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# Reversible Battery Charger for Vehicle to Grid Applications

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***Abstract-*** **Vehicle-to-Grid (V2G) technology is an interface between the power grid and electric vehicles that allows electricity to flow in both directions. The application of V2G to pure electric vehicles (PEV) and plug-in hybrid-electric vehicles (PHEV) has been a promising technology. This paper presents a reversible battery charger for electric vehicles with V2G function and associated control strategy for the power flowing between the grid and the EV. The reversible battery charger is being proposed to connect the power grid and the EV batteries. The method uses a matrix converter and bidirectional dc-dc converter. The reversible battery charger was designed, fabricated and simulated using MATLAB SIMULINK environment. The results are presented to show the reversible battery charger operation under both charging and discharges modes.**

***Index Terms*: battery charger, electric vehicles, Vehicle to Grid (V2G)**

## I. INTRODUCTION

For V2G to take place there has to be four components: mature electric vehicles pure and plug in hybrid, advanced generation of batteries that can store energy to drive a car more than100 miles on a single charge, at the core of V2G is a reversible battery charger for electric vehicles with V2G function and associated control strategy for the power flowing between the grid and EV, Finally the most important gradient for V2G to work is the two way communication between the EV and the grid. Electric vehicle technologies available today are normally divided into three categories [1-2]: (1) pure- EV (PEV); (2) hybrid electric vehicle (HEV) which in turn is classified into two types: Regular HEV and Plug-in electric vehicle (PHEV); and (3) fuel cell electric vehicles (FCEV). Figure 1 shows these types of EVs. However, only PEV and PHEV can be used in V2G without any modification, because they can be plugged to the grid. Pure- EV runs on an electric motor. The batteries size and cost issues are main challenge. Regular hybrid electric vehicle runs on gasoline with an electric motor. However, the batteries are only charged by the generator that is located in the electric car, it has no access to the grid. Plug- in hybrid electric vehicle runs under engine power like the regular HEV, but the batteries can be charged from the grid. Fuel Cell electric vehicle runs on an electric motor as Pure- EV. However, the difference is that FCEVs produce their primary electricity using fuel cells, which in turn are powered by hydrogen.

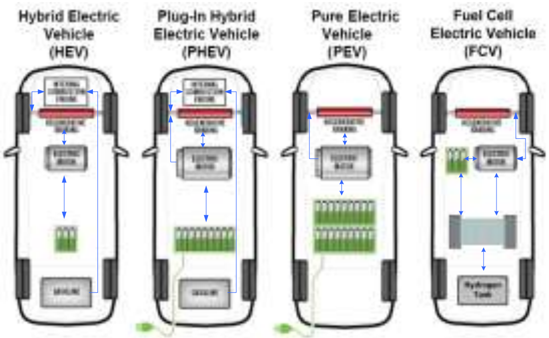


Figure 1 Types of EVs Diagram



The current generation of batteries [3-7]can only store energy to drive 50 to 150 miles with a single charge compared to that internal combustion engine ICV can drive 300- 500 miles with a full tank. Most potential manufacturers are looking at lithium ion batteries because they have the best balance between cost and performance. And the USABC are investigating on two batteries systems, lithium polymer and the lithium-ion battery systems. To achieve the Vehicle-to-Grid technology, a bi-directional electric grid interface is needed.Figure 2 shows the circuit of a type of converter called single-phase matrix converter (SPMC) [8-11].The SPMC consists of a matrix of four bidirectional switches. The single-phase matrix converter (SPMC) is quite a versatile power conversion topology that can work as a rectifier and inverter.

## II. METHODOLOGY

### *A. Power circuit design of a Reversible Battery Charger*

In this paper, a switch-reduced, single phase matrix converter (SPMC) and bidirectional DC- DC converter are proposed to implement the reversible battery charger of EVs.

The proposed switch-reduced SPMC is a three- switches topology rather than four. The system topology and the two operational modes principles are described. Simulation results for both modes are presented. Also to implement the charger in practical realization, IGBT and microcontroller (PIC16F684) were used. The power circuit is shown in figure 4, the operation of these two stages will be described separately.

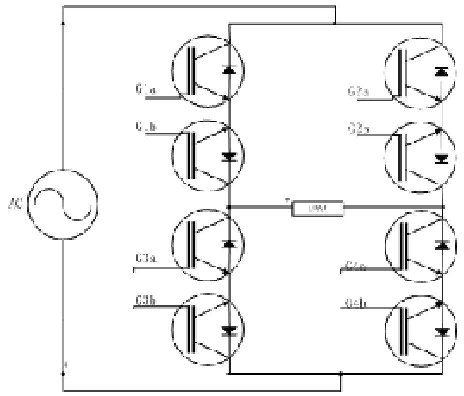


Figure 2 SPMC

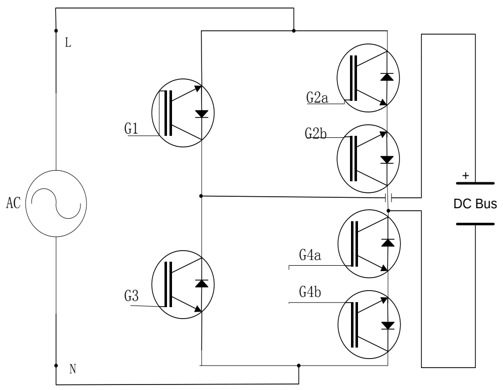


Figure 3 Switch reduced SPMC

## B. Switch- reduced single phase matrix converter operation

Two different switching strategies are used in this work; a) rectifier and b) inverter operation as they will be described. The SPMC as showed in figure 2. In this work we propose using the reduced single phase matrix converter with three bidirectional switches instead of 4. This configuration has the advantage of allowing within each leg, control of the current in both directions.

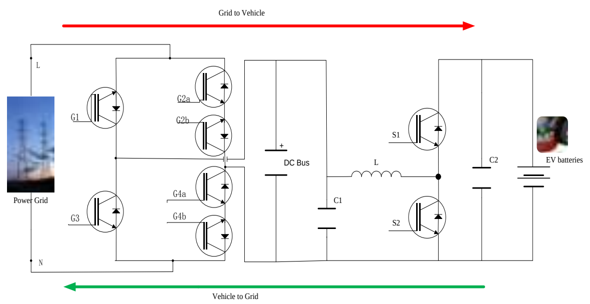


Figure 4 Power circuit of reversible battery charger

### 1. Rectifier Operation

In the positive half of the cycle G4a is conducting with PWM, in the negative half of the cycle G2b is conducting with PWM.The strategy is tabulated in table 1.

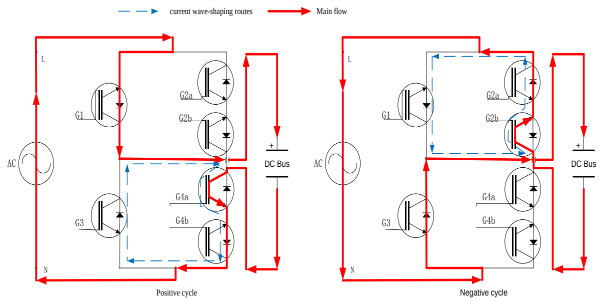

Figure 5 Switch- reduced SMPC rectifier operations

TABLE 1 SWITCH- REDUCED SMPC RECTIFIER MODE SWITCHING STRATEGY

| Switches | G1 | G2a | G2b | G3 | G4a | G4b |
|---|---|---|---|---|---|---|
| Positive | off | off | off | off | PWM | off |
| Negative | off | off | PWM | off | off | off |

Different switches pairs for positive or negative cycles, as well as current wave-shaping routes are needed in both cycles.

### 2. Switch- reduced SPMC inverter operations

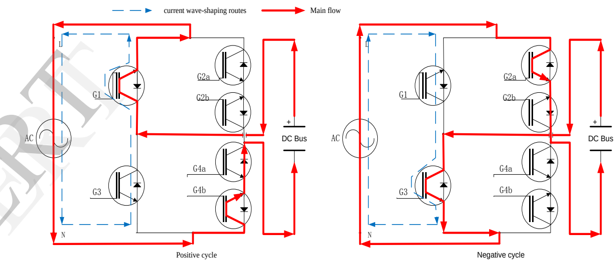

Figure 6 Switch- reduced SPMC inverter operations

In the Inverter mode two switches are conducting during the positive half cycle and two switches are conducting during the negative half cycle. Again different switches pairs for positive or negative cycles.Sinusoidal pulse width modulation (SPWM) is applied to AC/DC converter

TABLE 2 SWITCH- REDUCED SMPC INVERTER MODE SWITCHING STRATEGY

| Switches | G1 | G2a | G2b | G3 | G4a | G4b |
|---|---|---|---|---|---|---|
| Positive | PWM | off | off | off | off | on |
| Negative | off | on | off | PWM | off | off |

## C. Bidirectional DC- DC converter operation

The bidirectional boost buck DC- DC converter is used for the battery charging topology [5]. One of the advantages of the converter is that it is a transformer less type with less size, weight and cost. The power circuit includes two sets of anti-parallel connected IGBT and Diode as well as a boost inductor with two filtering capacitors. Charging or discharging the battery can be realized by controlling the two IGBT switches.

When the battery is being charged switch S2 and diode D1 conduct current alternately. With S2 turned on, current flows from the DC bus, passes through the inductor and flows through IGBT S2. Energy is stored in the inductor during this state. Once S2 is turned off the current continue to flow through D1. Inductor's energy will boost the voltage and charge the EV batteries. When the batteries are being discharged by the DC- DC converter the current flows from the batteries, passes through IGBT switch S1 and the inductor. After S1 is turned off the current keeps flowing through diode D2 to decay. In this case, the converter acts in buck mode. By controlling the duty cycle of the switches, required voltage output can be obtained. Figure 7 shows the four operation state.

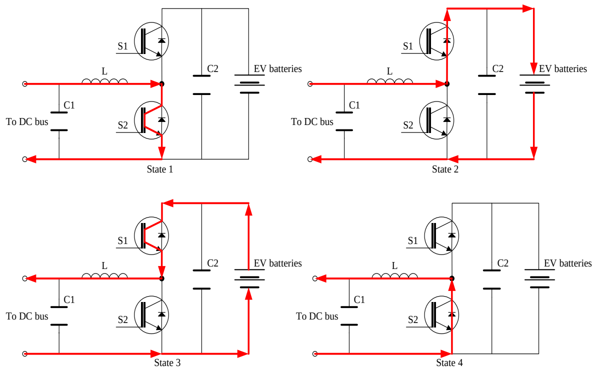


Figure 7 Operation of bidirectional DC- DC converter; state 1 and state 2 are charging mode, state 3 and state 4 are discharging mode.

## III. CONTROL CIRCUIT DESIGN

Figure 8 presents the proposed control circuit block diagram which is based on PWM controller, the global controller and gate drive circuit. The microchip microcontroller 16F684 is applied here. Microchip 16F684 is a 14- pin flash- based, 8-bit CMOS microcontroller with nano-Watt technology. With the multiple functions inside, it can complete the jobs of phase detector, PWM controller and global controller in the control circuit of the reversible battery charger. Reference voltage from the battery is used to control the DC- DC converter making sure that the charging voltage does not exit over 180V. There is a manual switch controlling the global controller to switch between charging and discharging mode.

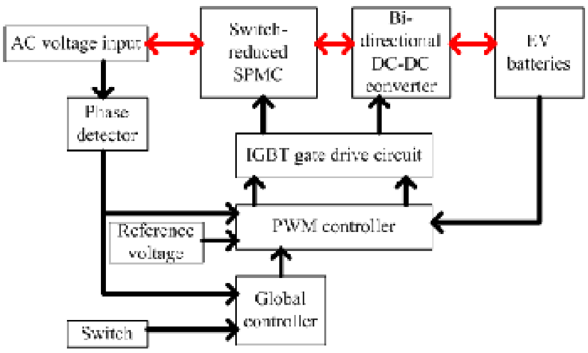


Figure 8 Control Circuit block diagram

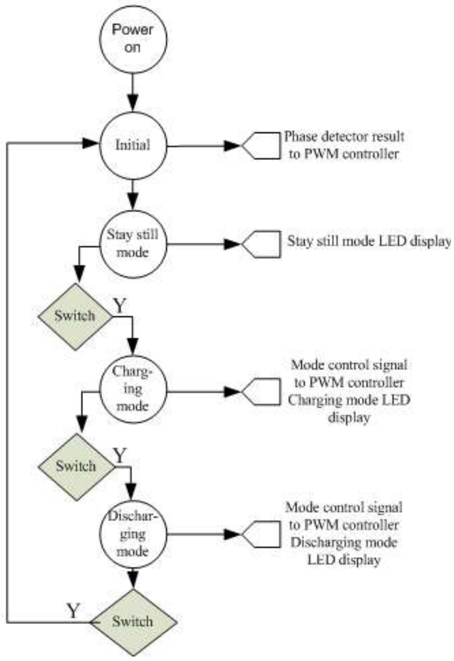


Figure 9 Global control data flow chart

### *A. Global controller*

The global controller has one microcontroller doing three tasks, phase detector, operation mode switching and operation mode display. The phase detector is implemented with the comparator in the PIC16F684. The control flow chart is given by Figure 9. PWM controller data flow chart is shown in figure 12.

### *B. Pulse width modulation controller*

Two pulse width modulation techniques are used in this paper. Sinusoidal pulse width modulation (SPWM) is appliedto AC/DC converter as illustrated in Figure 10 and single- pulse- width modulation showed in Figure 11 is applied to DC/DC converter. For realization, the PWM generator inside the 16F684 is used. Since each microcontroller only has one single PWM generator, four 16F684 are needed.

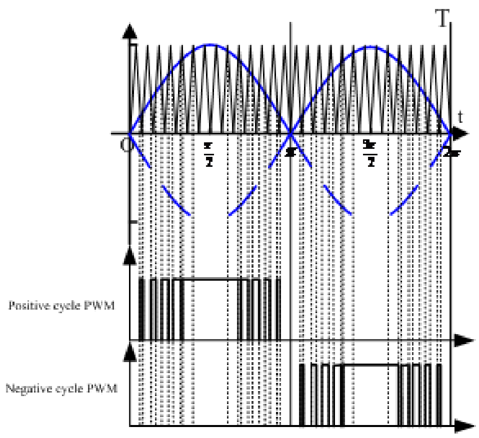


Figure 10 Sinusoidal Pulse width modulation

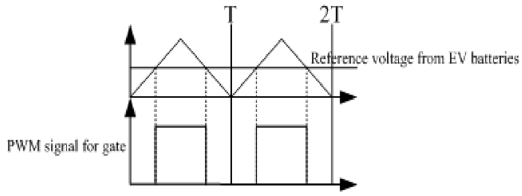


Figure 11 Single pulse width modulation

### C. Power supply and IGBT drive

Driving an IGBT means applying different voltages between pins of gate and emitter: 15V to turn on the IGBT and 0V to turn it off. Or shift up the voltage of emitter when a turning on operation is needed.When the IGBT is working in the switch- reduced SPMC, voltage of emitter can be very high at positive cycle and very negative at negative cycle.As well as the high- side IGBT in the bidirectional DC-DC converter has high voltage at emitter pin. These will burn the control circuit since it is formed by analog components. Thus, an IGBT driver circuit is provided with two functions. One is that the driver circuit must can shift the voltage of emitter alternatively and apply to the gate pin with a fast switch speed. The other is that it can insulate the control circuit from the high voltage power lines. As shown in figure 13, an opto-coupler IGBT driver with a 15V insulated power supply have been implemented for a diver circuit. For every emitter pin, it should connect to a ground of an insulated power supply. It will need several insulated power supplies for the whole circuit.

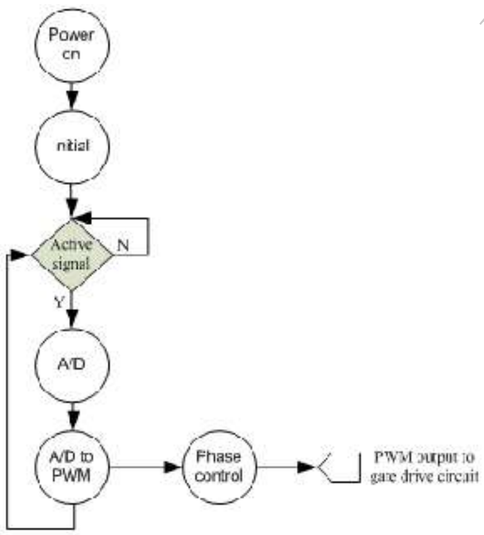


Figure 12 PWM controller data flow chart

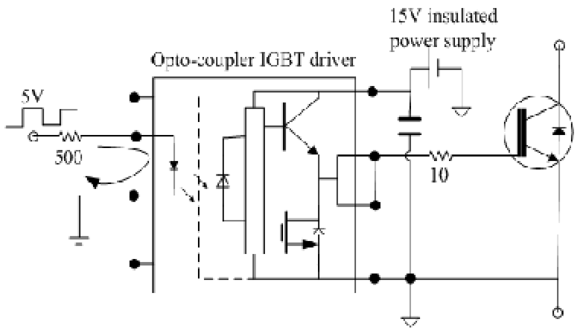


Figure 13 Single IGBT drive circuit.

## IV. SIMULATION AND EXPERIMENT RESULTS

MATLAB/SIMULINK is used to model and simulate the circuit to describe the behavior of the reversible battery charger for an electric vehicle owned by UML.Two different operation modes, charging and discharging, were simulated. In the simulation, different values of feedback gate were tested to determine the output charging voltage. It was found that the charger can boost the voltage to the maximum charging voltage 180V of the batteries which is the highest voltage of the electric car. It also can change the voltage feedback gate to control the charging current to 15A.

Figure 14, shows the simulated output voltageof the reversible battery charger. Figure 15, shows the simulated rms value of the supply current and the output charging current



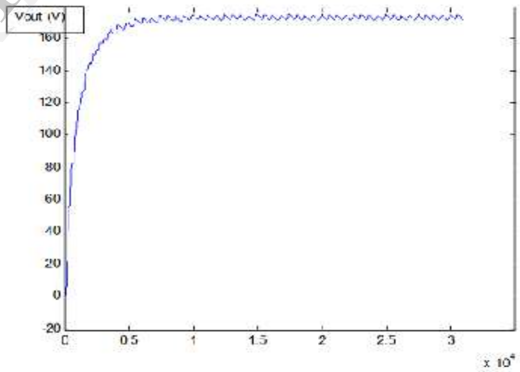


Fig. 14 Output voltages with RC load

## V. CONCLUSIONS

A reversible battery charger for electric vehicle has been designed, built, tested, and simulated. Two different operation modes, charging and discharging, were described. The test results and the simulation results showed that the electric vehicle battery charge works.The switch- reduced converter has less IGBTs, so it is cheaper and does the same function as the unreduced one. The simulation was conducted using MATLAB SIMULINK environment.

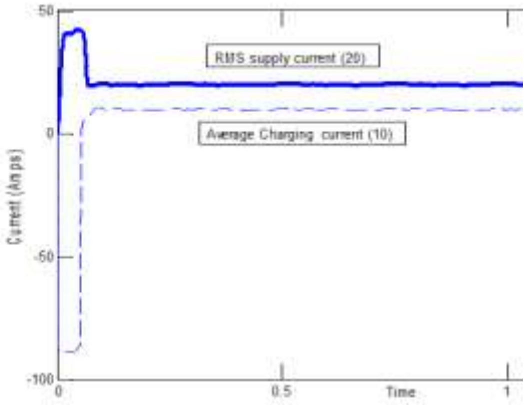


Figure 15 Average Charging current Vs. RMS supply Current

In the simulation, different values of feedback gate were tested to determine the output charging voltage. It was found that the charger can boost the voltage to the maximum charging voltage 180V of the batteries of an electric car with 12 lead acid batteries with a maximum voltage of 180 volts when fully charged. It also can change the voltage feedback gate to control the charging current to 15A. The author used PIC16F684 microcontroller in implementation of global controller and PWM controller.

## VI. REFERENCES


1 Larry Dickerman and Jessica Harrison, “A new Car, a New Grid”, IEEE Power& Energy, Vol. 8, no. 2, p.55- 61, March/April 2010.

2 Carl Sulzberger, “An Early Road Warrior: Electric Vehicles In The Early Years Of The Automobile”, IEEE power and Energy, Vol. 2, no. 3, p.66- 71, May/Jun 2004.

3 Kim Bong, F. Tredeau and Ziyad Salameh, ” Fast Chargeability of Lithium Polymer Batteries”. Annual IEEE_PES Meeting , PP. NO, 08GM0857.

4 Kim Bong, F. Tredeau and Ziyad Salameh,” Performance Evaluation of Lithium Polymer batteries for use in the Electric vehicles”, VPPC 2008 Harbin, Sep 3-7, China.

5 Tredeau, Kim Bong, and Ziyad Salameh, “Performance Evaluation of Lithium Cobalt Cells for use in Electric Vehicles” VPPC 2008 Harbin, Sep 3-7, China.

6 Kim Bong, and Ziyad Salameh, “Advanced Lithium Polymer Batteries”, IEEE PES GM09 ,July 2009, Calgary , Canada.

7 F. Tredeau, and Ziyad Salameh,” Evaluation of Lithium Iron Phosphate Batteries for Electric Vehicle Application. VPPC 2009, Dearborn, MI, Sep. 8-11.

8 A. Zuckerberger, D. Weinstock, A. Alexandrovitz, “Single-phase matrix converter”, IEE Proc. –Electr. Power Appl., Vol. 144, No. 4, July 1997.

9 Mustafar Kamal Hamzah, MohamadFadzilSaidon and SitiZaliha Mohammad Noor, “Application of Single Phase Matrix Converter Topology in Uninterruptible Power Supply Circuit incorporating Unity Power Factor Control”, Industrial Electronics and Applications, 2006 1ST IEEE Conference on, 24-26 May 2006.

10 R. Baharom, Mustafar Kamal Hamzah, A. Saparon and N. R. Hamzah, “Single- Phase Matrix Converter Operating as Buck and Boost Rectifier”, Industrial Electronics and Applications, 2009. ICIEA 2009. 4th IEEE Conference, 25-27 May 2009.