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Various battery models for various simulation studies and applications

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ABSTRACT

Batteries are one of the most common devices used for saving electrical energy in various applications. It is necessary to understand the battery behavior and performance during charge and discharge cycles. An accurate model of a battery with a specific application is needed for an appropriate analysis and simulation. Therefore, in the field of battery modeling, various models have been proposed. This paper presents an overview of several electrical battery models. These models are classified into six categories. The parameter details of a battery model will not be computed but a brief description of them is given. Furthermore, the applications of each model are discussed. Finally, a comparison between presented models will be made.

Contents

1. Introduction

Nowadays, energy storages have numerous applications. Batteries are the most famous of them. They are applied in several

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industries such as in electrical and hybrid vehicles [1–7], renewable energy systems [8–12], and marine current energy systems [13]. Batteries serve as a backup in wind energy conversion systems (WECS) or photovoltaic (PV) systems. They are implemented to store excess energy captured from wind energy or sunlight using wind turbines during windy or sunny days and also for releasing the stored energy during stationary times or at night time [8,9]. Another application of battery storage is in aerospace satellites. They are used to collect energy using PV panel for satisfying required energy when the satellite is exposed to the sun and to release the energy during eclipse [14]. In electric or hybrid trains and vehicles, a battery is used for storing energy from regenerative braking system and returning the energy to the system when the train is in traction mode [1–7]. Batteries can play a significant role when they used with other storages such as fuel cells, ultra-capacitors, and super-magnetic energy storages (SMES). They can increase reliability of the hybrid systems [15,16]. Various flexible AC transmission system (FACTS) devices such as dynamic voltage resistor (DVR), and static compensator (STATCOM) utilize a battery for improving power quality of electrical voltage such as voltage sags [17]. Furthermore, the battery accompanied by an inverter is implemented in an uninterruptible power supply (UPS) in order to satisfy the loads and burdens during voltage sag and power interruption [18]. In all the above mentioned applications, an accurate modeling and simulation of a battery for examining system performance is necessary. Battery modeling involves two categories of electrochemical modeling and electrical circuit modeling. The electrochemical model of a battery is structurally based on the internal electrochemical actions and reactions of a cell. It is not obtained from an electrical network. Although accurate, this model is complex and needs a precise recognition of the electrochemical processes in the cell. It is not applied in power and dynamic systems studies. Electrical circuit modeling is another useful model presented by many researchers. In the electrical circuit modeling, the electrical characteristics of the battery are considered and passive linear elements are used. Such models are easy to understand. For example, the battery capacity is modeled by a capacitor. Given that the voltage and internal resistance of a battery are dependent on temperature and state of charge, open circuit voltage of a battery represented by a controlled dc voltage source is changed by the state of charge and temperature. Moreover, internal resistance is modeled by variable resistance. The value of the internal resistance is changed by the state of charge and temperature as well. In this paper, the electrical circuit models are classified into six overall models. These models consist of simple models, Thevenin-based models, impedance-based models, runtime-based models, combined electrical circuit-based models, and generic-based models. Specifications and applications of each model are considered and discussed. Finally, advantages and disadvantages of each model are presented below.

2. Simple battery models

In this section, six simple-based models of a battery will be described briefly as follows.

2.1. Ideal battery model

The ideal battery model is the simplest model because the internal parameters are neglected. It is represented by only an ideal voltage source. This model is shown in Fig. 1 [19]. It is mainly suitable in some simulations where the energy released from the battery is supposed to be infinite. In this model, the state of charge and internal parameters of the battery are not considered.

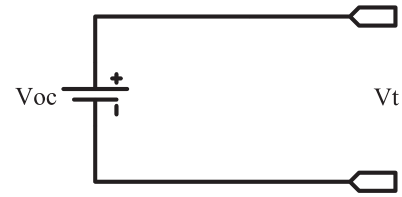

Fig. 1. Ideal battery model.

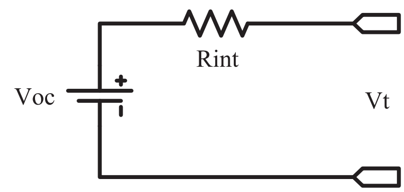

Fig. 2. Simple battery model.

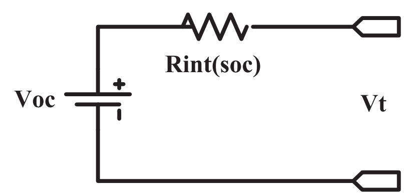

Fig. 3. Modified simple battery model 1.

Furthermore, the application of this model is mainly in the simulation of slag bus in steady state studies of power systems.

2.2. Simple battery model

A simple battery model, shown in Fig. 2, is composed of a series of internal resistance connected to an ideal voltage source. State of charge (SOC) is not considered in this model. In this figure, V_o is an ideal open-circuit voltage, V_t is the terminal voltage of battery and R_{int} is the internal series resistance. In the simple battery model, V_t can be clarified by an open circuit voltage measurement test. R_{int} is assumed to be constant while it is changed when a load is connected to a battery. Thus, this model is just appropriate in circuit simulations where the energy released from the battery is supposed to be infinite or the state of charge is not important [20]. For example, this model is not suitable for electric trains or vehicles application. However, it can be used with ultra-capacitor or fuel cell as hybrid energy storage. Also, this model is applied as an input source connected to the inverter power electronic devices [21].

2.3. Modified simple battery model 1

A model made up of an ideal voltage source accompanied by an internal resistance is discussed in [22]. Here, the voltage source and internal resistance are a function of the SOC. This model is shown in Fig. 3. In this battery model, the state of charge is considered by making the R_{int} and V_{oc} of battery changes in accordance with its state of charge. R_{int} is determined through following equation:

$$R_{int} = \frac{R_0}{S^K} \tag{1}$$

where S and R_0 are the state of charge and initial battery internal resistance respectively. R_0 is calculated when the battery is fully