Analysis of a Hybrid Energy Storage System Composed from Battery and Ultra-capacitor

KORAY ERHAN, AHMET AKTAS, ENGIN OZDEMIR
Department of Energy Systems Engineering / Faculty of Technology / Kocaeli University
Umuttepe Campus, 41380, Kocaeli
koray.erhan@kocaeli.edu.tr, ahmet_aktas_1987@hotmail.com, eozdemir@kocaeli.edu.tr

Abstract: The main disadvantages of renewable energy sources are that they are much expensive and intermittent. The intermittency is one of the reasons they are so expensive compared to traditional energy sources. An energy storage system can solve this intermittency problem. Nowadays, roles of energy storage systems for the stability of power system have been growing. The most important benefit of the energy storage is to support the power grid in order to achieve its load demand continuously. The energy storage is able to enhance system stability, help power transfer, and improve power quality in the power system. One major disadvantages of energy storage is the relatively low round trip efficiency, typically around 85 %. Since energy storage does not produce its own power but rather takes power from other energy producing facilities, it effectively reduces the energy produced by those other facilities and hence lower their profitably. In this paper, a hybrid energy storage system (HESS) composed from a battery and ultra-capacitor is proposed to solve transient energy requirements. In case of transient energy requirements, there is need for additional power sources to provide over-current demand. High current demand is provided by ultra-capacitor. Thus the batteries in hybrid energy storage system are exposed to less electrical stress. In addition, HESS’s performance analysis was done with an experimental set. As a result, it's experimented that in which condition ultra-capacitor and battery are operated effectively.

Keywords: Hybrid energy storage system, Ultra-capacitor, Battery.

1. INTRODUCTION

With the advancing technology device sensitivity is increasing which powered with electrical energy. Power quality is become more important as a result of increasing the share of the renewable energy sources in the power grid. One of the biggest disadvantages about renewable energy sources is intermittency. It is also difficult to control the electrical network when it grows. During control of power grid some undesirable situations may occur. This events cause short interruptions. To prevent this situations energy storage systems play major role in the power grid. And also energy storage system (ESS) increases the reliability of the power system. ESS is designed for different requirements and conditions. In some cases the amount of stored energy is significant but in some cases the magnitude of the instantaneous maximum power that can be drawn are the main factors.
In this study, an experimental set was designed which consists the most important part of HESS composed from an ultra-capacitor and a battery. Different conditions experimentally tested it by drawing high current at starting. At first condition, a DC resistive load was supplied and all current was drawn from the battery. At second condition, battery and ultra-capacitor were used together as parallel connected. High current requirements were supplied from HESS. The obtained results and the advantages of HESS system interpreted. An analysis of the HESS composed from a battery and ultra-capacitor for integrating energy storage system to electrical power systems has been done. And also the effect of over-current on battery life has been observed.

2. HYBRID ENERGY STORAGE SYSTEM

Energy storage system is important for a micro-grid and renewable energy sources. It can improve the power quality of the system to make sure that the load in this system works properly. Also it can get rid of the power fluctuations caused by the renewable energy sources such as wind turbines whose power depends on the weather and PVs which can only work in the day time. It can discharge immediately to keep the DC voltage stable when a sudden load is switch into the system. In order to get a good performance, a hybrid energy storage system has been set up, which consists of a battery and an ultra-capacitor [1-4].

Traditionally, the lead acid battery is the most popular energy storage device due to its low cost and wide availability. However, renewable energy systems are not an ideal source for battery charging as the output is unreliable and heavily dependent on weather conditions. The charging/recharging frequency of the batteries is increased and the batteries are often deep discharged, which damages the battery and shortens its service life. In addition, the battery stores energy by electrochemical reaction and it has a lower power density, which makes it cannot compensate a large power for the load over a short period of time. The ultra-capacitor, which stores energy by physically separating positive and negative charges, becomes a good candidate to provide a convenient and reliable power source for renewable energy systems. Its service life is much longer than the battery and it can tolerate voltages up to the devices maximum voltage rating. Another advantage that the ultra-capacitor has over a battery is its fast charge/discharge time and its ability to be stored at any state of charge. The ultra-capacitor can work better than the battery in extreme conditions. Battery and ultra-capacitor have been finally chosen in this paper to form a hybrid energy storage system, taking advantage of the battery's high energy density and the ultra-capacitor's high power density [5-8].

This paper mainly focuses works on the battery and ultra-capacitor hybrid combination. The battery is designed to be used for the purpose of providing longtime and continuous energy for all the loads and the ultra-capacitor is used to charge and discharge immediately to give a transient compensation when a sudden load is put into the system to reduce the decrease of the DC voltage [9,10].
3. EXPERIMENTAL STUDY AND RESULTS

The experimental setup is shown in Fig. 1. Batteries which are used for energy source charged by solar simulator before starting the experiment. Solar simulator can be seen in Fig. 2. In the experimental setup, three current probes and a voltage probe were used. Ultra-capacitor through a resistor before the series is connected then the resistance switching off the ultra-capacitor is in parallel with the battery.

In the first section, battery supplied all electrical energy for the load. First, the resistive load was connected to the battery. Following this step the motor load switched on while the resistive load still running. In Fig. 3 the current drawn from the battery and voltage of battery can be seen as graphically.

At first the current drawn by the resistance is about 12 A. Then motor load was switched on. After running the motor load, the inrush current value is approximately 85 A. Continuous state current drawn by the motor and dc load approximately 60 amper. Unloaded state battery voltage is 12.5 volts. When the load is switch on battery voltage drops 10.5 volts.

In the second step, ultra-capacitor and battery connected in Fig. 3 parallel as a part of the HESS to supply the load. The drawn current from the battery (Bt_A), the voltage of battery (Bt_V), the load current (L_A) can be seen. When battery and ultra-capacitor connected parallel, they shares the load current for a certain time period. Inrush current drawn from battery is higher than the ultra-capacitor current. Energy of ultra-capacitor reduces faster than battery. If drawing current condition continues long period in parallel wiring, there is a potential balance between ultra-capacitor and battery. For this reason after a period, the current drawing from the ultra-capacitor would be zero. Experimental setup circuit diagram is shown in Fig. 4.
Fig. 2 Photograph of solar simulator

Fig. 3 The currents of battery and load in the first case
The hybrid energy storage system block diagram is shown in Fig. 5. We can see the system which includes battery and ultra-capacitor as parallel. They connected with the DC bus and the loads. The configuration of the hybrid energy storage system parameters is shown in Table 1.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Type</td>
<td>Lead-Acid</td>
</tr>
<tr>
<td>Nominal Voltage (v_{bt})</td>
<td>12 V</td>
</tr>
<tr>
<td>Rated Capacity (Ah)</td>
<td>125 Ah</td>
</tr>
<tr>
<td>Voltage (v_{uc})</td>
<td>15 V</td>
</tr>
<tr>
<td>Capacitance (F)</td>
<td>58 F</td>
</tr>
<tr>
<td>DC Equivalent Series</td>
<td></td>
</tr>
<tr>
<td>Resistance (ESR)</td>
<td>19 mΩ</td>
</tr>
<tr>
<td>R, RL</td>
<td>144 W, 800 W</td>
</tr>
</tbody>
</table>

In Fig. 6 battery voltage (Bt_V), the current drawn from the ultra-capacitor (Uc_A), and the power of load (L_W) are shown respectively.
With the experimental setup observations has been made for three different operating conditions. In Fig. 6 these different working situations can be seen. In the first part resistance bank was supplied by HESS. The big part of the current was supplied by battery. In the second part, motor load switched on addition to the resistance load. Owing to the inductive nature of the motor load inrush current was drawn. The energy of the ultra-capacitor decreases when the motor is working on nominal conditions. For this reason the current value drawn from the ultra-capacitor drops approximately zero amper. In addition to this battery current increases instead of the ultra-capacitor current. In this way there is a balance between ultra-capacitor and battery. In Fig. 7 first part is defined in detail.

In the last part is shown in Fig. 8 motor load switched off. After the switching off the motor load, the ultra-capacitor whose current in the range of zero has been started to charge. Because of the charging to ultra-capacitor, battery current couldn't drop to the first level when it supplied only the resistance bank. Until providing equilibrium condition between ultra-capacitor and battery, ultra-capacitor draws current from the battery. The ultra-capacitor current drops to zero amper, after balancing of the ultra-capacitor and battery. When cutting off the resistance, ultra-capacitor was charged a little by the battery and potential balance was provided.
Fig. 7 The first part of the drawn currents

Fig. 8 The second part of the drawn currents
4. CONCLUSION

In this study a hybrid energy storage system was designed to perform analysis for different load cases which supplied from a battery and ultra-capacitor. In the first section load current was drawn only the battery pack and obtained current, voltage and power values were given. After incorporating the ultra-capacitor to the system, HESS was generated and analyses were performed. Result of the analysis it has been observed that ultra-capacitor served as the auxiliary source in case of short time over current situations. Studies shows that the transient currents which drawn from the battery shortens the battery life. So paralleling the ultra-capacitor and battery prolongs the battery life.

5. Acknowledgements

This paper was supported by within TUBITAK project number of 113E143.

References


