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Electric hybrid storage systems and their applications

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The evolution of electricity storage driven by the increase in energy generation from renewables, such as solar and wind, and by less reliance on conventional energy, such as fossil fuels, has led to the development of "clean" technologies that imply a decarbonized power system. These include electric transmission systems, such as electric vehicles (EVs), and energy-optimized industrial production systems based on low or medium voltage distribution networks. Most challenges that arise in their implementations refer to storage limitations, such as reliability/temperature dependence, capacity, aging, cyclability, and cellularity; flexibility issues, such as load variations, operating voltages and currents; and power control, such as efficiency, and losses. For the applications proposed herein, the authors integrate a hybrid electric storage system (HESS) based on supercapacitors and batteries. The solutions based on "hybrid" storage cells are shown to comply with the application requirements by experiments on the prototype.

Keywords: Electric Storage Systems, DC-DC Converters, Energy Management

Electricity storage has a fundamental role in its efficient use [1]. In the last decades, the distributed generation, the increase in energy production due to wind and by photovoltaic devices have determined the modification of the electrical networks, mainly of the power flow control: transport, distribution and low voltage. Also, the increase in polluting gases, due to human activities, has forced companies to focus on the development both of "clean" technologies such as electric transmission systems and of automated and energy-optimized industrial production systems [2]. The need to consume or store electricity when it does not balance the demand for electricity, transforms storage systems into significant energy saving elements necessary for human activities.

Following the companies' effort to develop and improve renewable energy sources, the new step in achieving more efficiency is the intelligent use of storage facilities so that the distance between generators and consumers is minimized and, with it, the "power trip" from generator to consumer, and vice versa. Another essential parameter is time. RES-based production is dependent on climatic and weather factors. Its pattern does not usually meet the requirements of consumers. Therefore, it is mandatory to adapt the two demand-consumption processes with the help of storage facilities. For example, in the case of electric vehicles, their speed, which depends on traffic and transport loads, requires significant variations in power and energy exchanged between the vehicle (its kinetic energy) and the source of electricity found on the vehicle. The principles underlying storage facilities still reflect many unsolved issues, from low reliability and high temperature dependence to limited power / energy density capacities [3]. Despite remarkable advances in power electronics, however, efficient power control systems require both more efficient switching subsystems and more versatile control subsystems that should be more easily adaptable to the variations in the control requirements of the systems that integrate storage facilities.

Storage cells are very diverse, considering the charge carriers and the chemical reactivity that intervene in the reversible /quasi-reversible reactions [4] corresponding to the charging and supplying of electricity. Such type of device in which the chemical reactivity is the one that implements the storage of electricity is called a faradic device. Batteries are such devices. However, there are storage devices whose operation is based only on the separation of charges of distinct polarity, known as non-faradic devices [4][5][6], such as supercapacitors. Their specific time constants differ, as well as their capacity, energy, and power densities. Also, operating temperature ranges differ, as well as their cyclability and reliability.

The evolution of fundamental research in chemistry, nanotechnologies and materials science has allowed the improvement of energy storage devices, mainly batteries, and also of energy sources based on fuel cells. However, certain aspects remain critical, such as: limiting the operating voltage and current related to storage, limiting the range of variation of the operating temperatures, and the speed of the aging process that intervene in the cell's operation, reflected by the low or medium cycling. All these shortcomings complicate both the control of the charging-discharging processes, and the energy efficiency of the systems in which storage is integrated.

The above limitations, and also the cellular organization of the storage systems bring new complications in the implementation of applications. Thus, balancing the instantaneous parameters requires real-time systems. Likewise, energy management (as an integral parameter) poses problems of correlated planning of the generation/consumption or the load, depending on the state of the energy system to which the storage system is connected. Two other aspects essentially influence the integration of energy storage systems: i. their customized design in relation to the implemented application; ii. sizing of the storage capacity to satisfy the constraints relative to the instantaneous quantities (voltage, current, power) and integrals (energy, temperature).

This paper emphasizes the importance of optimizing the structure and operation of storage cells so that their parameters are improved, as well as the reliability and the conditions under which they can function. In this sense, the "hybrid" storage cells (Hybrid Electric Storage System -HESS), consisting of supercapacitors, batteries, and combustion cells [7] are particularized herein, together with the electronics and the related control system [8], [9], [10]. The sizing methodology of HESS is further detailed, as well as its operation. This report insists on optimizing the power electronics and simplifying the power flow control to ensure maximum robustness in control, as well as the highest possible system reliability. Two applications are addressed: a stationary and a mobile one. In terms of power electronics, bidirectional back-boost DC-DC converters were reviewed, as in [8], including the galvanically isolated ones. The mobile application refers to an electric bike equipped with a hybrid storage system (battery & supercapacitor). It represents an elastic, robust and reliable control solution. The proposed model is based on the principle of superposition in power flow control. This example, typical for personal electric vehicles (PEVs), can be extended to stationary applications for power and energy management as in the case of buildings with zero or negative energy consumption (ZEB). The authors considered two designs for the power control of the hybrid storage source. The first design, in Figure 1, senses the voltage trend on the supply line and depends on the voltage derivative which will activate the DC-DC converter. The sense of activation corresponds to the sign of the voltage derivation.

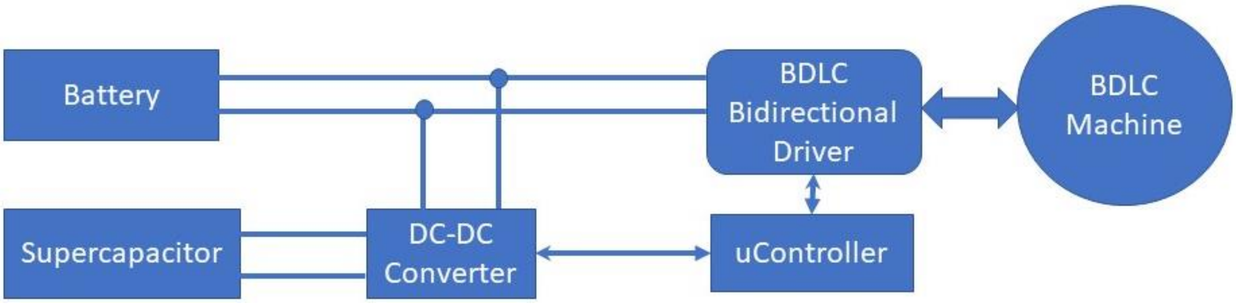

Fig.1. Common rail HESS

The microcontroller has a 16-bit resolution and a sampling rate of 1kSps. The second design, in Figure2, uses two primary windings for battery, respectively supercapacitors, the secondary winding is connected to the BLDC Driver. Therefore, the transfer of power is done by magnetic field produced in the transformer magnetic circuit. In this case the microcontroller assures the switching of power flow between battery, supercapacitor, and BLDC bidirectional driver, controlling the MOSFET bridges.

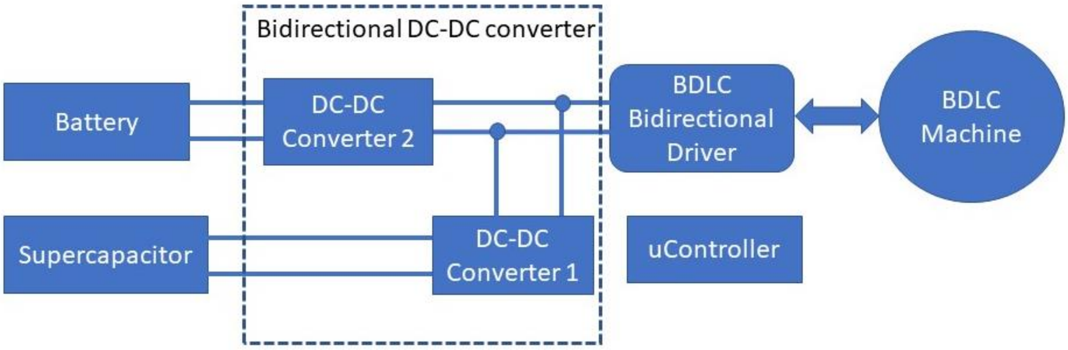

Fig.2. Insulated HESS with transformer

The proposed solution is scalable, allows a robust control in relation to the variation of the load as well as a high reliability. A model in Simulink reveals the evolution of time-dependent parameters in correlation with the proposed control methodology [11]. The energy efficiency is evaluated, and the advantages and disadvantages of the solution are depicted herein. Simulation was performed on the prototype shown in Figure 1 with the following parameters: a battery at 48.1V/600Wh and a 29F/32V supercapacitor pack. The e-bike's motor is an electrical machine at 1.8kW. The achieved range was 70km. During the tests, a maximum speed of 75km/h was reached.

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