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Modeling of rechargeable batteries

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Development of accurate, real time models for rechargeable batteries is essential for efficient battery management and their safe operation. This paper presents a short review on the various existing rechargeable battery models. We propose a new classification of the models as being first principles based, surrogate first principles based, data-based and/or a hybrid of first principles and data based approaches. While we describe the state of the art in modeling, avenues for future research work in this area are also identified. We also evaluate these models from the perspective of their use in various operational tasks and their application potential.

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Introduction

Rechargeable batteries or secondary cells are those batteries which can be charged and discharged multiple times. They have gained importance because of their significant application potential, acceptable recharge cost, and reduced environmental impact when compared to non-rechargeable batteries. Based on the chemistry and materials used, there are different kinds of batteries available in the market. Lead acid, nickel cadmium (NiCd), nickel metal hydride (NiMH) and lithium ion are some of the well-known rechargeable batteries. The performance characteristics of each of these batteries are, naturally, different and depend on their respective chemistries and operational strategies. Li-ion batteries, which have high energy density and low self-discharge, are currently quite popular and have been considered for a wide range of applications.

Models for rechargeable batteries can be leveraged in developing strategies for optimal battery operation with improved efficiency. Figure 1 describes what an optimal battery operation implies, factors that need to be considered and tools needed to achieve optimal battery operation. Optimal operation of battery results in prolonged battery life with maximum capacity by reducing capacity losses while ensuring safety. This optimal operation is achieved by operating a battery with optimal charge discharge cycles (provided by an optimizer), through a controller. A model (representative of a battery) is involved as an integral component in the optimizer, controller, as well as state of charge (SOC) estimator. Estimation of SOC is usually performed through an estimator (Kalman filter) for linear models and UKF or EKF for nonlinear models. Online data collection is needed for the process engineering tasks that maintain the battery operation to be optimal.

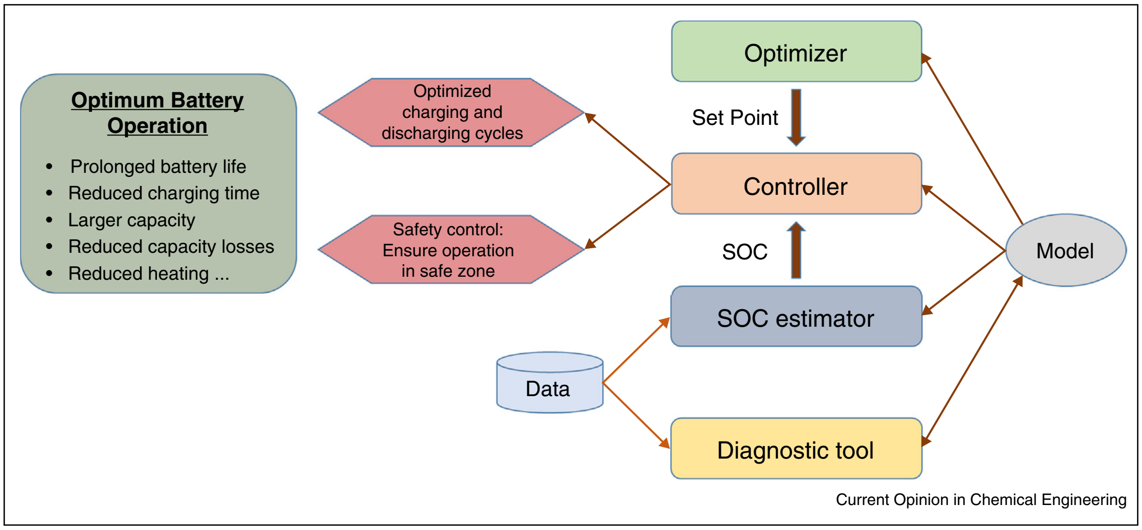
There are different states associated with batteries such as, state of charge (SOC), voltage, current, capacity etc. These states have to be monitored and maintained at their desired levels for optimal battery operation, and real time battery models can help realize such desirable performance. For a model to be useful, it should include all the significant phenomena that occur inside a rechargeable battery. A reasonably comprehensive list of such phenomena would include: dynamic *V–I* characteristics, nonlinear capacity, SOC, aging effect, recovery effect (present in Lead acid batteries), hysteresis effect (present in Ni–Cd batteries), memory effect (present in Ni–Cd batteries, recently found to exist for Li ion batteries as well [1]), thermal effects, cycling effects, and capacity fade mechanisms (passive film formation, active material dissolution and so on).

Dynamic behavior in a battery can be instantaneous, fast or slow depending on the physical phenomena that is at the root of the behavior [2]. Instantaneous effects due to ohmic resistance are likely to happen in a time-scale of microseconds. Charge transfer and double layer formation are examples of fast transient processes, whose time-scale can be in the order of few milliseconds up to several minutes. Slow transient processes influence the battery characteristics in several hours, days, or even years. For example, mass transfer across the electrolyte and aging are slow transient effects.

Figures 1 and 2 explain the perspective of this review article, which covers the following aspects

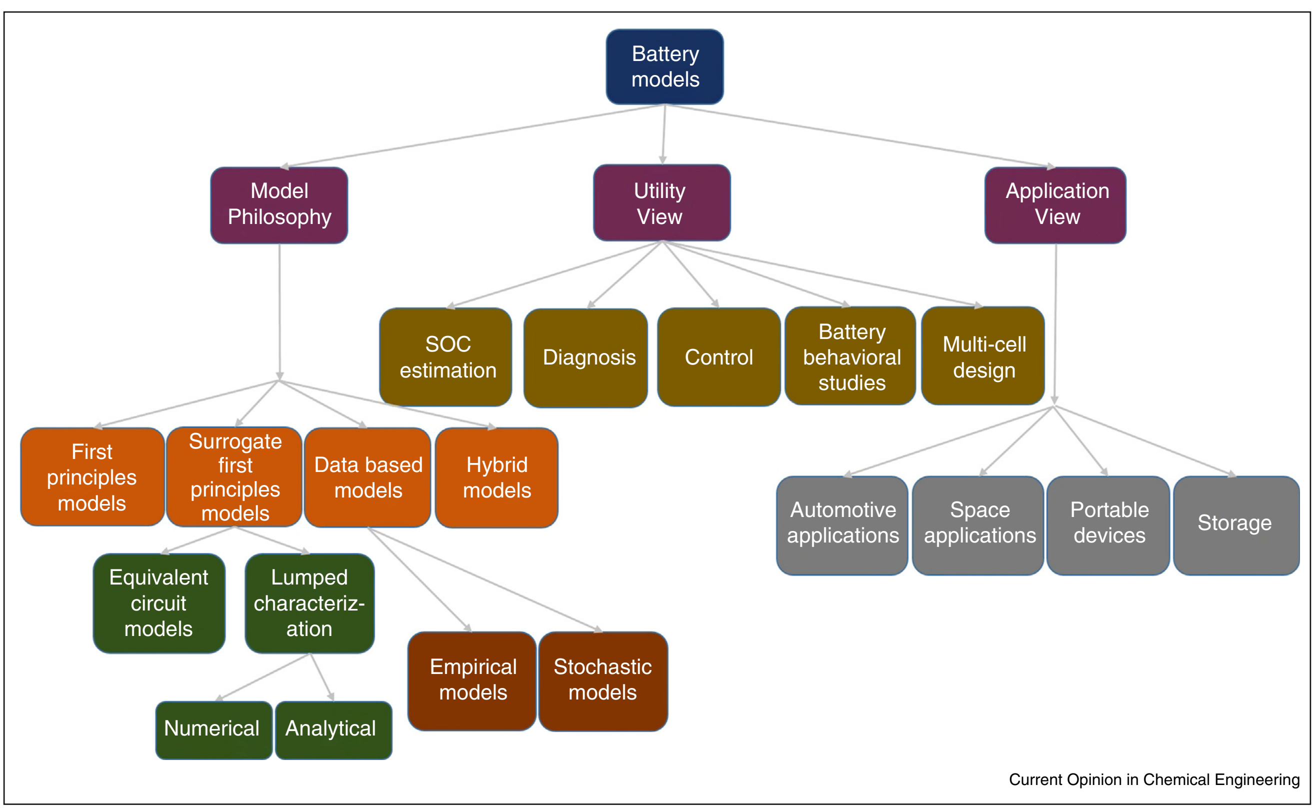
(a) Classify the various models that are available in the literature (Model philosophy branch).

Figure 1



Framework for optimal battery operations.

Figure 2



Overall perspective of the present review.