Using Artificial Intelligence for Microgrid Operation and Control in Presence of Sustainable Power Systems

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Abstract. Nowadays, and with the growth use of renewable energy sources (RESs), an intelligent control scheme is requisite to ensure a stable power generation system especially in isolated and small areas. In the classical grid, the load frequency control loop (LFC) is widely used to cope with sudden and random load variation. However, with the large share of RESs and due to their stochastic behavior, a robust controller is needed to suppress frequency deviation and handle system frequency at scheduled value. In this scope, this paper aims to propose the use of first time a recently population-based optimization algorithm named Sine Cosine Algorithm (SCA) as artificial intelligence strategy to design an optimal LFC controller that allow the integration of large amount of RESs in the microgrid (MG). A hybrid microgrid including diesel engine, wind farm and photovoltaic generator was investigated. The SCA algorithm was employed to optimize the PI controller parameters of the LFC loop. To promote the use of RESs and minimize the use of fuel, a Hybrid Energy Storage System (HESS) combined Redox Flow Batteries (RFB) and Superconducting Magnetic Energy Storage (SMES) was considered. The HESS was used to support the LFC loop and reduce frequency fluctuation in presence of RESs. To prove the validity of the proposed strategy, various scenarios have been simulated. In addition, a comparative study between the proposed SCA algorithm and some metaheurisctic algorithms such PSO and GA have been performed. Furthermore, robustness analysis have been carried out with different rate of RESs penetration. Finally, the obtained results demonstrate the effectiveness and superiority of the developed strategy for dynamic microgird control.

Keywords: Artificial Intelligence, Microgrid, Frequency Control, Sustainable Power Systems, Sine Cosine Optimization Algorithm (SCA).

1 Introduction

Electric power system is an essential factor in the development and evolution of human societies, whether in terms of improving living conditions or the development of industrial activities. The electrical system is an assembly of electrically connected installations that provide via the network, the transfer of electrical energy from producers to consumers [1-2]. This energy can be produced from sources as diverse as hydraulics, fossil fuels, nuclear fission, wind and sun. This electrical system, which is at the base of these energies, operates in an environment in constant evolution: load, generation power, system topology. Increasing the electrical dependence of modern society involves power systems that are 100 % exploitable in their capabilities with maximum safety. The quality of this electrical power has become a major concern for consumers and providers of electrical energy today [3-5]. Also they are more and more demanding, rigorous development of exploitation of the electrical networks. Under these conditions the stability of the power system becomes a permanent concern for the suppliers of electrical energy. These systems must remain normally stable for small variations in the vicinity of operating points. Presently, the use of sustainable and green power systems has become increasingly of major interest around the world. Compared to the conventional power generation units, solar and wind power have a huge energy potential [6]. This kind of power are the most promising for producing electricity in the modern power system due to their functioning friendly to the environment with low CO2 emissions. However, the integration of wind or PV solar generation on an electrical network (distribution, transmission or interconnection) can lead to constraints related to various aspects such as network congestion, voltage plan, short circuit current, protection, dynamic behavior and system stability [7-13]. A lot of research paper have been published in the topic of power system and microgrid control considering RESs integration. The main aim of these works was to analyze the impact of RESs integration and enhance system stability and control. In reference [14] authors have discuss the issue of applied Artificial Intelligence for operation and control in microgrid. Where, in reference [15] Serdar Ulusoy et al. have proposed a different feedback strategies for optimum tuned PID controller. In [16], authors have proposed a cascade-fractional order ID with filter controller to promote AGC loop adequately in electric power systems incorporated with renewable energy sources. Moreover, a lot of researcher have investigated various storage system to enhance frequency regulation in microgrid. In reference [17], authors have presented a review of Redox Flow Batteries (RFB) for the storage of renewable energy. In [18], Abhijith Pappachen et al. have suggested the application of Adaptive Neuro Fuzzy System (ANFIS) controller based LFC in two area hydrothermal power system under deregulated combined with Super Conducting Magnetic Energy Source (SMES) and Thyristor Controlled Phase Shifters (TCPS). In [19,20], authors, have proposed a comparative assessment on different types of Hybrid Energy Storage System (HESS) related to energy management techniques. In this paper, a hybrid microgid consisting of photovoltaic, wind and diesel power generation operated in isolated mode and including a combined energy storage system involving RFB and SMES was analyzed. The main contribution was to analyze the dynamic behavior of the microgrid in presence of renewable energy sources, and show the utility of investigating HESS in frequency stability and control improvement, then demonstrate the advantages of the implementation optimization algorithm to design a robust LFC loop. The rest of the paper is organized as follows. Section 2 presents the microgrid model. Section 3 was devoted to presents the optimal LFC loop and the Sine Cosine Algorithm (SCA). The obtained simulation results are presented in Section 4. Finally, Section 5 concludes the paper.

2 Microgrid Model

Microgrids (MGs) are a vital part of distribution systems that includes various kinds of distributed generation (DG), renewable energy sources (RESs), storage devices and loads. The MG have the capability to be operated in isolated or connected mode [9]. The microgrid provides the ideally platform to study the impact of integration various distributed generation (DG) such wind and PV in remote or small isolated area. The schematic layout of the assumed isolated hybrid microgrid in this work is shown in Fig.1, it consists of a Diesel, Wind, PV units, RFB, SMES and Load.

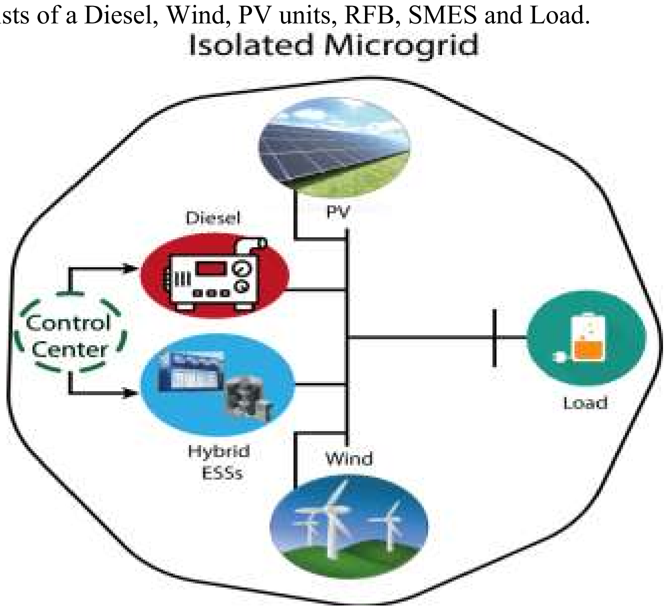

Fig.1. Isolated Microgrid Model.

2.1 Diesel Generator Model

The diesel generator presents a small power generation unit that can increase or decrease his output by the fuel regulation depending on frequency deviation and following the load variation. This kind of power generation is widely used in microgrid to satisfy power demand. The used DG model is shown in Fig.2 [10].

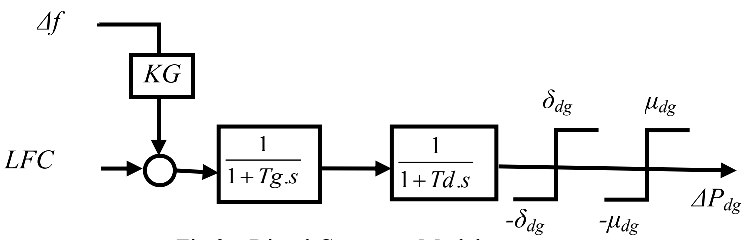

Fig.2. Diesel Generator Model.

2.2 Wind Farm Model

A wind turbine uses the force of the wind to drive the blades of a rotor. The mechanical energy produced by the rotation of the blades is converted into electrical energy by a generator. The power of a wind farm is of the order of MW, it requires several wind turbines to produce as much power as a nuclear unit. To optimize the simulation time, an aggregated wind farm was used as shown in Fig.3. The negative dynamic load model in [5,10] was used for modeling the wind farm. This model was generated by a random output fluctuation, which is derived from white noise block diagram with a low pass and high pass filters as shown in Fig.3.

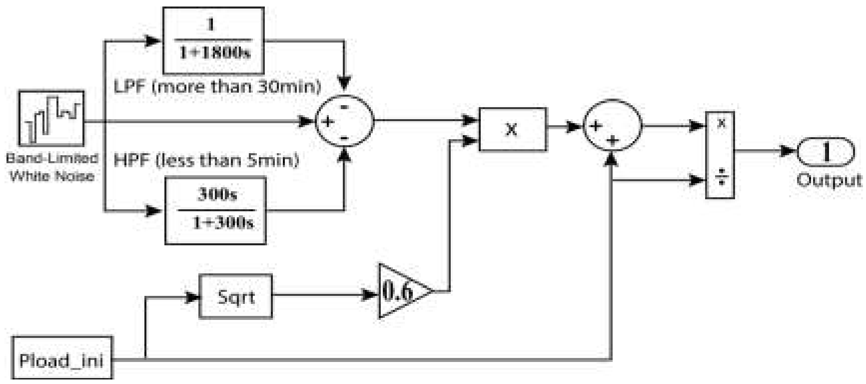

Fig.3. Wind Farm Model [5].

2.3 Solar PV Array Model

The photovoltaic solar energy is one of the promising renewable energy sources. They have recently gained huge interest among researchers and industrialists. PV produced from solar radiation. The photovoltaic cell is the basic electronic component, using the photoelectric effect as shown in Fig.4. Several interconnected cells form a photovoltaic solar module (PV); several bundled modules form a solar installation producing electricity that can be used on site, or power a distribution network [12].

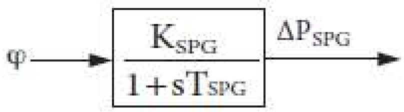

Fig.4. Solar PV Array Model [12].

2.4 RFB Model

A fast acting energy storage system (ESS) can effectively reduce the frequency fluctuations in power system by providing storage capacity in addition to the kinetic energy of generator rotor. Many ESS have been used to support the LFC loop during disturbances. The RFB is considered as a very helpful device in meeting the sudden load requirements especially in presence of RESs due to their fast and outstanding performance. Fig.5 show the investigated RFB in this work.

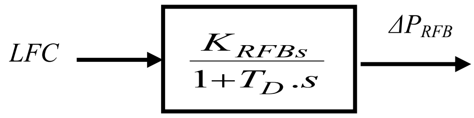

Fig.5. Dynamic RFB Model.

2.5 SMES Model

Increasing the share RESs in microgrids may lead to system instability issues due to intermittent nature of these sources and low inertia of MG generating units. In this view, a fast and effective storage system such the SMES is needed to help the classical LFC loop and cope with load changes. The feasibility of SMES for mitigating power system dynamics problems has been reported in many published works. A simplified transfer block of the SMES is given in the Fig. 6.

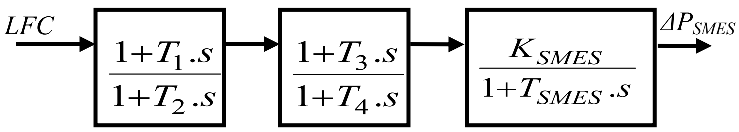

Fig.6. Dynamic SMES Model.

3 Proposed Optimal LFC Control Scheme

The competence of the LFC loop is stated in terms of fast and smooth control action. With the integration of RESs, the grid requires robust and efficient control strategy to withstand its controllability and stability in the presence of stochastic nature of RES. To boost LFC outcome, different tuning approaches have been proposed in the recent literature. Some of them implemented in various traditional and restructured systems. However, a lot of Artificial Intelligence (AI), Nature-Inspired (NI) and Bio-Inspired (BI) algorithms based controllers have been applied to solve the LFC problem by a wider section of researchers. Those methods have helped in the design of variety of controllers based LFC loop. In this paper, a new optimal LFC scheme coordinated with hybrid energy storage system involving both of RFB and SMES was designed. The novel nature-inspired metaheuristic algorithm SCA was used as shown in Fig.7.

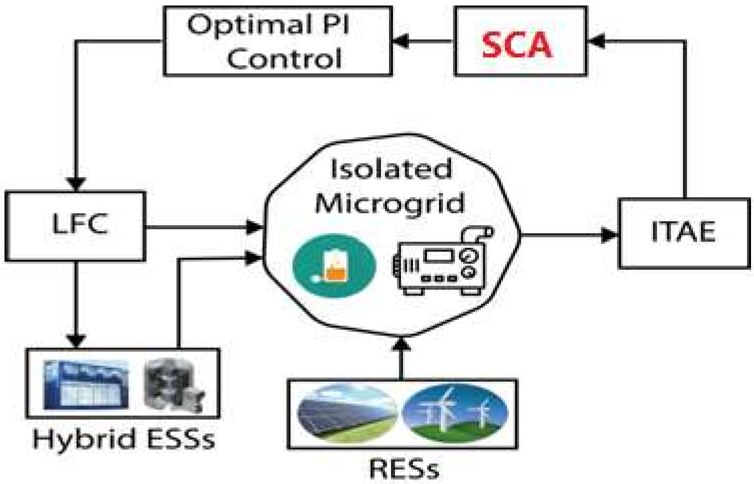

Fig.7. Proposed Control Scheme.

3.1 Sine Cosine Optimization Algorithm (SCA)

In the last few years, Artificial Intelligence (AI) has been a very important topic in almost scientific and engineering fields. Research on AI has advanced significantly, which leads to create a variety of AI algorithms that have shown great promise in a large number of applications area. In this section, a recently optimization algorithm named Sine Cosine Algorithm (SCA) was introduced to be used in the microgrid frequency control. SCA algorithm was proposed by Seyedali Mirjalili in 2016 to solve optimization problems [21]. The SCA is a new optimization algorithm which combines the random solutions in the set of solutions abruptly with a high rate of randomness to find the promising regions of the search space. Using a mathematical model based on sine and cosine functions, the SCA creates multiple initial random candidate solutions and requires them to fluctuate outwards or towards the best solution. Several random and adaptive variables also are integrated to this algorithm to emphasize exploration and exploitation of the search space in different milestones of optimization. The pseudo code of SCA algorithm is shown in Fig.8 [21].

```
Initialize a set of search agents (solutions)(X)
Do
   Evaluate each of the search agents by the objective function
   Update the best solution obtained so far (P=X*)
   Update r1, r2, r3, and r4
   Update the position of search agents
While(t< maximum number of iterations)
Return the best solution obtained so far as the global optimum
```

Fig.8. Pseudo code of Sine Cosine Algorithm[21].

3.2 Objective Function

The Time Multiplied by Absolute Error (ITAE) given in Eq.(1) was used as objective function. The SCA algorithm was applied to minimize Eq.(1) subject to the PI controller gains lower and upper bounds given in Eq.(2).

$$ObjFun = \int_{0}^{tsim} t.(|\Delta f|).dt \quad (1)$$

$$\begin{Bmatrix} K_{p\,min} \leq K_p \leq K_{p\,max} \\ K_{i\,min} \leq K_i \leq K_{i\,max} \end{Bmatrix} \quad (2)$$

4 Simulation Results

In this section, three scenarios have been analyzed to show the impact of RESs integration on microgrid and the contribution of both HESS and optimal LFC loop in frequency stability and control enhancement. The simulation results were presented in this section. In the first scenario, the microgrid was simulated without HESS, then a combined RFB-SMES storage system was installed, where a comparative study was performed to show the contribution of HESS. In the second scenario, an optimal LFC loop was designed using SCA optimization algorithm, then a comparative study with some optimization algorithms such PSO and GA was presented. Finally, in the third scenario robustness analysis was carried out with various rate of RESs penetration.

4.1 Evaluation of Hybrid Storage System

The focus of this scenario is on the use of HESS involving combined RFB and SMES to support the frequency regulation in presence of RESs. The microgrid was firstly simulated without storage system then with storage system. The results of the frequency system are depicted in Fig.9.

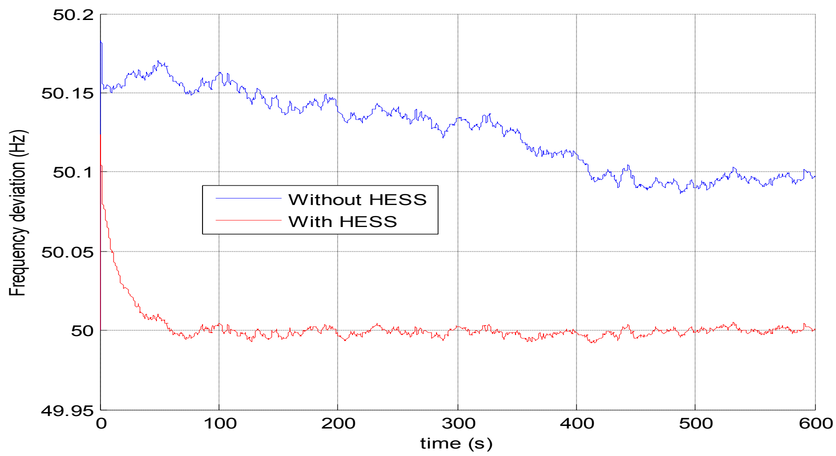

Fig.9. Contribution of HESS to Reduce Frequency Deviation.

From the results, after integration PV and Wind units with penetration rate of 10%, the system show several oscillations, which requires auxiliary control actions. After the use of HESS, the frequency fluctuations are suppressed the most effectively and the system remains stable at 50 Hz. It can be said that energy storage system was the right solution on how create an autonomous microgrid with sustainable energies and achieve a good power quality and stable system.

4.2 Intelligent LFC Scheme Design

To enhance dynamic behavior of microgrid and improve the HESS control, an optimal LFC loop was designed using SCA algorithm. The MG was simulated firstly with fixed step load deviation of 0.1 pu as shown in Fig.10, then the simulation was extended in presence of RESs as presented in Fig.11. The optimal PI controller gains are listed in Table.1. It is clear that the optimal LFC based SCA gives better results.

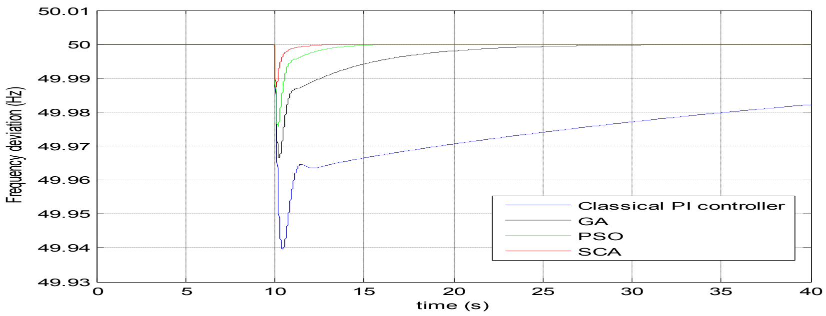

Fig.10. Frequency Deviation With Step Load Deviation.

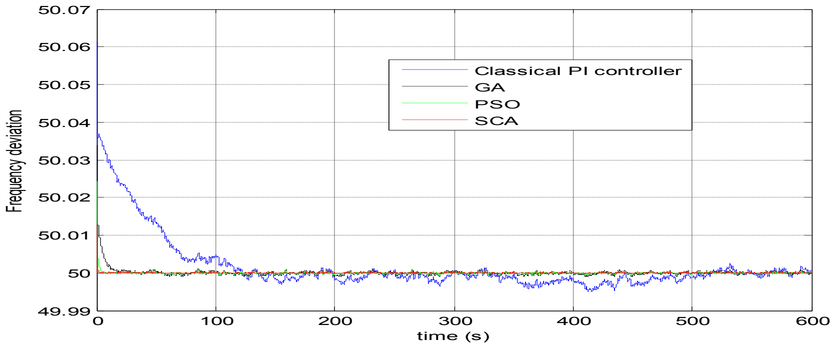

Fig.11. Frequency Deviation in Presence of RESs.

Table 1. Optimal PI Controller Parameters.

Algorithm	*KP*	*Ki*
Conventional PI	5	0.1
GA	9.2758	1.7458
PSO	13.1856	7.7457
SCA	29.4125	27.2674

4.3 Robustness Analysis

In this scenario, robustness analysis was performed to show the validity of the proposed coordinated optimal LFC based SCA algorithm with the combined RFB-SMES storage system. The penetration rate was varied form +%25 to +100% of RESs units. It can be seen from the obtained results depicted in Fig.12, that the designed controller gives better results in term of reducing frequency fluctuation and system stability. Moreover, the proposed strategy allows to share large penetration of RESs in the MG, which gives more benefits in view of minimization of fuel cost and carbon emissions.

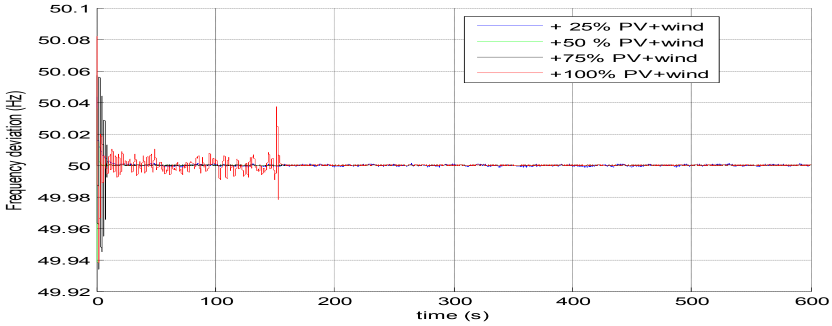

Fig.12. Frequency Deviation With Various Rate of RESs Penetration.

5 Conclusion

This paper has proposed a sophisticated control strategy involving both of intelligent LFC based optimal PI controller and hybrid energy storage system. The storage system combine both of RFB and SMES. The main objective was to analyze the microgrid dynamic behavior in the presence of wind and PV units, as well as the study of the possibility to share a massive integration of renewable energies. In addition, the contribution of storage system was also examined in view of frequency stability and control enhancement. The proposed HESS shows great performances that allows the integration of large amount of RESs. Furthermore, the employed SCA optimization algorithm has proved an excellent results in tuning PI controller for the LFC loop. Where, the coordinated optimal LFC with HESS can considered as robust tool for microgrid power management and controller in presence of RESs. Finally, in the near future, this study will be extended to study various model of microgrids including electric vehicles (EVs), FACTS devices and AC/DC transmission link.

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