A REVIEW OF BATTERY-SUPERCAPACITOR

HYBRID ENERGY STORAGE SYSTEM SCHEMES FOR POWER SYSTEM APPLICATION

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***Abstract* —** The paper discusses typical hybrid Energy storage applications in power systems, Such as frequency and voltage regulation, demand management, load shaving and energy arbitrage. The review has provided the state of the art in the field of battery supercapacitor hybrid energy storage topologies for power systems application . A comparison of advantages and disadvantages of the passive, the semi-active and the active dc and ac schemes has been made. The parallel active hybridization scheme has been chosen as the most appropriate solution for power system application. The review has proven relevancy of the research in the field. The steps for the future research have been identified.

Keywords - battery, super capacitor, hybrid energy storage system

I.INTRODUCTION

Power systems around the world are changing. Simultaneously with the increase in power consumption, it is necessary to find a way to solve the problem of global warming due to the greenhouse effect and high CO2 concentration in the atmosphere. A need for a greener energy drives the employment of the renewable energy resources and electric transport. The drawback of wind and solar energy utilization is the volatility and intermittence of the power supply. The electric vehicles integration into power systems results in stochastic behaviour and frequent changes of the load. In the new conditions, the operation of the power grids becomes more complicated than it used to be. In order to overcome these technical problems, new technologies concepts are being developed such as demand side management, smart grids, microgrids and energy storage system. Development of the new types of electrical energy storage and their massive production is making their cost competitive and the technology become applicable in power systems.

II.TABLE

Characteristics of different electrical energy storage technologies

	SUPERCAPACITORS	LEAD-ACID	Li-Ion	NaS	Redox-flow
Energy density	2-10	50-100	200-350	150-250	20-70
Installation costs ,kw	150-200	150-200	150-200	150-200	1000-1500
Installation costs ,kwh	10000-20000	1000-250	500-700	500-700	300-500
Reaction time,ms	<10	3-5	3-5	3-5	>1000
Self-discharge rate	<25% /24hrs	0.1-0.4%/day	10%/day	10%/day	0.1-0.4% /day
Cycle lifetime	>1mln	500-2000	5000-10000	5000-10000	>1000o
Lifetime,years	15	5-15	15-20	15-20	10-15
Transformation efficiency	0.75-0.83	0.70-0.75	0.68-0.75	0.68-0.75	0.7-0.8

Despite a large selection of technologies, none of them alone can provide a fast response and a long cycle-lifetime at the same time. The hybrid energy storage system (HESS) approach is aimed to effectively combine storage technologies with supplementary operating characteristics. HESS technology has been applied in many applications, such as electric vehicles (EVs) microgrids and renewable energy systems HESS for residential use has been proposed. HESS technology for EVs integration in microgrids and large power systems is being studied. This paper is aimed to discuss the ESS-applications in power systems and provide an overview of the energy storage coupling topologies.

III.METHODS

The review was aimed to provide the state of the art in the field of battery-supercapacitor hybrid energy storage topologies for power systems application and prove relevancy of the research in the field The search has been conducted among peer-reviewed academic and industrial journals. Five databases have been included in the search, namely SciVerse ScienceDirect, SciVerse Scopus, Web of Knowledge, IEEE Xplore, Google Scholar.

2.1. HESS in power systems

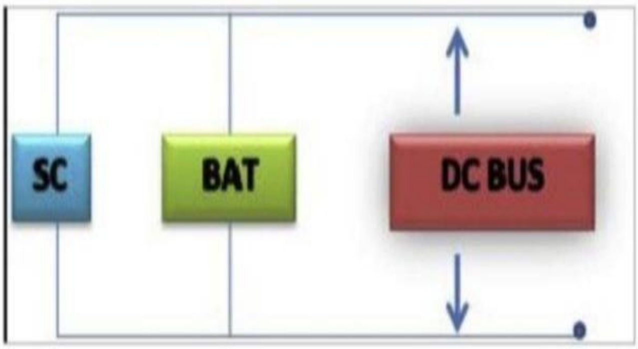
Application of energy storage technology in power system is still in the development state. The effective ways of energy storage are being actively explored. Electrical energy storage technologies can provide a great benefit to power systems, enable RES integration and help to increase supply security and system stability.

Power transmission from generators to consumers in the electric power system occurs instantaneously and continuously. At the same time, power demand during the day is unequal. For this reason, it is necessary to constantly regulate the supply of electricity to the network, maintaining at any time the balance between the generated and consumed active power. This power balance determines the frequency of the electric current, which is the one of the essential power quality indicators and the most important parameter of the regime of the power system. . Usually, the power balance in the network is maintained by changing the output power of generators at power plants. This mode of control significantly increases the wear rate and lower utilization cost of the generating equipment, and as well, results in an additional fuel consumption. The over-consumption of fuel is especially noticeable when large power plant units are involved in the regulation of the variable part of the load schedule. Apart from the regulation costs, there is not always a technological ability to quickly start/stop a generating unit. In addition, in case of emergency situations, when capacity reserves of power plants are not enough, demand management is applied to restore the permissible frequency level. This in its turn can lead to a significant damage cost associated with the interruption of consumers power supply. The new type of electrical load such as the electrical vehicles (EVs) is penetrating the power system. The nature of this type of load is stochastic and fast changing. The conventional generators will soon face the limit of regulation capability to follow the highfrequency load fluctuations. The promising solution may be the application of the energy storage systems along with the renewable energy sources (RES) and conventional generators. The key application of the energy storage technology in power systems is the development of RES integration. One of the main problems associated with the use of RES is the volatility and intermittency of the storage to absorb or give out the energy for hours. Lithium-Ion batteries are a promising technology that has already found use in many applications, such as hybrid and fuel-cell powered electric vehicles , renewable autonomous energy supply systems , large-scale wind- and PV-park power management , and other applications. Lithium-Ion technology can be as the “high energy” storage with a low self-discharge rate and lower energy specific installation costs. The drawback of this technology is the low cycle lifetime. In order to increase the total system efficiency and storage lifetime and reduce the total investment cost compared to a battery-only energy storage, the supercapacitor technology is applied. Supercapacitors are dedicated to cover “high power” demand, transients and fast load fluctuations and they are characterized by a fast response time, high efficiency and high cycle lifetime. Hybridization of batteries and supercapacitors allows decoupling energy and power (the batteries only have to cover average power demand, whereas the SC undertakes fast fluctuations), optimizing the operation of the batteries at high efficiency operating points and reducing dynamic losses and stress of the batteries. In order to achieve the abovementioned characteristics an effective HESS energy management system has to be applied. A number of research papers are devoted to the problem of development of effective real-time management strategies

III. REVIEW ON BATTERY-SUPERCAPACITOR HESS HYBRIDIZATION SCHEMES -

As it was mentioned, in the battery-alone system suffers from the natural limitations of the batteries technology, i.e. short cycle life and low cycle efficiency due to fast charge and discharge cycles for regulation services. A solution helping to overcome these problems is the hybridization of batteries and supercapacitors. The supercapacitors can effectively absorb and give out the fluctuating power requests and reduce the stress of the batteries. The different ways of connecting the energy storages into a HESS are known. The simplest HESS scheme is the passive parallel configuration. Fig. 1 shows a passive HESS scheme. In this scheme, the battery and the supercapacitor are connected in parallel without any power electronic converters. The power drawn from each element will be shared in the proportion of their internal impedances. As the internal impedance of the supercapacitors is much lower than that of the battery, it acts as a low-pass filter and handles the most of the dynamic power fluctuations. Compared to the battery-alone system, the passive HESS shows an obvious improvement on peak power capability under a pulsed load profile. This scheme is easy for implementation and does not require any power distribution control. However, since the supercapacitors impedance is finite they cannot fully shield the batteries from frequent charge and discharge operations. The disadvantage of this scheme is that it does not allow efficiently utilizing the energy stored in the supercapacitors. Since the supercapacitors are connected parallel to the batteries, they cannot operate beyond the voltage range allowed for the batteries resulting in the limitation of the effective supercapacitors capacity. to a converter. This scheme uses a bidirectional dc/dc converter in order to handle the power of the supercapacitor in a wide range of voltage**s**. The nominal voltage of the supercapacitor bank can be lower than that of the battery bank. Since the battery is connected directly to the dc link, the dc-link voltage cannot be varied. The disadvantages of this scheme are the high rating of the dc/dc converter and the fact that the battery may still sometimes partly supply the dynamic currents.

FIG-1



Supercapacitor semi-active HESS Scheme-

The battery is connected to a converter and the supercapacitor bank is connected directly to the dc link. The battery current can be independently limited to a safe near constant value. This scheme allows the voltage of the battery to be lower or higher than the supercapacitor voltage, which extends the design freedom of the battery and supercapacitor banks. The supercapacitor bank performs as a lowpass filter. The dc/dc converter rating can be chosen according to the average load power (a few times lower than the peak power). The dc/dc converter operates in current-controlled mode. The drawback of this solution is that the dc-link voltage variation is allowed during the supercapacitor charging and discharging. However, thus the supercapacitor energy can be more effectively used. In order to adjust the voltage variations to the permissible range for the load, the capacitance may be increased to a very large value.

Battery semi-active HESS scheme-

Active cascade or series active hybrid scheme allows extending the working range of the supercapacitor of the previous scheme. The second dc/dc converter is added between the supercapacitor bank and the dc link. It solves the problems of supercapacitor voltage variation and adjustment. The main disadvantages of this scheme are the requirement for a full-scaled dc/dc converter and reduced efficiency because of the two conversion stages between the battery and the dc link. Series cascade scheme is generally more expensive and more difficult to be controlled that the parallel one.

Series active HESS scheme (cascade) –

The parallel active hybrid combines the output of the two converters. This scheme is the most flexible and optimal solution. It allows maintaining the voltages of both the UC and the battery lower than dc-link voltage. It helps to ensure less balancing problems of the cells and maximum utilization of the supercapacitor energy. Besides, it allows keeping the current flow from the battery at nearly constant value. The main disadvantage of the scheme is that it needs two dc/dc converters. One converter (batteryconnected) should be rated at the load average power. Another one(supercapacitorconnected) should be rated in accordance with the dynamic peak power. The trade-off of the flexibility of control is the complexity and additional losses in the system.

Parallel active HESS scheme-

There are different dc/dc converter topologies, isolated and non-isolated, can be applied in HESS, such as buck/boost, half-bridge, full-bridge. A special trend to highly efficient and cost-effective multi-port converters. Due to a reduced number of conversion stages a multiple input converter configuration allows reducing the cost of the overall system .

Parallel ac coupling

There is also a HESS topology that does not use common dc link Instead of it, two parallel bi-directional dc/ac power converters are used. This scheme has been implemented in 200kW peak-power prototype and tested in nearly-real conditions

IV. RESULTS AND DISCUSSIONS In order to summarize the review of the battery-

supercapacitor, HESS hybridization schemes let us consider the advantages and disadvantages of the schemes. The main advantages of passive topology are the simplicity and the lack of power electronics and control, and high overall energy, and power density. The main disadvantage is the uncontrollable current flows, determined only by the elements impedances and low utilization of the supercapacitor. The utilized energy of the supercapacitor is limited in the passive scheme by the battery terminal voltage, which has to be increased by connecting a number of capacitors in parallel. Compared with the fully active HESS, the semi-active HESS is considered a practical solution in terms of reduced complexity and losses because only a single dc/dc converter is required. The active scheme provides full regulation of power distribution control between the batteries and the supercapacitors and seems the most promising solution for the power systems application. The parallel AC coupling scheme can also be considered, provided the proper control algorithm is applied.

V. CONCLUSION

Hybrid energy storage systems showed good efficiency in many areas, such as electric vehicles, renewable energy systems and microgrids. Electrical energy storage is the enabling technology for wide application of renewable energy resources. In power systems, HESS can be successfully applied for frequency and voltage regulation, demand management, load shaving and energy arbitrage, as well as to help upgrade deferral of the existing infrastructure. Lithium-Ion technology has obtained highly promising characteristics, such as high power density, high power transformation efficiency and low self-discharge current. However, they rapidly deteriorate if applied for rapidly fluctuating power regulation in power systems. Supercapacitors effectively supplement the characteristics of the batteries and allow the system lifetime extension, thus reducing the operational costs. A review of hybridization schemes has been represented. Advantages of each scheme and the drawbacks were discussed. Despite the increased cost of the required power converters, the parallel active hybrid scheme is the most appropriate scheme for power system application due to control flexibility. Determination of batteries and supercapacitors capacities is not a straightforward task taking into account a tradeoff between revenue and costs. Considering HESS application for power systems, a further research in HESS sizing and optimal power management strategies has to be continued.

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