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Super-capacitor based energy storage system for improved load frequency control

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ABSTRACT

A fuzzy-logic controlled super-capacitor bank (SCB) for improved load frequency control (LFC) of an interconnected power system is proposed, in this paper. The super-capacitor bank in each control area is interfaced with the area control bus through a power conversion system (PCS) comprising of a voltage source converter (VSC) and a buck-boost chopper. The fuzzy controller for SCB is designed in such a way that the effects of load disturbances are rejected on a continuous basis. Necessary models are developed and control and implementation aspects are presented in a detailed manner. Time domain simulations are carried out to demonstrate the effectiveness of the proposed scheme. The performance of the resulting power system under realistic situation is investigated by including the effects of generation rate constraint (GRC) and governor dead band (DB) in the simulation studies.

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1. Introduction

The successful operation of interconnected power system requires the matching of total generation with total load and the associated system losses. Due to sudden load perturbations which continuously disturb the normal operation of a power system, two variables of interest, system frequency and tie-line power exchanges, undergo variations. The approach of most of the researchers [1] towards solving this problem has been to obtain the best method of controlling the governor action so that the system frequency and tie-power deviations are kept to a minimum. As a result, the problem of load frequency control (LFC) has become synonymous with automatic generation control (AGC). However most of the solutions proposed so far for AGC have not been implemented due to system operational constraints associated with thermal power plants. The main reason is the non-availability of required stored energy capacity other than the inertia of the generator rotors.

Fast-acting energy storage systems can effectively damp electromechanical oscillations in a power system, because they provide storage capacity in addition to the kinetic energy of the generator rotors which can share sudden changes in power requirement. An attempt to use battery energy storage system (BESS) to improve the LFC dynamics of West Berlin Electric Power Supply has appeared in the literature [2,3]. The problems like low discharge rate, increased time required for power flow reversal and maintenance requirements have led to the evolution of superconducting magnetic energy storage (SMES) for their applications as load frequency stabilizers [4–7]. However SMES is expensive and requires a continuously operating liquid helium system.

Very few researchers [8–10] have pursued the application of capacitive energy storage units to load frequency control problem. The energy density of these common capacitive energy storage systems is very low and hence their application to power systems is not appealing. Recently a promising technology (super-capacitors) has been introduced that has the potential to rival all the fast acting storage devices and can outperform in several key parameters. Also known as, ultra capacitors, pseudo capacitors and double layer capacitors, super-capacitors are essentially powerful, high cycle life and high energy capacitors. They have two outstanding features; their energy density is approximately 100 times higher than that of conventional capacitors and power density is approximately 10 times higher than those of the batteries. Super-capacitors have already been used in applications such as dc motor drives, uninterruptible power supply (UPS) systems and electric vehicles. In recent years ultra capacitor banks have also been used in power system applications [9–11] like voltage sag compensator, intermittent renewable storage and smoothing of strong and short-time power solicitations of distribution network.

The analysis [12–15] with regard to usage of energy storage devices shows that super-capacitors are best suited for short-term low power (<100 kW) applications. Magnetic energy storage systems are not viable for low power mainly due to their high cost. The

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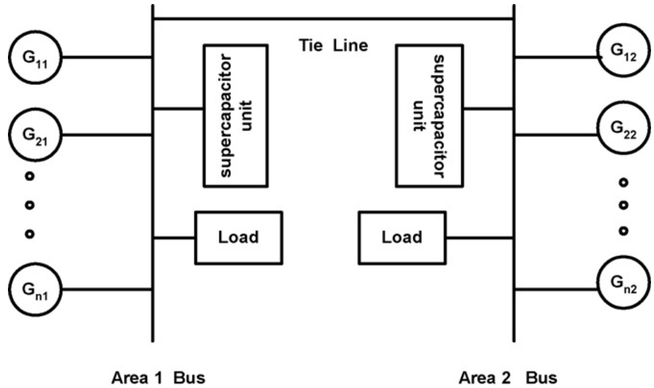

Fig. 1. Single line diagram of two area power system with super-capacitor units.

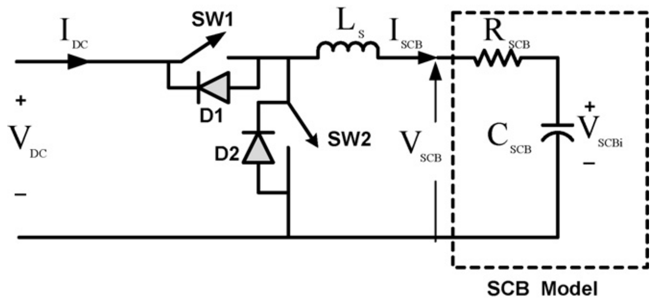

Fig. 3. Equivalent circuit of super-capacitor bank and its power conversion system.

losses of kinetic energy storage systems, which scale non-linearly with power level, become unacceptable in comparison to those of the other technologies when the power level goes below a few hundred kW.

In this paper we are proposing the incorporation of ultra capacitor banks in an interconnected power system for improved load frequency control. A fuzzy logic control strategy is used to generate the power command for the super-capacitor bank (SCB). The fuzzy logic control strategy developed has two fold targets; to reduce the deviations in system frequency and tie-line power and to restore the super-capacitor bank voltage to its nominal value after dealing with a load disturbance. All the modeling and control aspects concerning the proposed scheme are presented and a complete realistic simulation model is developed. The computer simulation results exhibit the effectiveness of the proposed scheme.

2. Super-capacitors

A super-capacitor is an electrochemical device consisting of two porous electrodes, an ion-exchange membrane separating the two electrodes and a potassium hydroxide electrolyte. In many ways, an ultra capacitor is subject of same physics as a standard capacitor. That is, the capacitance is determined by the effective area of the plates, the separation distance of the electrodes and the dielectric constant of the separating medium. However, the key difference is that the liquid electrolyte structure and porous electrodes in ultra capacitor give rise to enormous surface area compared to a conventional structure. Also the formation of a double layer of very small thickness in ultra capacitors results in a high value of specific capacitance. These two factors lead to a very high capacitance compared to a conventional electrolytic capacitor [16]. Super-capacitors can have 100–1000 times the capacitance per unit volume compared to a conventional electrolytic capacitor. Compact in size (ranging from approximately the size of a postage stamp to the size of a small soda can), ultra capacitors can store in-comparably higher amount of energy than conventional capacitors. Super-capacitors offer high values of power density and energy density compared, respectively, to batteries and conventional capacitors. They can be charged/discharged faster as compared to batteries and conventional capacitors. Moreover they are capable of cycling millions of times and are thus virtually maintenance free and have much longer lifetime. All these attributes of super-capacitors make them ideal for improved load frequency control in interconnected power systems.

The single line diagram of a two area power system with super-capacitor storage units is shown in Fig. 1, where G_{ij} represents ith generator in jth control area When there is sudden rise in power demand in a control area, the stored energy is almost immediately released by the SCB through its PCS as a line quantity ac. As the governor control mechanism starts working to set the power system to the new equilibrium condition the SCB stores back its nominal energy. Similar is the action when there is a sudden decrease in load demand. The SCB immediately absorbs some portion of the excess energy in the system, and as the system returns to its steady state the excess energy is released by SCB to the system and the stored energy again attains its nominal value.

Fig. 2 shows the proposed configuration of super-capacitor system in each control area of the power system. The voltage source converter (VSC) consists of a 6-pulse, pulse width modulated (PWM) rectifier/inverter using insulated gate bipolar junction transistors (IGBTS). The PWM converter and the dc–dc buck boost chopper are linked by a dc link capacitor. The dc voltage across the dc link capacitor is kept constant throughout by a 6-pulse PWM converter [13,17]. The bidirectional dc–dc converter is operated in boost mode if the electric power is to be supplied to the super-capacitor bank from the power system. The smoothing reactor is used for energy transfer and filtering. Keeping in view the fact that voltage at dc links is maintained constant by VSC, system of Fig. 2 is equivalent to that of Fig. 3 [13,17].

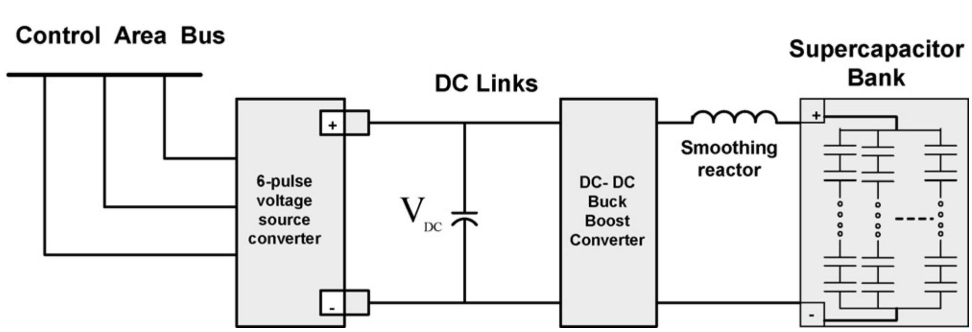

Fig. 2. Configuration of super-capacitor bank in control area.

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