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Adaptive predictive control of a small capacity SMES unit for improved frequency control of a wind-diesel power system

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Abstract: Energy storage is becoming increasingly important for isolated power systems having overall low inertia. Among many energy storage devices, superconducting magnetic energy storage (SMES) is most suited for improved frequency control in isolated power systems, due to its outstanding advantages. However, a small rating SMES device has operational constraints, therefore a suitable control strategy is required for its profitable and constrained operation. An adaptive controller which encapsulates on-line identification with model predictive control is proposed in this paper. A recursive least-squares algorithm is used to identify a reduced-order model of wind-diesel power system on-line. Based on the identified model and a simple discrete time model of SMES unit, an adaptive generalized predictive control scheme (AGPC) considering constraints on SMES current level and converter rating is formulated. The scheme yields a control signal which on one hand keeps the system frequency deviations to minimum and on the other hand forces the SMES device to operate within and near its operational constraints, for profitable operation. Simulation studies are performed to illustrate the potency of the proposed strategy in achieving all the control objectives.

1 Introduction

There are many remote public communities worldwide which are not connected to the grid and electric power to them is usually supplied from diesel generators. However, use of diesel incurs heavy fuel, transportation and storage costs. Fortunately, many such isolated areas have good wind potential, therefore wind power generation systems can be installed and linked to the existing diesel generator sets resulting in economic wind-diesel power systems. The control of power quality in such systems is, however, a challenging task. The changing nature of generated wind power and overall low system inertia would adversely affect such power systems [1, 2]. These systems, therefore, require suitable remedial measures in order to provide good quality service to the consumers. Fast acting energy storage devices are more appropriate candidates to achieve this end [3, 4].

A superconducting magnetic energy storage (SMES) device is considered to be an attractive energy storage device because of its outstanding advantages like quick response time, a significantly higher power density, very long life time and high cyclic efficiency [5]. Its dynamic performance is much superior to other energy storage devices. Its operation and life are not affected by the number of charge-discharge cycles, unlike battery storage systems. The application of the SMES device to power systems has been under study since the early 1970s. The possible applications of SMES include transient stability, dynamic stability, load levelling, power quality improvement and automatic generation control [6–8]. For improved frequency control of standalone power systems/micro-grids, a small rating SMES device can be employed as a buffer storage for transient compensation [9].

In frequency control application, several approaches [10–14] have been used for designing a controller for the SMES unit. In [10], an application of an adaptive control scheme based on the set-membership affine projection algorithm (SMAPA) was proposed for the SMES unit. It has been demonstrated that with SMAPA-based adaptive control SMES units, the wind farm's output can be smoothened easily avoiding the huge effort for fine tuning of the controller parameters. However, constraints on upper and lower values of the SMES current have not been considered.

In [11], the use of non-linear neural adaptive predictive control for active power modulation of SMES was proposed. Though limits on the control signal and thus the converter rating have been considered in an ad-hoc manner, yet the scheme does not consider any constraints on the SMES current level. The step load changes of the magnitude of 1% are considered and there is no guarantee that the scheme will function properly with load changes of higher magnitude.

In [12], a discrete time model of a power system with SMES was developed and the effect of a small capacity SMES was studied in relation to supplying a sudden active power requirement. However, the potency of the proposed scheme in tackling the various control issues like non-violation of operational constraints of the SMES unit and continuous control have not been touched and demonstrated.

In [13], adaptive automatic generation control with SMES is presented. The scheme is effective in damping out power frequency and tie-power oscillations. Though there is provision for continuous control yet operational constraints of SMES are not considered in controller formulation. Moreover, the SMES unit considered uses thyristor-based technology which has a drawback of draining reactive power from the system while exchanging active power with it.

In [14], a fuzzy logic controlled SMES device to damp the frequency oscillations of a two-area power system under load excursions was proposed. The simulation results indicate the superiority of the proposed scheme over the conventional proportional integral (PI) controller in damping the system oscillations. However, important control issues like the handling of operational constraints of SMES are not addressed in this work.

Keeping in view the deficiencies with the control schemes existing in the literature (described above), in this study, a novel scheme is proposed for control of the SMES unit. The achievements of the proposed scheme are as follows:

(i) The frequency deviations are kept to a minimum both under load and wind perturbations.
(ii) SMES is forced to operate near its constraints for effective and profitable operation.
(iii) Power handled by the SMES converter never exceeds its rated value.
(iv) SMES current always remains within the limits dictated by operational constraints.

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