Active Battery Cell Balancing Simulation Using Cell to Cell Pulse Width Modulation (PWM) Controlled Converter by Fuzzy Logic Controller (FLC)

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***Abstract*—Battery as an energy storage has unique characteristics in its operation. It made the battery necessary special treatment to handle. In large application, batteries need to configure in series-connected to fulfill its power consumption. Battery Management System (BMS) collect all these issue and handle it using cell balancing technique to keep it save, observed, high performance, easy to maintenance and long life time in usage. In this paper, Pulse Width Modulation (PWM) Controlled Converter using fuzzy logic as the controller to balance among the cells has been provided. For the result, absolute error compared by ideal SOC value for experiment with frequencies: 50 Hz and 100 Hz are 7.2% and 6.2%.**

Keywords*— *BMS; Cell Balancing; PWM; Fuzzy Logic

I. Introduction

Availability of fossil fuels in earth continues to decline. It coused a great attention to renewable energy research development[1]. In this term, battery becomes the most commonly used to storage the electrical energy that ready to convert to other kind of energies such kinetic, heating, lighting, etc. Electric vehicle (EV) is one solution of fuel energy crisis also necessary batteries as energy storage. Lithium-ion batteries with high lithium density and weak weight making them the most promosing for this application[2]. By serial connection of lithioum-ion batteries to build battery pack is usefull to get power wich need for this application. Using it configuration will make new problems appears related to the caracteristic of batteries. Batteries, especially lithium-ion batteries has their own state-of-charge range to keep it save in charge and discharge condition, also long life time usage. This characteristic makes the battery storage need sepecial treatment, and it called Battery Management System (BMS).

BMS has several important variable that need to observe. They are current, voltage, State of Charge (SOC), State of Health (SOH), and fault detection. SOC is battery capacity in terms of its reted capacity[3][4]. SOH drawn as condition of the battery in terms compared with the ideal condition[5].

This paper itself provide active cell balancing wich necessary current, voltage and SOC as the commonly variable to control the capacity of each cells battery in battery pack. Cell balancing itself is the condition when each cells battery connected in series configuration in battery pack has equal capacity either charge or discharge state[5].

Advantege using this methode is lies on its ability to trensfer energy from higher-capicity-cell to lower-capacity-cell using active control. In active cell balanciing there many method that proposed to make cells balance. In this paper we used cell to cell Pulse Width Modulation (PWM) controlled converter with fuzzy logic. Implementation fundamental principle of buck-boost converter is used to transfer energy among the cells, and will explain more in methodology section.

II. Methodology

Before, there are three methods that have been provided. They are battery selection, passive and active method. Battery selection method is cell balancing technique by selecting cell which we want to charge and discharge as determined SOC. Passive balancing is cells balancing process without using active component in its operation. Active balancing is balancing technique that active component is required to control SOC among the battery cells.

In terms, PWM control using buck-boost converter circuits for transferring energy among the cells. Fuzzy logic is used to control output PWM based on SOC input.

A. Buck-Boost Converter

Buck-boost Converter circuit produced DC voltage higher or lower than the input voltage and level of DC voltage depend on PWM output trough MOSFET. Fig.1 shows the buck-boost converter circuit.

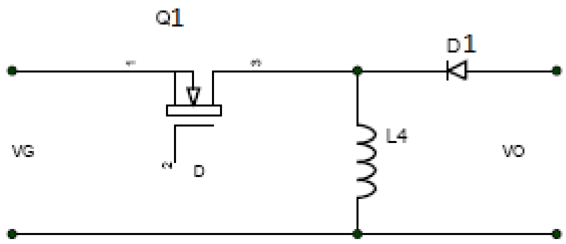

Fig. 1. Buck-Boost Circuit Converter (Without Capacitor)

When transistor Q1 ON, current from input voltage VG trough to inductor and implies diode D1 in OFF state. MOSFET turn OFF current I_L beings to build up trough VO. Current steady state on inductance and PWM signal t MOSFET represented as following graph.

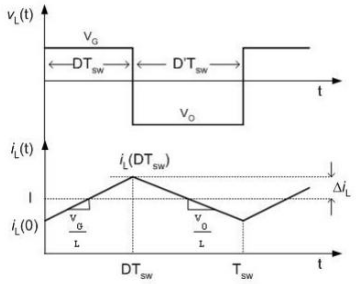

Fig. 2. VIltage steady state on inductor and current waves of buck-boost convevrter circuit[7]..

Result of steady state equation using balance voltage inductance principle as follows.

$$Vg.Ton + Vo.Toff = 0 \tag{1}$$

$$\frac{V0}{VG} = \frac{Tsw}{Toff} = -\frac{D}{1-D} \tag{2}$$

Variation of D (duty cycle) from 0 to 1 with nominal frequency will yield output voltage able to be lower or higher than input voltage[7].

B. Cell to Cell PWM Controlled Converter

Configuration and basics theory in this research inspired from Javier's et.al. journal which the title is Battery Equalization Active Method[6]. Basics topology of PWM control converter circuit shows on Fig. 3. Every component in module has a function to balance every voltage or SOC which connected between two different cells. The higher capacity will transfer its energy to the lower one. Firstly, controller will activate the MOSFET which has a higher capacity to reload the inductance. Second stage, the previous MOSFET will turn off and the next MOSFET ON, it caused electrical charge from inductance through to the lower capacity cell respectively. The process will occur continuously until the cells are balanced.

C. Fuzzy Logic Configuration

In this case, fuzzy logic has used to control the output of PWM through the MOSFET's. Fuzzy logic itself consist of four basics component in its operation, they are Fuzzifier, Fuzzy rule base, Fuzzy inference engine, Defuzzifier[8].

$$\mu[x]NICE = \begin{cases} 1; \leftarrow (x \le 0) \\ \dfrac{0.4-x}{0.4-0}; \leftarrow (0 < x < 0.4) \\ 0; \leftarrow (x \ge 0.4) \end{cases} \tag{3}$$

$$\mu[x]GOOD = \begin{cases} 0; \leftarrow x \le 0.078 \mid x \ge 1.34 \\ \dfrac{x-0.078}{0.205-0.078}; \leftarrow 0.078 < x < 0.205 \\ \dfrac{1.34-x}{1.34-0.838}; \leftarrow 0.838 < x < 1.34 \\ 1; \leftarrow 0.205 \le x \le 0.838 \end{cases} \tag{4}$$

$$\mu[x]BAD = \begin{cases} 0; \leftarrow x \le 0.5489 \\ \dfrac{x-0.5489}{1-0.5489}; \leftarrow 0.5489 < x < 1 \\ 1; \leftarrow x \ge 1 \end{cases} \tag{5}$$

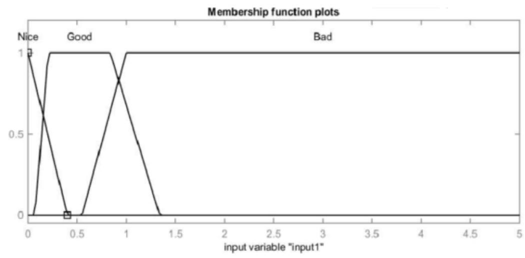

Fig. 3. A set of fuzzy for input

In output rules, membership function to determine area of the output PWM area configurated as follows:

$$\mu[x]LOW = \begin{cases} \dfrac{0.012-x}{0.012-0}; \leftarrow (0 < x < 0.012) \\ 0; \leftarrow (x \ge 0.012) \end{cases} \tag{6}$$

$$\mu[x]NORMAL = \begin{cases} 0; \leftarrow x \le 0.02513 \mid x \ge 0.7871 \\ \dfrac{x-0.2513}{0.3351-0.2513}; \leftarrow 0.2513 < x < 0.3351 \\ \dfrac{0.7871-x}{0.7871-0.5421}; \leftarrow 0.5421 < x < 0.7871 \\ 1; \leftarrow 0.3351 \le x \le 0.5421 \end{cases} \tag{7}$$

$$\mu[x]HIGH = \begin{cases} 0; \leftarrow x \le 0.0992 \\ \dfrac{x-0.0992}{0.95-0.0992}; \leftarrow 0.0992 < x < 95 \\ 1; \leftarrow x \ge 95 \end{cases} \tag{8}$$

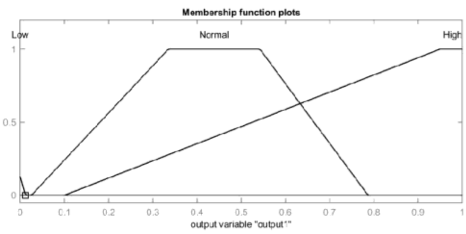

Fig. 4. A set of fuzzy for output

Rules of fuzzy logic using mamdani rule determine as follows:

1. If (SOC is Nice) then (PWM is Low)
2. If (SOC is Good) then (PWM is Normal)
3. If (SOC is Bad) then (PWM is High)

In this case, correlation either output and input membership function from every rules, drawn in surface graph represented as follows.

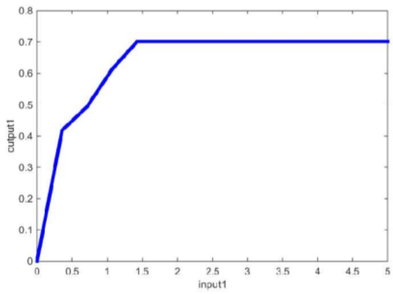

Fig. 5. Surface Output and input

Flowchart of the balancing strategy is shown in Figure 7

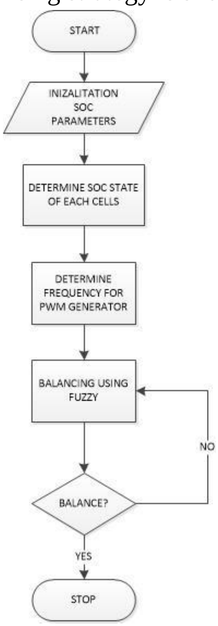

Fig. 6. *System FL-PWM Controlled Converter flowchart*

III. Result and Analysis

In this experiment, correlation between nominal frequency and optimization in balancing process was observed. Fast balancing in its operation and efficiency of the loss power that occur when balancing process influenced by nominal frequency on PWM output. In simulation, inductor with 1 mH with rate current is 2 Ampere has used. Figures below displayed the result which the characteristics can observe directly.

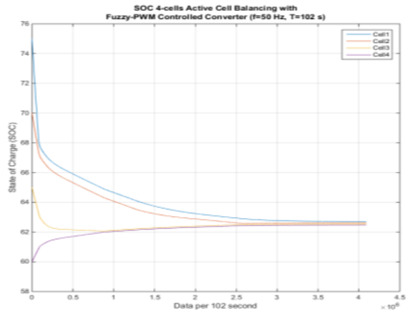

Fig. 7. **SOC balancing state in T= 102 s, f=50 Hz**

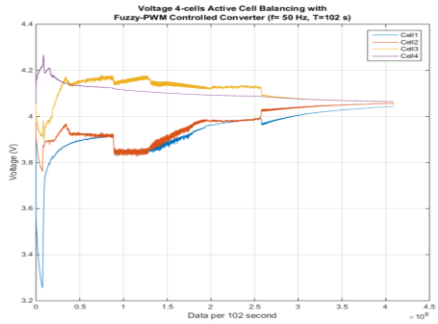

Fig. 8. **Voltage state in T=120 s, f=50 Hz**

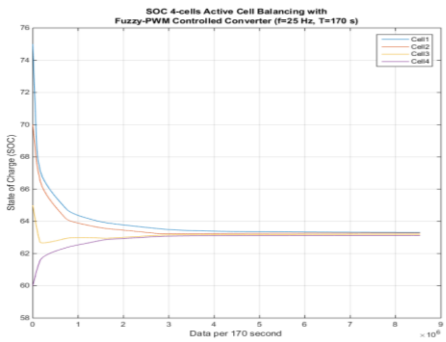

Fig. 9. **SOC balancing state in T= 170 s, f=100 Hz**

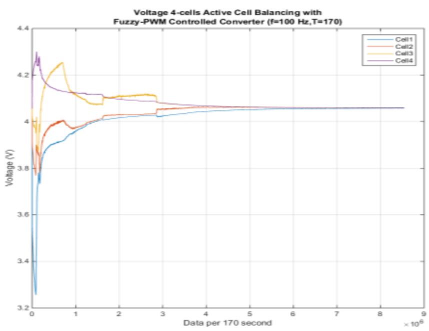

Fig. 10. **Voltage state in T=170 s, f=100 Hz**

From the result above, we can compare the calculation with avoiding the *Ploss* in all components in its balancing circuit with a simple mean of SOC calculation:

$$SOCtotal = \frac{SOCcell1 + SOCcell2 + SOCcell3 + SOCcell4}{4}$$
$$SOCtotal = 67.5\%$$

And we can determine the nominal of absolute error[9] of ideal nominal SOC that occur for each frequency as follows:

For f=50 Hz, we get:

$$SOCtotal = \frac{62.696 + 62.617 + 62.544 + 62.470}{4}$$
$$SOCtotal = 62.582\%$$
$$absolute\ error = \left|\frac{62.606 - 67.5}{67.5}\right| \times 100\% = 7.3\%$$

For f=100 Hz, we get:

$$SOCtotal = \frac{63.316 + 63.271 + 63.198 + 63.316}{4}$$
$$SOCtotal = 63.275\%$$
$$absolute\ error = \left|\frac{63.275 - 67.5}{67.5}\right| \times 100\% = 6.2\%$$

TABLE I. SOC and Voltage state at begin to end of simulation

variable name	initial value SOC(%) AND VOLTAGE (V)	f = 50 Hz, T = 102 s	f = 100 Hz, T = 170 s
		end value (%,V)	end value (%,V)
SOCcell1	75	62,696	63,316
SOCcell2	70	62,617	63,271
SOCcell3	65	62,544	63,198
SOCcell4	60	62,470	63,125
Vcell1	4,064	4,043	4,058
Vcell2	4,062	4,051	4,058
Vcell3	4,060	4,063	4,058
Vcell4	4,000	4,064	4,058

IV. CONCULISION

The main purpose balancing for unbalance cells capacity in battery pack using proposed method was successfully done. Absolute error by ideal SOC value for experiment by frequencies: 50 Hz and 100 Hz are 7.2% and 6.2%. In this experiment also describe correlation between nominal frequency produced by PWM generator related with performance and efficiency in balancing operation. It also shows positive trend of SOC absolute error by increasing nominal frequency in PWM generator. It made the average of SOC nominal is increasing but balancing term became slowly.

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