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Microgrid energy management in grid-connected and islanding modes based on SVC

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ABSTRACT

Microgrids are small scale energy grids that can provide adequate energy supply to cover regional demand by integrating renewable energy generation and storage technologies. This paper develops a high performance dynamic model of a microgrid system comprising a wind turbine, a PV, a fuel cell, a micro gas turbine generator, an energy storage, electric loads with variable load profile and flexible AC transmission system (FACTS) devices. The FACTS devices based on static VAR compensators have been employed as a supervisory controller. Key performance indicators such as microgrid power losses, buses voltage deviations, buses power factor, buses voltage total harmonic distortion and voltage-frequency deviation are used to evaluate the performance of this microgrid in grid-connected and islanding modes. The results obtained from the Matlab/Simulink environment show that the proposed microgrid design with SVC has the ability to meet its special requirements such as bus voltages stabilization, reduction of feeder losses, power factor enhancement and mitigation of total harmonic distortion using SVC in grid-connected and islanding modes.

1. Introduction

A microgrid is a special form of grid which is integrated with a variety of distributed generation (DG) technology and power electronics technology. The microgrid contains sources of generation and a number of local loads or customers and the distribution network connecting them. The main emphasis in literature is on microgrids containing sufficient generation to supply the local load. The aim of a microgrid is to allow the control of active and/or reactive power independent from the grid. The development of microgrids is seen as an important part of the successful integration of massive amounts of distributed generation and renewable energy resources [1–3]. Microgrids have become possible through the developments in power-electronics, control and communication where they provide complete ways of thinking in design and operation of power systems [4]. Possible applications of microgrids include: participation on the day-ahead and balancing market; providing system support during low operational security; controlled island operation during grid outages; and improving voltage quality. However, the end-use of electrical energy has not changed and the performance requirements on microgrids are at least equal as those on the existing grid. However, there is no reason to put excessive requirements on the performance of microgrids. Both overly low and overly high requirements could result in the erection of a barrier against the introduction [5]. Microgrids can operate in two common operation modes, the grid- connected mode, where the Distributed Energy Resources (DER) interact with the electrical grid, and the standalone mode, islanding or autonomous mode, where it is possible to feed the local loads without the use of the distribution network [6].

The integration of renewable DGs in power system can improve energy efficiency and system reliability and reduce greenhouse gas emission and power loss. However, a drawback of renewable DGs is the unpredictable nature and dependence on weather and climate conditions, which causes the fact that the renewable power output may not totally satisfy the power demand of the load at each instant [7]. This problem can be solved by integrating different type resources, AC resources or DC resources in a suitable hybrid combination which provides the potential to improve the system efficiency and the energy supply reliability [8]. This type distribution network is called hybrid microgrid. Another shortcoming of DGs is the harmonic impact on system power quality along with the integration of DGs. This problem can be solved via the utilization of flexible alternative current transmission system (FACTS). The distribution FACTS (D-FACTS), as the power electronics technology applied in the distribution system, has been widely

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studied [9–11]. In general, FACTS devices are used in transmission control whereas custom power devices are used for distribution control. Since the introduction of FACTS and custom power devices such as synchronous static compensator (STATCOM), unified power flow controller (UPFC), dynamic voltage restorer (DVR), static VAR compensator (SVC), solid-state transfer switch and solid-state fault current limiter have been developed for improving power quality and reliability of a system. For example, in [12,13], STATCOM, which is a shunt compensator, is used for reactive power and voltage sag compensation while UPFC works well for power flow control [14] and DVR, which acts as a series compensator, is used for voltage sag compensation [15]. The common SVC model only consists of internal devices, which are part of the SVC, and local devices, which are installed at the same substation as the SVC [16]. The main drawback of the published works is that FACTS devices have not been used in microgrids with multiple of distributed generations and variable demand profile loads and this paper is focused on covering this drawback.

This paper develops a detailed dynamic model of a microgrid system comprising wind turbine, PV, fuel cell, micro gas turbine generator, energy storage and AC/DC loads with variable load profile. FACTS devices based on static VAR compensators (SVC) have been employed as a supervisory controller to stabilize the buses voltage, reduce the power losses, improve power factor, mitigate the harmonic distortions and decrease voltage-frequency deviation. The performance of this microgrid is evaluated using potentially selected key performance indicators (KPI) such as microgrid power losses, buses voltage deviations, buses power factor and buses voltage total harmonic distortion in grid-connected and islanding modes. The results shown are generated from MATLAB simulation of the presented microgrid, where comparisons of with and without SVC modules are presented.

2. Modeling of microgrid components and SVC

The proposed configuration of the AC/DC microgrid system is shown in Fig. 1 where various AC and DC sources and loads are connected to the corresponding AC and DC sub-grids, respectively and are connected to the utility grid. Wind generator and micro gas turbine are connected to AC bus to simulate AC sources. PV arrays, fuel cells, battery are connected to DC bus through boost converters to simulate DC sources. A battery with bidirectional DC/DC converter is connected to DC bus as energy storage. A hybrid AC load composed of motorized load, non-linear load and linear load is connected to AC bus to simulate AC loads. A hybrid DC load is connected to DC bus to simulate DC loads.

2.1. Distributed generators modeling

In order to generate the models of the distributed system components, a selected study period of one year is divided into four seasons and a typical day will be created for each season to describe the random behavior of the different renewable resources during this period. For the problem under study, the load model is generated using the IEEE-RTS system, while the hourly wind speed and solar irradiance data will be modeled by Weibull and Beta probability density functions (pdf), respectively.

The proposed hybrid AC/DC microgrid consists of the following devices:

2.1.1. Wind turbine

Choosing a suitable model is very important for the wind turbine power simulations. For a typical wind turbine, the power output characteristic can be assumed in such a way that it starts generating at the cut-in wind speed v_{ci}, the power output increases linearly as the wind speed increases from v_{ci} to the rated wind speed v_r. The rated power P_{rated} is produced when the wind speed varies from v_r to the cut-out wind speed v_{co} at which the wind turbine will be shut down for safety considerations. Then the wind turbine power output can be simulated by [17]:

$$P(v) = \begin{cases} 0 & 0 \leqslant v_i \leqslant v_{ci} \\ P_{rated} * \frac{(v_i - v_{ci})}{(v_r - v_{ci})} & v_{ci} \leqslant v_i \leqslant v_r \\ P_{rated} * h_{vi} & v_r \leqslant v_i \leqslant v_{co} \\ 0 & v_i \leqslant v_{co} \end{cases} \tag{1}$$

The output power of the wind turbine is depending on the wind speed at the site, as well as, the parameters of the power performance curve. Therefore, once Weibull pdf is generated for certain time segment; the output power during the different states of this segment can be calculated [18]. The specifications of the wind turbine that is used in this paper are stated in Table 1.

2.1.2. Micro gas turbine

The micro gas turbine is considered as a firm generation DG. In other words, the output power of such DG is considered constant at its rated value with no associated uncertainties. Recently, several micro gas turbines with a power output of 20–100 kW have become available [19]. The specifications of the used micro gas turbine are stated in Table 2.

2.1.3. Photovoltaic

A series and parallel combination of PV cells constitute a PV array. The dominant factor of affecting the output power of PV module is the solar irradiance intensity. The relationship between the irradiance intensity and the output power of a PV module can be described as [20]:

$$P_s = \begin{cases} P_{s-rated} * \frac{s}{s_r}, & 0 \leqslant s \leqslant s_r \\ P_{s-rated}, & s_r \leqslant s \end{cases} \tag{2}$$

where s is irradiance intensity, s_r is the rated value, and $P_{s\text{-}rated}$ is the rated output power of the PV module.

For the same hour of the typical day in the season, the irradiance data usually have a bimodal distribution function. The data are divided into two groups; each group has a unimodal distribution function. Therefore, to describe the random phenomenon of the irradiance data, Beta pdf will be utilized for each unimodal [18]. Beta pdf is described as:

$$f_b(s) = \begin{cases} \frac{\Gamma(\alpha+\beta)}{\Gamma(\alpha)\Gamma(\beta)} * s^{(\alpha-1)} * (1-s)^{(\beta-1)} & for\ 0 \leqslant s \leqslant 1, \alpha \geqslant 0, \beta \geqslant 0 \\ 0 & otherwise \end{cases} \tag{3}$$

where s – solar irradiance KW/m^2; $f_b(s)$ – beta distribution function of s; α, β – parameters of beta distribution function.

To calculate the parameters of the beta distribution function, the mean (μ) and standard deviation (σ) of the random variable s is utilized as follows:

$$\beta = (1-\mu) * \left(\frac{\mu * (1+\mu)}{\sigma^2} - 1 \right) \tag{4}$$

$$\alpha = \frac{\mu * \beta}{1+\mu} \tag{5}$$

Therefore, once Beta pdf is generated for certain time segment; the output power during the different states of this segment can be calculated using [18]. The PV specifications are depicted in Table 3.

2.1.4. Fuel cell

In this paper, typical PEMFC stacks are connected in series /parallel combination to achieve the rating desired. A boost