ARTICLE IN PRESS

Journal of Network and Computer Applications ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Network and Computer Applications

journal homepage: www.elsevier.com/locate/jnca

Reactive power control for an energy storage system: A real implementation in a Micro-Grid

D.A. Sbordone [a,*], L. Martirano [a], M.C. Falvo [a], L. Chiavaroli [a], B. Di Pietra [b], I. Bertini [b], A. Genovese [b]

Q1

[a] DIAEE - Electrical Engineering, University of Rome Sapienza, via Eudossiana 18, 00184 Rome, Italy
[b] ENEA, Italian National Agency for New Technologies, Energy and Sustainable Economic Development, Via Anguillarese 301, 00123 Roma, Italy

ARTICLE INFO

Keywords:
Charging stations
Energy storage
Information and communication technologies
Smart Grid
Micro-Grid
Smart metering

ABSTRACT

In last years, the power system operators are tackling many challenges for the renewable energies integration on the grid. Further, the expected increase of electrical demand due to the uncoordinated contemporary charging of a huge number of Electric Vehicles (EVs) can create chaotic phenomena with a negative impact especially on the distribution network. Help can be offered by the deployment of Smart Grid technologies, such as Smart Metering Systems (SMSs), Information and Communications Technology (ICT) and Energy Storage Systems (ESSs). In particular, in Micro-Grids, Battery ESSs (BESSs) can play a fundamental role and can become fundamental for the integration of EV fast charging stations and distributed generations. In this case the storage can have peak shaving, load shifting and power quality functions. The ESSs can provide ancillary services also on the grid as the reactive control to adjust the power factor. In the present paper, a monitoring control program to manage the reactive power of a real ESS in a Micro-Grid has been implemented. The system is a prototype, designed, implemented and now available at ENEA (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) labs. A wide experimental activity has been performed on the prototype system in order to test this functionality for the integration in a bigger Smart Grid available at the same ENEA labs including the Micro-grid. The integration has been possible, thanks to the free ICT protocols used by the researchers and which are described here. The results of the experimental tests show that the system can have good performance to adjust the power factor in respect to the main distribution grid and an EV charging station.

1. Introduction

A Smart Grid is commonly defined as a portion of an MV/LV distribution network, assembled and operated by the Distribution System Operator (DSO) with the help of ICT, in order to improve the efficiency, reliability, economics, and sustainability of the production and distribution of electricity (Jackson 2014). The typical scale of a Smart Grid can be considered as a portion of an MV system supplied by an HV/MV substation.

A Micro-Grid is commonly defined as a group of interconnected loads and Distributed Energy Resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the main grid. In other words it is a smaller portion of the network, typically supplied by an MV/LV substation operated by a private user (or even by an aggregator) with the help of ICT (Tao et al., 2011). Typically, Smart Grids and Micro-Grids contain Distributed Generation (DG), Smart Metering Systems (SMSs) and an ICT infrastructure (Skopik et al., 2014; Falvo et al., 2013; Arboleya et al., 2015). The differences between Smart Grid and Micro-Grid are not only in terms of energy scale and voltage level but also in terms of goal of the operation (Huang et al., 2014). A Smart Grid operates in order to resolve the power unbalancing issues and other technical problems in real time and the DSO, that is, its player could offer new energy services to the users. A Micro-Grid operates in order to optimize the energy fluxes and, mostly, the energy costs and the user (or the aggregator), that is, the player could offer new services to the DSO (López et al., 2015). So, the distribution networks are strongly going to change their infrastructure allowing high penetration of DG such as wind power plants, photovoltaic plants and cogeneration units. Further, the EVs will spread more and more (Ustun et al., 2013; Pillai et al., 2012). So, due to partial unpredictability of both load and power generation from some renewable sources, power unbalances occur between the generation and the load on the grid. The DSOs are developing Smart Grid examples to supply intelligence to the grid through SMSs and an ICT infrastructure. Main capabilities of the Smart Grid system include the integration and aggregation of distributed

* Corresponding author. Tel.: +39 3402818606.
E-mail address: danilo.sbordone@uniroma1.it (D.A. Sbordone).

http://dx.doi.org/10.1016/j.jnca.2015.05.006
1084-8045/© 2015 Elsevier Ltd. All rights reserved.

energy resources (as DG, EV), demand response (DR) large-scale Renewable Energy Sources (RES), and ESS units (Weitemeyer et al., 2015). The ESSs have started to be used for multiple applications, such as wind and solar power smoothing, peak-shaving, frequency regulation, EV charging stations and others applications (Luo et al., 2015). In the short term, the ESS needs to fill the gap between the ramping down time of wind and solar and the ramping up time of these back-up plants. In addition, the main energy storage functionalities such as energy time-shift, quick energy injection and quick energy extraction are expected to make a large contribution to security of power supplies, power quality and minimization of direct costs and environmental costs (Zakeri and Syri 2015). The main challenge is to increase existing storage capacities and increase efficiencies and security.

The ESS can be integrated at different levels of the electricity system:

- Generation level: arbitrage, balancing and reserve power, etc.
- Transmission level: frequency control, investment deferral, etc.
- Distribution level: voltage control, capacity support, etc.
- User level: peak shaving, time of use cost management, etc.

The ESSs can inject/absorb the reactive power also and that can be the main control approach to mitigate voltage rise issue in distribution networks (Rouco and Sigrist, 2013). This feature can be managed by inverter's ESS using the available capacity at a specific moment in accordance with the demand of the electrical grid. This control is added to the regulation resources on-load tap changers. The experimental ESSs were based on electrochemical batteries on the grid lately. The BESSs offer a very dynamic system (Ma and Yang, Lu). It is adapted for power and energy applications. Actually, the BESS are used to develop the Micro-Grids and the future smart grid.

In the present paper the results of experimental activities performed on the prototype of BESS in order to test the reactive power compensation into the integration in a Micro-Grid available at the ENEA labs (Italian National Agency for New Technologies, Energy and Sustainable Economic Development) are reported. The reactive power control is part of CEI 0-16 and CEI 0-21, Italian standards defining the rules of connection of active and passive users to the grid (Delfanti et al., 2015). The aim of the monitoring activity was to define the best BESS's control in a Micro-Grid to provide ancillary services to the main grid, in particular, a reactive power service provided by the MV/LV transformer (Cavey et al., 2013). The later permits to use the BESS not only for energy and active power service but also to help the grid to stay stable and to increase the power quality in the presence of renewable generations. The experimental activities performed also deal with a special load that is an EV fast charging station included in the Micro-Grid: the survey has been extended to the control of the reactive and active power required by an EV fast charging station, giving the priority to the reactive power. The whole monitoring activities have been possible, thanks to the implementation of a customized communication and control system able to integrate the ESS with a smart metering system present into the Micro-Grid. The original point of this research is the analysis by using open protocols to manage a new service provided by the BESS. Further, a smart metering model has been developed and validated by experimental data to check the load of future systems.

2. Smart Grid and Micro-Grid: BESS integration

2.1. European case studies

Based on the content of the M/490 EU Mandate the CEN, CENELEC, and ETSI have been requested to develop a framework to enable European Standardization Organizations to perform continuous standard enhancement and development in the field of Smart Grids (Knapp and Samani, 2013). The EU wants to provide greater coherency of actions, as well as technological cooperation and a wider market. Energy storage is closely related to policy on renewable electricity. Here, member states have differing interests and possibilities and are at different stages of development (from near zero to over 50% of electricity generation). Support for storage within the EU internal electricity market and regulatory adjustments to enable storage facilitate the progress towards a single internal electricity market in Europe. Energy storage should be integrated into, and should be supported by, all relevant existing and future EU energy and climate measures and legislation, including strategies on energy infrastructure, the Connecting Europe Facility, RES promotion, Smart Cities and Communities, completion of the Internal Market, Energy Efficiency Directive, Horizon 2020, 2050 Roadmap, as well as the forthcoming discussion on a 2030 Strategy.

Different projects in EU have been founded to optimize and manage a wide range of different services that the storage can provide. These services need ICT infrastructure and a smart metering system. Some of these projects are provided here:

1) *Orkney Storage Park Project: In 2013 Mitsubishi Heavy Industries, Ltd. with Scottish Hydro Electric Power Distribution (SHEPD) created a demonstration project using the UK's Orkney Islands distribution grid* (Foote et al., 2013)*. The system capacity is 800 kW h nominal and the BESS is based on lithium*
2) *Saft Enel Substation Energy Storage Project: Saft's substation is located in the Puglia region of Italy, an area with a high level of variable and intermittent power from renewable energy sources that can cause reverse power flows on the high/medium voltage transformers. The role of Saft's lithium batteries in the ESS is to reduce the variability of power flow as well as allowing for more controllable energy exchange between the substation and the Italian national grid* (Bianco et al., 2015).
3) *Smarter Network Storage project: It is the largest such facility in Europe, a 6-MW/10-MW h lithium-ion battery storage project in U.K. The fully automated system is intended to provide balancing support for the grid and test how battery storage can make the network more efficient, as well as to improve the economics of battery storage systems and support the UK Carbon Plan* (Lidula and Rajapakse, 2011).

2.2. USA and rest of the world projects

Some smart grid projects are developing in USA and in the rest of the world. They provide an integration with the BESS. Some of these projects are reported here:

1) *The frequency regulation services and a firm wind project: AES is installing a 32 MW/8 MW h BESS based on lithium ion battery technology at the Laurel Mountain facility in West Virginia (USA).*
2) *CCET Technology Solutions for Wind Integration: Samsung SDI and Xtreme Power is installing a 1 MW to 1 MW h Lithium Ion based Battery Energy Storage System (BESS) system at the Reese Technology Center in Lubbock, Texas as part of a Smart Grid Demonstration Project (SGDP).*
3) *Fujian Electric Power Research Institute Mobile Energy Storage Station: the Fujian Electric Power Research Institute developed a mobile energy storage prototype project consisting of two sets of 125 KW/250 KW h battery systems and one of 125 KW/375 KW h hour battery system. The unit provides peak electricity for 10–15 commercial electricity consumers in the tea production industry* (Marmiroli et al., 2012).

Please cite this article as: Sbordone DA, et al. Reactive power control for an energy storage system: A real implementation in a Micro-Grid. Journal of Network and Computer Applications (2015), http://dx.doi.org/10.1016/j.jnca.2015.05.006