Indonesian Journal of Electrical Engineering and Computer Science
Vol. 5, No. 3, March 2017, pp. 508 ~ 514
DOI: 10.11591/ijeecs.v5.i3.pp508-514

Battery Charge Control by State of Health Estimation

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Abstract

Battery lifetime is one of importance consideration in smart system with energy storage system, because it is shorter than others. Extended of battery lifetime can give benefit to entire system, especially to reduce cost. The lifetime is commonly estimated by State of Health (SOH). Decreasing of SOH indicates degradation of battery. It can be influenced by the battery operation, so that operational management is needed. This study proposes control block for charging battery by using decreasing value of SOH as reference. The control block is implemented in battery system that connected to DC bus by bidirectional chopper. Numerical simulation study is performed by using PSIM software version 10.0. The result shows that the proposed block control is successfully used. Moreover, the relative error is less than 2% for delta SOH and less than 1% for battery power.

Keywords*: Battery, charge control, battery lifetime, state of health, bidirectional chopper*

1. Introduction

Electricity demand increases day by day. Concerning about carbon emission and global warming pumps up the need of sustainable sources such as photovoltaic (PV). It also may change the people lifestyle [1]. Recently, smart systems such as smart house and smart building are becoming more and more popular. It is necessary to use storage system such as battery for managing peak demand and improving reability of the system [2]. It makes the used of battery increase.

Battery has shorter lifetime compare to other parts in system [3]. When reached its end-of-life (EOL), the battery needs to be replaced. Generally, the limit is set to 80% of nominal capacity [4]. If there are many changes of battery along the whole system lifetime, it can increase total investment cost. Degradation of battery depends on its operation which can be influenced by the operational management [5]. Several studies proposed method to extend battery lifetime, such as optimization based on life loss cost [6] and replacement cost [7].

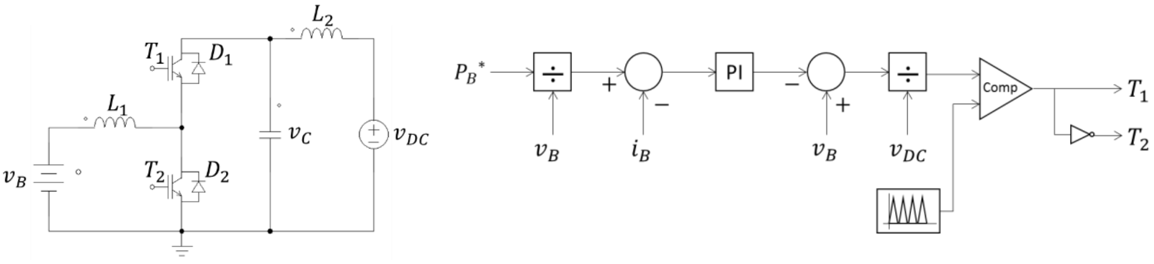
State of Health (SOH) is commonly used for estimating battery lifetime. There are several indications that can be used to evaluate SOH, such as series resistance [8], capability of storing energy [9], and restriction of cycle number. This paper proposes additional block control which is using decreasing of SOH as reference. Aim of this block is to control the battery power and manage battery lifetime, all at one. Further, it can be used for more advanced optimization charge control, such as to extend battery lifetime or optimize investment and operational cost.

2. Battery Control Method

Bidirectional chopper circuit is used for charging and discharging the battery as shown in Figure 1 (a). The power control block, as shown in Figure 1 (b), use battery power reference ($P_B{}^*$) value command as a reference value and, current-loop and voltage-loop as feedbacks [10] which are used to achieve constant load voltage. By adjusting duty cycle of switch T_1 and T_2, amount of charge or discharge power can be controlled. The duty cycle is the comparison of the desired battery voltage, $v_B{}^*$ and dc bus voltage, v_{DC}. This paper proposed additional block control which is using decreasing of SOH as reference. In this section, the proposed control method will be explained.

Received December 2, 2016; Revised February 1, 2017; Accepted February 17, 2017

New battery is indicated by SOH value equal to 1, and battery reached the end of life is indicated by SOH value equal to 0. Energy-throughput based of SOH estimation is chosen here. We define (1) to calculate SOH at $t + \Delta t$.



(a) (b)

Figure 1. Bidirectional chopper (a) circuit and (b) control block for the battery

$$SOH(t + \Delta t) = SOH(t) - \frac{1}{2 \cdot N \cdot Q_{new}} \cdot \int_{t}^{t+\Delta t} \frac{|P_B(\tau)|}{3600} d\tau \tag{1}$$

Where, t indicates time in second, $SOH(0)$ indicates battery state of health initial value, N is a total number of cycles before end-of-life, Q_{new} is initial energy capacity of the new battery in kWh, and $P_B(t)$ is charge or discharge power of battery at time t in kW. In order to distinguish charge and discharge condition, positive value is defined as discharge power and negative value is defined as charge power. Generally, value of N is not constant. It depends on battery operating condition [11]. However, in order to keep the simplicity of this study, value of N is assumed to be constant.

Equation (2) shows that the value of SOH always decrease time by time. For simplicity in calculation, decreasing value of SOH, $\Delta SOH(t + \Delta t)$, is defined by (3).

$$SOH(t + \Delta t) - SOH(t) = -\frac{1}{2 \cdot N \cdot Q_{new}} \cdot \int_{t}^{t+\Delta t} \frac{|P_B(\tau)|}{3600} d\tau \tag{2}$$

$$\Delta SOH(t + \Delta t) = \frac{1}{2 \cdot N \cdot Q_{new}} \cdot \int_{t}^{t+\Delta t} \frac{|P_B(\tau)|}{3600} d\tau \tag{3}$$

By time discretization, equation (4) can be derived from (3) for calculating P_B along period of Δt. Here, reference of battery power can be driven by desired decreasing value of SOH. However, other command is necessary to decide the battery flow, whether to charge or discharge. This command is defined by $P_{B,flow}$ as shown in (5), where positive value for discharging and negative value for charging.

$$|P_B(t)| = \frac{2 \cdot N \cdot Q_{new} \cdot 3600 \cdot \Delta SOH(t+\Delta t)}{\Delta t} \tag{4}$$

$$P_{B,flow} = \begin{cases} +1, & for\ discharging \\ -1, & for\ charging \end{cases} \tag{5}$$

In order to control the battery charging and discharging process by using decreasing value of SOH as reference, an additional calculation block is proposed as shown in Figure 2. The function of this block is to calculate the value of $P_B{}^*$. The calculation block is defined by referring to (4) and (5). Figure 3 shows the detail calculation of the additional block. This block will calculate battery power reference value based on desired value of ΔSOH, Δt, and $P_{B,flow}$. The value of $P_B{}^*$ is determined by how much SOH is allowed to decrease along period of Δt. While $P_{B,flow}$ gives command for the direction of power flow, which is to charge or discharge?

For evaluating the proposed control block, measured voltage and current of the battery is used for calculating instantaneous value of P_B. Then this value is used for calculating the estimation of decreasing SOH by modifying (4).

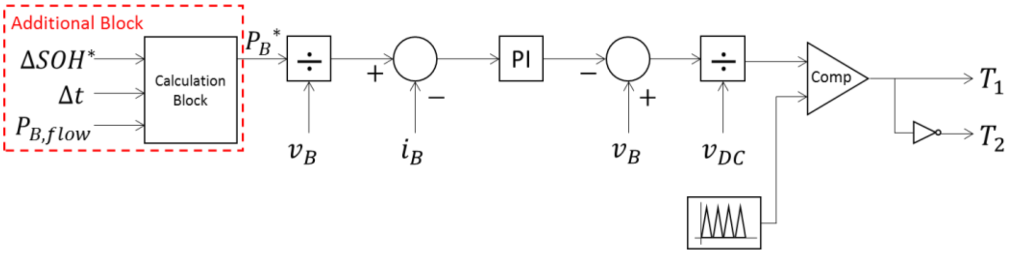


Figure 2. Control block with SOH calculation block

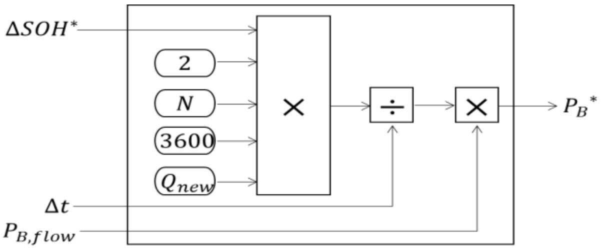


Figure 3. Detailed of additional block

3. Simulations and Results

In order to validate the performance of the proposed design, following simulation procedure is used. Battery system as shown in Figure 4 is built by using PSIM software 64-bit Version 10.0. In this system, lithium ion battery model is adopted then connected to DC bus by bidirectional converter. Parameter of battery is shown by Table 1. Whole system parameter is shown by Table 2. Bidirectional converter is used to charge and discharge the battery, which is controlled by switch $T1$ and $T2$.

Figure 5 depicts the battery charge control block that gives the command to by switch $T1$ and $T2$. Input values of ΔSOH, Δt, and $P_{B,flow}$ are entered to generate battery power reference. The measured values of battery voltage, vb and current, ib are used for feedback loops. Proportional-Integral (PI) controller is setted with gain 10 and time constant 0.1. The control block will generate signal reference to control the switches in bidirectional converter. The block may generate control signal that makes the circuit produce the current higher than rating capacity. In order to avoid this higher current flow through the circuit, a current limiter is added in the control block. For the numerical simulation, total number of cycles before end-of-life is assumed to be 4000 cycles. Initial energy capacity of the new battery in total is 4800 kWh. For evaluating the proposed control block, calculation block in Figure 6 is used. This block will calculate the actual estimation of SOH by using actual output of battery power which is obtained from measured values of battery voltage, vb and current, ib.

Three cases of delta SOH reference value (as shown in Table 3) are demonstrated for each operating condition, charge and discharge. This delta SOH reference value is claimed as decreasing amount of SOH along simulation duration, which is 60 seconds. The simulation is done in computer with Intel® Core™ i5-6500 CPU @ 3.20GHz processor and 4 GB RAM. Each simulation takes around 45 minutes to simulate 60 seconds of operation.

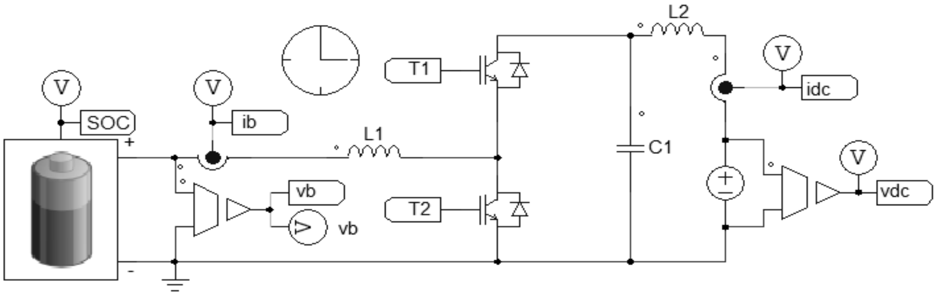


Figure 4. Simulation circuit

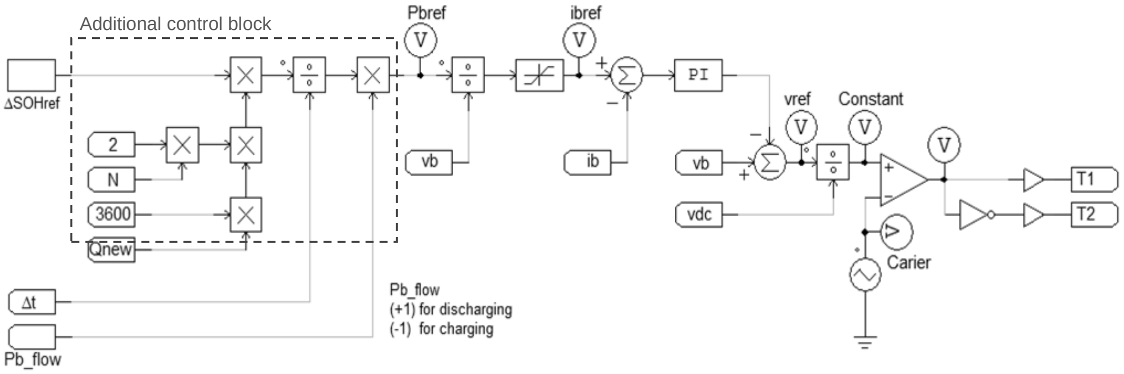


Figure 5. Charge control block

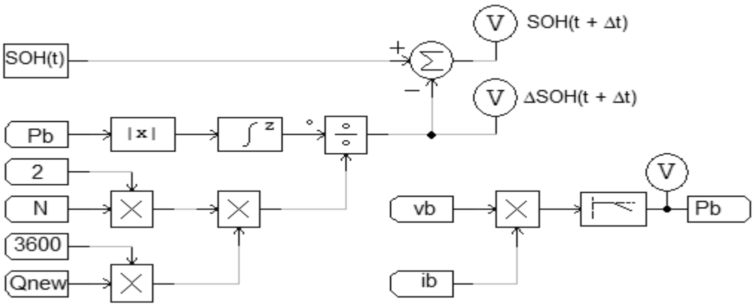


Figure 6. Actual battery power and SOH calculation block

Table 1. Battery Parameter

Parameter	Value	Unit
Rated voltage	48	V
Discharge cut-off voltage	32	V
Rated capacity	20	Ah
Internal resistance	0.05	Ohm
Full voltage	57.6	V
Exponential point voltage	54	V
Nominal voltage	51.2	V
Maximum capacity	24	Ah
Exponential point capacity	5	Ah
Nominal capacity	22	Ah
Initial SOC	80%	

Table 2. System Parameter

Parameter	Value	Unit
L_1	4	mH
L_2	0.1	mH
C_1	4000	μF
DC bus voltage	400	V
Number of batteries in series	4	

Table 3. Value of Delta SOH Reference

Case	ΔSOH^*
Case 1	0.5×10^{-6}
Case 2	1.0×10^{-6}
Case 3	1.5×10^{-6}

Simulation results are shown for battery conditions, discharging (Figure 7) and charging (Figure 8) conditions. These plots show that the proposed additional block control is successful to control discharging and charging power output by using decreasing of SOH as reference. Greater allocated value of delta SOH obtains higher power discharge or charge amount as expected.

Table 4 and Table 5 present comparison between the relative error for delta SOH and battery power in discharge and charge condition. The relative error is calculated by using (6). Measured value for delta SOH is the value in the end of simulation, and for battery power is the average value in steady state (in this study, it is assumed start from 50 ms).

$$relative\ error = \left|\frac{measured - reference}{measured}\right| \qquad (6)$$

Table 4. Relative Error for Delta SOH

Case	Discharge			Charge		
	ΔSOH^*	ΔSOH	error	ΔSOH^*	ΔSOH	error
Case 1	0.5×10^{-6}	0.509×10^{-6}	1.72%	0.5×10^{-6}	0.491×10^{-6}	1.83%
Case 2	1.0×10^{-6}	0.991×10^{-6}	0.91%	1.0×10^{-6}	0.991×10^{-6}	0.91%
Case 3	1.5×10^{-6}	1.509×10^{-6}	0.57%	1.5×10^{-6}	1.491×10^{-6}	0.61%

Table 5. Relative Error for Battery Power

Case	Discharge			Charge		
	$P_{B,ref}$ (W)	$P_{B,ave}$ (W)	error	$P_{B,ref}$ (W)	$P_{B,ave}$ (W)	error
Case 1	1,152	1,162	0.83%	−1,152	−1,142	0.84%
Case 2	2,304	2,314	0.41%	−2,304	−2,294	0.42%
Case 3	3,456	3,466	0.27%	−3,456	−3,446	0.28%

There is no significant different of relative error value between discharging and charging condition, both in delta SOH and Battery power. In these cases, value of relative error is less than 2% for delta SOH and less than 1% for battery power. Besides the decreasing trend of error value is seen in quadratic trend with increasing of delta SOH. The changing conditions of discharge-to-charge, and vice versa are also simulated, but only for case 1 is shown Figure 9. These figures show that the proposed control block is also successfully used to control the system. When the command changed from discharge to charge, current fluctuated less than 150 ms, and power fluctuated around 50 ms.

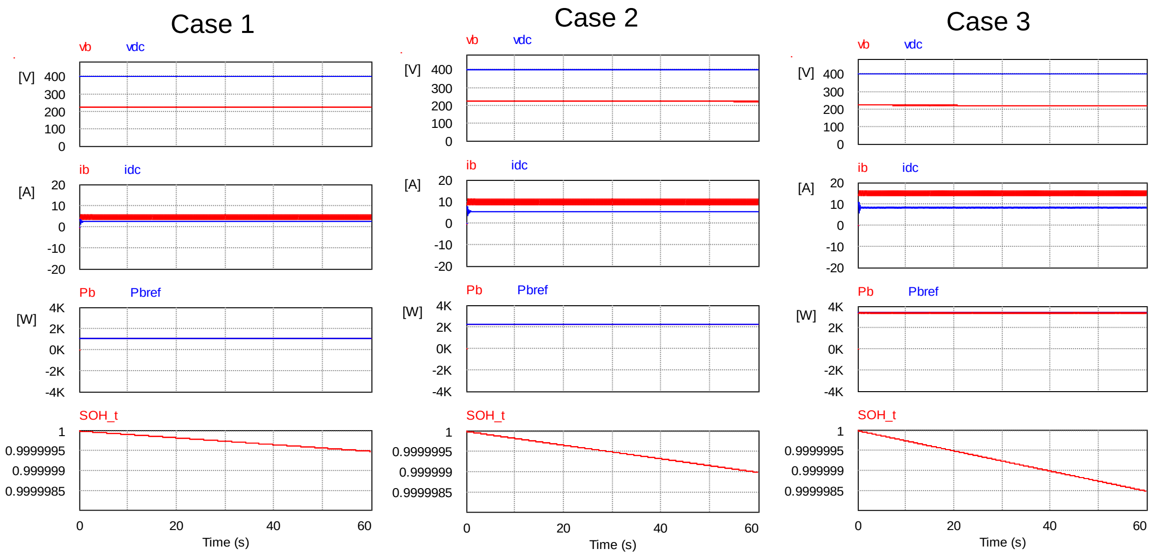


Figure 7. Simulation result for discharging condition

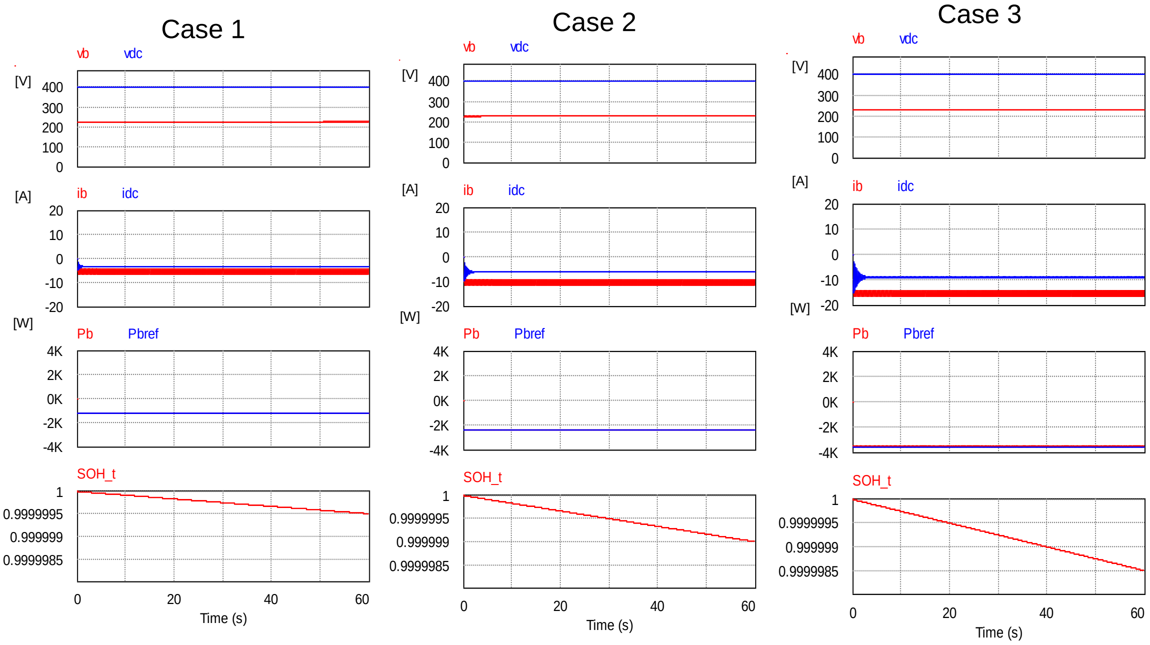
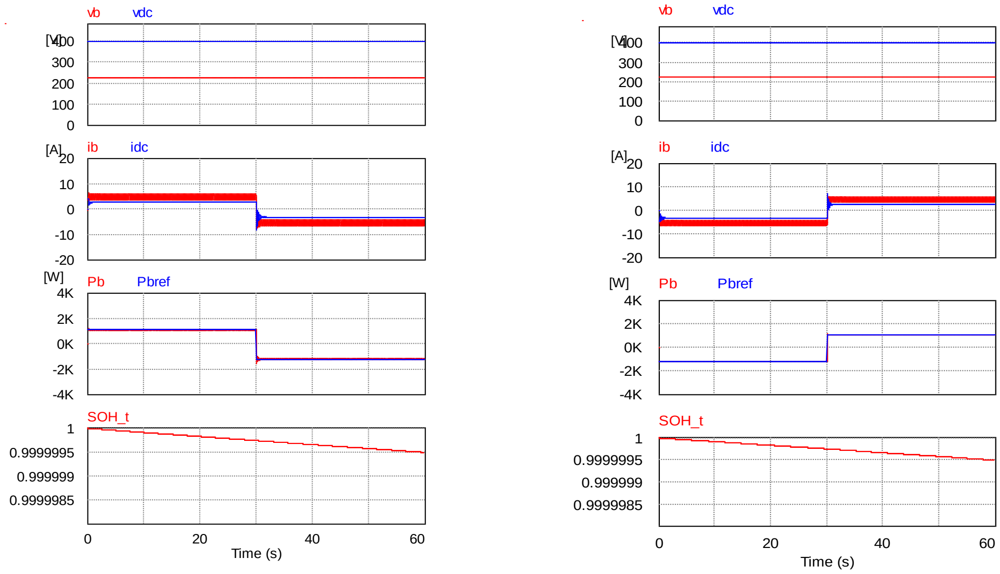


Figure 8. Simulation result for charging condition



(a) (b)

Figure 9 Simulation result for (a) discharging to charging condition, (b) charging to discharging condition

4. Conclusion

In this paper, battery charge control using delta SOH as reference is proposed. Battery system which is connected to DC bus by bidirectional converter is used to implement the proposed control block. Simulation results show that the proposed block control is successfully used. Moreover, the control block gives relative error less than 2% for delta SOH and less than 1% for battery power. There is also no significant different between discharging and charging condition. However, the simulation is required long time. In order to reduce the simulation duration, the average model of system would be developed to be used in future work.

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