Comparison of Battery Models for Battery Energy Storage System Development

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Abstract. Battery Energy Storage System (BESS) can be utilized in various ways to improve the reliability, durability, and efficiency of grid operations. With the advancement of battery technology and rapid cost reduction, BESS has become very promising. An accurate BESS model in simulation platform is very important to design an efficient BESS-connected powered system. Battery as one of the main components that govern BESS performance need to be modeled. There are many battery models that has been developed. In this paper, some of battery models will be studied and the comparison of different battery models is also presented.

1. Introduction
Impact of BESS on dynamic properties on an isolated power system showed that the negative effects of dynamic disturbances were able to be mitigated by BESS and it enhanced the stability of the power system. However, an unexpected temporary degradation in the power quality was also observed. Therefore, an assessment is necessary before a BESS can be employed on an isolated power system [1]. In order doing so, a model of BESS is needed to simulate its effects on power system. Battery, power conversion and control systems are the main component of BESS that need to be simulated. Therefor, their accurate model in simulation platform is very important to design an efficient BESS, but for some other use also there is also a need for using a simple model for simulation speed.

There are many battery models that has been developed over the year. Lithium ion battery model can be classified to electrochemical, performance, thermal and coupling model [2]. This paper will focus on the study on comparison of some performance models of lithium-ion battery, including Shepherd, Non-Linear, Partnership for a New Generation of Vehicles (PNGV), Two Order RC and Three Order RC.

The rest of paper is organized as follow. Section 2 introduces the battery model and explains its structure. Comparison is presented in Section 3. Future development is discussed in Section 4 concludes the paper.

2. Battery models
2.1. Shepherd model
The voltage-current model which describes how the terminal voltage of a battery changes with the current is the most vital battery submodule for electrical system study. The best known
voltage-current model for constant-current discharge is the Shepherd model[3]:

\[ V_{\text{batt}} = E_0 - K \left[ \frac{Q}{Q - i_t} \right] i - R_0 i \]  

where \( E_0 \) represents the open circuit voltage (OCV) of a battery at the full capacity, \( K \) is polarization resistance coefficient (\( \Omega \)), \( Q \) is battery capacity (A hr), \( i \) is battery current (A), \( R \) is internal resistance and \( i_t = \int i \delta t \) (A hr). The second term is associated with the polarization ohmic voltage loss, and the last term stands for the internal resistance loss [4].

2.2. Non-Linear model
Non-Linear Battery model are developed from remapped Randles’ lead–acid battery model [5] to model nonlinear open circuit voltage (OCV) characteristics of the Lithium-ion Polymer Battery. The model consists of: nonlinear characteristics of the OCV is represented by nonlinear voltage source as a function of state of charge (Voc(Z)), polarization effect is modelled by a capacitance (\( C_p \)), propagation resistance is modelled by a propagation resistor (\( R_b \)), a diffusion resistor (\( R_p \)) as a function of current \( I \), an ohmic resistance (\( R_t \)) and terminal voltage (\( V_t \)) as shown in figure 1(a) [6].

2.3. PNGV model
Consideration of the effect of load current was added on OCV based on Thevenin. the model consists of: OCV (\( V_{oc} \)), capacitance (represent the change in OCV by the load current \( I_L \)) (\( C_b \)), polarization resistance (\( R_p \)), polarization capacitance (\( C_p \)), ohmic internal resistor (\( R_0 \)) and terminal voltage (\( V_t \)) as shown in figure 1(b) [7].

2.4. Two order RC model
The model consists of: OCV (Voc), resitance (\( R_0 \)), parallel resistance-capacitance 1 describes electricity and chemical polarization, the polarization means the part of fast voltage change of the battery. (\( R_1 \) and \( C_1 \)), parallel resistance-capacitance 2 describes concentration polarization, the polarization means the part of slow voltage change of the battery. (\( R_2 \) and \( C_2 \)), and terminal voltage (\( V_t \)) as shown in figure 2(a) [8].

2.5. Three order RC model
The model consists of: OCV (\( V_{oc} \)), resistace (\( C_b \)), parallel resistance-capacitance 1 that is the part of fast voltage change of the battery. (\( R_1 \) and \( C_1 \)), parallel resistance-capacitance 2, that is the part of slow voltage change of the battery (hysteresis). (\( R_2 \) and \( C_2 \)), parallel resistance-capacitance 3, that is the part of fast voltage change of the battery. (\( R_3 \) and \( C_3 \)), and terminal voltage (\( V_t \)) as shown in figure 2(b) [9].
3. Comparison of results from several papers

In [10] Krishnan et al has proposed a performance enhanced battery model based on Shepherd model that combined electrical and thermal model including the effect of self-discharge. The Simulink model of the battery is tested for Sony US 18650 Li-ion battery. In [11] Miniguano et al used general parameter identification procedure with a reduced number of steps and an easy user interface, which requires circuits or equations to implement any type of battery model and has test five different battery model using simulink for lithium-ion polymer HRB 8048145. Haoran et al has described In [12] the process of estimating battery SOC using extended Kalman filter algorithm with PNGV battery model which showed that it can quickly and accurately estimate the SOC of the battery, but the effect of an increase in discharge current leading to an increase in battery temperature was not taken into consideration. The Simulink model of the battery is tested for LiFePO4 (LFP).

Battery model based on two order RC that accounts for all dynamic characteristics of the battery, from nonlinear open-circuit voltage, current-, temperature-, cycle number-, and storage time-dependent capacity to transient responses, which the results of the experiment using 850-mAh TCL PL-383562 polymer Li-ion batteries showed that it predicts both the battery runtime and I–V performance accurately has propose by Min and Ricon-Mora [13]. In [14] Liao et al has proposed a dynamic equivalent circuit model based on two order RC to describe the dynamic characteristics of the LiFePO4 (LFP) batteries. In [15] Yao et al has developed a LFP battery model based on two order RC using Matlab/Simulink and validated it with experiment results.

The the performance of battery models may vary for different battery types and also depends on what algorithms are used for the model extraction and how data are selected from the measured characteristic curves [4]. Comparison of output voltage error from many different papers can be seen in table 1. The test methodes, softwares, tools and batteries used to extract the error data is not taken into consideration for this comparison. These could be factors for different result from similar battery model.

| Model          | Max voltage error (%) | Average voltage error (%) |
|----------------|-----------------------|----------------------------|
| Shepherd       | 10 [10], 6.3026 [11]  | 0.4635 [11]                |
| Non-linear     | 3.5664 [11]           | 1.211 [11]                 |
| PNGV           | 3.2684 [11], 4 [12]   | 0.4853 [11], 2 [12]        |
| Two Order RC   | 0.091 [14]            | 0.0293 [14], 0.395 [13], 0.635 [15] |
| Three Order RC | 2.2356 [11]           | 0.1068 [11]                |

From the comparison table, the Shepherd model gave the biggest maximum voltage error which was 10% [10] and the biggest value of average voltage error was given by PNGV model.
which was 2% [12]. The lowest error of both maximum and average voltages was given by Two Order RC [14] which were 0.091% and 0.0293% respectively. From this result, it can be concluded the best model to use for short and long duration of simulation at this point is given by Two Order RC model from Liau et al.

4. Conclusions
This paper summarized the literature about some performance types of battery models. The comparison of output voltage errors from result of several papers for different battery model is also presented. From this comparison, it can be concluded the best model to use for short and long durations of simulation at this point is given by Two Order RC model which gave the best result for maximum and average voltage errors.

Acknowledgments
This research was supported by Ministry of Research and Technology/National Research and Innovation Agency (Indonesia) through Penelitian Terapan Unggulan Perguruan Tinggi (PTUPT) grant 2020.

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