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ScienceDirect

Energy Procedia 110 (2017) 14 – 19

Energy Procedia

1st International Conference on Energy and Power, ICEP2016, 14-16 December 2016, RMIT University, Melbourne, Australia

Significance of energy storages in future power networks

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Abstract

As a result of the major challenges the world is facing today due to global warming and the ever decreasing conventional sources of energy such as fossil fuels, developing methodologies for harnessing all possible forms of renewable energy has become a heavily researched area within the power and energy research communities. Deploying energy storages increases the possibilities of harnessing several sources of renewable energy in a more meaningful manner. Some of the key areas where energy storages could make things better, when it comes to harnessing renewable energy sources are, Wind energy, Bio energy, Geothermal energy, Solar energy and Wave energy. The paper investigates application examples of energy storages in these areas through a thorough review of reported scientific literature. On the other hand, major energy consuming areas such as transportation, manufacturing, electricity consumers etc. could also benefit by the introduction of energy storages. As an example, in transportation, increasing usage of hybrid electric vehicles, plug-in electric vehicles and emerging new concepts in transportation such as electric highways have raised the significant role of energy storage solutions for transportation to its highest level. It is believed that this way of looking at the energy storages will strategically position them with the significance they deserve within the energy and power engineering research community.

Peer-review under responsibility of the organizing committee of the 1st International Conference on Energy and Power.

Keywords: energy storages; power network; renewable energy; energy efficiency; micro grid; transportation

1. Introduction

As a result of the major challenges the world is facing today due to global warming and the ever decreasing conventional sources of energy such as fossil fuels, developing methodologies for harnessing all possible forms of renewable energy has become a heavily researched area within the power and energy research communities. With the

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Peer-review under responsibility of the organizing committee of the 1st International Conference on Energy and Power.
doi:10.1016/j.egypro.2017.03.098

aging power networks the world over reaching their limits, demand side management, distributed generation, harnessing renewable energy sources and incorporating energy storages have become extremely important for the power industry [1]. Looking at energy storages in renewable energy integration from a grid operator's point of view is done in [2]. Hierarchical management of energy storages in a distribution grid is addressed in [3]. Use of energy storages to enhance the distribution feeder capacity is presented in [4]. The fact that energy storages are making an impact on the future power networks is further confirmed by the study in [5] which analyses different storages and different time-variable operation modes of energy storages in future electricity markets. Interestingly, all these modern aspects of power networks are associated with incorporating some form of energy storages in the network. As such, it is possible to observe a near exponential increase in research in energy storages in power networks. These investigations can be categorized from various points of views. Two of the main categories that are reviewed in this paper are; power network configuration in which energy storage is incorporated and the type of renewable energy source harnessed using the energy storage.

Under the category power network configuration in which energy storage is incorporated; energy storages in Smart Grid initiatives [6 - 9], energy storages in Micro Grid applications [10 – 14] and Hybrid Energy storages [15 – 22], Under the category type of renewable energy sources harnessed using the energy storage; use of energy storages in wind energy harnessing [23 - 30] and photovoltaic energy harnessing [31 - 35] can be highlighted as key applications. However, due to space limitations all of these applications will not be reviewed in this paper.

The paper then focus on energy storages in transportation giving emphasis to automotive sector considering its significance with emerging concepts such as electric highways etc., which has a bigger impact on the future power networks. With battery technologies being the key energy storage solution in future power networks; the paper also summarizes capabilities of some widely used battery technologies towards the end.

2. Energy storages and power network configuration

Looking at the energy storage system from the power network configuration point of view becomes important from various aspects. Some of these key aspects are, sizing of the energy storage, selection of the type of energy storage and control aspects of energy storages.

2.1. Energy storages in Smart Grid Systems

In Smart Grid applications, the use of Plug-in Hybrid Electric Vehicles (PHEV s) and Battery Electric Vehicles (BEV s) as configurable distributed energy storages has been heavily researched [6]. This concept allows the utilities to treat large parking areas of densely populated cities to treat as energy storages. The charging times can be managed depending on the supply demand patterns so that all other associated strategies such a demand side management, peak shaving and voltage regulation issues related to solar power generation can also be successfully addressed [6]. A review of such applications in the United States can be found in [6]. Apart from the use of PHEV and BEV as energy storages, a more mathematical approach to the problem by proposing a cost-based optimization strategy for the optimal placement, sizing and control of energy storages in Smart Grids is proposed in [7]. Such energy storages can support energy management as well as power management at all three major stages of a power network; generation & transmission, distribution, consumer as shown in Table I [7].

Table 1. Energy Storage System Services (Functions).

Stages of a power network	Applications in Energy	Applications in Power
Generation & Transmission	Electric energy time-shift, Electric supply capacity, Transmission congestion relief, Transmission upgrade deferral	Voltage support, Power Oscillation Damping, Black start, Supplemental reserve
Distribution	Distribution upgrade deferral, Power reliability, Intermittent mitigation	Voltage support, Power Quality
Users	Electric energy time shift, Interruption backup	Demand charge management, Power Quality

2.2. Energy storages in Micro Grid Systems

Most of the energy storage applications in Micro Grids are hybrid systems. The hybrid here is from the point of view of combining two types of energy storages such as capacitor and battery. AC-DC Micro grid applications incorporating hybrid energy storages are presented in [8]. The general topology of such Micro Grids is that the hybrid energy storages are connected to the utility grid and the DC Micro Grid which consists of DC generators such a solar PV systems as well as any DC loads connected to a DC bus. The DC bus is interlinked to the utility grid through a hybrid energy storage having a DC-DC boost converter between the energy storage and DC Micro Grid and a AC-DC converter between the AC bus and the hybrid energy storage as shown in Fig. 1(a) [8].

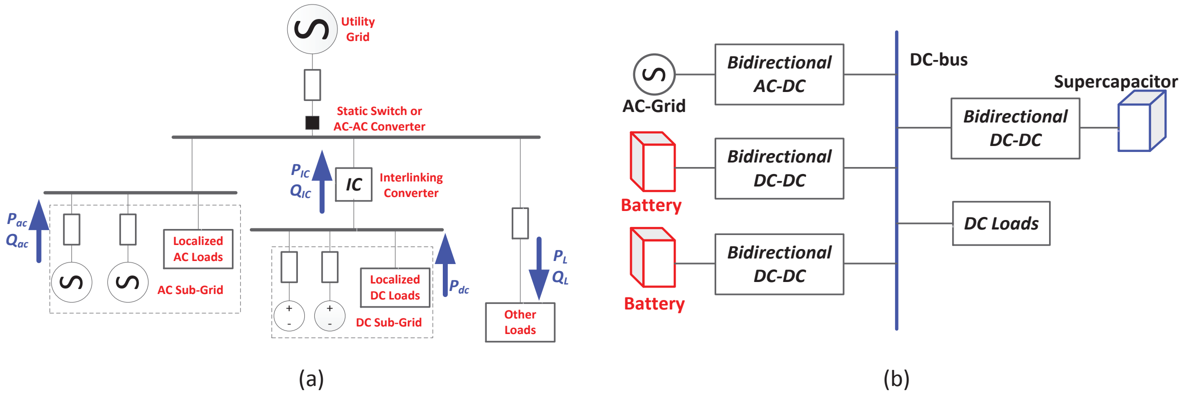

Fig. 1. (a) Energy Storage in hybrid AC-DC Micro Grid; (b) Energy Storage in DC-DC Micro Grid.

In case of DC-DC Micro Grid topology shown in Fig. 1(b) [11], the DC bus is connected to the grid through a bidirectional AC-DC converter. There can be several energy storages connected to the DC bus [9]. Multilevel energy management [10], Control strategy of multiple energy storages [11] and optimal operation of the Micro Grid [12] are the other important aspects that have been researched in case of Micro Grids with energy storages reported in literature.

2.3. Hybrid Energy storages

It is possible to find several reported work on hybrid energy storages. The concept involves combining two different energy storage systems together to realize a hybrid energy storage, which makes use of different properties of the energy storages combined which complement each other. As an example, fast charging properties of supercapacitors and slow charging properties of Li-Ion batteries are combined in [13] to form a better performing energy storage system for power networks. In [14], a battery bank and a flywheel connected to a Permanent Magnet Synchronous Generator (PMSG) as hybrid energy storage is used for compensation for the power fluctuation of a large scale wind farm. Other important aspects in relation to hybrid energy storages that have been researched and are worth mentioning here are; smoothing control of large-scale wind farm based on hybrid energy storage [15], optimized planning of power split in a hybrid energy storage system [16], stability analysis of hybrid energy storage system [17], low voltage hybrid renewable energy system management [18] and hybrid energy storages in propulsion systems [19, 20].

3. Energy storages and renewable energy sources harnessed

Looking at the energy storage system from the point of view of various renewable energy sources harnessed also becomes important from various aspects. Some of these key aspects are, sizing of the energy storage, selection of the type of energy storage and control aspects of energy storages. The focus here will be limited to wind energy, and solar energy.

3.1. Wind energy harnessing

In relation to application of energy storages in wind energy harnessing, optimal coordination of battery energy storages and demand response programs [21], optimal sizing of energy storage system [22] and optimal onshore wind power integration [23] are heavily researched. An analysis on the influence of the wind system type (fixed-speed and variable-speed systems) and wind farm size on the capacity of the energy storage system is presented in [24]. Design and dynamic power management of energy storage system for wind plant energy storage systems is presented in [25, 26]. The Fig. 2(a) and (b) shows two popular topologies for locating the energy storage system in wind power generation systems [25, 26]. Comparison between demand response programs [27], power smoothing and power ramp control [28], sensitivity analysis on locations of energy storage [29] and power fluctuation alleviation using cascade STATCOMs [30] in wind power generation systems incorporating energy storages are other key aspects worth mentioning here.

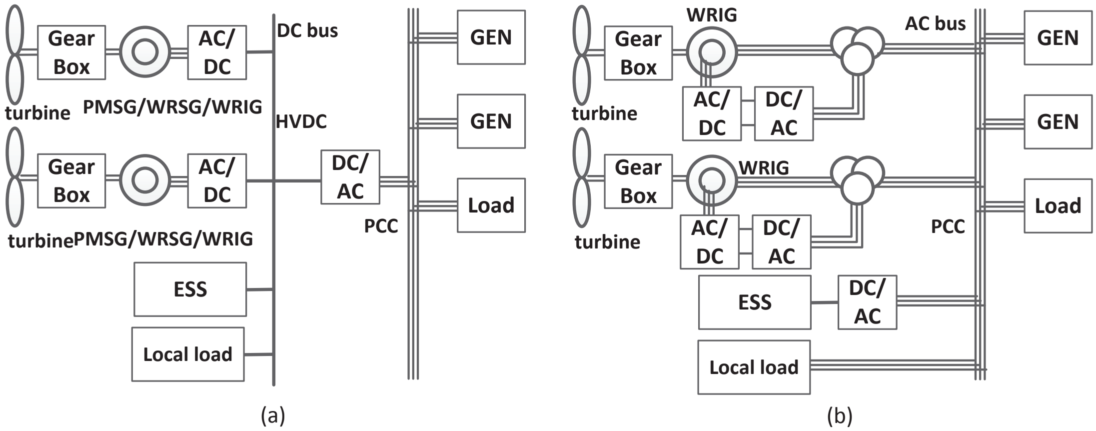

Fig. 2. (a) Energy Storage coupled to the DC bus; (b) Energy Storage coupled to the AC bus through DC/AC converter.

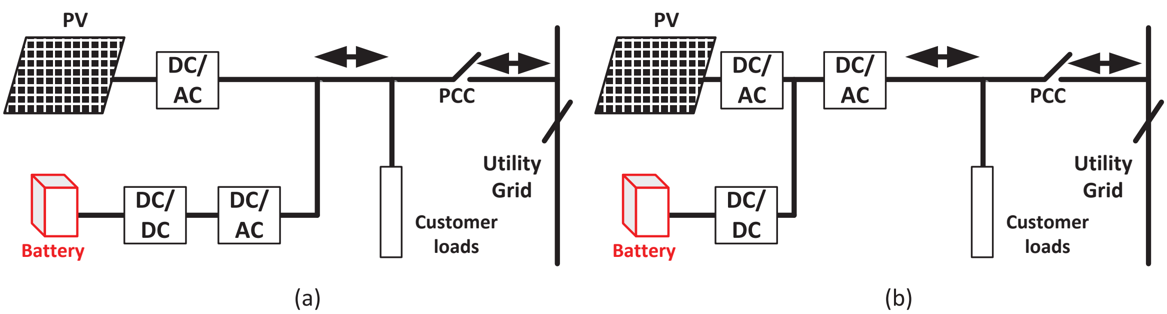

Fig. 3. (a) AC-Linked PV-battery-storage power conditioning system; (b) DC-Linked PV-battery-storage power conditioning system.

3.2. Photovoltaic energy harnessing

Just like in case of wind energy applications, optimal allocation of PV and energy storage systems in a given power network configuration is a significant research question addressed in several publications [31, 32]. Use of PV power plants oriented east, west and south with energy storage system for electricity generation in different time intervals is analyzed in [33]. A cascaded photovoltaic system integrating segmented energy storages is presented in [34]. Two circuit configurations of PV-battery-storage power conditioning systems are shown in Fig. 3(a) and (b) [34]. The bigger picture of Stochastic-based scheduling in a Micro Grid having integrated wind turbines, photovoltaic cells, energy storages and responsive loads is presented in [35], which is the more likely scenario of a future power network.

4. Conclusion

As a result of the major challenges the world is facing today due to global warming and the ever decreasing conventional sources of energy such as fossil fuels, developing methodologies for harnessing all possible forms of renewable energy has become a heavily researched area within the power and energy research communities. The paper identified three major categories under which use of energy storages can be in future power networks can be reviewed. They are; power network configuration and renewable energy sources harnessed. In all these categories, use of energy storages could be seen as an essential feature in regard to future power networks. Various research approaches are available within reported scientific literature on choosing the most suitable energy storage solution, optimizing its performance, controlling the energy storage and the overall power network etc. It can therefore be concluded here that energy storages will be an essential and significant feature in future power networks.

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