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Smart power management algorithm in microgrid consisting of photovoltaic, diesel, and battery storage plants considering variations in sunlight, temperature, and load

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ABSTRACT

Integration of utility scaled solar electricity generator into power networks can negatively affect the performance of next generation smartgrid. Rapidly changing output power of this kind is unpredictable and thus one solution is to mitigate it by short-term to mid-term electrical storage systems like battery. The main objective of this paper is to propose a power management system (PMS) which is capable of suppressing these adverse impacts on the main supply. A smart microgrid (MG) including diesel, battery storage, and solar plants has been suggested for this purpose. MG is able to supply its local load based on operator decision and decline the power oscillations caused by solar system together with variable loads. A guideline algorithm is also proposed which helps to precisely design the battery plant. A novel application of time domain signal processing approach to filter oscillating output power of the solar plant is presented as well. In this case, a power smoothing index (PSI) is formulated, which considers both load and generation, and used to dispatch the battery plant. A droop reference estimator to schedule generation is also introduced where diesel plant can share the local load with grid. A current control algorithm is designed as well which adjusts for PSI to ensure battery current magnitude is allowable. MG along with its communication platform and PMS are simulated using PSCAD software. PMS is tested under different scenarios using real load profiles and environmental data in Malaysia to verify the operational abilities of proposed MG. The results indicate that PMS can effectively control the MG satisfying both operator and demand sides.

1. Introduction

Public needs in modern societies beside optimal consumption and/or generation of electricity necessitate the integration of intelligent power management systems (PMSs) into power networks. This matter has brought a new concept which is so-called "Smartgrid". Smartgrid incorporates advanced measurement technologies, control algorithms, and communication platforms into present power grid. These features are helpful to optimize the utilization of renewable energy (RE) prime movers which contribute in the generation of electricity in large scales [1,2]. A combination of distributed storage (DS), RE distributed generation (DG) systems and loads which can operate in parallel with the grid or in autonomous modes is so-called "Microgrid". Microgrid (MG) can be considered as a cluster of load and generation in smartgrid that brings many advantages for the system. The benefits can be pointed out i.e. increasing RE sources depth of penetration, decreasing environmental emissions, utilizing waste heat, providing ancillary services, making the balance between generation and consumption, and bringing continuous backup power supply for redundant and sensitive processes [3]. Renewable resources such as wind and solar photovoltaic (PV) are naturally intermittent and hence energy storage systems (ESSs) like battery can be exploited together with them to compensate for this drawback [4]. Solar PV plant in high penetration levels can modify the load profile and create technical challenges for the system in steady-state and transient operating modes. The fluctuating output power is one example brought to this end [5,6]. Ramp ups/downs in solar plant output power are completely unpredictable. These fluctuations can be governed by several factors i.e. passing clouds, PV

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power plant placement, depth of penetration, and power network topology. In the case that these oscillations are out of control, main AC network equipments such as motors, generators, and voltage regulating devices can be affected adversely [4]. This oscillatory nature may create voltage and angle instability in the main grid to which DG is connected especially where DG depth of penetration is high. There have been suggested many methods in the literature to resolve this problem [7–10]. For instance, in [7], generation curtailment, dump load usage, and using ESS have been recommended as remedies for this purpose. However, the role of load variation based on a real pattern has not been studied in this research. The use of ESS has become very popular recently [8,9] in collaboration with fuel cell [10] in order to suppress addressed oscillations. In this case, battery energy storage (BES) has been mostly proposed by the researchers for short-term to mid-term applications [6,8,9].

Batteries are expensive equipments and thus adopting elaborated control strategies in order to efficiently exploit them is mandatory. A conventional inertial filter has been utilized in [11] to smooth output power of a wind farm and make a reference value for current controlled inverter of BES. In [6,12], state of charge (SOC) feedback controllers for BES have been suggested which limit battery charging/discharging currents within the acceptable range. However, finding an accurate time constant for SOC by these two methods is not a straightforward task and hence highly depends on assumptions made by the planner which may not be the same at all the times. In [6], genetic algorithm (GA) has been also used to optimize the control parameters for solar plant which may increase the computational burden instead. In all above mentioned cases, there has not been considered the role of rotary based DG systems such as diesel generator power plant in conjunction with the intermittent RE sources where the system supplies loads based on actual profiles. The lack of a unified power management system (PMS) which can govern a MG including RE sources together with the conventional DGs is completely obvious as well. In [13,14], coordinated energy management algorithms have been proposed which can control a MG consisting of only electronically interfaced (EI) DGs in grid-connected and stand-alone modes. However, the role of rotary based DG has not been investigated and smoothing power fluctuations of solar plant together with a real load profile have not been addressed in these works.

In this paper, MG is investigated which consists of both rotary (diesel power plant) and EI based DGs. A power smoothing index has been formulated to mitigate the fluctuations resulted by intermittent solar PV system together with the variable load. In this case, moving average filtering (MAF) which is a time domain signal processing approach is utilized to smooth these oscillations. This index can be applied for any kind of intermittent RE sources since it is easy to implement and has not relied on complicated computational methods. A load model is also proposed which can be suitable for real-time applications where the actual load profile has to be simulated for dynamic studies. A current control algorithm is designed as well to ensure the battery charge/discharge current is within the specified limitation. This work also suggests a guideline algorithm for the purpose of the battery house sizing taking into account the ramp rate limits of the main network. In addition, a power management algorithm (PMA) is suggested which helps the system owner to exploit the battery plant in the most efficient way. The concept of agent is included in this algorithm to define different level of hierarchy where a communication channel acts as the platform to exchange information between the operator, DGs, and loads. To dispatch diesel and BES plants a new application of droop control mechanism is introduced which makes it possible for the operator to schedule the generation units for both active and reactive powers. A droop mechanism for diesel plant excitation controller is also designed so that it can share the local reactive power with BES proportional to their ratings.

In what follows, Section 2 presents the proposed MG configuration. Section 3 describes the MG components dynamic models and controllers. Section 4 explains the data input preparation approaches for generation units and loads. Section 5 analyses the proposed PMA and highlights the role of MAF in smoothing out the aforementioned fluctuations. In Section 6, simulation results have been brought to the readers and technical matters have been investigated in depth. Section 7 concludes this work.

2. System configuration and operation

The proposed microgrid (MG) incorporates both rotary and electronically interfaced distributed generation (EIDG) systems (see Fig. 1). MG is subject to operate in grid-connected (G.C) mode. The primary source of power is a diesel engine which provides the mechanical torque required for a 1.28 MV A synchronous generator. Another DG unit is a 1080 kV A (1026 kW h, 1125 A h) battery energy storage system (BESS) which consists of a Lead-acid battery bank connected to the grid through a three-phase bi-directional voltage sourced converter (VSC). BESS is capable of operating as either source or sink of power. As a demand, a six steps AC load in two categories (i.e. industrial and domestic loads) are interconnected to the load bus and each group consists of three similar feeders. The demand is supposed to vary during 24 h. A 1 MW_p photovoltaic distributed generation (PVDG) plant is also considered to inject the available power from the sun into the MG in unity P.f during the whole day.

BESS is dispatched to smooth the power fluctuations in system caused by solar plant together with loads and hence it reduces the ramp rate stresses on the main AC network. Diesel plant is dispatched to shift up or down the grid active power profile and thus shares the load active power with AC network.

Depending on the power management strategy, BESS operates either in inverting or rectifying modes. Diesel plant is assumed to decrease or increase its active power generation according to PMS commands. BESS and diesel plant can be dispatched in order to share the load reactive power proportional to their ratings.

As shown in Fig. 1, there exist four agents in MG, namely, unit agents, generation agent, load agent, and main agent [15]. Generation agent is assigned to receive and/or send the data from/to DG unit agents through the communication channel (bus) indicated by dotted black line. Each DG unit agent collects the local information such as DG breaker status, output voltage and current, and availability of prime mover. There is a forecasting module embedded in PV unit agent and along with this module the estimated solar pattern is sent to the main agent to be filtered yielding averaged solar irradiation profile. In BESS, unit agent calculates SOC of battery and sends it to generation agent. All these information is gathered in generation agent and then sent to the main agent. Local agents also generate and compute the feedback signals required for the internal controllers (red dotted lines) such as current or power loops, governor, and excitation controllers. Load agent also registers the status of load breakers and the power which is flown in each feeder together with the forecasted load profile. These data are sent to the main agent (which is in the highest level of hierarchy) to inform the operator about the system states (dotted blue lines). Then the operator calculates the dispatching references and issues required commands for the DGs and loads breakers.

3. System components and controllers

3.1. Voltage sourced converter (VSC)

Two-level three-leg converter topology has been utilized in this work. This topology consists of six insulated gate bipolar transistor