharging mode.

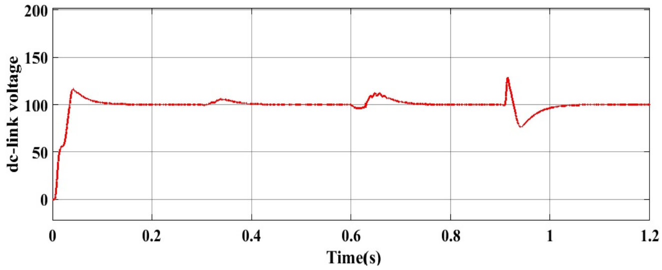

Fig. 8. DC link voltage.

The Fig. 8 shows the change in the DC link voltage for the entire operation of the proposed system. It is visible from Fig. 8 that the DC link voltage is maintained constant (100 V) throughout the operation (charging and discharging) . This will make the system more stable for bidirectional power flow.

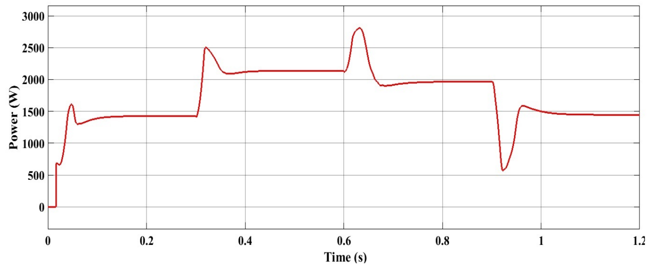

Fig. 9. Grid active power.

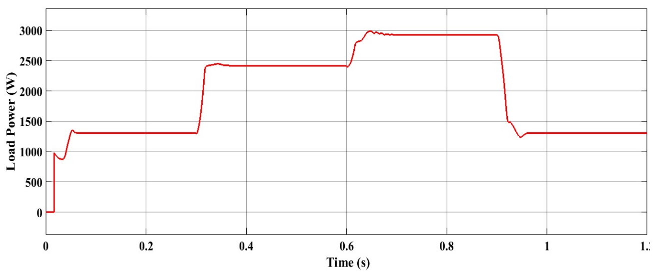

Fig. 10. Load active power.

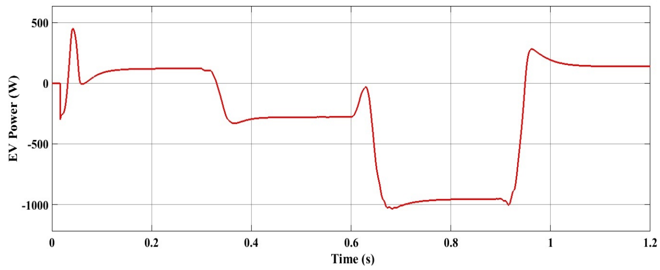

Fig. 11. EV active power.

The Fig. 9, 10, 11, show the change in active power of the grid, load and the EV charger according to sudden variation in the load. In the above mentioned figures, from 0s to 0.3s the grid to vehicle charging operation is happening under stable condition. In this condition, the active power of the grid is shared by the load and the EV charger. It is visible in Fig. 9, 10, 11 that the total active power during time 0s to 0.3s is 1450 W, which is hared by the load (1310 W) and the EV charger (140 W). during the 0 to 0.3s the load connected is maintained constant (1000 W). During the time 0.3 to 0.6s a extra new load (2000 W) is connected, which makes distribution transformer to work in overloaded condition. In the same time (0.3 to 0.6s) in order to prevent the over loading and fulfill the demand, the batter will discharge to the grid. In the same time (0.3 to 0.6s) the load active power (2390 W) is provided by the grid (2090 W) and the EV charging system (300 W). From 0.6s to 0.9s another extra load (2500 W) is added to the grid and the same active power load sharing mentioned above (0.3s to 0.6s) will happen.

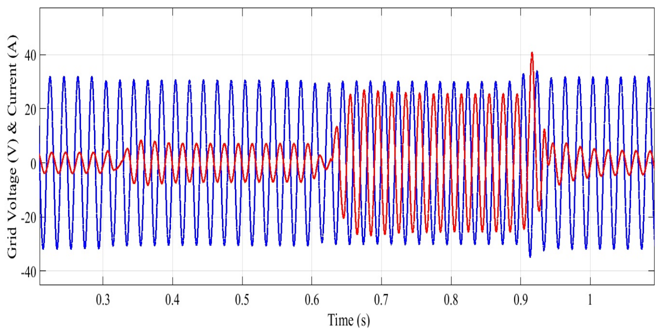

Fig. 12. Grid voltage and current waveform.

The phase relationship of the grid voltage ($\frac{V_g}{10}$) and current $10i_g$ is presented in Fig. 12, the grid current and grid voltage are in phase from 0.0s to 0.3s (charging condition). From 0.3s to 0.9s an extra of 2500 W is connected and the grid current will be 180 degree out of phase with the gird voltage (discharging condition). From 0.9s to 1.2s the extra load (2500 W) has been disconnected and the grid current and the grid voltage are in same phase (charging condtion)

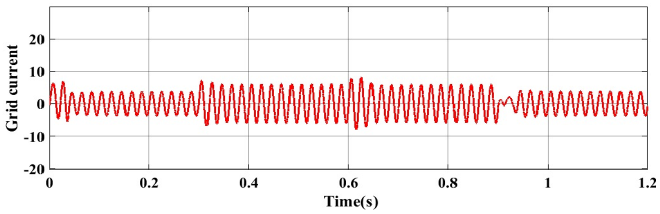

Fig. 13. grid current during charging and discharging mode

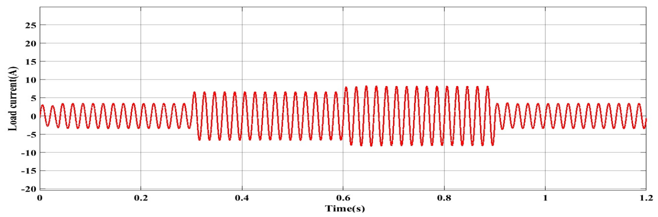

Fig. 14. load current during charging and discharging mode

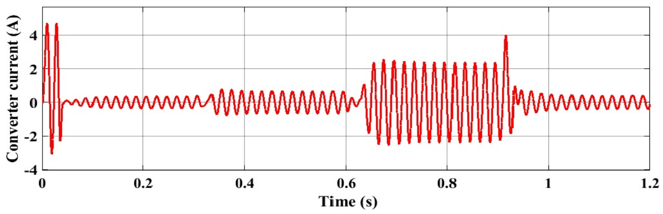

Fig. 15. EV current during charging and discharging mode

Fig. 13, 14, 15 show the change in the grid current, load and the EV charger current according to sudden variation in the load. In the above mentioned figures, from 0s to 0.3s the grid to vehicle charging operation is happening under stable condition. In this condition, the the grid current is shared by the load and the EV charger. It is visible in Fig13, 14, 15 that the total grid current during time 0s to 0.3s is 4 A, which is shared by the load (3.5 A) and the EV charger (0.5 A). during the 0 to 0.3s the load connected is maintained constant (1000 W). During the time 0.3s to 0.6s an extra new load (2000 W) is connected, which makes distribution transformer to work in overloaded condition. In the same time (0.3 to 0.6s) in order to prevent the over loading and fulfill the demand, the batter will discharge to the grid. In the same time (0.3 to 0.6s) the load current (6.6 A) is provided by the grid (6 A) and the EV charging system (0.6 A). From 0.6 to 0.9s another extra load (2500 W) is added to the grid and the same load current sharing mentioned above (0.3 to 0.6s) will occurs.

V. Conclusion

In this paper, a new control strategy for the DC-DC converter in the charging station of the EV charging system has been proposed. This proposed control strategy helps to avoid the transformer overloading condition during a sudden change in the load in an EV charging system. A detailed simulation study has been conducted using MATLAB/Simulink software to verify the functionality of the proposed control strategy. The simulation study shows that EV charging system is working in stable mode even if a sudden change is happening to the load. This proposed method have many practical applications since the EV charging systems all over the world is always working in the change in load condition. The proposed control strategy enables the power system to work under less loss condition by the automatic charging and discharging operation.

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