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Optimal Energy Management of Hybrid MicroGrid Using Storage System and Fuzzy-GA Method

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Abstract

Due to the increase of the demand for electrical power and the gaining of momentum of decentralized electrical production, the importance of microgrids is increasing constantly. Therefore, it is pertinent to understand how microgrids work and develop efficient systems to supervise and manage the produced electrical power. This paper deals with an optimal energy management system (EMS) for multi-sources hybrid microgrid. The investigated hybrid system incorporating Diesel Engine (DE), Photovoltaic generator (PV), Wind farm, Fuel Cells (FCs) and Electrolyzers. The proposed strategy was based on a combined optimal Fuzzy Logic and Genetic Algorithm (GA). The GA have been employed to optimize the scaling factors of fuzzy logic to give better results. The power demand variation was considered as disturbance, where, the optimal Fuzzy-GA was implemented to ensure microgrid balance. The effectiveness of the proposed strategy was demonstrated througth various scenarios, and the behavior of the microgrid was analyzed without and with storage system. The obtained results were compared and the proposed strategy proves the validity as a strong optimization tool that can cope with load variation.

Keywords: Optimal Energy Management System; Microgrid; Renewable Energy Sources; Storage system; Fuzzy Logic; Genetic Algorithm.

1. Introduction

Electrical 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. Power 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 [3-4]. 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. Power Flow or load balancing is the solution for the normal operating conditions of a steady-state three-phase power grid in other words, it's looking for a point stable operation of an electrical network through a complete information of the voltages, currents and powers put into play in the power systems. The insertion of a wind or photovoltaic installation on microgrid can lead to constraints related to various aspects such as voltage plan, short circuit current, plan protection, dynamic behavior and contribution to voltage and frequency adjustment services, stability of wind farms, photovoltaic and voltage quality defect resolutions [5-8]. This kind of power are the most promising for producing electricity in the modern power systems due to their functioning friendly to the environment with *low* CO_2 *emissions*. Moreover, with the large use of renewable energy sources (RESs), a robust and intelligent energy management scheme is requisite to ensure a stable power system especially in isolated areas. During many years, a very interesting number of research papers have been published in the topic of power system, microgrid power management and control considering RESs integration. The main aim of these works was to analyze the impact of RESs integration and enhance system stability and control with robust energy management strategies using smart and modern developed algorithms [9]. In reference [10] authors have discuss the issue of applied Artificial Intelligence for operation and control in microgrid. Where, in reference [11], authors have presented a review of Redox Flow Batteries (RFB) for the storage of renewable energy. In [12,13], authors, have proposed a comparative assessment on different types of Hybrid Energy Storage System (HESS) related to energy management techniques. In reference [14], authors have suggested an optimal operation and management for smart grid including high penetration of renewable energy. In reference [15], julius k. tangka have proposed an intelligent electronic module for energy management of hybrid microgrid. In this paper, a hybrid microgid consisting of photovoltaic, wind and diesel power generation operated in isolated mode and including Fuel Cells (FCs) and Electrolyzers as storage system was analyzed. The main contribution was to analyze the behavior of the microgrid in presence of renewable energy sources, and show the utility of investigating the storage system to support to power generation and enhance the microgrid stability during load variations. Where, the key contribution of this paper is the design of an optimized Fuzzy-GA scheme supported with energy storage system to nhance the microgrid power management. The rest of the paper is organized as follows. Section 2 presents the microgrid model. Section 3 was devoted to presents the optimal Fuzzy-GA Method. 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 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 [16]. The investigated isolated microgrid proposed in this work was presented in Fig.1. The used system contains Photovoltaic (PV), Wind farm, Diesel generator, Fuel Cells (FCs) and Electrolyzers, where, two case study have been analyzed, which are: with and without storage system.

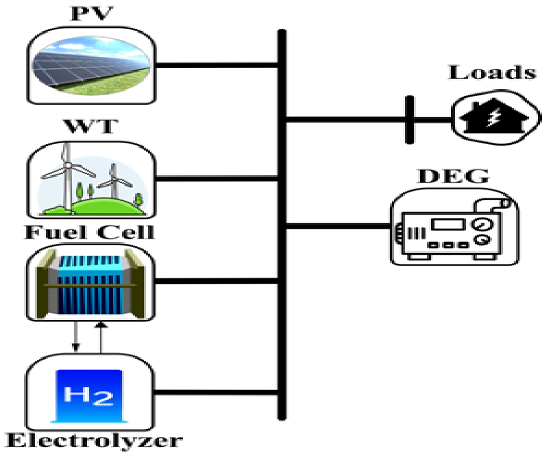

Fig 1. Isolated Microgrid Model.

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 [17].

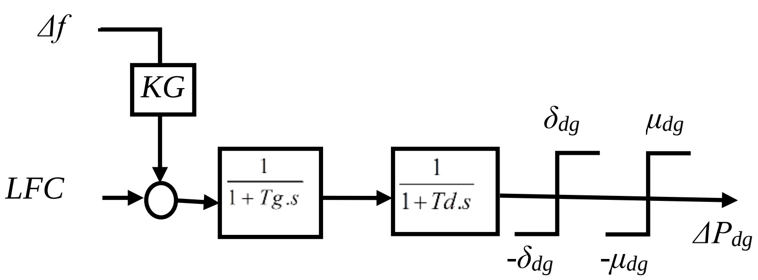

Fig 2. Diesel Generator Model.

2.2 Wind unit 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 electricity as a nuclear power plant.The wind turbine that was used is a wind turbine type *Doubly-Fed Induction Generator* (*DFIG*) as shown in Fig.3. The dual power supply refers to the voltage of the stator taken from the network and the rotor voltage supplied by the converter. This system allows variable speed operation over a specific operating range [17]. The kinetic energy of wind is converted firstly into mechanical energy by the rotation of blades of the wind turbine, which is then turned into electrical energy by a generator. The aerodynamic power of wind collected by the turbine is determined by the wind velocity and blade length as follows:

$$P_{Aero} = \frac{1}{2} pSV^3 \tag{1}$$

Where, p is the air density, S is the swept area and V is the wind speed. The conversion of aerodynamic power to mechanical power depends on the power coefficient $Cp\ (\lambda, \beta)$ which is subject to the Betz limit. The mechanical power of the wind turbine is calculated as follows:

$$P_m = C_p(\lambda, \beta) P_{Aero} \tag{2}$$

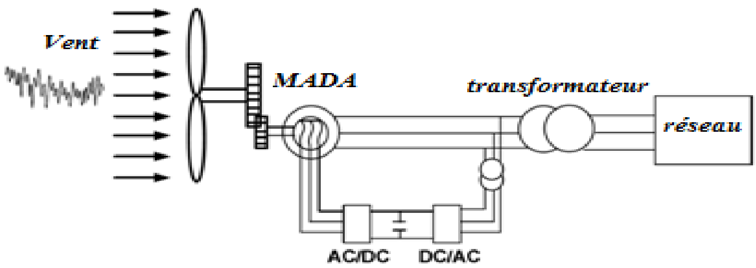

Fig 3. Wind Unit Model.

2.3 Solar PV Array Model

Solar energy remains one of the oldest types of energy exploited by human beings. In modern era, the collected sunlight is transformed into electrical power by assembling multiple photovoltaic cells. These cells are the junction of two or more semiconductor layers [16-19]. The corresponding electrical scheme of a photovoltaic cell is essential for the modelling. In our case, the single diode model illustrated in Fig.4 has been considered to demonstrate the mathematical model of solar panel, the output current of the photovoltaic cell is obtained as follow:

$$I = I_{ph} - I_D - I_{Rsh} \tag{3}$$

The photo current *Iph* is related to solar irradiance and temperature. It is expressed as:

$$I_{ph} = [I_{ph,STC} + I_{sc,ref}\,(T - T_{STC})]\,.\,(\frac{E}{E_{STC}}) \tag{4}$$

Where, *STC* are the standard conditions *(1000W/m², 25°C)*, $I_{sc,ref}$ is the short-circuit current given by the manufacturer. Both of I_D and I_{Rsh} are given as:

$$I_D = I_{sat}[e^{\frac{q(V+R_S.I)}{A.K.N_ST}} - 1] \tag{5}$$

$$I_{Rsh} = \frac{V + R_sI}{N_sR_{sh}} \tag{6}$$

Where *Isat* is the saturating current, *K* is Boltzmann's constant, *q* is the elementary charge and *A* is the junction ideality factor. Ns is the number of cells in a row.

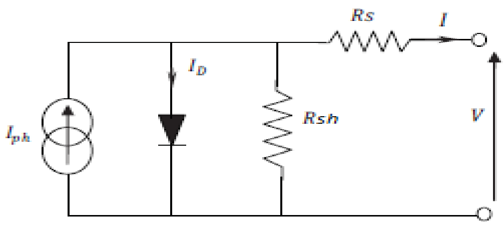

Fig 4. Solar PV Model.

2.4 Fuel Cells Model

In view of guaranteeing good operation of the system and ensuring continuous supply, a fuel cell has been considered and used as storage system to support the microgid power during load variation and minimize the use of the diesel generator. Based on water electrolysis, hydrogen is produced and combusted at low temperature to produce heat which is then transformed into electrical energy. The output voltage of the fuel cell can be expressed as follows [18-19]:

$$V_{FC} = E + \eta_{act} + \eta_{ohmic} \tag{7}$$

The activation voltage η_{act} and ohmic overvoltage η_{ohmic} are given by:

$$\eta_{act} = -B\ln(CI_{FC}) \tag{8}$$

$$\eta_{ohmic} = -R^{int}I_{FC} \tag{9}$$

Where, I_{FC} is the fuel cell current, *B* and *C* are constants to mimic the activation overvoltage in the fuel cell and R^{int} is the internal resistance of the fuel cell. The actual Nernst voltage *E*can be expressed as follows:

$$E = N_O\left[E_O + \frac{RT}{2F}\,log\left[\frac{P_{H2}\sqrt{P_{O2}}}{P_{H2O}}\right]\right] \tag{10}$$

Considering *U* as the utilization factor and *rH-O* is the hydrogen-oxygen flux coefficient. The input flux of hydrogen q_{H2}^{in} and oxygen q_{o2}^{in} are as follows:

$$q_{H2}^{in} = \frac{N_O\, I_{FC}}{2FU} \tag{11}$$

$$q_{o2}^{in} = \frac{q_{H2}^{in}}{rH-0} \tag{12}$$

3. Proposed Fuzzy-GA Method

During the last decades, 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 [17]. This work proposes the design of an optimal Fuzzy scheme in coordination with storage system for hybrid microgrid power management and stability enhancement. The proposed methodology involves the combination of both Fuzzy Logic controller and Genetic algorithm as shown in Fig.5. The power management between the different sources: PV, wind, diesel generator, fuel cell, and the electrolyzer is provided by the proposed Fuzzy-GA technique. It has been designed taking into account two scenarios of functioning of the autonomous microgid wich are: with and without storage system. The operating principle of the proposed strategy is based on the power deviation ΔP. We therefore estimated the total power produced by the photovoltaic system P_{PV} , the wind generation unit P_{wind} and the demand of the load P_L evaluated at each moment, in order to calculate the power deviation ΔP.

$$\Delta P = P_{Gen} - P_L \tag{13}$$

In case without storage system : $P_{Gen} = P_{PV} + P_{wind} + P_{DG}$ (14)

In case with storage system : $P_{Gen} = P_{PV} + P_{wind} + P_{DG} + P_{FC}$ (15)

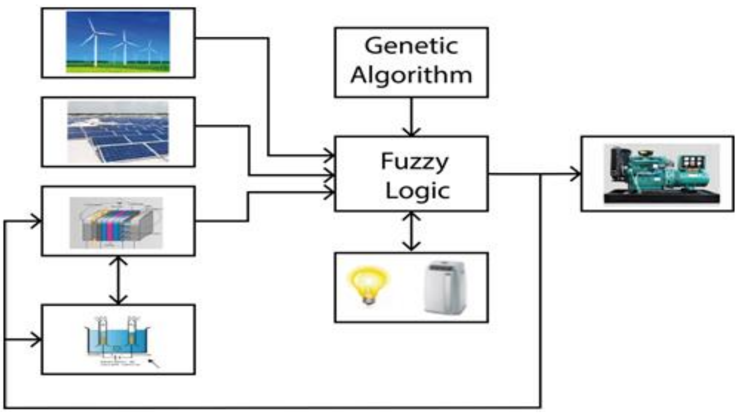

Fig 5. Proposed Fuzzy-GA Method for Microgrid Management.

During the optimization process, the integral time multiply absolute error (*ITAE*) was used as objective function as given in Eq.(16). The GA algorithm was applied to minimize Eq.(16) subject to the scaling factors of fuzzy logic lower and upper bounds given in Eq.(17).

$$ObjFun = \int_{0}^{tsim} t.\left(\left|\Delta P\right|\right).dt \tag{16}$$

$$\begin{Bmatrix} K_{1e\,min} \le K_{1e} \le K_{1e\,max} \\ K_{2e\,min} \le K_{2e} \le K_{2e\,max} \end{Bmatrix} \tag{17}$$

3.1 Fuzzy Logic Controller

In 1965, an effective control method proposed by Pr. Lotfi A. Zadeh named fuzzy logic have shown a high performance in the regulation and control area. Unlike binary logic, this technique allows an infinite number of degrees of truth to be taken into consideration. The first use of this technique go back to Professor Mamdani in 1975. While, the first industrial application of fuzzy logic was made later in 1978 by the Danish company F.L. Smidth [2].

The Sugeno fuzzy inference mechanism was used to ensure the power management between the diesel generator, fuel cell, and the electrolyzer in the aim to keep the microgrid equilibrium. Noting that K_{1e} and K_{2e} are scaling factors of the fuzzy logic controller. As shown in Fig. 6, the power deviation ΔP has been chosen to represent the input. Table.1 presents the linguistic terms that have been considered in this work.

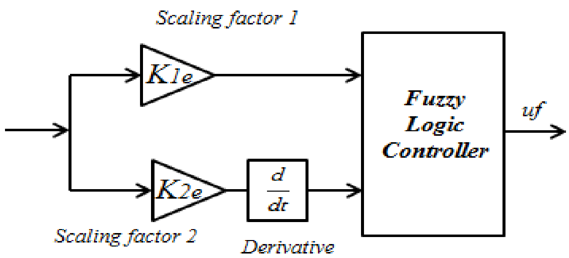

Fig 6. Proposed Fuzzy Logic Scheme.

Table.1. ProposedFuzzy Logic Rules.

Input 1 / Input 2	N	NS	Z	P
L	[OFF, OFF, ON]	[OFF, ON, ON]	[OFF, OFF, OFF]	[ON, OFF, OFF]
G	[ON, OFF, OFF]	[ON, OFF, OFF]	[OFF, OFF, OFF]	[ON, OFF, OFF]
H	[ON, OFF, OFF]	[ON, OFF, OFF]	[OFF, OFF, OFF]	[OFF, ON, OFF]

3.2 Genetic Algorithm (GA)

Genetic Algorithm is a heuristic global searching algorithm based on the mechanisms of biological evolution and natural genetics developed by J.H. Holland in early 1970s. This algorithm is the most used among various optimization methods, which presents a global optimization algorithm and is suitable for solving optimization problems with linear or non-linear objective functions by the generational evolution of the population (selection, crossover and mutation), it solves the optimal solution and satisfactory solution. In generally GA comprises three basic stages [20]:

1- Creating an initial population.

2- Evaluating a fitness function.

3- Producing a new population.

The basic algorithm of GA is shown in Fig.7 [20]:

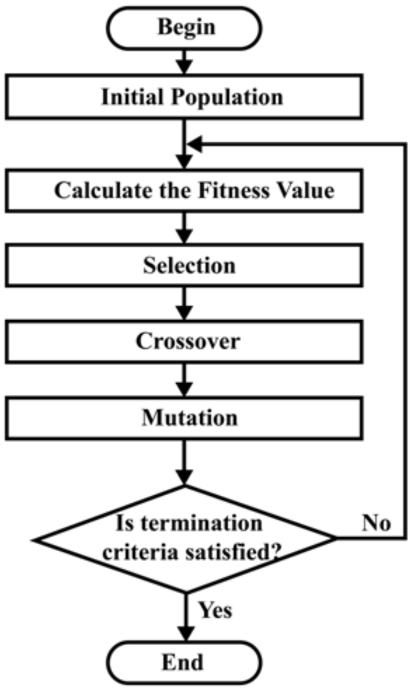

Fig 7. Pseudo Code of the Genetic Algorithm.

4. Results and discussion

In this section, two scenarios have been analyzed and presented to show the contribution of the storage system. In the first scenario, only the isolated hybrid solar PV-wind-diesel system was simulated without storage system. While, in the second scenario, the isolated hybrid solar PV-wind-diesel-FC system was simulated considering the storage system.

The Fuzzy-GA hybrid approach has been employed in this part to improve energy management with and without consideration of energy storage system and also to minimize the diesel generator contribution. In first part, the Fuzzy Logic based on has been used to manage the generation sources present in the microgrid. Subsequently, the Genetic Algorithm has been used to improve the Fuzzy Logic by optimizing the scaling factors K_{1e} and K_{2e} gains.

The total power generated by the solar PV and wind units is presented in Figs.8 and 9 respectively.

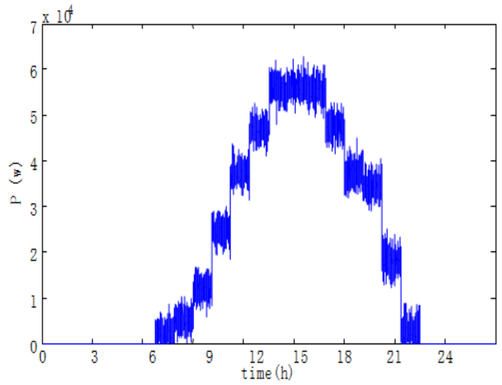

Fig 8. Solar PV power.

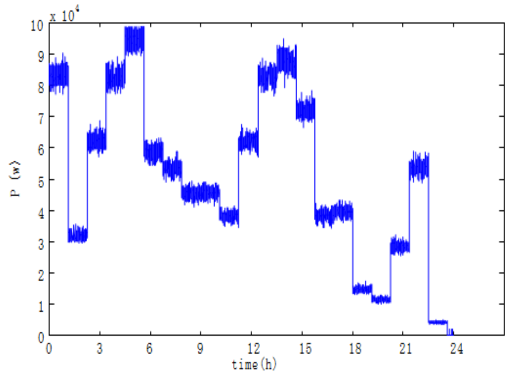

Fig 9. Wind unit power.

4.1 Without storage System

This part presents the hybrid PV-wind-DG microgrid without storage system. The inputs of the model are the climatic conditions and the load demanded as a function of time. The power management of the system is done by the load shedding of the overload to maintain microgrid balance. The diesel generator generated power and the unloaded power demand in this case are presented in Fig.10 and Fig.11respectively.

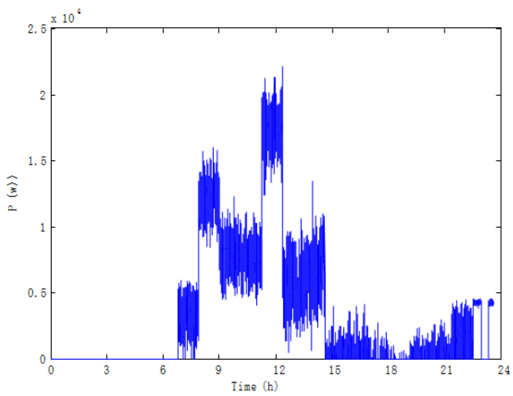

Fig 10. diesel generator generated power.

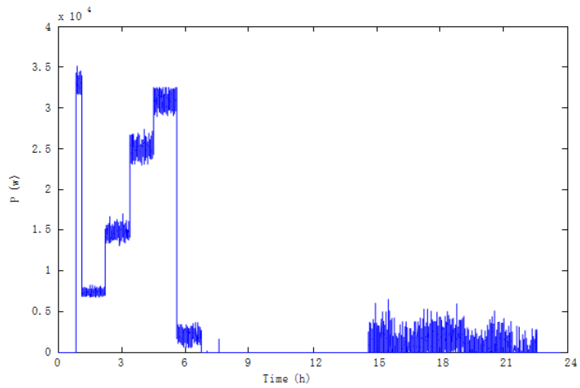

Fig 11. Application of Load Shedding

In this scenario, and due to the load increase, the microgrid supply was not enough to satisfy the load, we must therefore use the load shedding algorithm to be able to maintain the management of the microgrid. the total load profile is given in Fig.12, where, Fig. 13 shows the evolution of the powers involved in the hybrid microgrid without storage system.

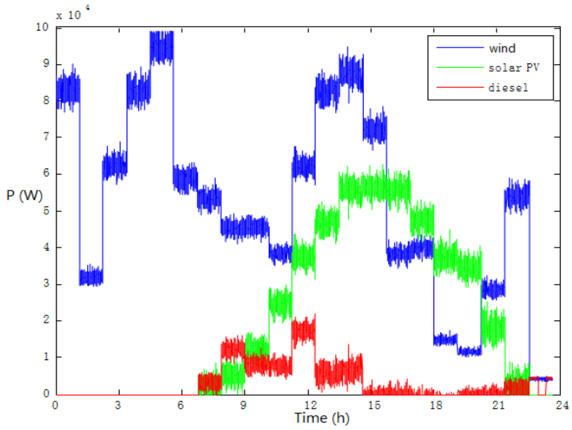

Fig 12. Evolution of Microgrid Powers.

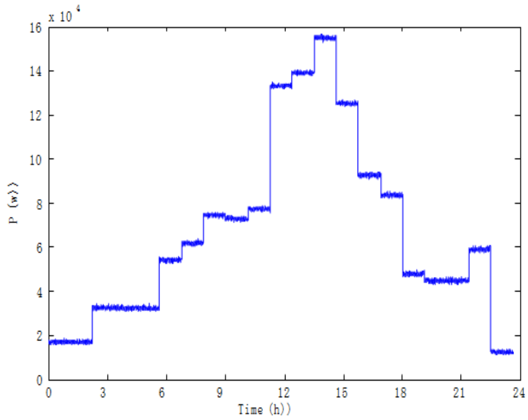

Fig 13. Total Load profile.

Fig.14 presents a comparative study between the generated and consumed power in the microgrid.

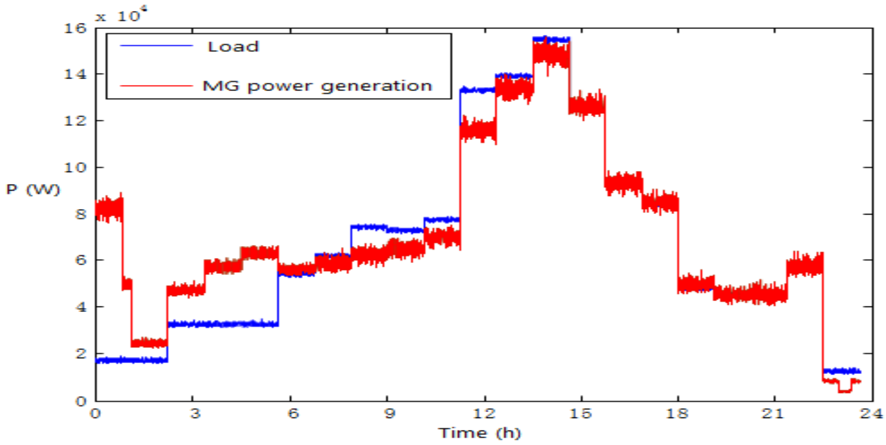

Fig 14. Evolution of Microgrid Powers without storage system.

4.2 With storage System

In this part, the hybrid PV-wind-DG microgrid was supported with Fuel Cells (FCs) and Electrolyzers as storage system. This storage system was used as solution to avoid the load shedding of the first scenario. The storage system was proposed to achieve a more robust solution that encompasses the management, control and stability for enhancing the operation of the proposed microgrid. On the other hand, an optimal Fuzzy-GA scheme was used in the aim to improves the power management strategy performances. Table.2 presents the optimal fuzzy logic parameters. It can observed from the comparative study between the supplyed power and load in both cases without and with storage system showed in Figs. 15 and 16, that the proposed strategy gives good results in view of keeping microgrid equilibrium.

Table.2. Optimized Scaling Factors of fuzzy logic based GA.

	K_{1e}	K_{2e}
Without Storage	0.9029	0.5233
With Storage	0.4888	0.9843

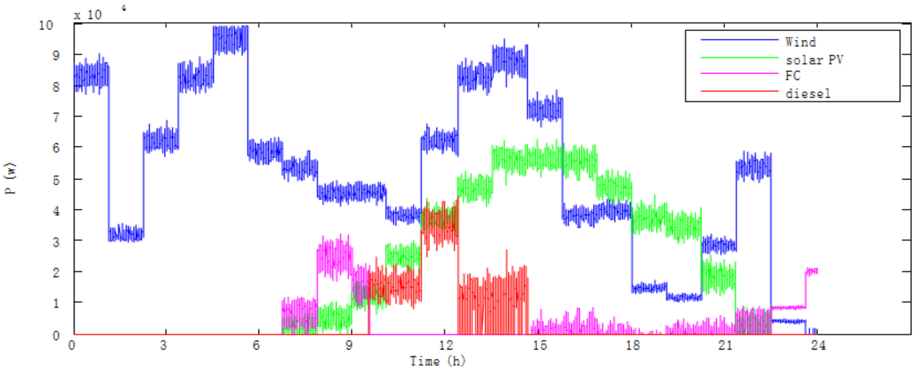

Fig 15. Evolution of Microgrid Powers in presence of storage system.

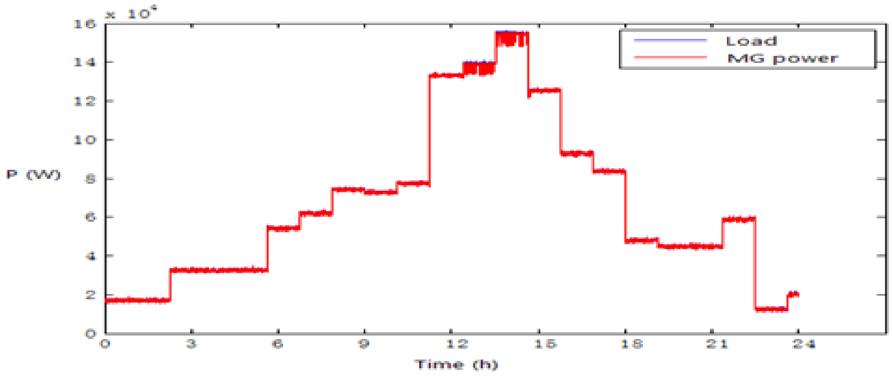

Fig 16. Evolution of Microgrid Powers with storage system.

4.3 Comparative study

In this part, a comparative analysis between the investigated microgid without and with storage system is presented in Fig.17. It is clear from the results that the storage system can support the microgrid power generation, minimize the use of the diesel generator and avoid load shedding, which conduct to ensure a good power quality.

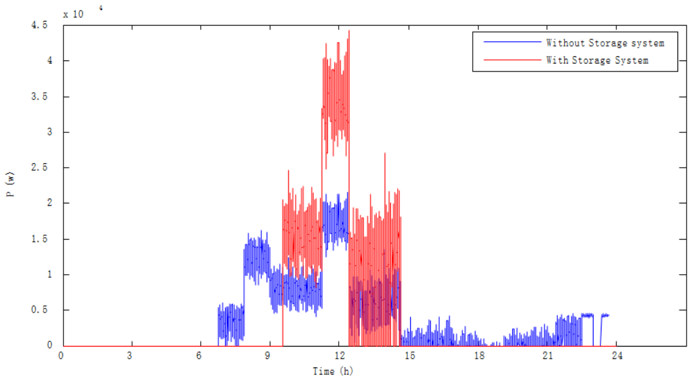

Fig 17. Diesel generator participation without and with storage system.

5. Conclusion

This paper has presented an optimal power management strategy for isolated microgrid including energy storage system. The proposed hybrid microgrid model have been simulated with and without storage system. This latter was used firstly to support to power generation and then to minimize the use of the diesel generator. During the optimization process the Genetic Algorithm (GA) was employed to fine tune the controller parameters. Several scenarios have been presented to demonstrate the effectiveness of the proposed optimal Fuzzy-GA strategy. Finally, the obtained results confirm the effectiveness of the proposed strategy.

6. References

[1] Nour EL Yakine KOUBA, Mohamed BOUDOUR , ' Intelligent Load Frequency Control in Presence of Wind Power Generation', Renewable Energy Systems, Springer Nature 2019, Chapter 14, pp.281-314.

[2] Nour EL Yakine KOUBA, Slimane SADOUDI, Smail HAROUN and Mohamed BOUDOUR, 'Optimal Tuning of Fuzzy-PIDN Controller for Autonomous Microgrid Incorporating Various Renewable Energy Sources and Multiple Energy Storage Systems', International Journal of Control, Energy and Electrical Engineering, 2019, Vol.7 (1), pp.47-52

[3] M. Younes, F. Khodja, and M. Laouer, "Management optimization of the algerian network electricity with renewable energy", *J. Ren. Energies*, vol.17 (2), pp.217 -, Jun. 2014.

[4] L. Meng, E. R. Sanseverino, A. Luna, T. Dragicevic, J. C. Vasquez, and J. M. Guerrero, "Microgrid supervisory controllers and energy management systems: A literature review," Renewable and Sustainable Energy Reviews 2016, vol. 60, pp. 1263-1273.

[5] L. I. Minchala-Avila, L. E. Garza-Castañón, A. Vargas-Martínez, and Y. Zhang, "A review of optimal control techniques applied to the energy management and control of microgrids," *Procedia Computer Science* 2015, vol. 52, pp. 780-787.

[6] L. Meng, E. R. Sanseverino, A. Luna, T. Dragicevic, J. C. Vasquez, and J. M. Guerrero, "Microgrid supervisory controllers and energy management systems: A literature review," *Renewable and Sustainable Energy Reviews* 2016, vol. 60, pp. 1263-1273.

[7] L. I. Minchala-Avila, L. E. Garza-Castañón, A. Vargas-Martínez, and Y. Zhang, "A review of optimal control techniques applied to the energy management and control of microgrids," *Procedia Computer Science* 2015, vol. 52, pp. 780-787.

[8] M. Sechilariu, F. Locment, and I. Houssamo, "Multi-source power generation system in semi-isolated and safety grid configuration for buildings," in *15th IEEE Mediterranean Electrotechnical Conference MELECON*, 2010, pp. 967-972.

[9] Y. Yoldaş,et al., "Enhancing smart grid with microgrids: Challenges and opportunities,"

[10] WU, Tao et WANG, Jianhui. Artificial intelligence for operation and control: The case of microgrids. *The Electricity Journal*, 2021, vol. 34, no 1, p. 106890.

[11] CHIDAMBARAM, I. A. et PARAMASIVAM, B. Control performance standards based load-frequency controller considering redox flow batteries coordinate with interline power flow controller. *Journal of power sources*, 2012, vol. 219, p. 292-304.

[12] Sankarkumar RS, Natarajan R. Energy management techniques and topologies suitable for hybrid energy storage system powered electric vehicles: An overview. Int Trans Electr Energ Syst. 2021;e12819. https://doi.org/10.1002/2050-7038.12819.

[13] ALOTTO, Piergiorgio, GUARNIERI, Massimo, MORO, Federico. Redox flow batteries for the storage of renewable energy: A review. *Renewable and sustainable energy reviews*, 2014, vol. 29, p. 325-335.

[14] R. Shigenobu, A. S. Noorzad, C. Muarapaz, A. Yona, and T. Senjyu, "Optimal operation and management for smart grid subsumed high penetration of renewable energy, electric vehicle, and battery energy storage system," *International Journal of Emerging Electric Power Systems* 2016, vol. 17, no. 2, pp. 173-189.

[15] J. K. Tangka, P. Tchakoua, H. Fotsin, and A. Fomethe, "Development of an intelligent electronic module for energy management in wind/diesel or photovoltaic/diesel hybrid systems," *British Journal of Applied Science & Technology* 2012, vol. 2, no. 3, pp. 275-295.

[16] Renewable and Sustainable Energy Reviews 2017, vol. 72, pp. 205-214.

[17] Nour El Yakine Kouba ; Mohamed Menaa ; Mourad Hasni ; Mohamed Boudour, " A novel optimal frequency control strategy for an isolated wind–diesel hybrid system with energy storage devices", *SAGE, Wind Engineering*, 2016, Volume 40, Issue 6, pp. 497–517.

[18] N.KOUBA, et al.," Optimal Power Management and Control of Photovoltaic-H2-Fuel Cell Hybrid Microgrid Considering Energy Storage System", *ICRAES,2019, pp.111-116*.

[19] M. Mostefaoui, B. . Belmadani, A. . Babouri, and A. . Djerdir, "Performances system management: fuel cell / photovoltaic", *J. Ren. Energies*, vol. 11, no. 2, pp. 207 -, Jun. 2008.

[20] Nour EL Yakine Kouba, Mohamed Menaa, Mourad Hasni and Mohamed Boudour, "A New Optimal Load Frequency Control Based on Hybrid Genetic Algorithm and Particle Swarm Optimization**",** International Journal on Electrical Engineering and Informatics, September 2017 , Vol. 9 No. 3, pp. 418-440.