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A Comparative Analysis of Integrated DC Microgrid with Hybrid Power Generation Systems by an Intelligent Control Strategy

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Abstract: **The modern electric power system is dealing with issues such as environmental protection, rising worldwide electricity demand, high dependability requirements, energy cleanliness, and planning constraints. Most people nowadays desire to live and work in smart areas such as smart towns and smart institutions that incorporate smart grid technologies. Energy management is a complicated issue since a large portion of these smart grid systems rely on HES. As a result, the possibility of microgrid emerges, where a microgrid can manage as a single controllable system and is believed to be a cluster of loads and distributed energy resources, which may comprise numerous RES and energy storage devices. For the microgrid system to function consistently, energy management of a large number of distributed energy resources is necessary. An intellectual energy management controller for a smart DC-microgrid based on a combination of ANFIS and fractional-order proportional-integral-derivative (FO-PID) controller approaches in this paper. Among the HES integrated into the DC-microgrid are a battery bank, wind energy, and a photovoltaic (PV) energy source. The novel intelligent fractional order PID approach is used to regulate the source-side converters (SSCs) in order to extract as much power as possible from RES(wind and PV) and enhance the power quality provided to the DC-microgrid. The proposed control system is implemented in MATLAB/Simulink simulation results and should compare with step changes and random changing conditions from conventional technique. The suggested controller assures continuous service and steady output power when compare with the existing method.**

Keywords: **DC microgrid, ANFIS, FOPID, Management control, Renewable sources.**

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1. INTRODUCTION

Rapid worldwide population growth, digitization, and industrial change are the key causes of rising electricity demand. Because of the rising demand for electricity, new electric power producing sources must be installed. Electricity, on the other hand, is primarily produced by centralized conventional generating sources (CGSs) located distant from load ends. These CGSs are often diesel, gas, or coal-fired electric power generators, which are substantial contributors to carbon emissions and global warming. When a result, as more CGSs is installed, carbon emissions will rise. Environmental issues, infrastructure challenges, and the integration of novel technology affect the traditional electric power system. To solve the above-mentioned issues of the centralized power system, the globe requires an alternative environmentally acceptable option. For at least two decades, government policies and academic research have focused on the maturity and deployment of RES(RESs) such as solar energy, wind energy, marine energy, biomass, and so on. In the recent decade, RESs have demonstrated a great potential for large-scale deployment, with the goal of meeting increasing energy demand, attaining sustainability, and lowering carbon emissions. Furthermore, they can be deployed on the distribution side, close to load ends, reducing transmission line congestion issues.

Electric power systems are currently growing into more complex and interacting sets of systems at numerous levels as a result of the development of new technologies, as well as changes in business models and legislation. As a result, the overall system tends to be a mash-up of smarter grids that interconnect hardware, software, and communication technologies. A smart grid (SG) is defined as "an electrical system that can brightly add the events of all users linked to it

— generators, consumers, and those who do both – in order to resourcefully offer sustainable, economical, and secure electricity supplies."

Because of modern advancements in power electronics, the autonomous DC microgrid can operate at peak efficiency. However, because RESare stochastic, smooth operation and continuous power transmission to loads need the deployment of an extra energy management unit. In reality, in the standard DC microgrid arrangement, the load converters and energy sources are parallel linked, with energy consumed or supplied via the DC-link. Controlling the DC-link voltage is thus essential for the DC microgrid to work effectively and dependably. Several control techniques have been offered in the literature to address the DC-link voltage problems. The aforementioned control approaches are linear and may regulate the DC-link in a short operating interval, such as a combined fuzzy controller and voltage control or a fuzzy logic control strategy with fewer rules. Thus, nonlinear constraints have been evaluated in the existing scheduling nonlinear controls show limitations in appearances in the case of droop control approach and optimum resource management has given the multiple integrated energy storage system, poor stability for the H method, chattering issues concerning the sliding mode. Furthermore, the majority of these controllers are heavily reliant on fixed gains, which are extremely susceptible to parameter uncertainty and external disturbances.

In the same manner, the current work proposes a new fractional order PID controller combined with an ANFIS technique to overcome the issues encountered by traditional integer controls in hybrid energy management. Fractional-order controllers provide several advantages over integer-order controllers, including robustness to oscillations and measurement noise and a high degree of freedom. The suggested novel controller is combined with an energy management unit for a DC-microgrid that includes various stochastic sources and important DC loads. The suggested IFO-PID controls will be employed as a low-level controller, while the energy management unit will function as a high-level controller, generating appropriate references for the IFO-PID and monitoring produced and consumed power. The primary objectives of this research are to control SSCs in order to harvest the greatest power from RESutilising the recommended IFO-PID. The second task is to enhance the power quality delivered to the DC-microgrid by using the energy management unit to adjust reactive power and DC-link voltage to their appropriate references (EMU). For a DC-microgrid integrated with numerous stochastic sources and important DC loads, a new FO-PID controller integrated with an ANFIS method is designed. The ANFIS method is used as an adaptive gain supervisor to iteratively adjust gains of the FO-PID, considerably improving the proposed approach's resilience against various uncertainties and external disturbances. The fundamental feature of this approach is the relatively low number of fixed gains used by the suggested strategy, which eliminates its sensitivity to parameter variations and greatly increases the system's robustness and global stability. The system's overall stability is ensured and proven by thorough simulation results.

2. MODEL CONFIGURATION

Figure 1 describes the evaluated HES integrated intelligent DC-microgrid, with three core elements: HES made up of wind energy, solar energy, and BSS linked to the DC-link via their individual converters. In the case of a smart university, the second half depicts the loads deemed important, which could include based on the experimental tables, fans, and lights. A maximum power point tracking technique is used to control wind and solar (PV) conversion systems to work at maximum power. To select the appropriate control modes, the energy management essentially defines the total used and produced energy.

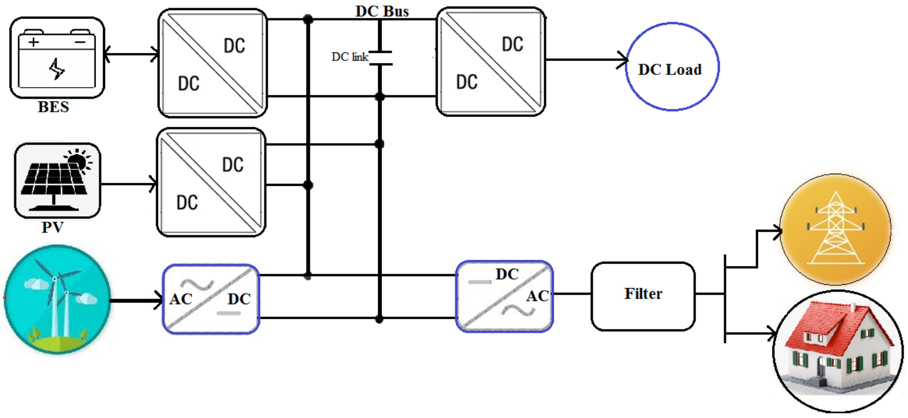


Fig.1. Proposed system configuration.

A. PV Modeling

The PV system is associated to DC-DC boost converter with the DC-link to form the solar conversion system (SCS). The SCS mathematical model is as follows:

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

$$\frac{V_{pv}}{L_{pv}} = \frac{dI_{pv}}{dt} + (1 - U_2)\frac{V_{dc}}{L_{pv}} - D_3$$

$$\frac{dV_{dc}}{dt} = (1 - U_2)\frac{I_{Lpv}}{C_{dc}} - \frac{I_{Opv}}{C_{dc}} + D_4$$

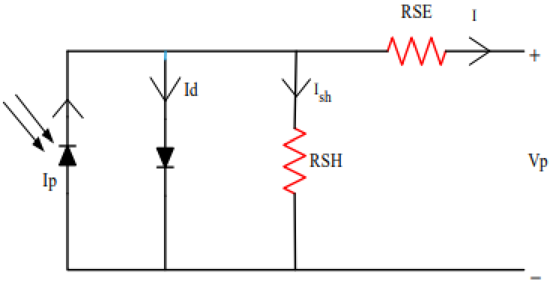


Fig.2: PV equivalent circuit.

In the event of excess Due to limited storage space in the battery system and limited electrical generation, the proposed energy audit switches the PV controller from MPPT to off-MPPT mode to reduce produced power and legitimacy regulated power in the microgrid. The voltage reference in off-MPPT is carried out as follows:

$$V_{ref} = \frac{P_L - P_{pv}}{I_{pv}}$$

B. Wind system modeling

Wind power P_w is derived by varying wind speed V_w, with turbine blades cutting an area A,

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

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

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

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

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

The model of the SCCs must be expressed in order to build the proposed control mechanism. As a result, the wind source converter model is given as,

$$\begin{aligned}\frac{dV_w}{dt} &= \frac{I_w}{C_w} - \frac{I_{Lw}}{C_w}\\ \frac{V_w}{L_w} &= \frac{dI_w}{dt} + (1-U_1)\frac{V_{dc}}{L_w} - D_1\\ \frac{dV_{dc}}{dt} &= (1-U_1)\frac{I_{Lw}}{C_{dc}} - \frac{I_{Ow}}{C_{dc}} + D_2\end{aligned}$$

The wind system can be run under Depending on the type of the storage system, which will be specified in the energy managerial hierarchy, MPPT for maximum power extraction or off-MPPT for power balance will be used, as illustrated in Fig. 3.

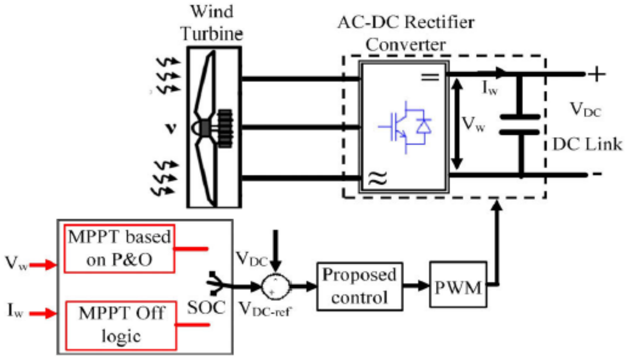


Fig.3. WES Controller.

C. Battery model

In this scenario, a standard battery is connected to the DC-link via a bidirectional DC-DC back-boost converter attached to the micro grid's DC-link. The job of this converter is to maintain a constant DC-link voltage across power changes in the sources and load. As shown in Fig. 4, the DC-link voltage is regulated at its ranges in calculate the battery's system response and then create the voltage controller using the proposed approach. The suggested supervisory system must detect the battery SOC in order to make decisions based on its status and required power.

$$SOC_{\min} \leq SOC \leq SOC_{\max}$$

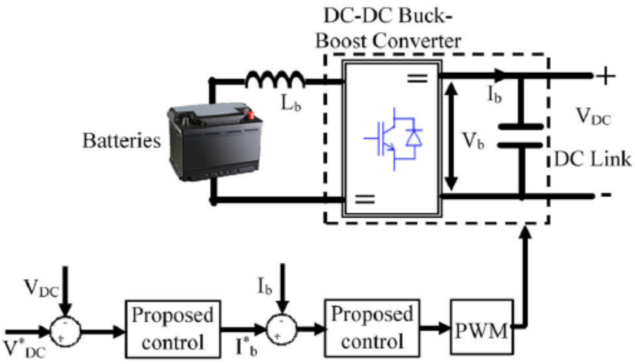


Fig.4. BES controller.

D. Fuzzy Controller Design

The degree of truth is used in fuzzy logic, which is a computer approach. A fuzzy logic system's degree of truth and linguistic elements are employed to create a certain result. The state of this input determines the kind of output.

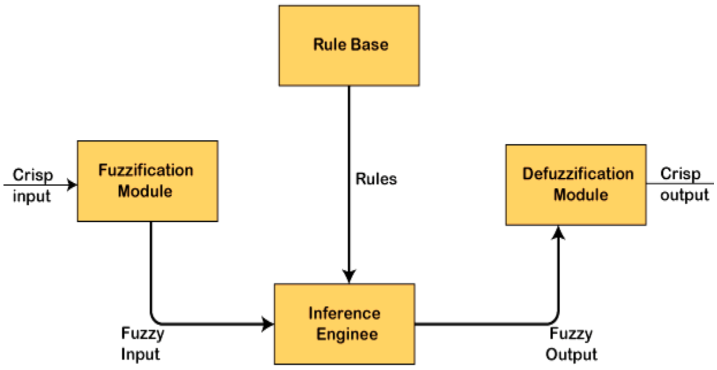


Fig.5: Structure of fuzzy logic system

Rules that link the inputs of an expert with the desired outcomes are used in fuzzy logic to designate and implement solutions. Fuzzy sets, membership functions, linguistic variables, and fuzzy rules all have a significant impact on fuzzy logic. This function is used to estimate or compute how much a given input element belongs to an abstract set, such as a fuzzy set. The x-axis represents the Universe, and the y-axis represents the degrees of participation in that Universe. The figure below is an example of a membership function.

E. FO-PID Controller

Control engineering's fractional order dynamic system and controls are relatively new study fields. The traditional PID control method is the most widely used control strategy, in which the integrator and derivative are of integer order. Recently, in the fractional order calculus community, a trend of using non-integer integrators or non-integer derivatives for accurate profile monitoring in controlled-output has emerged, referred to as fractional order PID control. The fractional order PID (FOPID) controller is a fractional calculus-based augmentation of the ordinary PID controller. For many years, proportional - integral - derivative (PID) controllers are frequently utilised in process control applications. Finally, higher control performance and simulation results of the Fractional-Order PID (FOPID) controllers will be attained in these controllers as compared to those of the classical order PID controllers. For modelling FOPID controllers, a new prediction procedure for time delay systems and a clever optimization strategy based on the DE algorithm are suggested. Fractional calculus can provide a unique and higher efficiency extension for FOPID controllers. Despite this, the challenges in computing FOPID controllers increase because FOPID controllers, unlike typical PID controllers, take into account the integral order and derivative order. We reduced the percentage over rise and settling time by Using a PID controller with a fractional coefficient. In terms of quality, the simulation results suggest that the fractional PID controller outperforms the integer PID controller.

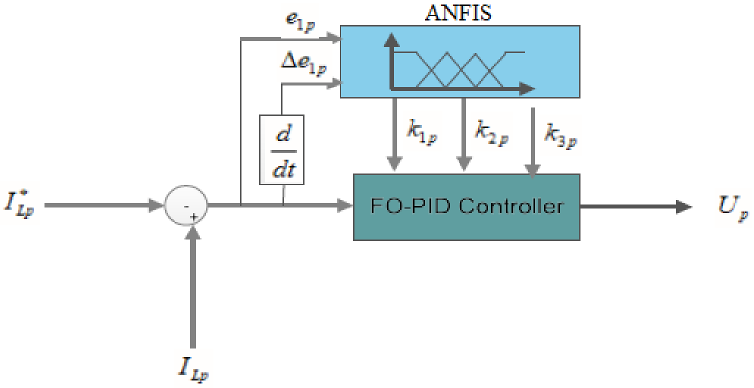


Fig.6. ANFIS-FOPID Controller.

3. SIMULATION RESULTS

Source-side converters (SSCs) are proposed in order to acquire the greatest power from RES (wind and PV) and enhance the power quality provided to the DC-microgrid system in MATLAB/SIMULINK. The proposed control system is implemented in MATLAB/Simulink simulation results and should compare with step changes and random changing conditions from conventional technique.

Case-1: step change

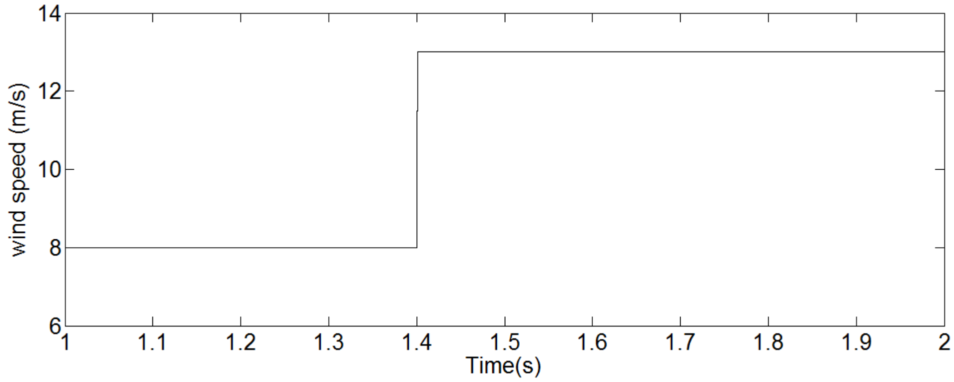
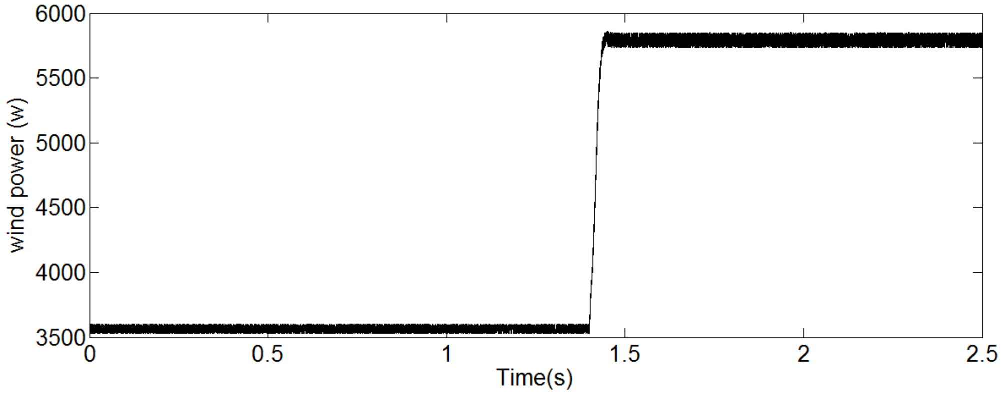
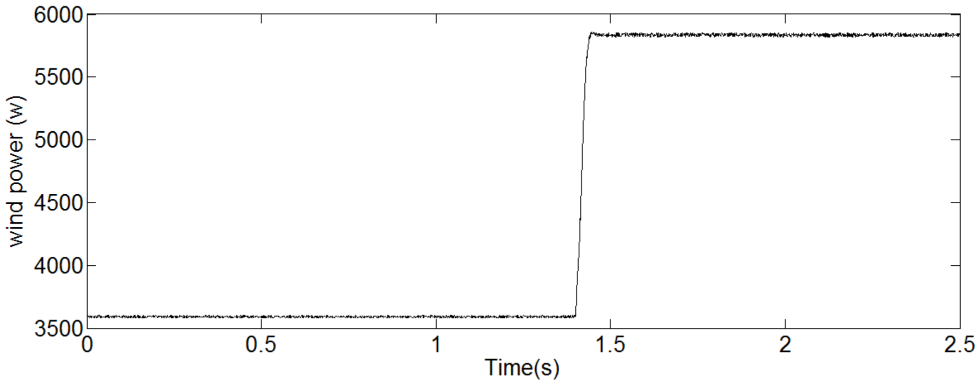


Fig.7. wind speed



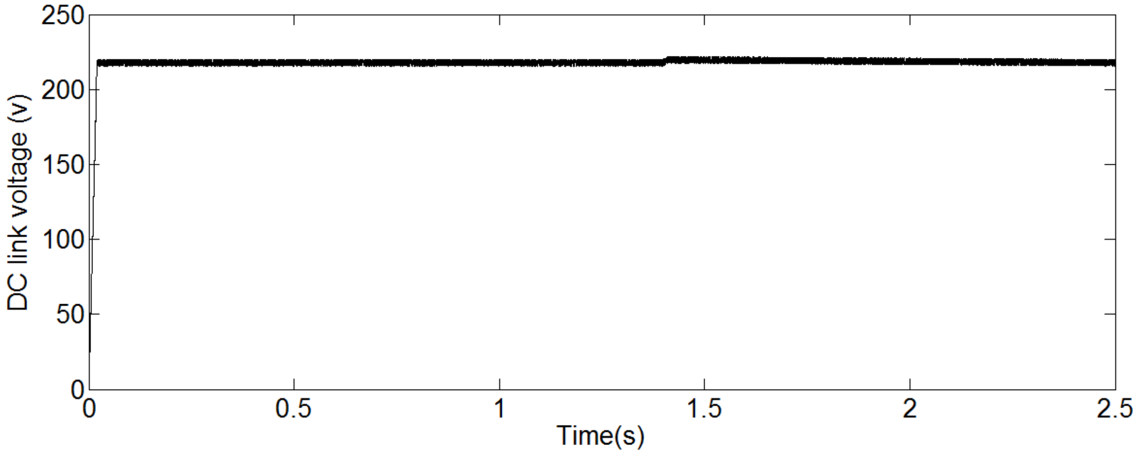
Conventional



Proposed

Fig.8. wind power

Figures 7 and 8 illustrate the wind description at 8-13m/s and created wind energy ranging from 4000 to 10000 watts due to wind speed.



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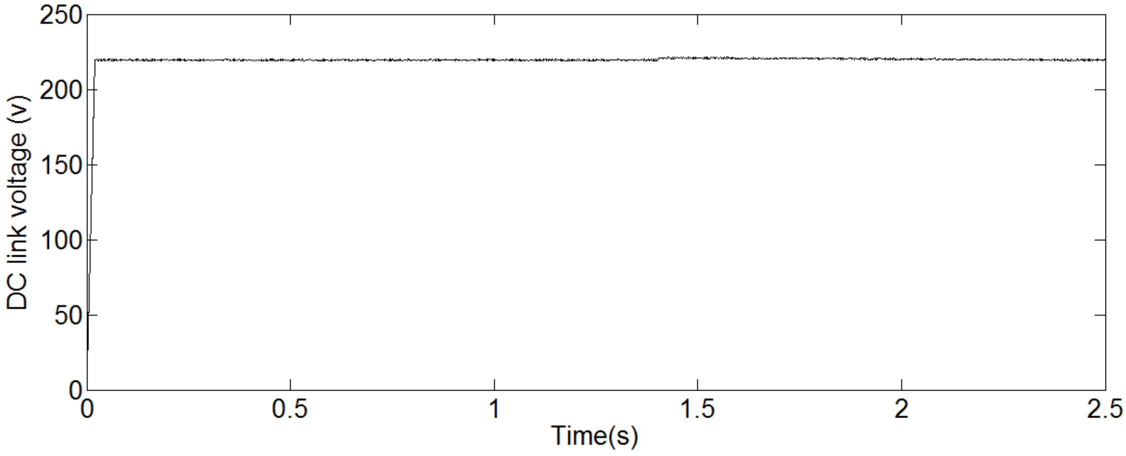
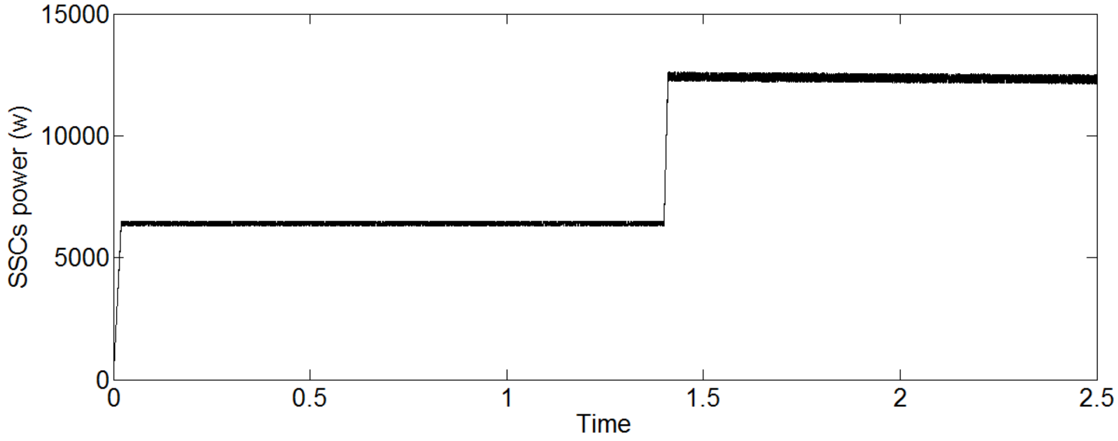


Proposed

Fig.9. DC link voltage

Figure 9 depicts the SSC and LSC DC-link voltages for the PI and proposed IFO-PID, proving that both maintain the DC-link at its set point. However, in terms of steady-state error and closure criterion, the proposed IFO-PID beats the others.



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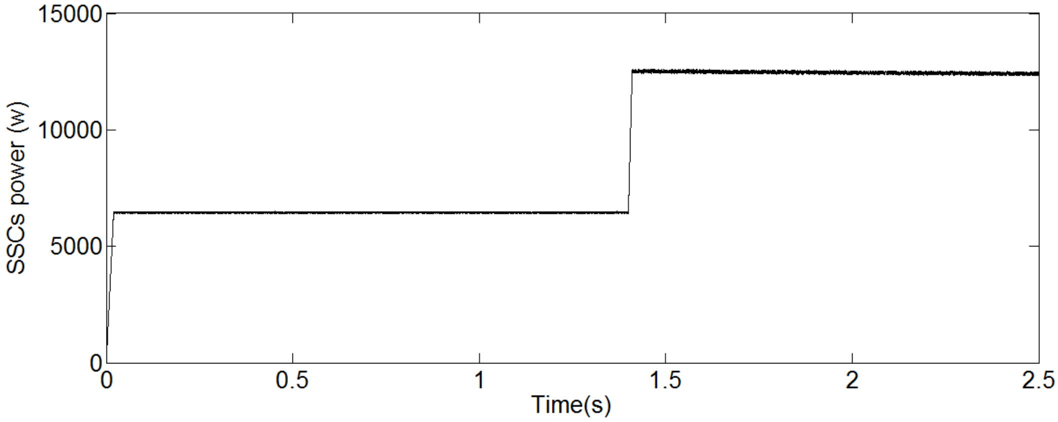


Proposed

Fig.10. SSCs power

The electricity produced by combined PV and wind sources is depicted in Fig. 10. The produced power P_{dg}, according to the current response, ranges between 7000 and 13000 watts.

Case-2: Random changes

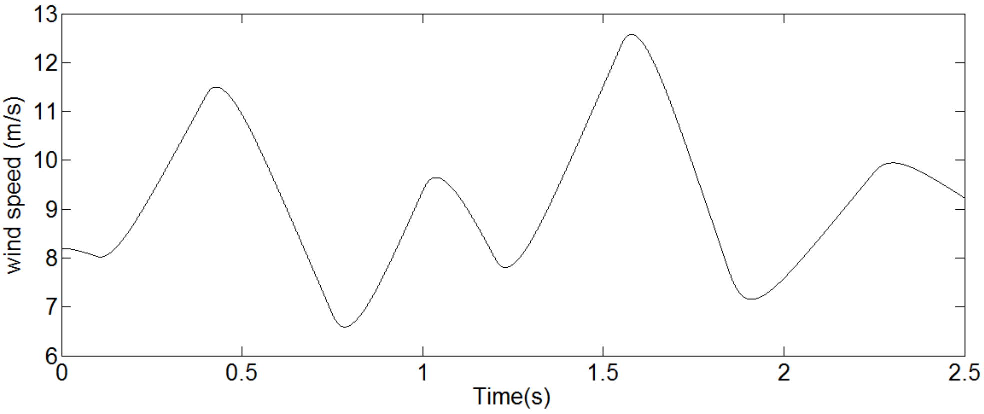
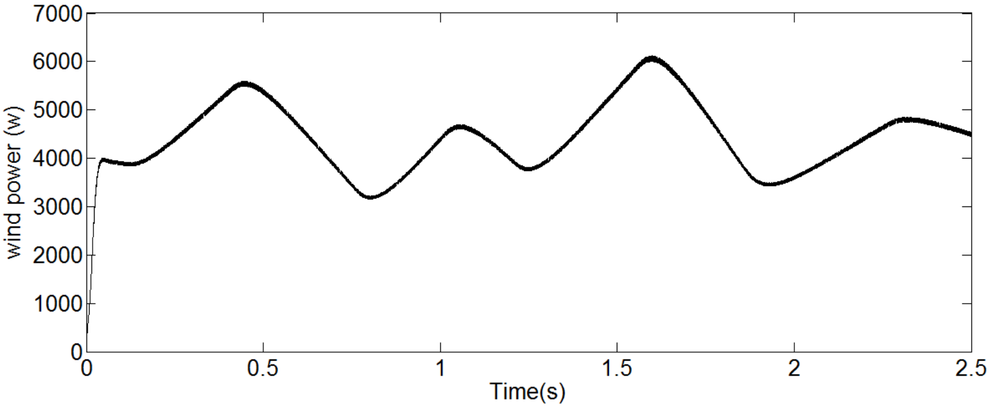


Fig.11. random wind speed

A random fluctuation of wind speed is utilized to assess the durability of the suggested energy management technique, as shown in Fig. 11. Figure 12 depicts the A variable wind pattern produces wind power. The wind system certainly works at MPPT based on the data provided.



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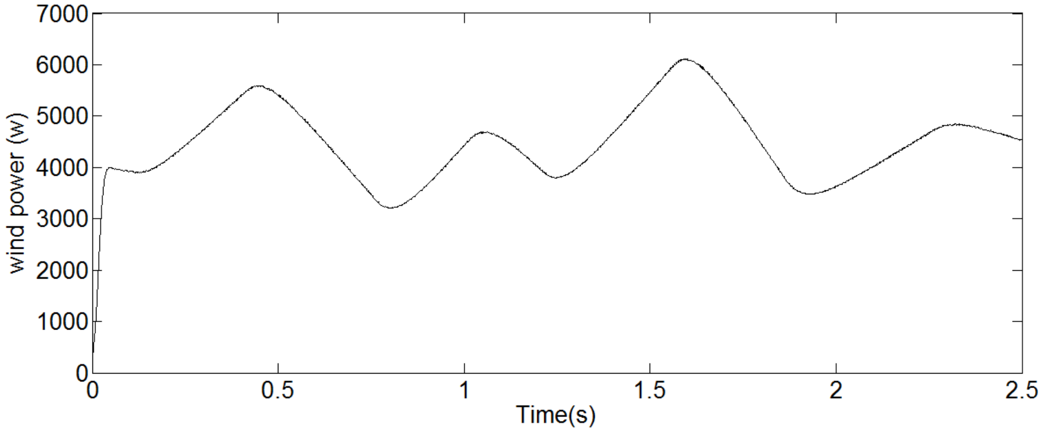
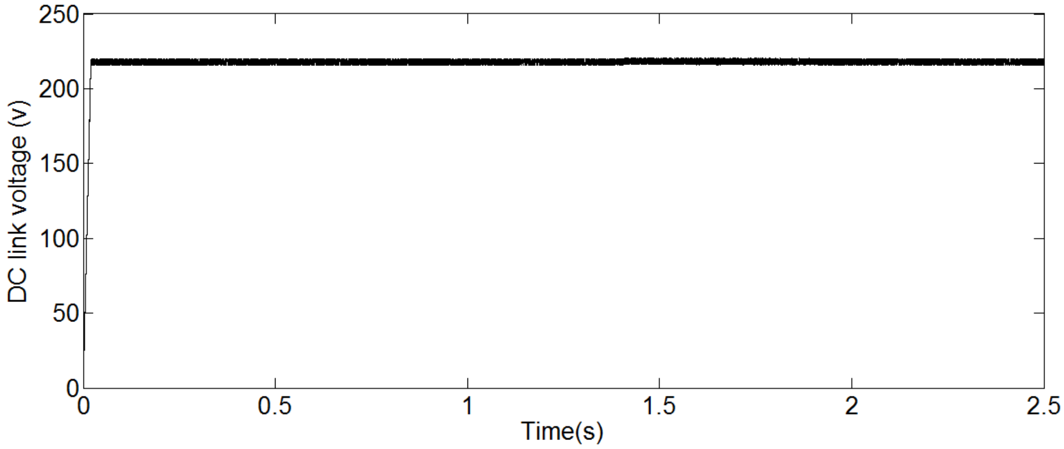


Proposed

Fig.12. wind power



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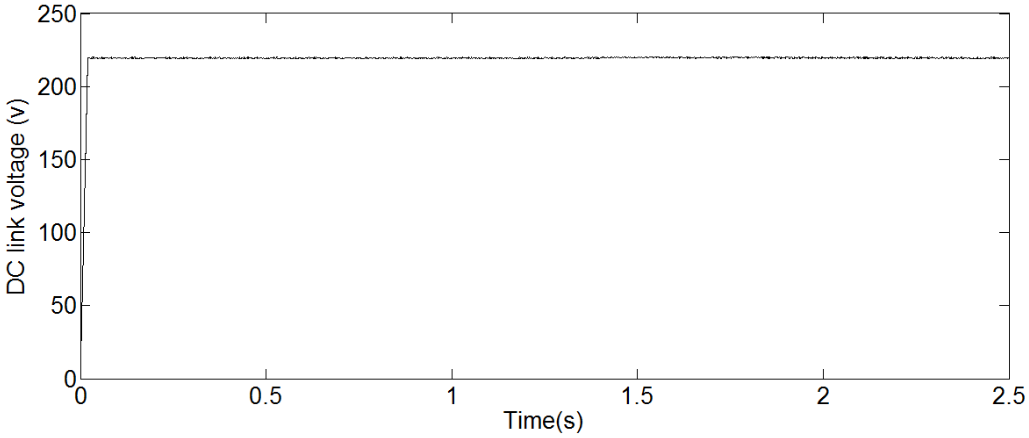

Proposed

Fig.13. DC link voltage

Figure 13 depicts the DC-link voltage response. According to the indicated result, the suggested scheme involves managing the DC voltage at its reference. As a result, even in the face of random variations, the proposed energy management method confirms the targets, assuring consistent output power and high availability.

4. CONCLUSION

This paper provides a one-of-a-kind intelligent FO-PID controller for HES attached to a smart grid via a DC-link voltage's energy efficiency. Among the HES included into the DC-microgrid are a battery bank, wind energy, and a photovoltaic (PV) energy source. The innovative intelligent fractional order PID technique is utilised to manage the source side converters (SCCs) in order to increase power collection from RES(wind and PV) and improve the voltage profile given to the DC-microgrid. Wind and PV energy sources are preferred to reduce the cost of the microgrid as much as feasible. The suggested method changes that the output power is consistent and that the service is available at all times. The proposed control technique simulation results in simulation results is demonstrated and contrasted with other dynamic systems.

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