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SUPER TWISTING SLIDING MODE CONTROL BASED VOLTAGE SOURCE CONVERTER FOR POWER MANAGEMENT OF HYBRID ENERGY SYSTEM

R Lakshmi[1],
[1]Associate Professor, Department of EEE, Siddharth Institute of Engineering and Technology, Puttur, Andhra Pradesh, India.

N Ramesh Raju[2],
[2]Professor & Head, Department of EEE, Siddharth Institute of Engineering and Technology, Puttur, Andhra Pradesh, India.

K. Beby[3], K. Imran Hussain[4], J. Anjali[5], T. Lokesh[6], S. Jaya Siva Prasad[7]
[3,4,5,6,7] UG Student, Department of EEE, Siddharth Institute of Engineering and Technology, Puttur, Andhra

ABSTRACT:
This paper proposes a method for controlling and coordinating energy management in hybrid microgrids, which is a complex task due to the integration of different power generation resources. To efficiently integrate renewable energy sources (RES) like solar, wind, and battery storage, multiple power converters are required. The overall performance of hybrid microgrid power system network heavily depends on the operation of these power converters. Voltage Source Converters (VSCs) play a crucial role in optimizing power flow within the microgrid by providing advanced control capabilities such as voltage regulation, reactive power control, and dynamic response to system changes, enhancing efficiency and reliability of system. In this paper, a Super Twisting Sliding Mode Control (STSMC) strategy is developed to operate single-phase VSC at the load side. The system incorporates battery support alongside solar and wind power generation to meet load demand and improve power quality. The performance of proposed STSMC-based hybrid microgrid is evaluated under two scenarios: steady load connected to variable solar and wind energies, and dynamic load connected to constant PV and wind power. This project is implemented in 2024a Matlab Simulink.

Keywords:
Energy Management Systems, Hybrid power generation, STSMC

I INTRODUCTION

The increasing integration of RES and battery storage has driven the evolution of hybrid energy systems, making them more efficient, reliable, and environmentally friendly [1, 2]. Hybrid energy systems can address the fluctuating nature of renewable sources by leveraging the complementary characteristics of different energy inputs [3-5]. Voltage Source Converters (VSCs) are vital components in these systems, responsible for managing power flow, regulating voltage, and ensuring reactive power balance. Their ability to dynamically respond to changes in energy generation and load conditions enhances system stability. However, achieving optimal control in such systems requires advanced strategies to manage the complexity of various interconnected components [6].

Artificial Neural Networks (ANNs) have been extensively utilized for the control of VSCs due to their capability to handle non-linearities and adapt to varying system dynamics. ANNs offer fast response times and improve the performance of microgrids by anticipating fluctuations in power generation and load demand. These networks are capable of learning from historical data to optimize energy distribution across the system [7, 8]. However, the primary challenges of using ANNs include high computational requirements, reliance on extensive training data,

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and susceptibility to overfitting. These limitations make it necessary to explore alternative control methods that can achieve high performance with reduced computational overhead [9-12].

Super Twisting Sliding Mode Control (STSMC) emerges as a robust alternative to traditional ANN-based control methods, offering superior performance in terms of stability, accuracy, and resilience to disturbances. STSMC belongs to the class of sliding mode control techniques, [13-16] known for their robustness against parameter variations and external disturbances. STSMC mitigates the issue of chattering while ensuring finite-time convergence. These attributes make STSMC a promising solution for the complex control demands of hybrid energy systems, where rapid adjustments to fluctuating inputs are crucial for maintaining operational stability. This paper proposes an STSMC-based approach for controlling the Voltage Source Converter in a hybrid energy system comprising RES and battery sources. The main objective is to demonstrate how STSMC outperforms ANN in terms of power management efficiency, dynamic response, and system robustness. By implementing STSMC, the system can achieve faster convergence to the desired state, minimize power fluctuations, and maintain a stable DC-link voltage under varying load and generation conditions [17-21]. The proposed method simplifies the control process while ensuring high performance, making it ideal for real-time applications in hybrid microgrids [22-24].

Simulation results comparing STSMC and ANN-based control show the advantages of proposed STSMC method [25]. The results highlight its ability to deliver superior power quality, faster transient response, and greater resilience to disturbances. Scenarios involving variable load conditions and fluctuating renewable energy inputs reveal that STSMC provides smoother power transitions, reducing the strain on the battery and other system components. The findings suggest that STSMC not only improves energy management but also enhances overall reliability and longevity of hybrid energy system. This paper establishes the superiority of STSMC over ANN for VSC control in hybrid energy systems. The integration of STSMC offers a scalable, efficient, and robust control framework that addresses challenges associated with renewable energy variability [26]. By enhancing system stability and optimizing power flow, STSMC contributes to the development of resilient and sustainable hybrid energy solutions. This research underscores a potential of STSMC as a valuable control strategy for future microgrid applications and hybrid energy system advancements.

The organization of the following paper contains: Section II provides a comprehensive system description. Section III introduces a proposed method, focusing on the implementation of STMC controller for enhanced voltage regulation. Section IV presents the simulation results along with the corresponding discussions. Finally, Section V concludes the paper with key findings and suggests avenues for future research.

II SYSTEM CONFIGURATION

The configuration of the hybrid microgrid is illustrated in Fig. 1. To optimize the performance of solar energy, the Perturb and Observe (P&O) algorithm is utilized. The wind energy generated by the permanent magnet synchronous generator (PMSG) is converted from A.C to D.C using three-phase rectifiers. Boost converters are employed to elevate the D.C voltage output from the rectifier. Additionally, bidirectional DC-DC converters (BIDC) are used to manage battery's operation in both discharging and charging modes. To supply the combined solar, wind, and battery power to the load, a voltage source converter based on the STMC is implemented.

A) Solar Energy Conversion System (SECS)

The P&O MPPT algorithm is a commonly employed method in photovoltaic (PV) systems to enhance the efficiency of solar panels by ensuring they operate at their optimal power point. MPPT algorithms are essential in maintaining the solar panel at its MPP, where output power is at its peak. The P&O algorithm adjusts operating point of solar panel by making small modifications, either to converter's duty cycle or the panel's voltage. After each adjustment, the algorithm measures the panel's power output and compares it to the previous value. If power increases, the algorithm continues in same direction to approaches MPP. Conversely, if power drops, it changes direction, indicating that it may have surpassed the MPP, and adjusts accordingly to maintain optimal performance.

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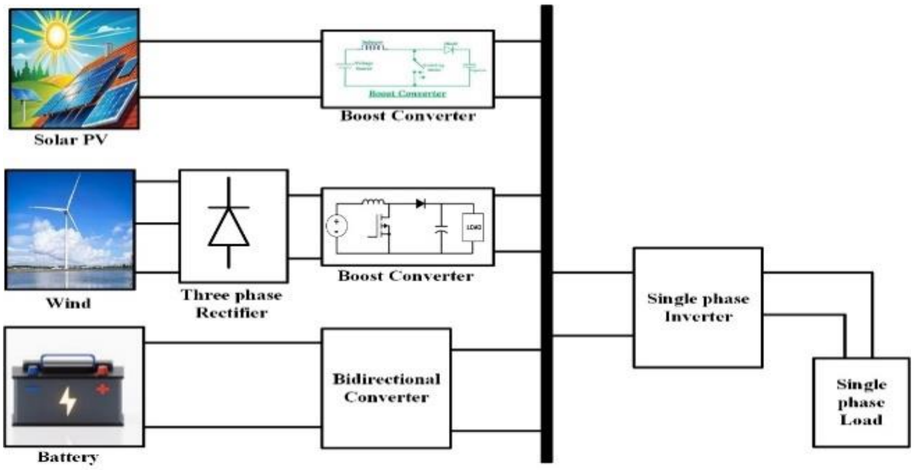

Fig.1 proposed circuit diagram of hybrid system

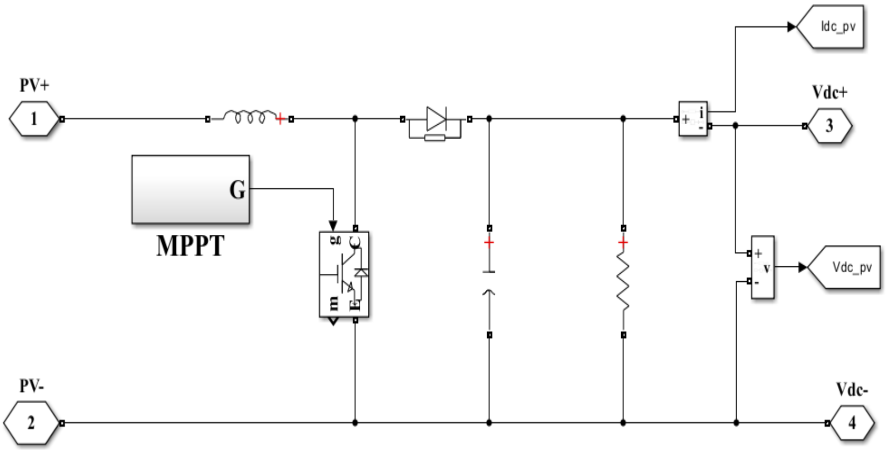

Fig.2 controlling of boost controller

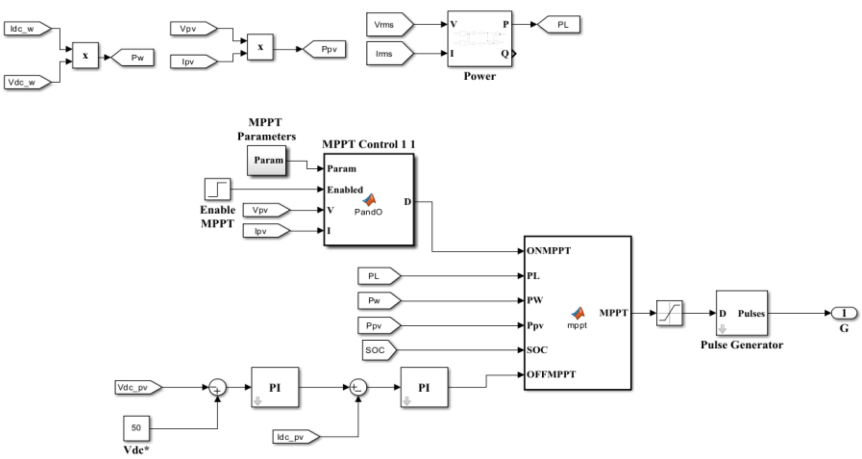

Fig.3 control topology of solar MPPT of boost converter

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This procedure is performed periodically to continuously fine-tune the operating point, ensuring that the system adapts to fluctuations in environmental conditions or load variations. The P&O algorithm is straightforward to implement and demands minimal computational resources. In most situations, it efficiently tracks the MPP, even under changing conditions. The schematic of the solar energy using the P&O MPPT is illustrated in fig. 2, while the configuration of P&O MPPT algorithm is presented in Fig. 3.

B) Wind energy conversion

The wind energy utilizing a PMSG is an adaptable and efficient solution that integrates smoothly into hybrid microgrids. Its capability for variable-speed operation, when paired with advanced control techniques and energy storage integration, significantly improves the overall efficiency, stability, and sustainability of the microgrid.

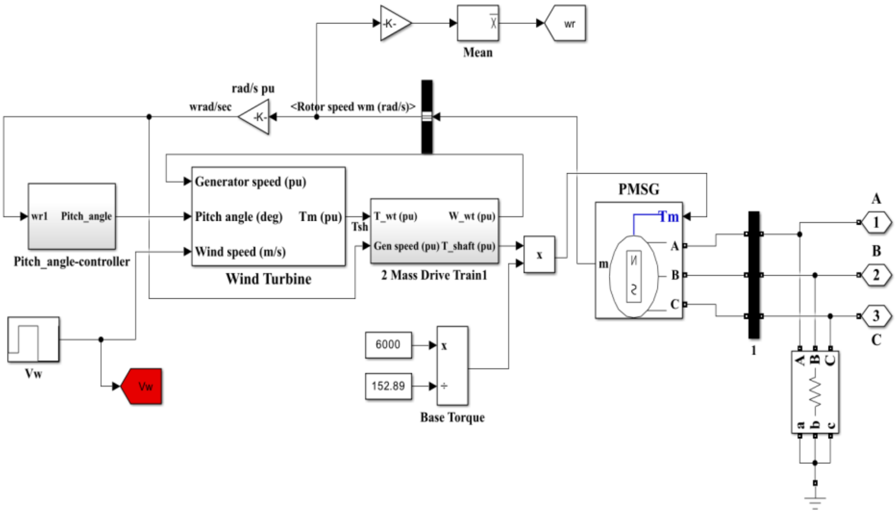

Fig.4 control topology of wind energy storage

Fig 4 presents the block diagram of PMSG-based Wind Energy. PMSGs are designed to operate effectively across a wide range of wind speeds, enabling them to adapt to fluctuating wind conditions. Their variable-speed operation offers a significant advantage by capturing more energy over a broader spectrum of wind speeds compared to fixed-speed generators. These wind turbines are typically equipped with power electronics, such as converters or inverters, to transform the variable-frequency AC output from the generator into a consistent AC output that is compatible with the microgrid. In the case of a grid failure, PMSG-based wind generation can remain operational in islanded mode, providing power to essential loads within the microgrid. This feature strengthens the microgrids resilience.

C) Battery Energy Storage (BES)

The BESS plays a crucial role in integrating solar and wind energy by enhancing flexibility, reliability, and providing essential grid support. It addresses the intermittency and variability of RES by storing and releasing energy as needed, thereby contributing to a more sustainable and resilient energy framework. During periods of high RES generation, such as unclouded or blowy days, BESS stores excess energy. This energy can then be discharged when renewable generation is low or when there is an increase in demand, effectively shifting the availability of renewable power. A PI controller is employed to manage discharging and charging processes of battery, ensuring the SOC remains within desired range for optimal performance. The PI controller continuously computes the error, which is difference between the actual SOC and reference SOC (SOC_ref), and adjusts the operation of the bidirectional converter accordingly.

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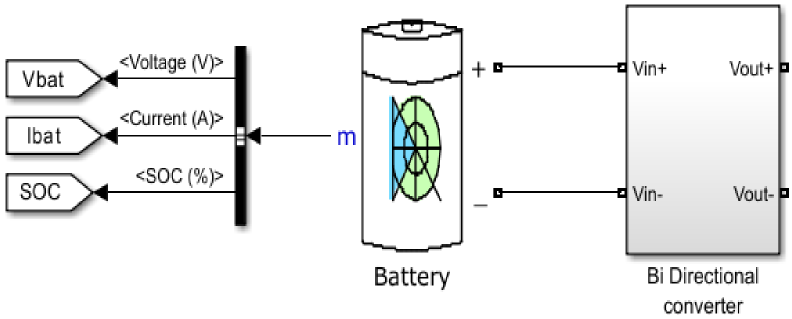

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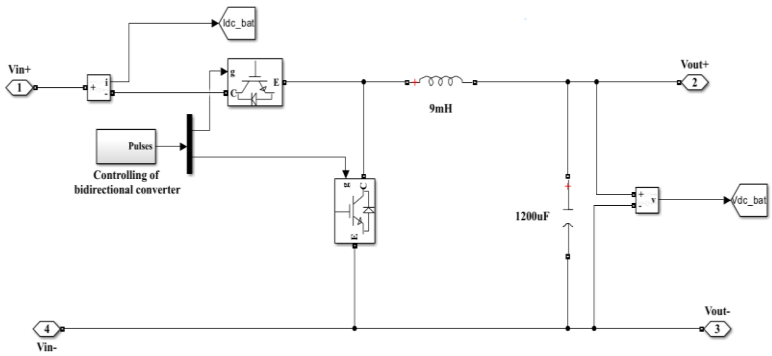

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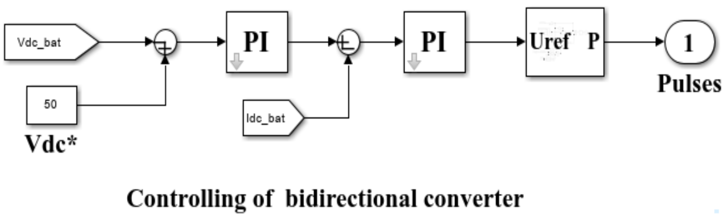

(c)

Fig.5 (a, b, c) battery storage and controlling of bidirectional converter

III PROPOSED METHOD

D) Integration of STMC for VSC

Designing a STSMC based controller for a VSC on the load circuit side of a hybrid microgrid involves addressing the specific challenges associated with managing multiple energy sources and dynamic load conditions. The STSMC controller must handle inputs such as load demand, battery state of charge, solar and wind power generation, and other relevant system parameters. The primary objective is to provide control signals for the VSC, ensuring stable voltage regulation and efficient power flow from the hybrid energy system. To integrate STSMC effectively, the controller is designed to operate under various load and generation conditions, ensuring robustness against disturbances and uncertainties. The STSMC-based controller uses a sliding mode surface to drive system state toward the desired operating point, while minimizing chattering and improving dynamic performance. The control law is derived from the system's dynamics and incorporates parameters such as the load voltage and current, as well as output power of the RES.

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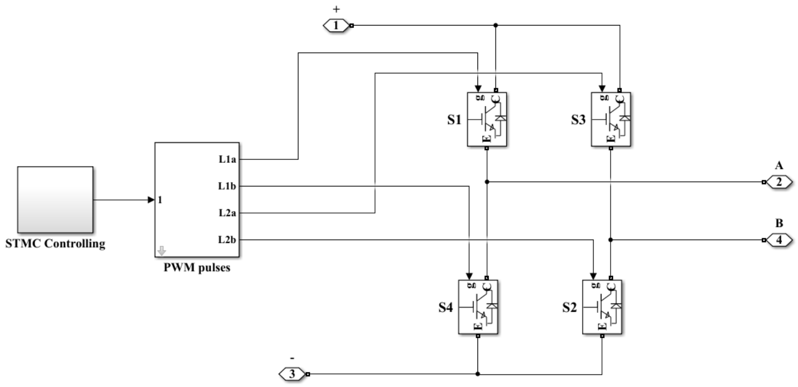
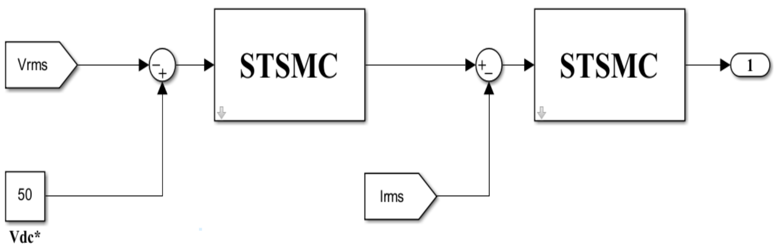
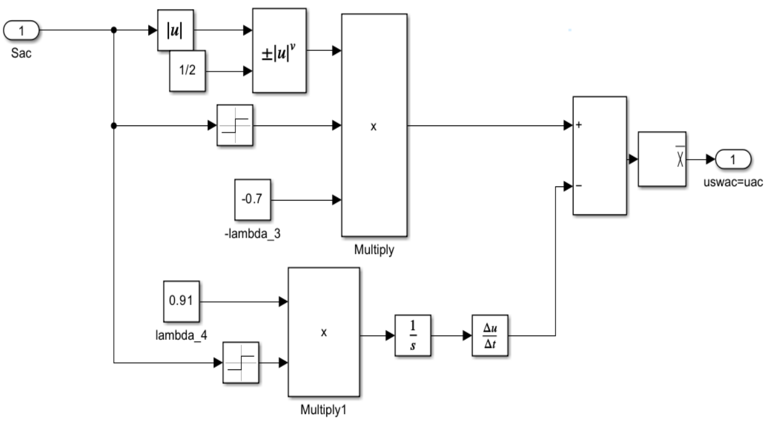
The STSMC controller continuously adjusts the switching control signal based on real-time measurements of the load demand and power generation. By defining appropriate sliding mode surfaces, the controller guarantees that the system's performance remains stable even under fluctuating renewable energy availability. The system is designed to handle both steady-state and transient conditions effectively, allowing the VSC to provide consistent power to load while maintaining system stability. The STSMC controller is implemented in the microgrids control architecture, where it interacts with the VSC to regulate power flow, manage the integration of solar, wind, and battery storage, and compensate for reactive power when needed. The controller ensures that the load receives the required power while optimizing energy management between the different power sources. Additionally, the robustness of the STSMC enables the system to adapt to changes in environmental conditions and load, maintaining operational reliability and improving overall system performance.



(a) Structure of voltage source converter



(b) Controlling of STMC



(C) Internal Structure of STMC

Fig.6 (a, b, c) shows the voltage source converter with STMC control topology

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IV RESULTS AND DISCUSSION

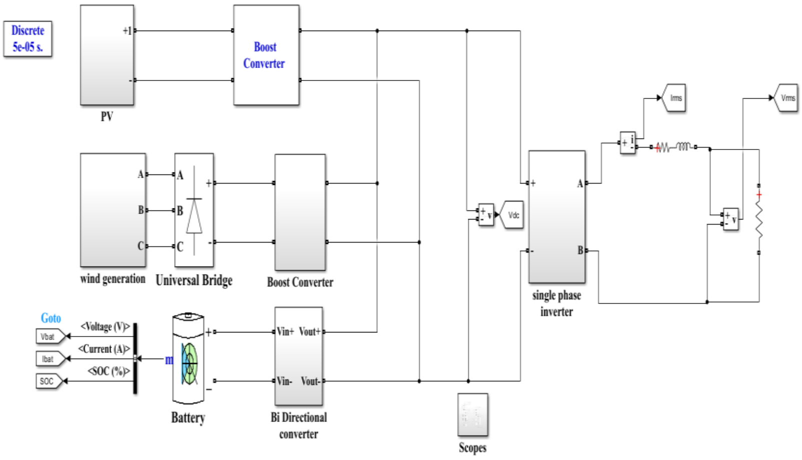
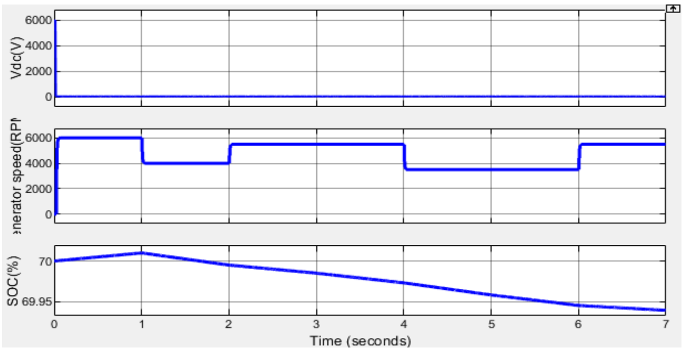


Fig.7 simulation model of proposed hybrid system

Figure 7 illustrates the integration of solar, wind, battery storage, and the VSC with an STSMC controller. It facilitates real-time control and power flow regulation, ensuring stable voltage and optimal energy distribution. The STSMC controller dynamically adjusts the system based on changing load and renewable generation conditions. Using Simulink's graphical interface, the system's performance can be easily simulated and analyzed. Two operational cases are implemented: steady-state and dynamic-state scenarios, as detailed below.

Case – 1

Performance of hybrid energy system under steady state load condition Acronyms



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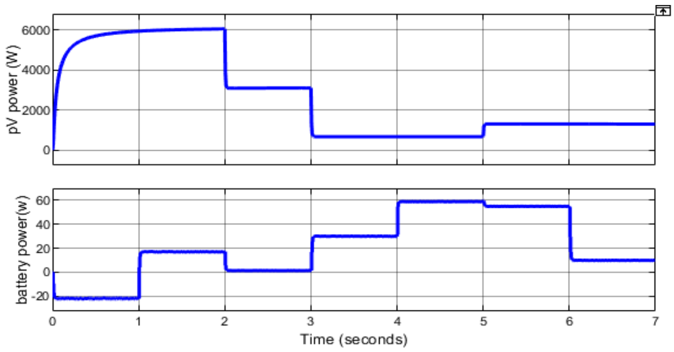

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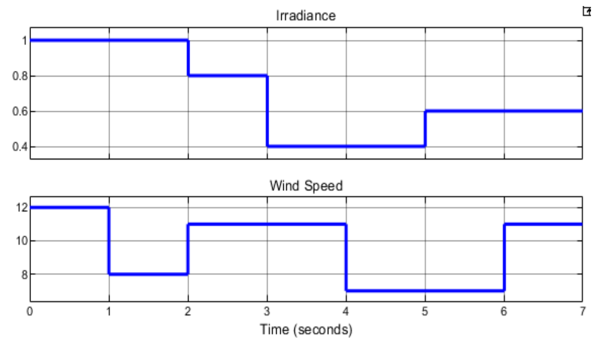

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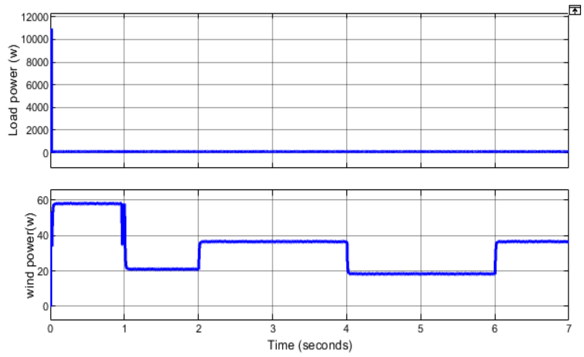

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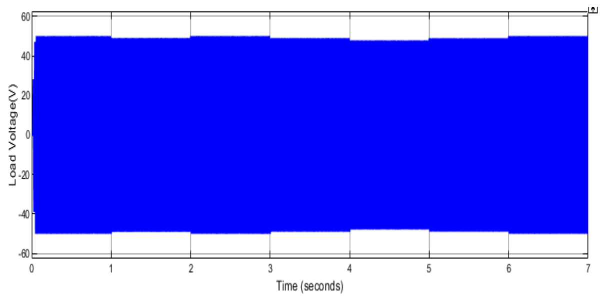

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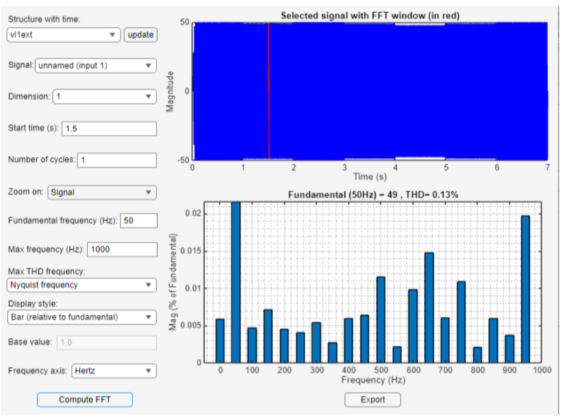

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Figure.8 (a, b, c, d, and f) shows the steady state outcomes

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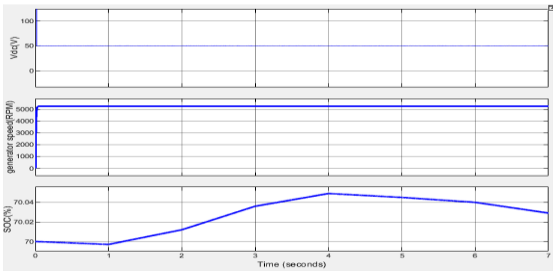
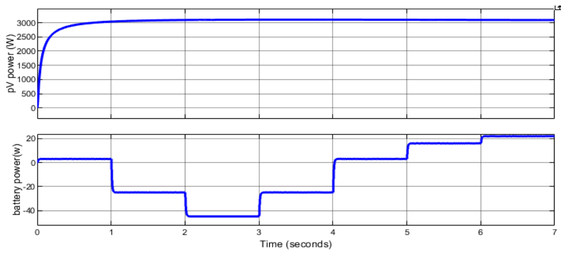
In steady-state scenario, system demonstrated stable voltage regulation with the STSMC controller managing power flow effectively between RES and battery sources. The battery storage played a crucial role in maintaining load power during periods of low RES generation, ensuring that the load demand was met without interruptions. The results indicated that the STSMC controller provided smooth power transitions and maintained a consistent DC link voltage, even under varying renewable inputs. This shows that the system is capable of operating efficiently in steady-state conditions, with optimal power management and minimal fluctuation in load power.

Case_2

Performance of the hybrid energy system under dynamic load condition



(a)



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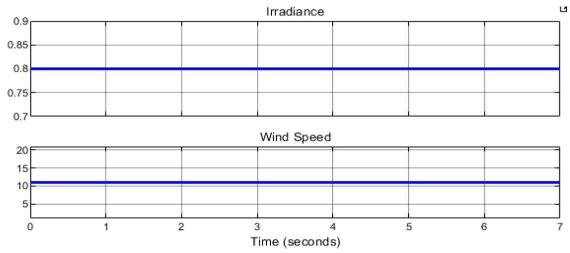

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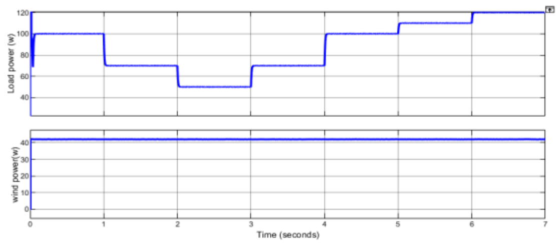

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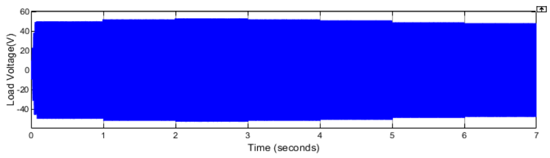

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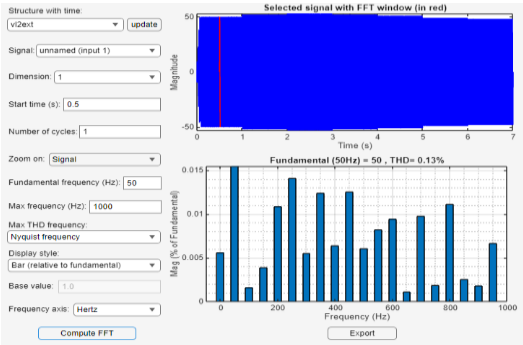

(f)

Figure.9 (a, b, c, d, and f) shows the dynamic load outcomes

In the dynamic-state scenario, the hybrid system was subjected to varying load conditions while solar and wind generation remained constant. The STSMC controller's response to these dynamic changes was robust, quickly adapting to fluctuations in power demand. The system was able to manage the transient effects of load variations without any significant instability or voltage dips. During periods of increased demand, the battery storage discharged to supply power, and conversely, during lower demand, the battery was charged by excess renewable energy. The dynamic-state simulation demonstrated the controller's capability to maintain stable power flow and voltage levels, ensuring the microgrids resilience to sudden changes in load and generation. These results highlight the STSMC controller's ability to effectively handle real-time operational changes, offering a reliable solution for hybrid microgrid power management.

Table-1 THD% Comparison

With NN	With STSMC
Case – 1 (Load Voltage = 2.50%)	0.13%
Case – 2 (Load Voltage = 2.36%)	0.13%

From the above data we can say that STSMC controller is giving quality input voltage to the load when compared to NN controller.

V CONCLUSION

In this paper, a STSMC established single-phase VSC is developed to control load voltage and power at load side of a hybrid energy system. Solar and wind energy sources, supported by a battery, are utilized to meet power demand. The battery operates in charging and discharging modes depending on availability of solar and wind power. The STSMC controller at the load side effectively manages the voltage and power flow, ensuring stable operation even under varying conditions. Simulation studies with constant load and variable solar-wind power generation, as well as with variable load and constant power generation, confirm that the STSMC controller regulates DC voltage and ensures balanced power delivery to the load. Additionally, the use of STSMC at the load side significantly improves power quality by reducing THD %, leading to a more stable and efficient energy system. The STSMC's robust performance enhances reliability and power quality in hybrid microgrid applications.

REFERENCES

[1] C. Hua and C. Shen, "Study of maximum power tracking techniques and control of DC/DC converters for photovoltaic power system", PESC 98 Record. 29th Annual IEEE Power Electronics Specialists Conference (Cat. No. 98CH36196), vol. 1, pp. 86-93, May 1998.

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https://www.ijetrm.com/

[2] A.Attia and P. Horáček, Modeling Nonlinear Systems by a Fuzzy Logic Neural Network Using Genetic Algorithms, vol. 41, no. 6, pp. 69-76, 2001.

[3] K. Chomsuwan, P. Prisuwanna and V. Monyakul, "Photovoltaic grid-connected inverter using two-switch buck-boost converter", Conference Record of the Twenty-Ninth IEEE Photovoltaic Specialists Conference, pp. 1527-1530, May 2002.

[4] W. Xiao and W. G. Dunford, "A modified adaptive hill climbing MPPT method for photovoltaic power systems", 2004 IEEE 35th annual power electronics specialists conference (IEEE Cat. No. 04CH37551), vol. 3, pp. 1957-1963, June 2004.

[5] M.Q. Mao, S.J. Yu and J.H. Su, "Versatile Matlab Simulation Model for Photovoltaic Array with MPPT Function [J]", Acta Simulata Systematica Sinica, vol. 5, pp. 1248-1251, 2005.

[6] N. Femia, D. Granozio, G. Petrone, G. Spagnuolo and M. Vitelli, "Optimized one-cycle control in photovoltaic grid connected applications", IEEE Transactions on Aerospace and Electronic Systems, vol. 42, no. 3, pp. 954-972, 2006.

[7] Uğur Fesli, Raif Bayir and Mahmut Özer, "Design and implementation of a domestic solar-wind hybrid energy system", 2009 International Conference on Electrical and Electronics Engineering-ELECO 2009, pp. I-29, 2009

[8] Uğur Fesli, Raif Bayir and Mahmut Özer, "Design and implementation of a domestic solar-wind hybrid energy system", 2009 International Conference on Electrical and Electronics Engineering-ELECO 2009, pp. I-29, 2009.

[9] F. Ding, P. Li, B. Huang, F. Gao, C. Ding and C. Wang, "Modeling and simulation of grid-connected hybrid photovoltaic/battery distributed generation system", CICED 2010 Proceedings, pp. 1-10, September 2010.

[10] Y.-M. Lv, H.-W. Yuan, Y.-Y. Liu and Q.-S. Wang, "Fuzzy Logic Based Energy Management Strategy of Battery-Ultracapacitor Composite Power Supply for HEV", 2010 First International Conference on Pervasive Computing Signal Processing and Applications, pp. 1209-1214, 2010.

[11] R. Kadri, J.P. Gaubert and G. Champenois, "An improved maximum power point tracking for photovoltaic grid-connected inverter based on voltage-oriented control", IEEE transactions on industrial electronics, vol. 58, no. 1, pp. 66-75, 2010.

[12] Abd El-Shafy A. Nafeh, "Optimal economical sizing of a PV-wind hybrid energy system using genetic algorithm", International Journal of Green Energy, vol. 8, no. 1, pp. 25-43, 2011.

[13] B. S. Manju, R. Ramaprabha and B. L. Mathur, "Modelling and control of standalone solar photovoltaic charging system", 2011 International Conference on Emerging Trends in Electrical and Computer Technology, pp. 78-81, March 2011.

[14] W. Zhang, D. Dong, I. Cvetkovic, F. C. Lee and D. Boroyevich, "Lithium-based energy storage management for DC distributed renewable energy system", 2011 IEEE Energy Conversion Congress and Exposition, pp. 3270-3277, September 2011.

[15] D. V. De La Fuente, C. L. T. Rodríguez, G. Garcerá, E. Figures and R. O. González, "Photovoltaic power system with battery backup with grid-connection and islanded operation capabilities", IEEE transactions on industrial electronics, vol. 60, no. 4, pp. 1571-1581, 2012.

[16] H. Bo, C. Yanbo, T. Wen and G. Leijiao, "Implementation of battery charging and discharging system in photovoltaic system", 2013 5th International Conference on Power Electronics Systems and Applications (PESA), pp. 1-5, December 2013.

[17] Y. X. Wang, F. F. Qin and Y. B. Kim, "Bidirectional DC-DC converter design and implementation for lithium-ion battery application", 2014 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), pp. 1-5, December 2014.

[18] K. F. Krommydas and A. T. Alexandridis, "Modular control design and stability analysis of isolated PV-source/battery-storage distributed generation systems", IEEE Journal on Emerging and Selected Topics in Circuits and Systems, vol. 5, no. 3, pp. 372-382, 2015.

[19] N. Bigdeli, "Optimal management of hybrid PV/fuel cell/battery power system: A comparison of optimal hybrid approaches", Renewable and Sustainable Energy Reviews, vol. 42, pp. 377-393, 2015.

[20] N. T. Fernandes, R. Demonti, J. de Andrade, P. F. de Melo, C. G. Bianchin, A. R. de Almeida, et al., "Control strategy for pulsed lead acid battery charger for standalone photovoltaics", 2015 IEEE 13th Brazilian Power

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Electronics Conference and 1st Southern Power Electronics Conference (COBEP/SPEC), pp. 1-6, November 2015.

[21] K. V. S. Bharath and M. A. Khan, "Predictive Control of Energy Management System for Fuel Cell Assisted Photo Voltaic Hybrid Power System", Applications of Artificial Intelligence Techniques in Engineering, pp. 245-254, 2019.

[22] A.F. Bendary and M.M. Ismail, "Battery charge management for hybrid PV/wind/fuel cell with storage battery", Energy Procedia, vol. 162, pp. 107-116, 2019.

[23] Asmae Chakir et al., "Optimal energy management for a grid connected PV-battery system", Energy Reports, vol. 6, pp. 218-231, 2020

[24] Marcos Tostado-Véliz, Daniel Icaza-Alvarez and Francisco Jurado, "A novel methodology for optimal sizing photovoltaic-battery systems in smart homes considering grid outages and demand response", Renewable Energy, vol. 170, pp. 884-896, 2021.

[25] R. Sadeghi, S M. Madani, M. Ataei et al., "Super-Twisting Sliding Mode Direct Power Control of Brushless Doubly Fed Induction Generator", IEEE Transactions on Industrial Electronics, pp. 1, 2018.

[26] C. Lascu, I. Boldea and F. Blaabjerg, "Super-twisting sliding mode control of torque and flux in permanent magnet synchronous machine drives", Industrial Electronics Society IECON 2013 - 39th Annual Conference of the IEEE, 2013.