ENERGY MANAGEMENT AND CONTROL OF HYBRID RENEWABLE ENERGY SYSTEM WITH STORAGE BASED SMAART DC-MICROGRID USING INTELLIGNET NON-INTEGER CONTROL STRATEGY

Lethavadla Venkateswarlu
St'anns college of engineering and technology
Dr.Kaladhar Gaddala, M.Tech, Ph.D
Associate professor
Dr SVD Anil Kumar, M.Tech, Ph.D, Professor and HOD in EEE Department
Dr .K Jagadeesh Babu, M.Tech, Ph.D principal St'anns college of Engineering and Technology

ABSTRACT -Worldwide natural changes, atomic power gambles, misfortunes in the power network, and rising energy costs are expanding the longing to depend on more sustainable power for power age. As of late, a great many people like to reside and work in savvy places like brilliant urban communities and shrewd colleges which coordinating savvy framework frameworks. The enormous piece of these brilliant network frameworks depends on mixture energy sources which make the energy the executives a difficult errand. Hence, the plan of an astute energy the executives regulator is required. The current paper proposes a canny energy the board regulator in light of joined fluffy rationale and fragmentary request corresponding basic subsidiary (FO-PID) regulator strategies for a shrewd DC-microgrid. The crossover energy sources coordinated into the DC-microgrid are comprised by a battery bank, wind energy, and photovoltaic (PV) energy source. The source-side converters (SSCs) are regulator by the new savvy partial request PID procedure to extricate the most extreme power from the inexhaustible energy sources (wind and PV) and further develop the power quality provided to the DC-microgrid. To make the microgrid as financially savvy, the (wind and PV) energy sources are focused on. The proposed regulator guarantees smooth result power and administration coherence. Reproduction aftereffects of the proposed control pattern under Matlab/Simulink are introduced and contrasted and the very winding partial request regulator.

1. INTRODUCTION

Traditional electric power system can be broadly divided into three main categories: electricity generation, transmission, and distribution systems. The generating stations are connected to the distribution system through transmission lines and the distribution system supplies electricity to all loads in a particular region. For a number of reasons, mainly technical and economical, individual power systems are connected together to form power pools. These regional or area electric grids operate independently, but are also interconnected to form a utility grid. Nowadays, electric power systems are evolving to more complex and interacting sets of systems at multiple levels by means of the development of new technologies, along with innovations in business models and policies. In this way, the whole system tends to be a conglomerate of smarter grids that interconnect hardware, software and communication technologies. The European Technology Platform Smart Grids defined a smart grid (SG) as “an electricity network that can intelligently integrate the actions of all users connected to it - generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies". In SG, information and communication technology (ICT) enhanced appliances can adjust their electricity demand according to grid conditions and local energy generation. Currently, grid operators can already have agreements with industries on electricity demand for economic use of the electricity grid, but ICT technologies can enable a diverse set of household appliances to automatically shift their demand. For example, a smart washing machine can start its cycle when PV solar panels are producing energy, stops operating when production is low because of a passing cloud, and continue its operation again when the sky is clear again. However, all of the electrical appliances are not suitable for shifting their demands subject to grid conditions, for example, the electricity demands of appliances such as lightning and television can largely be considered as non-shiftable demands. Hence, demand response (DR) can also reduce the impact of clean energy technologies on the demand side, by alleviating peaks in electricity demand of technologies such as heat pumps and electric vehicles (EVs). Accordingly, distributed solutions are becoming an integral part of the modern electric power system, providing improvements in energy efficiency, generation, and demand-side flexibility, as well as integrating diverse distributed energy resources (DERs) such as renewable energy sources (RES), energy storage systems (ESS), electric vehicles, smart devices and appliances, among others. In this context, distributed autonomous systems known as microgrids (MGs) have appeared as a natural component of the SG to provide controllability and management to local power areas and enhance the power system with resiliency properties.

1.1.LITERATURE SURVEY

H. T. Dinh, J. Yun, D. M. Kim, K. Lee, and D. Kim [1], With the development of new technologies in the field of renewable energy and batteries, increasing number of houses have been equipped with renewable energy sources (RES) and energy storage systems (ESS) to reduce home energy cost. These houses usually have home energy management systems (HEMS) to control and schedule every electrical device. Various studies have been conducted on HEMS and optimization algorithms for energy cost and peak-to-average ratio (PAR) reduction. However, none of papers give a sufficient study on the utilization of main grid's electricity and selling electricity. In this paper, firstly, we propose a new HEMS architecture with RES and ESS where we take utilization of the electricity of the main grid and electricity selling into account. With the proposed HEMS, we build general mathematical formulas for energy cost and PAR during a day. We then optimize these formulas using both the particle swarm optimization (PSO) and the binary particle swarm optimization (BPSO). Results clearly show that, with our HEMS system, RES and ESS can help to drop home energy cost significantly to 19.7%, compared with the results of previous works. By increasing charge/discharge rate of ESS, energy cost can be decreased by 4.3% for 0.6 kW and 8.5% for 0.9 kW. Moreover, by using multi-objective optimization, our system can achieve better PAR with an acceptable energy cost.

C. Byers and A. Botterud [2], Current capacity markets often consider capacity credits from each resource independently, irrespective of the portfolio of resources, potentially overvaluing or undervaluing the capacity contribution of variable renewable energy (VRE) and energy storage (ES) in the grid. We propose a method for calculating the standalone and integrated capacity value of an added VRE resource with existing ES resources. The difference between the integrated and standalone value is the portfolio effect. This is the additional capacity value gained by the synergy of VRE and the existing fleet. Using chronological dispatch simulations and two different reliability metrics to estimate firm capacity, we demonstrate on a small test system that the portfolio effect can be substantial.

M. Rizwan, L. Hong, W. Muhammad, S. W. Azeem, and Y. Li [3], Renewable energy sources powered distributed generation (RES-DG) is getting more indispensable to encounter the considerable increase in demand for electric energy owing to its techno-economic benefits and eco-friendly nature. An economic solution to this demand can only be obtained with the optimal placement and sizing of RES-DGs. The optimal siting and sizing of RES-DG, such as Photovoltaic (PV) and Wind Turbine (WT) is still a hot topic due to the uncertainties in solar irradiance (SI) and wind speed (WS). The main objective of this research paper is to develop a RES-DG siting and sizing strategy for the discrete, nonlinear siting and sizing pattern of RES-DGs using a novel hybrid Harris' Hawk optimizer (HHHO), considering the stochastic nature of SI and WS. The Weibull and Beta probability density functions (PDFs) are utilized for modeling the stochastic nature of WS and SI, respectively. The optimization of the multi objective function comprises active power loss reduction, enhancement in voltage profile, and improvement in voltage stability index (VSI). Different scenarios of single and multiple RES-DGs and capacitor banks (CB) are examined to validate the efficiency of the proposed novel HHHO based RES-DGs siting and sizing strategy. The results show a considerable reduction in power loss, enhancement in the system voltage profile, and improvement in VSI. Evaluation of results by comparing with state-of-art hybrid algorithms shows that the proposed solution using HHHO algorithm is globally optimum.

Y. Sun, Z. Zhao, M. Yang, D. Jia,W. Pei, and B. Xu [4], The integration of renewable energy, such as PV and wind power, has exerted great impacts on the power system with its rapid development. If the corresponding energy storage system is configured, the power system could be able to hold a higher proportion of renewable energy. Focusing on energy storage application for the output fluctuation mitigation of renewable energy, this paper first analyses the reason for renewable energy power fluctuation mitigation from the four aspects of frequency, unit ramp, low frequency oscillation and cascading failure. In addition, the fluctuation rate standard of grid-connected renewable energy, the energy storage type and the mitigation topology are introduced. Then a summary and analysis on mitigation strategy and hybrid energy storage allocation strategy are presented. Finally, the demonstration application and development trend of energy storage are analyzed to provide reference for the promotion of energy storage in renewable energy.

T. Salameh, M. A. Abdelkareem, A. G. Olabi, E. T. Sayed, M. Al-Chaderchi, and H. Rezk [5], Renewable energy resources play a very important rule these days to assist the conventional energy systems for doing its function in the UAE due to high greenhouse gas (GHG) emissions and energy demand. In this paper, the analysis and performance of integrated standalone hybrid solar PV, fuel cell and diesel generator power system with battery energy storage system (BESS) or supercapacitor energy storage system (SCESS) in Khorfakkan city, Sharjah were presented. HOMER Pro software was used to model and simulate the hybrid energy system (HES) based on the daily energy consumption for Khorfakkan city. The simulation results show that using SCESS as an energy storage system will help the performance of HES based on the Levelized cost of energy (LCOE) and greenhouse gas (GHG) emissions. The HES with SCESS has renewable fraction (68.1%) and 0.346 $/kWh LCOE. The HES meets the annual AC primary load of the city (13.6 GWh) with negligible electricity excess and with an unmet electrical load of 1.38%. The reduction in GHG emissions for HES with SCESS was 83.2%, equivalent to saving 814,428 gallons of diesel.

1.2.PROBLEM FORMULATION

Due to the latest development in power electronics, the autonomous DC microgrid can work at its maximum performance. However, because of the renewable energy sources stochastic nature, the smooth operation and continuous power transmission to the loads need a supplementary energy management unit. In fact, in the standard design of the DC microgrid, the load converters and the energy sources are parallel connected where the energy is consumed or supplied through the DC-link. Thus, the control of the DC-link voltage is needed for an efficient and stable operation of the DC microgrid. Several control strategies have appeared in the literature to address the issues of the DC-link voltage. a combined fuzzy controller and voltage control, fuzzy logic control strategy with reduced rules, the aforementioned control strategies are linear and can regulate the DC-link in a small operating interval. Thus, to overcome this restriction, nonlinear controls have been investigated in the previous proposed nonlinear controls show limitations in performances in the case of droop control strategy and optimal energy management has given the multiple integrated energy storage system, poor stability for the H∞ method, chattering issues concerning the sliding mode. Also, the major part of these controls highly depends on fixed gains which are very sensitive to parameter uncertainties and external disturbances.

1.3.OBJECTIVE OF THESIS

In the same context, in the present work, a new fractional order PID controller is proposed combined with a fuzzy logic method to address the problems faced by the conventional integer controls in hybrid energy management. Fractional-order controllers offer additional advantages over integer order controls such as robust behavior to oscillations and the measurement noise and high degree of freedom. The proposed new controller is integrated with an energy management unit for a DC-microgrid integrated with several stochastic sources and essential DC loads. The proposed intelligent Fractional-Order PID (IFO-PID) controls will be used as a low-level controller, when the energy management unit serves as high-level controller which generates appropriate references for the IFO-PID and monitors the generated and consumed power. This paper addresses the following two main objectives: controlling the source-side converters (SSCs) to extract the maximum power from the renewable energy sources (wind and PV) using the proposed IFO-PID. The second task is to improve the power quality supplied to the DC-microgrid by regulating the reactive power and the DC-link voltage to their references using the energy management unit (EMU).

The novelty and contribution of the present work are summarized as follows:

1) The new fractional order PID (FO-PID) controller combined with a fuzzy logic strategy is developed for a DC-microgrid integrated with several stochastic sources and essential DC loads.

2) The fuzzy logic method is selected as a fuzzy gain supervisor to adaptively adjust gains of the FO-PID which greatly enhances the robustness of the proposed approach against various uncertainties external disturbances.

3) The essential characteristic of this approach is the extremely reduced number of the fixed gains used by the proposed strategy which avoids its sensitivity to parameter uncertainties, which highly improves the robustness property and global stability of the system.

4) The global stability of the system and is ensured and further validated by extensive simulation results.

2. SYSTEM MODELING

A new fractional order PID controller is proposed combined with a fuzzy logic method to address the problems faced by the conventional integer controls in hybrid energy management. Fractional-order controllers offer additional advantages over integer order controls such as robust behavior to oscillations and the measurement noise and high degree of freedom. The proposed new controller is integrated with an energy management unit for a DC-microgrid integrated with several stochastic sources and essential DC loads illustrated by Figure 4.1. The proposed intelligent Fractional-Order PID (IFO-PID) controls will be used as a low-level controller, when the energy management unit serves as high-level controller which generates appropriate references for the IFO-PID and monitors the generated and consumed power. The novelty and contribution of the present work are summarized as follows, the new fractional order PID (FO-PID) controller combined with a fuzzy logic strategy is developed for a DC-microgrid integrated with several stochastic sources and essential DC loads. The fuzzy logic method is selected as a fuzzy gain supervisor to adaptively adjust gains of the FO-PID which greatly enhances the robustness of the proposed approach against various uncertainties external disturbances. The essential characteristic of this approach is the extremely reduced number of the fixed gains used by the proposed strategy which avoids its sensitivity to parameter uncertainties, which highly improves the robustness property and global stability of the system. The global stability of the system and is ensured and further validated by extensive simulation results.

2.1.MATHEMATICAL DESCRIPTION OF THE HYBRID ENERGY SYSTEM

The studied hybrid energy system integrated smart DC-microgrid is illustrated by Figure 1, where three main parts can be distinguished: the hybrid energy sources constituted by the wind energy, solar energy, and the battery storage systems connected to the DC-link through their respective converters. The second part represents the loads assumed to be a priority which in the case of a smart university may include laboratory experimentation benches, fans, and lighting. Amaximum power point tracking algorithm is used on both the wind and solar (PV) conversion systems to force them to operate at maximum power. The energy management unit computes the total consumed and produced energy to select the adequate control modes.

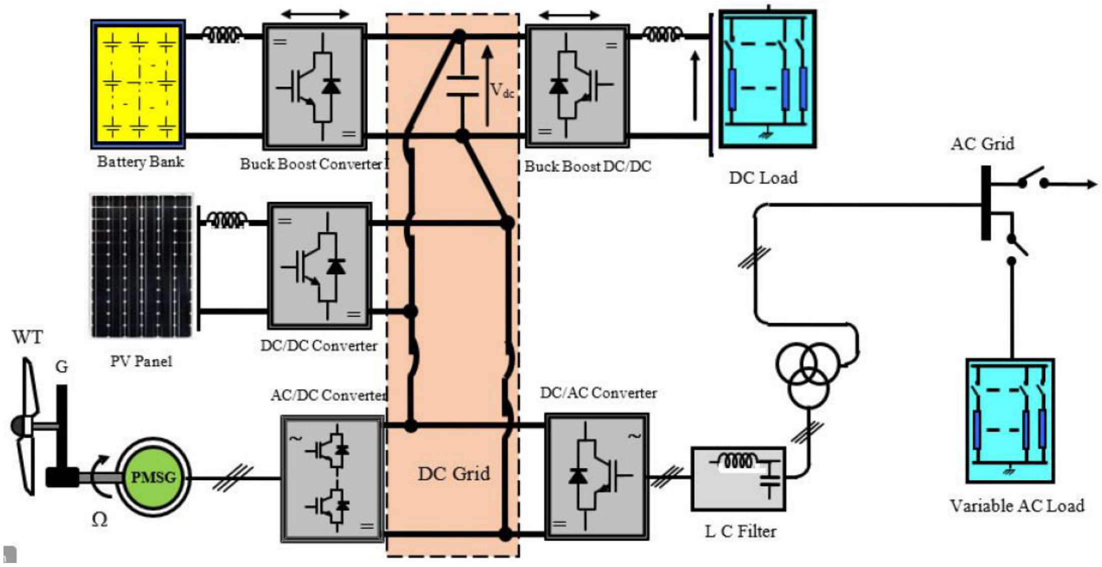


Fig.1. Studied hybrid system structure.

2.2.WIND SYSTEM MODEL

The mathematical model of the wind power that can be transformed by the turbine is given by:

$$P_m = \frac{1}{2}\rho C_p(\beta, \lambda) A v^3$$

$$T_m = \frac{P_m}{\omega_t}$$

$$C_p(\beta, \lambda) = \frac{1}{2}\left(\frac{116}{\lambda_i} - 0.4\beta - 5\right) e^{-\left(\frac{21}{\lambda_i}\right)}$$

$$\lambda_i^{-1} = (\lambda + 0.08\beta)^{-1} - 0.035\left(1 + \beta^3\right)^{-1}$$

$$\lambda = \frac{\omega_t R}{v},$$

Depending on the state of the storage system, which it will be discussed in the energy management section, the wind system can be operated under MPPT for maximum power extraction or off-MPPT for power balance as shown in Fig. 2. The MPPT algorithm is detailed in the flowchart of Fig. 3.

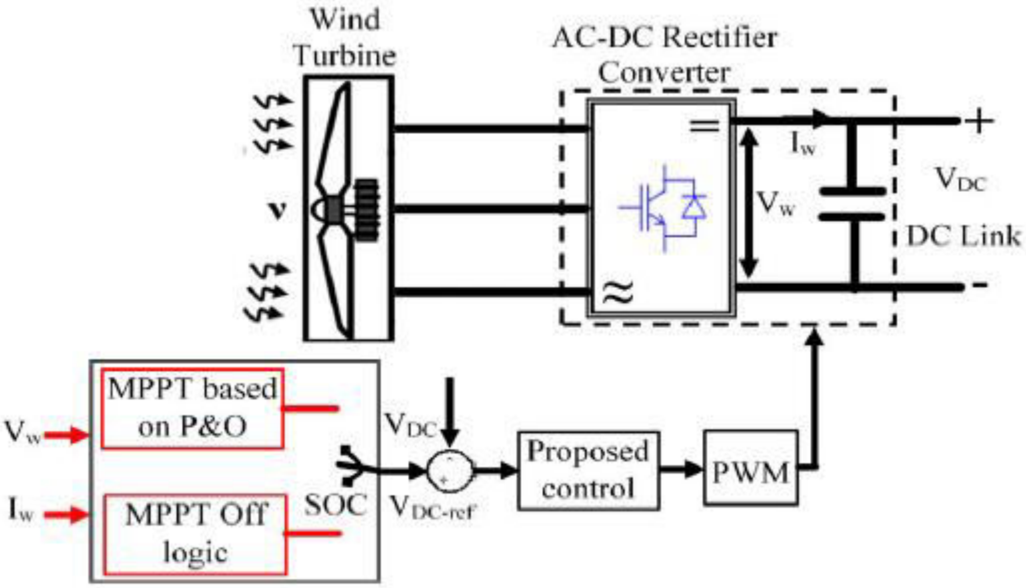


Fig.2. Wind energy system with controller.

In case of power generation excess and no storage capacity in the battery system, the proposed energy management unit (EMU) switches the wind controller from the MPPT mode to the off-MPPT mode in order to reduce the generated power and maintain a balanced power in the standalone system. In off-MPPT, the voltage reference is carried out as:

$$V_{ref} = \frac{P_L - P_w}{I_w}$$

Where, *PL* is the load power and *Pw* is the power from the wind energy system.

2.3.SOLAR POWER SYSTEM MODEL

The solar conversion system (SCS) is constituted by the PV panel connected to the DC-link through a DC-DC boost converter. The SCS mathematical model is given as below,

$$\frac{dV_{pv}}{dt} = \frac{I_{pv}}{C_{pv}} - \frac{I_{Lpv}}{C_{pv}}$$

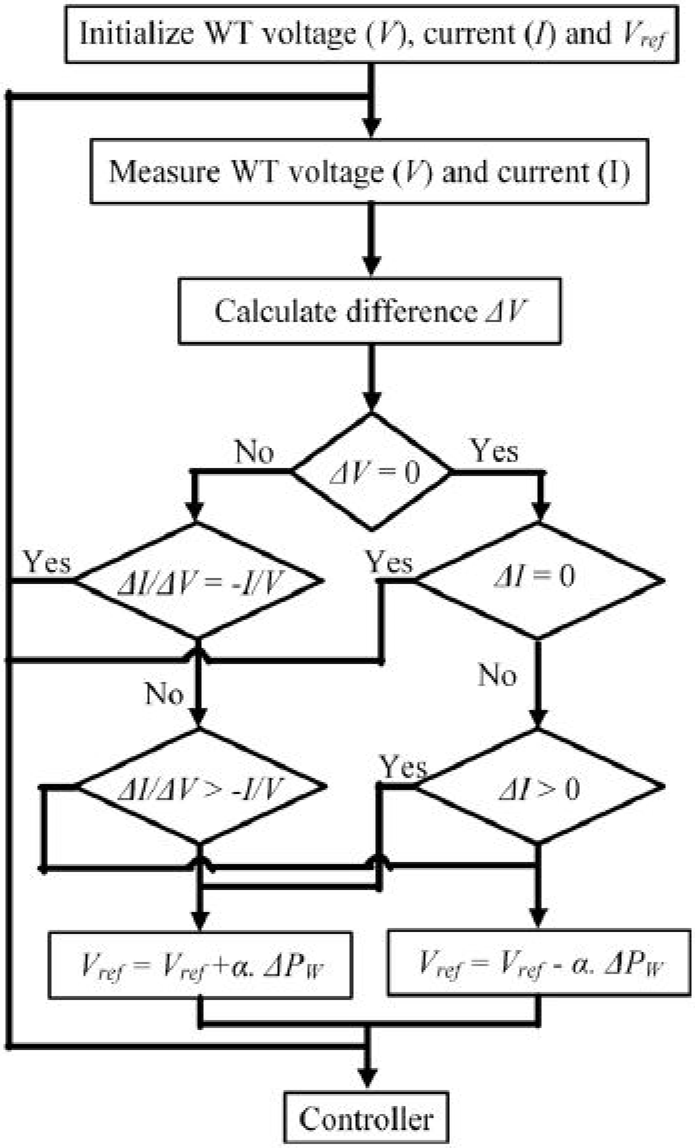


Fig.3. MPPT algorithm of the wind system.

2.4.BATTERY SYSTEM MODEL

In this application, a standard battery is connected to the DC-link through a bidirectional DC-DC back-boost converter connected at the DC-link of the microgrid. The role of this converter is to maintain the DC-link voltage constant despite the power changes in the sources and the load. The DC-link voltage is regulated at it references to compute the reference current of the battery and then design the voltage controller through the proposed strategy aThe Battery State of Charge (SOC) model is modeled as described below:

$$SOC = 100\left(1 + \frac{\int I_{bat}\,dt}{Q}\right)$$

The SOC, the amount of electricity stored during the charge, is an important parameter to be controlled. The battery SOC must detect by the proposed supervisory system to make decisions according to its status and the required power. In a battery, the ampere-hours stored during a time t corresponds to a nominal capacity Q and a charging current *Ibat*. The battery charge-discharge depends on the available power, the demand and the SOC.

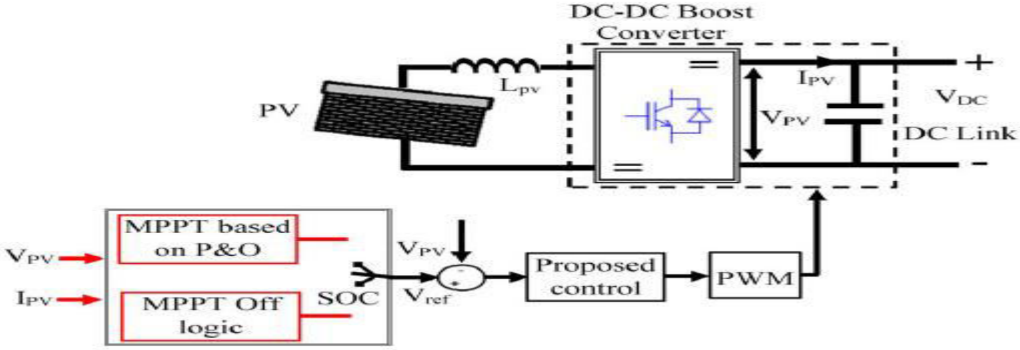


Fig.4. Solar energy system with controller.

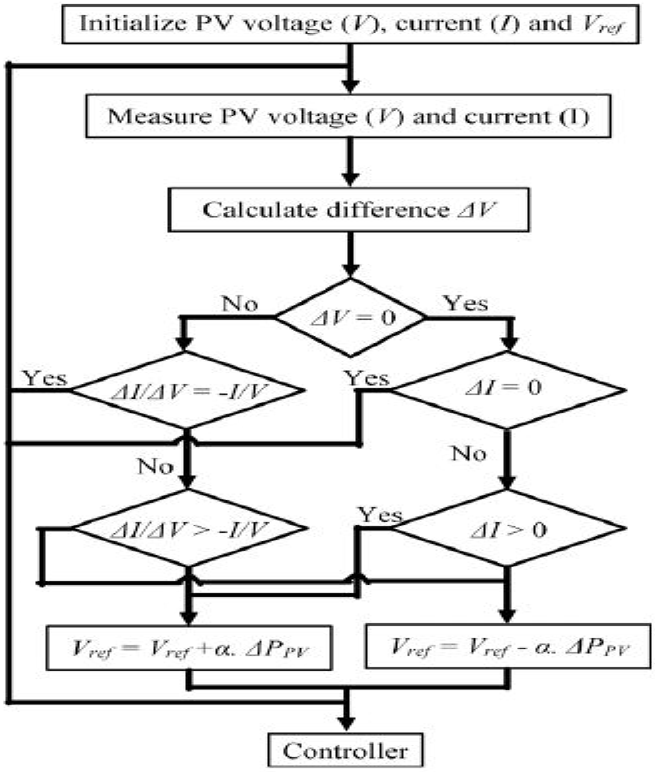


Fig.5. MPPT algorithm of the solar energy system.

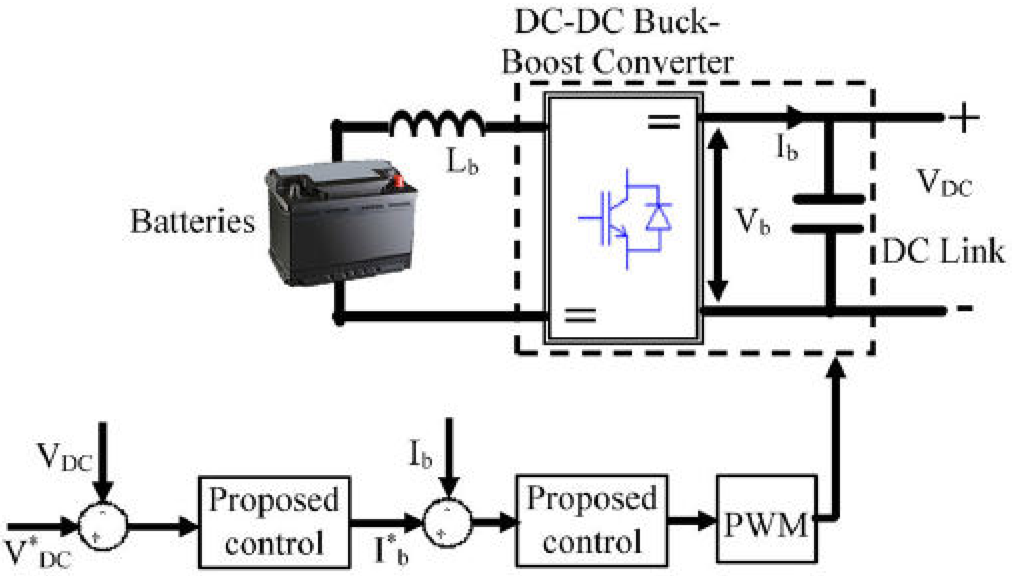


Fig.6. Battery storage system with controller.

2.5.AC GRID MODEL

Similar wind and AC grid converters are used which is a buck-to- buck converter (see Figure 7). Then, the mathematical modeling of the AC grid converter system can be expressed as given below,

$$\frac{dV_g}{dt} = \frac{I_g}{C_g} - \frac{I_{Lg}}{C_g}$$

$$\frac{V_g}{L_g} = \frac{dI_g}{dt} + (1 - U_4)\frac{V_{dc}}{L_g} - D_7$$

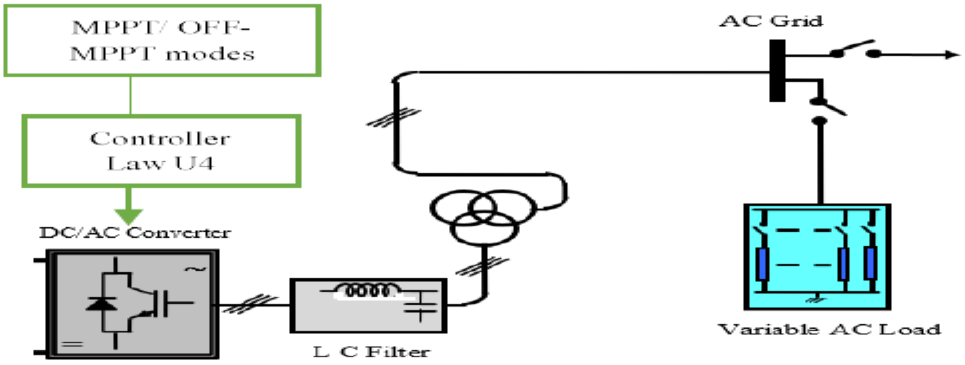


Fig.7. AC load system.

2.6.FO-PID Controller:

Fractional order dynamic system and controls are relatively newresearch areas in control engineering. Traditional PID control method is a most popular control approach where integrator and derivative are integer order. Recently, in fractional order calculus community, a trend of using non-integer integrator or non-integer derivative for the accurate profile tracking in controlled-output has appeared which so-called fractional order PID control is.

During the control system design the stability of fractional order system is the very fundamental and critical requirement. The known fact is that the continuous time-invariant time linear of an integer order system is stable, if and only if, characteristic polynomial has all of its roots are negative real parts. i.e, In the complex plane the roots must lie in the left half. The fractional order systems stability is the more complicated issue.

The fractional order PID (FOPID) controller is the expansion of the conventional PID controller based on fractional calculus. From many years, in industries proportional - integral - derivative (PID) controllers have been very popular in applications of process control. Their excellence consists in simplicity of design and its best performance, such as low percentage of overreach and small settling time (In slow industrial processes which are essential). The importance of PID controllers, continuous efforts are being made to improve their robustness and quality. In the automatic control field, the fractional order controllers which are the generalization integer order controllers would lead to robust control performances and more accurate. The important fact, that to attain the best performance in the fractional order models require the fractional order controllers, most of the cases the fractional order controllers are applied to regular linear dynamics or nonlinear dynamics to improve the system control performances. Historically there are four major types of fractional order controllers: (Xue and Chen, 2002)

- CRONE Controller
- Tilted Proportional and Integral (TID) Controller
- Fractional Order PI D Controller
- Fractional Lead-Lag Compensator

The five parameters of the FOPID controller, can be used to tune the controller, thus we can achieve a higher flexibility, than in the case of an integer order PID controller. For this reason we expect to attain with the FOPID controller better closed loop performances than that the ones obtained with the integer order PID controllers. Even though a easy tuning rule, as in the case of PID controllers, does not exists. For tuning FOPID controllers Barbosa proposed an experimental method. i.e determining the parameters by using Ziegler-Nichols methods. The parameters of the controller are varied until system obtaining a satisfactory response.

The approach is based on a composition of the Smith predictor control method and Differential Evolution (DE) algorithm to arrive meliorated control efficiency of the time delay process. Currently, Differential Evolution (DE) has been revealed as an ordinary but very powerful thing for real parameter optimization. The five Parameters of FOPID controllers consisted, derivative constant, integral constant, derivative order and integral order, proportionality constant, thus its scheme is more complicated than that of conventional integer-order Proportional-Integral-Derivative (PID) controller. Manufacturing of the controller illustrate here is depends on user- specified peak settling time and overshoot and has been formulated as optimization issue with a single objective. Finally, better control performance and simulation results of the Fractional-Order PID (FOPID) will be obtained in these controllers in collation with those of the classical order PID controllers. For modeling FOPID controllers a smith predictor procedure for time delay systems and sagacious optimization method Proposed based on the DE algorithm. For FOPID controllers Fractional calculus can provide original and higher efficiency extension. even though, the difficulties of calculating FOPID controllers addition, because FOPID controllers also take into account the integral order and derivative order in comparison with common PID controllers. Using fractional PID controller we have significantly reduce percentage over rise time and settling time. Simulation results gives that the fractional PID controller has better-quality performance than integer PID controller.

The advantages are,
(i) No steady-state error,
(ii) Phase margin and gain crossover frequency specifications,
(iii) Gain margin and phase crossover frequency specifications,
(iv) Robustness to variations in the gain of the plant,
(v) Robustness to high frequency noise,
(vi) Good output disturbance rejection

3. SIMULATION RESULTS

The present paper proposed a combined hybrid energy system integrated smart DC-microgrid is illustrated by Fig. 1, where three main parts can be distinguished: the hybrid energy sources constituted by the wind energy, solar energy, and the BSS connected to the DC-link through their respective

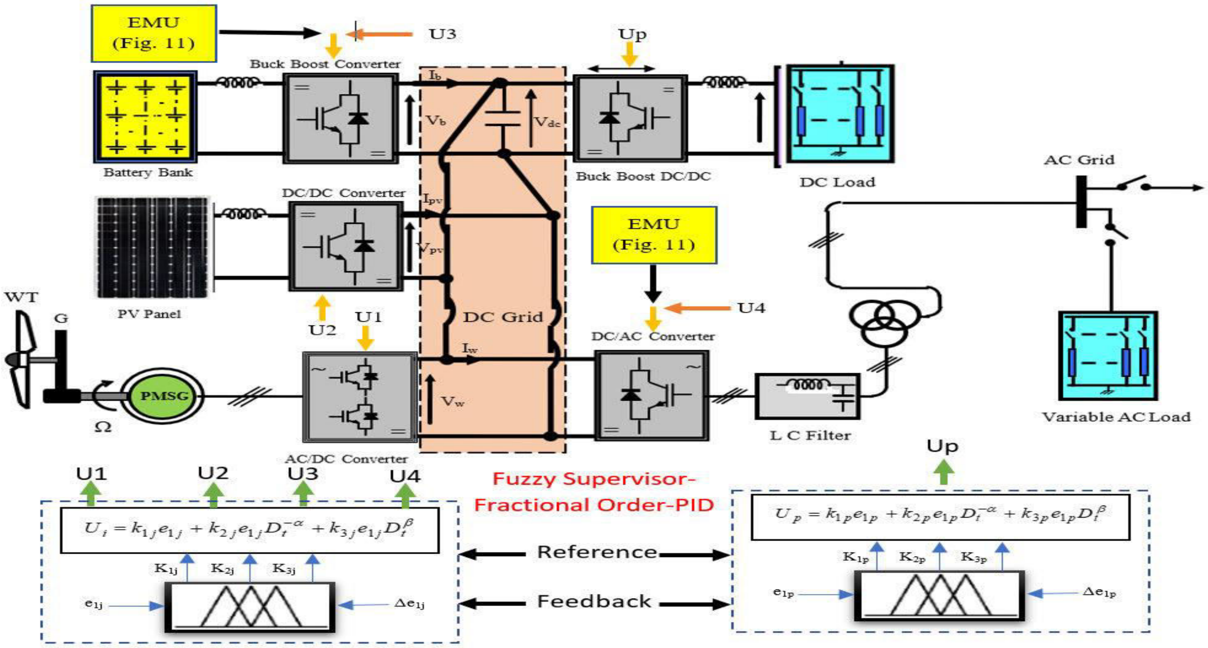


FIGURE 8. Proposed controller Structure.

converters. The second part represents the loads assumed to be a priority which in the case of a smart university may include laboratory experimentation benches, fans, and lighting. A maximum power point tracking algorithm is used on both the wind and solar (PV) conversion systems to force them to operate at maximum power. The energy management unit computes the total consumed and produced energy to order to select the adequate control modes.

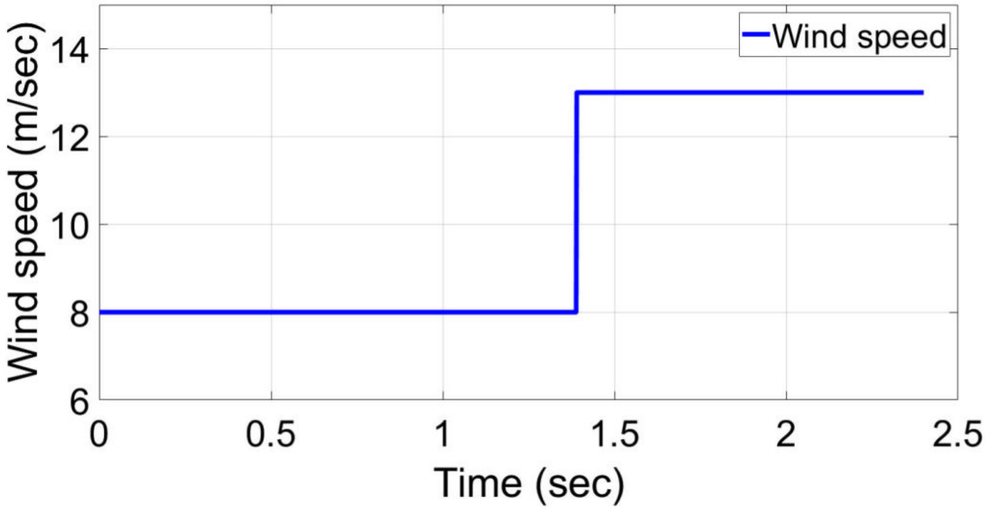


FIGURE 9. Wind speed.

The simulation results of the proposed system are performed under Matlab/Simulink and the used parameters can be found in [27]. The DC-link reference value is fixed to 240 V. The simulation test is focused on the energy management unit performances. Firstly,

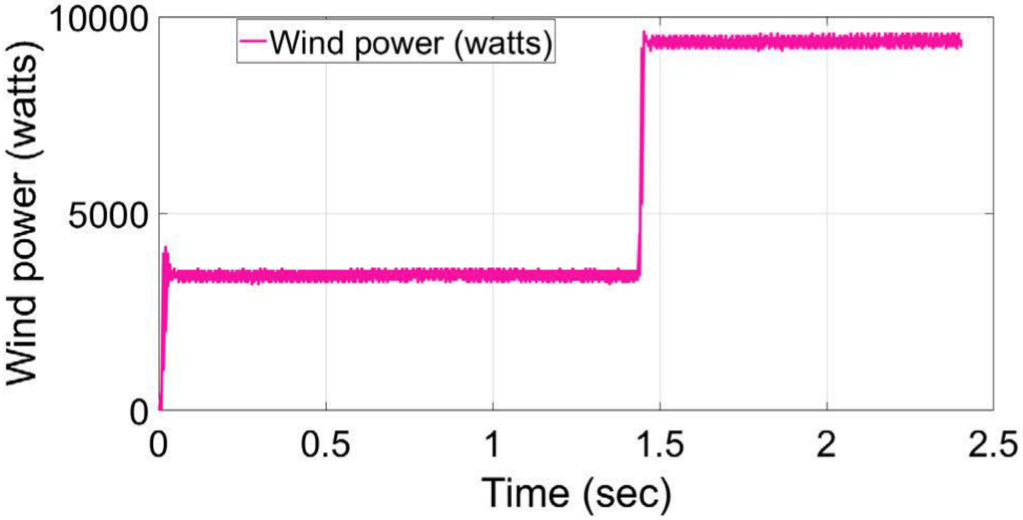
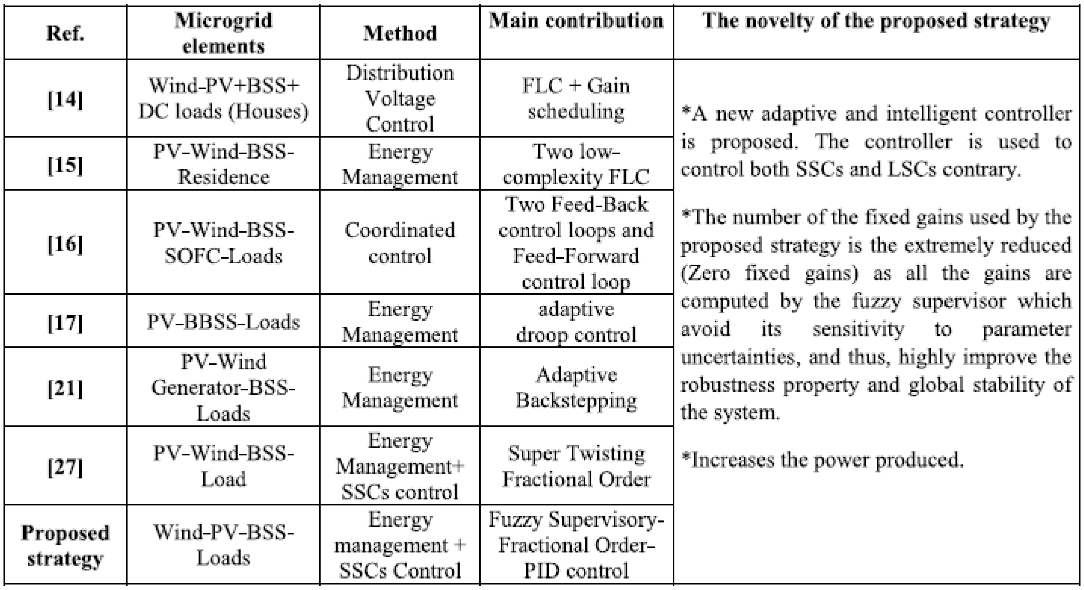


FIGURE 10. Wind power.

the DC load of 8000 watts is connected to the DC-link through two load-side converters when the battery storage system state of charge (SOC) is initially at 80 %. Fig.9, shows the wind pro_le between 8-13m/s. Fig. 10 shows the generated wind power which is varying between 4000 and 10000 watts) according to the wind speed. A 3000 watts PV power is generated as shown in Fig. 11 under a radiance of 600 watts/m2 and a temperature of 25_C. Fig. 12, depict the generated power *Pdg* from both PV and wind sources. According to the present response, the generated power *Pdg* varies between 7000 and 13000 watts. Figs. 13 and 14 show the battery power and its SOC. From the presented results, the battery supplies the microgrid with about 2300 watts in the time intervals [0-1.4] *s* when

TABLE 1. Comparative analysis of the proposed strategy with recent references.



Ref.	Microgrid elements	Method	Main contribution	The novelty of the proposed strategy
[14]	Wind-PV+BSS+ DC loads (Houses)	Distribution Voltage Control	FLC + Gain scheduling	*A new adaptive and intelligent controller is proposed. The controller is used to control both SSCs and LSCs contrary. *The number of the fixed gains used by the proposed strategy is the extremely reduced (Zero fixed gains) as all the gains are computed by the fuzzy supervisor which avoid its sensitivity to parameter uncertainties, and thus, highly improve the robustness property and global stability of the system. *Increases the power produced.
[15]	PV-Wind-BSS-Residence	Energy Management	Two low-complexity FLC	
[16]	PV-Wind-BSS-SOFC-Loads	Coordinated control	Two Feed-Back control loops and Feed-Forward control loop	
[17]	PV-BBSS-Loads	Energy Management	adaptive droop control	
[21]	PV-Wind Generator-BSS-Loads	Energy Management	Adaptive Backstepping	
[27]	PV-Wind-BSS-Load	Energy Management+ SSCs control	Super Twisting Fractional Order	
Proposed strategy	Wind-PV-BSS-Loads	Energy management + SSCs Control	Fuzzy Supervisory-Fractional Order-PID control	

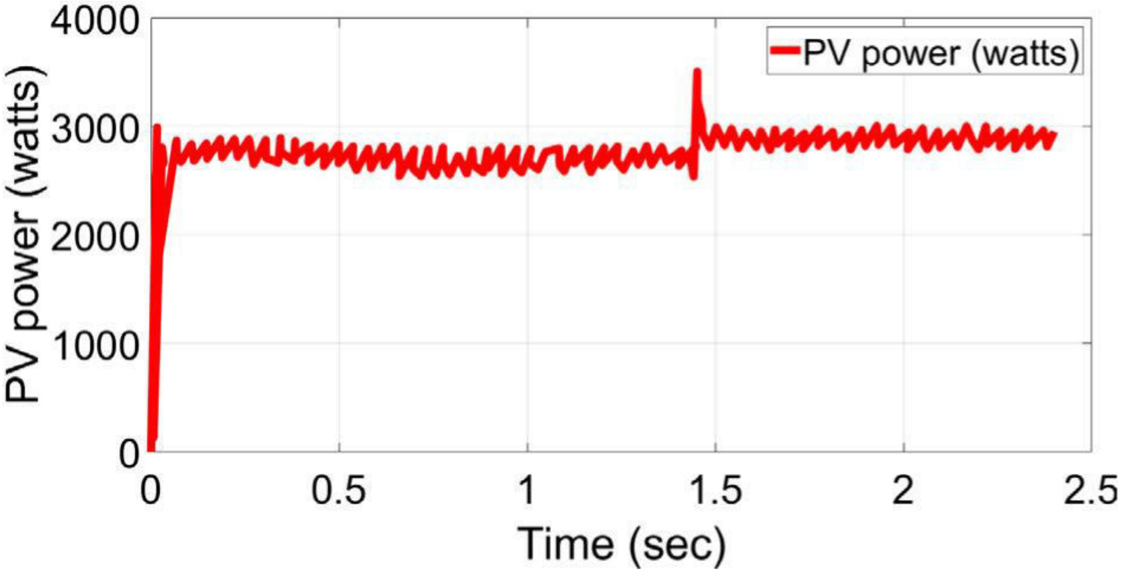


FIGURE 11. Solar power

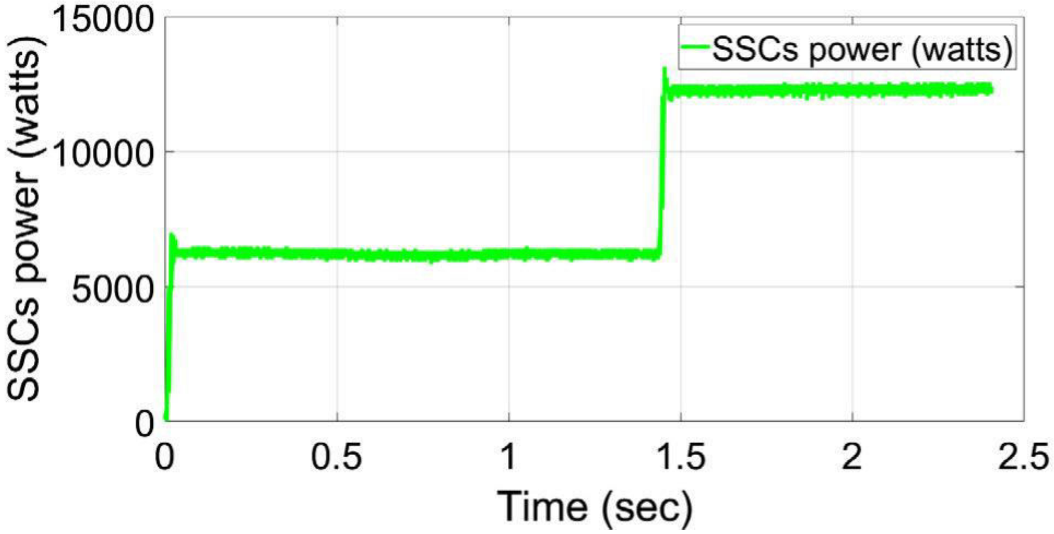


FIGURE 12. SSCs power.

SOC > 20%, while in the time intervals [1.4- 2.3] *s* the generated *Pdg* is more than the load power. Thus, the battery is charged with about 4500 watts from the microgrid. Fig. 15, shows the DC-link voltage of both the SSCs and LSCs for the PI and proposed IFO-PID, where it can be seen that both regulate the DC-link at its reference value. However, the proposed IFO-PID shows superior performances in terms of the steady-state error and the convergence criterion.

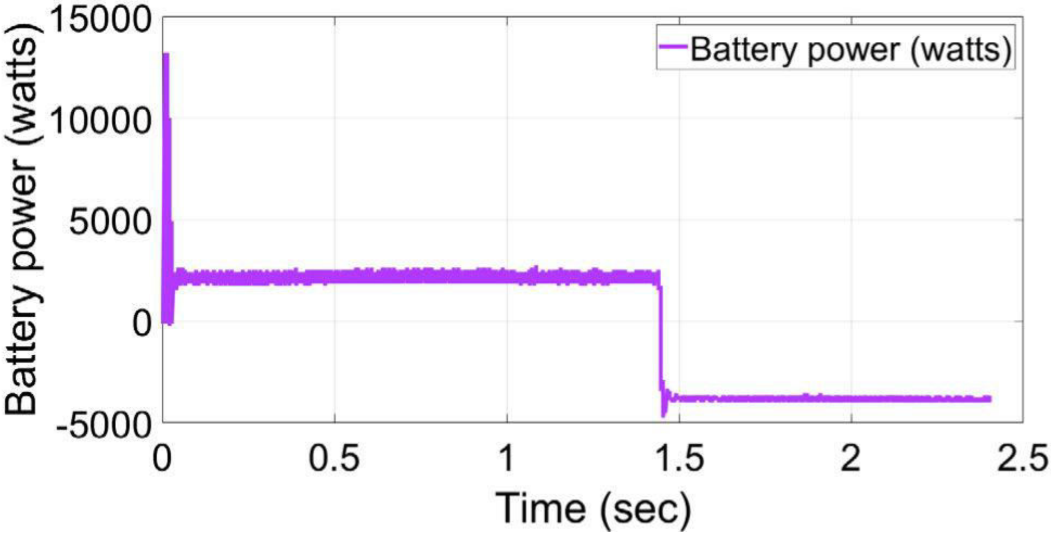


FIGURE 17. BSS power.

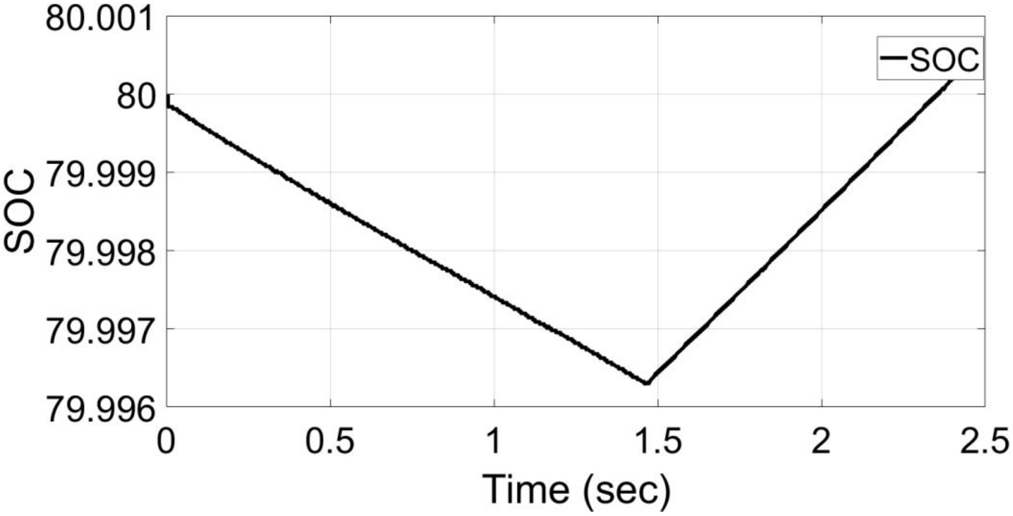


FIGURE 14. The battery SOC.

Fig. 16 shows that the proposed energy management control transmits a constant power to the loads, about 8300 watts. Fig. 17 clearly indicate that the proposed IFO-PID regulate the output voltage at its reference (220V).A comparative analysis with previous works has been performed in the present section to highlight the advantages of the proposed IFO-PID. The comparative analysis is shown by Table 2. Extensive comparative analysis with

TABLE 2. Results comparison of the proposed strategy with that of ref. [27], FO-PID and PID.

Controller	Proposed IFO-PID	Super Twisting Factional Order [27]	FO-PID	PID
Wind power (W)	9800 (+3.15%)	9500	9800	9400
PV power (W)	3000 (+50%)	2000	3000	1900
SSCs power (W)	13000 (+4%)	12500	13000	12300
BSS power stored (W)	2500 (+13.64%)	2200	2500	2100
BSS power supplied (W)	4500 (+12.5%)	4000	4500	4000
Load power (W)	8300 (+2.5%)	8100	8300	8000
Complexity	Low	High	Low	Very Low
Robustness	High (Zero fixed gains)	Poor (more than 7 fixed gains)	Low (more than 5 fixed gains)	Very poor (more than 10 fixed gains)
Performance	Very High	High	High	Low

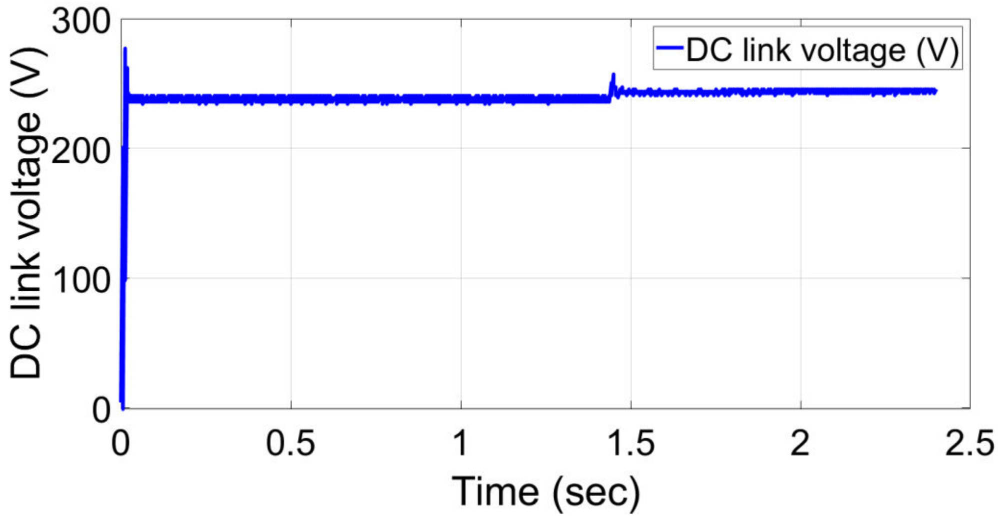


FIGURE 15. DC-link voltage.

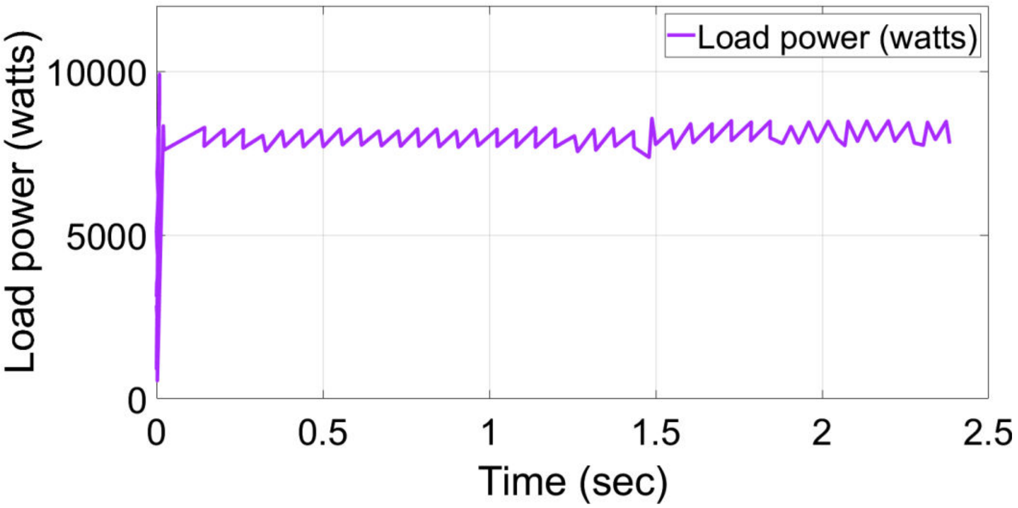


FIGURE 16. Load power

ref. [27], FO-PID and PID is demonstrated in Table 2, where it can be seen that the proposed strategy generates more power and show high performance over the compared control strategies. From the present comparative analysis, the proposed controller produces C3.15% wind power, C50% PV power, C2.5% load power over the super twisting fractional-order and more when compared to the PID control. In summary, the proposed control strategy has well managed the hybrid energy, and well achieved the objectives of the present work, and shows higher performances whencompared to the other methods.

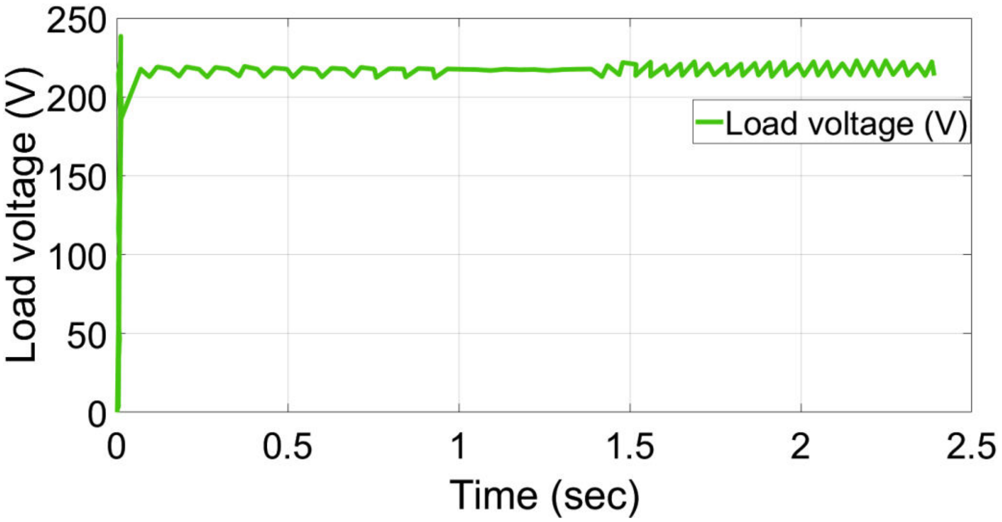


FIGURE 17. Load voltage.

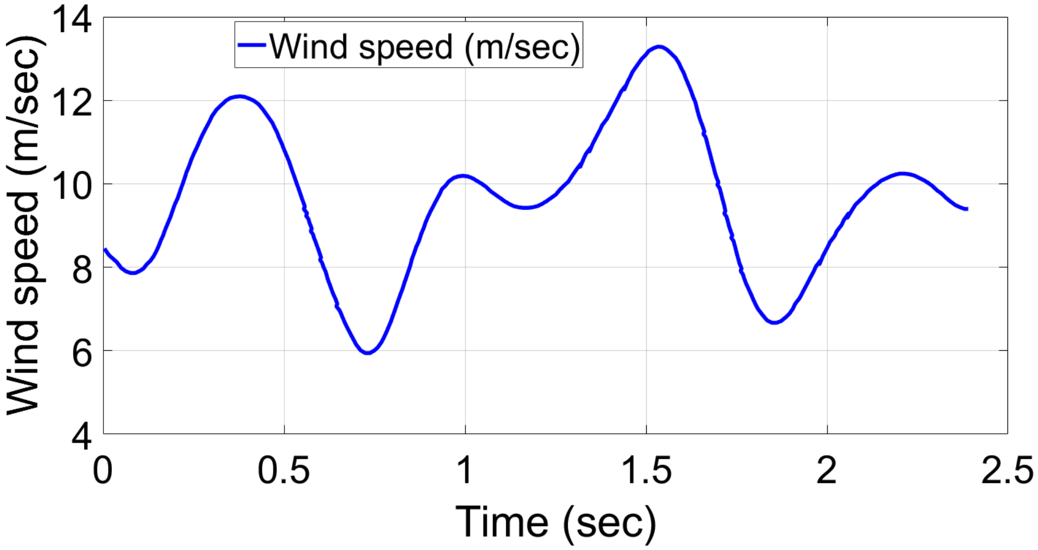


FIGURE 18. Random wind speed.

To test the robustness of the proposed energy management strategy, a random variation of the wind speed and solar radiance is used as shown by Fig. 18 and Fig. 19 respectively. Fig. 20 shows the wind power generated under random wind profile. The wind system appears to work at MPPT based on the reported results. Figure 25 clearly demonstrates how

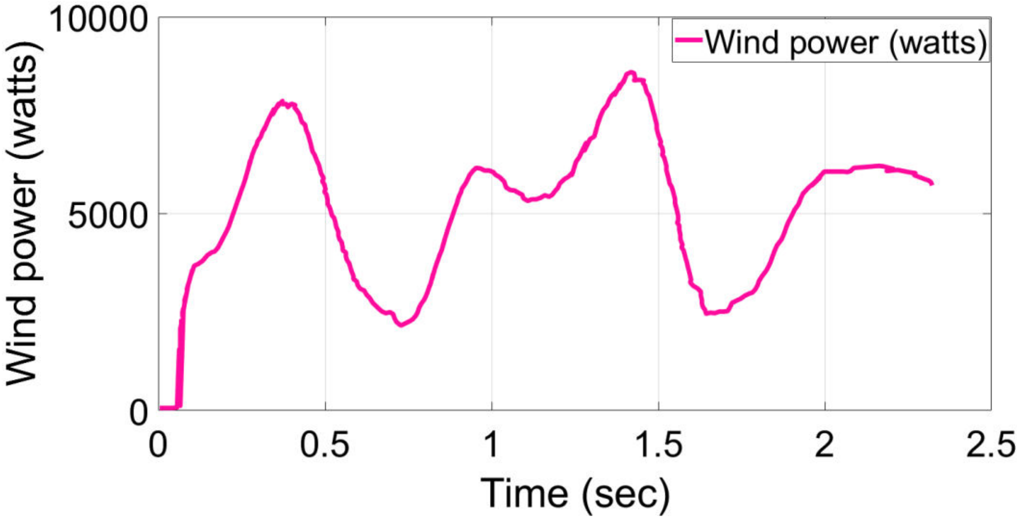


FIGURE 19. Wind power under random wind speed.

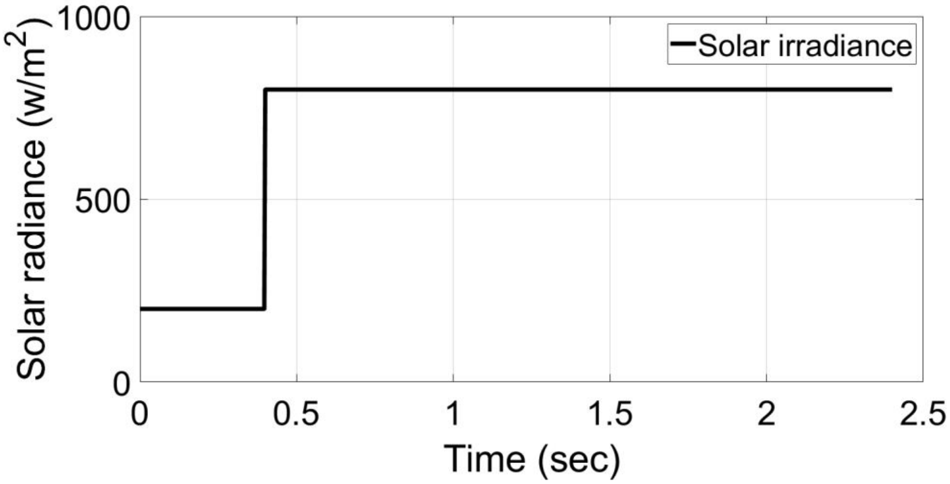


FIGURE 20. Solar radiance.

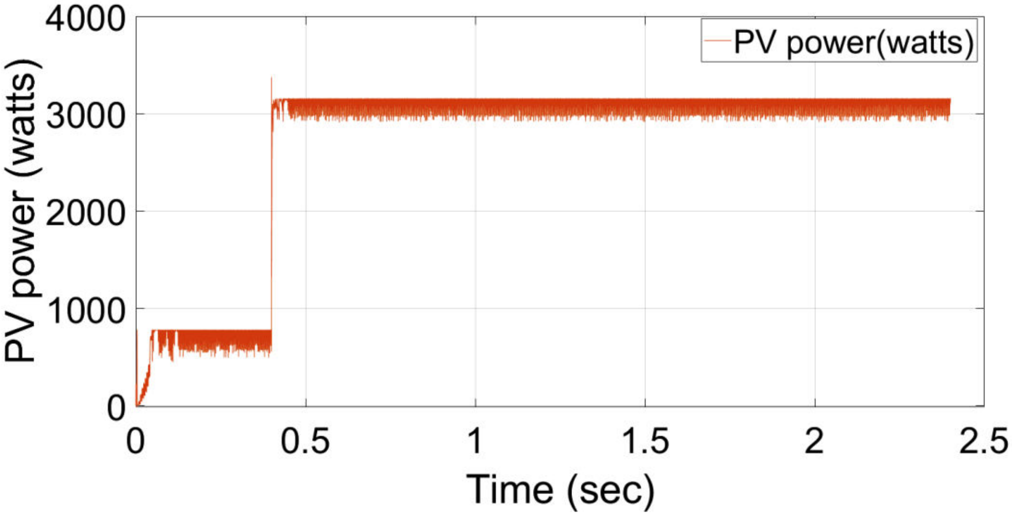


FIGURE 21. Solar power under random solar radiance.

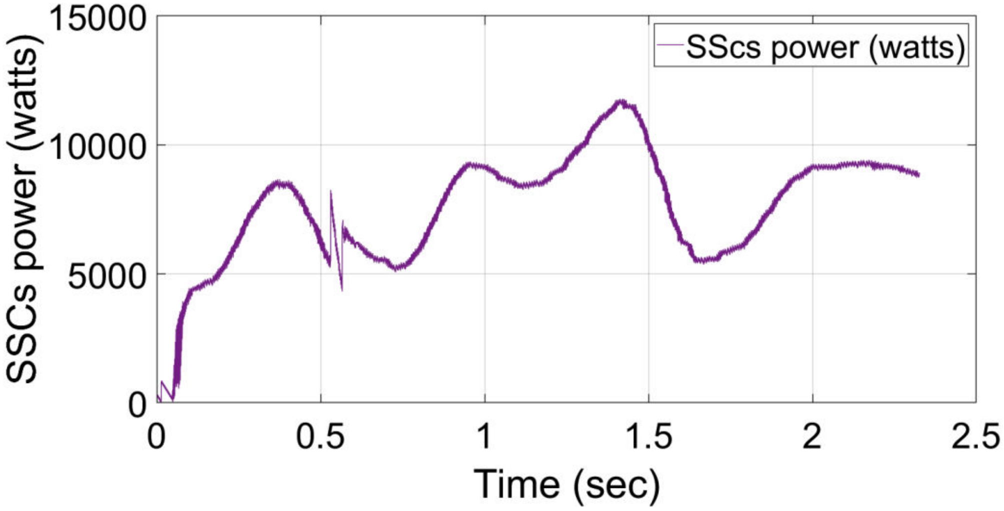


FIGURE 22. SSCs power under random variations.

the MPPT control (see Fig. 5) forces the PV panel to extract the maximum power regardless of solar radiation variations. Fig. 22 shows the power generated from both PV and wind sources. From the given results, it can be seen that the power generated is maintained between 5000-13000W which is the same as in the first test (see Fig. 12). Fig. 23 shows the BSS power under the random variations which is varying between 5000 and □5000W. The BSS works perfectly in

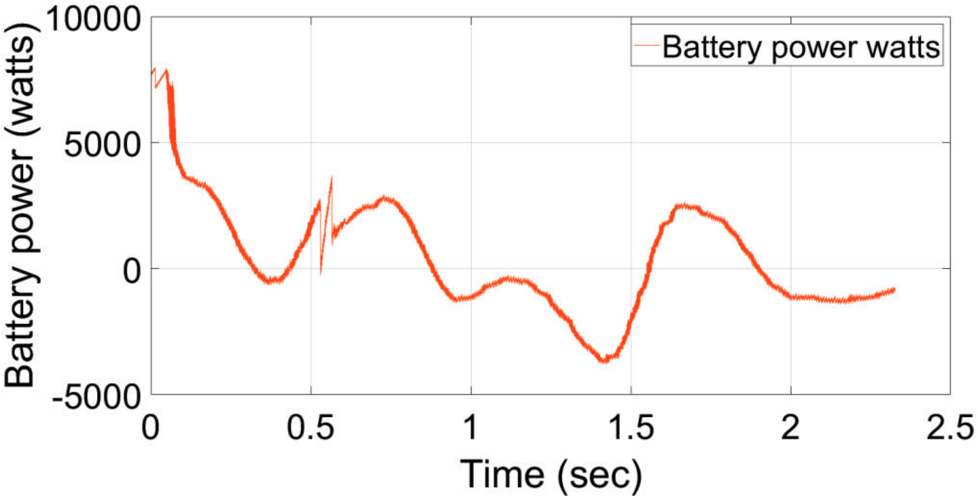


FIGURE 23. BSS power under random variations.

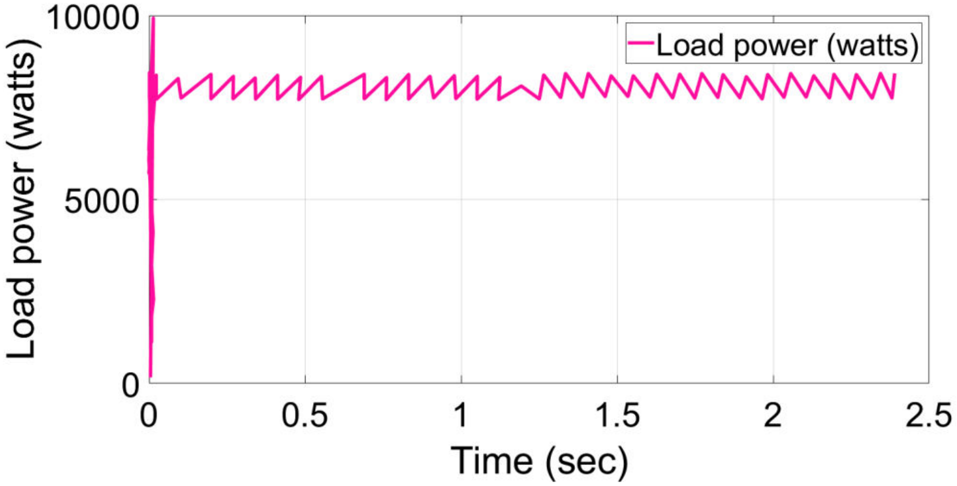


FIGURE 24. Load power under random variations.

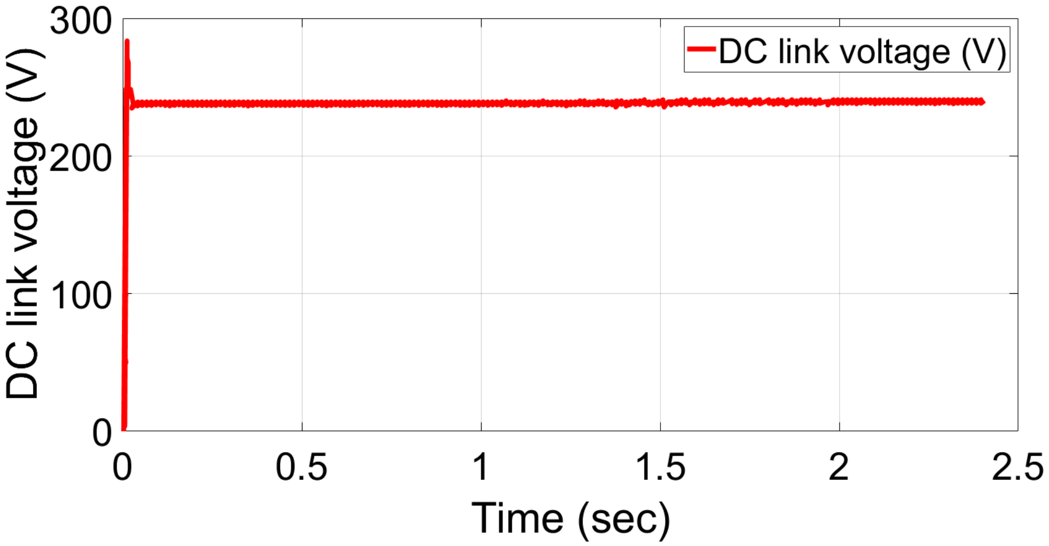


FIGURE 25. DC-link voltage under random variations.

charge/discharge mode. Fig. 24 depict that the proposed energy management control transmits a constant power to the load, about 8300W, here also it's the same as in the first case (see Fig. 16). Finally, Fig. 25 shows the DC-link voltage response. It is clear from the reported response that the proposed technique effectively regulates the DC voltage at its reference. Thus, the proposed energy management strategy well validates the objectives even under random variations, ensures smooth output power and service continuity.

4. CONCLUSION

In this project, a novel intelligent fractional order PID controller is proposed for the Energy management of hybrid energy sources contacted to a smart grid through a DC-link voltage. The hybrid energy sources integrated to the DC-microgrid are constituted by a battery bank, wind energy, and photovoltaic (PV) energy source. The source side converters (SCCs) are controller by the new intelligent fractional order PID strategy to extract the maximum power from the renewable energy sources (wind and PV) and improve the power quality supplied to the DC-microgrid. To make the microgrid as cost-effective, the (Wind and PV) energy sources are prioritized. The proposed controller ensures smooth output power and service continuity. Simulation results of the proposed control schema under Matlab/Simulink are presented and compared with the other nonlinear controls.

5. REFERENCES

[1] H. T. Dinh, J. Yun, D. M. Kim, K. Lee, and D. Kim, ``A home energy management system with renewable energy and energy storage utilizing main grid and electricity selling,'' *IEEE Access*, vol. 8, pp. 49436_49450, 2020.

[2] C. Byers and A. Botterud, ``Additional capacity value from synergy of variable renewable energy and energy storage,'' *IEEE Trans. Sustain. Energy*, vol. 11, no. 2, pp. 1106_1109, Apr. 2020.
[3] M. Rizwan, L. Hong, W. Muhammad, S. W. Azeem, and Y. Li, ``Hybrid Harris Hawks optimizer for integration of renewable energy sources considering stochastic behavior of energy sources,'' *Int. Trans. Elect. Energy Syst.*, vol. 31, no. 2, 2021, Art. no. e12694.
[4] Y. Sun, Z. Zhao, M. Yang, D. Jia,W. Pei, and B. Xu, ``Overview of energy storage in renewable energy power _uctuation mitigation,'' *CSEE J. Power Energy Syst.*, vol. 6, no. 1, pp. 160_173, 2020.
[5] T. Salameh, M. A. Abdelkareem, A. G. Olabi, E. T. Sayed, M. Al-Chaderchi, and H. Rezk, ``Integrated standalone hybrid solar PV, fuel cell and diesel generator power system for battery or supercapacitor storage systems in khorfakkan, united arab emirates,'' *Int. J. Hydrogen Energy*, vol. 46, no. 8, pp. 6014_6027, Jan. 2021.
[6] M. Çolak and Ä. Kaya, ``Multi-criteria evaluation of energy storage technologies based on hesitant fuzzy information: A case study for turkey,'' *J. Energy Storage*, vol. 28, Apr. 2020, Art. no. 101211.
[7] M. A. Hannan, M. M. Hoque, A. Mohamed, and A. Ayob, ``Review of energy storage systems for electric vehicle applications: Issues and challenges,'' *Renew. Sustain. Energy Rev.*, vol. 69, pp. 771_789, Mar. 2017.
[8] R. Amirante, E. Cassone, E. Distaso, and P. Tamburrano, ``Overview on recent developments in energy storage: Mechanical, electrochemical and hydrogen technologies,'' *Energy Convers. Manage.*, vol. 132, pp. 372_387, Jan. 2017.
[9] T. Ma, H.Yang, and L. Lu, ``Development of hybrid battery_supercapacitor energy storage for remote area renewable energy systems,'' *Appl. Energy*, vol. 153, pp. 56_62, Sep. 2015.
[10] X. Wang, D. Yu, S. Le Blond, Z. Zhao, and P. Wilson, ``A novel controller of a battery-supercapacitor hybrid energy storage system for domestic applications,'' *Energy Buildings*, vol. 141, pp. 167_174, Apr. 2017.
[11] A. Kadri, H. Marzougui, A. Aouiti, and F. Bacha, ``Energy management and control strategy for a DFIG wind turbine/fuel cell hybrid system with super capacitor storage system,'' *Energy*, vol. 192, Feb. 2020, Art. no. 116518.
[12] A. K. Barik, D. C. Das, A. Latif, S. M. S. Hussain, and T. S. Ustun, ``Optimal voltage_frequency regulation in distributed sustainable energy based hybrid microgrids with integrated resource planning,'' *Energies*, vol. 14, no. 10, p. 2735, May 2021.
[13] A. K. Barik, S. Jaiswal, and D. C. Das, ``Recent trends and development in hybrid microgrid: A review on energy resource planning and control,'' *Int. J. Sustain. Energy*, vol. 4, pp. 1_15, Apr. 2021.
[14] H. Kakigano, Y. Miura, and T. Ise, ``Distribution voltage control for DC microgrids using fuzzy control and gain-scheduling technique,'' *IEEE Trans. Power Electron.*, vol. 28, no. 5, pp. 2246_2258, May 2013.
[15] D. A. Aviles, J. Pascual, F. Guinjoan, G. G. Gutierrez, R. G. Orguera, J. L. Proano, P.

Sanchis, and T. E. Motoasca, ``An energy management system design using fuzzy logic control: Smoothing the grid power pro_le of a residential electro-thermal microgrid," *IEEE Access*, vol. 9, pp. 25172_25188, 2021.
[16] M. Kumar, S. C. Srivastava, and S. N. Singh, ``Control strategies of a DC microgrid for grid connected and islanded operations," *IEEE Trans. Smart Grid*, vol. 6, no. 4, pp. 1588_1601, Jul. 2015.
[17] H. Hajebrahimim, S. M. Kaviri, S. Eren, and A. Bakhshai, ``A new energy management control method for energy storage systems in microgrids," *IEEE Trans. Power Electron.*, vol. 35, no. 11, pp. 11612_11624, Mar. 2020.
[18] Y. Xu and X. Shen, ``Optimal control based energy management of multiple energy storage systems in a microgrid," *IEEE Access*, vol. 6, pp. 32925_32934, 2018.