

Economical and Technical Performance Analysis for Renewable Generators in the Oil Production Field

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Abstract-Applying renewable generator as an alternative generator in oil production location in Egypt is promising. Oil production fields are depend on diesel generators for supplying electrical power in remote areas. Therefore, diesel consumption and Greenhouse emission (GHE) can reduction in oil production location by implement renewable generator, as an alternative power resource. Implement renewable generators in oil field approached in this paper. Analysis of operating circumstances and economic considerations for renewable generators done with the HOMER software. Levelized cost of energy (LCOE), when implement renewable generator, reduce by 35% than using diesel generator system. In addition, there is a 45% annual reduction in diesel usage. From an environmental perspective, the renewable generators reduce a 45% of carbon emissions than diesel generator systems. Additionally, MATLAB model uses to simulate a variety of operating scenarios under steady state and transient conditions. The results of the simulation indicate that during transient conditions, the system experiences a voltage reduction of about 48% of its rating. Ultimately, the voltage controller value is adjusted using the equilibrium optimizer technique, and the simulation demonstrates a 50% reduction in the voltage dip, improving the voltage profile.

Keywords Techno-economic, renewable generators, oil production location, distributed generation, equilibrium optimizer.

1. Introduction

The Greenhouse emission products from oil and gas industry is around 5200 million tons of CO₂-equivalent per year, which represents 15% of total energy sector [1]. Wind turbines and PV are alternative electrical generators that supply power to oil production field. Implementation of renewable generators in the oil and gas production locations increases economic and environmental impact [2-6], but stability of voltage and frequency are a challenge. The operation of different electrical generators (wind turbines, PV generators, and diesel generators) requires a control strategy for voltage and frequency stability. In Egypt, The most of oil production location rich with renewable resources [7-9].

The implementation of renewable energy in the oil and gas industry presented as case study in [7]. The study depends on supplying electrical power from PV to offshore gas platforms. Electrical power from PV is used to supply control systems, including the SCADA system and RTU. Utilization

of PV is a technically and economically feasible solution for supply control systems as electrical load demand is relatively small. However, it is not applicable for large load demands (large pumping systems) due to its large footprint.

The PV plant and diesel generator supply electrical power to oil production location present in [10]. The 110-kW PV with 200-kW diesel generator supply electrical load of 113 KW sucker rod pump in Egypt. The study compares a renewable system with a diesel generator only, that it shows a reduction in diesel consumption and CO₂ emission by 15000 liters and 40 tons per year. Finally battery system recommend to add for improve system efficiency.

Wind turbines and batteries supply electrical power for offshore platforms with gas turbines present in [11]. The platform consists of a 10 MW load. MATLAB simulates scenarios for the outage of gas turbine. The transient stability of the power system shows an enhancement of the power profile when using a battery storage element, the power deviates by +0.2% in switching condition.

A simulation of a Micro grid consisting of a wind turbine, PV, and diesel generator to supply oil and gas fields in Russia is shown in [12]. The MATLAB model simulates power generation from each component. The authors intend to compare the efficiency of a PV-only system and a hybrid system. They simulate the PV plant supply load, so the stability power supply to oil and gas fields cannot implement by PV only. When they simulate a hybrid system, an uninterrupted power supply provided. The research does not select a control system for a hybrid system.

The HOMER used to study techno-economic feasibility studies for implementing PV in education buildings [13]. Authors simulate PV supply power with grid and standalone; they compare between two systems and without PV depending on three factors, levelized cost of energy (LCOE), net present cost (NPC) and return on investment (ROI). They find that the PV grid is more stable with a lower LCOE and a lower NPC. The research does not implement an environmental issue or a controller system.

The techno-economic case study of renewable energy implementation in the oil and gas location is presented in [8]. The research depends on using the HOMER program. They compare and contrast different renewable generators with diesel generators to study economic and environmental impacts. The Micro-grid consisting of a wind turbine, PV, batteries, and diesel generator, has the best performance for economic and environmental impact. The research does not review the control strategy of the system.

Micro-grid control strategies are surveyed in [14]. The research surveys different types of control systems for distribution generation based on renewable energy resources when using power electronics. It classifies distribution generation into three group: grid forming, grid following, and grid supporting. On the other hand, the hierarchical control system involved of primary, secondary, and tertiary levels is built. Author discusses the advantages and disadvantages of each type of control element; voltage and frequency stability are the main targets of the control system.

The droop control method for Voltage and frequency of micro-grids represented in [15]. The micro-grid consists of PV, a wind turbine, and a battery to supply power. The inverter controller is designed to set up a reference frequency for the droop controller according to the change of load and renewable power generation. The authors study two cases; the first case is constant power of renewable generation, the second case is variable power of renewable generation then they observe the battery controller. The frequency changes by 4.4% in the first case and 1.4% in the second case with a change in load.

In this paper, an implementation of renewable generators consisting of a wind turbine, PV, and battery storage system with a diesel generator in the Egyptian oil field is proposed. The paper will study economic and technical factors for the

proposed configuration. The Homer program uses an economical and operational case study. Controller strategy: select to operate the system stable for different conditions. A MATLAB model for the proposed configuration was built to evaluate voltage and frequency stability in steady-state and transient conditions. The equilibrium optimizer algorithm is used to enhancement performance of the system controller.

The paper is systemic as follows: Section 2 presents the Homer modelling and operation conditions. Section 3 presents the MATLAB model. Section 4 presents the simulation studies. Section 5 presents transient conditions by using equilibrium optimizer algorithm. Section 6 discuss conclusion.

2. HOMER Software

Homer program is used to study economics and operation models [16,17]. Homer achieve energy balance for a micro-grid every hour of the year. For each hour, the electric load compares to the energy that the micro-grid can supply and calculates the flow of energy to and from each component of the micro-grid. Moreover, it simulates how to operate the generators and whether to charge or discharge the batteries. The renewable generation operations depend on wind speed and solar radiation profiles, which taken from NASA Worldwide Energy Resources. The economic analyses depend on the net present value of energy cost (NPC) and levelized cost of electricity (LCOE) [18].

The average cost per kWh produced by the system defined by Levelized cost of energy (LCOE); it is given by Eq. (1) [18]:

$$LCOE = \frac{C_{ann,tot}}{E} \quad (1)$$

Where E is total annual electrical load and $C_{ann,tot}$ is total cost of the system per year, which is can calculate by Eq. (2) [18]:

$$C_{ann,tot} = CRF(i, n) \cdot C_{NPC,tot} \quad (2)$$

$C_{NPC,tot}$ is the total net present system cost by Eq. (3):

$$C_{(NPC,tot)} = \sum_0^i C_{capital,i} + C_{O\&M,i} + C_{replacement,i} + C_{Fuel,i} \quad (3)$$

$C_{capital,i}$ is of the capital costs, $C_{replacement,i}$ is replacement cost, $C_{O\&M,i}$ is operation and maintenance costs, and $C_{Fuel,i}$ is fuel costs. The revenues in lifespan include the project salvage value of system components [18].

$CRF(i,n)$ is The total net present value, i is the real discount rate per year, n is lifetime of the project and $CRF(i,n)$ is calculated by Eq. (4):

$$CRF(i,n) = \frac{i(1+i)^n}{(1+i)^n - 1} \quad (4)$$

Where, i_{nom} is nominal discount rate and r represent the expected inflation rate which calculate by Eq. (5) [18]:

$$i = \frac{i_{nom} - r}{1 + r} \quad (5)$$

2.1. Economic and Environmental Simulation

Economic and environmental simulations compared between the two systems. System 1 supplies power from a diesel generator only; system 2 supplies electrical power from a micro-grid consisting of PV plant, wind turbine, battery, and diesel generator. The time interval is ten years. The time interval is ten years as shown in Table 1.

The comparison depends on the LCOE, diesel consumption and carbon emission reduction. Carbon emission reduction has not only an environmental impact but also an economic impact due to the carbon price policy [4,20]. The comparison between the two systems with respect to LCOE, diesel consumption and carbon emissions is shown in Table 1.

Table 1. Comparison between two systems

System	LCOE (\$)	Diesel consumption (L/year)	Carbon emission (Kg/year)
System 1	0.39	1,255,090	3,315,557
System 2	0.25	699,036	1,846,634

From Table 1, supplying electrical power through a microgrid composed of a PV plant, wind turbine, battery storage, and a diesel generator (System 1) results in a 35% lower levelized cost of energy (LCOE) and a 45% reduction in annual diesel consumption, primarily due to the reliance on renewable energy sources. Furthermore, the environmental impact is significantly improved, with carbon emissions reduced by 45% compared to a system that relies solely on a diesel generator (System 2).

2.2. System Modelling

The system consists of a 648 kW diesel generator, 1 MW of photovoltaic, a 500 kW wind turbine with a 1000 kWh lithium battery and a load of 12240 kWh/d as shown in Fig (1).

Homer system model depends on the location of the case study; the oilfield is located in the western desert in Egypt as Fig (2) [18].

Renewable resources based on a database of wind speed and solar radiation from database of NASA Worldwide Energy Resources [18, 19].

The average monthly wind speed per year in the well location is around 5.85 m/s and daily radiation is varies from 3 to 8 kWh/m²/day solar radiation [18].

2.3. Operation Simulation

Different modes of renewable generator operation are studied in Homer software; the operation depends on two cases: case 1 is the worst solar radiation and case 2 is when wind speed is at its lowest value.

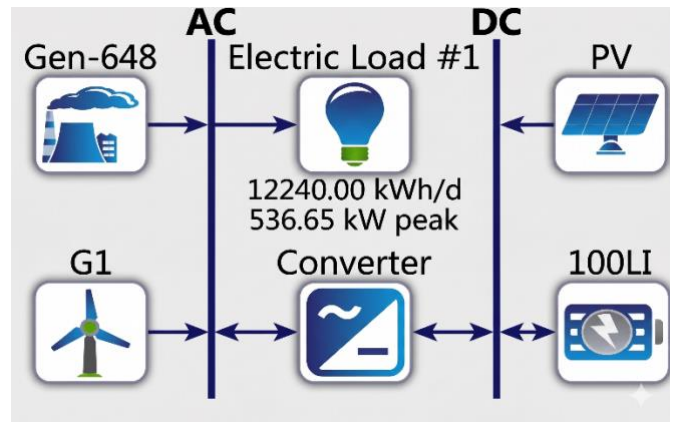


Fig. 1. HOMER Micro-grid model.



Fig. 2. The case study location.

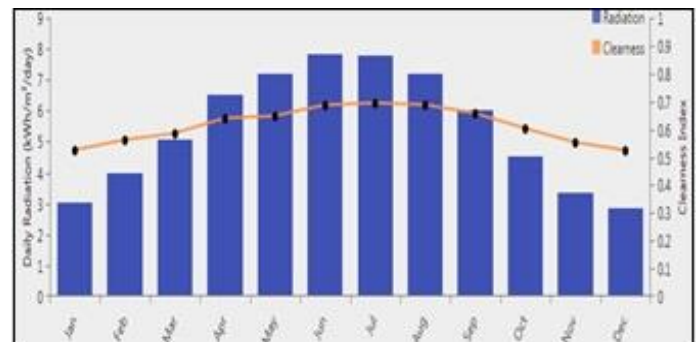


Fig. 3. Average monthly solar radiation per year.

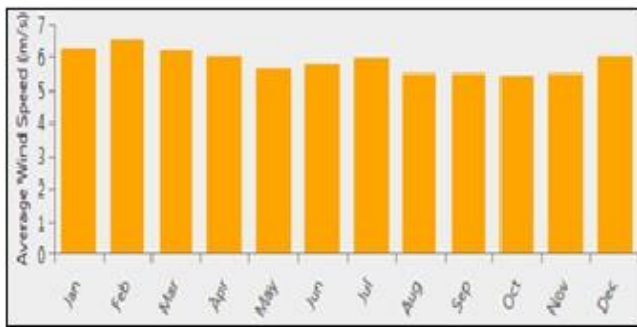


Fig. 4. Average monthly wind speed per year.

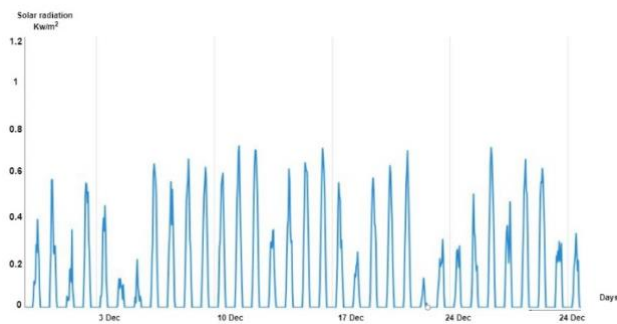


Fig. 5. Solar radiation in December.

Case 1: Solar radiation shows the lowest average daily solar radiation in December.

Form Fig. 5, the Average solar radiation is 0.2 kW/m² in fourth of December which will be studied in case 1. Fig. 6 shows the Wind speed and the solar radiation in 4 December, while Fig. 7 shows the power outputs from different generators.

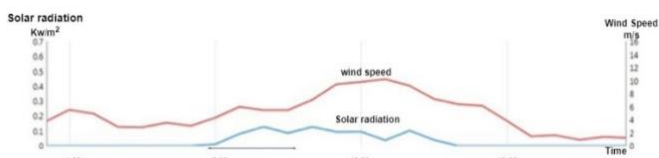


Fig. 6. Wind speed and solar radiation in 4th of December.

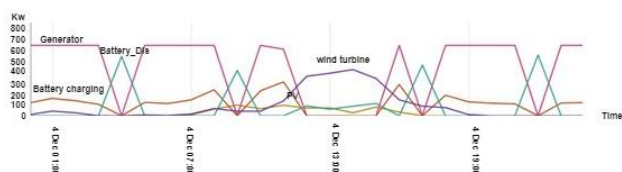


Fig. 7. Power output from different generator in 4th of December.

In Fig. 7, there are six different modes of operation: (1) Diesel Generator supplies power for the load and charging the battery system. (2) Diesel Generator, wind turbine and PV supply the load and charging the battery system. (3) The Wind turbine and battery system supply power to the load. (4) The Battery only supplies the load. (5) Wind turbine and Diesel

generator supply the load and charging the battery system. (6) Wind turbine, PV and battery supply power to the load.

Case 2: The Wind speed profile in Fig. 4 shows that the lowest wind speed is reached in October. The wind speed profile in October is shown in Fig. 8.

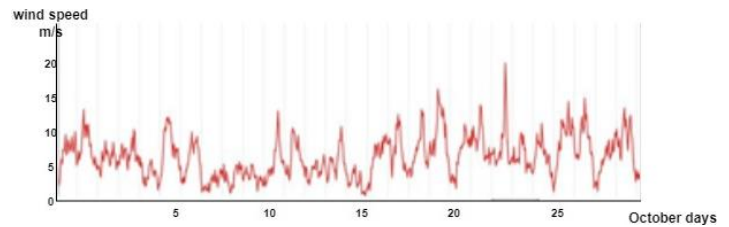


Fig. 8. Wind speed profile on October.

From Fig. 8, the Average value of wind speed is 2 m/s in 9th October, which will be studied in case 2. The Fig. 9 shows wind speed on 9 October, while the Fig. 10 shows the power outputs from different generators.

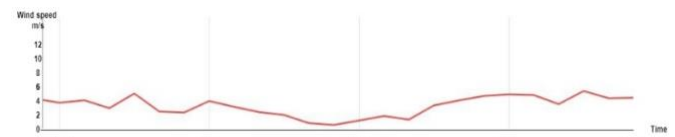


Fig. 9. Wind speed profile 9 October.

In Fig 10, there are another three different modes of operation: (1) PV system supplies the load. (2) PV and the battery systems supply the load. (3) Generator and PV supply load and charging battery.

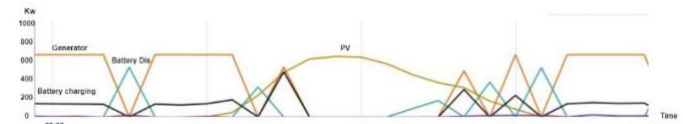


Fig. 10. Power output from different generator in 9 October.

In the next section, voltage and frequency stability will be studied for different modes of operation using MATLAB.

3. Matlab Model

Voltage and frequency stability are important factors in the reliability of oil production. Switching between power sources can lead to variations in voltage and frequency. A micro-grid consists of PV, wind turbines, batteries and a diesel generator with an electrical load built to study the stability of voltage and current values. The strategy of control system is designed to supply power from each source autonomously in different conditions. Fig. 11 shows Micro-grid components.

Diesel Generator Model The synchronous generator is driven by a diesel engine, which controls power output and frequency ; the excitation system is modeled by a small synchronous machine (exciter), then a rotating Diode Bridge rectifies the current output from exciter, the rotating diode and

exciter connected on the same shaft of the synchronous generator. Terminal voltage of generator controller by excitation system [21], as shown in Fig. 12.

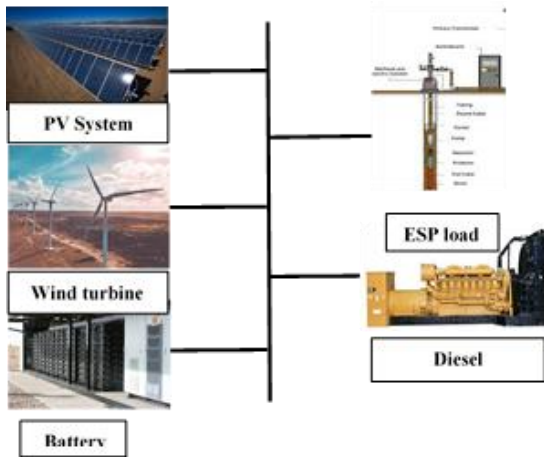


Fig. 11. Micro-grid Matlab simulation model.

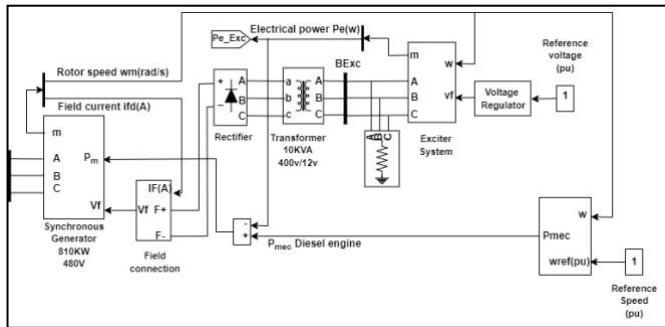


Fig. 12. Diesel generator model

3.2. Wind Turbine Model

The Wind turbine generator model consists of a synchronous generator controlled by a DC-DC IGBT-based PWM boost rectifier and IGBT-based PWM inverter. The maximum energy from the wind turbine is extract at low wind speed by optimizing the turbine speed, wind turbine model depends on a full scale converter and a synchronous generator type 4 [22], converter control Model depends on voltage source control (VSC) when connected to micro-grids, as shown in Fig. 13

3.3. PV Model

The PV system model generate 1 MW at 1000 W/m² of sun irradiance at 25 °C. The Maximum Power Point Tracker (MPPT) control PV system by using a boost converter. The MPPT depends on the Perturb and Observe method, which maximizes extract by varying the terminal voltage of the PV array. Fig. 14, 15 show P-V, V-I PV system characteristics.

The output voltage and frequency of the micro-grid control by 3-phase inverter. The inverter controller has feedback parameters from the main controller of the micro-grid. Fig. 16 shows PV array model

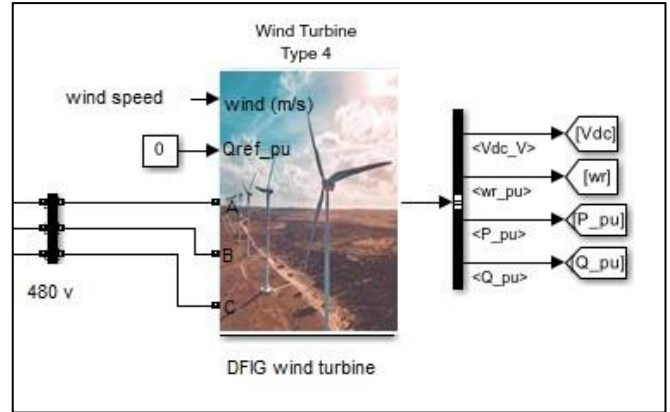


Fig.13.wind turbine model

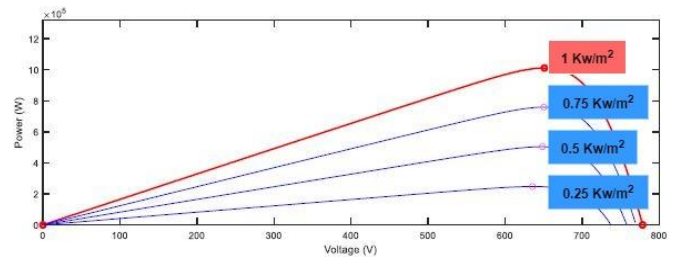


Fig.14.P-V characteristics for PV.

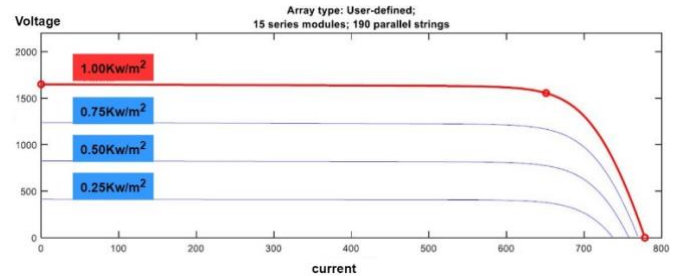


Fig. 15. V-I characteristics for PV.

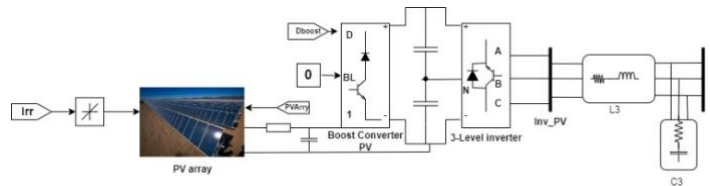


Fig. 16.PV array model.

3.4. Battery Model

The battery model rated at 1 MWh consists of 80 parallel strings, and every string contains 72 modules, the modules consist of 4 cells, the cell formed from Lithium-ion Iron Phosphate (LFP) battery of 3.2V, 14Ah. The battery discharge characteristics are shown in Fig. 17

Two level three-phase inverter as shown in Fig.18 controls the output of battery control.

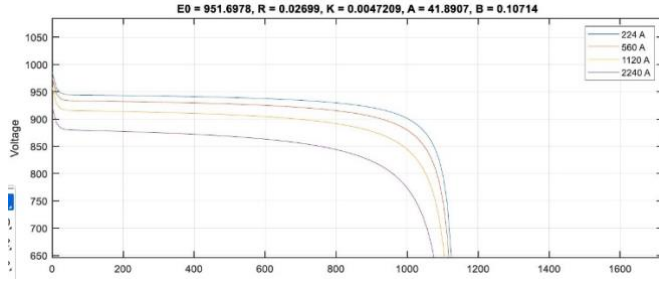


Fig. 17. the battery discharge C/S.

3.5. Control Strategy

The control strategy in the system depends on operation mode of diesel generator. In the case of diesel generation, the generator is responsible for adjusting voltage and frequency. The voltage and frequency values are adjusted by droop control technique ; the renewable generator power converter represent as ideal current sources; the renewable resources power converter delivers a specified amount of active and reactive power values; these controls of power converters is called grid following power converter. In the other case, when diesel generation shuts down, the battery converter is responsible for adjusting the frequency and voltage values of the micro-grid by grid-forming operation [24].

3.6. Autonomous controller

The battery converter is operated as a grid forming operation [23], and the power converter is designed for autonomous operation. It works as bidirectional switches to control voltage and frequency; it represents a voltage source converter with a fixed reference frequency. It balances generation power and load. The converter controls the voltage of the micro-grid by absorbing or injecting reactive power; on the other hand, frequency is adjusted by absorbing and injecting active power [24,25]. The converter includes two control loops: the outer loop and the inner loop.

3.7. Outer loop control

The outer loop controllers depend on the droop control characteristics for sharing active and reactive powers, they compare between the active and reactive power P_o^*, Q_o^* at reference voltage and frequency values, which are generated from the power converter, and measure the active and reactive power P_o, Q_o , voltage [24].

$$P_o = m(P_o^* - P_o) \quad (6)$$

$$Q_o = n(Q_o^* - Q_o) \quad (7)$$

Where m and n are droop characteristics coefficient. Fig 19 shows the droop control response.

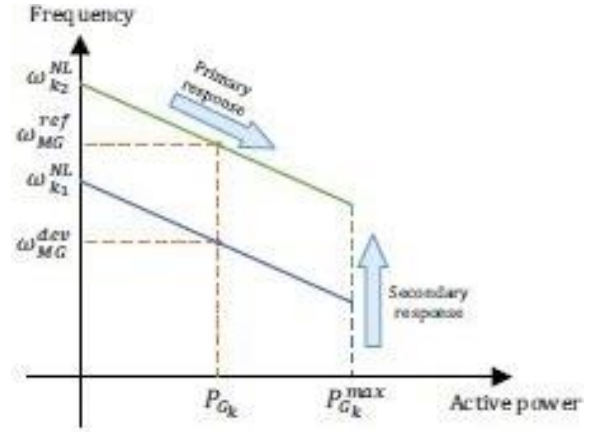


Fig. 19. Droop characteristics

3.8. Inner loop control

The inner loop control includes two layers: the first layer is the voltage controller, which depends on d – q components of voltage for reference voltage and output voltage to generate reference d – q components as shown in Fig .20. The second layer is the current controller, which depends on measurement current and compares it to reference current to generate a reference voltage d-q component for the inverter as Fig.21. The two layers use a PI controller [15, 26].

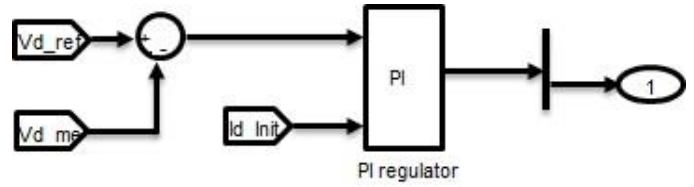


Fig. 20. The voltage control loop

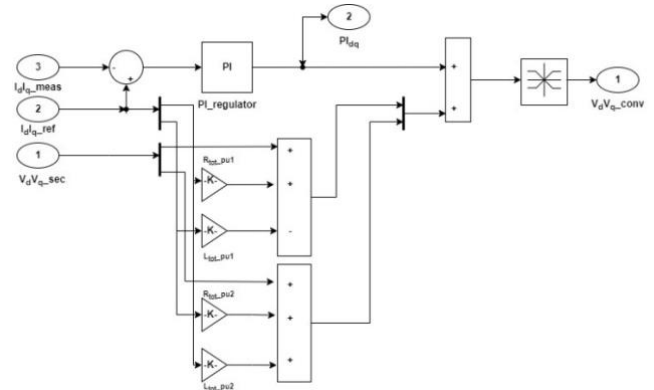


Fig. 21. The current control loop.

4. Simulation Studies

In this section, the MATLAB model simulates different cases of Micro-grid, we flow simulation as next flow chart in Fig.22

Which are divided into following cases: Case 1: Generator supplies the load and charging the battery system. Case 2: Generator, wind turbine and PV, supplies the load. In addition, these sources charge the battery system. Case 3: The load is supplied by a wind turbine and battery system. Case 4: A wind turbine and generator supply the load and charging the battery system. Case 5: the wind turbine, PV and battery system supply power to the load. Case 6: PV supplies the load. Case 7: PV and battery system supply power to the load. Case 8: Generator and PV supply the load and charging the battery system.

Steady-state condition In this section, each case will be studied alone without switching between cases and another voltage and frequency for each case will be shown from Fig. 23 to Fig.38

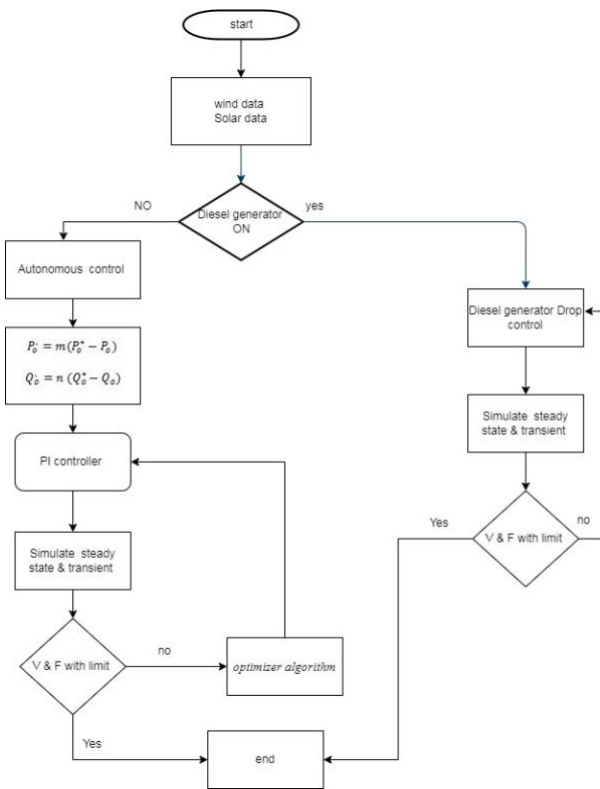


Fig. 22. Simulation flow chart.

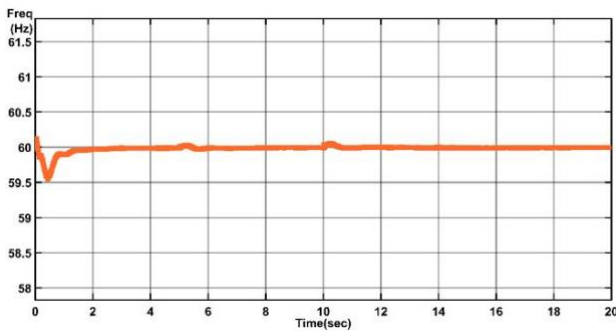


Fig. 23. Case1 frequency characteristic

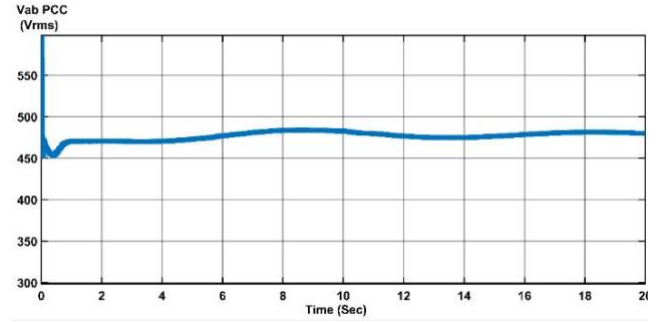


Fig. 24. Case1 voltage characteristic

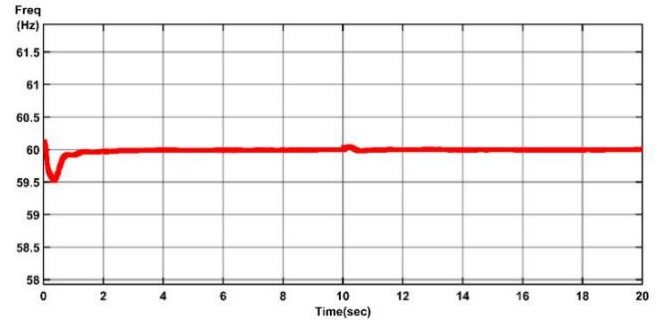


Fig. 25. Case2 frequency characteristic

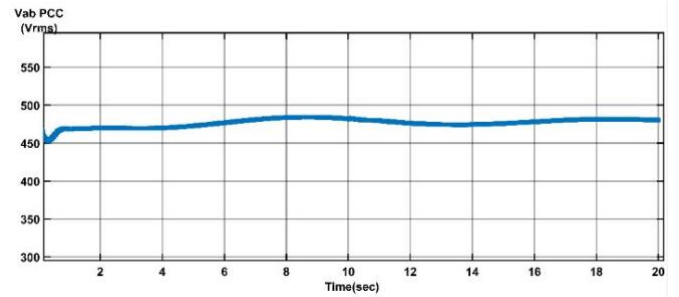


Fig. 26. Case2 voltage characteristic

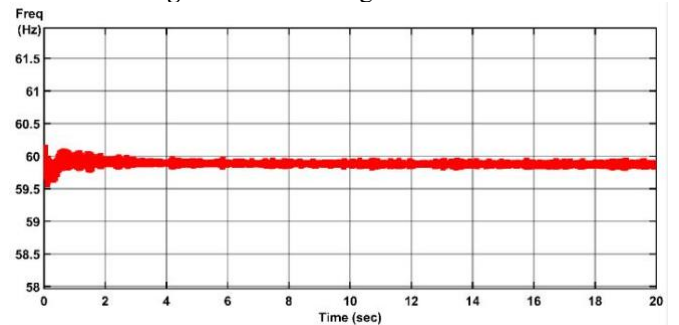


Fig. 27. Case3 frequency characteristic

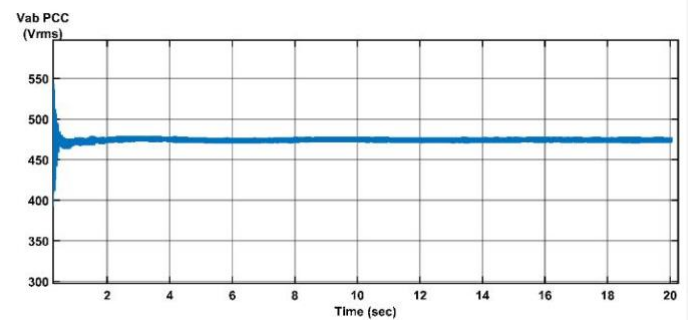


Fig. 28. Case3 voltage characteristic

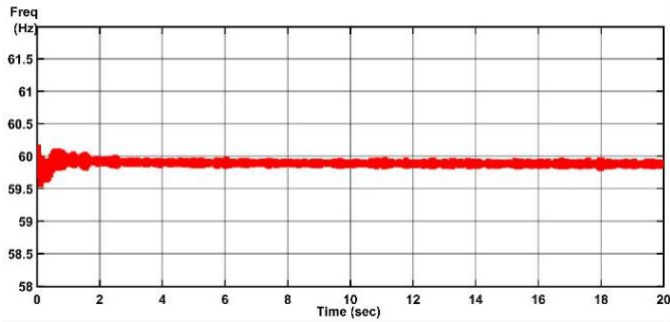


Fig. 29. Case 4 frequency characteristic

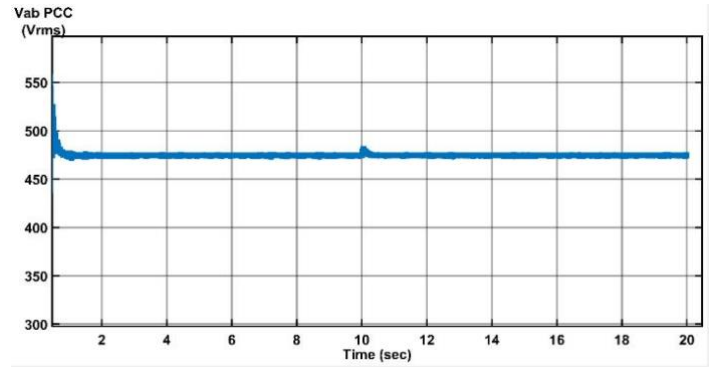


Fig. 34. Case6 voltage characteristic

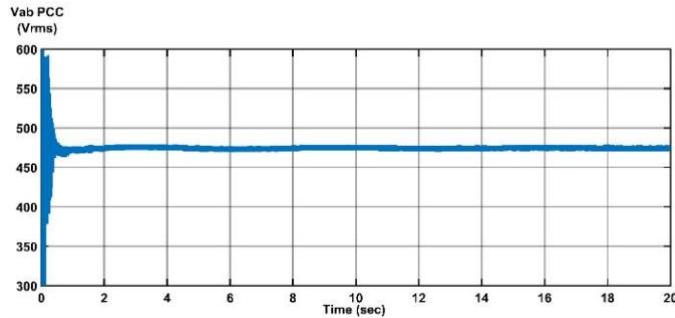


Fig. 30. Case 4 voltage characteristic

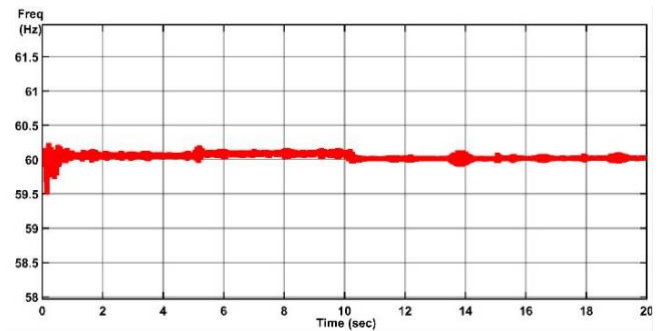


Fig. 35. Case7 frequency characteristic

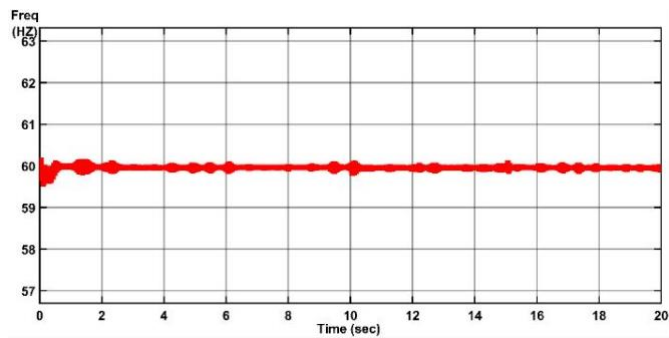


Fig. 31. Case5 frequency characteristic

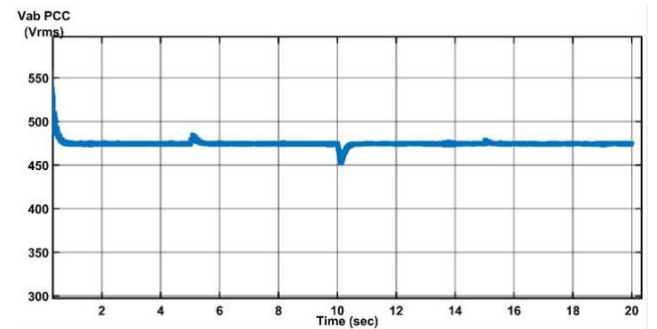


Fig. 36. Case 7 voltage characteristic

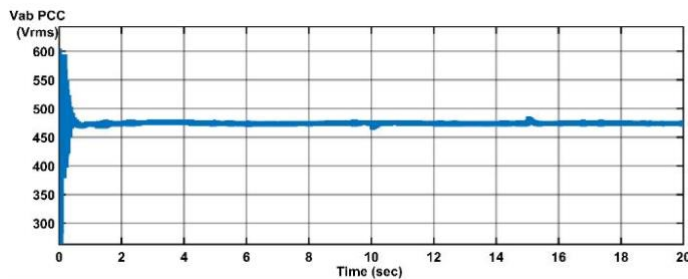


Fig. 32. Case5 voltage characteristic

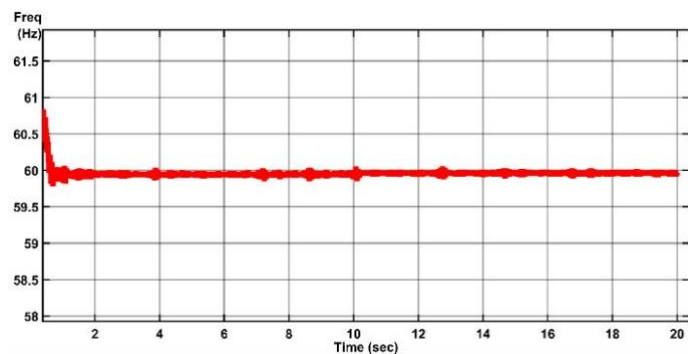


Fig. 33. Case6 frequency characteristic

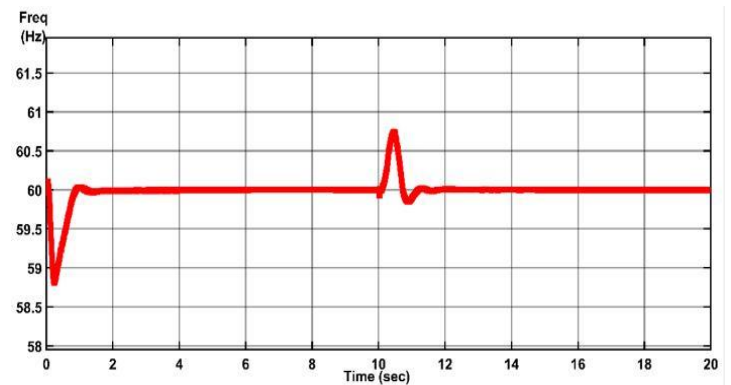


Fig. 37. Case 8 frequency characteristic

Steady-state condition for different cases shows stability in voltage and frequency where voltage is in the range of $\pm 10\%$ and frequency is in the range of $\pm 0.5\%$.

4.2. Transient condition

In this section, six transient conditions will be studied to simulate the transition between nine state cases.

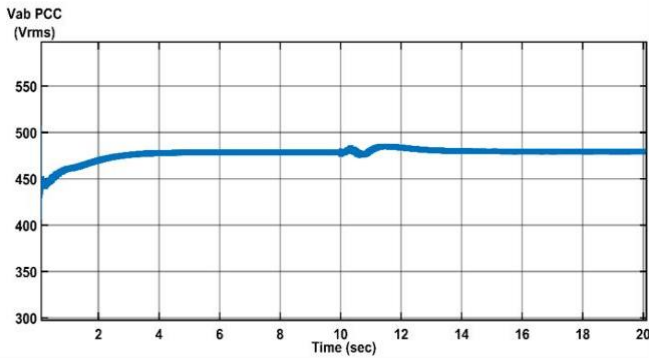


Fig. 38.Case 8 voltage characteristic

Case 1: the generator operator supplies the load and charging the battery system. Case 2: the generator, wind turbine and PV supply the load and charging the battery system. Case 3: Wind turbine and battery supply the load. Case 4: Battery only supplies the load. Case 5: Wind turbine and generator supply the load and charging the battery. Case 6: Wind turbine, PV and battery supply power to the load. Case 7: PV supplies the load. Case 8: PV and battery supply power for the load. Case 9: Generator and PV supply the load and charging the battery system.

Homer program as shown in Table (2) generates these conditions (Cond)

Table 2. Transitional conditions between different cases

Condition number	Transitional cases	Duration (hour)
Cond 1	Case1	3
	Case 4	2
	Case 1	6
Cond 2	Case2	3
	Case 6	4
	Case 2	2
Cond 3	Case 2	2
	Case 3	1
	Case 5	2
Cond 4	Case 9	2
	Case 8	1
	Case 9	2
Cond 5	Case 9	3
	Case 7	5
	Case 9	2
Cond 6	Case 9	3
	Case 8	1
	Case 1	8

Table 2 shows six different conditions, the first one is transient between Case 1, 4 and return to 1. The second one is transient between cases 2, 6 and return to 2. The third one is transient between Case 2, 3 and 5. The fourth one is transient between case 9, 8 and return to 9. The fifth one is transient between case 9,7 and return to 9. The final one is transient between case 9,8 and 1.

Fig.39 to Fig 50 show Voltage and frequency for each condition. The voltage profile shows decreasing to reach 62%

of the rating voltage. These decreasing values appear when the system transfers from generator mode (droop) to autonomous mode in different conditions.

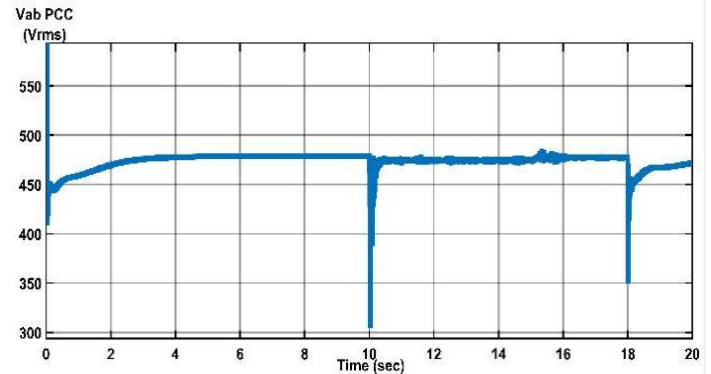


Fig. 39. Condition 1 voltage characteristic

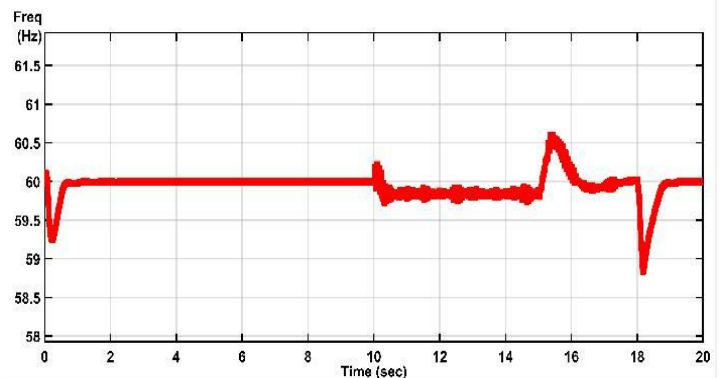


Fig. 40. Condition 1 frequency characteristic

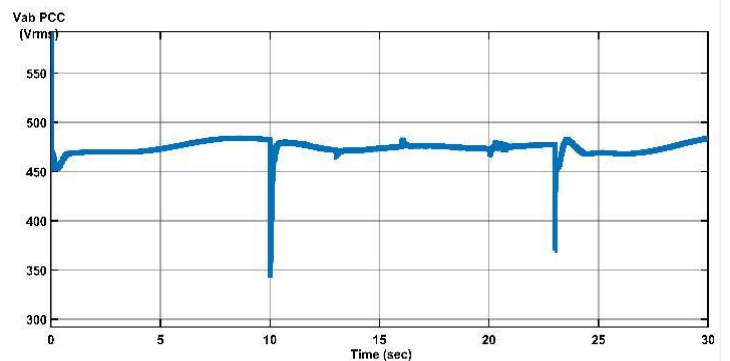


Fig. 41. Condition 2 voltage characteristic

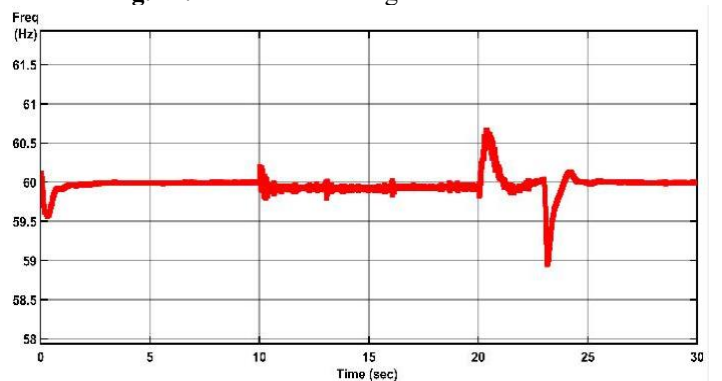


Fig. 42. Condition 2 frequency characteristic

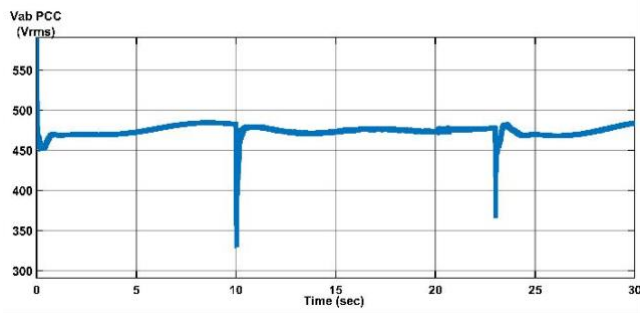


Fig. 43. Condition 3 voltage characteristic

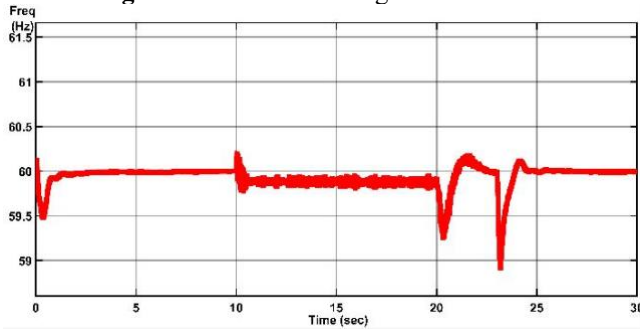


Fig. 44. Condition 3 frequency characteristic

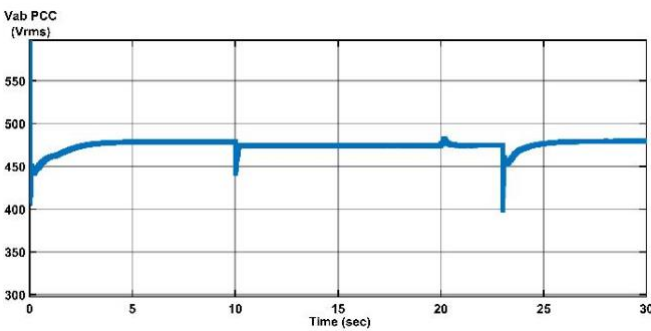


Fig. 45. Condition 4 voltage characteristic

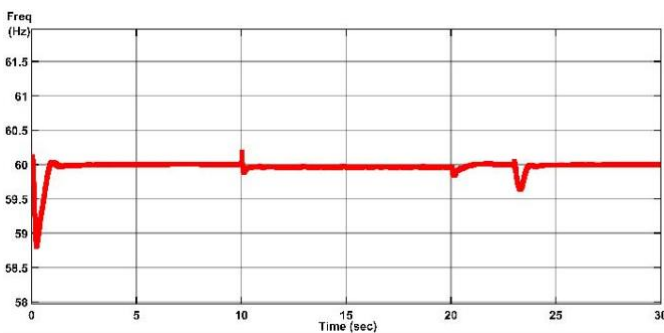


Fig. 46. Condition 5 frequency characteristic

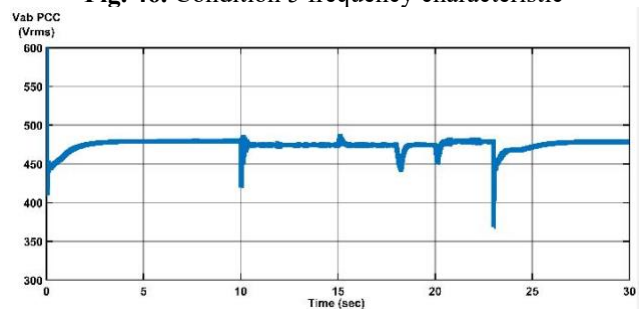


Fig. 47. Condition 5 voltage characteristic

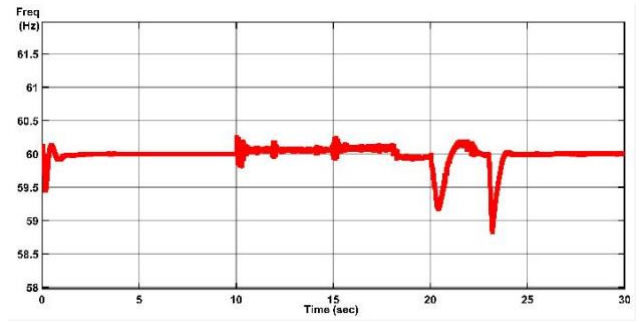


Fig. 48. Condition 5 frequency characteristic

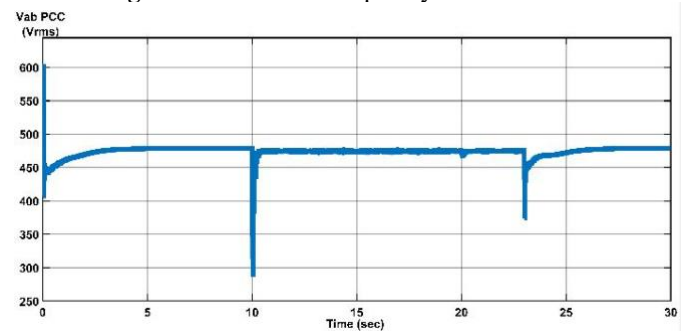


Fig. 49. Condition 6 voltage characteristic

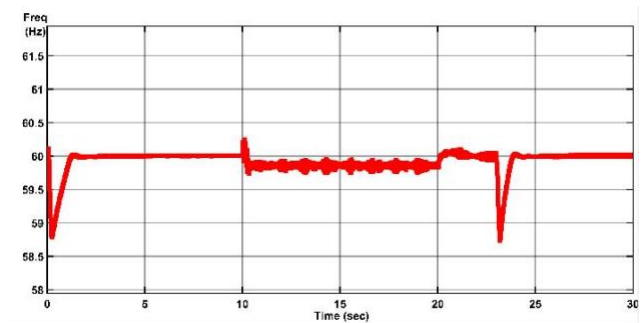


Fig. 50. Condition 6 frequency characteristic

Simulation shows a transient response for the system frequency in different conditions; the frequency value is varying by $\pm 4\%$ within limits.

In another transient situation, voltage decreases to reach 80% of its rated value when system transfer from autonomous mode to generator mode.

From the results, the voltage controller needs to be improved by an optimization technique to optimally tune its parameters. In the next section, the transient conditions will be studied again by using equilibrium optimizer algorithm to tune voltage controller parameters.

5. Transient Conditions by Using Equilibrium Optimizer Algorithm

In this section, the transient conditions will be studied again by using the equilibrium optimizer algorithm to tune voltage controller parameters.

5.1. Equilibrium optimizer algorithm

The equilibrium optimizer method is a physics based meta-heuristics algorithm announced by Afshin Faramarzi in

2020 [27, 28]. The equilibrium is based on mass conservation for nonreactive constituents moving in, out and generating inside the concentration volume. The first order different equation to express the change in mass with time describe as the following equation Eq. (8) :

$$V \frac{dC}{dt} = SC_e - SC + P \quad (8)$$

Where V represent the control volume, C is the concentration in V , $V \frac{dC}{dt}$ is the mass change rate inside V , S represent the volumetric surge rate in and out of V , C_e is equilibrium.

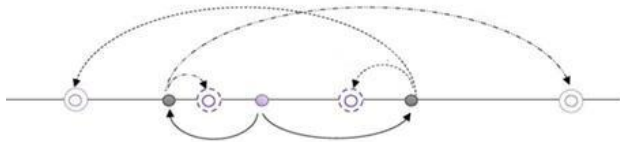


Fig. 51. Equilibrium particles update concentration, moving researcher recruits toward an equilibrium point, an equilibrium point, and expected particle position

The equilibrium optimization algorithm involves steps that start with initialization than search recruits, exploration and finally exploitation is next step, the final steps is rate of propagation [27, 29].

5.2. Simulation results

The voltage response of six-condition show from Fig 52 to Fig 56 after using equilibrium optimization algorithm depend on methodology in [27].

The simulation shows an improvement in the voltage profile where the maximum voltage dip reaches 20 % for 2 cycles rather than 62 % in the present condition

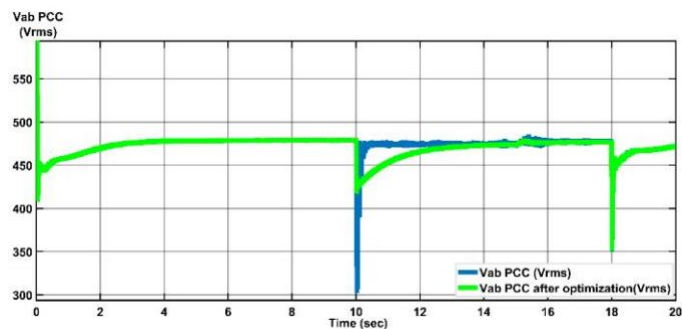


Fig. 52. Condition 1 RMS voltage characteristic

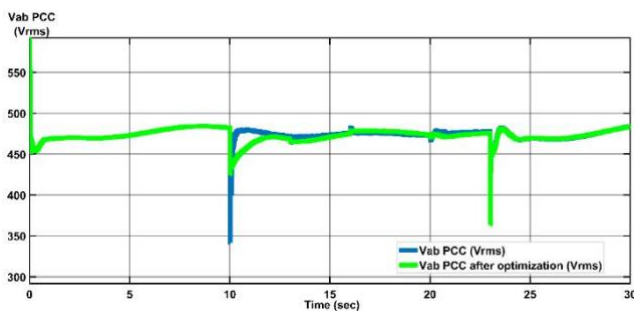


Fig. 53. Condition 2 RMS voltage characteristic

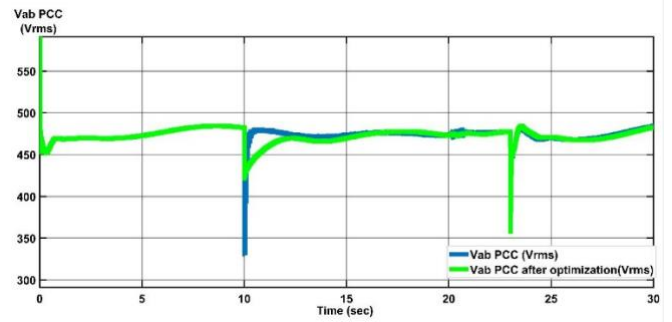


Fig. 54. Condition 3 RMS voltage characteristic

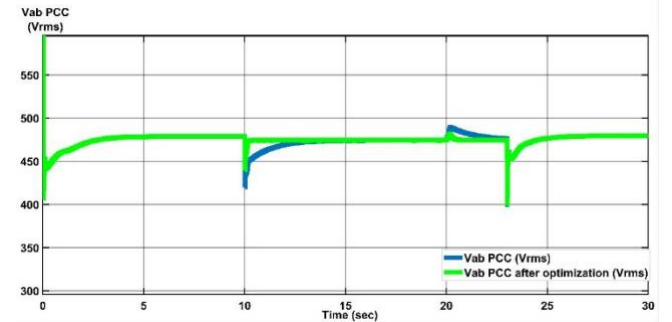


Fig. 55. Condition 4 RMS voltage characteristic

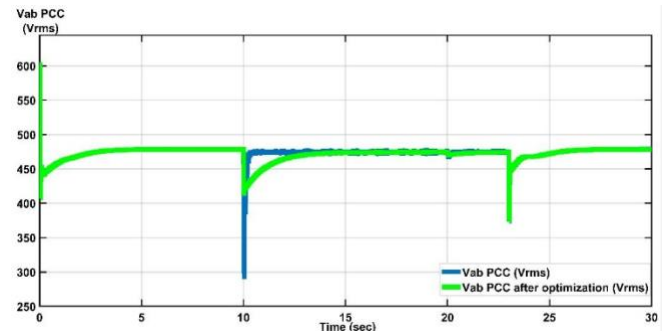


Fig. 56. Condition 6 RMS voltage characteristic

6. Conclusion

The paper presents a case study for applying renewable generator in oil production field. HOMER software is used to analyze economic factors and operation conditions for renewable generation. The implementation of renewable resources (system 1) shows a reduction in LCOE by 35 % compared to using a diesel generator only (system 2). Also, diesel consumption per year is reduced by 45%. While from an environmental impact point of view, using renewable energy in system 2 shows a reduction in carbon emissions by 45 % rather than system 1.

Moreover, the MATLAB model is used to simulate different cases of operation under steady state condition then transient condition; Simulation shows that the system in transient conditions suffers from a reduction in voltage by around 48 % of its rating in some cases.

Finally, the equilibrium optimizer method is used to tune the voltage controller parameter and the simulation shows an improvement in the voltage profile by reducing the voltage dip by around 50%.

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Author Contributions

Mohamed Abdel-Rahman was responsible for the conceptualization, validation, resources, data curation, software development, and project administration. Mahmoud Abdella Attia. and Mohamed Zakaria Kamh. jointly contributed to the methodology, formal analysis, investigation, original draft preparation, review and editing, visualization, supervision, and funding acquisition. All authors have read and agreed to the published version of the manuscript.

Conflict of Interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and publication of this article.

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