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Optimal design of model predictive control with superconducting magnetic energy storage for load frequency control of nonlinear hydrothermal power system using bat inspired algorithm

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ABSTRACT

This paper proposes bat inspired algorithm (BIA) as a new optimization approach of a model predictive control (MPC) and superconducting magnetic energy storage (SMES) for load frequency control (LFC) of a two-area interconnected hydrothermal system. The proposed power system model includes generation rate constraint (GRC), governor dead band, and time delay. Conventionally, the parameters of MPC controller and SMES are obtained by trial and error method or experiences of designers. To overcome this problem, the BIA is applied to simultaneously tune the parameters of MPC controller and SMES to minimize deviations of frequency and tie-line power flow of the interconnected power system against load disturbances. Simulation results show that the performance of the proposed BIA based MPC controller with SMES is superior to the conventional proportional-integral (PI) controller based integral square error technique and BIA based MPC controller without SMES in terms of the overshoot settling time and robustness.

1. Introduction

A lot of generating stations in the large power system are connected by the tie-lines to exchange power among them. Loads at any station can appear randomly and changeable so that the system frequency and tie line power will deviate from their nominal values [1]. This deviation in system frequency and tie line power causes the change of the generation demand. In this regard, load frequency control (LFC) develop a control system to maintain the system frequency and tie line real power flow at scheduled values when the system is subjected to load variations. Load frequency control in the interconnected power system is achieved by two different control loops, namely primary and supplementary speed control. Governors of the generators carry out the primary control, which provide control action to the sudden change of load. The supplementary control adjusts the frequency at its nominal value by controlling the output of selected generators [2]. In the past, load changes may no longer compensate by the governor due to its slow response [3]. This problem can be solved by superconducting magnetic energy storage (SMES). Superconducting magnetic energy storage capable of controlling active and reactive power simultaneously. It has been suggested as one of the most effective and significant stabilizers of power oscillation modes [4–6]. Superconducting magnetic energy storage is equipped with various control methods of LFC such as an integral control [4], an adaptive control [5], a fuzzy control [6], and a neural network [7] etc. All of these strategies is designed with conventional methods and have proved to be insufficient with nonlinear power systems. Model Predictive Control (MPC) is improved a fast response control method against nonlinearities [8]. Some applications of MPC on LFC are presented in [9–11]. The economic viewpoint is considered only in [9] to design MPC in a multi-area power system. The MPC is designed with finite horizon MPC technique and an additional state contractive constraint in [10]. The researchers in [11] presented MPC with LFC but not deal with the change of system's parameters and generation rate constraint (GRC). In previous papers about SMES and MPC, the parameters of SMES and MPC are designed with trial and error method which makes the system performance is unacceptable with the change in system parameters and large disturbance. In an effort to overcome these problems, researchers in [12] used an artificial intelligence method named cuckoo search algorithm

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(CSA) for optimal tuning of SMES, but the considered system model are symmetrical and not include the governor dead band and the communication time delay. This paper proposes a new optimization technique, which is named bat inspired algorithm (BIA) to an optimal tuning of SMES and MPC parameters to control frequency for a two-area interconnected hydrothermal system including SMES units. The BIA is simple requires and a compatible optimization tool for LFC design [13]. The considered system includes the GRC, the governor dead band and communication time delay. The results compare with the conventional PI controller and BIA with conventional PI controller and BIA based MPC controller without SMES.

2. Superconducting magnetic energy storage principles

Superconducting magnetic energy storage provides rapid recovery method in the demand of deficit or excess real power in LFC of the multi-area power system, by using a large inductor [4–7]. The SMES unit as shown Fig. 1 consists of superconducting inductor, Y-Y/Δ transformer, and a 12-pulse bridge ac/dc thyristor-controlled converter. The inductor coil is connected to the AC grid through a power conversion system (PCS). The PCS operate in two modes namely, rectifier and inverter corresponding to charging and discharging of the superconducting coil. The charging and discharging of the superconducting inductor are achieved by the application of adequate positive or negative voltage to the inductor, through the control of firing angle of the converter bridges.

$$E_d = 2V_{do}.\cos(\alpha) \tag{1}$$

Where

E_d :Converter output voltage in KV

V_{do} :Maximum open circuit voltage of the converter in the SMES device in KV

α :Firing angle (degree)

The converter output voltage E_d is held constant at a suitable positive value depending on the desired charging period through the initial charging of SMES unit. Due to the variation of E_d between a wide range of positive and negative values the converter dc output current I_d being unidirectional, the control for the direction and magnitude of the inductor power flow P_d is achieved by continuously regulating the firing angle. The dc current flowing through the inductor I_d can be calculated as follows:

$$I_d = \frac{1}{L}\int E_d.dt \tag{2}$$

Where

L :Inductance of the coil in H

The inductor current rises exponentially until reaches to its rated value I_{do} by maintained zero voltage across it since the coil is superconducting. The energy stored in the inductor at any instant,

$$W_L = \frac{L.{I_d}^2}{2} \tag{3}$$

The SMES unit is then ready to be coupled with the power system for LFC operation. In LFC operation, the dc voltage E_d across the superconducting inductor is continuously controlled depending on the frequency deviation signal Δf. In this paper, inductor voltage deviation of SMES unit of each area is based on Δf of the same area in the power system. Moreover, the negative inductor current deviation feedback ΔI_d is used in the SMES control loop. So, the current variable of SMES unit restores its steady state value quickly after a system disturbance, so that it can respond to the next load disturbance. The block diagram of SMES unit is shown in Fig. 2.

$$\Delta E_d = \frac{1}{1+sT_{dc}}(K_o.\Delta f - K_{Id}.\Delta I_d) \tag{4}$$

$$\Delta I_d = \frac{1}{sL}\Delta E_d \tag{5}$$

$$\Delta P_{SM} = I_{do}.\Delta E + \Delta I_d.\Delta E \tag{6}$$

Where

K_o : Gain of the SMES control loop in kV/Hz

K_{Id} : Gain of the inductor deviation feedback loop in kV/kA

T_{dc} : Converter time delay in sec

ΔP_{SM} : Deviation in the inductor real power of SMES unit in Mw

The optimal design of SMES leads the inductor to adjust the power delivered from it. In this paper, The BIA is proposed to get the best value of K_o, K_{Id} and L of SMES unit.

3. Model predictive control modelling

The presence of nonlinearities, uncertainties, and time delays in power system effect on its performance. The MPC has been improved as an effective control strategy to stabilize dynamical systems in the presence of these problems [8–11]. The general MPC model consists of prediction and controller unit. The prediction unit forecasts future control action of the system depends on its current output, disturbance and control signal on a finite prediction horizon. The predicted output is used by the control unit to minimize the objective function in the presence of system constraints [8,14]. The MPC compensated the measured disturbance by the method of feedforward control. The feedforward control compensates most of the measured disturbance before affect on the system, unlike the feedback controller. The feedforward control cooperates the feedback control to reject most of the measured disturbance effect, and the feedback control rejects the rest in addition to this deal with unmeasured disturbances. This control method could be found exhaustively in [14,15]. As shown in Fig. 3, MPC unit consists of a system model, disturbance model, and measurement noise model. These models will be illustrated in the following sections in details.

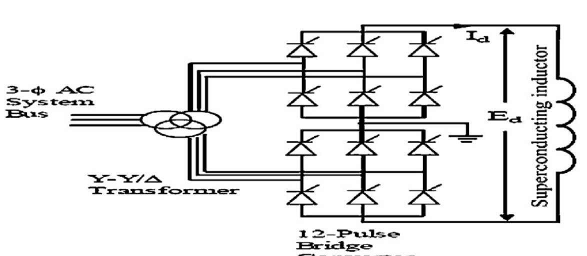

Fig. 1. the schematic diagram of the SMES unit.

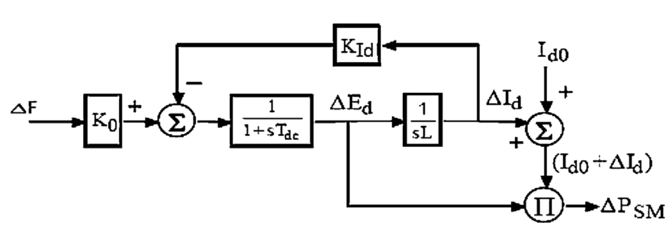

Fig. 2. Block diagram of SMES unit.