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Optimal Tuning of Fuzzy-PIDN Controller for Autonomous Microgrid Incorporating Various Renewable Energy Sources and Multiple Energy Storage Systems

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Abstract— **In this paper, a new efficient Fuzzy-PID controller with Derivative Filter (Fuzzy-PIDN) optimized via Grasshopper Optimization Algorithm (GOA) was proposed for Load Frequency Control (LFC) of an interconnected microgrid. The GOA was employed to fine tune the scaling factors of fuzzy logic and PIDN controllers gains by generating their optimal settings. The investigated microgrid system includes two interconnected areas incorporating Diesel engine, Wind turbine, Solar Photovoltaic (PV), and Energy storage systems including Redox Flow Batteries (RFBs), Superconducting Magnetic Energy Storage (SMES), Fuel Cells (FCs) and Aqua Electrolyzers (AEs). The frequency control of the addressed autonomous microgrid was studied using a dynamic modeling of each unit. The power demand variation was considered as disturbance, where, the conventional controllers PID, Fuzzy-PID and Fuzzy-PIDN were implemented for comparative analysis of the LFC performance. The superiority of the proposed GOA strategy was demonstrated under various scenarios using four performance criteria functions, which are : Integral Square Error (ISE), Integral Absolute Error (IAE), Integral Time multiply Absolute Error (ITAE) and Integral Time multiply Square Error (ITSE). The behavior of the microgrid was analyzed in several case studies, and some control actions were suggested to improve the frequency control in presence of renewable energy. The obtained results were compared in view of peak undershoot / overshoot and settling time. The performed simulations prove the validity of the used GOA optimization tool, and shows that GOA optimized Fuzzy-PIDN controller was robust and can cope with system disturbance to solve frequency regulation problem.**

Keywords— Microgrid, Photovoltaic, Wind turbine, Redox Flow Batteries (RFBs), Superconducting Magnetic Energy Storage (SMES), Fuel Cells (FCs), Aqua Electrolyzer (AE), Fuzzy-PIDN Controller, Grasshopper Optimization Algorithm (GOA).

I. INTRODUCTION

In a near future, modern electrical networks will contain many types of renewable energy sources (RESs) in large numbers. In small power system such as a microgrid, which majorly includes various kinds of RESs such as wind, solar, wave energy,...etc, the control actions such as frequency regulation need to be of high performance to avoid system instability [1-2]. Presently, the microgrid is considered as a new developing technology, which can be operated in two modes namely, the utility-grid-connected mode and the autonomous or isolated operation mode. The microgrid can be considered as a closed small network that consist of micro-turbines and diesel engine generators. The microgrid reliability can be improved using the Distributed Generation (DG) like wind and solar sources [3-5].

The DG units are mostly installed near to the load centers to satisfy the power demand locally. On one hand, the use of DG units is an attractive tool to deliver a clean power. On the other hand, power system control is required to enhance the quality of power supply in such system that includes several DG units, because the equilibrium between the power supply and consumption is of major concern. Basically, the microgrid includes mainly two kinds of power sources that can be classified as inertial or non-inertial in terms of power flow control. The inertia sources are that kind of units which their output power can be controlled to maintain the desired microgrid frequency at nominal value such as micro turbines, fuel cells and diesel generators. However, non-inertial sources like wind and PV, are used to supply only a portion of the total power demand. Whereas, the output power of this kind of sources depends on the environmental conditions. Thus, it is difficult to handle the large number of DGs during disturbances [6-10].

Regarding the problem of network instability, the microgrid system sometimes witness instability due to load change. According to the event of load disturbance, the system frequency gets affected due to unbalance between power supply and load. To ensure that, the frequency of the autonomous microgrid that is operated in isolated operation mode is maintained within scheduled limits, a secondary control action named Load Frequency Control (LFC) comes as an auxiliary control system to maintain the frequency at nominal value during load change using the Area Control Error (ACE). Moreover, to operate the microgrid as fast as possible, a robust regulation including the LFC in coordination with some rapid dynamic response devices such as the Energy Storage System (ESS) is required [10-11].

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Conventionally, the microgrid frequency fluctuation is handled using the droop control and power sharing method in the microgrid. In addition, the LFC loop can be associated with a PI controller to enhance the frequency regulation. In contrast, the integration of DG units like wind and solar PV makes the frequency control more difficult, which requires an efficient control strategy to mitigate the frequency fluctuation. Therefore, it is very important to contribute for enhancing the microgrid frequency regulation in presence of various renewable energy sources by the use of some strategies that can bring more robustness to the microgrid control.

Over the last years, several strategies have been published in the scope of the microgrid control employing Artificial Intelligence (AI) and nature-inspired optimization algorithms. Most of the developed techniques for microgrid regulation were based on PI or PID controller. Some interesting applications of fuzzy logic and neural networks have been also proposed. In reference [12], Leong Kit Gan et al., have proposed to study a hybrid power system in Scotland. In reference [13], S. Rehman and I. El-Amin, have proposed to study a hybrid power system in the Saudi Arabia, where, in reference [14], J. G. Mcgowan et al., have proposed to study a hybrid power system in the South American. In reference [15], Julius K. Tangka have proposed an intelligent electronic module for energy management of hybrid microgrid, whereas, M. Venkatesh and G. Sudheer have proposed an optimal LFC of microgrid using Dragonfly Algorithm [16].

Furthermore, some researchers have discussed the applications of energy storage system (ESS). In reference [17], Gayathri Nair S and Nilanjan Senroy have studied the dynamics of a Flywheel energy storage system. In [18], authors have studied the optimal sizing of ESS using GSA optimization algorithm. In [19], authors have proposed an optimal management of smart grid system using PSO algorithm. In [20], authors have studied the LFC control using the vehicle-to-grid (V2G) technique. In reference [21], authors have studied the dynamic frequency control support by ESS to reduce the impact of RESs integration, where, in reference [22], authors have proposed the use of an optimized fuzzy-cuckoo controller to enhance the control of the storage system in a hybrid microgrid.

Based on the above literature study, the key contributions of this paper are:

- A new optimized Fuzzy-PIDN controller was employed and optimized using the recently developed Grasshopper Optimization Algorithm (GOA).
- An effective LFC scheme support with multiple energy storage systems such as Redox Flow Batteries (RFBs), Superconducting Magnetic Energy Storage (SMES), Fuel Cells (FCs) and Aqua Electrolyzer (AE) was proposed.

The rest of the paper is organized as follows. Section II presents the dynamic model of the investigated microgrid. Section III describes the proposed optimized Fuzzy-PIDN controller, followed by a brief description of the employed GOA optimization algorithm. Section IV presents the simulation results with a detailed discussion of each case study. Finally, Section V concludes the paper.

II. AUTONOMOUS HYBRID MICROGRID MODEL

In recent years, the integration of decentralized generation units (DGs) in power systems is significantly increasing [23]. This results from the liberalization of the electricity market and the desire to promote renewable energies. As a consequence, new and stricter connection constraints are being developed to address the issues associated with the intermittent energy sources. Their dependence on climatic conditions will be a problem when participating in the power management. To deal with this situation, hardware and algorithmic solutions can be used to minimize this intermittent aspect, as a set of control strategy, support and control systems such as storage devices, frequency/voltage control systems and conventional generators. Fig.1 presents the investigated two-area interconnected microgrid. The used system contains Diesel engine, Solar Photovoltaic, Fuel Cells and Aqua Electrolyzers in Area-1, and comprise Diesel engine, wind turbine, Redox Flow Batteries and Superconducting Magnetic Energy Storage in Area-2.

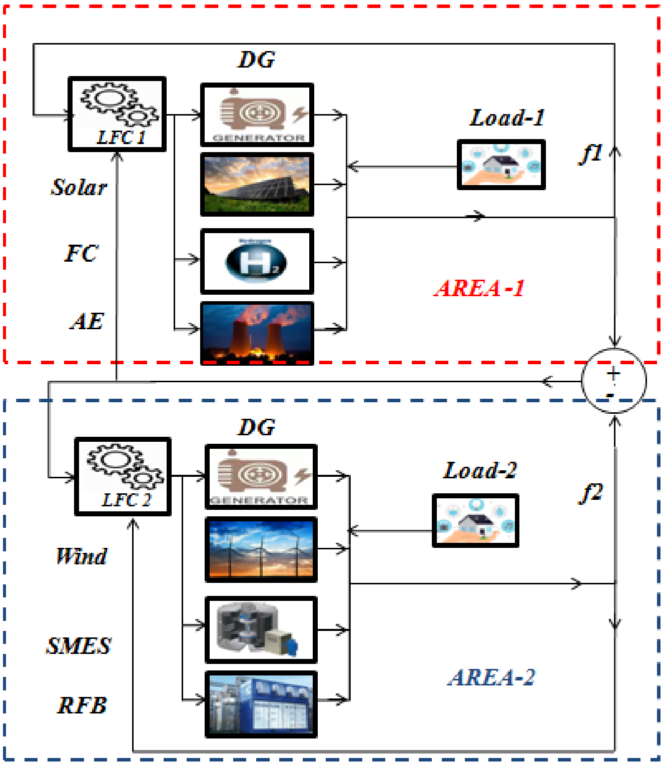

Fig. 1. Interconnected Two-area Hybrid Microgrid.

Focusing mainly on the frequency control (LFC), each area was modeled separately. The two-area system was modeled as shown in Fig. 2 and Fig. 3 respectively. The storage was used to compensate the LFC regulation capacity in presence of both wind and solar PV units. The dynamic modeling of each unit can be found in references [1, 2, 5 and 6]. In other hand, to improve the LFC loop, an optimal Fuzzy-PIDN controller with Derivative Filter was associated to each control area to handle the frequency fluctuation due to the wind and solar PV power variations. During this study, each area was analyzed independently as a hybrid microgrid, then an interconnection between the two areas was established and studied.

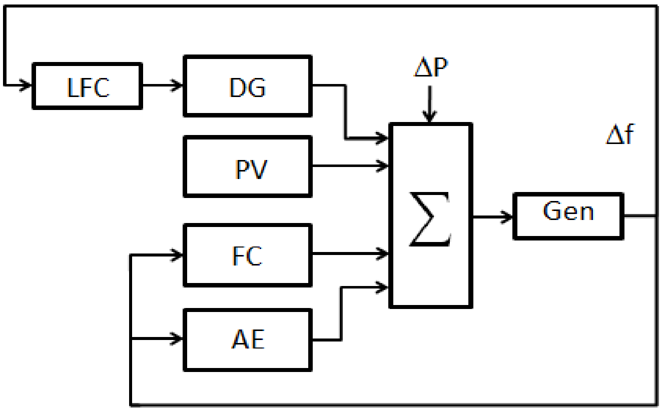

Fig. 2. Hybrid Solar PV-Diesel Microgrid with Storage System.

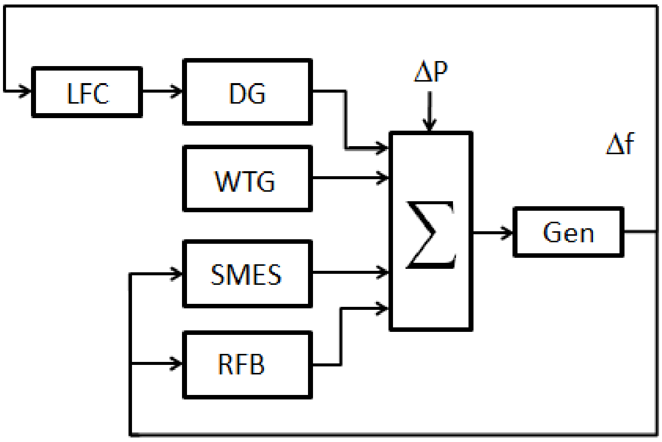

Fig. 3. Hybrid Wind-Diesel Microgrid with Storage System.

III. PROPOSED CONTROL STRATEGY

During the last decades, various LFC schemes have been proposed to enhance the frequency regulation. This work proposes the design of a new optimal LFC controller in coordination with storage system for interconnected hybrid microgrid. The proposed methodology involves the combination of both Fuzzy Logic controller and the PID controller with a Derivative Filter. In addition, the controller parameters where tuned using the recently developed Grasshopper Optimization Algorithm (GOA). During the optimization process, four objective functions were used to show the robustness of the applied control strategy, which are : ISE, IAE, ITAE and ITSE.

A. Fuzzy-PID Controller with Derivative Filter

Conventionally, most of the regulation systems are based on the PI or PID controllers. Nowadays, such controllers are widely used in industry, where more than 90% are composed from the three actions: Proportional (*P*), Integral (*I*), and Derivative (*D*), since that present an efficient solution and has a simple construction. The PIDN is a classic PID controller associated with a Derivative Filter (*N*) [24]. The PIDN comprise a low pass first-order filter with a coefficient (*N*), that presents a solution for eliminating the undesirable noise caused by the Derivative (*D*) action.

On the other hand, a robust control technique developed by Pr. Lotfi A. Zadeh in 1965 called fuzzy logic have shown a high performance in the regulation area. Unlike binary logic, fuzzy logic allows an infinite number of degrees of truth to be taken into consideration. The first application of this technique go back to Professor Mamdani in 1975. The first industrial application of fuzzy logic was made later in 1978 by the Danish company F.L. Smidth.

This paper proposes a new controller based on combining both of fuzzy logic and PIDN controllers in order to enhance system regulation by assembling the advantages of both controllers. In Fig. 4 the structure of the used PIDN controller is presented [24-27], where, the PIDN controller transfer function is given by the Eq.1. The input of the PIDN controller is taken from the output of the Fuzzy Logic controller (FLC), where the input of the fuzzy controller is the Area Control Error (ACE) given in Eq. 2 as shown in Fig. 5.

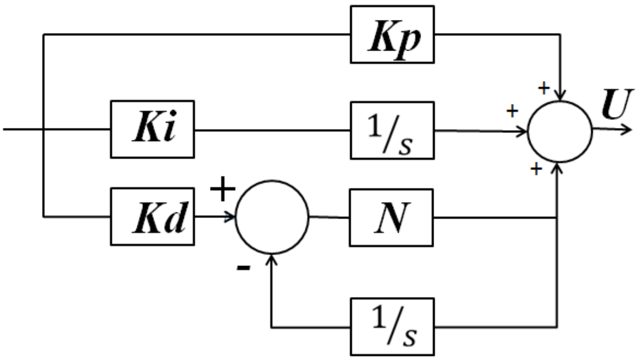

Fig. 4. *PIDN Controller Structure* [24].

$$TF_{PIDN} = Kp + K_i \frac{1}{s} + K_d \frac{N.s}{N} \qquad (1)$$

$$ACE = \Delta P_{tie} + \beta_f \Delta f \qquad (2)$$

The Mamdani fuzzy inference mechanism with a center of gravity method of defuzzification was used, where the triangular membership functions were selected for the inputs and outputs. Noting that *K*1e and *K*2e are scaling factors of the fuzzy logic controller. As shown in Fig. 6, the triangular membership functions have been chosen to represent the input linguistic variables ACE, the derivative of ACE, and the FLC output *uf*. Five linguistic terms have been considered, which are: Negative Big (NB), Negative Small (NS), Zero (ZE), Positive Small (PS), and Positive Big (PB), as cited in Tab.1.

Table.1. FLC Control Rules.

dACE	*ACE*				
	NB	NS	ZE	PS	PB
NB	NB	NB	NS	NS	ZE
NS	NB	NB	NS	ZE	ZE
ZE	NS	NS	ZE	PS	PS
PS	ZE	PS	PS	PB	PB
PB	ZE	ZE	PS	PB	PB

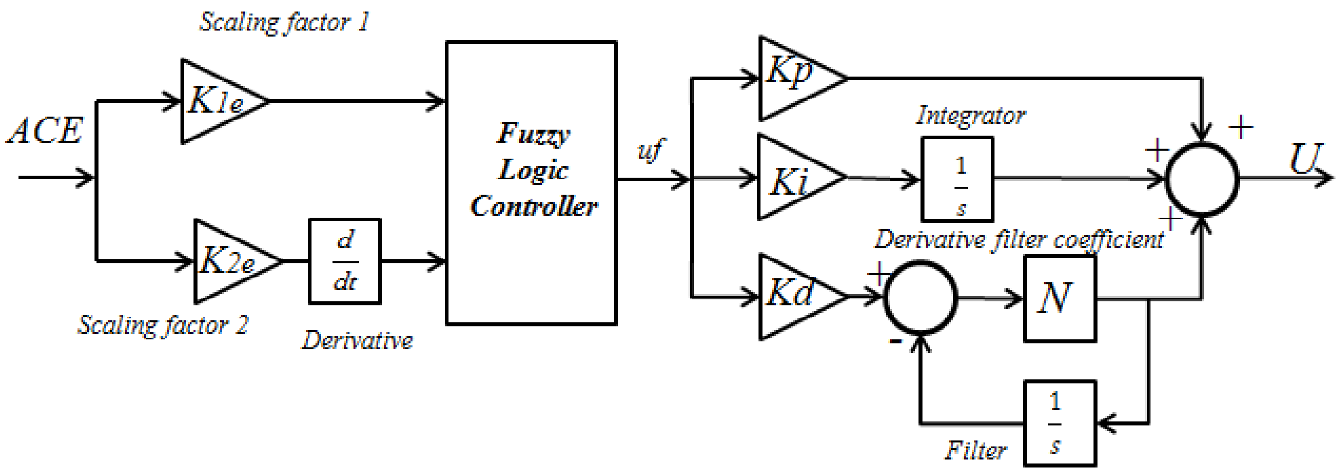

Fig. 5. Fuzzy-PIDN Structure [27].

The control signal is given by:

$$uf = A + (K1eP.ACE) + (K2eD.\frac{dACE}{dt}) \quad (3)$$

$$U = (Kp.uf) + (Ki\int_0^t uf(t)dt) + (\frac{duf(t)}{dt}) \quad (4)$$

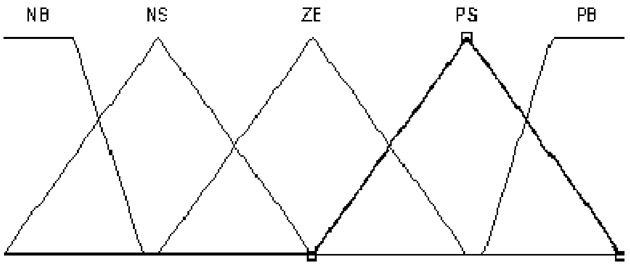

Fig. 6. Membership Functions for FLC Inputs and Outputs.

B. *Grasshopper Optimization Algorithm (GOA)*

Grasshopper Optimization Algorithm (GOA) is a new developed meta-heuristic algorithm proposed by Shahrzad Saremi et al. in 2016 [28]. GOA was inspired from the social life and hunting behavior of Grasshopper in nature. The pseudo code of the GOA algorithm is shown in Fig.7.

C. *Objective Function*

In order to solve the optimal LFC problem in the interconnected hybrid microgrid, four performance criteria functions (*Fit*) have been used as given in Eqs. 5 to 8:

- Integral Square Error (*ISE*).

$$ISE = \int_0^\infty \left(x(t) - y(t)\right)^2 .dt = \int_0^\infty \left(e(t)\right)^2 .dt \quad (5)$$

- Integral Absolute Error (*IAE*).

$$IAE = \int_0^\infty \left(\left|x(t) - y(t)\right|\right).dt = \int_0^\infty \left(\left|e(t)\right|\right).dt \quad (6)$$

- Integral Time multiply Square Error (*ITSE*).

$$ITSE = \int_0^\infty t.\left(x(t) - y(t)\right)^2 .dt = \int_0^\infty t.\left(e(t)\right)^2 .dt \quad (7)$$

- Integral Time multiply Absolute Error (*ITAE*).

$$ITAE = \int_0^\infty t.\left(\left|x(t) - y(t)\right|\right).dt = \int_0^\infty t.\left(\left|e(t)\right|\right).dt \quad (8)$$

```
Initialize the swarm $X_i$ ($i = 1, 2, ..., n$)
Initialize cmax, cmin, and maximum number of iterations
Calculate the fitness of each search agent
T=the best search agent
while (l < Max number of iterations)
    Update c
    for each search agent
        Normalize the distances between grasshoppers in [1,4]
        Update the position of the current search agent
        Bring the current search agent back if it goes outside the boundaries
    end for
    Update T if there is a better solution
    l=l+1
end while
Return T
```

Fig. 7. Pseudo Code of the GOA Algorithm [28].

The frequency variation Δf and the tie-line power flow exchange deviation ΔP_{tie} have been used as inputs for the above equations, where t represents the simulation time. The optimization problem constraints are the fuzzy logic scaling factors and the PIDN controller parameters bounds. Therefore, the design problem can be formulated as the following optimization problem:

- Minimize the objective function *Fit* given in Eqs. (5-8) using GOA algorithm, subject to:

$$\left\{\begin{matrix} K_{p\,min} \le K_p \le K_{p\,max} \\ K_{i\,min} \le K_i \le K_{i\,max} \\ K_{d\,min} \le K_d \le K_{d\,max} \\ N_{min} \le N \le N_{max} \end{matrix}\right\} \qquad \left\{\begin{matrix} K_{1emin} \le K_{1e} \le K_{1emax} \\ K_{2emin} \le K_{2e} \le K_{2emax} \end{matrix}\right\}$$

IV. SIMULATION RESULTS

To evaluate the performance of the interconnected two-area microgrid, shown in Fig. 1, a series of simulation have been executed. The presented scenarios were updated concerning load variation in each area of the microgrid. Three scenarios have been analyzed and presented. In the first scenario, only the isolated hybrid solar PV-diesel system was simulated with and without storage system. In the second scenario, only the isolated hybrid wind-diesel system was simulated with and without storage system. Finally, in the third scenario, the interconnection between the two isolated hybrid systems was established, and the interconnected two-area microgrid was simulated. The simulation was performed in presence of 0.1 pu step load disturbance. A comparative study between the employed objective functions was carried out, then a comparative study between the classical PID, Fuzzy-PID, and Fuzzy-PIDN controllers based GOA was presented.

A. Scenario 1 : Hybrid Solar PV-Diesel with Storage System

Fig.8 presents the frequency variation in the hybrid PV-diesel system with and without storage system.

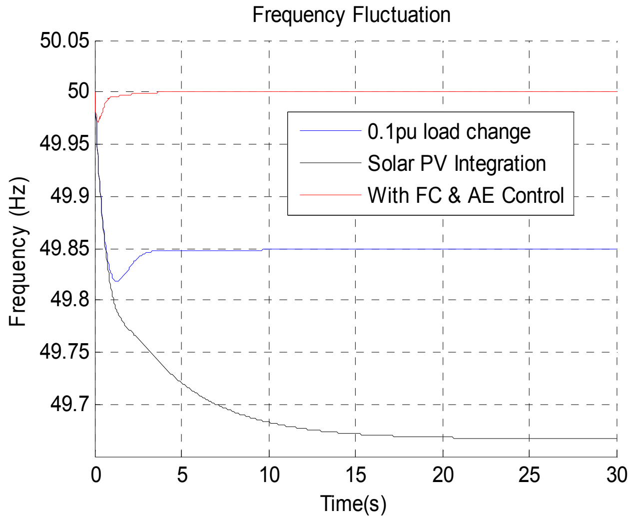

Fig. 8. Frequency Deviation in Area-1.

B. Scenario 2: Hybrid Wind-Diesel with Storage System

Fig.9 presents the frequency variation in the hybrid wind-diesel system with and without storage system. The impact of both RFBs and SMES devices was analyzed in view of frequency deviation minimization in presence of load change and wind power fluctuations.

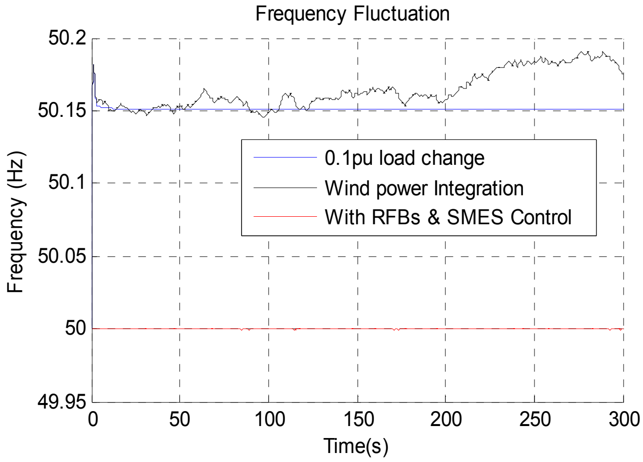

Fig. 9. Frequency Deviation in Area-2.

C. Scenario 3 : Interconnected Two-Area Microgrid

In this scenario, an interconnection between the solar PV-diesel and the wind-diesel hybrid systems was established. The interconnected microgrid was simulated for 0.1 pu step load change in presence of both wind and solar fluctuations. A comparative study between four performance criteria (ISE, IAE, ITSE and ITAE) is presented in Fig.10, where a comparative analysis between the tested controller is presented in Fig.11. The ITAE was chosen as best objective function.

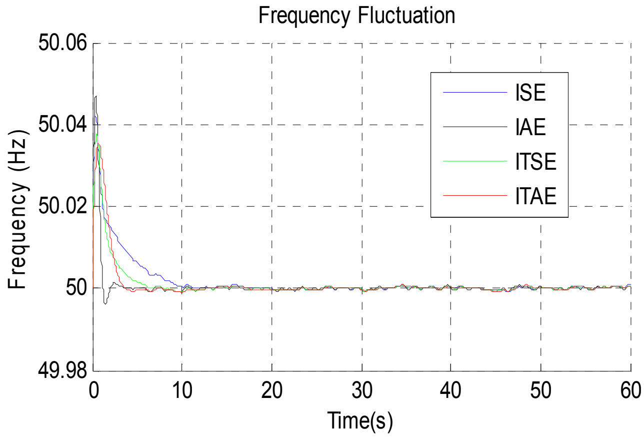

Fig. 10. Comparative Performance Analysis.

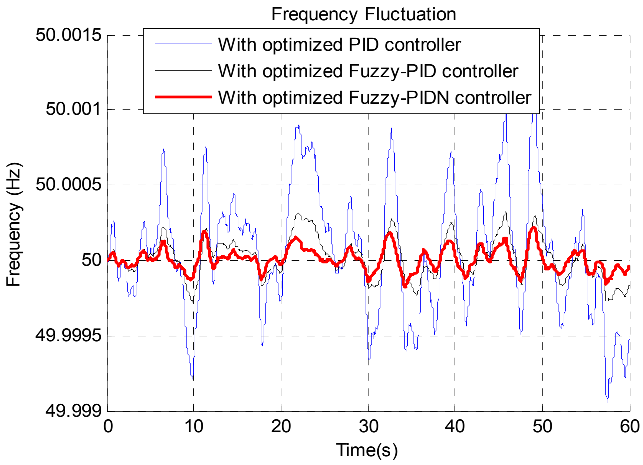

Fig. 11. Frequency Deviation with Optimal LFC.

The microgrid was analyzed in presence of wind and solar PV units. The LFC was supported with storage system in each area of the microgrid. From the obtained results, it can be seen that the storage system (FC, AE, RFBs and SMES) can help the secondary LFC loop to handle the frequency fluctuation in presence of renewable energy sources. Several objective functions have been tested, where the ITAE presents the best performance in view of settling time, peak undershoot and overshoot. Furthermore, as seen from the presented Figures above, the optimized Fuzzy-PIDN controller quickly regulates the system frequency towards the nominal value, where the proposed controller improves the LFC performance further and outperforms all other controllers tested in this work.

V. CONCLUSION

This paper has presented a novel optimal control strategy for microgrid frequency regulation involving a combined fuzzy-PID controller with derivative filter. A Recently developed optimization algorithm named Grasshopper Optimization Algorithm (GOA) was employed to fine tune the controller parameters. The developed controller was applied to a hybrid two-area microgrid including various renewable energy sources. The LFC loop was supported with multiple energy storage systems to enhance the microgrid stability. Several scenarios have been presented to demonstrate the effectiveness of the proposed approach. Finally, the obtained results confirm the effectiveness of the proposed strategy.

REFERENCES

[1] N. E. Y. Kouba, A. Benseddik, Y. Amrane, M. Hasni, and M. Menaa, "Coordinated Control of Optimal LFC Method and Energy Storage System for Microgrid Frequency Regulation in Presence of Wind Farm," *International Journal of Electronic and Electrical Engineering Systems* 2018, vol. 0, no. 0, pp. 9-15.

[2] L. Wang, D.-J. Lee, W.-J. Lee, and Z. Chen, "Analysis of a novel autonomous marine hybrid power generation/energy storage system with a high-voltage direct current link," *Journal of Power Sources* 2008, vol. 185, no. 2, pp. 1284-1292.

[3] M. Vahedipour-Dahraie, H. R. Najafi, A. Anvari-Moghaddam, and J. M. Guerrero,"Study of the effect of time-based rate demand response programs on stochastic day-ahead energy and reserve scheduling in islanded residential microgrids,"*Applied Sciences* 2017,7(4),pp.378-397.

[4] M. Vahedipour-Dahraie, H. Rashidizaheh-Kermani, H. R. Najafi, A. Anvari-Moghaddam, and J. M. Guerrero, "Coordination of EVs participation for load frequency control in isolated microgrids," *Applied Sciences* 2017, vol. 7, no. 6, pp. 539-555.

[5] S. K. Pandey, S. R. Mohanty, N. Kishor, and J. P. Catalão, "Frequency regulation in hybrid power systems using particle swarm optimization and linear matrix inequalities based robust controller design," *International Journal of Electrical Power & Energy Systems* 2014, vol. 63, pp. 887-900.

[6] P. SANKI and M. BASU, "New approach in two-area interconnected AGC including various renewable energy sources using PSO," *Turkish Journal of Electrical Engineering & Computer Sciences* 2018, vol. 26, no. 3, pp. 1491-1504.

[7] 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.

[8] 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.

[9] T. Ota, K. Mizuno, K. Yukita, H. Nakano, Y. Goto, and K. Ichiyanagi, "Study of load frequency control for a microgrid," in *Power Engineering Conference*, *AUPEC 2007*. Australasian Universities, pp. 1-6.

[10] Y. Sawle, S. Gupta, and A. Kumar Bohre, "PV-wind hybrid system: A review with case study," *Cogent Engineering* 2016, 3, (1), pp. 1-31.

[11] Y. Yoldaş, A. Önen, S. Muyeen, A. V. Vasilakos, and İ. Alan, "Enhancing smart grid with microgrids: Challenges and opportunities," *Renewable and Sustainable Energy Reviews 2017*, vol. 72, pp. 205-214.

[12] L. K. Gan, J. K. Shek, and M. A. Mueller, "Hybrid wind–photovoltaic–diesel–battery system sizing tool development using empirical approach, life-cycle cost and performance analysis: A case study in Scotland," *Energy conversion and management* 2015, vol. 106, pp. 479-494.

[13] S. Rehman and I. El-Amin, "Study of a solar PV/wind/diesel hybrid power system for a remotely located population near Arar, Saudi Arabia," *Energy Exploration & Exploitation* 2015, 33: (4), pp. 591-620.

[14] J. McGowan, J. Manwell, C. Avelar, and C. Warner, "Hybrid wind/PV/diesel hybrid power systems modeling and South American applications," *Renewable energy* 1996, vol. 9, no. 1-4, pp. 836-847.

[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] M. Venkatesh and G. Sudheer, "Optimal load frequency regulation of micro-grid using dragonfly algorithm," *International Research Journal of Engineering and Technology* 2017, vol. 4, no. 8, pp. 978-981.

[17] G. Nair and N. Senroy, "Dynamics of a flywheel energy storage system supporting a wind turbine generator in a microgrid," *International Journal of Emerging Electric Power Systems* 2016, 17:(1), pp. 15-26.

[18] A. Mahesh, K. S. Sandhu, and J. V. Rao, "Optimal Sizing of Battery Energy Storage System for Smoothing Power Fluctuations of a PV/Wind Hybrid System," *International Journal of Emerging Electric Power Systems* 2017, vol. 18, no. 1, pp.1-13.

[19] 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.

[20] J. Yang, Z. Zeng, Y. Tang, J. Yan, H. He, and Y. Wu, "Load frequency control in isolated micro-grids with electrical vehicles based on multivariable generalized predictive theory," *Energies* 2015, vol. 8, no. 3, pp. 2145-2164.

[21] G. Delille, B. Francois, and G. Malarange, "Dynamic frequency control support by energy storage to reduce the impact of wind and solar generation on isolated power system's inertia," *IEEE Transactions on Sustainable Energy*, vol. 3, no. 4, pp. 931-939, 2012.

[22] M. Einan, H. Torkaman, and M. Pourgholi, "Optimized Fuzzy-Cuckoo Controller for Active Power Control of Battery Energy Storage System, Photovoltaic, Fuel Cell and Wind Turbine in an Isolated Micro-Grid," *Batteries* 2017, vol. 3, no. 3, pp. 23-41.

[23] 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.

[24] S. J. Safi, S. S. Tezcan, I. Eke, and Z. Farhad, "Gravitational Search Algorithm (GSA) based PID Controller Design for Two Area Multi-Source Power System Load Frequency Control (LFC)," *Gazi University Journal of Science* 2018, vol. 31, no. 1, pp. 139-153.

[25] A. Kumar and S. Suhag, "GWO Algorithm Based Fuzzy-PID Controller with Derivative Filter for Load Frequency Control of Multi-Source Hydrothermal Power System," *The 5th International Conference on Control, Mechatronics and Automation*, 2017, pp. 50-55.

[26] R. K. Sahu, G. C. Sekhar, and S. Panda, "DE optimized fuzzy PID controller with derivative filter for LFC of multi source power system in deregulated environment," *Ain Shams Engineering Journal* 2015, vol. 6, no. 2, pp. 511-530.

[27] A. Kumar and S. Suhag, "Multiverse optimized fuzzy-PID controller with a derivative filter for load frequency control of multisource hydrothermal power system," *Turkish Journal of Electrical Engineering & Computer Sciences* 2017, vol. 25, no. 5, pp. 4187-4199.

[28] S. Saremi, S. Mirjalili, and A. Lewis, "Grasshopper optimisation algorithm: theory and application," *Advances in Engineering Software* 2017, vol. 105, pp. 30-47.