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Optimal size allocation of superconducting magnetic energy storage system based unit commitment

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ABSTRACT

SMES has gained developments in recent years because of its high efficiency with no site limitation, and faster response to meet the peak load demands. By incorporating high efficient Superconducting magnetic energy storage systems (SMES) has a greater impact on daily load scheduling of thermal units and pave the way for optimal unit commitment to meet the load demands with reduced load shedding. In this paper, IEEE 10 unit thermal unit system is incorporated with and without SMES and the results are analysed for studying the impact of SMES in unit commitment scheduling. For this purpose effective Modified Lagrangian relaxation based Particle swarm optimization (LR-PSO) algorithm is used for calculating the operating cost and the results are compared with existing algorithm using MATLAB.

1. Introduction

In recent years incorporation of renewable energy sources meets the power demand in electric power system because of its cleanliness and cost effectiveness behaviour [1]. Due to the uncertainty nature of renewable energy sources power fluctuation occurs and it can affect the stability of the system [2,51,52]. This can be overcome with energy storage devices [3–5]. Among many energy storage devices, most viable devices are battery energy storage systems (BESS), pumped storage hydroelectric systems and superconducting magnetic energy storage systems (SMES) [6,7]. However, among this SMES is gaining more importance and it will be feasible option to meet the peak load demands because of its high efficiency, high life cycle nature and it’s no site limitation behaviour [8,9]. An Energy storage device like battery energy storage systems BESS suffers from drawbacks like limited lifespan, environmental hazards and limitation of voltage and current and pumped hydro system has disadvantages like large unit sizes and large environmental limitations. However SMES has no site limitation and has high efficiency and high life cycle so it is gaining more attraction nowadays [10].

SMES is a large super conducting coil stores large amounts of electric energy in the form of magnetic field without resistive losses and discharges the energy in short span of time. In order to maintain the system in charged condition, the coil should always be kept in cryogenic condition and hence indefinite current flows with zero loss and the energy is stored in the form of magnetic field. SMES is used for load leveling, stability, and power quality improvement, etc [50]. Integration of large scale SMES with the thermal unit system has greater benefits such as it can meet the peak load demand with more efficient and faster response, maintain the stability of the system [11,12]. Integration of SMES with power system is shown in Fig. 1.

Normally SMES system has four major components, they are the super conducting coil, the power conditioning equipment with control unit, and the cryogenic unit. The super conducting coil helps to carry and store DC current in the form of magnetic field at cryogenic temperature which further get converted to electrical energy. The power conditioning unit helps to connect the SMES into the power system. It first converts the DC power into AC power by means voltage source converters or current source converter and smoothens voltage by the filter components. The rectified voltage is then stepped up to the utility grid voltage by a step up transformer and fed back into the power system. Depends on positive or negative voltage across the cryogenic coil the coil discharges the energy. Liquid hydrogen is required to maintain the low temperature super conducting coil, thus makes the system more expensive. However, with the advent of high temperature superconducting coil, refrigeration cost is reduced because of liquid nitrogen, which is less cost than liquid hydrogen and also increased the reliability. [12,13] and the operation of SMES of is shown in Fig. 2.

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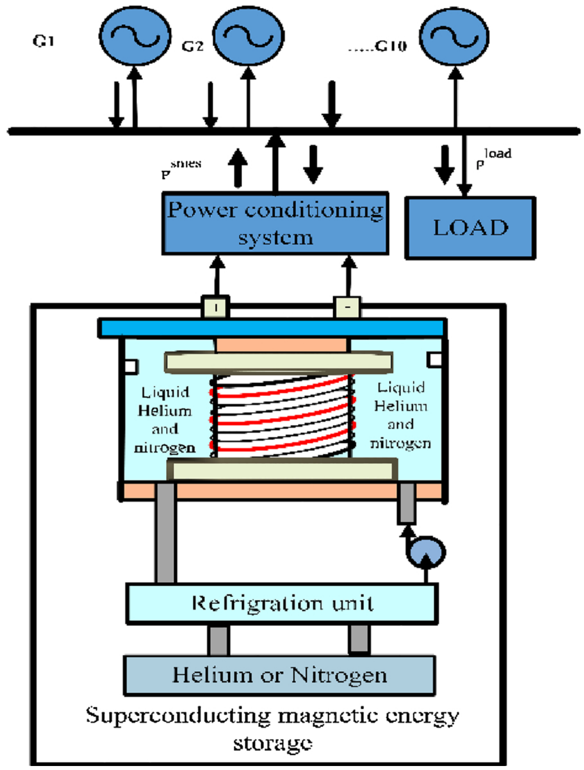

Fig. 1. Block diagram of SMES with 10 unit thermal system.

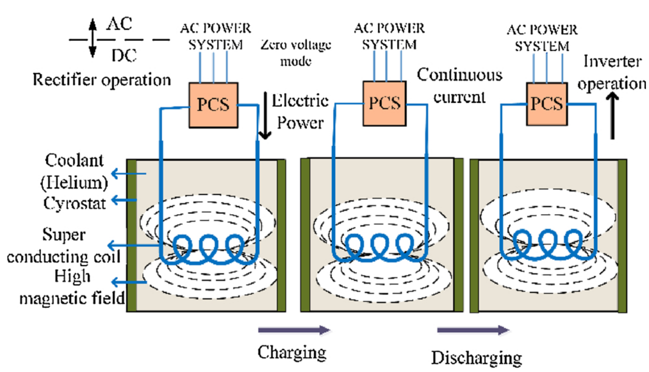

Fig. 2. Operation of Superconducting magnetic energy storage system.

In the previous studies, SMES is used as energy storage to compensate the stochasticity of wind and to maintain the reliability of the system [14]. The SMES finds more applications related to stability, compensating load fluctuations, power swings, generation fluctuations, frequency control and daily load levelling [15]. The design of 360 MW h YBCO has made SMES more feasible for daily load levelling [16]. However due to its fast response and capability it is more feasible for daily load scheduling. Unit commitment is a combinatorial optimization problem [17] which schedules thermal generating unit economically to meet the hourly demand with reduced cost subjected to various constraints such as minimum uptime, minimum downtime constraint, power balance constraint, power demand constraint, spinning reserve constraint etc., In order to mitigate the power quality problems, SMES seems to be a promising technology as it can compensate power demand efficiently with fast response. The advanced technical developments like 2.4 GJ YBCO SMES [12] and 48 GJ MgB2 SMES [13], has become an underlying support for developing large scale SMES for daily load levelling. A preliminary study on large-scale SMES as energy storage seems to be more compromise [18,19] and can replace the pumped storage plant [20]. The techno and economic analysis of SMES system has been presented in [20,21,45,46–49]. Due to its high efficiency, the annual cost is reduced to (50–60) % when compared to pumped hydro storage. Although the capital cost is doubled for SMES, there is possibility to decrease the annual cost compared to pumped hydro storage. SMES has been developed in the range of several MWh to meet load fluctuations, generation fluctuations and frequency control. The economics concerned with the SMES states that for 1 kW rating of SMES the capital cost is 2000 USD [20]. Few energy storage systems in the form of compressed air energy storage (CAES) has drawback of site limitation and hence the cost of CAES is same as that of pumped hydro storage. Also, for NaS battery, the lifetime is shorter compared to that of SMES, and hence the annual cost of NaS battery is doubled when compared with SMES in addition to disposal cost. Hence, the annual cost of SMES is significantly lower than that of NaS battery though the capital cost of SMES is twice that of NaS battery. The cost evaluation of SMES is based on the New Energy and Industrial Technology Development given in [20]. Here, it clearly mentioned that SMES is more feasible for daily load levelling. For 100 MW/500 kW h SMES costs were estimated as 1970 USD/kW and 690 USD/kW in the case of 100 MW/15 kW h SMES. Superconducting Magnetic Energy Storage system, is characterized by fast operation, high energy density, high efficiency and better controllability in compensation of power [22,23,45,46]. The design of optimal size of optimised SMES with maximum energy storage is gaining importance [26,46]. The optimal size of energy storage is important because it has greater impact on the decision problem like unit commitment and economic dispatch [24,25,26]. In recent years, only a few preliminary studies have been given in unit commitment with SMES [18–20]. The impact of integrating different ranges of larger scale SMES in unit commitment is not analysed. Many of the work focusses on sizing of an energy storage, but did not consider optimal sizing of SMES [23]. In this paper the 10 units 24 h thermal system integrated with different ratings of SMES is considered and analysed for different constraints to study its impact on the operational cost.

For this purpose many optimization techniques including classical as well as evolutionary algorithms have been studied to find the effective approach during respective time horizon subjected to different constraints such as power balance constraint, minimum uptime and downtime constraint, generation limit constraint, ramp constraint, etc., [25]. The classical optimization method, the priority list (PL) is easy and fast but gives the higher operating cost [25]. Branch and bound method give optimal solution, but execution time of the unit commitment problem increases with size [27]. Mixed integer linear programming has the advantage of giving flexible and accurate optimal solution. However, the computational complexity is increased [28]. The Lagrange relaxation (LR) method is very fast and can be easily modified due to its flexible nature to handle different types of constraints [29]. The researcher attempted bio inspired techniques which is based on their biological behaviour to find the optimal solution such as simulated annealing [30], genetic algorithm [31], ant colony [32] imperialistic algorithm [33] and particle swarm optimization [34–38], Extended priority list [39], integer coded genetic algorithm [40], binary grey wolf optimisation [41], bacterial forging [42], binary shuffled frog leaping [43], invasive weed optimisation [44], etc. Among these particle swarm optimization (PSO) is robust to solve the nonlinear and non differential problem, also has an easy implementation, fast convergence rate, higher flexibility to control, but has slow convergence [34]. Some of the literature focuses on improving the PSO method [35,35,36,37,38]. Hence the modified LR method with PSO is implemented and found to be effective, in solving IEEE 10 unit 24 h thermal bus systems with and without SMES system. The results of unit commitment SMES charging and discharging is analysed by modified Lagrange Relaxation based Particle Swarm optimization (LR-PSO) algorithm.