Industrial Engineering Journal

ISSN: 0970-2555

Volume : 54, Issue 01, January : 2025

Energy Management With ANFIS Controller For Non-Integer Control In A Smart DC-Microgrid

V.B.Shalini, Assistant professor, Department of Electrical and Electronics Engineering, JNTUH College of Engineering, Jagtial, Telangana-505501, India : shalini815@yahoo.com

Kalvakota Vamshidhar, M. Tech Student, Department of Electrical and Electronics Engineering,JNTUH College of Engineering, Jagtial;Telangana-505501, India : kalvakotavamshidhar@gmail.com

ABSTRACT

An intelligent energy management controller is introduced to enhance the power quality supplied by the DC Micro grid. This controller integrates Adaptive Neuro-Fuzzy Inference System (ANFIS) and fractional-order proportional-integral-derivative (FO-PID) method. The hybrid energy sources within the DC-micro grid include a battery bank, wind energy, and photovoltaic (PV) energy source. The source-side converters (SSC) are regulated by the intelligent fractional-order PID strategy, leveraging ANFIS, to maximize power extraction from the renewable energy sources (wind and PV) and enhance the power quality delivered to the DC-micro grid. Prioritizing cost-effectiveness, the (wind and PV) energy sources are given precedence. This controller ensures a seamless output power and uninterrupted service.

Key words: solar power generation, wind energy, ANFIS controller, Hybrid energy system, FO-PID, PID, PV power generation, SSC(Source Side Converters), DC micro grid.

I INTRODUCTION

The production of electrical energy in the world generates various types of pollution. Thermal power plants (coal, oil) are responsible for atmospheric emissions linked to the combustion of fossil fuels. On the other hand, nuclear power plants, whose development incensed following the oil crisis, have not had a negative impact on air quality. On the other hand, they produce radioactive waste which causes major problems in terms of storage, processing, and transport. Today, the fear of using only one energy source with all its risks, and the opening of the electricity production are all factors that give renewable energies (hydraulic, wind, solar, biomass, etc.) an important place in electricity production .

The demand for energy by consumers is generally not evenly distributed over time and problems of the phasing of energy produced versus energy consumed arise. The stability of the grid depends on the balance between production and consumption. The increase in the penetration rate of renewable energies will therefore be conditioned by their participation in these different services, which will be favored by the clean energy sources, of electrical energy storage systems . Storage is therefore the key to the penetration of these energies in the electricity grid. Not only does it provide a technical solution for the grid operator to ensure a real-time balance of production and consumption, but it also enables the best possible use of renewable resources by avoiding load shedding in the event of overproduction. Combined with local renewable generation, decentralized storage would also have the advantage of improving the robustness of the electricity network by allowing is landing of the area supplied by this resource. Also, a well-placed energy storage system (ESS) increases the quality of the power supplied by providing better control of frequency and voltage and reduces the impact of its variability by adding value to the current supplied, especially if the electricity is delivered during peak periods .

The integration of renewable energies together with the energy storage system in a standalone micro grid is an emerging research area. Generally, it is preferred to integrate different renewable energies such as tidal, wind, and PV to yields a positive impact on the maximum capacity of the energy storage system. Usually, ESS is constituted by a combination of a battery and super capacitors, which helps extend battery life-time and offers a fast system response to compensate the transients . However, loads are necessary when all (energy sources and battery storage systems (BSS) are connected; thus, the AC grid is used instead of super capacitors . A micro grid is classified into DC, AC, or a combination of both types. Compared with AC micro grid, DC micro grid shows several benefits such as fewer parameters to control, facilitate integration, and simple structure. On the other hand, AC type needs more information like the synchronization of the frequency and reactive power, which makes the control design process a challenging task. Moreover, a DC micro grid offers the possibility to work in different modes like AC micro grid, standalone, or integrated with the AC micro grid [9,10].

Due to the latest development in power, the autonomous DC micro grid 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. Research works on the energy management control dedicated to AC micro grids can be found in the given important differences between the AC and DC micro grid dynamics, these control strategies cannot be adopted for DC micro grids. In fact, in the standard design of the DC micro grid, the load converters and the energy sources are paralleled 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 micro grid [11,12]. Several control strategies have appeared in the literature to address the issues of the DC-link voltage. In [13], a review of the recent trends and development in hybrid micro grid topology with energy resource planning and control is presented. In [14], a combined fuzzy controller and voltage control are proposed to regulate the DC voltage. In [15], a fuzzy logic control strategy with reduced rules is investigated.

The main objective is controlling the source-side converters (SSC) 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).

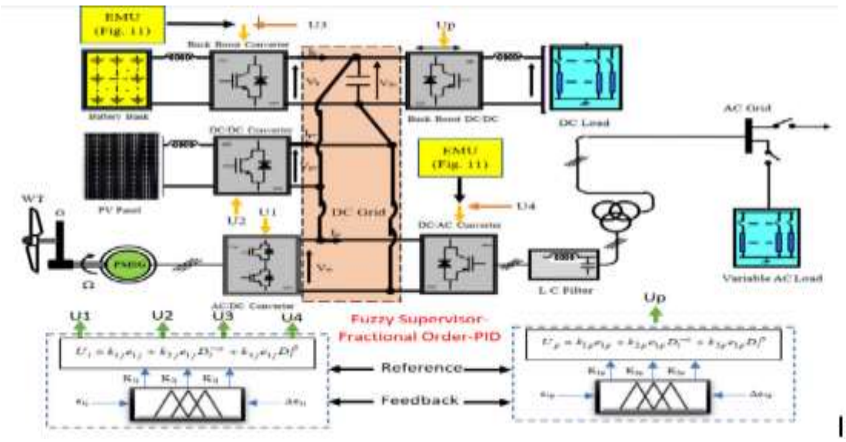


Fig.1 Proposed controller Structure

II LITERATUR REVIEW

A. Kadri, H. Marzougui, A. Aouiti, and F. Bacha, This paper deals with a modeling and control of a hybrid power system based on fuel cell and wind turbine (WT) system based a Doubly Fed Induction Generator (DFIG). To improve the performance of the hybrid energy system, a super-capacitor storage system is associated with a fuel cell which is not able to compensate the fast variation of the load power demand. In this case, rule based energy management algorithm should be applied to share energy between three source elements in order to satisfy load power demand. The main originality of this work lies in the new topology of the WT-DFIG/Full cell/super capacitor hybrid power system which presents an easier accessibility of DC and AC grid.

For the wind energy conversion system, the proposed control is the Maximum Power Point Tracking algorithm based a torque control loop (TCL).

T. Salameh, M. A. Abdelkareem, A. G. Olabi, E. T. Sayed, M. Al-Chaderchi, and H. Rezk, , 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 super capacitor 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.

M. Çolak and Ä. Kaya, Energy storage technologies (EST) enable to scope with the energy sources by storing excess energy to use when it is needed. Therefore, evaluation of energy storage alternatives (or technologies) is completely critical and can be exactly considered as a muti-criteria decision making (MCDM) problem. It is clear that we have to evaluate this problem in terms of both qualitative and quantitative criteria. We should also take into account decision makers' linguistic evaluations and their experiences. At this point, the fuzzy set theory (FST) that is an effective tool to utilize from human judgments and linguistic evaluations in the decision making process can be successfully used. Hesitant fuzzy sets (HFSs) that enable to have several membership values between 0 and 1 for an element of the set can be used for this aim as an extension of ordinary fuzzy sets. In this paper, an integrated MCDM model consists of Analytic Hierarchy Process (AHP)

T. Ma, H.Yang, and L. Lu,`, A hybrid energy storage system (HESS), which combines battery for long-term energy management and super capacitor for fast dynamic power regulation, is proposed for remote area renewable energy power supply systems. The operation of a passive connected HESS was examined via both theoretical analysis and numerical simulation using Matlab/Simulink. An electric inductor was further introduced to improve the performance of the HESS. An experimental test bench was developed to validate the simulation results. It was demonstrated that the HESS can stabilize energy provision, not only for the intermittent renewable energy (RE), but also for fluctuating load applications.

X. Wang, D. Yu, S. Le Blond, Z. Zhao, and P. Wilson, Electrical energy storage is an attractive technology for complementing domestic scale Combined Heat and Power (CHP) because when CHP is dispatched to meet the heating load, the storage can reconcile any mismatch between the electrical load and CHP generation. Hybridization of electrical storage technologies reduces the compromise between power and energy density and extends storage system lifetime but necessitates a more complex control scheme. This paper proposes a novel control scheme for a domestic battery-super capacitor hybrid energy storage system (HESS) for use with micro-combined heat and power (micro-CHP) generation.

III PROPOSED SYSTEM

The proposed system describes the 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 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.

By controlling reactive power and DC-link voltage, the proposed IFO-PID seeks to optimize electricity from renewable sources and enhance power quality in the DC-microgrid.

Industrial Engineering Journal

ISSN: 0970-2555

Volume : 54, Issue 01, January : 2025

The combined hybrid energy system integrated smart DC-micro grid is illustrated by Fig. 2, where the hybrid energy sources constituted by the wind energy, solar energy, and the BSS connected to the DC-link through their respective converters. The other 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.

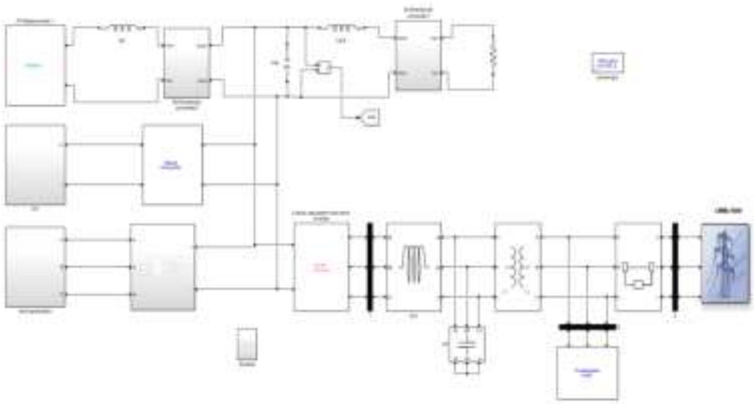


Fig.2 Simulink Model of Hybrid Wind/PV/Battery Energy Management-Based Intelligent Non-Integer Control for Smart DC-Microgrid of Smart University

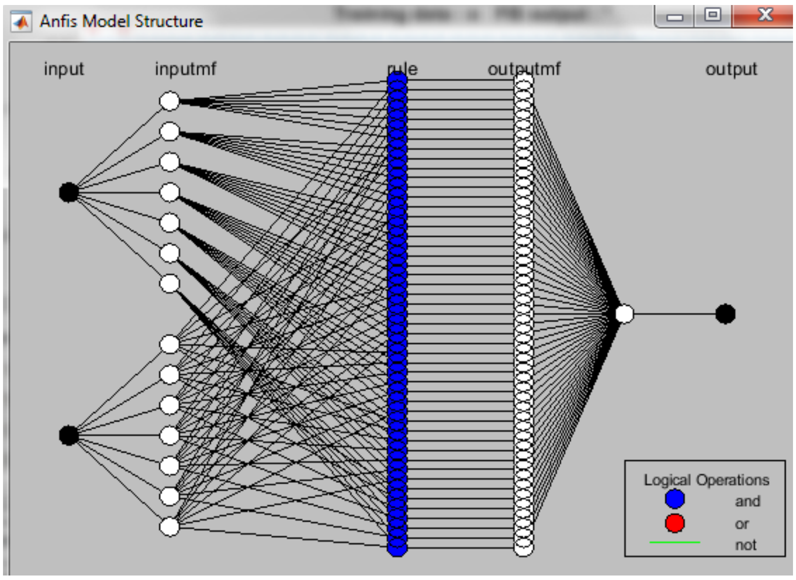


Fig.3 Anfis Model Structure

ENERGY MANAGEMENT UNIT (EMU)

The energy management unit aim is to coordinate and control all the operations in the micro grid system. The energy management unit described by the MPPT Mode off MPPT mode algorithm is used to generate the references of the SSC and load-side converters controller

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 01, January : 2025

law. The energy management unit generates the references based on the measured input power available and the consumed for both the SSC and LSC. The renewable sources are prioritized as mentioned previously on the loads.

The BSS works in charge/discharge mode and regulates the DC-link voltage at its reference value. The power in the micro grid is balanced under different power generation forms oh the renewable sources and the load demand condition. When the source-side converters generate abundant power, the supply power is used to charge the battery storage system. In case the power generated by the source-side converters is not enough, the power in the AC grid is used to supply the loads. The mathematical model of the power balance is given as

$$P_w + P_{pv} + P_g = P_{Load} + P_{Battery} \quad \text{-------------------(1)}$$

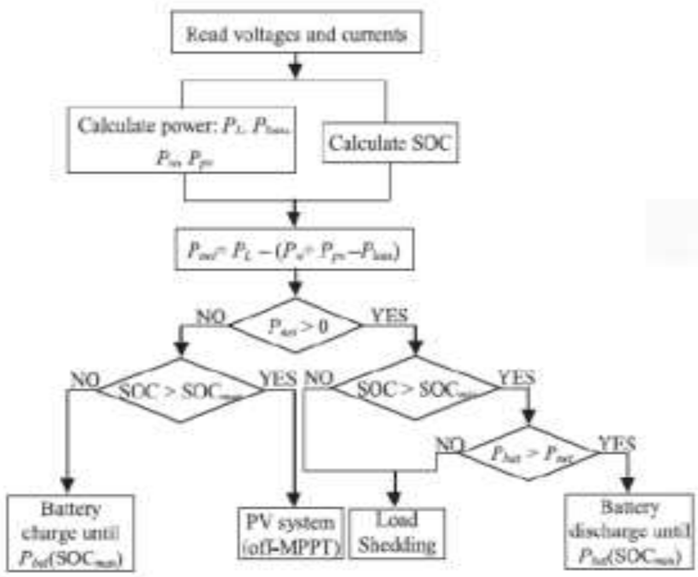


Fig 4 Energy management system

According to fig 4, four modes of the energy management unit can be distinguished and each mode depends on two conditions: the battery state and the generated power. When the generated power from the renewable energies is more than the load demand, the additional power is transferred to charge the battery to its SOC max, at this limit the MPPT is switched to off-mode. In case the generated power cannot meet the load demand, the required power is supplied by the battery storage system until SOC min, and in case the power generated by the source-side converters is not enough, the power in AC grid is used to supply the loads. Thus, the generalized energy management controller structure is illustrated in Fig 2.

Industrial Engineering Journal

ISSN: 0970-2555

Volume : 54, Issue 01, January : 2025

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

Fig 5 Results comparison of the proposed strategy with that of FO-PID and PID

IV RESULTS & ANALYSIS

Case1:

In this particular case, a step signal has been utilized as the input parameter, representing the wind speed for the simulation. Within this simulation scenario, various parameters are observed, including the DC link voltage, State of Charge (SOC), PV power, wind power, battery State of Charge, Source Side Converters (SSCs) power, and Load Side power. The step signal serves as a dynamic representation of the wind speed, allowing for the comprehensive analysis of these key factors within the system. This approach enables a thorough understanding of the system's response and performance under varying wind conditions.

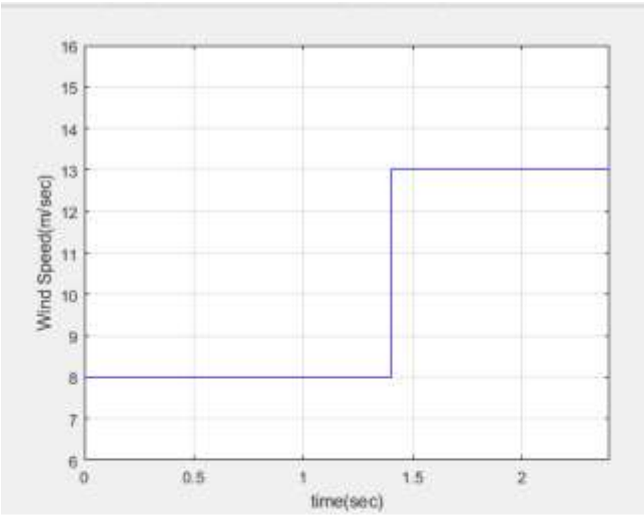


Fig. 6 Constant Wind Speed

The wind speed over time. In this particular scenario, a step signal has been employed as the input to represent the wind speed in meters per second. The initial value of the step signal is set at 8 m/s, with a step time of 1.4 seconds and a final value of 13 m/s. Notably, during the time interval from 0 to 1.4 seconds, the wind speed remains constant at 8 m/s. Subsequently, there is a discernible increase in wind speed from 8 m/s to 13 m/s precisely at the 1.4-second mark.

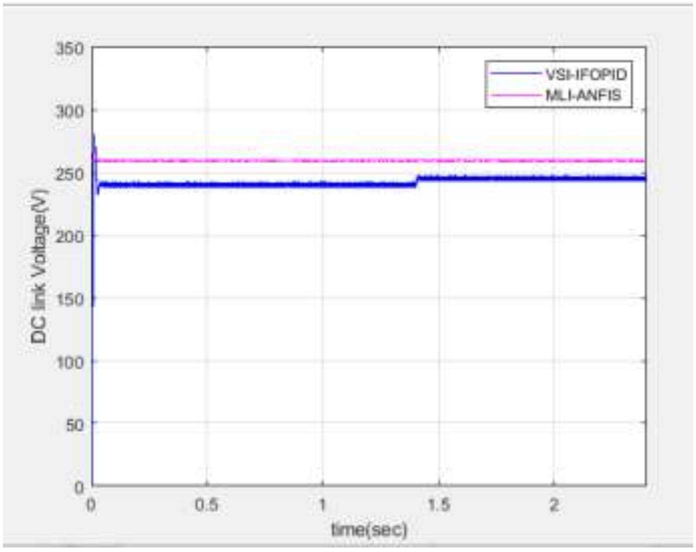


Fig.7 DC Link voltage of both SSCs and LSCs

Graph illustrates the DC link voltage over time, where the blue line corresponds to the DC link voltage obtained using the VSI-IFOPID, and the pink line represents the DC link voltage employing the ANFIS controller. Notably, in both cases, the DC link voltage remains constant from 0 to 1.4 seconds. Beyond this initial period, variations and fluctuations become apparent, attributed to harmonics in the DC link. Interestingly, the PID controller demonstrates inefficiency in handling these fluctuations. In contrast, the implementation of the Advanced ANFIS controller maintains a constant DC line voltage with minimized harmonics compared to the IFOPID controller. Following a sustained wind blow, there is a discernible increase in wind voltage, corresponding to an escalation in wind speed from 8 m/s to 13 m/s.

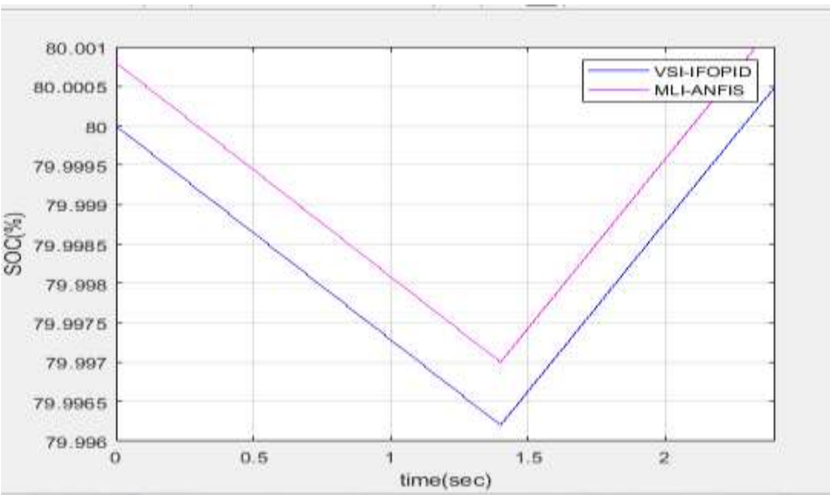


Fig.8 State of charge percentage

Illustrates the Battery State of Charge (SOC), denoting the battery's charging level in percentage. The blue line signifies the utilization of the VSI-IFOPID controller, while the pink line represents the advanced ANFIS controller. Notably, the battery discharges from 0 to 1.4 units of time, followed by a charging phase. During discharging, the battery supplies power to the load, and during charging, it receives power from the supply. It is

Industrial Engineering Journal

ISSN: 0970-2555

Volume : 54, Issue 01, January : 2025

noteworthy that, in comparison to the IFOPID controller, the ANFIS controller operates more efficiently in managing the battery's state of charge.

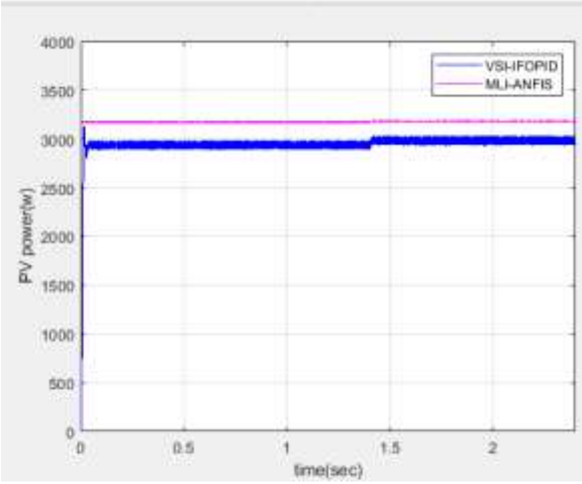


Fig.9 PV power

Illustrates PV power generation, wherein solar power remains constant from 0 to 1.4 seconds due to the utilization of a step signal representing a consistent temperature. Subsequently, as the step signal increases, leading to a rise in temperature, the PV power generation also experiences an increase. The blue line signifies PV power with the Conventional IFOPID controller, while the pink line represents PV power with the advanced ANFIS controller. Notably, the implementation of the ANFIS controller demonstrates enhanced efficiency and lower harmonics compared to the Conventional IFOPID controller, as evident in the observed power generation trends.

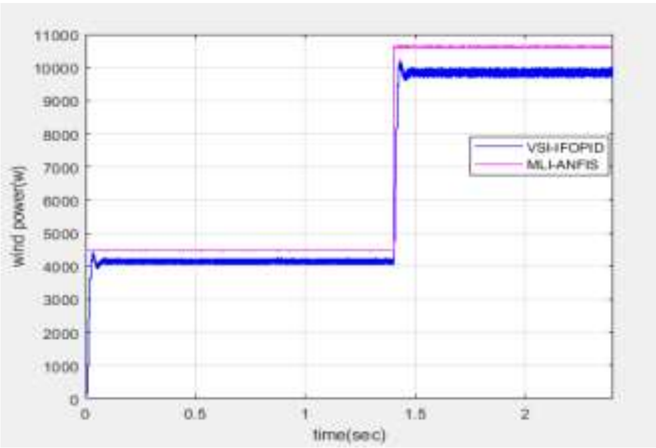


Fig.10 Wind power

Illustrates wind power generation over time. It is evident that power generation remains constant from 0 to 0.4 seconds, reflecting a consistent wind speed during this interval. Subsequently, the wind speed escalates to 13 m/s, resulting in an increase in wind turbine rotation speed and, consequently, a rise in wind power generation. Notably, the blue line represents wind power with the Conventional Controller, characterized by higher harmonics and lower power quality. In contrast, the pink line signifies wind power with the advanced ANFIS controller, exhibiting lower harmonics and efficient performance, thus enhancing power quality.

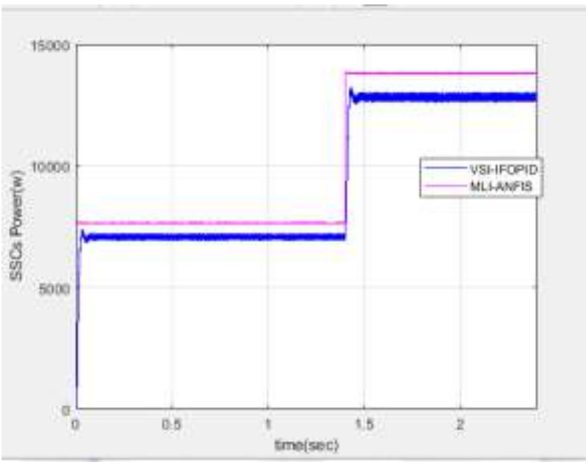


Fig.11 Source side converters power

Represents the power generated by the Source Side Converter (SSC). Positioned at the source side, the converter initially delivers a constant power output. Subsequently, as power generation increases, the converter accommodates the higher power demand. Notably, the pink line depicts the power with the implementation of the advanced ANFIS controller, while the blue line represents power with the IFOPID controller. It is evident that employing the ANFIS controller results in higher power generation, increased efficiency, and minimized losses, as observed in the depicted trends.

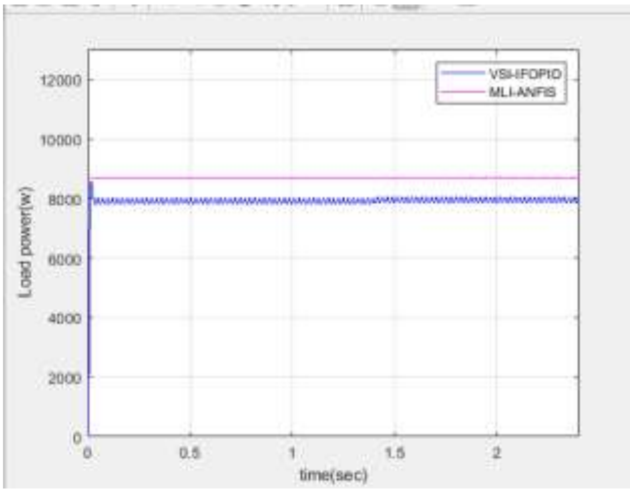
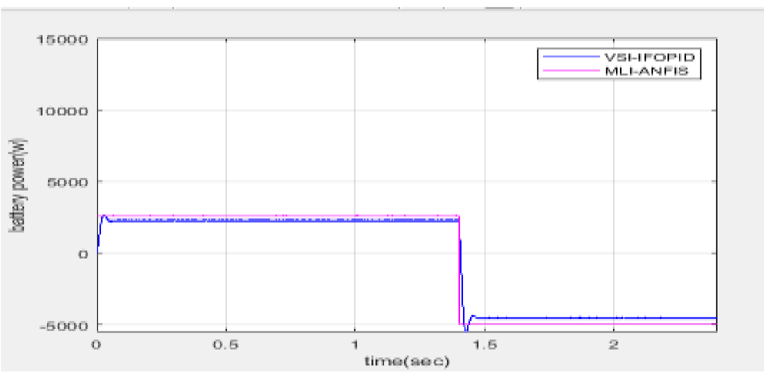


Fig.12 Load power



Industrial Engineering Journal

ISSN: 0970-2555

Volume : 54, Issue 01, January : 2025

Fig.13 Battery power

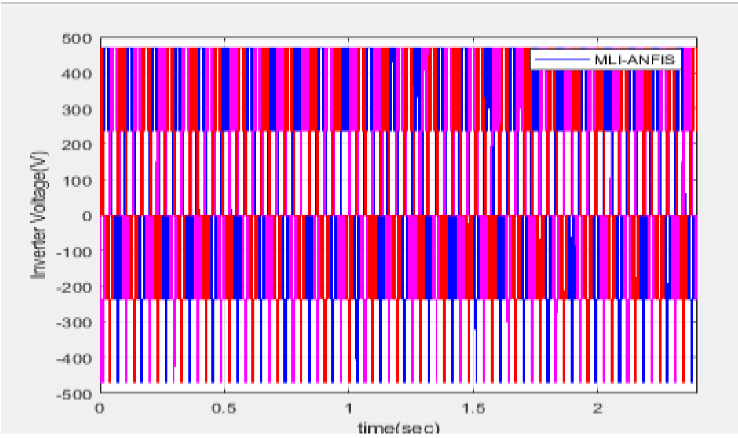


Fig.14 Inverter voltage under constant wind speed

Case2:

In Case 2, where wind exhibits temporal variations, we investigate parameters such as DC link voltage, State of Charge (SOC), PV power, wind power, battery State of Charge, Source Side Converters (SSCs) power, and Load Side power. Through the utilization of both the Advanced ANFIS controller and the IFOPID controller, we undertake a comparative analysis to observe and analyze the outcomes of these parameters. This comparison allows us to discern and assess the performance disparities between the Advanced ANFIS and IFOPID controllers under the dynamic conditions of varying wind speed.

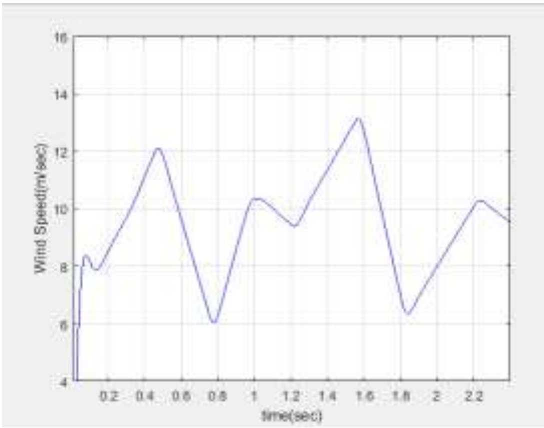


Fig.15 Wind speed under random variations

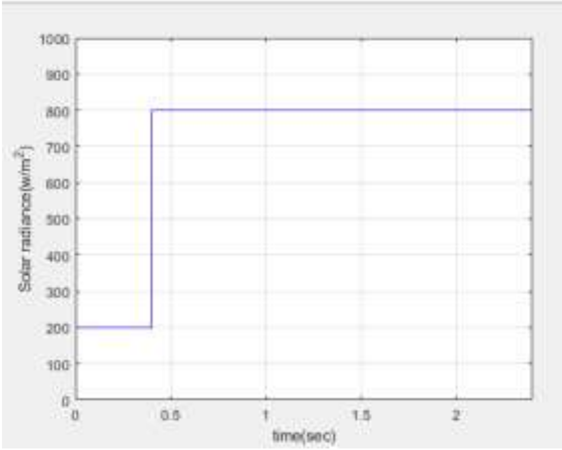


Fig.16 Solar Irradiance

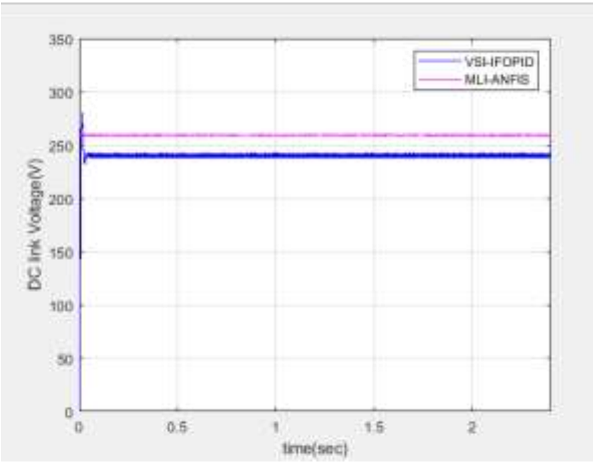


Fig.17 DC Link Voltage Under Random variations

The graph illustrates the DC link voltage over time, with the blue line representing the VSI-IFOPID and the pink line symbolizing the ANFIS controller. Significantly, the DC link voltage remains constant during varying wind speeds. It is noteworthy that during these wind speed fluctuations, the ANFIS controller demonstrates efficient performance, ensuring a consistently maintained DC link voltage. The contrast in controller effectiveness is apparent, as the PID controller exhibits inefficiency in managing the fluctuations. The Advanced ANFIS controller not only maintains a steady DC line voltage but also minimizes harmonics, showcasing its superior performance compared to the IFOPID controller, particularly in dynamic scenarios such as varying wind speeds.

Industrial Engineering Journal
ISSN: 0970-2555
Volume : 54, Issue 01, January : 2025

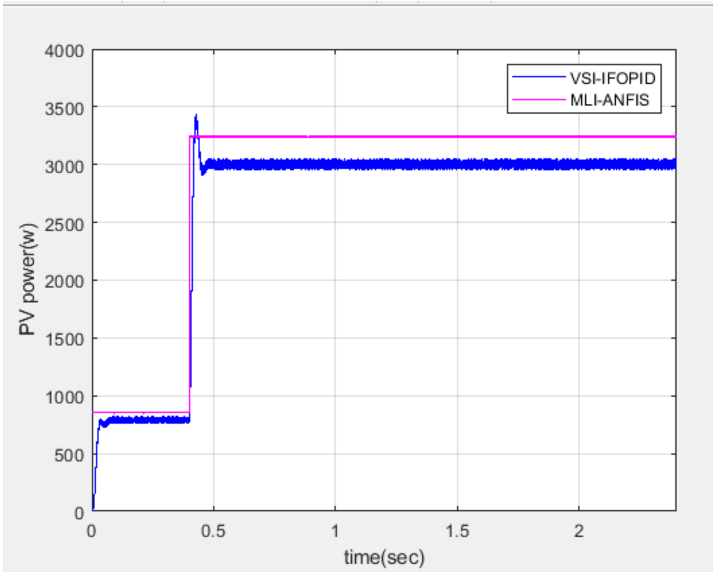


Fig.18 Solar Power under random solar radiance

Illustrates PV power generation, wherein solar power remains constant from 0 to 1.4 seconds due to the utilization of a step signal representing a consistent temperature. Subsequently, as the step signal increases, leading to a rise in temperature, the PV power generation also experiences an increase. The blue line signifies PV power with the Conventional IFOPID controller, while the pink line represents PV power with the advanced ANFIS controller. Notably, the implementation of the ANFIS controller demonstrates enhanced efficiency and lower harmonics compared to the Conventional IFOPID controller, as evident in the observed power generation trends.

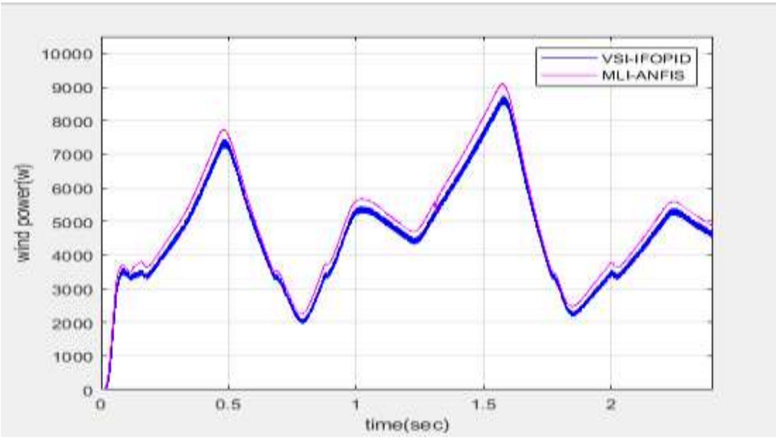


Fig.19 Wind power under random wind speed

The graph, illustrating the variation of wind speed over time, features the blue line representing the conventional PID controller and the pink line symbolizing the ANFIS controller. Clearly depicting dynamic changes in wind speed, the graph offers insights into its temporal variability during the observed period. Notably,these wind speed fluctuations, the ANFIS controller efficiently maintains a constant DC link voltage, as evident in the corresponding graph for DC link voltage. This underscores the effectiveness of the advanced controller in handling varying conditions. In contrast, the conventional PID controller, represented by the blue line, reveals inefficiency in managing the same fluctuations, experiencing losses. In summary, the pink line, denoting the ANFIS controller, not only showcases efficiency but also minimizes losses, emphasizing its superiority over the conventional PID controller in dynamic scenarios such as varying wind speeds.

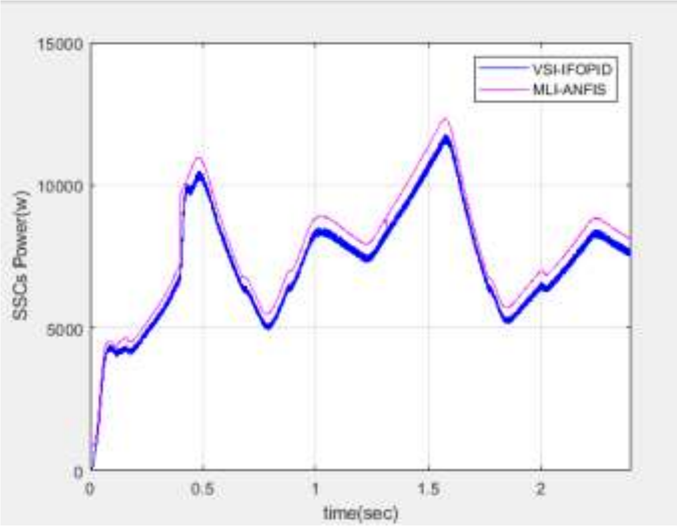


Fig.20 SSCs power under random variations

The variations in the power output of Source Side Converters (SSCs) are evident as we observe the impact of fluctuating wind speeds. The power generated by the converter is contingent on the varying wind speeds. Utilizing the Advanced ANFIS controller, the power curve of the SSCs closely mirrors the pattern of wind speed changes. In the representation, the pink line corresponds to the ANFIS controller, while the blue line indicates the Conventional IFOPID controller. Comparing the performance of the two controllers, the ANFIS controller, as depicted by the pink line, out performs the Conventional IFOPID controller. The ANFIS controller exhibits a better alignment between the SSCs' power curve and the variations in wind speed, showcasing its enhanced performance compared to the conventional counterpart.

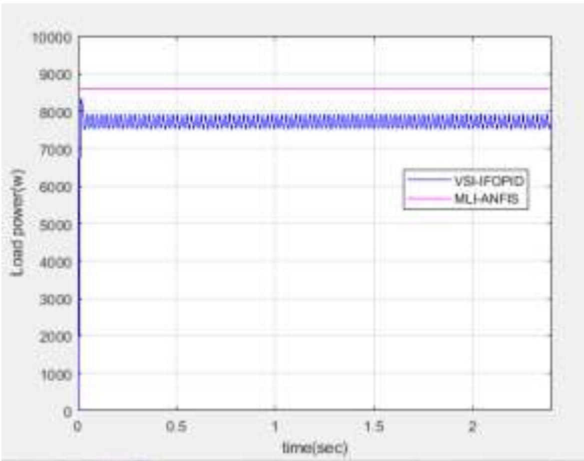


Fig.21 Load power under random variations

At varying wind speeds, a consistent load power is observed, emphasizing the stability of power generation across different conditions. The use of the Advanced ANFIS controller, depicted by the pink line, ensures constant power output with minimal harmonics. In contrast, the Conventional IFOPID controller, represented by the blue line, exhibits higher harmonic levels compared to the ANFIS controller. The observed constant load power and reduced harmonics with the ANFIS controller signify its superior performance in maintaining stable and high-quality power output, underscoring its advantages over the Conventional IFOPID controller in this context.

Industrial Engineering Journal

ISSN: 0970-2555

Volume : 54, Issue 01, January : 2025

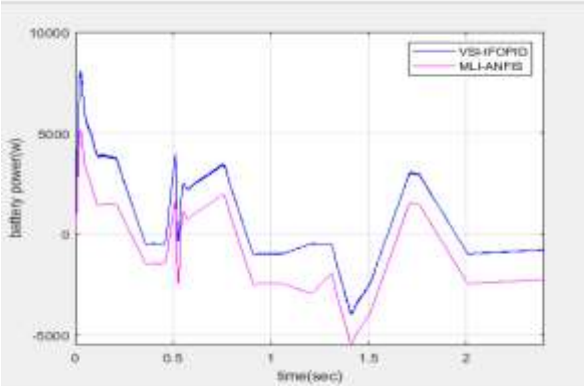


Fig.22 BSS power under random variations

The battery power is influenced by the source side, and in scenarios where the battery is discharging to provide a continuous supply to the load, the ANFIS controller, represented by the pink line, and the IFOPID controller, indicated by the blue line, play crucial roles. These controllers contribute to managing and optimizing the discharge process, ensuring a steady and uninterrupted power supply to the load. The visual representation of the pink and blue lines serves to distinguish the respective performances of the ANFIS and IFOPID controllers in regulating battery power during discharge cycles**.**

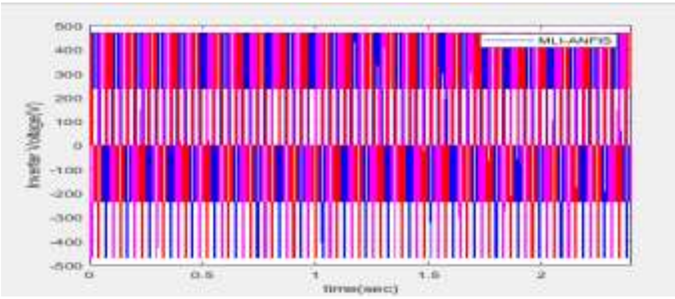


Fig.23 Inverter voltage under random variations

V CONCLUSION

This Project introduced a pioneering intelligent fractional-order PID controller for the energy management of hybrid energy sources within a smart grid connected via a DC-link voltage. The hybrid energy sources encompass a battery bank, wind energy, and photovoltaic (PV) energy, forming a crucial part of the DC-micro grid. Our proposed intelligent fractional-order PID strategy is employed to regulate the source-side converters (SCC), aiming to extract maximum power from renewable energy sources (wind and PV) while enhancing the power quality supplied to the DC-micro grid. An emphasis on cost-effectiveness is maintained by prioritizing the utilization of wind and PV energy sources. The proposed controller ensures seamless output power and uninterrupted service continuity. Simulation results, conducted using Matlab/Simulink, have been presented and compared with other nonlinear controls, including super twisting fractional order control, FO-PID, and PID. A comprehensive comparative analysis in Fig.5, reveals the superiority of our proposed strategy, demonstrating higher power generation and superior performance compared to the alternative control strategies. Specifically, the proposed controller yields a 3.15% increase in wind power, 50% increase in PV power, and 2.5% increase in load power compared to super twisting fractional-order control, with even greater advantages over the PID control.

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. 4943649450, 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. 11061109, 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, doi: 10.1002/2050-7038.12694.

[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. 160173, 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. 60146027, 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. 771789, 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. 372387, Jan. 2017.

[9] T. Ma, H.Yang, and L. Lu, ``Development of hybrid batterysupercapacitor energy storage for remote area renewable energy systems,'' Appl. Energy, vol. 153, pp. 5662, 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. 167174, 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 voltagefrequency regulation in distributed sustainable energybased hybrid microgrids with integrated resource planning,'' Energies, vol. 14, no. 10, p. 2735, May 2021, doi: 10.3390/en14102735.

[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. 115, Apr. 2021, doi: 10.1080/14786451.2021.1910698.

[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. 22462258, 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 prole of a residential electro-thermal microgrid,'' IEEE Access, vol. 9, pp. 2517225188, 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. 15881601, 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. 1161211624, 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. 3292532934, 2018.

[19] A.-R.-I. Mohamed, H. H. Zeineldin, M. M. A. Salama, and R. Seethapathy, ``Seamless formation and robust control of distributed generation microgrids via direct voltage control and optimized dynamic power sharing,'' IEEE Trans. Power Electron., vol. 27, no. 3, pp. 12831294, Mar. 2012.

[20] B. A. Martinez-Treviño, A. El Aroudi, E. Vidal-Idiarte, A. Cid-Pastor, and L. Martinez-Salamero, ``Sliding-mode control of a boost converter under constant power loading conditions,'' IET Power Electron., vol. 12, no. 3, pp. 521529, 2019.
[21] T. K. Roy, M. A. Mahmud, A. M. T. Oo, M. E. Haque, K. M. Muttaqi, and N. Mendis, ``Nonlinear adaptive backstepping controller design for islanded DC microgrids,'' IEEE Trans. Ind. Appl., vol. 54, no. 3, pp. 28572873, May 2018.
[22] A. Iovine, M. J. Carrizosa, G. Damm, and P. Alou, ``Nonlinear control for DC microgrids enabling efcient renewable power integration and ancillary services for AC grids,'' IEEE Trans. Power Syst., vol. 34, no. 6, pp. 51365146, Nov. 2019.
[23] X. Li, X. Zhang,W. Jiang, J.Wang, P.Wang, and X.Wu, ``A novel assorted nonlinear stabilizer for DCDC multilevel boost converter with constant power load inDCmicrogrid,'' IEEE Trans. Power Electron., vol. 35, no. 10, pp. 1118111192, Oct. 2020.
[24] J. Wu and Y. Lu, ``Adaptive backstepping sliding mode control for boost converter with constant power load,'' IEEE Access, vol. 7, pp. 5079750807, 2019.
[25] S. Tamalouzt, ``Performances of direct reactive power control technique applied to three level-inverter under random behavior of wind speed,'' Revue Roumaine Sci. Techn.-Serie Electrotechnique Energetiqu, vol. 64, no. 1, pp. 3338, 2019