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Lead–acid batteries in stationary applications: competitors and new markets for large penetration of renewable energies

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Abstract

With increasing deregulation of the European electricity market, the quality of supply is becoming an issue of growing importance. Grid-connected electricity storage systems (ESSs) can enhance the quality of supply by: (i) shortening black-out periods; (ii) shifting excess energy for use during periods of high demand; (iii) sustaining the grid for better power quality. These problems are being addressed by using technologies such as power electronics and ICT. But storage systems offer a cheap and efficient solution to such concerns. ESSs can also power high-value, ancillary services. This paper analyses the new potential markets for storage systems in the context of distributed energy resources with a high penetration of renewable energies in the electricity networks. While lead–acid batteries are the most used technology in all types of stationary applications, many different storage technologies are claimed to fulfil the technical requirements of the above applications, in particular the emerging ones. Therefore, a comparison is made of lead–acid technology and its competitors in terms of technical and economic considerations.

Keywords: Lead–acid battery; Distributed energy resources; Storage technologies; Stationary applications; Power quality; Renewable

1. Introduction

Deregulation of the European electricity market is highly favourable for an increased penetration of renewable energy sources (RESs). Wind energy and photovoltaic energy are, however, intermittent and unpredictable, but consumers require an electricity supply that is both highly reliable and of good quality. Therefore, in order to secure a grid with a high penetration of RESs and other distributed energy resources (DERs), 'quality of supply issues' need to be addressed such as:

(i) power quality concerns (flickers, voltage sags, harmonic distortion, reactive power consumption, etc.),
(ii) grid balance concerns (matching of energy consumption with total generated capacity), and
(iii) concerns relating to compliance with grid requirements (power flows limited by the thermal capacity of the lines, avoidance of over-voltage on the distribution line, etc.).

In many European countries, grid operators address these problems by setting stringent interconnection rules. These rules are designed to limit the penetration of RESs below a level that ensures that the above mentioned reliability concerns will not occur, and thus inhibit the development of RESs.

Most recent RES devices incorporate the latest advances in cutting-edge technologies such as power electronics and ICT to limit their grid impact. Indeed, modern wind turbines have rather small harmonic emissions, are controllable, and can even support the grid by providing reactive power when needed. Demonstrating the feasibility of grids with large penetration of RESs will, in turn, convince grid operators to allow larger access to small and distributed power producers.

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Energy storage systems (ESSs) have the potential to play a key role. Although they have been little studied for this application in Europe, ESSs appear to be complementary to ICT and power-electronic based solutions, since they can provide large capacity with a short response time and provide ancillary services such as uninterruptible power supply (UPS). It is therefore pertinent to consider more precisely the role of energy storage systems and evaluate their market potential. Since many different storage technologies are claimed to fulfil the technical requirements of the above applications, it is necessary to compare their performances and costs so as to identify the best candidates. The results presented here are taken mostly from work conducted by the INVESTIRE. Thematic Network [1,2].

2. RES integration in the grid and implemented solutions

Integrating renewable energy into electric networks causes some familiar power-quality problems, as well as some problems related to reliability of supply that are less common. These issues can be categorized as either interface (engineer) or operational/planning issues.

2.1. Interface issues

Interface issues are related to all the events that affect the power quality of the energy supplied to the end-users (harmonics, reactive power supply, voltage regulation, frequency control). Compared with conventional electricity-generating units, RES power plants have a larger impact on the quality of supply because their output power depends on external conditions such as wind speed or solar irradiation. Examples of the resulting phenomena that affect the grid are:

(i) transients of wind turbines (high consumption of reactive power for direct-connected turbines),
(ii) flickers emission due to the shadow effect of wind turbines (direct-connected turbines), and
(iii) harmonic injection of photovoltaic (PV) inverters using self-commutated converters, etc.

Interface problems are issues of growing concern for utilities because RES penetration tends to increase while the computer-based economy requires reliable electricity.

2.2. Operational/planning issues

Operational/planning issues essentially deal with the intermittent power output inherent to RES generation. This intermittence raises concerns over balancing of the grid. To ensure a constant grid balance, i.e., an energy production equal to the energy consumption, the grid operator has to address: operating reserve requirements, economic dispatch, consumption modelling, and RES output power prediction. When integrating RES into a utility system, reserve margins must account for the maximum probable decrease in wind or PV plant output over a given period. Whereas RES power quality issues are relatively well known, operational/planning issues remain the main barriers to the widespread penetration of renewables in present electricity markets.

2.3. Implemented solutions

So far, grid integration issues have mainly been addressed by improving RES technologies, by integrating latest advances in power electronics, and by developing new grid concepts. Experience has shown, however, that these solutions do not address all the grid-integration problems and that energy storage systems could provide a cheap and efficient response to the remaining technical issues.

2.3.1. Development of grid-friendly RES technologies

Wind turbines were once considered to be a major grid polluter. Indeed, the first Danish wind turbines consumed a considerable amount of reactive power during transients and injected a large level of harmonics in the grid. This was a source of concern when turbines were connected to weak grids. The latest wind turbine models are equipped with more sophisticated power electronics and/or more advanced generators (e.g., the doubly-fed induction generator, DFIG) than their predecessors. These newer systems have largely eliminated past problems associated with harmonics and reactive power.

Photovoltaic inverters now use leading-edge power electronics technologies that greatly improve the quality of current injected into the grid. The same trend exists for all RES technologies and improvement in performance, reliability, and controllability tends to limit the impact on the grid. Most recent wind turbines (advanced DFIG wind turbine) can even support the grid by consuming or producing reactive power when needed.

The extent to which grid integration of RES is a cause for concern today appears to be largely a function of the grid strength at the point of integration.

2.3.2. Development of innovative grid concept including ICT and power electronics

Recent advances in ICT technologies and microelectronics have enabled the development of a new concept of grid structure that can manage the fluctuating output power of RES power systems. This innovative structure is generally called a micro-grid or a mini-grid.

The micro-grid structure assumes an aggregation of loads and small generating sources (including RES) to be a single system that provides both heat and power. The majority of the generating systems are power electronics based to provide the required flexibility to insure controlled operation as a single aggregated system. Such systems are generally connected to the conventional grid through a single interconnection point. But, given that the energy drawn from the main grid can be