© November 2018 | IJIRT | Volume 5 Issue 6 | ISSN: 2349-6002

Power Controllable Bidirectional Battery Charger for Electric Vehicles

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Abstract- **Energy demands are increasing day by day and need for energy saving along with it. This paper proposes a battery charger for electric vehicles that's equipped with an energy managements system to be used in a residential setting. EMSs help consumers obtain maximum potential benefits at minimum price. The battery charger has power controllable and bidirectional charging potential. The basic circuit diagrams and analysis for the same are presented.**

Index Terms- Energy management system, Plug in electric vehicles, bidirectional charger, vehicle-to-grid.

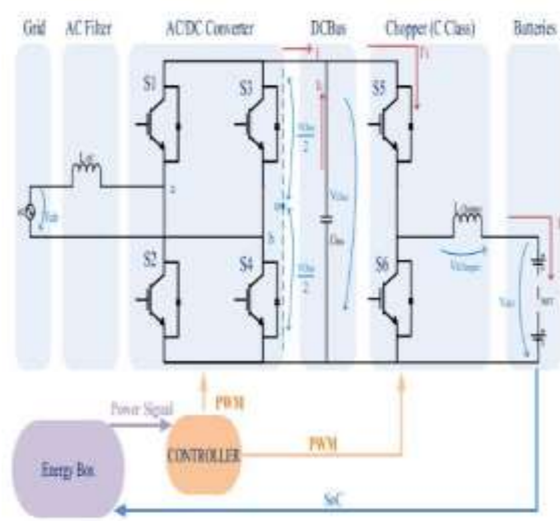
1. INTRODUCTION

Promoting energy efficiency policies and developing cutting edge technologies to realize these policies is a fundamental step towards sustainable development, as well as promoting the importance of renewable energy in a society. The evolution of present day grids into smart grids equipped with information and communication technologies, form the basis for developing smart EMSs, like an Energy Box. Energy Box is capable of providing the users the flexibility of load operation scheduling and thus obtain optimal global control of energy sources like grids, generators and storage etc. The inputs to an EB include demand price tariff rates, consumer comfort requirements, weather conditions and forecast. These inputs are then used by its algorithms to develop control strategies. These strategies help the consumers reduce their electricity bills without compromising the quality of their energy services. They also help systemoperators by assisting them in system/network management. EB also possess the ability to adapt and improve itself by learning from the users consumption habits and patterns.

We are designing a controllable bidirectional battery charger for plug in electric vehicles, which are basically special residential loads with potential ability to give power back to the grid i.e., G2V capability. The EB is responsible for controlling the conversion operation. It gives command signal which act as references for the controllers. Along with solar and wind microsources, we can potentially create a residential/neighbourhood standalone microgrid.

2. CHARGER CIRCUIT DIAGRAM

PEVs are an increasing trend, crucial towards present day smart grids. Chargers are what helps connect the vehicles and the grids, so their relevance is even greater.



The main characteristic of the charger is its bidirectionality, high power quality, power factor equal to one and its simplicity. It's also designed to be compatible with 16A single phase plug which meets the EU standards.

The charger topology is made of three legs of two Insulated Gate Bipolar Transistors(IGBTs). IGBTs are used mainly due to their high switching frequency and compatibility with voltage and current limits. This arrangements forms an AC/Dc converter that acts as both a rectifier and an inverter in G2V and V2G operation respectively. They also form C class chopper arrangement which is used to restrict the power used in both modes of operation. The chopper operates in buck and boost modes in the two operations. The passive elements help in filtering and energy storage purposes which is necessary for stability and power quality.

3. CONVERTER ANALYSIS

DC/DC Converter:-

The DC/DC Converter is a Class C Chopper that operates in the first two quadrants. The buck and boost mode operations are expressed in equations (1) to (4) and equations (5) to (8) respectively.

$$V_{BAT} = V_{Cbus} - L_{Chopper} \cdot \frac{dI_L}{dt} \tag{1}$$

$$I_L = \frac{1}{L_{Chopper}} \cdot \int_0^{Ton} (V_{Cbus} - V_{BAT})\, dt \tag{2}$$

$$V_{BAT} = -L_{Chopper} \cdot \frac{dI_L}{dt} \tag{3}$$

$$I_L = \int_{Ton}^{Toff} -\frac{V_{BAT}}{L_{Chopper}} dt \tag{4}$$

$$V_{BAT} = L_{Chopper} \cdot \frac{dI_L}{dt} \tag{5}$$

$$I_L = \frac{1}{L_{Chopper}} \cdot \int_0^{Ton} V_{BAT}\, dt \tag{6}$$

$$V_{BAT} + V_{LChopper} = V_{Cbus} \tag{7}$$

$$I_L = \frac{1}{L_{Chopper}} \cdot \int_{Ton}^{Toff} (V_{BAT} - V_{Cbus})\, dt \tag{8}$$

The Energy box controls the charger operation by means of PWM signals where drive and cut-off times form one switching period T. The voltage conversion ratio is given by the Duty Cycle defined by equations (9) and (10) for buck mode and (11) and (12) for boost mode respectively.

$$D = \frac{T_{on}}{T} \tag{9}$$

$$V_{BAT} = V_{Cbus} \cdot \frac{T_{on}}{T} = V_{Cbus} \cdot D \tag{10}$$

$$\frac{1}{1 - D} = \frac{V_{Cbus}}{V_{BAT}} \Leftrightarrow D = -\frac{V_{BAT}}{V_{Cbus}} + 1 \tag{11}$$

$$V_{BAT} = V_{Cbus} \cdot (1 - D) \tag{12}$$

The DC bus capacitor is used for stabilizing the DC bus voltage. The $L_{Chopper}$ inductor is used for limiting the energy flow for each chopper side in both buck and boost modes. They also help filter ripples, mitigate current spikes etc.

For Buck mode we get

$$L_{Chopper} = \frac{V_{Cbus} - V_{BAT_{nom}}}{2 \cdot \Delta I_L} \cdot T_{on} \tag{13}$$

Using (9) and (10) we get

$$DT = T_{on} \rightarrow \begin{cases} T_{on\_min} = \frac{V_{BAT_{min}}}{V_{Cbus}} \cdot T \\ T_{on\_max} = \frac{V_{BAT_{max}}}{V_{Cbus}} \cdot T \end{cases} \tag{14}$$

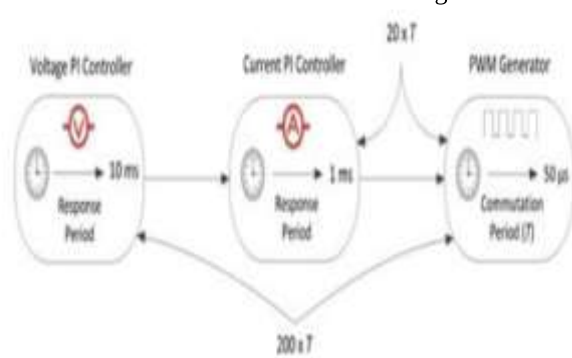
For Boost mode we get

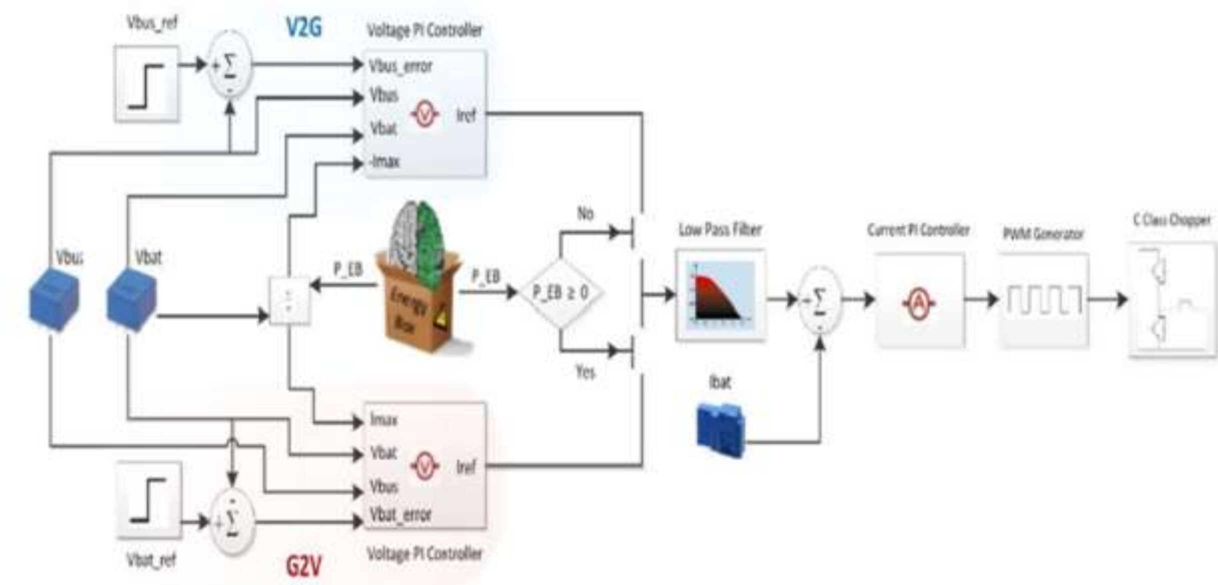
$$\Delta I_L = \frac{V_{BAT}}{2 \cdot L} \cdot DT \Leftrightarrow \Delta I_L = \frac{V_{BAT}}{2 \cdot L} \cdot T_{on} \tag{15}$$

Using (9) and (10) we get

$$DT = T_{on} \rightarrow \begin{cases} T_{on\_min} = 1 - \frac{V_{BAT_{max}}}{V_{Cbus}} \cdot T \\ T_{on\_max} = 1 - \frac{V_{BAT_{min}}}{V_{Cbus}} \cdot T \end{cases} \tag{16}$$

The DC/DC Controller time structure is given below





DC/DC Converter Controller architecture for G2V and V2G operation Modes

AC/DC Converter:-

The AC/DC Converter act as both controlled rectifier and as an Inverter in G2V and V2G operations respectively. For each operation modes we can thus ensure flexibility by controlling the power switch drive. By using unipolar switching method, the switches are not turned on at the same time and thus we can control the output voltage fluctuations.

We consider an arbitrary point n and based on the different switching frequencies, we find Van and Vbn and finally Vab. The IGBTs are turned 'on' and 'off' as per unipolar switching frequency, based on comparison between carrier signal and modulation signal. The inductive filter on AC side is used to remove the ripples, improve power quality, power factor and reduce the current spikes.

TABLE I
UNIPOLAR INVERTER RULES

S_1	S_2	S_3	S_4	V_{an}	V_{bn}	$V_{ab} = V_{an} - V_{bn}$
on	–	–	on	V_{Cbus}	0	V_{Cbus}
–	on	on	–	0	V_{Cbus}	$-V_{Cbus}$
on	–	on	–	V_{Cbus}	V_{C_bus}	0
–	on	–	on	0	0	0

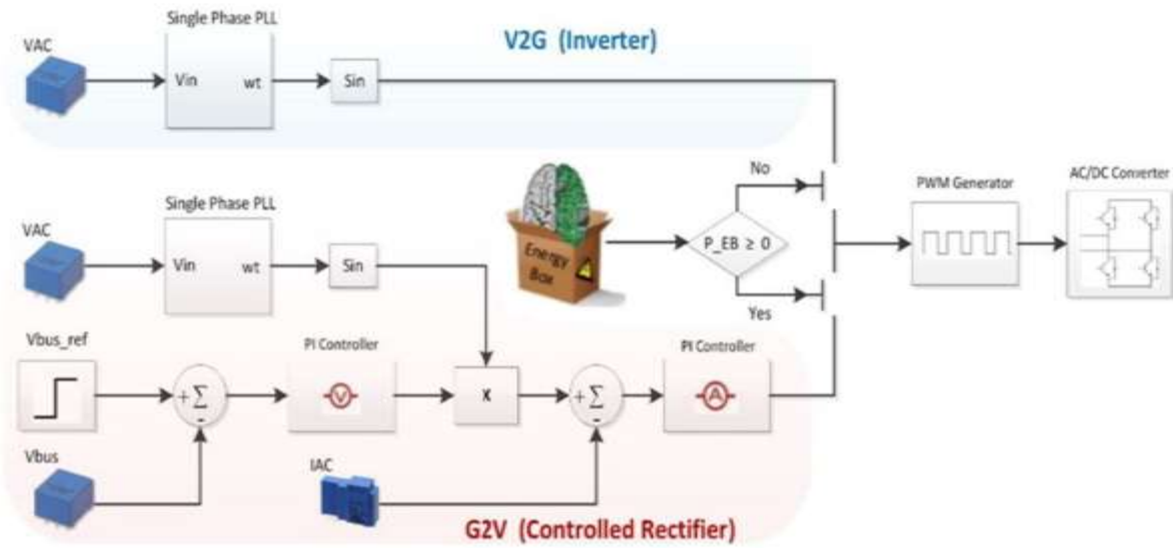
4. DESIGNING OF CONTROLLERS

Chopper Controller:-

For designing chopper controller, we assume that the capacitors on both sides of chopper are very high. The chopper controllers are based on two PI based architecture which can perform effective power level control. The ratio between the EMS and measured battery voltage sets the current limit output response of voltage control.

TABLE II
GLOBAL SYSTEM SPECIFICATIONS

Energy Levels	
$V_{AC_{RMS}}$	230 V
$I_{AC\_Max_{RMS}}$	10 A
P_{Max}	2.3 kW
$V_{DC_{Bus}}$	325 V
$V_{Bat_{Max}}$	127.5 V
$I_{Bat_{Max}}$	30 A
Passive Elements Size	
L_{AC}	7.6 mH
C_{Bus}	10 mF
$L_{chopper}$	1.9 mH
PI Controllers Values	
fs	20 kHz
PI Current Chopper's Controller:	
$K_P = 0.0522; K_I = 163.98; W_n = 6283.19$ rad.s^{-1}; $\tau = 3.10e^{-4}$ s	
PI Voltage Chopper's Controller:	
$K_P = 12.56; K_I = 3.97; W_n = 628.319$ rad.s^{-1}; $\tau = 0.0032$ s	
PI Current Rectifier's Controller:	
$K_P = 5.2; K_I = 1.3$	
PI Voltage Rectifier's Controller:	
$K_P = 11.7; K_I = 0.87$	



AC/DC Converter Controller Architecture for G2V and V2G Operation Modes

AC/DC Converter Controller:-
Unlike chopper controller, the controller for only rectifier is PI based. Meanwhile, a phase locked loop is used in inverter for providing control references. The controller is primarily tuned and then is used to provide IGBT control PWM signals.
The controller only works when unipolar switching method is used. The sinusoidal reference provided by the PLL is used to synchronise with the voltage grid. The DCbus power is restricted by the chopper so only by inverting it can it be used.

5. CONCLUSION

In this paper, a controllable, bidirectional battery charger for plug-in-electric vehicles is proposed. The bidirectional nature makes it more flexible. The main intention in designing the charger is help create a potential stand-alone microgrid by pairing it with some solar and wind microsources. By combining these different sources, we can convert a small residential neighbourhood into a standalone microgrid. By applying this concept in different neighbourhoods, we can help develop a self sustaining system which is essential in today's society. The EMS is a smart device that can help in this regard. We can simply plug in our electric vehicle and set the time for when we need it next and the EMS system can calculate the most optimal charging mode and potentially calculate ways to sell energy back to the grid. This methodology is also applicable for higher power sources by slightly varying the component specifications. Its compatible with any type of batteries and its voltage, current and recharge limits.

6. ACKNOWLEDGMENT

The author is grateful to all the supporting faculties and the department in giving both the opportunity and facility for doing the work.

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