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Sodium-nickel chloride battery experimental transient modelling for energy stationary storage

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ABSTRACT

The paper presents the analysis of Sodium Nickel chloride batteries in transient operation, and proposes a simple but very precise model to represent both the transient and steady battery behaviours. Hence, the main purpose of this model is to foresee the battery voltage during the most important network services, which require very fast transitions from the battery charge operation to the discharge one. In order to validate the model, several comparisons between experimental measures and model results are shown.

1. Background

Sodium-Nickel chloride ($NaNiCl_2$) batteries, part of Na-beta battery family, are one of the most promising technologies for electrical energy stationary storage in the electrical networks for load levelling, frequency and voltage regulation, time shifting and power fluctuations mitigation of renewable energy sources [1]. In the paper, the transient modelling and behaviour of a $NaNiCl_2$ module are presented. Some installations are described in [2]. In a previous paper [1] the authors have presented the steady-state behaviour of this technology by means of a $NaNiCl_2$ experimental modelling approach. The purpose of [1] was to represent the sodium nickel chloride battery "energy intensive" application on the electrical high voltage network, which requires battery charging or discharging in long intervals. $NaNiCl_2$ battery rated charge/discharge time (from 3 to 5 h) fits very well with this application. The steady state model was tested for both constant and variable charge/discharge currents, and the model results were compared with battery measurements, performed on a Fiamm Sonick $NaNiCl_2$ ST523 module, with a very good agreement. This comparison demonstrated the effectiveness of this modelling approach for representing energy intensive applications. The steady state $NaNiCl_2$ modelling was derived from a set of standard cell measures, from which it was possible to infer a simple but very precise modelling structure. The used $NaNiCl_2$ cell measures for both charge and discharge operation were [1]:

- Open Circuit Voltage (OCV) as a function of the battery depth of discharge (DoD) both in charge and discharge mode. Fig. 1a) shows the set of discharge OCV measurements;
- Internal resistance as a function of DoD and of charge/discharge current rate. Fig. 1b shows the set of discharge internal resistance measurements;
- Battery temperature as a function of DoD and of discharge current rate. Fig. 1c shows the set of discharge temperature measurements.

It is worth highlighting that the above mentioned measurements have to be performed during charge operation as well (Fig. 1 reports only the discharge measurement set for the sake of brevity), since the discharge OCV, internal resistance and temperature dependence are different from the charge ones, as it is explained in [1]. Refs. [3,4], moreover, propose an interesting explanation of the electrochemical phenomena which render the charge internal resistance different from the discharge one in batteries.

The core of the steady state modelling procedure was the handling of the performed measures, which were represented by means of a matrix approach and interpolated by means of a set of interpolation functions. Fig. 1 represents the cell discharge measures and the corresponding matrix representations. The

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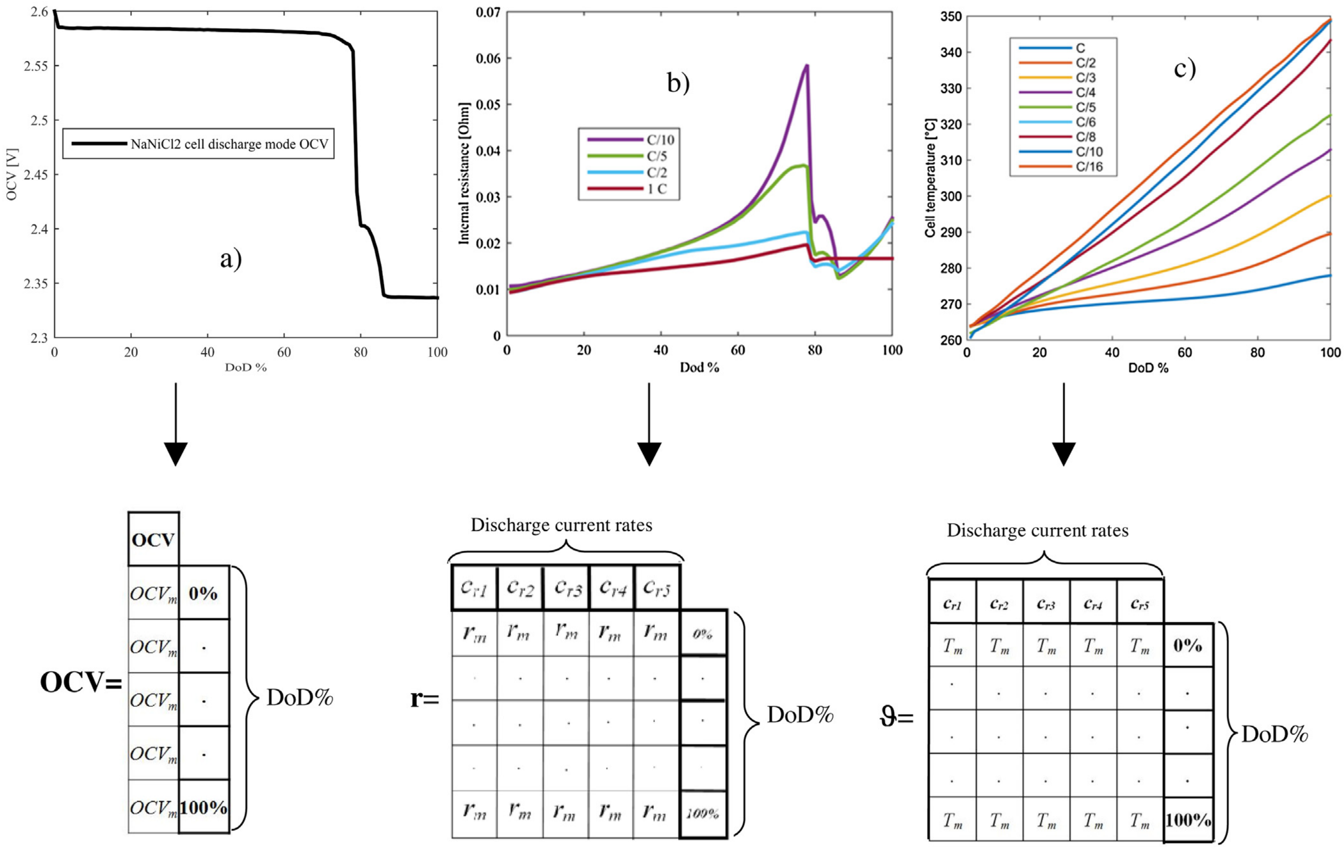

Fig. 1. Set of steady state discharge measures and their matrix representation.

chosen software environment was Matlab Simulink. The aim of the present paper is to analyse the $NaNiCl_2$ technology transient behaviour, which is typical of $NaNiCl_2$ "power intensive" applications, and contemporaneously to generalize the previous steady state model to the battery transient operations. This involves the analysis of fast transitions from the battery charge operation to the discharge one.

Differently from the most common battery model approaches which are available in literature [5–11] and briefly described in [1], a steady state measurement based model is easier. It allows modelling the battery by means of a single variable resistance, and despite this simple representation, it is remarkably precise in both transient and steady state conditions.

Table 1
Fiamm Sonick $NaNiCl_2$ ST523 module electrical characteristics.

Rated discharge power	7.8 kW (3 h discharge time)
Rated voltage and cell connections	620 V in series connection of 240 cells
C	38 Ah
Regeneration rated Power	6 kW
Stored Electrical Energy	23.5 kWh
Initial discharge temperature	240 °C
Calendar life/life cycles as a function of DoD	15 years/4500 cycles DOD 80%
Weight	≅256 kg
Freeze-thaw	no limitations
Operating temperature [°C]	260

2. Experimental evidences

A measurement campaign was carried out by Terna, the Italian transmission system operator, in the Italian National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) laboratory in Rome, Italy, on March 2016. A Fiamm Sonick $NaNiCl_2$ ST523 module, whose electrical characteristics are reported in Table 1, was tested. At first, a sinusoidal charge/discharge cycle was applied to the battery, by imposing a variable charge current, with a peak value of 10 A (0.26 C) for 5 s and immediately after that, the battery was discharged for 5 s, by imposing a discharge current equal to the one of the previous charge operation (see Fig. 2a)).

The battery initial state of charge (SoC) was equal to 20%. What was observed is that battery internal voltage drop during the discharge was much lower than the expected one. In fact, because of the initial battery DoD was equal to 80% (obviously DoD = 1 − SoC), the battery internal resistance value should have been very high, by considering the experimental relation between internal $NaNiCl_2$ cell resistance and DoD shown in Fig. 1b). In fact, by representing the sinusoidal cycle test by means of the steady state $NaNiCl_2$ module model presented in [1], a considerable discrepancy (more than 10%) was observed between measurements and model results (see Fig. 2b)). This is due to the fact that the steady state model represents the sinusoidal discharge by assuming that the relationship between DoD and battery internal resistance, which is reported in Fig. 2b), is true. Evidently, this is no longer verified in transient conditions.

In order to understand the reason of this phenomenon, it is worth highlighting that the battery internal resistance represents the $NiCl_2$ reaction front depth inside the battery [12]. In other