# Coordinated Control of Optimal LFC Method and Energy Storage System for Microgrid Frequency Regulation in Presence of Wind Farm

N. El. Y. Kouba, A. Benseddik, Y. Amrane, M. Hasni and M. Menaa

**Abstract**—This paper presents a dynamic frequency and active power control of an isolated microgrid integrated wind farm. An Energy Storage System (ESS) including the Redox Flow Batteries (RFBs) and Superconducting Magnetic Energy Storage (SMES) was used to improve the dynamic performances of the isolated microgrid. A new metaheuristic approach know as Whale Optimization Algorithm (WOA) was employed to design an optimal load frequency control (LFC) to enhance frequency stability and control of the investigated system. The WOA algorithm was applied for searching the parameters of PI controller to make the microgrid more stable and overcomes system disturbances. To prove the effectiveness of the proposed control strategy, the microgrid was simulated under load variation and wind power fluctuation. The obtained results reveal the good performance of the proposed control strategy and show its ability to deal with frequency fluctuation due to wind farm integration.

**Index Terms**—Load Frequency Control (LFC), Optimal Control, Microgrid (MG), Energy Storage System (ESS), Wind Farm.

## 1 Introduction

One of the most important problems in power systems is to deal with the fossil-fuel resources consequences related to the CO2 emissions and the environmental issue [1]. To ensure a clean energy and avoid as much as possible the carbon dioxide emissions (CDE), an environmentally-sustainable sources are required [2]. In this context, an important contribution has been attracted in the field of renewable energy sources (RESs) and distributed generation (DG) integration within power systems. In todays world, RESs such as wind and photovoltaic have become alternative power sources especially for small and isolated distributed areas [3].

In the other hand, the major challenge is to ensure system stability with good power quality and overcome disturbances. Moreover, the main issue is to keep the frequency and voltage of power systems at their nominal values within an acceptable range. Regarding the problem of power system instability, distributed generation is usually preferred for stand-alone and isolated microgrid operations [4]. Furthermore, the energy quality depends on equilibrium between the power supply and consumption including power losses. However, isolated power system sometimes witness instability due to load variation, which causes a perturbation in the system frequency [5].

Renewable energy sources such as wind power are considered as a kind of distributed generation that has increasingly been used for decades. The wind power is not stable because it depends on wind speed, which may cause some fluctuation on power system [6]. In this context, the increasing wind penetration causes the increase of frequency variation. In the aim to mitigate the increasing frequency variation, it's needed to establish a proper control strategy with an effective frequency-stabilization scheme. This is achieved through the automatic generation control (AGC) of power system named as load frequency control (LFC), where the main objective is to maintain the frequency at specified value [7].

Conventionally, the frequency fluctuation is mitigated using the primary and secondary control loops via the governor-turbine and the LFC system [8]. In contrast, the integration of wind farm leads to a drastic disturbance, which requires an effective control strategy to compensate the conventional LFC and suppress this fluctuation. It is therefore important to contribute in the subject associated to the frequency regulation in presence of wind farm connected to the microgrids [9].

Several techniques have been used to provide a supplementary frequency control for isolated microgrid comprising wind farm. Such approaches include the use of classical Proportional-Integral (PI) or Proportional-Integral-Derivative (PID) controllers [10], [11]. Some references have presented an interesting applications of intelligent controller using fuzzy logic [12] and neural networks [13]. Recently published papers have presented the application of nature-inspired metaheuristic algorithms as optimization tools to enhance system frequency regulation [14], where the problem is generally referred as an optimal load frequency control (LFC). Furthermore, some researchers have discussed interesting applications of energy storage system (ESS) such Redox Flow Batteries (RFBs) and Super Magnetic Energy Storage (SMES) applied for control and compensation of frequency and active power regulation [15]–[18]. This paper presents a new control strategy to enhance the dynamic behavior of an isolated microgrid in presence of wind farm. An effective LFC scheme coordinated with RFBs and SMES was designed using optimal PI controller employing the

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WOA algorithm.

## 2 System Modeling

### 2.1 Microgrid model

The microgrid is defined as a closed small power system, which provides an ideally platform for integration of various distributed generation (DG). A typical microgrid can comprise several sources such: wind unit, solar panel, fuel-cell, micro-turbines, diesel engine, electric vehicles and storage devices [19]. Usually the microgrid can be operated in two alternative modes, which are: the isolated mode and the grid-connected mode. These operating modes are achieved by connecting or disconnecting the microgrid from the main network at the point of common coupling named PCC. The microgrid under study designed in Fig.1 was operated as an isolated hybrid system, which consists of: diesel generator, gas unit, wind farm and energy storage system.

### 2.2 Gas unit model

With the availability of natural gas, a wide use of gas turbines in electric power system was attracted. Several microgrid are equipped with gas unit to supply the load. A typical model of gas turbine to study microgrid frequency stability and control during normal operating conditions was devlopped in this work. The assumed model consists of LFC loop, which is the main control loop for frequency stability study. Fig. 2 depict a simple-cycle gas turbine with analog governor/compensator [20].

### 2.3 Diesel generator model

The diesel generator (DG) is a small power generation unit, which presents the connection of a diesel engine with an alternator [1]. This kind of micro-turbines is controllable and can increase or decrease his output by the fuel regulation depending on frequency deviation and following the load variation. Noted that, the diesel generator have the characteristics of fast starting speed, durability and high efficiency. Fig.3 shows the used DG model for the dynamic frequency and active power control based LFC loop [8], [21].

### 2.4 Energy storage system model

In microgrid operation, the energy storage system (ESS) is considered as the most suitable option to supply power demand and ensure power balance in isolated mode [22], [23]. Among various storage systems, the battery energy storage system (BESS) and the fuel-cells (FC) store energy during a long time, whereas super-conductor and ultra-capacitor store energy during a short period of time [4]. The ESS discussed in this paper are the Redox Flow Batteries (RFBs) and the Superconducting magnetic energy storage (SMES), which significantly offer better performance especially in frequency regulation during disturbances. The Dynamic models of RFBs and SMES devices are illustrated in Fig 4. [24] and Fig.5 [25], [26] respectively.

### 2.5 Wind farm model

During the last years, the use of wind power generation has growth very rapidely. As the wind power depends on

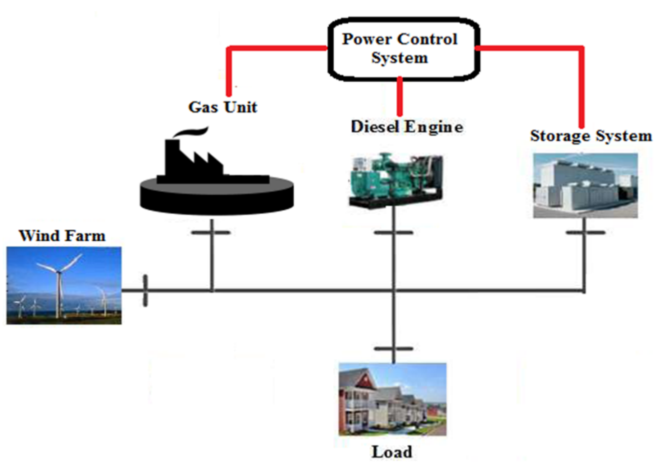



Fig. 1. Isolated Microgrid Assumed in this Work.

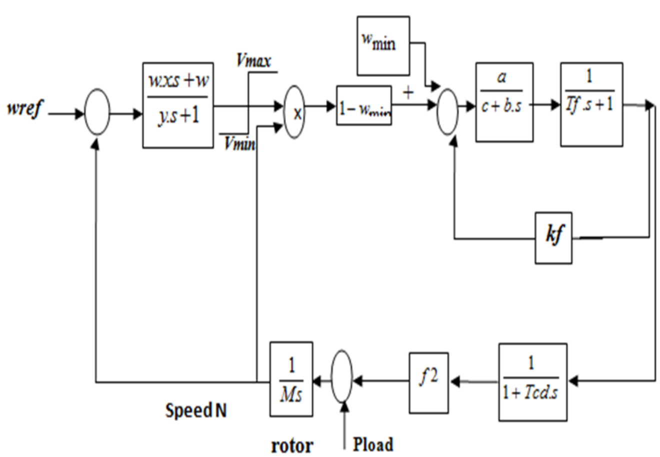



Fig. 2. Simple-cycle Gas Turbine Model.

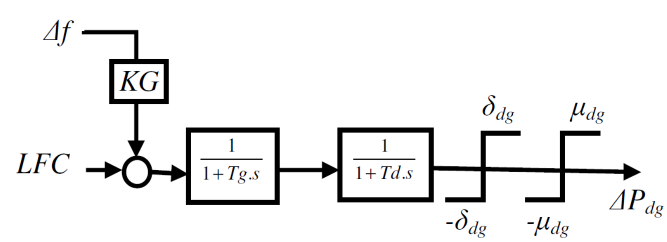



Fig. 3. Diesel Generator Model [8].

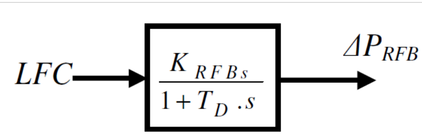



Fig. 4. Dynamic Model of RFBs.

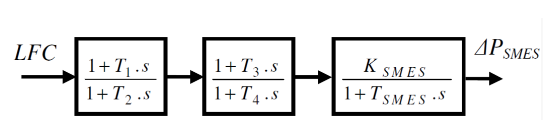



Fig. 5. Dynamic Model of SMES.

the wind speed as a natural source, the output power of a wind turbine is not stabel due to the time-variant wind direction and the wind speed [1], [2]. Mainly, the wind turbine convert the kinetic energy of wind into electrical energy using different types of wind turbine technologies [27]. Due to the random of wind speed, their output generate some fluctuations, which may affect microgrid frequency stability.

A wind farm consists of several wind power plants, which are connected at the point of common coupling (PCC), then, the whole wind farm is connected to the microgrid through a tie-line power flow and a transformer.

In this work, an aggregated wind farm is assumed to be integrated in the microgrid. The wind farm was modeled as a negative dynamic load using the developed model in reference [28] based on a random output fluctuation derived from white noise block and a low pass filter (LPF) as shown in Fig.6.

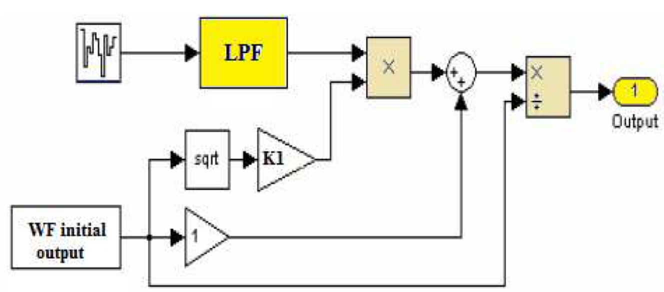



Fig. 6. Wind Farm Model.

# 3 Optimal control technique

## 3.1 Proposed frequency and active power control scheme

Frequency and active power control know as Load Frequency Control (LFC) has long been implemented in the industry to keep system frequency at the scheduled value. During many years, various LFC schemes have been developed using classical, empirical or intelligent techniques, where, all of those methods aim to enhance LFC mechanism and deals with frequency fluctuation. In this paper, a new optimal LFC scheme coordinated with storage devices employing a novel nature-inspired metaheuristic algorithm named WOA was designed as shown in Fig.7.

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

$$ObjFun = \int_0^{tsim} t\,(|\Delta f|)\,dt \tag{1}$$

$$\left\{ \begin{array}{c} K_{pmin} \leqslant K_p \leqslant K_{pmax} \\ K_{imin} \leqslant K_i \leqslant K_{imax} \end{array} \right\} \tag{2}$$

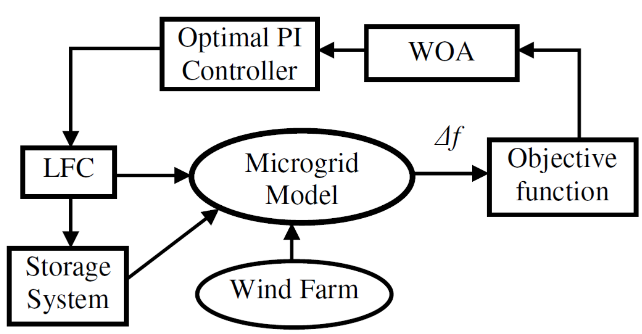



Fig. 7. Proposed Control Scheme.

## 3.2 Whale optimization algorithm (WOA)

During many decades, researchers have proposed several optimization algorithms in order to find the appropriate solution for many issues [29]. The current research tends towards intelligent methods based nature-inspired algorithms for global optimization.

This work aim to use a recently developed metaheuristic approach named the Whale Optimization Algorithm (WOA). WOA is a new nature-inspired optimization algorithm, developed in 2015 by S. Mirjalili and A. Lewis.

WOA mimics the social feeding mechanism of humpback whales. The main inspiration of WOA was come inspired from the unique bubble-net hunting strategy. This special behavior includes three basic steps as shown in Fig.8: 1) The whales create bubbles in spiral shape as an attacking method; 2) Encircles the prey (fishes); 3) Swims up towards the surface. WOA, was used in solving various mathematical optimization problems and structural design problems [30].

# 4 Simulation and results

To verify the effectiveness of the proposed LFC scheme and show the contribution of storage system in frequency regulation enhancement, the microgrid was simulated under load variation and wind power fluctuation. The microgrid assumed in this work was modeled and simulated using MATLAB/SIMULINK. The simulation was divided into two scenarios, with load variation, and with wind farm integration, where, the storage system was connected only in presence of wind farm.

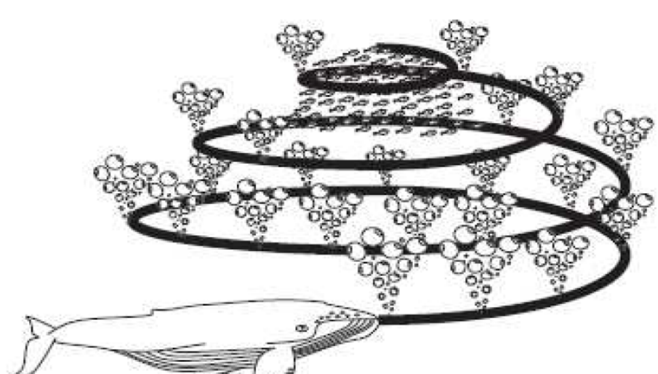
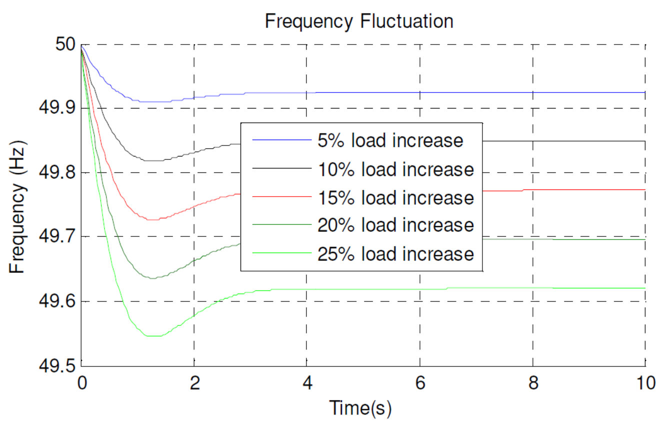


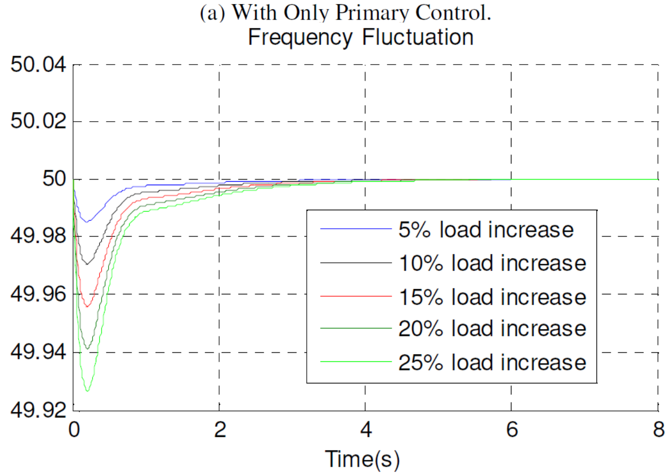
Fig. 8. Bubble-net Feeding Behavior of Humpback Whales.

### 4.1 Load variation

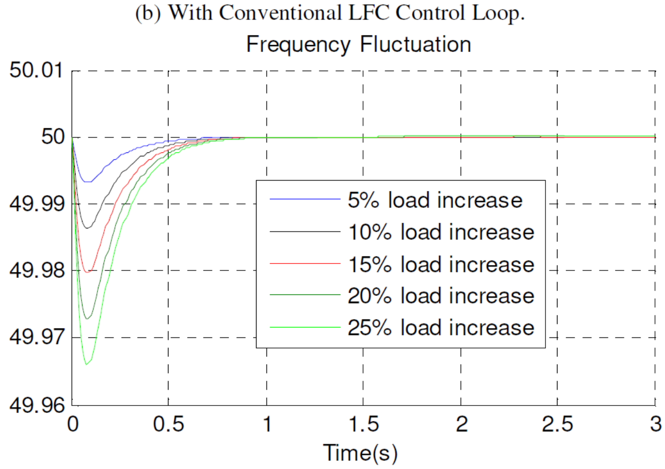
In this scenario, the microgrid was simulated for [5%, 10%, 15%, 20%, 25%] load increase. Three case studies are presented. In the first case study the system was simulated using only the primary control, which is available on both diesel and gas units as shown in Fig.9 (a). In the second case study, a secondary LFC loop was added to prove a dynamic support to the governor-turbine control system as shown in Fig.9 (b), then in the third case study, an optimal PI controller using WOA was employed as shown in Fig.9 (c).




(a) With Only Primary Control.




(b) With Conventional LFC Control Loop.




(c) With Optimal LFC Control Loop.

Fig. 9. Fluctuation of System Frequency.

In this part, some results of the optimal control strategy obtained by the proposed WOA algorithm are presented. Based on the obtained results of Fig.9 (a, b, c) and comparison of settling time and peak undershoot for frequency deviations of each case study, a good dynamic performance of the proposed controller against load variations is achieved. A comparison between the obtained results with the proposed WOA algorithm and those yielded using primary controller and conventional LFC was performed. From the simulation, it can be observed that using the optimal LFC loop, the frequency fluctuations are suppressed most effectively.

The obtained results confirm the efficiency of the proposed optimal LFC scheme in improving frequency regulation, which insures the ability of the WOA algorithm in searching the optimum PI controller parameters.

### 4.2 Wind farm integration

In this scenario, the wind farm is assumed connected to the microgrid to supply the load. Otherwise, without wind farm, the load will be supplied by coordinated control of the diesel generator and the gas unit. A small wind farm of average 10 MW as shown in Fig.10 was added to the microgrid.

The obtained optimal PI controller form the first scenario was also tested in presence of wind fluctuation. In addition, a storage system was also installed to cope with frequency fluctuation due to wind power generation.

The RFBs and SMES units are used to support the conventional LFC control for reducing frequency fluctuations due to wind power generation. To investigate the impact of RFBs and SMES, the microgrid was simulated with and without ESS. The fluctuations of system frequency are presented in Fig. 11 (a,b).

In this scenario, the effect of wind farm integration on system frequency was discussed. The contribution of the installed energy storage system (RFBs and SMES) was also analyzed. Considering Fig.11 (a, b), it is clear that the wind farm affects the system frequency. On the other hand, it is apparent that the controlled storage system can compensate the LFC capacity in presence of wind fluctuation. From the simulation, it can be observed that the frequency deviation is more reduced when the RFBs and SMES are installed.

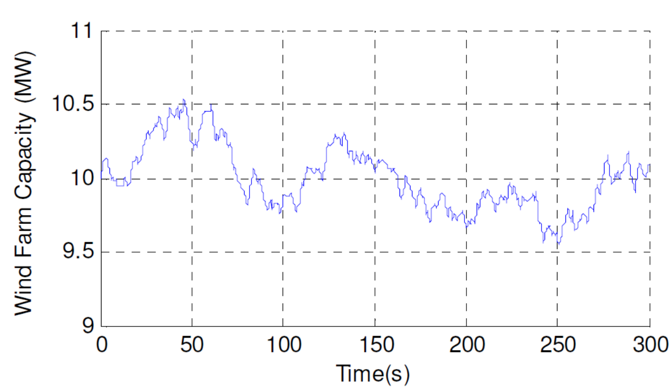
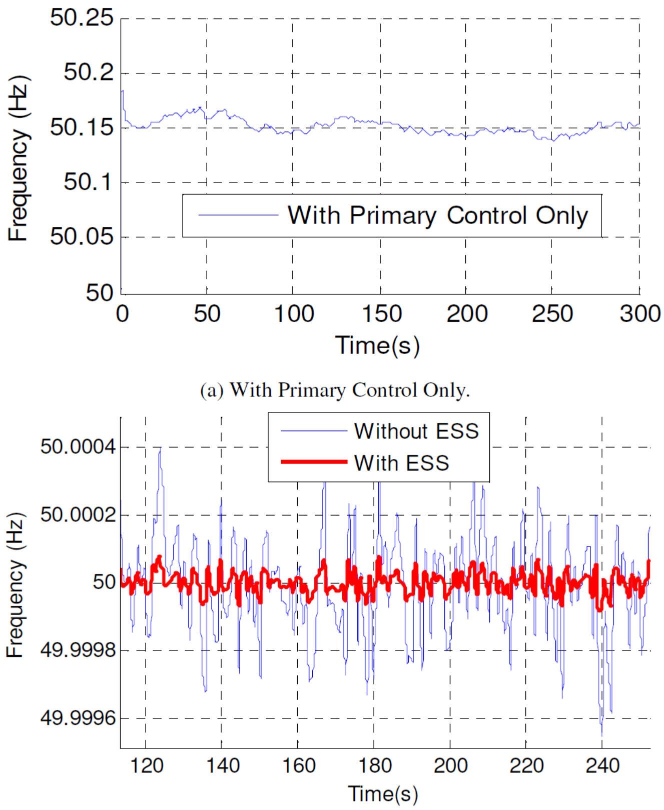



Fig. 10. Installed Wind Farm Capacity.




(a) With Primary Control Only.

(b) With LFC and Energy Storage System (RFBs and SMES).

Fig. 11. Fluctuation of System Frequency.

From both simulated scenarios, it can be concluded that in presence of load changes, the optimal LFC can deal with frequency fluctuation and ensure system stability. On the other hand, in presence of wind farm, a supplementary controller is needed to provide dynamic support for the LFC loop and reduce frequency deviation. The results validate the proposed method and prove their performance in terms of solution quality and fluctuation attenuation.

## 5 Conclusion

In this paper, a microgrid dynamic frequency control in hybrid system with energy storage system has been studied. An intelligent LFC scheme using optimal PI controller based on WOA optimization algorithm was proposed to solve frequency regulation problem in presence of wind farm. The proposed control strategy was associated with RFBs and SMES devices to compensate the LFC loop for attenuating frequency fluctuation due to wind power generation. The WOA algorithm shows its capability to obtain the optimum solution for the LFC problem. The results clearly show the high ability of the proposed control strategy to reduce frequency deviations and maintain the stability of the microgrid in presence of wind farm.

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