

# Design of Bidirectional Converter Using Fuzzy Logic Controller to Optimize Battery Performance in Electric Vehicle

Sasikumar S<sup>1</sup>, Krishnamoorthi K<sup>2</sup>, Soniya N<sup>3</sup>Research Scholar, Department of Electrical Engineering, Sona College of Technology, Salem, India <sup>1</sup>Associate Professor, Department of Electrical Engineering, Sona College of Technology, Salem, India <sup>2</sup>PG Scholar, Department of Electrical Engineering, Sona College of Technology, Salem, India <sup>3</sup>

**ABSTRACT**— Hybrid Electric Vehicle (HEV) is an electric vehicle which has more than one energy source. HEV is powered by battery, photovoltaic (PV), or fuel cell. It needs boost converter linked by bidirectional converter to achieve maximum power output. Maximum power point is achieved by setting reference power to manage bidirectional converter duty cycle. This paper shows design of HEV using PV and battery controlled by fuzzy logic controller. Bidirectional converter is used to adjust the charging current and discharging current of the battery. Regulation of the current is aimed to prevent damage to the battery, and reduces gassing phenomena that occurs in lead-acid batteries. Fuzzy logic controller is designed to optimize battery lifetime and used capacity. Simulation result shows that bidirectional converter has 90 percents efficiency and can regulate the charging current and discharging current. The bidirectional converter also can maintain the output voltage constantly.

**KEYWORDS:** Bidirectional DC-DC converter, HEV, PV with Coupled Inductor.

## I. INTRODUCTION

Battery is an important part in modern electrical system, including application for hybrid power systems [1] and electric vehicle systems. The developments of battery management systems [2], the use of better inverter control [3], the use of efficient dc converter [4] are known to improve the battery performance and lifetime. HEV driving cycle (acceleration, braking, maintaining to a constant velocity) needs a bidirectional converter to manage Battery charging and discharging. Bidirectional converter will manage the DC link voltage constant. Charging and discharging processes would make voltage of battery changed. The battery voltage change can make a gassing effect that can reduce the lifetime of battery. This study is taken to achieve maximum power in PV, so it not only can receive maximum power of PV, but also can reduce the dimension and weight of HEV. This method is expected to be an alternative method to increase HEV Performance, so the usage of HEV would be increased in the future. The aim of this research is to design a battery charging and discharging system using bidirectional converter with coupled inductor that optimized by Fuzzy Logic Controller.

## II. ELECTRIC VEHICLE SYSTEM

In this study, general configuration of battery charging system is shown in Fig. 1. This system includes PV arrays as the source, boost converters combination as the main converter, bidirectional converter with inductor coupled, and battery[5]. Photovoltaic system that used on this study is used Neural Network Multi Model (NNMM) Maximum Power Point Tracking (MPPT) [4, 6]. This study uses two level converters for PV system which correlated with battery. They are boost converter as MPPT, and bidirectional converter with coupled inductor as inductor to manage the battery

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charge and discharge current. Bidirectional converter system with coupled inductor is more efficient than common bidirectional converter [5].

## A. PHOTOVOLTAIC MODELING

PV is used as the main source of the system. PV is Modeled as an equivalent series as shown in Fig.2. Rsh and Rsis intrinsic resistance; they are arranged in parallel connection and serial connection. Rsh value is very high and Rs value is very low. Both variables are neglected in the analysis process. PV cells which is arranged to bigger units called PV modules. These modules are connected in parallel and serial to make PV arrays [7].

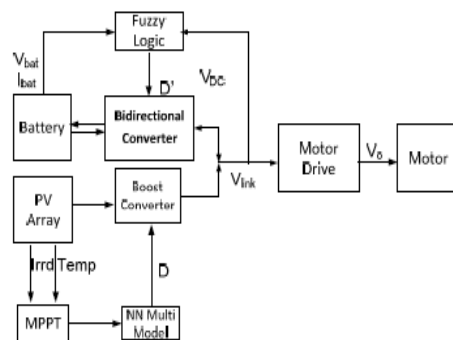


Fig .1. System diagram

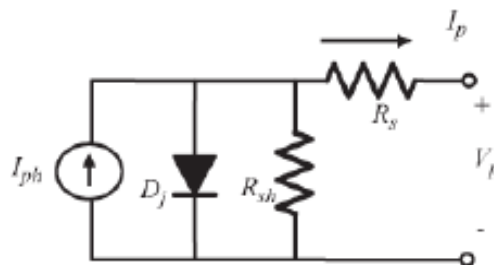


Fig.2. Equivalent circuit of PV

Mathematic model of PV arrays is presented below:

$$I = I_{pv} - I_0 \left[ \exp \left( \frac{V + R_s I}{V_t n_s} \right) - 1 \right] - \frac{V + R_s I}{R_{sh}} \quad (1)$$

I is output current of PV module (Ampere), V is output voltage from PV module, and I<sub>0</sub> is saturated current of PV. V<sub>t</sub> = N<sub>s</sub>kT/q is thermal voltage of PV, and N<sub>s</sub> is connected in serial connection.

## B. BATTERY MODELING

The battery used in this study is the kind of Lead-Acid. Equivalent circuit of the battery is shown in Fig.3. The circuit consists of an internal resistance, controlled voltage source, with f1 and f2 is a function of charge and discharge. For lead acid batteries charge and discharge functions are as follows [8]:

$$f_2 (it, i^*, i, Exp) = E_0 - K \frac{Q}{Q-it} i^* - K \frac{Q}{Q-it} it + \text{laplace}^{-1} \left( \frac{\text{Exp}(s) \frac{1}{s}}{\text{Exp}(s) \frac{1}{s}} \right) \quad (2)$$

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$$f_2(it, i^*, i, Exp) = E_o - K \frac{Q}{Q - 0.1Q} i^* - K \frac{Q}{Q - it} + \text{laplace}^{-1} \left( \frac{Exp(s)}{Sel(s)} \frac{1}{s} \right) \quad (3)$$

$I_{batt}$  is the current flowing through the battery. SOC that the battery can be written by the following equation:

$$SOC = 100 \left( 1 - \frac{1}{Q} \int_0^t i(t) dt \right)$$

Battery thermal modeling is obtained by performing an experiment. From experiments obtained mathematical model of thermal battery is:

$$T(T_{ambient}, h) = T_{ambient} \frac{r}{0.1C} h$$

T is temperature, C is battery capacity in Ah, and h is operating time.

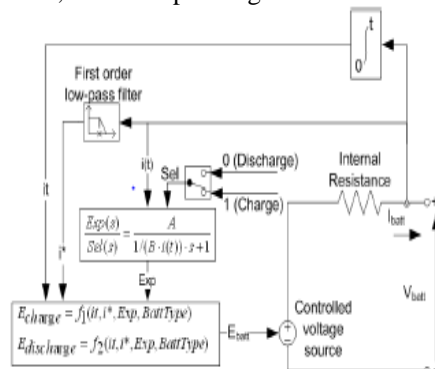


Fig.3. Equivalent circuit of lead-acid battery

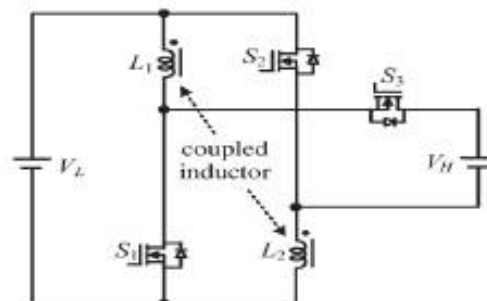


Fig.4. Topology of Bidirectional Converter with coupled inductor

### C. BIDIRECTIONAL CONVERTER MODELING

Coupled inductor of bidirectional converter is used to regulate the process of charging and discharging of the battery. The topology is shown in Fig. 4. [5]. Amount of output power which flows to DC link based on operation mode. Output power is obtained from this equation[5]:

$$P_{DC} = V_{DC} I_{DC} \quad (4)$$

VDC is the DC bus voltage and IDC is the current flowing to the inverter. Value of the output voltage of Bidirectional Converter should be equal to the DC bus voltage. The output voltage on Bidirectional Converter can be set using this equation [5]:

$$V_H = \frac{1+D}{1-D} V_L \quad (5)$$

D is the duty cycle of the switches S1 and S2. Bidirectional converter is connected to the battery, and the converter works in two modes: When the battery is in Boost mode, equation (4) can be applied. When the battery is in Buck mode, equation changes to [5]:

$$V_L = \frac{D}{2-D} V_H \quad (6)$$

#### D. BIDIRECTIONAL CONVERTER CONTROL DESIGN

Scheme of the main converter system control circuit that proposed is shown in Fig.5. Converter control circuit is divided into 2 parts: controls the bidirectional converter in charging mode, and controls the bidirectional converter in discharging mode. The combination of control used by the converter depends on the operating conditions of the system as shown in Table I and Table II.

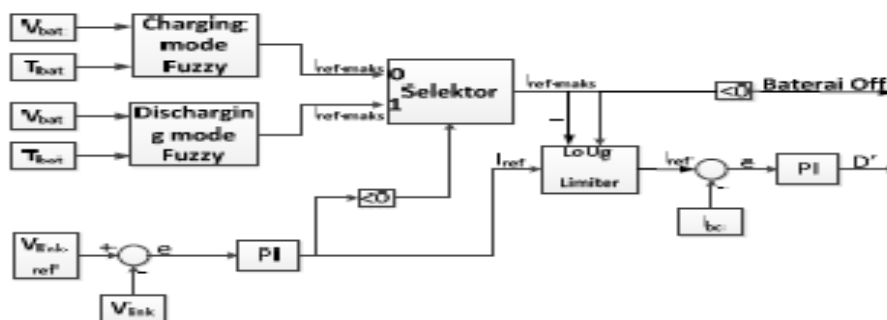


Fig.5. Proposed bidirectional converter control for boost mode and buck mode.

Bidirectional converter is set by changing the value of the duty cycle D. The control system works when voltage direct current (DC) link is not equal to the reference voltage. If the DC link voltage is more than the reference voltage, the value of D is reduced. If the DC link voltage is less than the reference voltage, the value of D is enlarged. In this study, DC link Voltage is maintained at 600 V. Table I and Table II is used as a reference value of discharge. The amount of boost charge is 0.4 C, trickle charge is 0.1 C, boost discharge is 0.4 C, trickle discharge is 0.2 C. C is the capacity of the battery [2, 9, 10]. Membership function in the control of bidirectional converter can be seen in Fig.6 and Fig.7. Fig.6 presents MF 3:16 inputs and Fig.7 presents output membership function. Controller works with the rule in Table I and Table II so the gassing phenomena in lead-acid batteries can be reduced.

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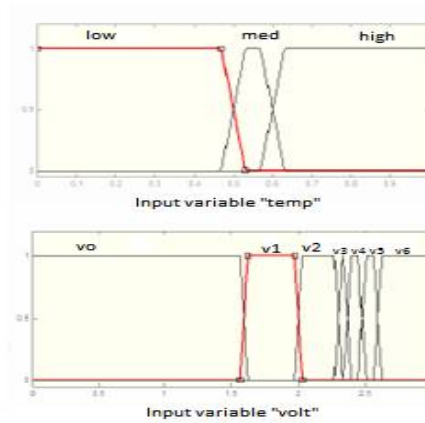


Fig.6.Membership function input fuzzy logic controller.

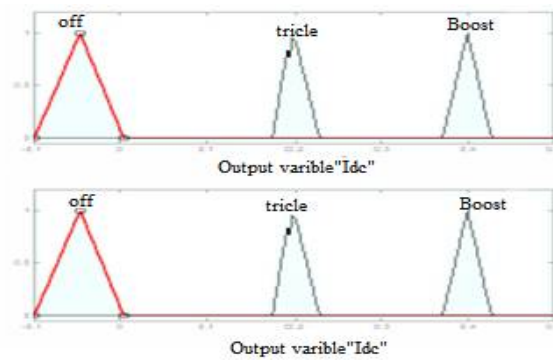


Fig.7.Output membership function of fuzzy logic controller.

TABLE I. MEMBERSHIP FUNCTION IN CHARGING MODE

Charging Mode				
	V/T	T<50	60>T>50	T>60
V6	$V_{bat} \geq 2.6$	Off	Off	Off
V5	$2.6 > V_{bat} \geq 2.48$	Trickle	Off	Off
V4	$2.48 > V_{bat} \geq 2.37$	Boost	trickle	Off
V3	$2.37 > V_{bat} \geq 2.3$	trickle	trickle	Off
V2	$2.3 > V_{bat} \geq 2.0$	Boost	Off	Off
V1	$V_{bat} < 2.0$	trickle	trickle	Off
V0	$V_{bat} < 1.6$	trickle	trickle	Off

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TABLE II. MEMBERSHIP FUNCTION IN DISCHARGING MODE

Discharging Mode				
V/T		T<50	60>T>50	T>60
V6	$V_{bat} \geq 2.6$	Off	Off	Off
V5	$2.6 > V_{bat} \geq 2.48$	Boost	Trickle	Off
V4	$2.48 > V_{bat} \geq 2.37$	Boost	Trickle	Off
V3	$2.37 > V_{bat} \geq 2.3$	Boost	Trickle	Off
V2	$2.3 > V_{bat} \geq 2.0$	Trickle	Trickle	Off
V1	$V_{bat} < 2.0$	Boost	Off	Off
V0	$V_{bat} < 1.6$	Trickle	Trickle	Off

### III. SIMULATION AND RESULTS

Bidirectional converter is used as a regulator of charging and discharging of the battery. Charging / discharging should not exceed the limits of charging / discharging, and a stable DC voltage link.

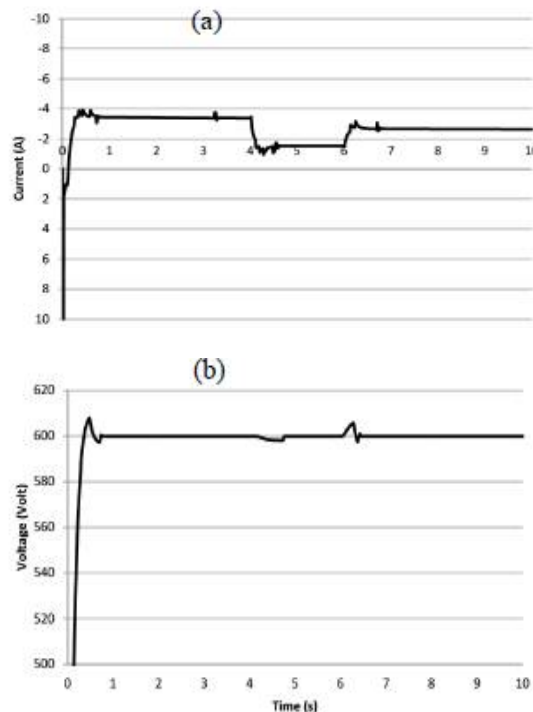


Fig.8. Battery charging current (a) DC link voltage (b)

#### A. SIMULATION RESULT IN LOAD CHANGES

Test of the charging current parameters shown in Fig.8. It shows that the current flows are able to follow the different references. Boost converter testing is also done by observing the voltage DC link as in Fig.11. The picture

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shows that the voltage is maintained at 600 Volts. It shows that the bidirectional converter as a voltage regulator was able to regulate the flow of power so that the voltage becomes stable.

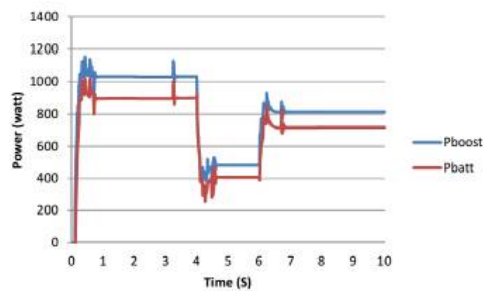


Fig.9. Battery power and bidirectional input power.

TABLE III. BIDIRECTIONAL CONVERTER EFFICIENCY

No.	Battery Current (A)	$P_{in}$ (Watt)	$P_{bat}$ (Watt)	Efficiency
1	30	7843	6890.0	87.85%
2	20	5227	4598.0	87.97%
3	15	3921	3451.0	88.01%
4	10	2614	2369.0	90.63%
5	5	1308	1252.5	95.76%
			Mean	90.04%

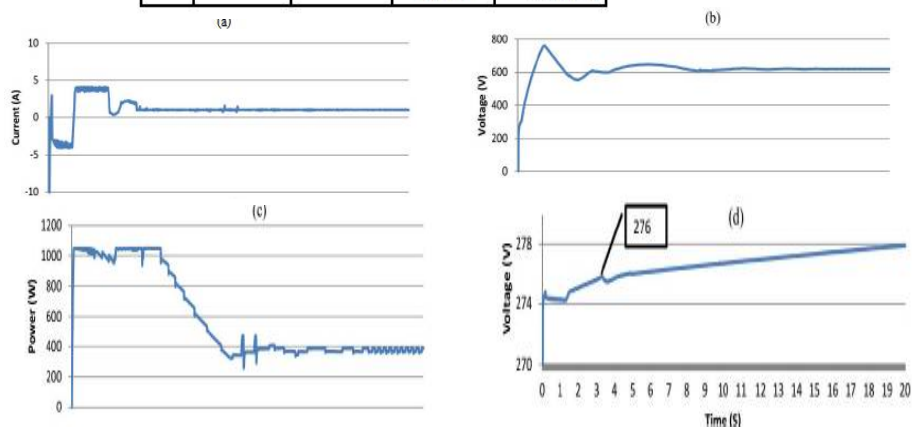


Fig.10. The process of change in boost mode charge into trickle charge. (a) Battery current, (b) Voltage DC link, (c) PV power, (d) The battery voltage

### III. CONCLUSION

Fig.9. presents changes in input and output bidirectional power converter. The picture shows the charging process. It also shows the power that flows to the bidirectional converter is impaired due to losses in the circuit. Table III shows us that the bidirectional converter efficiency is 90.04 percents. Fig. 10 presents the simulation results of the power Required exceeds the PV power. Fig. (a) Present battery voltage continues to rise due to the charging process. Fig. 10 (a) presents the current flowing curve of the battery. When the battery voltage has exceeded 267 volts, the



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battery current change of mode boost charge into trickle charge. Fig. 10 (b) presents the DC link voltage. DC link voltage momentarily increased when there is a change charging mode. However, as the operation of the controller in the PV power down, the voltage stabilizes at a value of 620 Volts. PV power reduction can be observed in Fig.10. (c). The controller responds excess PV power by reducing the power output of PV. Thus the DC link voltage can still be maintained despite the PV power exceeds the power charging.

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