Communication in Physical Sciences, 2023, 10(1): 155-162

Comparative Analyses amongst 3 Hybrid Controllers - MPC-HGAFSA, LQR-HGAFSA and PID-HGAFSA in a Micro Grid Power System Using MAD and RMSE as Measures of Performance Metrics

Godwin Ezikanyi Okey*, **Yusuf Jibril and Gbenga Abidemi Olarinoye**

Received: 21 June 2023/Accepted 09 November 2023/Published 11 November 2023

Abstract: *Adverse effects in a power generating system, such as frequency instability, voltage profile degradation, poor power delivery and power outages, are caused by frequency and voltage fluctuations. These fluctuations are caused by load variations and generation losses, which are inevitable in a power-generating system. Power controllers such as model predictive controller (M.P.C.), linear quadratic regulator (L.Q.R.) and proportional integral derivative (P.I.D.); and controller optimizers such as genetic algorithm (G.A.), artificial fish swarm algorithm (AFSA) and particle swarm optimization (PSO) with their hybrids are often used to mitigate the aforementioned effect. This paper tends to compare the efficiency of each of the three mentioned controllers with the optimizers using mean absolute deviation (MAD) and root mean square error (RMSE) as performance metrics. The hybrid of .A.G.A. and AFSA (HGAFSA) was used to optimize each of the controllers (MPC-HGAFSA, LQR-HGAFSA and PID-HGAFSA) in a micro-grid power system. the M.P.C.- HGAFSA based approach demonstrates an outstanding frequency and voltage control capability when compared with the other two control strategies, while PID-HGAFSA-based strategy is the least performing strategy.*

Keywords: *Comparative Analyses, Hybrid Controllers, Micro Grid Power System, Mean Absolute Deviation and Root Mean Square Error.*

Godwin Ezikanyi Okey
[1]Department of Electrical Engineering, Ahmadu Bello University (A.B.U.), Zaria, Nigeria
[2]Department of Physics, Federal College of Education, P.M.B 1041, Zaria, Nigeria
Email: okeyeziks@yahoo.com
Orcid id: 0009-0001-13841066

Yusuf Jibril
Department of Electrical Engineering, Ahmadu Bello University (A.B.U.), Zaria, Nigeria
Email: iyusuf@abu.edu.ng
Orcid id: 0000-0003-3653-9393

G. A. Olarinoye
Department of Electrical Engineering, Ahmadu Bello University (A.B.U.), Zaria, Nigeria
Email: baolarinoye@abu.edu.ng
Orcid id: 0000-0002-7034-0452

1.0 Introduction

A microgrid (M.G.) is a small network of electricity with local primary sources such as wind, hydro, solar and gas that are usually linked to a centralized national grid (N.G.) but can function independently (Lasseter and Piagi, 2021). Defined it as any small-scale zlocalized power station that has its own generation and storage resources with definable boundaries. It is a discrete energy system consisting of distributed energy resources (D.E.R.) which includes: demand, management, storage, generation and loads capable of operating in parallel with or independently from the utility grid (U.G.). .G.M.G. can help make better use of energy generated, stored and used at a local level, thereby enhancing the local reliability and flexibility of the electric power system. In times of need, it can draw energy from the .G.U.G. and supply the same to the .G.U.G. in times of excess energy availability. It can be autonomously isolated from the .G.U.G. under emergency during grid faults and/or as an energy source in remote locations where the cost of providing transmission lines may be very high. Integration of .E.R.D.E.R. units with energy storage has brought about the concept of M.G. ((Lasseter and Piagi, 2021). Katiraei and Iravani (2005), stated that it ouldcould operate in grid-connected mode, islanded mode and ride-through between the two modes ,giving rise to multiple micro-grid power systems. To enable exchanges between different utilities and to improve security, neighbouring systems were interconnected (Prabha, 1994).. Hence, power systems are the products of a long-lasting building process resulting in very large and complex systems (Prabha, 1994). Outages in a power system affect everyday life severely and, more often than not, paralyze day to day activities of many countries, including Nigeria. Moreover, extensive failures cause enormous economic losses. The blackouts in the past years have unveiled this. In August 2003, the blackout in the United States of America and Canada left around 50 million people without electricity for more than four days in some areas and the costs were estimated 4 to 10 billion U.S. dollars [4]. In September of the same year, a line trip between Switzerland and Italy initiated a major blackout in Italy, affecting 56 million people (Anderson *et al*., 2005; U.S.A-Canada power system Outage Task Force, 2004)). Therefore, a secure and reliable operation of power systems cannot be over-emphasized. The electrical energy demand increases continuously, leading to an augmented stress on the transmission system and higher risks for outages. In addition, electric power trades across borders have been enhanced due to the liberalization of electricity markets. The resulting regularly changing load-flow patterns require a transmission grid which can cope with daily modified generation and load distributions. Therefore, the transmission grid requires intelligent controllers such as M.P.C., L.Q.R., .I.D.P.I.D. and zoptimizers such as genetic algorithm (G.A.), artificial fish swarm algorithm (AFSA) and particle swarm optimization (PSO) and hybrids of them that will handle the effects of load changing to avail it from stress. A hybrid of differential evolution and sequential quadratic programming (D.E.–S.Q.P.) algorithms has been successfully applied in power systems to solve this problem (Chatterjee and Laudato, 1997). .A.G.A. is one of the most popular stochastic search algorithms. It is very suitable for solving continuous/discrete optimization problems because of its ability to be either coded in real-number or binary (Li *et al*., 2013). . It has been widely and successfully applied to many optimization problems (Li *et al*., 2013). .

AFSA is a population-based intelligent algorithm which was inspired by the various social behaviours of fish (LI *et al*., 2013).Each fish searches its own local optimum and passes on information in its self-organized system and finally obtains the global optimum. AFSA has the advantage of possessing similar attractive features of G.A., such as independence from gradient information of objective function and the ability to solve complex nonlinear high dimensional problems (Li *et al*., 2013). Furthermore, it can achieve faster convergence and require few parameters to be adjusted. The AFSA does not possess the crossover and mutation processes used in G.A. AFSA can enhance the searching ability and avoid being trapped in local optimum. It has been proven effective in many engineering problems. The hybridization of .A.G.A. and AFSA to form HGAFSA makes full use of their advantages. .A.G.A. is capable of exploring new and more promising solution spaces and gives a good direction to the optimal global region (Azad *et al*., 2014). AFSA on the other hand, can fine-tune a solution to reach the global optimal solution. Therefore, the integration of .A.G.A. and AFSA to form a hybrid of the HGAFSA algorithm has a good global exploration capability of .A.G.A. as well as the local exploitation capability of AFSA. It can obtain better solutions with faster convergence. HGAFSA is applied to estimate a set of load frequency control (L.F.C.) and automatic voltage regulator (A.V.R.) parameters (governor speed regulation, integral control gain, amplifier gain, and frequency bias) suitable for voltage regulation and damping oscillation in system's frequency. Electrical power systems are more often than not exposed to increasing stress, but measures are taken through research to ensure their security and stability. In this study, M.P.C., .Q.R.L.Q.R. and .I.D.P.I.D. were hybridized with HGAFSA, respectively, to form MPC-HGAFSA, LQR-HGAFSA and PID-HGAFSA controllers and were used to control a micro-grid power system individually and their performances were compared using mean absolute deviation (MAD) and root mean square error (RMSE) as performance metrics.

2.0 Controllers Performance Comparison Model

To demonstrate the performances of the zhybridized controllers - MPC-HGAFSA, LQR-HGAFSA and PID-HGAFSA; a single micro-grid model shown in Fig. 2 was considered. A model of the controller comparison shown in Fig. 1 was achieved using MATLAB. In Fig. 1, the controllers were applied one after the other to control the single microgrid by subjecting them to simultaneous voltage and frequency disturbances. The output from the controllers was fed into a measurement block and finally delivered to a scope for viewing. The measurement block is used to convert the output voltage and frequency from the three single-area control blocks to the required format needed for display. The hybrid of HGAFSA was integrated into the convention M.P.C., .Q.R.L.Q.R. and .I.D.P.I.D. control strategies to serve as a modification for better performance. The results of the controllers are presented and discussed in Figs. 6 to 8.

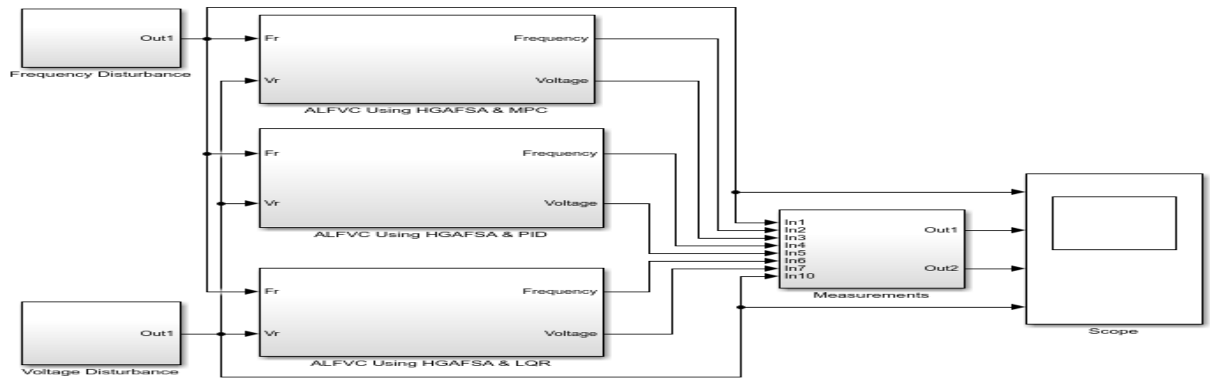


Fig. 1: Simulink Model Schematic of Controllers Performance Comparison

It is technically demanding that the controllers should be compared using a single area power system control problem. Therefore, there is the need to model the problem as a single entity such that the controllers can be attached externally to form an adaptive load frequency and voltage control (ALFVC) system. This may go a long way in simplifying the design problem since the single-area power system can then be modelled only once and separately attached to the various controllers. Each of the ALFVC blocks in Fig. 1 consists a single area power system modelled as a subsystem using the .P.C.M.P.C. model identification toolbox in MATLAB. The single-area power system model used for this comparison is shown in Fig. 2.

2.1 Single area Control using MPC-HGAFSA

An improved control strategy of a single area power system was achieved using a combination of two control techniques (.P.C.M.P.C. and HGAFSA). This zhybridized controller controls the power system voltage and frequency simultaneously. Fig. 3 is observed to look like Fig. 5. However, the only difference is that the frequency and voltage .P.C.M.P.C.s are added. These controllers serve to further control the power system voltage and frequency after being initially controlled by the developed HGAFSA. Furthermore, it should be noted that Fig. 3 represents the content of the 'ALFVC using M.P.C.-HGAFSA block in Fig. 1.

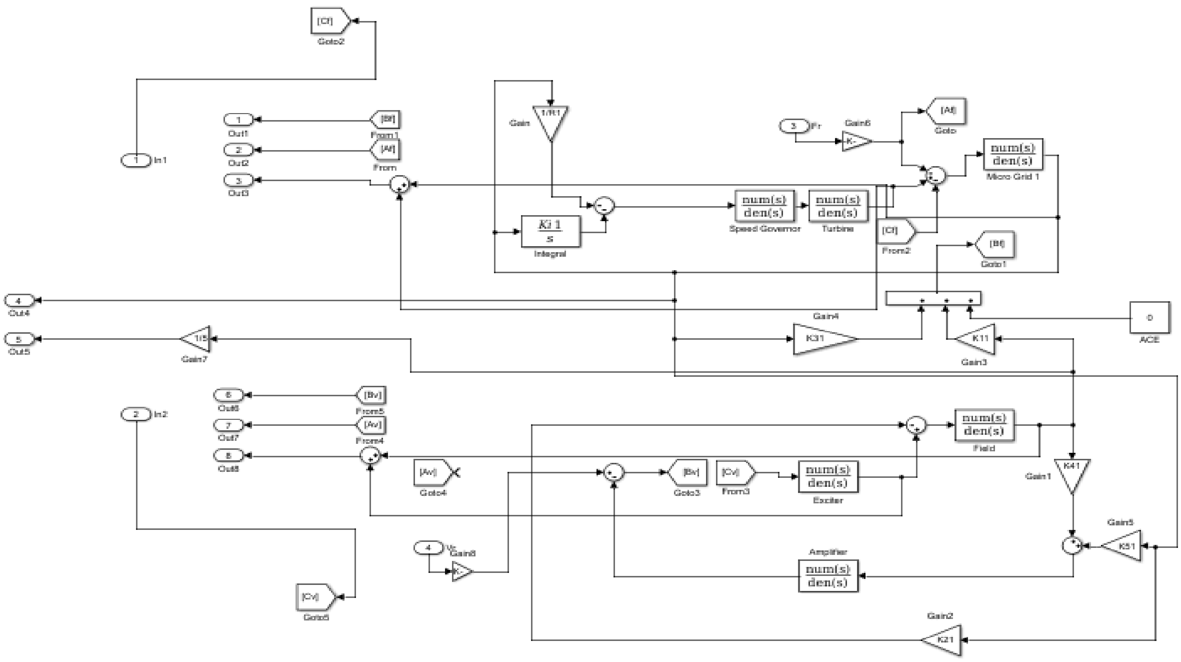


Fig. 2: Simulink Model of a Single Area Power System Control Problem for Controller Performance Comparison.

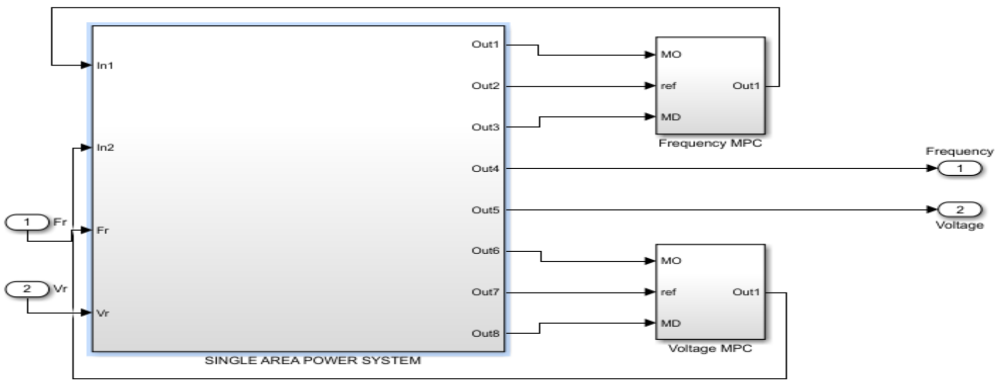


Fig.3: Simulink Model of Single Area ALFVC Using MPC-HGAFSA

2.2 Single Area control using LQR-HGAFSA

To achieve a single-area power system adaptive load frequency and voltage control using L.Q.R., the model of the power system shown in Fig. 2 was deployed into the model identification toolbox in MATLAB. The state space model parameters for the frequency and voltage control of the power system were extracted. The parameters were then used to develop a single area .F.C.L.F.C. and .V.R.A.V.R. models separately. Finally, the .F.C.L.F.C. and .V.R.A.V.R. models were used to design a single area power system - A LFVC using .Q.R.L.Q.R. as shown in Figure 4. In Figure 4, the .Q.R.L.Q.R. Gain was designed as a MATLAB function that uses the command 'lqr (A, B, Q, R, T_s)'. Furthermore, it should also be noted that, Fig. 4 represents the content of the 'ALFVC Using HGAFSA-LQR' block shown in Fig. 1.

This control strategy is much like that achieved using the MPC-HGAFSA. The major difference is that the .P.C.M.P.C. is replaced with a .I.D.P.I.D. and the HGAFSA performs an extra control function. Here, after the determination of the optimal power system control gains stated in 2.0, the HGAFASA is also used to predict the optimal .I.D.P.I.D. controller gains (P, I, D and N) that can be used to achieve a better stability in the voltage and frequency of the power system. However, the value of N was set equals zero for simplicity and better performance. Fig 5 represents the content of the 'ALFVC Using PID-HGAFSA block in Fig. 1.

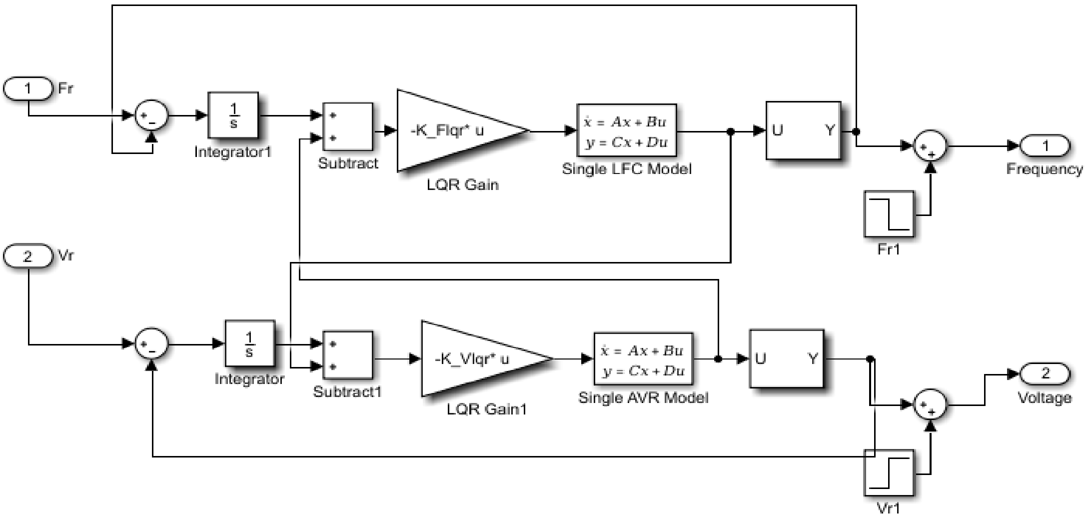


Fig. 4: Simulink Model of Single Area ALFVC Using LQR-HGAFSA

2.3 ***Single area control using PID-HGAFSA***

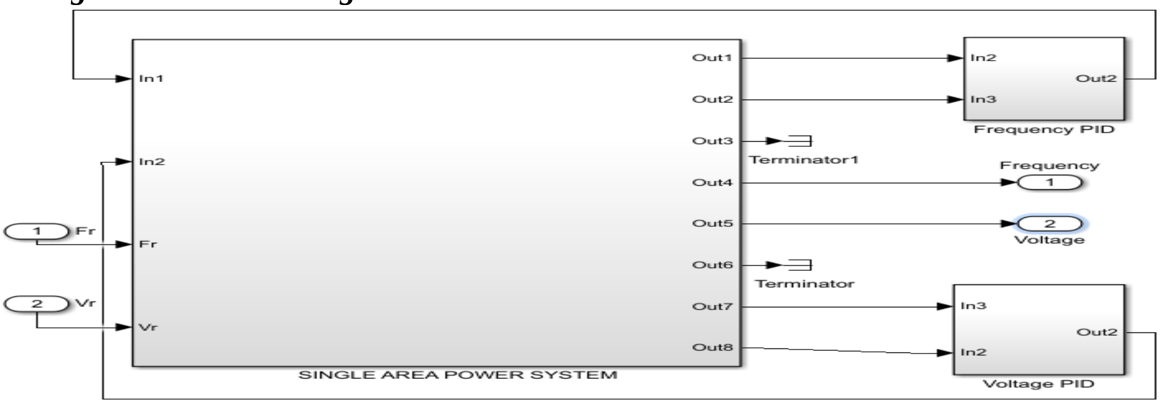


Fig. 5: Simulink Model of Single Area ALFVC Using PID-HGAFSA

3.0 Performance Comparison of the Controllers

A MATLAB function was used to zorganize the controller comparison results. In this work, the performance of the MPC-HGAFSA is compared with the other controllers using two different scenario cases of input voltage and frequency disturbances. The target reference set point for both voltage and frequency was chosen to be zero (0), and as such, two performance metrics/indices were used as the bases for comparison. These performance indices are formulated (A and B) as follow:

3.1 The Root Mean Square Error (RMSE)

Since the reference set point is zero, the RMSE of a given output signal *S(t)* over a time interva l [*0*, $N\Delta t$] such that $t = n\Delta t$ and $n \in \{0,1,2,3,\ldots,(N-1),N\}$ can be calculated using equation (1).

$$RMSE = \frac{1}{N}\sum_{n=0}^{N\Delta t}(S(n\Delta t))^2 \quad (1)$$

3.2 The Mean Absolute Deviation (MAD)

Given a set point of 0pu, the MAD of a given output signal *S(t)* over a time interval [*0* $N\Delta t$]

such that $t = n\Delta t$ and $n \in \{0,1,2,3,...,(N-1), N\}$ can be calculated using equation (2).

$$MAD = \frac{1}{N}\sum_{n=0}^{N\Delta t}|S(n\Delta t)| \quad (2)$$

3.3 Scenario case 1

In this scenario, the performance of the controllers is compared by simulating a single area micro-grid control in the presence of a constant/step signal as input disturbance.

The simulation only lasted for 10 seconds and the resulting frequency and voltage deviations and input disturbances were then plotted as shown in Fig. 6. However, the performance metrics discussed in 6.0 are used as a measure of performance. It can be deduced from Fig. 6.0 that the PID-HGAFSA based approach suffers a higher frequency undershoot with frequency disturbance and a higher frequency overshoot with voltage disturbance than all other approaches, followed by the LQR-HGAFSA based approach which suffers a relatively lower frequency undershoot with both disturbances.

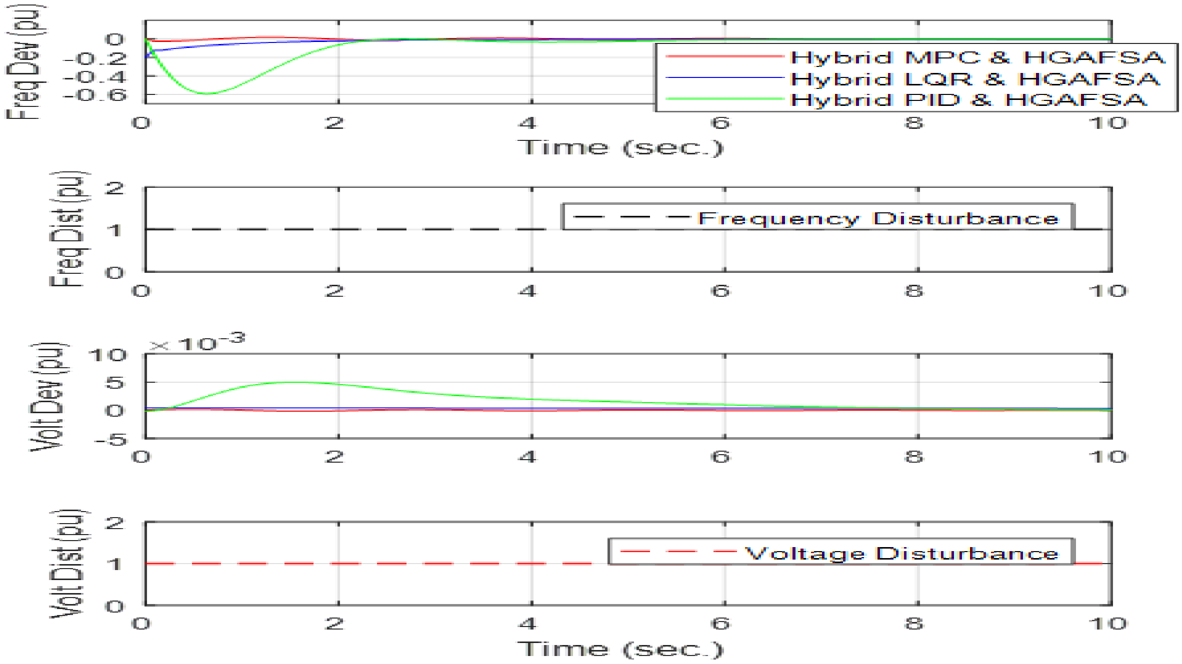
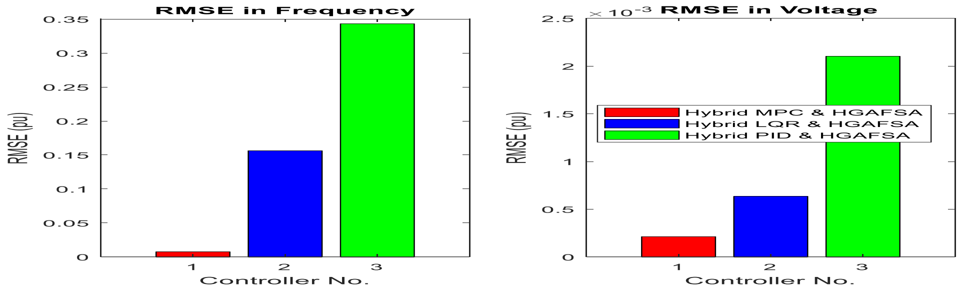


Fig. 6: Input-Output Relationship of Single Area Power System Based on the Three Control Strategies in Scenario Case 1.

2.3 Scenario case 2

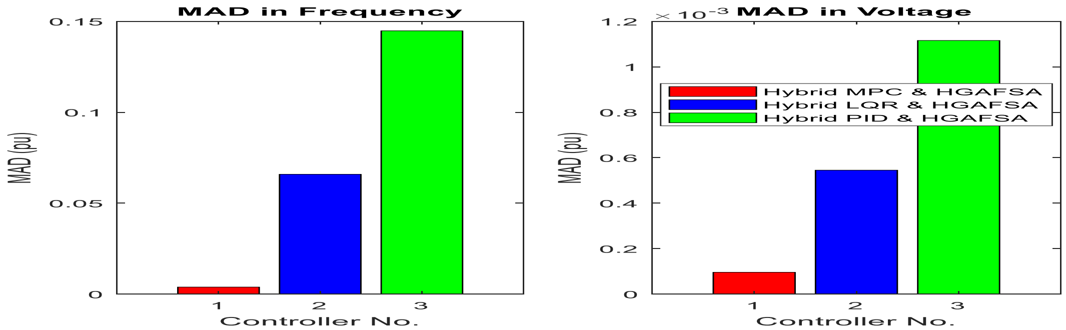
To further ascertain the superiority of each of the three controllers over one another, the RMSE and MAD in both voltage and frequency obtained by each of the controllers were also evaluated and plotted as shown in Figs. 7(a) and (b); and 8(a) and (b). The .P.C.M.P.C. based controller was still found to outperform the other two controllers as it has the least RMSE of 0.018pu and 0.00057pu for frequency and voltage control respectively. The order of controller performances is MPC-HGAFSA> LQR-HGAFSA> PID-HGAFSA for both frequency and voltage respectively. PID-HGAFSA based control strategy was found to emerge as the least performing strategy based on all the indices evaluated so far and in the two scenarios.

In both Figs. 7 and 8, the frequency RMSE and MAD of the three controllers are observed to increase following the controllers' order (1, 2, and 3), with controller 1 having the least RMSE and MAD and therefore emerging as the best-performing controller over frequency control. Furthermore, the order of frequency control performance can be said to descend in the form MCP., LQR., and finally PID. However, the MPC. based controller still stands as the best-performing controller in terms of voltage control. So also, the order of voltage control performance is still MPC-HGAFSA> LQR-HGAFSA> PID-HGAFSA.



(a) (b)

Fig. 7: The RMSE of: (a) Frequency and (b) Voltage, for the Three Control Strategies in Scenario Case 2.



(a) (b)

Fig. 8: The MAD of: (a) Frequency and (b) Voltage for the Three Control Strategies in Scenario Case 2

4.0 Conclusion

From the results shown in Figs. 6, 7 and 8, it can be clearly seen that the M.P.C.- HGAFSA based approach demonstrates an outstanding frequency and voltage control capability when compared with the other two control strategies while the PID-HGAFSA based strategy is the least performing strategy. Notwithstanding, each of the hybrid controller's results is less than the standard percentage error (±5%) pu of a power generating system according to the Institute of Electrical Electronics Engineers (IEEE).

Since the MPC-HGAFSA controller can gives best performance, among the three controllers, it is highly recommended for power system control at all times. But in the absence of the MPC-HGAFSA controller, other controllers can be applied in power system control as each of their performances is less than the standard percentage error (±5%) pu of a power generating system, according to the IEEE.

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Compliance with Ethical Standards Declarations

The authors declare that they have no conflict of interest.

Data availability

All data used in this study will be readily available to the public.

Consent for publication

Not Applicable

Availability of data and materials

The publisher has the right to make the data Public.

Competing interests

The authors declared no conflict of interest.

Funding

There is no source of external funding

Authors' contributions

All the authors contributed equally to the work.