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DEVELOPMENT OF HYBRID NETWORK ENERGY STORAGE. PART 1: EMBODIMENT

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ABSTRACT

This article describes possibilities to expand functionality of energy management system in independent power system by integration of network power storage based on battery units and supercapacitors. Major advantages of energy storage in electric power system are substantiated, namely: expanded integration of renewable energy sources, possibility to control network frequency and voltage, provision of energy arbitrage, possibility of delayed upgrading of existing infrastructure. A scheme of hybrid energy storage is presented comprised of battery units and supercapacitors for application as network energy storage intended for parallel operation with infinite power network, parallel operation in local isolated network with flexible loads and operation for independent load.

Key words: hybrid energy storage, lithium-ion batteries, supercapacitors, ultracapacitors, energy storage for power system.

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1. INTRODUCTION

In addition to increased demand for electricity caused by fast development of power networks in the world, the issues of global warming and decrease in carbon dioxide content in environment are also very important. Demand for environmentally clean energy promotes development of renewable energy sources and electric vehicles. A disadvantage of wind power and solar energy is nonuniformly generated power depending on weather conditions. Integration of electric vehicles into energy system results in stochastic behavior and frequent load variations. Under new conditions operation of electric networks becomes more complicated. Aiming at elimination of these problems, new engineering concepts are being developed such as price responsive demand, active-adaptive networks, microgrids, and energy storage systems. Development of innovative energy storage systems and their wide-scale fabrication provide their cost competitiveness; this technology can be applied in energy systems.

An important problem of global energy complex is management of generated power aiming at balance between generated and consumed energy. Modern energy system is characterized by such features as instant and continuous power supply from power plant to consumers, unavailable resources for energy accumulation comparable with output as well as nonuniform energy consumption within 24 hours.

The existing approaches to balance generated power do not permit complete solution of the problems occurring during this process because the capacities of generation facilities involved in the management are limited. It should be mentioned that during equalization, the wear rate of expensive equipment sharply increases. Taking into account that start-up and shut-down of generation facility can take from several minutes to several hours, and in emergencies, the balance is restored by restriction of consumer loads, the chance of negative effects for consumers related with energy failure is high.

Among numerous existing approaches, the most important is the use of network energy storage systems (NESS). First of all, the NESS improve flexibility of generation facilities, that is, provide possibility to vary generation power in accordance with current consumption amounts. Herewith, NESS can be applied both as additional equipment for generation facilities, thus increasing safety, efficiency, functionality and improving power quality, and as independent system compensator aimed at increased reliability, efficiency, and stability of energy systems.

NESS based on battery units only are the most popular among various types of network energy storage systems of high power and capacity aimed at support of energy networks. Battery storage systems are characterized by certain advantages in comparison with other storage systems, such as flexibility of installation place at the stage of construction as well as quick response to system perturbations. Energy storage systems based on battery units are widely applied in various industries. They contain independent power supply sources, including renewable energy sources (RES) [1,2], backup power supplies [3], various electric vehicles, and others. Energy storage systems are the basis for arrangement of Smart Grids intended for implementation of RES integration and distributed generation.

The most advanced are lithium-ion batteries, in particular lithium–iron–phosphate and lithium–titanate ones [4]. They are characterized by high specific energy capacity, can provide high charge/discharge current, have no memory effect and self-discharge, nearly do not require maintenance and are safe upon appropriate operation. However, application of lithium-ion batteries as network storage systems with RES and nonuniform load impairs battery operation life and decreases efficiency due to sharp drops of charge/discharge current with respective abundant increase in number of batteries in the storage system and its price.

Another widely applied technology of energy storage is based on capacitors with double electric layer or supercapacitors [5]. They provide high short-term power and are frequently used in starting circuits of driving and traction electric motors. In addition to high charging/discharging rate, supercapacitors are also characterized by high lifetime and permit high number of charge/discharge. At the same time, supercapacitors are characterized by certain disadvantages, such as low specific energy capacity and propensity to self-discharge.

Development of semiconductor and supercapacitor appliances enabled usage of battery units and supercapacitors in one facility known as hybrid energy storage system (HESS), allowing to combine positive properties of both technologies and to compensate for their disadvantages [6]. A portion of load in HESS, characterized by frequent and short peaks of generation or consumption, is taken up by supercapacitors, providing optimum charge/discharge curve of battery units. Herewith, such positive effects are achieved as increase in lifetime of battery units, improvement of system response time in dynamic modes, no oversized battery units are required for peak powers, expenses for battery replacement and operation costs are reduced. Therefore, the issue of development of hybrid network energy storage systems on the basis of supercapacitors and battery units for local and isolated networks is very important.

2. OPERATION OF NETWORK ENERGY STORAGE SYSTEMS

Network energy storage systems are used in energy system in order to implement numerous functions, such as integration of RES and smoothing of nonuniform generation of RES [7, 8], power adjustment and load monitoring [9], time shift of energy supply, peak load provision, load flattening, maintaining generator mode at network voltage failure, provision of reliable transmission and distribution of energy, post-emergency system start-up, voltage adjustment, suppression of network oscillations, spinning power reserve, uninterrupted power supply, as well as possibility to delay upgrading of transmission lines, etc. [10-12].

Adjustment of Frequency and Voltage

During operation, NESS can both absorb active power when network frequency exceeds preset limits, and supply the stored energy to the network when the frequency drops below the allowable threshold. Therefore, NESS can be used for network frequency stabilization. Voltage can be controlled similarly to frequency together with generation and absorbing of reactive power. Herewith, the use of NESS for management makes it possible to reduce the portion of adjusting facilities of generation, to decrease necessary investments, to increase installed capacity of power plants and infrastructure, as well as to reduce operating expenses.

Smoothing of nonuniform Generation of RES

Integration of RES requires for solution of the problem on nonuniform power generation. Herewith, NESS can be considered as a key solution of this problem. Information in [13-15] demonstrates the use of NESS with battery units in wind power and solar electric plants.

The concept of active-adaptive network (Smart Grid) is actively discussed by researchers. In this concept, energy network is converted from passive system used for power transmission into active one where all elements can dynamically vary their properties depending on operation mode of energy system. Peculiar position in this concept is intended for network energy storage systems. NESS should possess sufficient flexibility and response rate in order to provide storage of energy generated by RES, as well as to provide energy quality and steady operation both during operation in parallel with the network and in isolated network as uninterrupted power source [16].

Peak Load Provision and Load Flattening

NESS operates as energy buffer, which compensates deviations between prescheduled generation and actual demand for power. If the prescheduled generation does not satisfy the demand for load, NESS can compensate the difference. If prescheduled generation exceeds the load demand range, NESS can store the excess energy. NESS provide peak loads and support power balance. In a similar way it is possible to adjust load. The difference is that provision of peak loads is mainly concentrated on smoothing of peak load and load equalization is used for equalization of overall load profile [17].

Power Quality Improvement

The properties of NESS with battery units permit to use them for improvement of energy quality in energy system, applying them as Flexible Alternating Current Transmission System (FACTS) and Static synchronous compensators (STATCOM) [18]. NESS can be used for improvement of energy quality and for maintaining voltage in allowable limits. They can be applied for solution of problems of nonsymmetry and harmonic composition of supply network as well as compensation of the system reactive power capacity.

Spinning Reserve

Spinning or rotating reserve is referred to generators connected to network and activated so that they can respond faster to demand of power from the operator, since start-up of generators requires for a long time. NESS can response faster than regular generators [19]. In the emergency case regarding energy transmission, NESS can add its complete power sufficiently quickly (in several minutes) in order to provide network frequency in permitted range until troubleshooting completion.

Selection of Hybridization Topology of Energy Storage System

Despite numerous technologies of energy storage, none of them can provide independently and simultaneously quick response and long lifetime of NESS. Application of HESS is aimed at efficient combination of technologies with supplementing properties.

Several flowcharts of HESS arrangement are available, the most flexible and optimum one for energy systems is parallel active topology based on the use of two DC converters (Fig. 1) [20].

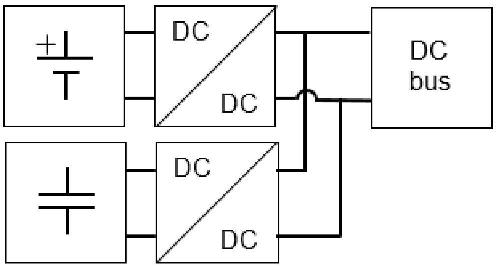

Figure 1 Active parallel flowchart of hybrid energy storage

It permits to maintain voltage of both supercapacitor unit and battery units below that of DC unit, thus simplifying equalization of battery cells and enabling maximum usage of supercapacitor energy. In addition, it permits adjustment of battery current. The main disadvantage of the circuit is that two DC/DC converters are required for its operation. One converter, connected to battery units, should be adjusted for average load power and the other one, connected to supercapacitor unit, should be adjusted for peak dynamic power [21]. The disadvantage of the flexible control is a complicated fabrication and additional losses in the system. Despite the relatively high cost of power converters, the parallel active hybrid circuit which provides complete management of power distribution between battery units and supercapacitors is the most preferable for application as HESS for energy systems due to perfect flexible control [22].

3. HESS ON THE BASIS OF LITHIUM-ION BATTERIES AND SUPERCAPACITORS

Figure 2 illustrates an embodiment of NESS layout [23, 24]. Battery unit (BU) is comprised of serially connected lithium-ion cells, which provide rated power and required energy capacity of the storage system, control system and bidirectional DC power converter, which provides coordination of voltages on BU and common DC bus, as well as control of BU power flow. Functions of lithium-ion batteries require for application of control system providing safe BU operation by temperature monitoring and voltage equalization on each element. In passive hybrid circuits voltage on the element is restricted by a resistor parallel to the cell. Active hybrid circuits are the most promising since they decrease energy loss for equalization.

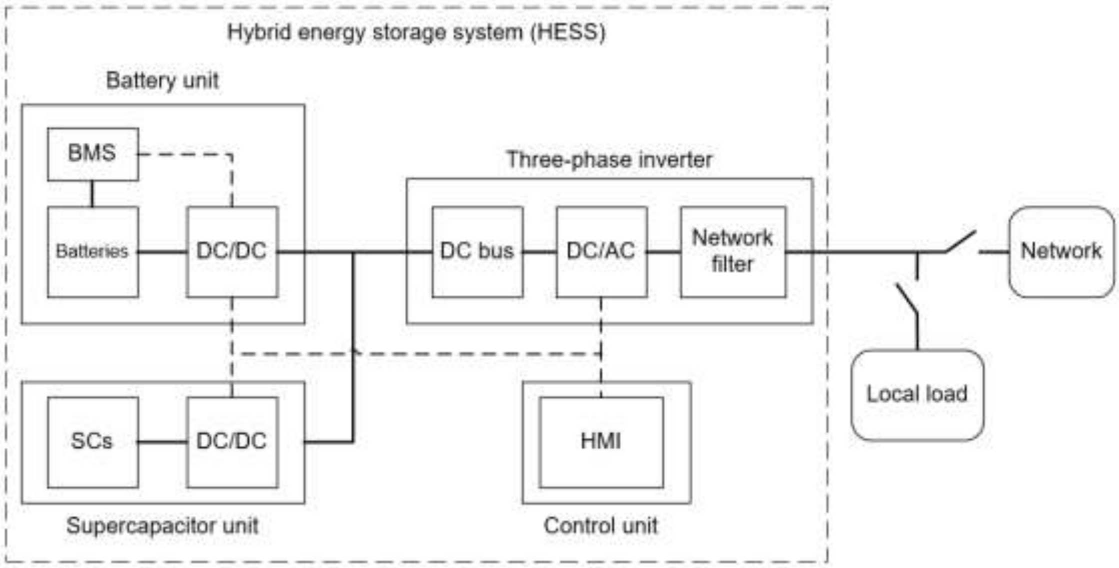

Figure 2 Hybrid energy storage scheme: BMS – battery management system, SCs – supercapacitors, HMI – human-machine interface, DC/DC – dc-to-dc power converter, DC/AC – three-phase power inverter (dc-to-ac power converter).

Supercapacitor unit (SC) is comprised of supercapacitors which provide balance between elements and bidirectional DC power converter similar to that applied BU.

BU and SC are connected to common DC bus of bidirectional inverter which provides an interface with 3-phase AC network and generating required power.

DC converters of BU and SC, as well as bidirectional inverter, collect and transfer data via a common data bus in real time. HESS is equipped with the control panel. This panel makes it possible to carry out adjustments and to select HESS operation mode.

HESS is intended for operation in the following modes:

- Parallel operation with infinite power network. In this mode, HESS is adjusted to provide preset charge/discharge power and does not participate in maintaining network frequency and voltage.
- Parallel operation in local isolated network with variable load. In this mode, HESS should provide coordinated operation with other power sources, maintain frequency and voltage for the load.
- Operation with independent load. In this mode, HESS generates network voltage, controls its frequency and provides supply for the local load.

4. CONCLUSIONS

Application of network energy storage systems based on high power and high capacity electrochemical sources is very promising both for independent power supply systems and auxiliary power supply and for independent facilities of energy system for parallel operation.

One of the major advantages of energy storage in energy systems is expanded integration of RES which promotes electrification of remote localities. In order to override problems of nonuniform power generation by RES, NESS are widely applied in combination with wind power plants, diesel, petrol or gas generators. Due to quick response and flexible management, the electricity storage systems can be applied for adjustment of network frequency and voltage. The network storage systems can be applied for energy arbitration providing additional profit for a consumer. Installation of the storage system in the overloaded node would permit to delay upgrading of existing infrastructure and to free up some funding for other infrastructure projects.

Application of HESS in the power engineering industry is especially important. They efficiently maintain the balance between generated and consumed energy, providing frequency adjustment, correction of power coefficient using reactive power, they can be used with the aim of improvement of power supply quality and as a spare source of power supply for essential consumers. Installation of HESS in strongly overloaded networks makes it possible to relieve overloaded power transmission lines, thus delaying the necessity of system upgrading.

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