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Fast screening techniques and process for grid interconnection of wind-storage systems

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A B S T R A C T

This paper presents fast screening techniques and process for grid interconnection of wind-storage systems. In a smart grid, the wind turbines are likely installed accompanying with battery energy storage systems, called "wind-storage system", to largely increase the penetration of renewable energy. A fast screening approach based on a genetic algorithm with self-adaptive evolution provided from a commercial software, OPTIMUS, is applied to predetermine the maximum power output of a wind farm. The total power generation of a wind farm can be greatly increased without violating these limitations through the assistant of a battery energy storage system. Time-varying distribution system operating status make the operation problem of a wind-energy system further complicated. The results show that the maximum power output of a wind farm and the required capacity of the battery energy storage systems in a wind-storage system mainly depend on the system short-circuit capacity at the interconnection point of the wind-storage system. This paper confirms the effectiveness of the proposed algorithm using actual wind farm data and a physical distribution system of Taiwan. The outcomes of this paper are of value to fast screening the grid-interconnection applications of wind-storage systems.

1. Introduction

1.1. Background

Recently, many researchers focus on the development of techniques to increase the penetration level of renewable energy sources (RESs) in a smart grid and enhance the utilization factors and capacity factors of distributed generations (DGs), such as wind, solar, tidal energy, and so on. The main objectives are reducing pollution and avoiding energy crises [1]. Among the various RESs, wind turbine generation (WTG) systems are the most competitive due to lower investment costs – compared with other sources such as photovoltaic (PV) and tidal generation systems [2]. The installed capacity of the large-scale wind farms (WFs) has therefore rapidly grown in recent years [3], and wind power is expected to grow to 20% of the total energy production in the coming two decades [4]. It is also regarded as an important alternative to traditional power generation sources.

1.2. Literature reviews

There are many problems related to the interconnection of the WFs to a distribution network. Some critical issues are always necessary to be discussed in more detailed [5] such as (1) power quality (e.g., voltage deviation, flicker, harmonic, frequency) due to the intermittent characteristics of the output power of WFs, (2) output current prohibition due to the constrain of the feeder thermal capacity (FTC), (3) protective coordination and (4) the loss of power grid. Furthermore, the interconnection point of a WF along a distribution feeder is usually far away from substation and therefore has a relatively small system short-circuit capacity (SCC). That is, the operation of grid interconnection of a WF will cause significantly impacts on the grid, and may bring about stability and power quality problems for the grid. Practically speaking, the FTC and steady-state voltage deviation (SSVD) of a distribution feeder are primarily concerned with the operation of the distribution feeder. An impact analysis of wind farms in the Jeju island power system concludes that a loss of wind farms significantly affects the power quality (frequency and voltage magnitude) of the distribution system since they are integrated within the distribution system [6]. A calculation method is proposed to determine the maximum penetration of wind farms in the small isolated power

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system in Jeju Island. The frequency and duration of wind power rejection are of greatest interest in this study [7].

The stochastic behavior of wind and important fluctuations of daily and seasonal electricity loads pose a strict penetration limit for the contribution of wind energy to the corresponding load demand. The application of this limit is necessary in order to avoid hazardous electricity grid fluctuations and to protect the existing thermal power units from operating near or below their technical minima. Hence, Kaldellis presented an integrated methodology to estimate the maximum wind energy penetration in autonomous electrical grids based on available wind potential existing in the Aegean Archipelago area [8]. On the other hand, the system operators of most power grids have to set a limitation of total output power for the wind power generation. If the total output power of WFs exceeds the specified limitation, the extra electricity should be curtailed. There are remedial measures for all problems that may be caused by the connection of generation and storage to distribution feeders, with the exception of connection to secondary networks. Smart grid innovations can improve system performance in many ways, including distribution-level and customer-level storage that can even out the fluctuations in generation produced by intermittent generation sources. Furthermore, the associated smart inverter can aid in the control of voltage [9].

It is imperative that the issues are solved. Therefore, two kinds of studies are currently popular in many countries: one is on adding control algorithms in each WTG system, and the other on installing additional storage devices. The impact power fluctuation of large-scale WFs is a concern in both these types of studies. The control algorithms used in a WTG system mainly apply to short-term and very short-term periods, such as fault ride through (FRT) [10] or low-voltage ride through (LVRT) [11]. The LVRT is the capability of WTGs to stay connected during short periods of lower electric network voltage. This is required at the distribution level (wind farms) in order to avoid a short circuit at a high voltage (HV) or extra high voltage (EHV) level that may lead to a wide-spread loss of power generation. Installing a smart energy storage system (ESS) is, however, mainly applied to improve WF power fluctuations during medium- and long-term periods. A comprehensive comparison analysis of the reviewed electric energy storage technologies is presented in Ref. [12]. The application of the ESS in addressing WF intermittency is proposed in many papers. Various simple schemes have been introduced to improve battery energy storage system (BESS) charging and discharging. Zeng et al. present a concept in which the BESS can be applied to power smoothing of a generation system with considerable power production fluctuations [13]. The simulation results of a simple charging and discharging scheme indicate that the BESS has the potential to improve a wind farm's performance. Yoshimoto et al. present a control method, state-of-charge feedback control, to maintain the charge level of the battery within its proper range [14]. In this study, Vanadium redox-flow batteries (VRBs) are adopted as energy storage devices and a washout-filter-based scheme is applied to smooth out the short-term power fluctuations of a WF. Similarly, in Ref. [15], supercapacitors are adopted as the energy storage device and a washout filter is applied for improving the output power characteristics of an offshore WF. In Ref. [16], the output power prediction technique of a WF and real-time control of a large-scale grid-level BESS are applied to even out the short-term fluctuations of the WF power output and to enhance the utilization of the BESS capacity. In the previously mentioned studies, the aim of installing additional battery energy devices in a large-scale WF is mainly to smooth the power production fluctuations to improve the voltage quality along a primary distribution feeder.

Nowadays, the BESS is still an expensive option for the WF operation improvement. Optimization of the required capacity of a BESS, therefore, becomes a critical issue for future power grids, especially smart grids. A number of recent studies are inspired this point of view. In Ref. [17], nine possible sizes of the ESSs are taken into account (in combinations of three power and three energy capacities). The sizing criteria adopted in this paper is based on simple trial and error. In Ref. [18], a similar approach to [17] is proposed. In Ref. [19], a probabilistic method is developed for calculating the usefulness of a storage system with a finite energy capacity for evening out electricity generated from a combined wind and solar power system. In Ref. [20], the statistical scenario forecast for the short-term wind power production is used to assess the dynamic sizing of an electrical energy storage system. Daily ESS size is calculated by considering the degree of risk that was represented by a loss function. In Ref. [21], discrete Fourier transform (DFT) is used to decompose the required balancing power into different time-varying periodic components in order to quantify the maximum energy storage requirement for different types of energy storage. In Ref. [22], a Model-Predictive-Control (MPC) method based operational model following NERC standard recommendations, is adopted to determine the optimal sizing of energy storage. In addition [12], survey current developments in electrical energy storage technologies and their application potential in power system operations. It provides a comprehensive and clear picture of installation and operation of a power generation, storage, and distribution system. In Ref. [23], an energy storage system is applied to support the penetration increase of renewable energy in island systems. As mentioned above, many methods are used to determine the proper capacity of BESSs used in large-scale WFs for various reasons. However, they all require a complex procedure. They are not suitable for a feasibility study stage or project review due to their complicated and time-consuming characteristics. Therefore, fast screening techniques must be employed in the review process or in a feasibility study of a wind-storage capacity installation.

1.3. Aim and contributions

Based on the recent theoretical and practical foundations mentioned above, this paper applies the genetic algorithm with self-adaptive evolution (GA-SaE) algorithm to solve the maximum allowable installation capacity problem for the grid interconnection of wind-storage systems. The differences in the power output characteristics of a WF with and without the assistance of a BESS is compared and discussed in detailed. Accordingly, this research proposes a practical approach for simplifying the review process and reducing the review time without requiring a time-consuming power-flow analysis. The effectiveness of the proposed fast screening technique and process is demonstrated by a physical Taiwan Power Company (Taipower) distribution system and actual WF data during different seasons. The proposed method and obtained results are of value to system managers, engineers, and operators, especially during the periods of feasibility study and project review of wind-storage systems.

1.4. Paper organization

The paper is organized into six sections. Section 1 is an introduction of this paper. Section 2 describes the basic concept of a wind-storage system within a utility framework. Section 3 contains the problem definition and solution approach. In Section 4, the proposed method is tested by a typical distribution system of Taipower. In Section 5, actual WF data is applied to demonstrate the effectiveness of the proposed algorithm. Results and discussions are presented in Sections 4 and 5. Finally, Section 6 draws a brief conclusion.