Enhancing PV System Stability in the Angolan Power Network through Modeling and Simulation of Fuzzy Logic Controllers

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Abstract – *The power transmission network is responsible for transporting the electrical energy from generating plants to different substations. Electrical energy has become extremely important in this current world. Companies, churches, schools, and households need more electricity to satisfy their daily needs. This increase in demand causes several challenges to the power transmission networks in Angola such as power outages. The output power for renewable energy such as wind and solar energy systems depends on many factors such as solar irradiance, temperature, wind speed, geographical location, air density, swept area, wind turbine configurations, and many other factors. These factors are responsible for the inconsistency and variability of the wind and solar energy systems. Therefore, it is important to develop an efficient controller that can operate in different systems such as solar and wind energy systems to maintain a stable power and continuous flow of electricity. In this research, the Fuzzy Logic Controllers based Maximum power point tracking (MPPT) was used to obtain a stable output power and also to mitigate the faults in the system. The proposed controller was introduced into a PV system which was integrated into an unstable power network to increase the PV system's performance by enabling the PV grid to generate its maximum power which is 30MW and to maintain the power network stability. Furthermore, The voltage per unit in all three phases of the power network was increased from 0.92 p.u to 1 p.u due to the integration of the proposed controller into the PV system. The integration of the PV system alone was able to increase the per-unit voltage profile during high load demand, but for better stability, the Fuzzy controller was introduced to ensure that the additional voltage supplied by the PV system to the network is within the standard voltage allowable limits to keep a safe and stable operating of the system.*

Keywords: *Fuzzy Logic Controllers, Maximum power point tracking, Photovoltaic energy, Power network, Renewable energy system.*

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I. Introduction

The electricity access rate in rural Angola is significantly lower compared to urban areas, estimated to be around 20-25% as of 2023 [13]. Many remote and sparsely populated rural communities remain off the national grid and rely on small-scale, decentralized power solutions [6]. The Angolan government has strongly emphasized rural electrification in recent years, launching several initiatives and programs to expand access. One of the key objectives is the "Angola Rural Electrification Program" which aims to connect 1 million rural households to the grid by 2025 [18]. This program involves extending the medium and low-voltage distribution networks to reach remote villages and communities. In parallel, the government is also promoting the deployment of standalone solar home systems and mini-grid solutions in areas that are not feasible to connect to the main grid [7]. Various development partners and international organizations are supporting these rural electrification efforts through financing and technical assistance [11]. Various factors cause the occurrence of faults in the power network of rural areas and one of the main factors is the instability of the power supply. The power generated from different sources in the initial phase of the power system is mostly unstable. For instance, the power generated from solar, or wind energy is unstable due to the fluctuations in the wind and the sunlight. The sun does not always shine at the same intensity and the wind does not always blow at the same speed, these sources of energy are highly affected by the location, the weather, and many other factors. Therefore, it is important to have a device that can control the power input and can also supply the desired power output [3]. Given the limited grid coverage in rural areas, off-grid and decentralized power solutions have become increasingly important for expanding electricity access [12]. Solar home systems are one of the fastest-growing off-grid technologies, with several private companies actively deploying these systems in remote communities [4]. Mini-grid systems, powered by a combination of solar, diesel generators, and in some cases, small-scale hydropower, are also being installed to serve rural villages and settlements. The government has been providing subsidies and incentives to promote the uptake of these decentralized renewable energy solutions [2].

The majority of the population in Angola has no access to electricity due to various factors and one of the major factors is the failure of the power networks. These failures have been occurring constantly in urban and rural areas of the country due to the unstable power supplied by the generation system [15]. This paper aims to develop the most suitable controller to control and improve the performance of the PV system when it is integrated into the Angolan power network. The main objective of this paper is to improve Angola's power transmission network. The other objectives of this research are:

- To improve the monitoring of the power transmission network in Angola.
- To make effective and efficient use of renewable resources in Angola.
- To perform load flow analyses to investigate the performance of the power network when disturbances occur.
- To perform load flow analyses to investigate the impacts of disturbances due to the integration of PV or Wind in the power network.

Section 2 of this paper presents the research methodology. Section 3 provides The Fuzzy Logic Controllers development and modelling. Section 4 discusses the case studies conducted in this research. Section 5 discusses the simulation results. Section 6 provides some recommendations and Section 7 provides the conclusion.

II. Research Methodology

The load flow analysis on the network model in Fig. 1 is performed using MATLAB/SIMULINK software to examine the power network behaviour.

The selected Angolan power network in this paper consists of three buses connected through three 150 kV transmission lines 200 km, 150km, and 150km long corridor from Queve towards Namibia in the south going through the province of Huila as shown in Fig.1.

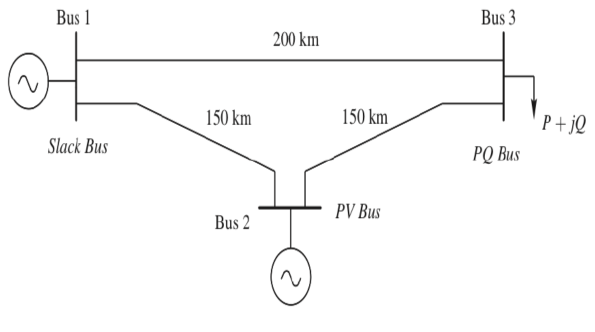

Fig. 1. A Three-bus system

The first activity was to conduct the load flow analysis of the Angolan power network in Fig.1. The simulation model focused on the province of Huila power network. This electrical grid comprises three transmission lines spanning a distance of 200km each, along with two lines covering a distance of 150km each.

The load flow analysis of the chosen power network involved the following steps:

Modelling of Slack Bus, Loads, and Generators: The main elements needed for a load flow analysis were constructed to determine the crucial parameters of the power network such as the true power, the apparent power, the reactive power, and the total power losses.

Modelling of the Buses: The three main buses were modelled to allow the connection of components of the power network

Determine the Parameters of each branch: The parameters of each branch were determined such as the resistance, Inductance, Voltage, Power, and Frequency.

Analysis and discussion of load flow results: The results before and after simulations will be analysed in detail by taking into consideration the parameters of each element of the Slack bus, the load bus, and the generator bus.

Several crucial factors were accounted for during each of these tasks. In the load flow analysis, variations in voltage were carefully assessed. Additionally, details regarding the power network, including both real and reactive power, were taken into consideration to assess and regulate the network's performance.

Because of its focus on calculating power flow and voltage magnitudes of the power system at the nodes or branches. Authors in [2], have stated that the power Flow analysis is extremely important for any electrical system because it investigates many important aspects of a system. In this paper, the load flow analysis investigated the following points:

- The behaviour of the power network when it is subjected to various operating conditions.
- The behaviour of the power network without and with the controller integrated into the PV system.
- The flow of the power in the power network
- Running conditions and load distribution to develop an efficient fuzzy logic controller.

The increasing demand for electricity in Angola is much greater than what has been generated, resulting in the transmission network being heavily loaded and stressed beyond permissible limits. Therefore, the load flow analysis is the best tool to use to understand better Angolan power network better as well as to find the best alternative solution to mitigate instability in the power network.

III. Fuzzy Logic Controller Development and Modelling

The Fuzzy Logic Controllers (FLC) are used for systems that are non-linear such as electrical systems because electrical systems have dynamic behaviours [5]. FLC does not need a specific mathematical model. The inference mechanism of the FLC consists of ensuring that the understanding of the data is performed according to the rules and the membership functions [8]. There are two input variables in the Fuzzy Logic Controller which are Error (E) and Change of Error (CE) as shown in Equation 1 and Equation 2 [16].

$$E_{(K)} = \frac{P_{(K)} - P_{(K-1)}}{V_{(K)} - V_{(K-1)}} = \frac{\Delta P}{\Delta V} \tag{1}$$

$$E_{(K)} = E_{(K)} - E_{(K-1)} = \Delta E \tag{2}$$

The CE(k) input consists of defining exactly the motion operating point in the Maximum PowerPoint direction. This process is represented in Equation 3.

$$D_{(K)} = D_{(K-1)} + \Delta D_{(K)} \tag{3}$$

A. Membership Functions

The membership functions were used for the fuzzification process. The variable inputs Error (e), Change of Error (ec), and the output Duty cycle (D). The membership below functions were used. The “Zero” membership function is redundant with "NB" membership function.

- NB (Negative big)/Zero
- NM (Negative medium)
- NS (Negative small)
- PS (Positive small)
- PM (Positive medium)
- PB (Positive big)

The state error, the rate at which the state error is changing, and the membership functions can have different shapes depending on the variables the error is trapezoidal shaped, the error change is Gaussian shaped and the output is triangular shaped as shown in Fig.2 [14]. The range of the membership function for a duty cycle, particularly in fuzzy logic applications, is typically defined based on the specific context and requirements of the system. In this project, the range of the membership function of the duty cycle was set using triangular and trapezoidal functions which consist of the fuzzy rules as shown in Table I.

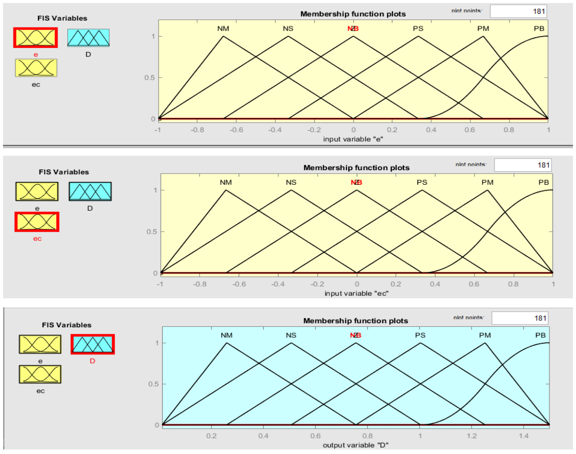

Fig. 2. Membership Functions. (Error; Change of Error and Duty Cycle)

B. Fuzzy Rules

The proposed controller developed in this paper consists of 49 fuzzy rules. Fig.3 shows the graphic representation of the error, change of error, and duty cycle for the 49 fuzzy rules [17]. The Fuzzy Logic rules were determined through the Mamdani method which is a method developed by Ebrahim Mamdani while he was trying to control a steam engine [10]. It consists of controlling the system with the help of a set of linguistic control rules shown in Table 1 [9].

Fig. 3. Graphic representation of the error, change of error, and duty cycle)

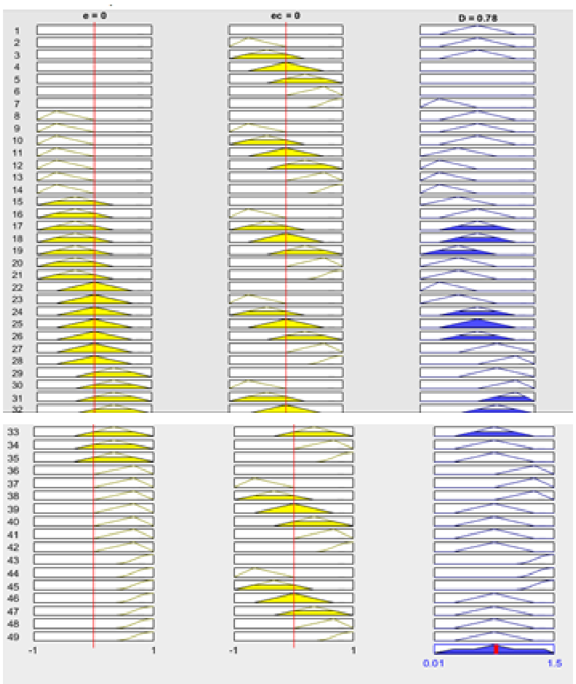

TABLE I
FUZZY RULES

(E) / (CE)	NB	NM	NS	Z	PS	PM	PB
NB	Z	Z	Z	NB	NB	NB	NM
NM	Z	Z	Z	NS	NM	NM	NM
NS	NS	Z	Z	Z	NS	NS	NS
Z	NM	NS	Z	Z	Z	PS	PM
PS	PS	PM	PM	PS	Z	Z	Z
PM	PM	PM	PM	Z	Z	Z	Z
PB	PB	PB	PB	Z	Z	Z	Z

C. Optimizing PV Injection with Fuzzy Controller

The optimization of the amount of the PV injection consists of various steps as shown in Fig.4. The starting point consists of beginning with the optimization process, and then assess energy demand by evaluating the current energy demand of the system. After that, the PV generation can be measured and an analysis of the grid conditions needs to be conducted to check grid stability and capacity.

The next step is the decision point and the question is to find out if the grid is ready for more injection? If "yes", then proceed to the next step and if "No" then adjust the injection strategy. The Fuzzy input processing is the next step which consists of defining the fuzzy sets for input parameters such as the demand or generation. Then Apply fuzzification to convert inputs into fuzzy values and Use a fuzzy inference system to determine the optimal injection level based on fuzzy rules. Furthermore, the optimal injection level needs to be calculated and the injection strategy needs to be implemented, then finally the system performance needs to be monitored.

Fig.5 shows the Fuzzy logic Controller-based maximum power point technique that was modelled using MATLAB/SIMULINK. ΔV and ΔP are calculated through this modelling. This controlled development was used for the PV system to provide stability.

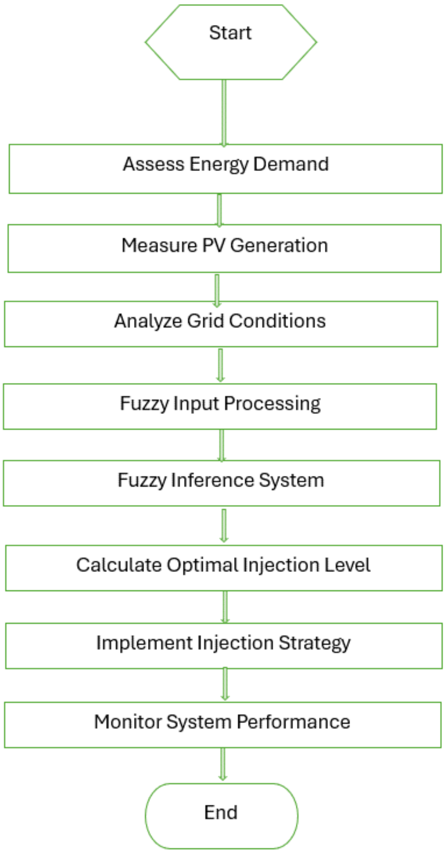

Fig. 4. Flowchart for Optimizing PV Injection

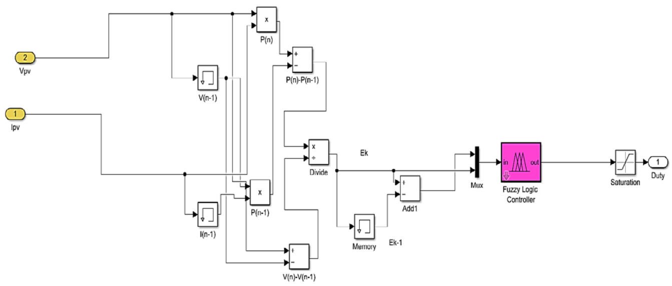

Fig. 5. Fuzzy Logic Controller-based Maximum Power Point Technique

IV. Case Studies

Three cases are studied in this work.

i. Case 1- Load flow analysis for the Angolan Power System

ii. Case 2- Analyze of the Angolan's Power Network with the PV system but without the Proposed Controller

iii. Case 3- Analyze the Angolan Power Network with the PV system and the Proposed Controller.

The first case involves analyzing the power flow of three 150 kV transmission lines in Huila Province, Angola. These lines are 200 km, 150 km, and 150 km long, respectively as shown in Fig.6. The analysis excludes consideration of the PV system and the proposed controller. In this network, the load demand is 50MW, while the power supply is only 36MW, indicating that the demand exceeds the supply. The Angolan Power Network is experiencing instability due to the higher load demand than the load supply. Bus 2 and Bus 3 are not within the standard voltage permissible limit of ± 5 % which is between 0.95 p.u and 1.05 p.u because there is no PV system or controller to supply the necessary voltage and power to keep the system stable.

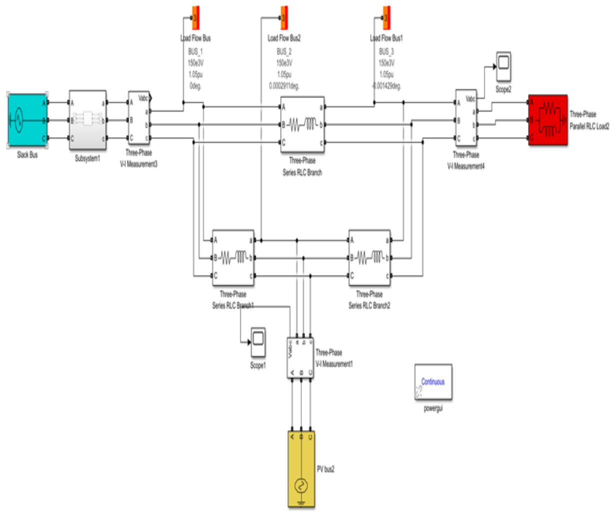

Fig. 6. Load flow analysis for the Power System of three 150kV transmission lines without the Proposed Controlled and the PV system)

The second case study consists of the same Angolan power network that was discussed in the first case. It was observed in the first case that the power network was experiencing voltage instability due to load demand that was higher than the power supply. In this scenario, The PV system is introduced without a controller to support the power network to keep it stable and to satisfy the load demand needed as shown below in Fig.7. Furthermore, it was observed that in the initial scenario, the Angolan power network, incorporating the PV system, underwent analysis without employing the suggested controller. This analysis was conducted using MATLAB/Simulink through load flow analysis. In the second scenario, the Angolan power network, incorporating the PV system, underwent analysis with the implementation of the recommended controller. This analysis was carried out using MATLAB/Simulink through load flow analysis. The integration of the PV system only in the Angolan power network has increased the voltage per unit in Bus 2 (PQ load) and BUS 3 (Generation Bus) to 1 p.u so that it can be within the standard voltage permissible limit for all three phases. The PV grid was only generating 2.8MW while the PV grid developed in this paper can generate 30MW when it is operating at the maximum power point. So, the PV system cannot operate at its maximum power point without the proposed controller.

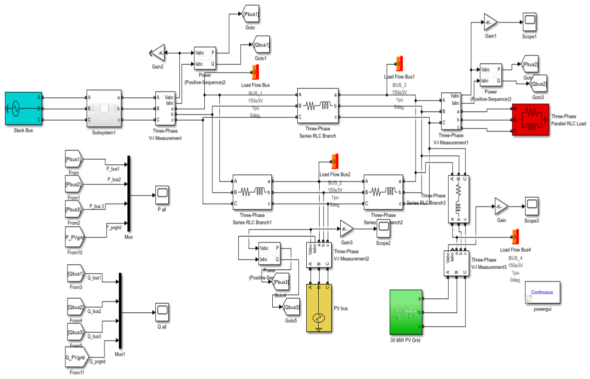

Fig. 7. Angolan's Power Network with the PV system but without the Proposed Controller

The third case study consists of the same Angolan power network with the PV system and the proposed controller when the load demand is at 50 MW and the load supply is at 36 MW as shown in Fig.8. It was found in the first scenario that there was a significant decrease in PV voltage and PV current as well as in the power of the grid inverter. Furthermore, it was found that the PV grid was not operating at its maximum power point in the second case study when the PV system was connected to the power network without the proposed controller. The controller integrated into the PV system was able to control the system and enable it to operate at its maximum power point. The proposed controller was also able to control the PV system to supply a voltage that is within the standard voltage allowable limit as well as to ensure that additional power supply in the system is not excessive.

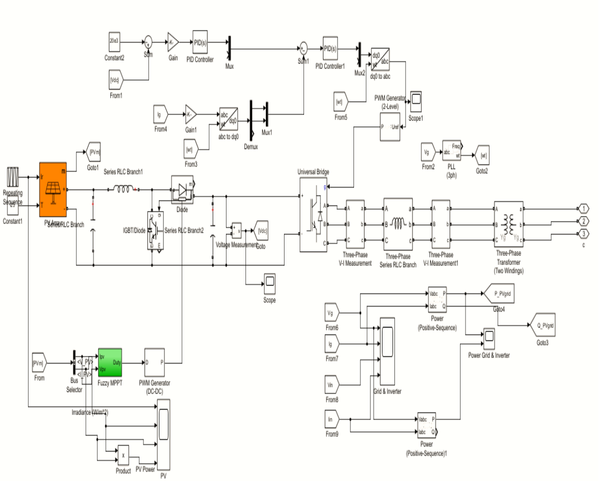

Fig. 8. Angolan's Power Network with the PV system and the Proposed Controller

It was found in the first scenario that there was a significant decrease in PV voltage and PV current as well as in the power of the grid inverter. Furthermore, it was found that the PV grid was only generating 2.8MW while the PV grid developed can generate 30MW when it is operating at the maximum power point. Therefore, the contingency plan was to have a controller integrated into the PV system so that it could control the system and able it to operate at its maximum power point. The proposed controller was also able to control the PV system to supply a voltage that is within the standard voltage allowable limit and to ensure that additional power supply in the system is not excessive.

V. Simulation Results

This section focuses on the investigation related to the behaviour of the three-bus power network located in Angola with and without the PV system and the Fuzzy Logic Controller.

i. To improve the monitoring of the power transmission network in Angola.
ii. To make effective and efficient use of renewable resources in Angola.
iii. To perform load flow analyses to investigate the performance of the power network when disturbances occur.
iv. To perform load flow analyses to investigate the impacts of disturbances due to the integration of PV or Wind in the power network.

A. Load flow analysis for the Angolan Power System.

The load flow analysis of the power network was conducted to understand and study the performance of the power network when disturbances occur. The load flow analysis was also able to investigate the impacts of disturbances due to the integration of PV in the power network as stated in the research objectives.

Table II shows the parameters for all the buses and other components before load flow simulations through MATLAB/SIMULINK. It can be observed that the voltage drop on each feeder, the voltage magnitude, the phase angle at each bus, and the real and reactive powers flowing in all branches in the system are only determined after running the simulations. Bus 1 in this power network represents the slack bus. Table III shows that the slack bus is not generating power because there is a malfunction or disruption in the generator that is acting as a slack bus. This indicates a fault condition at the slack bus which results in a zero power injection at that bus. There is only one generator bus operating in this power network which is Bus 2 and Bus 3 is the load bus.

TABLE II
PARAMETERS OF BUSES, LOAD AND GENERATOR BEFORE LOAD FLOW SIMULATION

Bus ID	**Vbase (Kv)**	**Vref (pu)**	**Vangle (deg)**	**P (MW)**	**Q(Mvar)**
BUS_1	150.0000	1.0500	0	0	0
BUS_2	150.0000	1.0000	0	50.0000	15.0000
BUS_3	150.0000	1.0400	0	36.0000	0
Bus ID	**Qmin (Mvar)**	**Qmax (Mvar)**	**V_LF (pu)**	**P_LF (MW)**	**Q_LF (MVA)**
0	0	0	0	0	0
Inf	Inf	0	0	0	0
0	0	0	0	0	0

After load flow simulations, the unknown parameters were determined as shown in Table III.

Table III was extracted from MATLAB/SIMULINK with all the results after simulation for the real power (MW) and reactive power (MVA) as well as the voltage angles. After load flow analysis it was observed that the generator bus 1 was still injecting zero power into the network because it is a faulty bus that is unable to supply or absorb any power.

TABLE III
PARAMETERS OF BUSES, LOAD AND GENERATOR AFTER LOAD FLOW SIMULATION

V_LF (pu)	**Vangle (deg)**	**P_LF (MW)**	**Q_LF(MVA)**
1.0500	0	0	0
1.0500	-0.0014	50.0000	15.0000
1.0500	0.0003	36.0000	0.0000

In case study 1, the power network located in Angola operates with the load demand higher than the power supply. The load demand represented by Bus 3 is 50MW, while the power supply represented by Bus 2 is 36MW. The power supplied into the power network is not sufficient to satisfy the needs of the consumers and due to this situation, the system power network was unstable. The voltage per unit at the load bus (Bus 3) and the generation bus (Bus 2) is not within the standard voltage permissible limit of ± 5 % [1]. The standard allowable voltage range is between 0.95 p.u and 1.05 p.u, anything above or below this range is considered a non-permissible voltage for the power network because it will cause disturbances and instability in the power network which will directly have a negative impact on the consumers [1]. In this power network, the voltage profile value is 0.921 p.u for all three phases at the load bus (Bus 3) and is 0.93 p.u for all three phases at the generation bus (Bus 2) as shown below in Fig.9 and Fig.10.

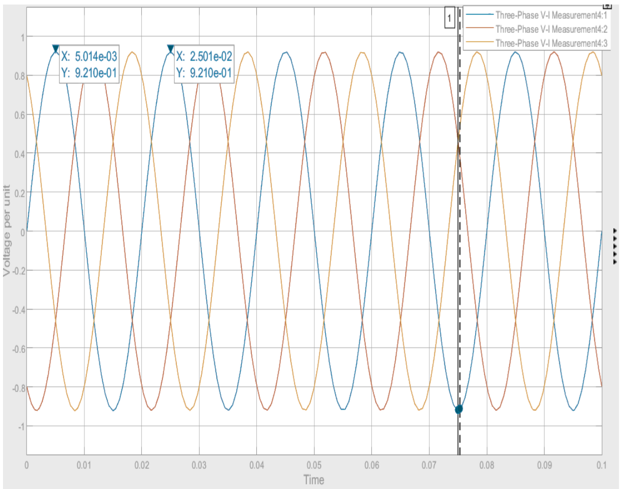

Fig. 9. Per Unit Load Voltage Profile at Bus 3 (PQ-Load) when the load demand is higher than the load supply.

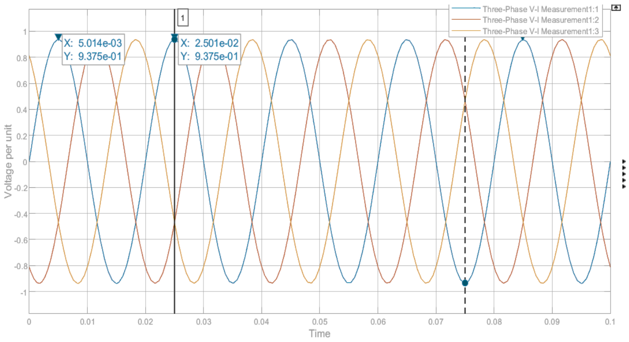

Fig. 10. Per Unit Load Voltage Profile at Bus 2 (PV-Generation) when the load demand is higher than the load supply.

If the electricity demand continues to rise in the future, the disruptions and instability within this power network will be exacerbated. Hence, integrating a PV system into the network is crucial as a contingency measure to bolster its resilience. In analyzing the system's response to potential contingencies, such as increased voltage requirements due to demand surpassing supply, introducing a PV system can regulate voltage within the permissible range outlined in the grid code. This ensures the safe operation of the power transmission network.

B. *Analyze the Angolan Power Network with the PV system but without the Proposed Controller.*

The PV system was integrated into the power network to improve the performance of the power network by supplying the necessary voltage required so that the system can operate at the standard allowable voltage range. The findings after integration of the PV system show that Angola can make more use of solar energy for the power network as mentioned in the research objectives.

It can be observed in Fig.13 that the solar irradiance in the system is 1000 W/m2. There is an increase in PV voltage to 6kV then a decrease in PV current from 6000 A to 44.9A, and then a decrease in power from 26MW to 0.15MW. The decrease in PV voltage and PV Current is because the system is not operating at the maximum power point and there is no controller to maintain the system stability at a certain point. Fig.14 shows that the grid and inverter have been operating at 2.8MW at a period of 0.025s, then there is a significant drop from 2.8MW to 1.2KW. This drop in power in the grid and inverter is also due to the absence of a controller operating at the maximum power point.

The PV system in the Angolan power network has increased the voltage per unit in Bus 2 (PQ load) and BUS 3 (Generation Bus) to 1 p.u on for all three phases as shown in Fig.15 and Fig.16, but there is a risk of having an excessive voltage in the system if the load demand decreases exponentially during a certain period of the day because when the load decrease the voltage increases. It is important to understand that the load demand is never the same during the day. There are periods of the day with higher load demand and periods of the day with less load demand. Therefore, a controller can be a good tool to control this change in load demand and to confirm that the system is operating at a safe operating voltage range and maximum power point.

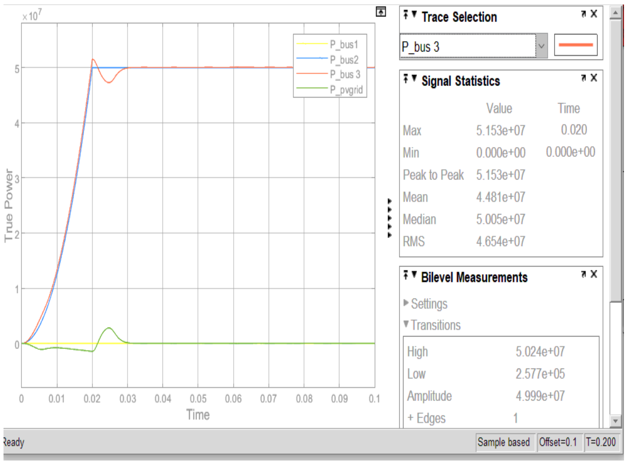

Fig. 11. True Power of the power network with integration PV system

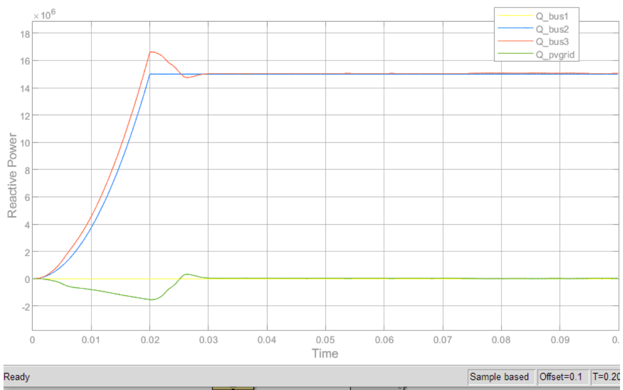

Fig. 12. Reactive Power of the power network with integration PV system

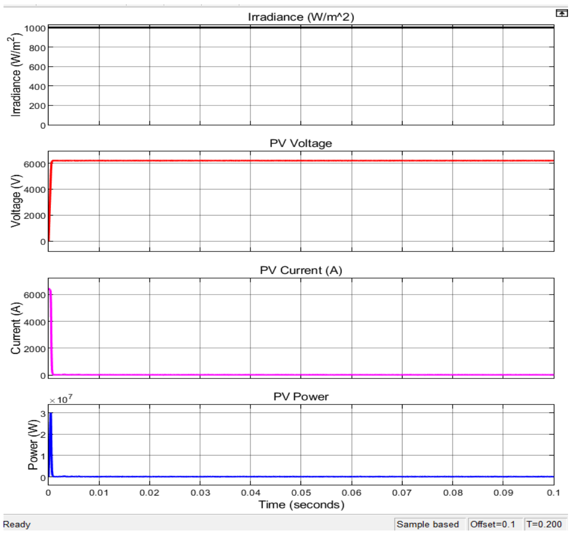

Fig. 13. Solar Irradiance, PV voltage, PV current, and PV power of the PV grid system

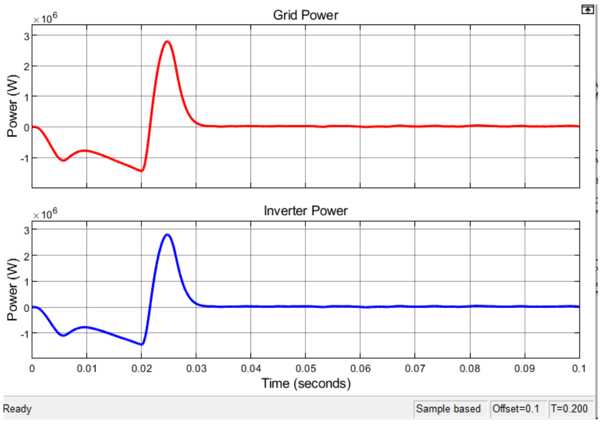

Fig. 14. Power for the Grid & Inverter

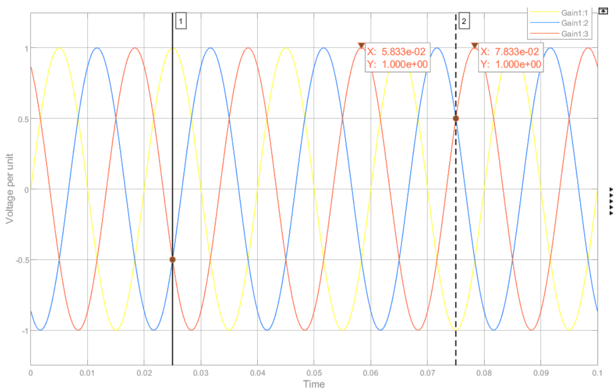

Fig. 15. Per Unit Load Voltage Profile at Bus 3 (PQ-Load) when the load demand is higher than the load supply with the PV system but without the controller

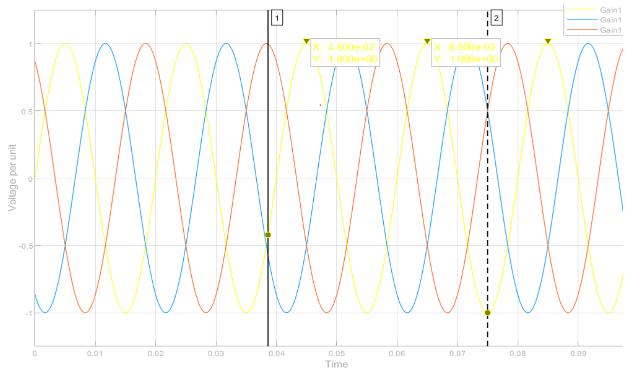

Fig. 16. Per Unit Load Voltage Profile at Bus 2 (PV Generation) when the load demand is higher than the load supply with the PV system but without the controller

C. Analyze the Angolan Power Network with the PV system and the Proposed Controller.

The integration of the proposed controller in the PV system was able to improve the monitoring and the controlling function of the power network in Angola by allowing the PV system to operate at its maximum point and also to control the voltage in the power network so that it does not exceed the standard allowable voltage range. The PV grid has been operating at its maximum power point and it has been generating and supplying 30MW. Furthermore, the integration of the PV system with the proposed controller has been controlling the power network so that the power supplied from Bus generation (Bus 3) is 20 MW. The sum of the PV grid power with the power from Bus generation (Bus 3) gives a total generation capacity of 50MW as shown in Fig.17.

It is also important to note that the time between 0s to 0.03s is the transient time and the system is at its steady state only after 0.03s. At the steady state, the true power supplied by the PV grid is 30MW and the generation Bus 3 is supplying 20 MW as shown below in Fig.17. It can also be observed that the true power is stable in the power network after the transient period. The reactive power supplied from the PV grid is 3.7MW and the generation Bus 3 is supplying 11.8MW as shown in Fig.18. Furthermore, it can be observed in Fig.18 that the solar irradiance in the system is 1000 W/m2. There is an increment in PV voltage to 6KV and a decrease in PV current from 6000 A to 44.9A, then another increase to 6000 A after 0.01s. There is also a decrease in power from 30MW to 0.15MW, then another increase to 30MW only after 0.01s. It can be observed that there is a decrease in PV voltage, PV Current, and PV power but because the system is operating at the maximum power and the controller is now included, the PV voltage, Current, and power are increasing again and they are stable after 0.01s.

Fig.20 shows that during the transient state from 0 to 0.03s the power in the grid and inverter have been increasing up until it reaches the steady state after 0.03s at 30MW. After 0.03 s the power in the grid is stable. The PV system's integration in the Angolan power network has increased the voltage per unit in Bus 2 (PQ load) and BUS 3 (Generation Bus) to 1 p.u on all lines as shown below in Fig.21 and Fig.22.

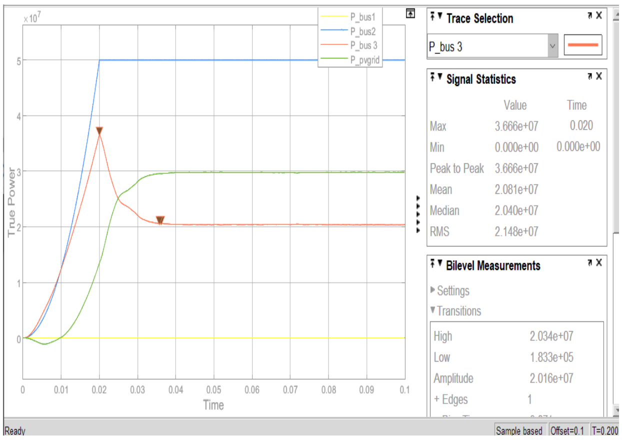

Fig. 17. True Power of the power network with integration PV system and the controller

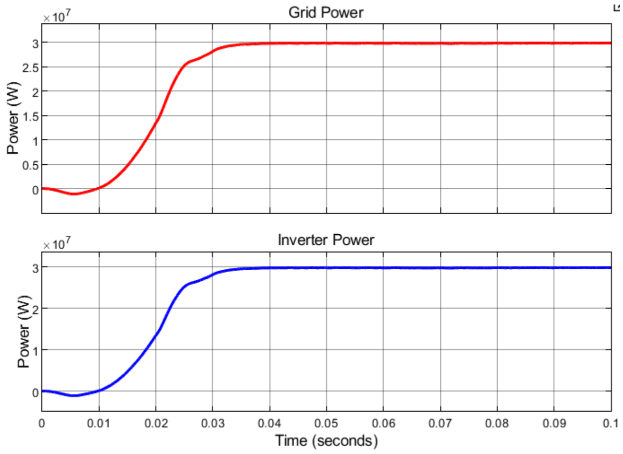

Fig. 20. Power for the Grid & Inverter

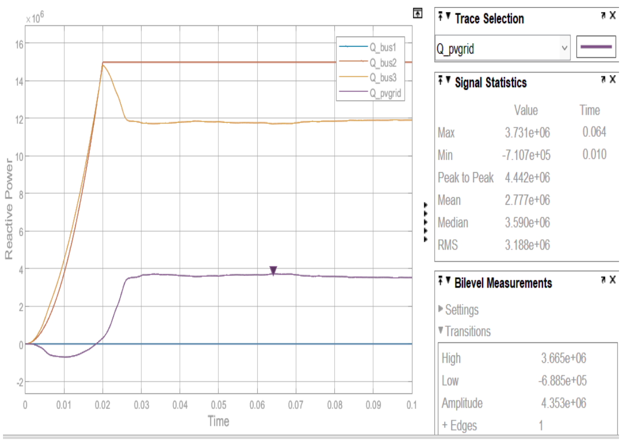

Fig. 18. Reactive Power of the power network with integration PV system and the controller

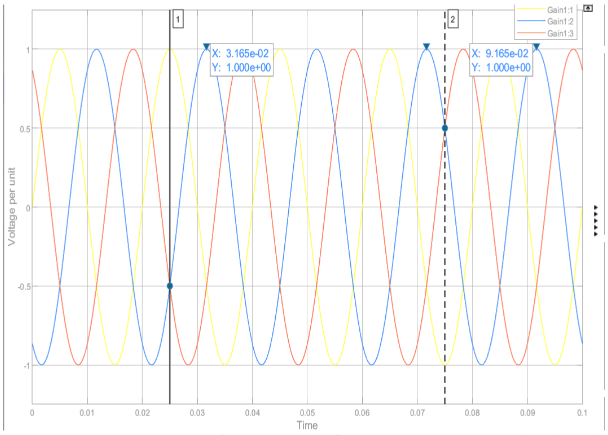

Fig. 21. Per Unit Load Voltage Profile at Bus 3 (PQ-Load) when the load demand is higher than the load supply with the PV system and the controller

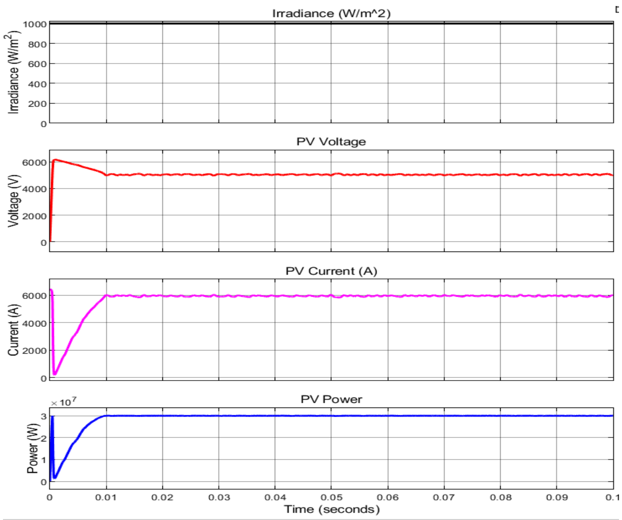

Fig. 19. Solar Irradiance, PV voltage, PV current, and PV power of the PV grid system

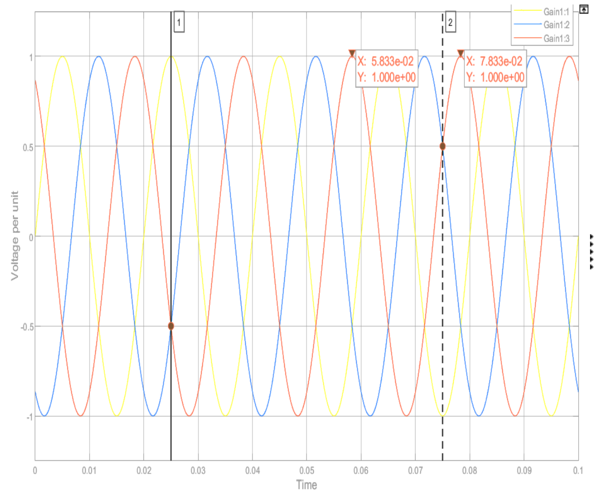

Fig. 22. Per Unit Load Voltage Profile at Bus 2 (PV-Generation) when the load demand is higher than the load supply with the PV system and the controller

The summary of the key results for each case study is presented in Table IV.

TABLE IV
SUMMARY OF THE KEY RESULTS

KEY RESULTS	
A. Load flow analysis for the Angolan Power System	The voltage per unit at the load bus (Bus 3) and the generation bus (Bus 2) is not within the standard voltage permissible limit of ± 5 %. The standard allowable voltage range is between 0.95 p.u and 1.05 p.u.
B. Analyze of the Angolan Power Network with the PV system but without the Proposed controller	A decrease in voltage and PV Current was because the system was not operating at the maximum power point due to the absence of the proposed controller.
C. Analyze of the Angolan Power Network with the PV system and the Proposed Controller.	The PV grid has been operating at its maximum power point and it has been generating and supplying 30MW. The PV system's integration with the proposed controller in the Angolan power network has increased the voltage per unit in Bus 2 (PQ Load) and BUS 3 (Generation Bus) to 1 p.u on all lines.

VI. Discussion and Recommendation

The primary aim of this research was to establish optimal modelling and control of The proposed controller has been tested in a three-bus power network with the integration of a PV system. Firstly, it was observed that the selected Angolan power network was facing instability due to the load demand which was higher than the load supply causing a decrease in voltage, then the PV system's integration into the power network was able to supply additional power to satisfy the load demand, but the PV system was poorly performing because it was not operating at its maximum power point and it was not generating its maximum power, it was only generating 0.00293 MW. Afterwards, the proposed controller was introduced into the PV system which significantly increased the performance of the PV system by enabling the PV grid to generate 30MW and also to maintain the power network stability. Furthermore, The voltage per unit in all three phases was increased from 0.92 p.u to 1 p.u due to the integration of the PV system and the controller.

The integration of the PV system alone was able to increase the per unit voltage profile during high load demand, but for better stability, the controller was introduced in the last scenario to ensure that the additional voltage supplied by the PV system to the network is within the standard voltage allowable limits to keep a safe and stable operating of the system. However, more studies need to be conducted to test the performance of the Fuzzy Controller for more complex power networks with PV and other renewable energy systems. Furthermore, the results in the last scenario represented graphically in Fig.14 show that the proposed controller can positively contribute to the stability of the Angolan power network.

Various research has been conducted in the past regarding the controller and different controllers have been developed for power transmission networks, PV systems, and other renewable energy systems but the problem of power stability was ignored and not addressed properly. Therefore, the implication and simulation applications of the study proposed controller's results demonstrate that it can enhance PV system performance.

When it is integrated into the power transmission network. The use of this proposed controller will not only have a positive impact on the energy sector, but it will also have a direct impact on the environment by increasing the use of green energy and by decreasing toxic gas emissions in the atmosphere. It will also have a direct impact on the economy of the country by allowing many industries to operate without interruption and by providing job opportunities.

VII. Conclusion

The load flow analysis conducted on the power network located in Angola was able to demonstrate the behaviour of the power network. The voltage per unit at the load bus (Bus 3) and the generation bus (Bus 2) was not within the standard voltage permissible limit of ± 5 %. The standard allowable voltage range is between 0.95 p.u and 1.05 p.u, anything above or below this range is considered a non-permissible voltage for the power network because it will cause disturbances and instability in the power network which will directly have a negative impact on the consumers.

The PV system's integration into the Angolan power network has increased the voltage per unit in Bus 2 (PQ load) and BUS 3 (Generation Bus) to the standard allowable voltage range for all three phases, but there is a risk of having an excessive voltage in the system if the load demand decreases exponentially during a certain period of the day because when the load decreases the voltage increases. It is important to understand that the load demand is never the same during the day. There are periods of the day with higher load demand and periods of the day with less load demand. As a result, a controller can be a useful tool for managing this variation in load demand and guaranteeing that the system is running within a safe voltage range and at its maximum power. The proposed controller was able to enable the PV system to operate at its Maximum Power Point and it was also able to control the PV system to supply a voltage that is within the standard voltage allowable limit as well as to ensure that additional power supply in the system is not excessive.

Furthermore, the proposed controller in the Angolan power network was able to inject additional power to satisfy the load demand and to control this additional power so that it does not exceed the load demand to avoid the occurrence of instability due to excessive power supplied.

Conflict of Interest

The authors declare no conflict of interest in the publication process of this research article.

Author Contributions

A.F. Catraio conceptualized and designed the research. M.E.S. Mnguni oversaw the project, and reviewed the manuscript, providing feedback and final approval for submission.

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