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Particle-filtering-based estimation of maximum available power state in Lithium-Ion batteries

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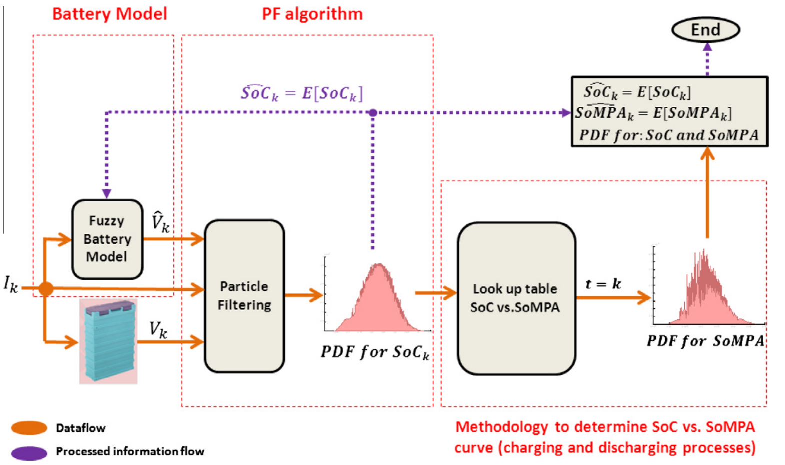
HIGHLIGHTS

- Approach to estimate the state of maximum power available in Lithium-Ion battery.
- Optimisation problem is formulated on the basis of a non-linear dynamic model.
- Solutions of the optimisation problem are functions of state of charge estimates.
- State of charge estimates computed using particle filter algorithms.

GRAPHICAL ABSTRACT



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ABSTRACT

Battery Energy Storage Systems (BESS) are important for applications related to both microgrids and electric vehicles. If BESS are used as the main energy source, then it is required to include adequate procedures for the estimation of critical variables such as the State of Charge (SoC) and the State of Health (SoH) in the design of Battery Management Systems (BMS). Furthermore, in applications where batteries are exposed to high charge and discharge rates it is also desirable to estimate the State of Maximum Power Available (SoMPA). In this regard, this paper presents a novel approach to the estimation of SoMPA in Lithium-Ion batteries. This method formulates an optimisation problem for the battery power based on a non-linear dynamic model, where the resulting solutions are functions of the SoC. In the battery model, the polarisation resistance is modelled using fuzzy rules that are function of both SoC and the discharge (charge) current. Particle filtering algorithms are used as an online estimation technique, mainly because these algorithms allow approximating the probability density functions of the SoC and SoMPA even in the case of non-Gaussian sources of uncertainty. The proposed method for SoMPA estimation is validated using the experimental data obtained from an experimental setup designed for charging and discharging the Lithium-Ion batteries.

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Nomenclature

C_n	nominal capacity
I	battery current
I^*	feasible points
I_s	operational current limit given by the manufacturer (120 A for both charging and discharging processes)
I^C_{max}	maximum current at charging period
I^D_{max}	maximum current at discharging period
η	coulombic efficiency
R_{int}	internal resistance
T_s	sampling period
V	battery terminal voltage
V_s	operational voltage limit given by the manufacturer (28.6 V for charging process and 22.4 V for discharging process)

List of acronyms

AEKF	adaptive extended Kalman filter
BESS	Battery Energy Storage Systems
BEVs	battery electric vehicles
BMS	Battery Management Systems
DCIR	direct current internal resistance
DEKF	dual extended Kalman filter
EKF	extended Kalman filter
HEVs	hybrid electric vehicles
HPPC	hybrid pulse power characterisation
NCRE	non-conventional renewable energy
PDF	probability density function
PF	Particle Filtering
SoC	State of Charge
SoH	State of Health
SoMPA	State of Maximum Power Available
SOA	Safe Operating Area
Voc	open circuit voltage

1. Introduction

In recent years the interest in environmental protection and energy sustainability has steadily increased; this fact has promoted research activities and projects focused on non-conventional renewable energy (NCRE) sources as a replacement for fossil fuels [1–4]. In this context, the concepts of hybrid electric vehicles (HEVs), battery electric vehicles (BEVs), and solar automobiles are nowadays commonly found in electro-mobility companies. Battery Energy Storage Systems (BESSs) are of paramount importance in the technologies where they fulfil the role of principal energy source. In this regard, Lithium-Ion battery banks have been widely used in electro-mobility applications due to of their high energy density and excellent cycling performance [5–7]. For the management of this sort of battery banks is important to use suitable Battery Management Systems (BMS), which consists of both dedicated hardware and software, with the purpose of providing monitoring, diagnosis, control, and estimation of relevant parameters of the battery and improving the system reliability. Important parameters related to battery banks are: State of Charge (SoC), State of Health (SoH) and State of Maximum Power Available (SoMPA). The first is associated with vehicle autonomy, the second provides information to the driver about the necessity of replacing an old or damaged battery bank. In the case of electric (or hybrid) vehicle applications, the third parameter, SoMPA, is useful for both (i) the driver when he/she has to decide how to meet requirements in terms of acceleration, regenerative braking, and gradient climbing power (without fear of over-charging or over-discharging the battery) [8,9], and (ii) the automotive companies for optimal design of the battery banks in terms of power [10,11].

The SoMPA can be defined as the maximum power that is possible to draw from or inject to the battery bank at a specific operating point without violating the Safe Operating Area (SOA). This zone is determined by temperature, current, voltage, and SoC limits, which are usually provided by the battery manufacturer in order to ensure a safe battery operation [8,10,12]. The SoMPA cannot be directly measured in a battery-based storage system; this parameter must be inferred from the observation of other

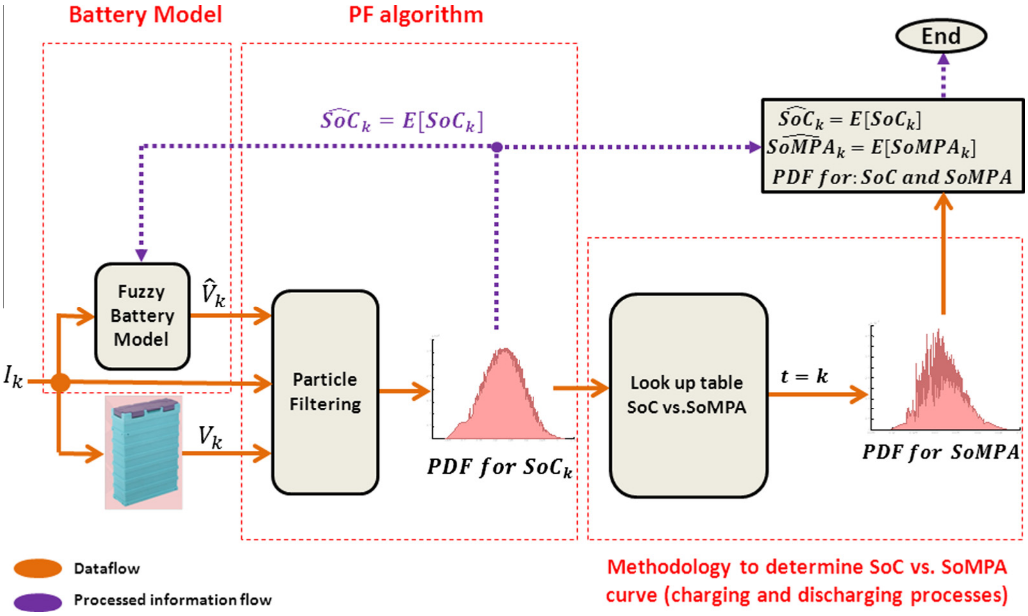

Fig. 1. The proposed SoC and SoMPA estimation scheme.