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Original article

Fuzzy based virtual inertia emulation in a multi-area wind penetrated power system using adaptive predictive control based flywheel storage

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ABSTRACT

The concept of virtual synchronous generator (VSG), which imitates the behaviour of a real synchronous generator, is considered as a solution for lack of inertia caused due to integration of renewable sources. Unlike most of the existing VSG techniques, which are based on the idea of infinite energy, this paper takes into consideration the energy level of energy storage. This paper proposes a fuzzy based VSG topology to adjust VSG parameters according to the magnitude of perturbation while addressing the constraints on key operational parameters of energy storage. The proposed fuzzy logic controller (FLC) provides set point to an adaptive predictive controller, which in turn provides reference power command to energy storage. Particle swarm optimization (PSO) is employed so that flywheel energy storage system (FESS) tracks any random reference signal. To facilitate VSG operation while addressing operational limits, adaptive predictive controller for FESS is implemented. The FESS speed and converter power rating constraints are directly stated in the supervisory controller development, which are mostly included in an ad hoc way. For various disturbances, the efficacy of the controller is validated in MATLAB/Simulink as well as in real-time by means of the OPAL-RT (OP4510) device. The real-time simulations validate the superior performance of the proposed VSG technique.

1. Introduction

Renewable energy sources (RESs) are being incorporated into the power system to minimize harmful gas emissions from the burning of fossil fuels. Transmission losses are reduced and system reliability is improved by integrating distributed generators (DGs)/RESs. On the other hand, the decrease of system inertia deteriorates the performance of power systems significantly. The influence of low inertia and damping effect on dynamic performance and stability of power system grows as the penetration level of DGs/RESs rise. Power oscillations owing to the alternating nature of RESs, as well as frequency regulation deterioration, are some of the negative consequences caused due to integration of RESs [1]. The adding of virtual inertia to such a power system is one way to stabilize it. A power electronics converter/inverter, an energy storage and an appropriate control technique can be used to generate virtual inertia. A solution for virtually adding inertia to such a power system is to give extra inertia. This concept is referred to as a virtual synchronous generator [2]. Supercapacitors, ultrabattery, superconducting magnetic energy storage and flywheels are all viable VSG alternatives. Among these, the flywheel energy storage system (FESS) has features such as frequent power cycling, fast response time and long useful life [3–5].

Various control techniques/strategies for the usage of an energy storage system operating on the concept of VSG have been presented in the literature. For power systems connected to weak grid networks, Ref. [6] provides an interactive control that performs grid synchronization on a rotating reference frame and combines VSG control to improve system inertia to withstand disturbance. A fuzzy controller for generating virtual inertia to reduce the oscillations in AC microgrids has been presented in [7]. The governor output is enhanced by adding one more term to improve the inertial response. A VSG control strategy that coordinates the renewable generator with the ESS located on the AC side in order to replicate the inertial response of a synchronous machine accurately has been demonstrated in [8]. Auxiliary inertia has been introduced into the VSG governor unit with an additional power loop to increase convergence time and dynamic characteristics [9]. To ensure the frequency stability of renewable energy sources generation integrated into the power system, substantial focus has been placed on primary frequency regulation for RES generation managed by virtual synchronous generator [10]. Inertial control strategy for dynamic stability improvement using fuzzy logic for supercapacitors in multi-area microgrid clusters has been presented in [11]. Control

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