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Modelling of supercapacitor by using parameter estimation method for energy storage system

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ABSTRACT

Researches to increase efficiency in renewable energy systems are increasing the interest in high power density (HPD) energy storage units' day by day. HPD units form a hybrid energy storage system (HESS) when used together with a high energy density (HED) energy storage system. Supercapacitors are the most frequently used storage units among HPD with their features such as low cost, low self-discharge rate and high lifecycle. When systems need high power, supercapacitors which is used to support HED units to ensure that the transmitted power's stability, efficiency, and high quality. The use of supercapacitors in HESS with the exact timing has a significant impact on its performance. For this reason, supercapacitors must be modeled correctly and well-integrated with the system. In this study, parameter estimation was made by using the data obtained from the simulation study and the supercapacitor was modeled. The supercapacitor model has been tested for charging and discharging at different currents and successful results have been obtained.

Introduction

Renewable energy sources (RES's) are seen as the greatest alternative to fossil fuels' depletion and environmental impacts [1]. It is anticipated that RES's will play a major role in the energy world of the future, as they offer sustainable and environmentally friendly energy [2]. However, in addition to these advantages, it has disadvantages such as not being continuous and insufficient in terms of power quality. In order to overcome this situation, RES's are used in integration with energy storage systems.

Energy storage systems are divided into two categories: high energy density and high-power density. High energy density storage units can provide continuous but low power. High power density storage units, on the other hand, can provide short-term but high power. By using the advantages of these two different types together, hybrid energy storage systems (HESS) are obtained [3]. Supercapacitors (SC) are the most commonly used storage systems that provide high power density [4]. SC are used as secondary or backup storage, due to their higher power density and faster dynamic response. Also, SC has very long-life cycle and lower self-discharge rate [5].

A model is needed to know in advance how the SC will behave in different operating conditions [6]. Also, while using in hybrid energy storage systems, the use of SC at the right time is of great importance in terms of system performance and efficiency. To decide the right time while designing the energy management system, the exact mathematical model of the SC must be known by designer.

Material and Method

SC model, given in Figure 1, is constructed using Debye polarization equivalent circuit.

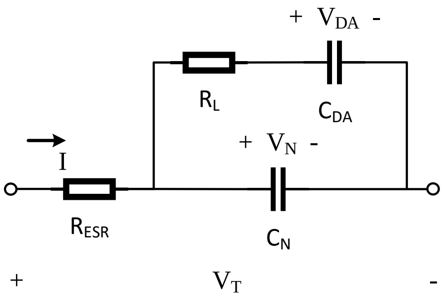

Figure 1. Debye polarization equivalent circuit model

where R_{ESR} is the equivalent series resistor, R_L is the leakage current resistance, C_{DA} is the Debye adsorption capacitance, and C_N is the nominal capacitance. The electrical behavior of the Debye polarization equivalent circuit model can be expressed as following equations:

$$\frac{dV_{DA}}{dt} = -\frac{1}{R_L C_{DA}} V_{DA} + \frac{1}{R_L C_{DA}} V_N \quad (1)$$

$$\frac{dV_N}{dt} = -\frac{1}{R_L C_N} V_{DA} + \frac{1}{R_L C_N} V_N - \frac{1}{C_N} I \quad (2)$$

$$V_T = V_N - IR_{ESR} \quad (3)$$

Parameter estimation toolbox was used in MATLAB/Simulink to determine the parameters representing the electrical behaviors in the Debye polarization equivalent circuit. The Simulink interface given in Figure 2 was created to verify the equivalent circuit model created after the parameter estimation.

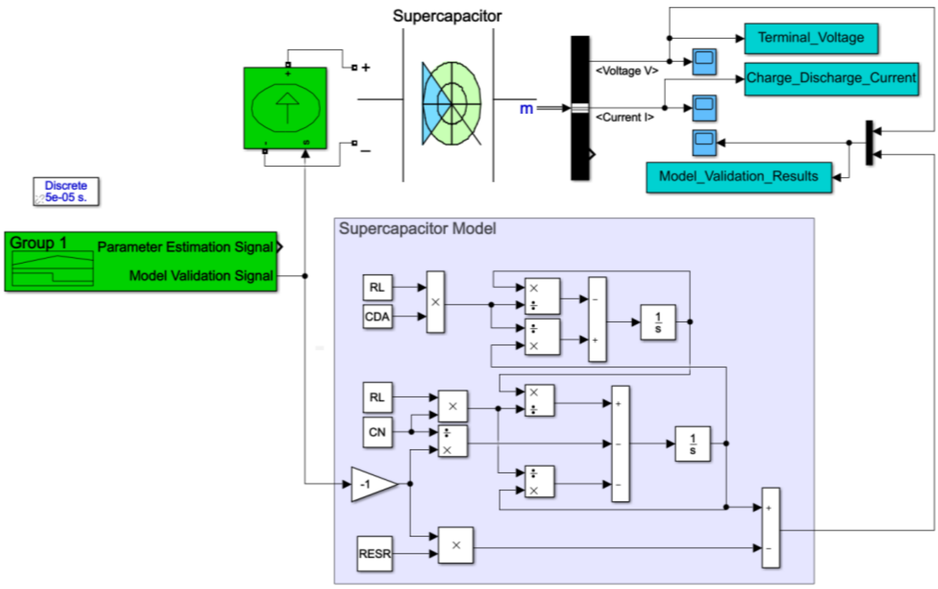

Figure 2. Validation of Debye polarization equivalent circuit model in MATLAB/Simulink

Results

Nonlinear Least Square method based on Trust Region Reflective algorithm was used for estimation of equivalent parameters. The input current given in Figure 3(a) was applied to the circuit model for parameter estimation. Comparison of model and actual terminal voltages as a result of parameter estimation is given in Figure 3(b). The estimation result was confirmed with a mean squared error of 1.7520e-04.

Different charge and discharge currents were used to validate the equivalent circuit model. The current values given as input to the model created in Figure 4(a) are given. Comparison of actual and model terminal voltage with respect to this given input matched as seen in Figure 4(b).

The mean square error was calculated for the comparison of terminal voltages. The generated supercapacitor model accuracy was verified with a mean square error of 0.0028 in the comparison.

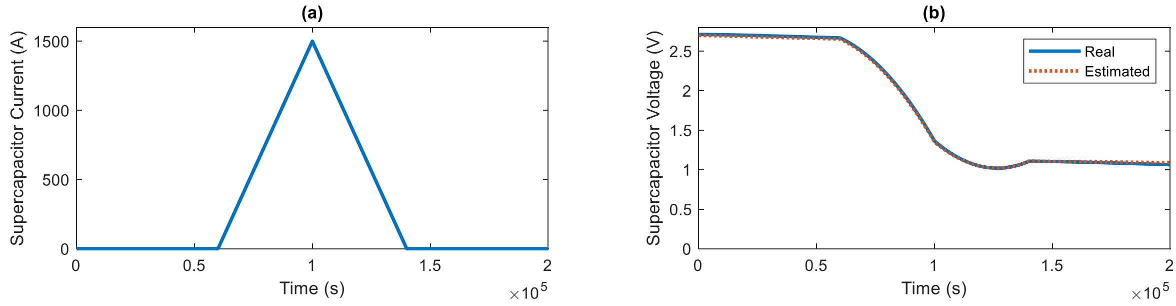

Figure 3. Parameter estimation results, (a) input current of Supercapacitor, (b) output voltage comparison

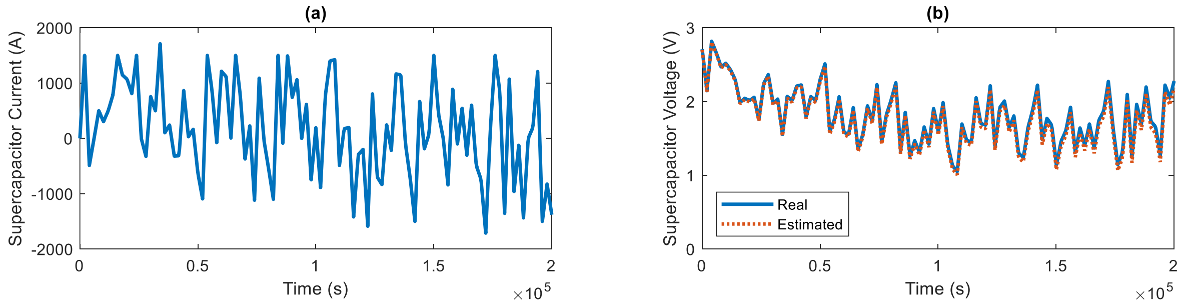

Figure 4. Model validation results, (a) input current of Supercapacitor, (b) output voltage comparison

Conclusion

In this study, mathematical model was determined by a suitable equivalent circuit. The estimation of the model parameters was determined in the MATLAB/Simulink parameter estimation toolbox with a maximum error rate of 0.17‰. The accuracy of the model has been proven with a maximum error of 0.28% under different operating currents.

Author contributions:

Gökhan Yüksek: Writing-Original draft preparation, Presentation. **Yusuf Muratoğlu:** Software, Validation. **Alkan Alkaya:** Investigation, Reviewing and Editing.

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