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Parallel Balancing Battery using Adaptive Power Sharing and ANN SOC Estimator

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***Abstract*—The battery balancing method is commonly used in cell circuits and battery circuits to maintain the power continuity on the DC Bus. The power continuity on the DC Bus is guaranteed if the load continues to get a power source, even if either the battery or power supply malfunctions. Besides, the battery balancing method is also used to protect the battery from excessive charging current pliers flowing into the battery. Therefore, the State-of-Charge (SoC) should be concern in balancing the maintained battery condition on both systems and avoiding overcharging. Artificial Neural Network (ANN) is used in this paper to determine the value of battery SoC. Based on simulations using MATLAB 2018, SoC values with ANN showed accurate results with error values below 0.1%. Based on the simulation results, the two batteries, which are arranged to have a difference of SoC value of 0.3%, will achieve a balanced SoC value for 28.45 seconds from the simulation.**

Keywords: ***artificial neural network, pararel balancing, state-of charge, overcharge***

***Abstrak*—Metode *battery balancing* biasanya digunakan pada rangkaian sel dan rangkaian baterai untuk menjaga kontinuitas daya pada Bus DC. Kontinuitas daya pada Bus DC terjamin jika beban tetap mendapatkan sumber listrik, meskipun baterai atau catu daya tidak berfungsi. Selain itu, metode *battery balancing* juga digunakan untuk melindungi baterai dari tang arus pengisian yang berlebihan yang mengalir ke baterai. Oleh karena itu, *State-of-Charge* (SoC) harus menjadi perhatian dalam menyeimbangkan kondisi baterai yang terjaga pada kedua sistem dan menghindari pengisian yang berlebihan. *Artificial Neural Network* (ANN) digunakan dalam makalah ini untuk menentukan nilai SoC baterai. Berdasarkan simulasi menggunakan MATLAB 2018, nilai SoC dengan ANN menunjukkan hasil yang akurat dengan nilai *error* di bawah 0,1%. Berdasarkan hasil simulasi, kedua baterai yang disusun memiliki selisih nilai SoC sebesar 0,3% akan mencapai nilai SoC yang seimbang selama 28,45 detik dari simulasi.**

Kata kunci: ***jaringan saraf tiruan, penyeimbangan pararel, state-of charge, overcharge***

I. Introduction

Batteries are one of the energy storage media that is reliable enough to be used in various industrial devices ranging from power supplies in communication systems, Uninterruptible Power Sources (UPS), electric vehicles to meeting electricity needs in space stations [1]. Problems that often arise in using batteries as the energy storage medium are how to keep the battery's service life so it would have a long service life. Besides, the issue of continuity of power in the system also becomes a paramount concern. Considering that the system must always be active even if one of the battery devices is faulty. It is essential to be a concern for some designs, such as power supply in underwater welding tools, and space explorers have cells that can not be repaired so that even if one battery is damaged, the system can still work well. Battery Management System (BMS) is needed to keep the battery's performance optimal even though it is used for a long time. According to[2], BMS has three main functions, protection, management, and balancing. Among the three functions above. Balancing is the most important because balancing can protect the battery to avoid Over-charge and Over-discharge, which causes short battery life.

Parallel balancing is the method that we are using in this paper. With this method, the continuity of power in the system can be more guaranteed. We use the Active Balancing method, which uses a bidirectional DC-DC converter to regulate the charging and battery consumption processes. This method has higher efficiency and has an easy control method[3].

The parameter used as a comparison value in balancing the two batteries is the battery's State of Charge (SOC) value. SOC is a percentage that represents the comparison between battery capacity and standard capacity. Various methods can be used to determine the SOC of a battery. The simplest method is the Open Circuit Test method, but the weakness of this method can only be used in open circuit conditions. The coulomb Counting method is a method that can be used to determine the SOC of a battery in a closed-circuit system. This method is easy to implement but requires data in the form of an initial

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SOC value (SOC0), which indicates the initial condition of the SOC at the beginning of the measurement[4]namely estimation of SOC. So it is expected that if the battery is connected to this system, then the SOC battery will always be monitored accurately.”,”container-title”:”2020 International Seminar on Intelligent Technology and Its Applications (ISITIA. Therefore, the estimation of the SOC value of the battery requires additional algorithms to determine its output value. It is necessary to apply machine learning with reliable computation capabilities to get accurate estimation results that can be done in real-time [5]. So that in this study, the Artificial Neural Network (ANN) method is used because this method is considered capable of solving nonlinear systems with a simple structural topology. In addition to requiring an accurate SOC estimation process, the battery balancing system also requires additional control methods, such as in this study [6], which requires an approach to regulate the converter’s work in distributing power to the battery and supplying power the load. However, among several studies regarding parallel balancing battery as in [7] and [8]. No one has yet discussed the method of protecting the battery from over-charging when the battery is in the charging process.

For this reason, this study will discuss the methods we use to provide additional protection to the battery to avoid over-charging. The method we propose is the Adaptive Power Sharing Method. This method works to optimize the balancing system between two Battery management systems (BMS). Besides, it is expected that this algorithm will improve battery durability and safety to increase battery life. According to the simulation result will achieve balanced result in 28.45 s after the system is started.

II. Literature Review

A. Balancing Battery

balancing is a method used to keep the charging status (SoC) of each cell in the battery balanced. This method balances charging current and voltage in multiple cells arranged in series or parallel [3].

Battery Balancing itself has the same function as Balancing cells, but the battery is the battery in balanced balancing. On the contrary, in Balancing Cell, the balanced is the arrangement of each cell in the battery. Battery Balancing serves more as Energy Balancing /Power Sharing than as a balance theory because of its function and working way. Based on the literature [1]. Energy Balancing works by making the power on the DC Bus an observation object. If the DC Bus is underpowered, then the battery as an Energy Storage Unit (ESU) will supply the DC Bus’s power shortage. On the other hand, if the power on the DC Bus is excessive, excess power will be channelled to the battery, or in other words, the battery will undergo a charging process.

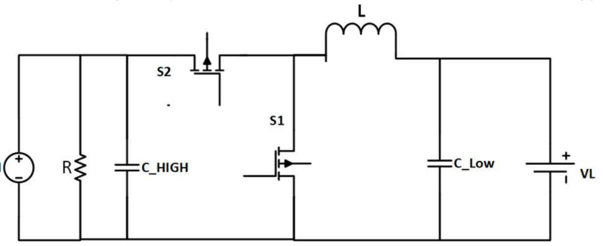

Fig. 1. Bidirectional converter topology circuit

In general, the Balancing Battery system consists of two parts. Battery Management System (BMS) and Power Converter System (PCS) [7]. BMS function is to balance the SoC battery circuit and adjust the output voltage. Meanwhile, PCS controls the converter’s performance and regulates the output current, power, and voltage. The balancing system will still work if there are only PCS circuits, but this type of circuit is not very suitable for decentralized microgrid systems.

B. Bidirectional Converter

The bidirectional DC-DC converter is one type of converter that can work in two directions, namely increasing and decreasing the voltage from the source side to the load and on the other side. Also able to drain power from the load side towards the source or the opposite direction. This converter is very suitable for using renewable energy systems (Renewable energy) and Microgrids [9]. Besides that, Bidirectional DC-DC converters are also applied in various fields such as Uninterruptable power supplies. (UPS), electric vehicles (Electric Vehicle) and also fuel cells [10].

Bidirectional DC-DC converters can be classified into two types, Non-Isolated and Isolated DC-DC converters. This final project will be using a Non-Isolated DC-DC converter because it has a topology and control scheme that is easier and can achieve higher efficiency[11]. The Topology of the Bidirectional converter can be seen in Fig. 1

The working principle of the Bidirectional DC-DC Converter can be divided into two [15], namely charging

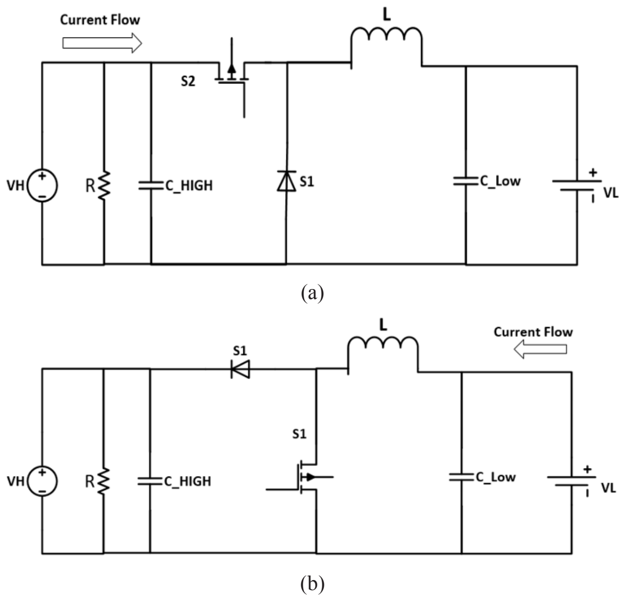

Fig. 2. Bidirectinal converter in (a) Boost Mode; (b) Buck Mode

mode (Buck mode) and discharging mode (Boost mode). When working in charging mode, the converter will drain power from the source to the battery by lowering the voltage from 48 V to 24 V. and vice versa when the battery is discharging. The converter will operate in boost mode, which will increase the voltage before entering the DC Bus. Both of the process can be seen in Fig. 2

C. ANN-Coulomb Counting SOC Estimator

In this paper, the coulomb counting method is used to determine the SOC value of the battery. Because it is pretty reliable in reading the SOC value when the battery is in a state of charging or discharging[12]. The equations used in the coulomb counting method include,

$$SoC = SoC_{(t0)} + \frac{Ah(T)}{Q_{rate}} \times 100\%, \quad (1)$$

Ah, value can be known through the current sensor readings. However, it is not possible to determine the initial SOC value (by direct measurement. Thus, in this paper, Artificial Neural Networks (ANN) is used to determine the value of (batteries. This method was chosen because it does not require physical battery data such as internal resistance and capacity. This method works by describing the relationship between the SOC and some measurable battery parameters[13]with the aim of better managing their use, due to the high changes in the electric vehicle dynamics and operational modes, which could cause severe damages to the battery if not properly managed. Recently lithium-ion (Li-ion. This paper will use the Feed-forward Neural Network (FFNN) algorithm model because this algorithm has a high estimation ability. After several simulations, the ANN structure is obtained, used as a SOC Estimator[14].

Table 1. Parameter of Bidirectional Converter

Parameter	Symbol	Value	Unit
Inductor	L	418,56	"μH"
Capacitor low voltage	C_{low}	270	"μF"
Capacitor high voltage	C_{high}	470	"μF"
Battery Voltage	V_o	24	V
DC Bus Voltage	V_{in}	48	V
Battery current	I_O	10	A
Resistance Load (discharge mode)	R	24	Ω
Battery Load (charge mode)	R	0.0018	Ω

III. Design and Method

The state-of-charge balancing battery range consists of two lead-acid batteries (ACLs) with a capacity of 45Ah - 24V. This battery is connected with Buck-Boost Bidirectional DC-DC Converter. This converter is used as a power converter to lower the charging voltage in buck mode from DC Bus to the battery and increase dc bus supply is the usage voltage in Boost mode. DC power supply will be used as the voltage source with limited voltage only 48 V. The diagram block of the system can

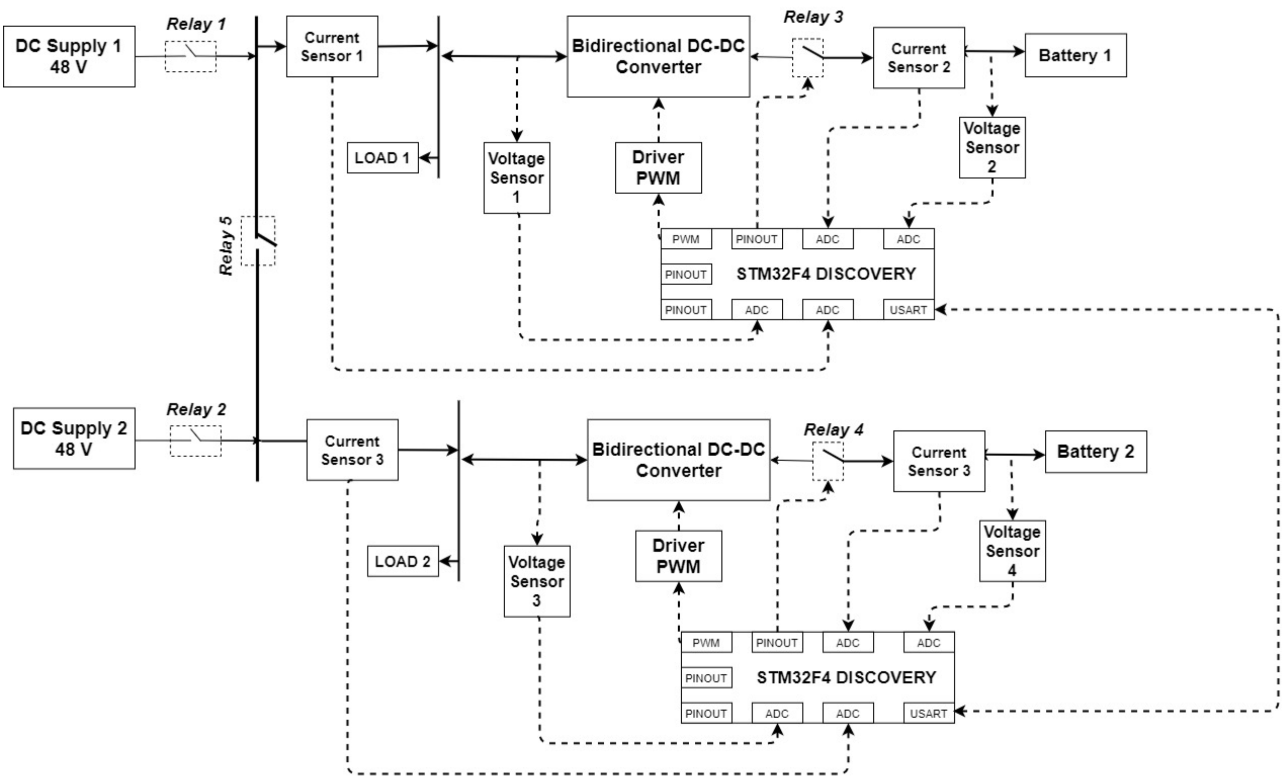

Fig. 3. Block diagram of the system

be seen in Fig. 3.

The analysis of the circuit work is done by simulation using MATLAB / SIMULINK software. The Pararel Balancing Circuit can be seen in Fig. 4. The simulation design stages include designing a bidirectional DC-DC converter, creating an ANN algorithm, and designing an Adaptive Power Sharing algorithm.

A. Designing Bidirectional DC-DC Converter

The bidirectional DC-DC converter used has a Buck-Boost Converter type. One side of the converter has a function like a buck converter, which can lower the voltage, while on the other hand, it works like a boost converter, which increases the voltage. It will meet the dc load's needs to determine the component parameters we want to use on the boost side.

The equation will be

$$D = 1 - \frac{V_L}{V_H}. \tag{2}$$

This duty cycle will be used to determine the average current flowing in the inductor , Thus becoming :

$$I_{L(avg)} = \frac{V_L}{(1-D)^2 \times R}, \tag{3}$$

after the value is obtained, To determine the inductance of the inductor used, it can be determined through (4):

$$L = \left[\frac{1}{f}\right] \times \left[V_H + V_f - V_L\right] \times \left[\frac{V_L}{V_H + V_f}\right] \times \left[\frac{1}{\Delta I_L}\right]. \tag{4}$$

Determine the capacitor need in the high voltage side can be determined through (5) :

$$C_{high} = \frac{V_H \times D}{R \times \Delta V_O \times f}. \tag{5}$$

Meanwhile, to determine the capacitor need in the low voltage side, it can be determined through (6):

$$C_{low} = \frac{\Delta i_L}{8 \times f \times \Delta V_O}. \tag{6}$$

Based on the results of the calculations that have been done, several parameters of the Bidirectional DC-DC Converter used in this study were obtained in Table 1.

B. Designing Adaptive Power Sharing Algorithm

The adaptive power-sharing algorithm is an algorithm used to adjust the Bidirectional DC-DC Converter's working mode. Setting the operating mode is done by setting which relays are in ON and OFF condition. When the relay on the input side is ON, the converter works in buck mode, charging into the battery. Meanwhile, if the relay on the input side is in the Off condition, the converter boosts working mode, which means that the battery discharges to the load. In addition to adjusting the converter's operating mode, this algorithm also protects the battery from overcharge and over-discharge by adjusting the relay work on its output side. The parameter used in regulating when the relay works in On or off conditions, both on the converter's input and output side, is the SoC reading value. In this research, a relay is used in this project to regulate the PCS circuit's performance. There are six relays used on this system; Relay 1 and Relay 2 are placed on PCS 1, consisting of 1 converter and one battery. Each relay is placed on the converter's input and output, while Relay 3 and Relay 4 are set on PCS 2. Relay 5, a connecting relay between two systems, is placed in a series between the two PCS.

C. Designing Artificial Neural Network (ANN)

ANN testing to determine SOC (t0) in coulomb counting was carried out using MATLAB, namely NNtool.

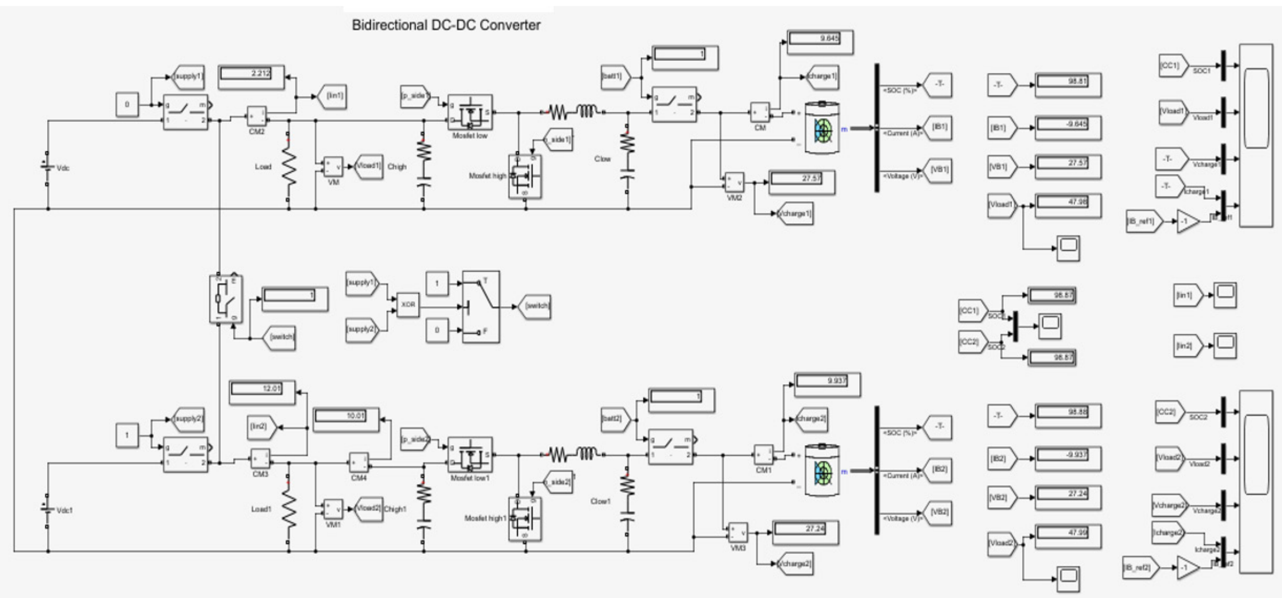

Fig. 4. Pararel balancing SIMULINK circuit

NNtool is

used to carry out the learning process. The data used in the ANN learning process are the battery voltage (VB) as the input and the SOC of the battery as the output. The battery voltage used as input is 17.03 - 26,179 V. VB and SOC data when the battery is open and obtained through battery simulation using MATLAB. The simulation is done by changing the SOC value of the battery with a charge of 1%. Then the simulation is run to get the value of the battery voltage when it is open circuit. Fig. 5 shows the ANN SOC structure consisting of 1 input, namely battery voltage (VB), ten hidden layers, and one output, namely SOC.

From the learning results, it can be seen that the learning process is accurate. It can be seen in Fig. 6 that the data is already on a diagonal line. Training has an R-value of 1, Validation of R-value of 1, and on Test, R's value is also 1. The All section is a combination of Training, Validation, and Test. The value of R is also 1. The more the R-value approaches 1, the more ANN results accurately.

Figure 7 shows that the performance of the ANN learning outcomes has a value of 0.006563 on the iteration (epoch) to 0. From the regression results and performance, it can be ascertained that the training results are good enough. To ensure that the learning process is good, The ANN will be tested in simulations using the Simulink feature. Based on the simulation results, At a battery voltage of 24.24 V when the battery is open circuit, the SOC value read on the SOC display feature is 70%, while the test using ANN algorithm reads 69.98%.

IV. Simulation Study

The simulation was conducted by connecting two sets of PCS connected to a parallelly arranged battery, as illustrated in Fig. 6. The switch is also used in a series of simulations to set the operational mode of the system. The simulation was conducted in 100s with a difference in SOC value in both batteries are 0.3%. Integration simulation was performed with SOC difference in both batteries by 0.3% due to long simulation time constraints. The simulation was conducted by connecting two sets of PCS connected to a parallelly arranged battery. The switch is also used in a series of simulations to set the operational mode of the system. The simulation was conducted in 100s with a difference in SOC value in both batteries are 0.3% due to long simulation time constraints. From the simulation results that have been done, the system can balance the battery SOC only when the SOC on battery 1 is lower than the SOC on battery two because it is constrained to the determination of both batteries initial SOC. The initial SOC of both batteries. SOCs on higher batteries work in discharging mode, while SOCs on lower batteries work in charging mode. When the SOC on both batteries is balanced, both batteries work in charging mode when there is a source on one of the bidirectional systems. If there is only a source on one of the bidirectional systems, the 2-system connect switch is connected. The charging process stops when the SOC on both batteries reaches 99%, and the switch on the battery is disconnected to avoid overcharging. The switches on the battery will reconnect when the source on both systems is off.

SOCs on higher batteries work in discharging mode, while SOCs on lower batteries work in charging mode. When the SOC on both batteries is balanced, both batteries work in charging mode when there is a source on one of the bidirectional systems. If there is only a source on one of the bidirectional systems, the 2-system connect switch is connected. The charging process stops when the SOC on both batteries reaches 99%, and the switch on the battery is disconnected to avoid overcharging. The switches on the battery will reconnect when the source on both systems is off. The parameters used in the battery balancing simulation can be observed in Table 2.

Table 2. Simulation parameters

Parameter	Symbol	Value	Unit
Initial SoC of Battery 1	SOC_1	98.5	%
Initial SoC of Battery 2	SOC_2	98.8	%
Battery Capacity	C_{bat}	45	Ah
Battery Voltage	V_{bat}	24	V
DC Bus Voltage	V_{load}	48	V
Resistance Load	R	24	Ω
Demand Power	P_{load}	96	W
Converter power rating	P_{max}	240	W

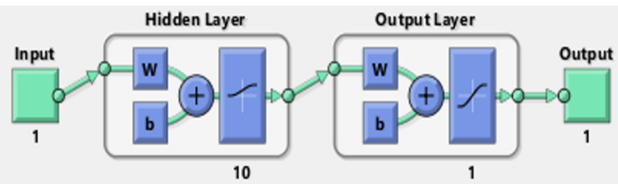

Fig. 5. ANN SOC structure

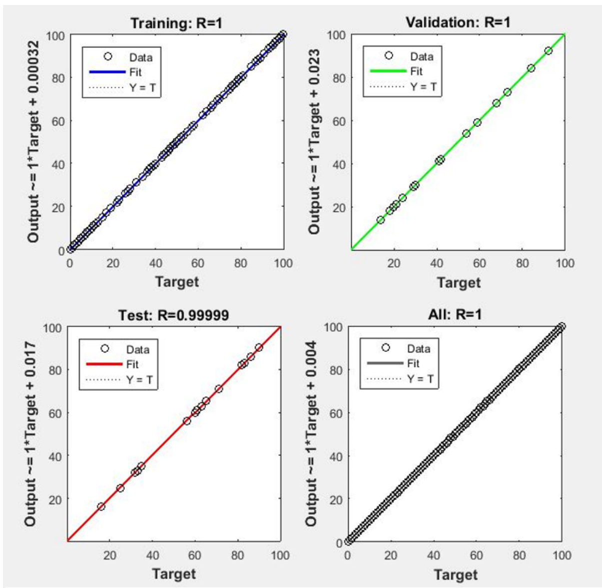

Fig. 6. Regression training, validation, test and all

The simulation process is carried out into four phases as follow:

1. Conditions when the SOC battery is not balanced (System 1 Charging, System 2 Discharging)

In the initial condition, battery 1, which has a SOC value lower than battery 2, will perform the charging process. Relay 1 will be OFF, so PCS 1 does not get dc supply from the power supply, and Relay 2 will be on so that the current from supply 48V can flow towards the battery. Charging current on Battery 1 is obtained from the second PCS, which at this stage Relay 3,4 and 5 are conditioned to be on so that Battery 2 can supply current to load 2. At this stage, battery 2 undergoes discharging process. Based on observations with scopes such as Fig. 9, this was charging and discharging cycle will stop when the SOC of both batteries has reached a balanced point. The SOC value equilibrium is achieved at 98.872% in 28,45s; After the two SOCs have been balanced, the following two batteries will simultaneously work in the charging mode. The current and voltage read on the side of PCS 1 do not show a significant increase, as illustrated in the picture below. The PI controller's addition as a current controller can reduce the number of spikes that appear when switching from charging mode to discharging, as shown in Fig. 7.

In Fig. 10, PCS 2, initially operated in discharging mode, switches to charging mode at 29.95s, from current's battery by -4,909 and rises to 10.76 A with a current spike appears by 18.57 during 0.002s. Negatively marked current indicates the current flow flowing out of the battery so that the battery can be said to be in discharging mode. In contrast, if the current is of positive value, then there is a current flow that enters the battery, or in other words, the battery in the charging process. The charging voltage on the battery increased from the original 24.43 V to 26.07 V during the 1.53s. Current and voltage charging on the pcs1 side still shows constant signs without any significant increase, as attached in Fig. 10.

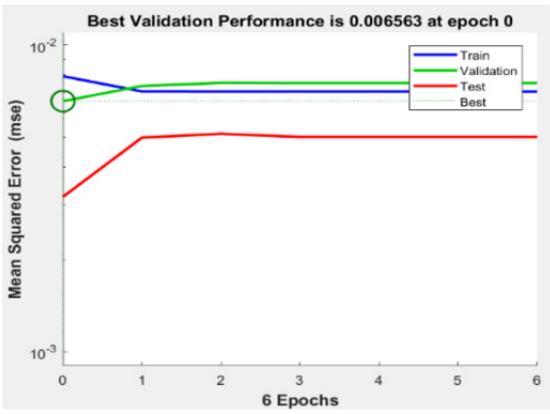

Fig. 7. Performance of ANN

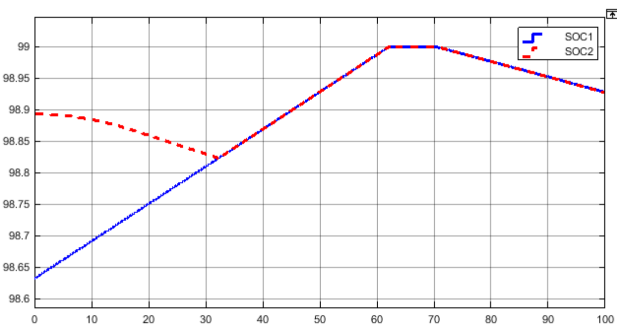

Fig. 8. Soc value comparison of two batteries

2. Charging Conditions on Both Systems

Both batteries are charging at the same time after reaching the balance point. Based on Fig. 9, this charging condition lasts for 28.45s since both batteries are in a balancing position. The charging process will stop when both soc batteries have reached the maximum soc limit determined when the battery SOC has reached above 99%.

The charging process on both batteries can still occur even if one of the voltage sources is OFF. In this condition, the voltage source on system 1 is disabled so that Relay 1 is off, while Relay 5, which serves as a link between the

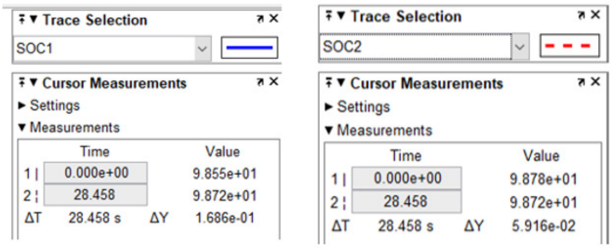

Fig. 9. Balancing phase of both batteries with the difference SoC = 0.3%

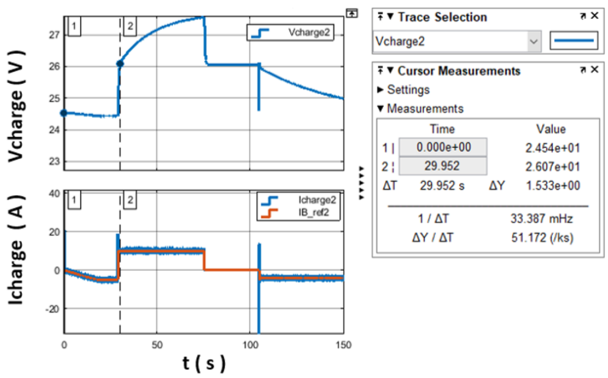

Fig. 10. Graph switching current and voltage charging the battery on PCS 2

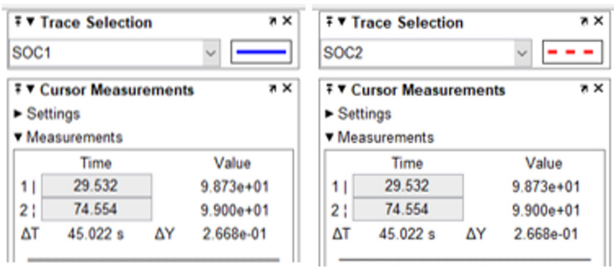

Fig. 11. The second phase of the battery balancing process when in charging mode

two systems, is on condition, so PCS 1 still gets power flow from the voltage source on the side of system 2. In both of these conditions, the power emitted by the power supply reaches 672 W (48 V, 14 A) because it has to supply both systems. Each system drains 336 W of power with details of 96 W (48 V, 2 A) flowing to Load and 240 W (24 V, 10 A) flowing to the battery.

3. The condition when the second SOC battery has approached the maximum limit value (SOC < 99%)

This third condition occurs when both batteries have exceeded the specified SOC upper limit of 99%). In this condition, the relay on the battery side, Relay 2 and Relay 4, will be in an OFF state, thus preventing the battery from charging and discharging. Both battery SOCs are stable, with neither addition nor reduction, as shown in Fig. 12.

In this part, the current flowing on the battery will drop drastically to 0 A. It is because Relay 2 and Relay 4 serve to disconnect the current flow on the battery when the battery SOC has exceeded the specified safe limit, as shown in Fig. 13, which the image (a) The voltage and charging current in PCS 1, while image (b) refers to the voltage and current in PCS 2. Although both PCS's current value is worth 0A, the same is not the case with battery-side voltages on both PCS, where the voltage of both batteries only drops to 26 V before constantly moving at the same number.

4. Discharging condition on both systems

The last condition is when both batteries work in discharging mode. On system 1, when Relay 1 and Relay 3 are OFF, Relay 2 and Relay 4 will be back in the ON position, so in this condition, Bidirectional DC-DC Converter 1 and 2 will work in boost mode (discharging). Battery 1 will be discharging to supply Load 1, while Battery 2 will be discharging to supply Load 2.

The power flowing from Battery 1 is 96W (24V, 4A), which is then converted by Bidirectional DC-

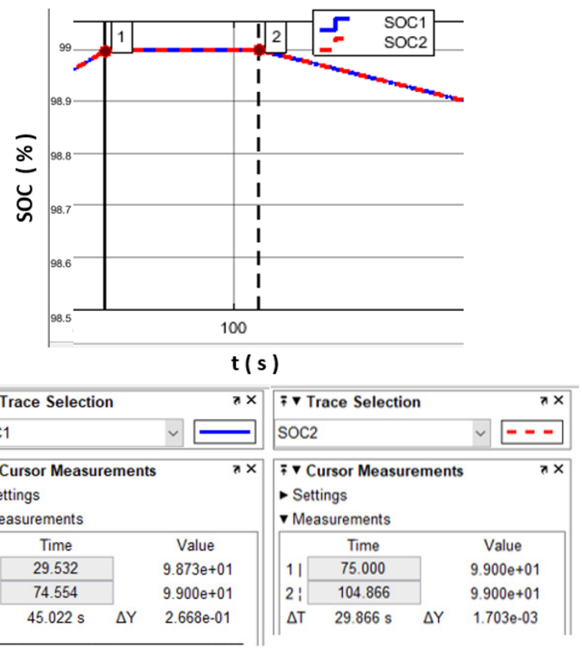

Fig. 12. The phase when both batteries pass the upper limit SOC (SOC < 99%)

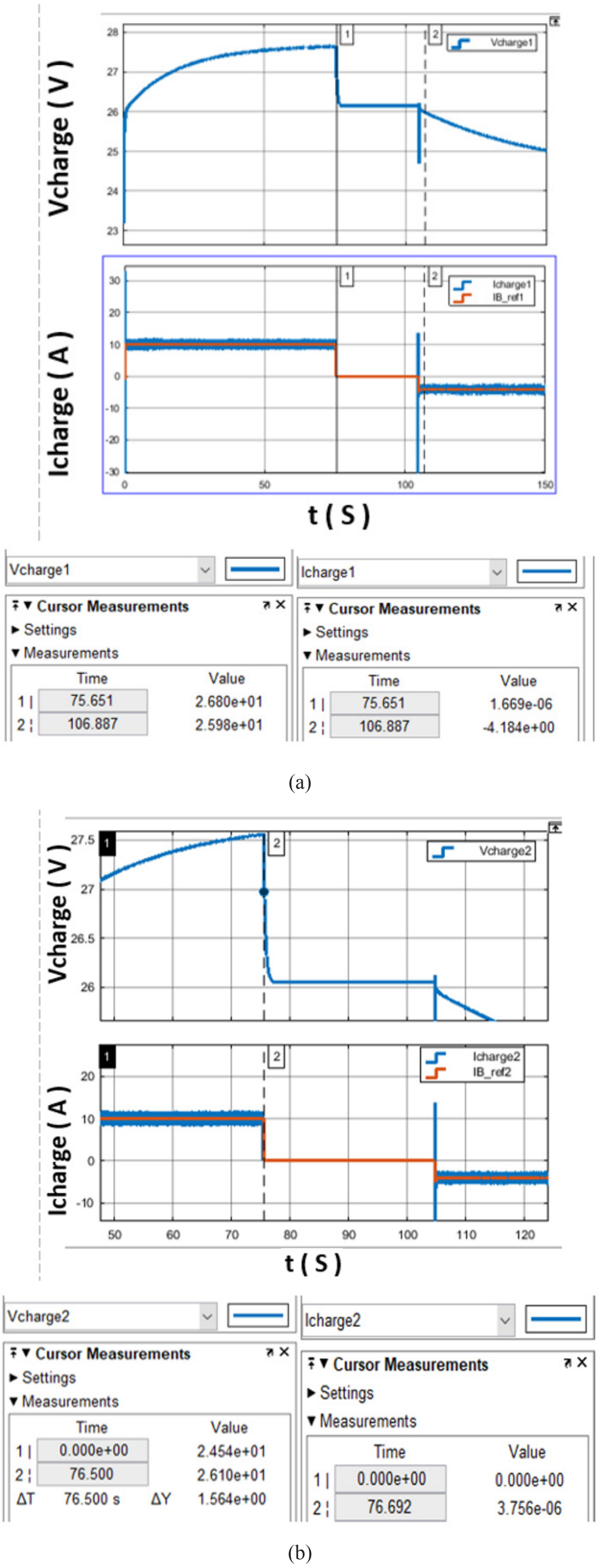

Fig. 13. Current and voltage supply when Soc both batteries reach 99% (a) Current and voltage on PCS1; (b) Current and voltage on PCS2

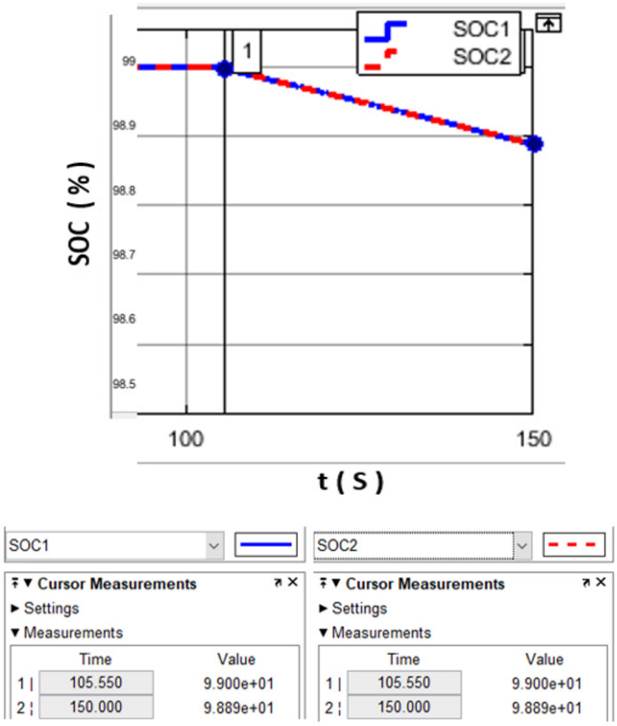

Fig. 14. Discharging conditions on both systems

DC Converter 1 boost mode to 96W (48V, 2A) to supply Load 1, 96W (48V, 2A). The SOC drop graph on both batteries can be observed in Fig. 12. In the 2nd system, the power flowing is the same as the first system because system 2 has the same parameters (supply, bidirectional DC-DC converter, battery, and load) as system 1.

Fig. 14 above shows a graph of current and voltage switching when both PCS. are in discharging mode. Based on the graph above, the current will be negative. This value indicates the flow of the current issued by the battery to load. The flowing current value of 5 A then moves constantly until the simulation ends. As for the battery, a voltage appears to spike when Relay 1 switches to OFF mode. The voltage spike occurs in the duration of 0.002s with the spike at 25.9 V, then down to 24.5 V before the voltage gradually dropped. All data from the simulation results can be observed in table 4. The table below shows SoC's comparison SoC data of the two batteries every 10s interval, accompanied by the voltage on the load side and the battery charging current.

V. Conclusion

Balancing simulation results from adaptive power-sharing methods can provide additional protection from excess costs on the battery. The simulation results for 150 s can be observed in Table 3. Based on the simulation results, The charging system will automatically stop when both batteries' Soc has reached a value of 99%. In the second study, the battery achieved a balanced SOC value in 28.45 seconds when the difference between the two SOCs was at 0.3%. The difference between the two batteries used is still relatively small due to MATLAB simulation time that takes a long time. The balancing system can perform the balancing process with the difference between the two larger batteries and achieve a faster balancing process for further development.

Table 3. Parallel balancing battery data simulation

T(S)	SOC1 (%)	SOC2 (%)	$I_{CHARGE1}$ (A)	$I_{CHARGE2}$ (A)	V_{LOAD1} (V)	V_{LOAD2} (V)
0	98.63	98.9	0	0	0	0
15	98.69	98.85	9.137	-3.564	47.99	47.99
30	98.72	98.72	10.69	-4.852	47.97	47.96
45	98.81	98.81	9.002	8.991	47.99	47.97
60	98.87	98.87	9.903	9.727	47.98	47.99
75	98.93	98.93	10.07	10.66	47.96	48.08
90	99	99	0	0	47.99	47.99
105	99	99	0	0	47.99	47.99
120	98.9	98.9	-3.815	-4.051	48.06	48.1
135	98.95	98.95	-4.385	-3.517	48.01	47.98
150	98.9	98.9	-3.667	-3.542	48.02	47.93

Reference

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