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Implementation of Energy Storage in a Future Smart Grid

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Abstract: Modernization of power usage and design is demanding for new control and operation strategies of the smart grid. The changes in load control system coupled with the variable and stochastic nature of renewable energy integrated in the smart grid offers a new set of challenges in balancing generation and consumption. The deployment of energy storage system throughout the grid from generation to end-user present an opportunity to transcend the power balance paradigm by storing energy during off-peak and redispatched when needed. It also makes process happen more effectively and improve system performance. This paper addresses commonly used energy storage technologies, their application and benefits. The simulation carried out using OpenDSS software shows the effectiveness of energy storage on intermittent renewable energy and its positive impact on the tasks of voltage control.

Key words:

INTRODUCTION

The inability to store electrical energy has made the utility industry to always operate on the principle of instantaneous supplying demand. There is need to maintain balance between generation and consumption, from generation capital planning to real-time control center operation. Smart grid seamlessly integrates renewable energy (RE) such as solar or wind power which they in turn solve the problem of energy crisis and climate change. However, the stochastic characteristic and the inherent property that exist in the solar and wind power presents difficulties for power system security operation. The deployment of energy storage [ES] system throughout the grid from generation to end-user (Fioravanti 2011) present an opportunity to transcend the power balance paradigm by storing energy during off-peak and redispatched when needed. Energy storage improves network performance in connection with other smart grid control technologies such as demand side integration. The event definitions and varying behavior of the network on both long and short timescale determine the level of contribution of the energy storage system. A greater number of problems could be solved by a higher energy capacity and power rating (1kW - 1GW) ES (Mohod and Aware 2008; Tanabe, Sato *et al*. 2008; Zhong, Zhang *et al*. 2008) but there is a balance of cost/benefit analysis (Wade, Taylor *et al*. 2010).

In addition ES can increase grid reliability and asset utilization (EPRI 2010; Rastler 2010) Energy storage facilities relieve congestion and constrains. They provide easy connection of renewable sources and make islanding possible (Hamidi, Smith *et al*. 2010), and allows load leveling and peak shaving (Kumar 2011). Energy storage such as battery, thermal, hydrogen, superconducting magnetic energy storage (SMES) devices, and ultra-capacitors play an important role to minimized the impact of sudden load changes and fluctuations in solar and wind generation, as well as to shift energy consumption from peak hours by providing energy balancing, load following, increased supply redundancy and system reliability. The capability of distributed storage to store non-despatchable energy from renewable energy sources can certainly improve system reliability (Shaaban and Majid 2010).

Application of Energy Storage in Smart Grid:

Energy storage is essential in the visions of the SG, most importantly with respect to renewable generation. Energy storage systems is needed throughout the transmission and distribution (T&D) systems; at the generation, in transmission system support, at different point in the distribution feeder and on particular equipment and appliances on the end-user's side of the energy meter (Mohd, Ortjohann *et al*. 2008) as shown in Fig. 1. The ES is applied to decouple the timing generation and consumption of electric energy. A typical application is load leveling, which involves the charging of storage when cost of energy is low and utilization as needed. ES is used to assume continuity of quality power.

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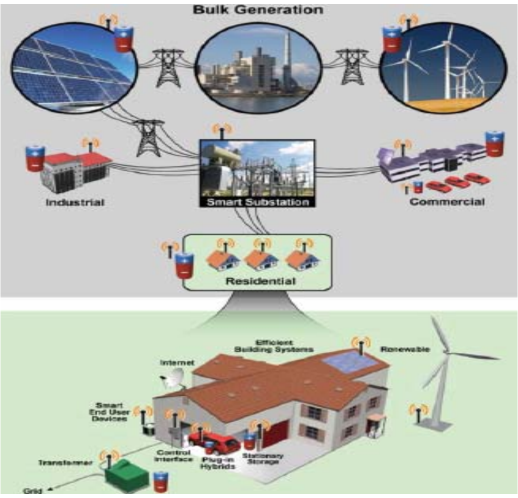

Fig. 1: Application of energy storage and future smart grid.

Without ES, RE penetration would be back up with fossil fuel that run at low efficiencies and release carbon dioxide emission which contradicts the purpose and benefits of RE. ES in conjunction with power electronics that interfaces the ES and the utility gird have a great technical application and enormous impact on future smart grid. this results in many benefits for managing the fluctuations in energy use as well as generation. Some of these benefits are summarized below:

- ***Grid Voltage Stability Enhancement:***

  ES can maintain the voltages of the generation and load ends within the normal values by providing additional reactive power and injection of real power for a period up to 2 seconds.

- ***Power Grid Reliability*:**

  ES increases power grid reliability by providing uninterrupted power supply.

- ***Power Quality Improvement*:**

  ES reduces harmonic distortions, and eliminates voltage sags and surges through the provision of ride through for momentary outages, and extended protection from longer outages, coupled with advanced power electronics. This improves the power quality.

- ***Renewable Support*:**

  ES facilitates the integration of RE and can improve the net power quality(Noce, Riva *et al*. 2012). Hybrid ES with Wind and solar PV, makes ES increase the value of the PV and wind generated electricity, thereby balancing energy supply with consumer demands (Choi, Tseng *et al*. 2008; Styczynski, Lombardi *et al*. 2009).

- ***Grid Energy Management Improvement*:**

  The ES provides both active and reactive support. It can be used in the energy management applications such as load shifting, peak shaving, load leveling and commodity storage where electricity storage technologies are used in daily cycles for financial benefit (Hamsic, Schmelter *et al*. 2006).

- ***Grid Frequency Excursion Suppression*:**

  It can provide prompt spinning reserve (or load) for mitigating load-generation imbalance with the ES discharging active power for a duration up to 30minutes which suppresses grid frequency excursion (Rebours and Kirschen 2005).

- ***Grid Angular Stability Enhancement*:**

  ES technology has the capability to keep all components in the system in synchronous with each other and mitigate system collapse by the production and consumption of active power at periods of 1 to 2 seconds.

- ***Customer Energy Management*:**

  ES can dispatch stored energy at off-peak or low cost times to manage demand on grid-sourced power.

Real planning and implementation strategy should be related to the real-time control and operational functionalities of the ES in conjunction with RE so as to get rapid integration process (Mohd, Ortjohann *et al*. 2008).

Energy Storage Technologies:

Energy storage technology is a conversion of electrical energy from a power system into a form in which it can be stored until converted back to electrical energy (DTI 2004). There are different types of ES technologies nowadays (Makansi and Abboud 2002; Ibrahim, Ilinca *et al*. 2008). Table 1 summaries commonly used ES technologies, their principle, advantages, drawback and applications.

Table 1: Commonly used energy storage technologies .

Type	Principle	Advantages	Drawback	Applications
Pumped hydro energy storage	Use up level water reservoir to store energy	Very large energy storage with long life	Slow response speed with geographic limitation	Energy management, frequency control and reserve provision
Superconductive Magnetic Energy storage (SMES)	Store energy in direct current (DC) magnetic field	Very high efficiency, fast response speed and relatively long lifetime	It is too expensive and relatively small storage	Power quality improvement, angular stability control and voltage support
Compress air energy storage (CAES)	It uses pre-compressed air to store energy, 40% less gas fuel for gas turbine generator	Very large energy storage with long life	Slow response speed with geographic limitation	Energy management, frequency control and reserve provision
Batteries	Customer-side energy storage device. Vanadium redox flow, NAS, Li-ion	Fast response speed with large storage facility	It is expensive with short lifetime	Voltage support, stability control and load leveling.
Super capacitor energy storage	It is a new kind of energy storage device with very high capacitance, thousands of times larger than that of the conventional capacitor	High density energy storage and fast response speed	Expensive and limited lifetime	Power quality stability control and voltage support
Flywheels energy storage.	Flywheels energy storage.	Flywheels energy storage.	Relatively small storage	Active and reactive stability control (Levine and Barnes 2010; Roberts and Sandberg 2011).

Community Energy Storage System (CES):

The development of an intelligent smart grid comes with a challenge of balancing all the variables in connection with dynamic load control powered from an ever increasing penetration of renewable energy resources. The balancing of these variables could be achieved through the installation of energy storage throughout the grid system. It provides significant contributions in overcoming the difficulty of random fluctuation created by RE (Lund and Paatero 2001; Liao, Liu *et al*. 2010). Design elements from demand response techniques in homes to dynamic loading of transmission and distribution (T&D) networks based on the intermittency of renewable energy (RE) will come to bear in true smart grid design. Community energy storage also known as distributed energy storage system (DESS) provides voltage control, peak load management, reactive support, capacity and ancillary service market, frequency regulation and other smart grid services (Zhou and Qi 2009) and could be controlled in real-time utilizing feeder or substation load signals. During system outages CES could also allow non-faulted subsections of the grid to operate in autonomous mode with proper relaying and protection schemes (Delille, François *et al*. 2010).

Just like microgrid, it is an aggregation of loads and micro-sources that operate as a single, self controlled system and produce reliable and high quality energy supply to customers (Lasseter, Akhil *et al*. 2007). The best approach to the application of CES is to use smaller systems rated 25kW-200kW with discharge time of 2-4 hours (Bjelovuk, Nourai *et al*. 2009) that are connected on the low voltage side of the distribution transformer and protect the final low voltage (LV) circuits to individual end- users. Another application is to use a larger 200kW- 5000kW system that is directly connected to three-phase distribution feeders or microgrids. Each CES power electronic converter (PCS) is capable of injecting kVARs for use in voltage control. Connection of control devices at the far end of the feeder that is very close to the end-user, provides ultimate in voltage control and service reliability. There is a major deviation from traditional utility system control philosophy when the challenges of even greater control of voltage at the point of end-users are met. Today, more sophisticated electronics loads are connected by customers who demand for greater service reliability and even larger loads such as plug highbred electric vehicle (PHEV) charging units are randomly added in the grid. Besides these changing load patterns there is high penetration of RE most especially solar roof tops which cause a growing amount of energy reverse back into the grid when RE generation exceed customers power demand. It is good to store the excess energy during off peak period for redispatch at peak period.

Location of CES throughout the distribution system will store the excess energy with less line losses and redispatched back to the same customers when required. The CES could equally control the local voltage during cloud pass over or voltage sag in solar PV. CES utilizes the power electronics in it to act as instantaneous capacitive VAR compensators to maintain proper voltage and power factor in local area. In addition, CES units could provide peak power in case of abnormal amount of PHEV quick charges.

Test Case/Results:

A sample circuit is taken from a modeled IEEE123 test feeder of an actual 115kV/4.16kV distribution circuit of approximately 10MW of total load distributed among commercial and residential energy consumers. The 123 test feeder consists of a three-phase feeder and a number of one, two and three phase laterals that taps off the mains. The circuit is implemented in OpenDSS, a simulation tool for electric utility distribution system, which can be used as both a stand-alone executable programme and a Com DLL (Dugan 2009) that can be driven from Excel, MATLAB, C++ etc. Off-line tools are utilized to generate intermittent RE (solar PV, wind) and loads curves.

The RE and the load are connected to the IEEE123 test feeder. A 3MW PV with a 3MWh rated capacity and 3MW ES are integrated to Node 450. The power factor of the power generated is unity. Solar radiation was obtained through OpenDSS capability. These profiles were used to later drive the shapes of the power generated. Different load shapes were created with OpenDSS capabilities and each of these shapes were connected to different nodes. The minimum storage capacity hold in reserve of the ES is assumed 25%. The 10MVA interconnection transformer remains the same, and the ES device is controlled to maintain the regulating transformer loading below 10MVA. Immediately the power injected by the PV falls below 1000kW, the ES device starts discharging until the energy level reaches the minimum capacity or the cycle starts again.

Figs. 2-5 show the simulation results. Fig. 2 shows the solar PV ramp. There was voltage overshoots at 1.05 pu as power output ramps up. The regulator taps up or down to compensate for voltage drop or rise as the case may be. The energy storage system in the test study level the power injection curve as shown in Fig 3 and mitigate transformer overloading as shown in Fig. 4, the power flowing through the interconnection transformer does not increase above 100kW while Fig. 5 shows per phase power injection and energy storage. The study therefore, reveals that ES can be integrated along with RE for load leveling and shifting, voltage regulation and VAR support in power system. A large size of ES system will be required for better leveling of the power produced by renewable energies The non-dispatchable and intermittent power generated by renewable energy most especially wind and solar PV can be dispatchable and non-intermittent (Smith, Sen *et al*. 2008; Martinez and Martin-Arnedo 2011).

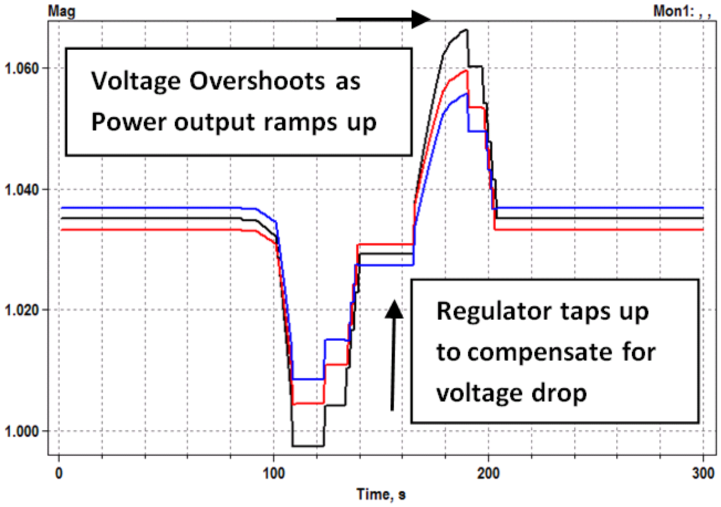

Fig. 2: Solar PV ramp without energy storage.

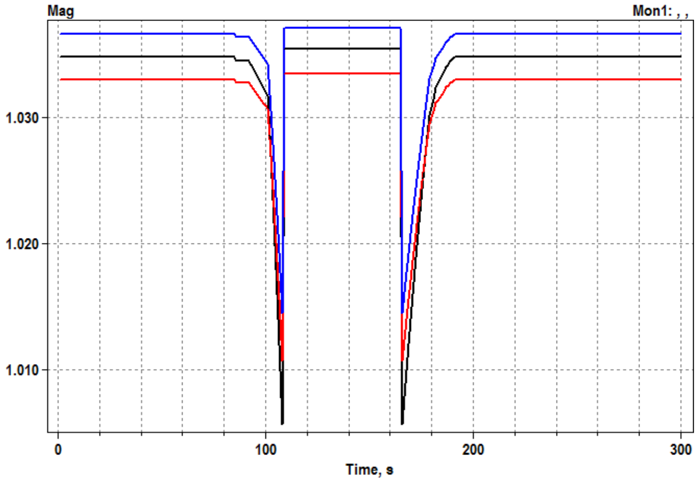

Fig. 3: Solar PV ramp with energy storage.

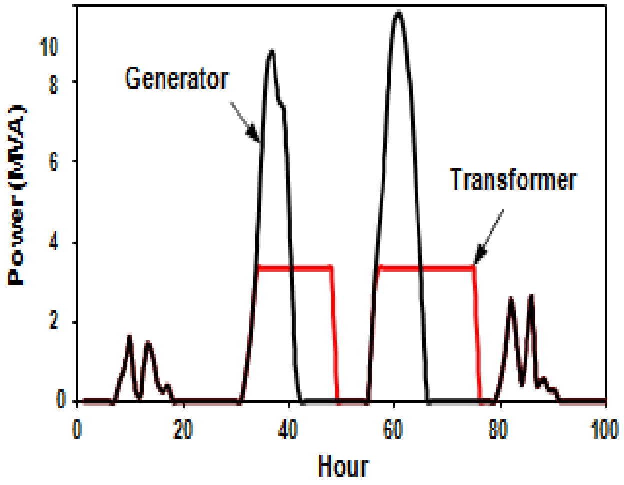

Fig. 4: Per phase power injection and power flow through the interconnection transformer.

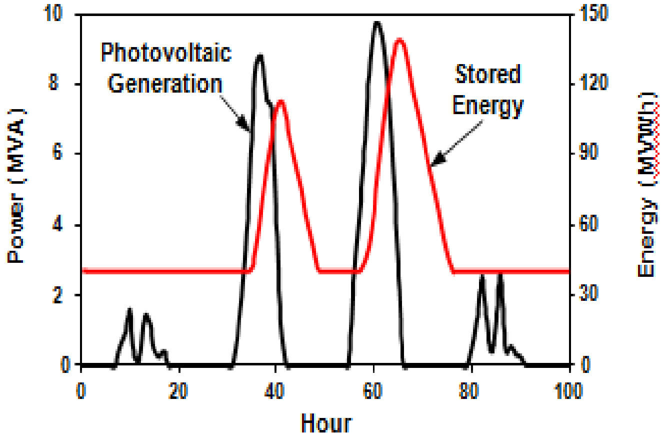

Fig. 5: Per phase power injection and stored energy.

Conclusion:

The recent drift towards balancing generation and consumption, reduction of carbon dioxide emission, mitigation of inherent characteristic of renewable energy along with increasing demands of high power quality and reliability, demands for the deployment and implementation of distributed energy storage system in the smart grid. Although, REs are environmentally beneficial but the stochastic and non-dispatchable nature of wind and solar power causes voltage and frequency variation on the grid. Electrical energy storage distributed in the grid will not only be a key enabler for a smart grid with high penetration of RE but provide reliable and quality power supply. The simulations conducted shows that deployment of ES with the RE has a positive impact on the task of voltage control and power flow management of the distribution system. The ES operates to improve network performance. Progressive transition to future intelligent grid will make ES deployed throughout the grid system become an integral part of the smart grid.

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