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Adaptive Droop Control Strategy for Frequency Regulation and Stability Enhancement of Grid-Connected DFIG-Based Hybrid Wind-PV Microgrid with Battery Energy Storage

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ABSTRACT

Wind energy is one of the fastest-growing renewable energy sources, playing a significant role in modern power systems. This paper presents a comprehensive investigation of a grid-connected Doubly Fed Induction Generator (DFIG)-based hybrid wind-photovoltaic (PV) energy system, including system configuration, power converters, and control strategies. An adaptive droop control strategy is implemented in the grid-side converter (GSC) to achieve effective frequency regulation and enhance microgrid stability under varying operating conditions. The proposed system also incorporates Maximum Power Point Tracking (MPPT) and DC-link voltage regulation to ensure efficient energy extraction and stable operation. A modified PV-DFIG configuration is employed, where PV power is injected into the grid through both rotor-side and grid-side converters, eliminating the need for an additional PV converter and improving system efficiency. The coordinated control approach enables simultaneous regulation of DC-link voltage, system frequency, and power flow. The system is modeled and simulated in MATLAB/Simulink using dynamic equations in multiple reference frames. Simulation results demonstrate improved voltage, current, frequency response, and power characteristics, validating the effectiveness of the proposed control strategy for enhanced stability and performance of hybrid renewable energy systems.

KEYWORDS: *PV systems, Maximum Power Point Tracking (MPPT) Techniques, Hybrid Energy, inverter, Renewable Energy, Battery, Wind System, Boost converter, PID controller.*

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I. INTRODUCTION

Renewable energy is obtained from natural resources such as solar, wind, wave, and geothermal energy. These resources are renewable and can be naturally replenished. In contrast to the depletion of conventional fossil fuels [1], these energy sources are considered sustainable and inexhaustible. The global energy crisis has accelerated the development and adoption of clean and renewable energy technologies [2]. In addition, environmental concerns related to greenhouse gas emissions from fossil fuel combustion have further emphasized the need for renewable energy sources, which are cleaner and have minimal impact on pollution.

A solar cell or panel consists of a configuration of solar cells interconnected in series or parallel to provide the required voltage and current. Solar photovoltaic (PV) systems convert solar energy into electrical energy and are widely used in residential, commercial, and remote applications. In a typical PV system, solar panels generate DC power, which is then converted into grid-compatible AC power using an inverter. Various protection and control devices are incorporated to ensure safe and reliable operation.

Energy storage systems, such as batteries, play an important role in renewable energy systems by storing excess energy generated during peak conditions and supplying it during periods of low generation. Solar power systems are commonly used in applications such as weather stations, communication systems, rural electrification, and standalone power systems.

The performance of solar cells is governed by semiconductor physics, particularly the band gap, which determines their efficiency in converting solar radiation into electrical energy.

Wind energy is another major renewable energy source, where wind turbines convert the kinetic energy of wind into mechanical energy and subsequently into electrical energy using generators. The turbine consists of blades, a rotor hub, a gearbox, and a generator. The mechanical energy captured from wind is transmitted through the drive train to the generator, which produces electrical power. The generated power is then stepped up using transformers and supplied to the grid. Additional components such as anemometers and wind vanes are used to measure wind speed and direction, enabling efficient operation and control of the turbine.

However, the integration of renewable energy sources such as solar and wind into the grid introduces challenges due to their intermittent and variable nature. These challenges include maintaining voltage stability, power quality, and frequency regulation in the power system. To address these issues, advanced power electronic converters and control strategies are required.

Doubly Fed Induction Generator (DFIG)-based wind energy conversion systems are widely used due to their capability of variable speed operation and independent control of active and reactive power. However, maintaining system stability and frequency regulation remains a significant challenge, especially in weak grid or microgrid conditions.

To overcome these challenges, Battery Energy Storage Systems (BESS) are integrated to provide fast dynamic response and support grid stability. In addition, advanced control strategies such as droop control are employed to regulate system frequency and improve overall stability.

In this work, an adaptive droop control strategy is proposed for a grid-connected DFIG-based hybrid wind-PV system integrated with BESS. The proposed approach aims to enhance frequency regulation, improve system stability, and ensure efficient power management under varying operating conditions.

II. PROPOSED SYSTEM

This research proposes a grid-connected Doubly Fed Induction Generator (DFIG)-based hybrid wind-photovoltaic (PV) energy system integrated with a Battery Energy Storage System (BESS) for power smoothing and enhanced stability. The rotor position estimation is carried out using a rotor position calculation technique to ensure accurate control of the system.

The main novelty of this work lies in the implementation of an adaptive droop control strategy in the Grid Side Converter (GSC), which enables effective frequency regulation and regulated power injection into the grid. The GSC is responsible for maintaining DC-link voltage stability and controlling the power exchange between the system and the grid, while the Rotor Side Converter (RSC) ensures maximum power extraction from the wind turbine through appropriate control of rotor currents.

The integration of BESS plays a crucial role in improving system performance by storing excess energy during high generation periods and supplying power during low generation conditions, thereby enhancing system reliability and dynamic response.

The performance of the proposed system is evaluated by comparing it with a conventional DFIG-based system under varying wind speed conditions. The results demonstrate improved power regulation, enhanced frequency stability, and better dynamic performance. The system operation is validated through simulations carried out under different operating conditions, both with and without solar integration.

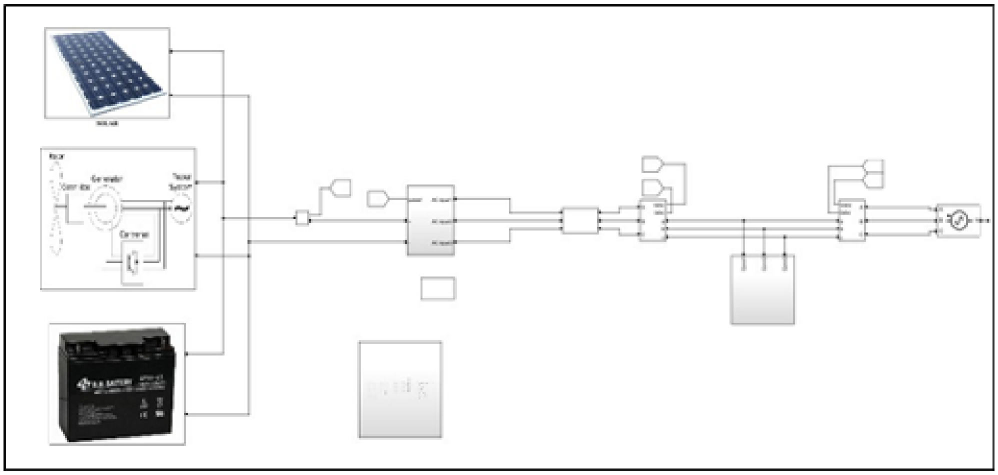


Figure 1: Proposed Simulink Model

III. Simulation Result

The effectiveness of the proposed adaptive droop control strategy is validated through simulation by analyzing the system response under varying operating conditions. The photovoltaic panel, wind turbine, and Doubly Fed Induction Generator (DFIG) system are modeled and simulated using MATLAB/Simulink (R2019b), and the results are presented below.

A comprehensive electromechanical model of the grid-connected DFIG-based wind energy conversion system integrated with a Battery Energy Storage System (BESS) is developed. The system is analyzed under both grid-connected and standalone operating conditions. The model includes detailed representations of the generator, converters, control systems, and energy storage components.

The boost converter is employed to regulate and enhance the DC-link voltage obtained from the photovoltaic system, ensuring proper voltage levels for grid integration. The control strategy effectively manages power flow, maintains DC-link voltage stability, and supports frequency regulation through the Grid Side Converter (GSC).

Simulation results demonstrate the dynamic performance of the system in terms of voltage, current, frequency response, and both active and reactive power. The proposed system shows improved power quality, stable operation, and enhanced frequency regulation capability under varying operating conditions.

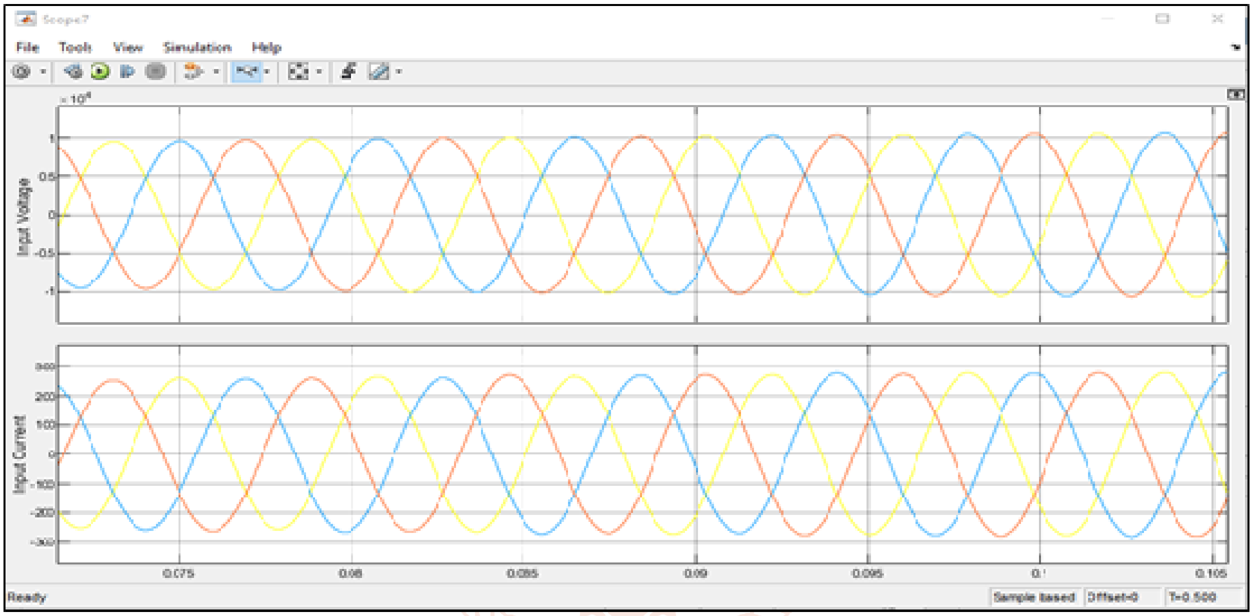


Figure 2: Input Voltage and Current

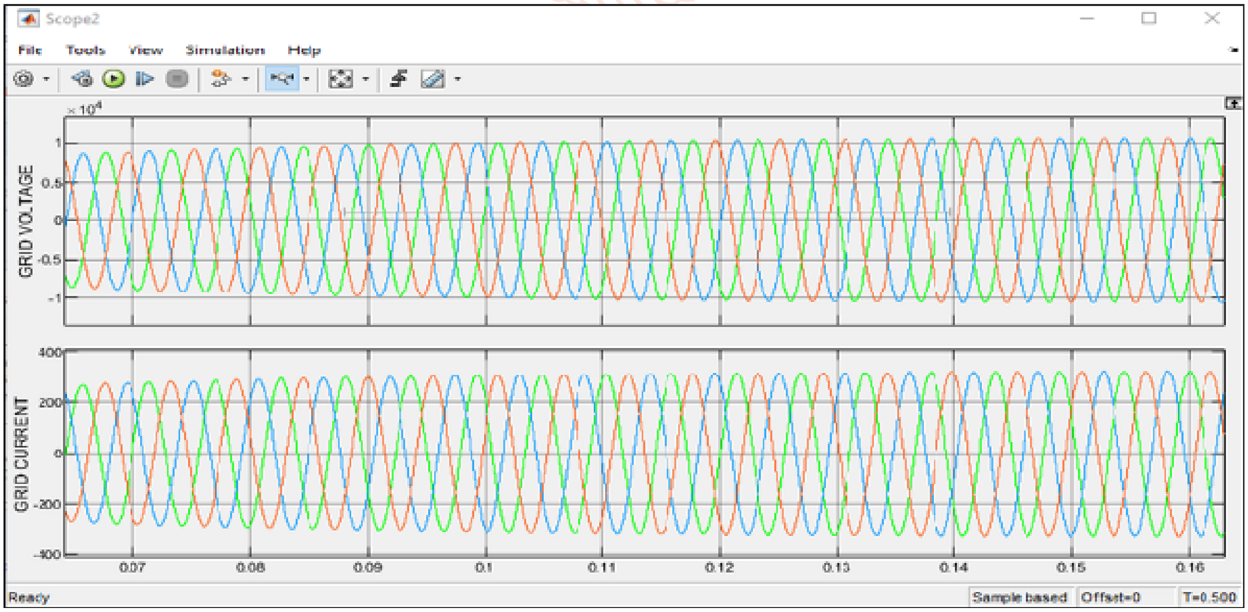


Figure 3: Grid Voltage and Current

Figure 4 showing the Grid Voltage and Current waveform, during simulation grid voltage generate 230v

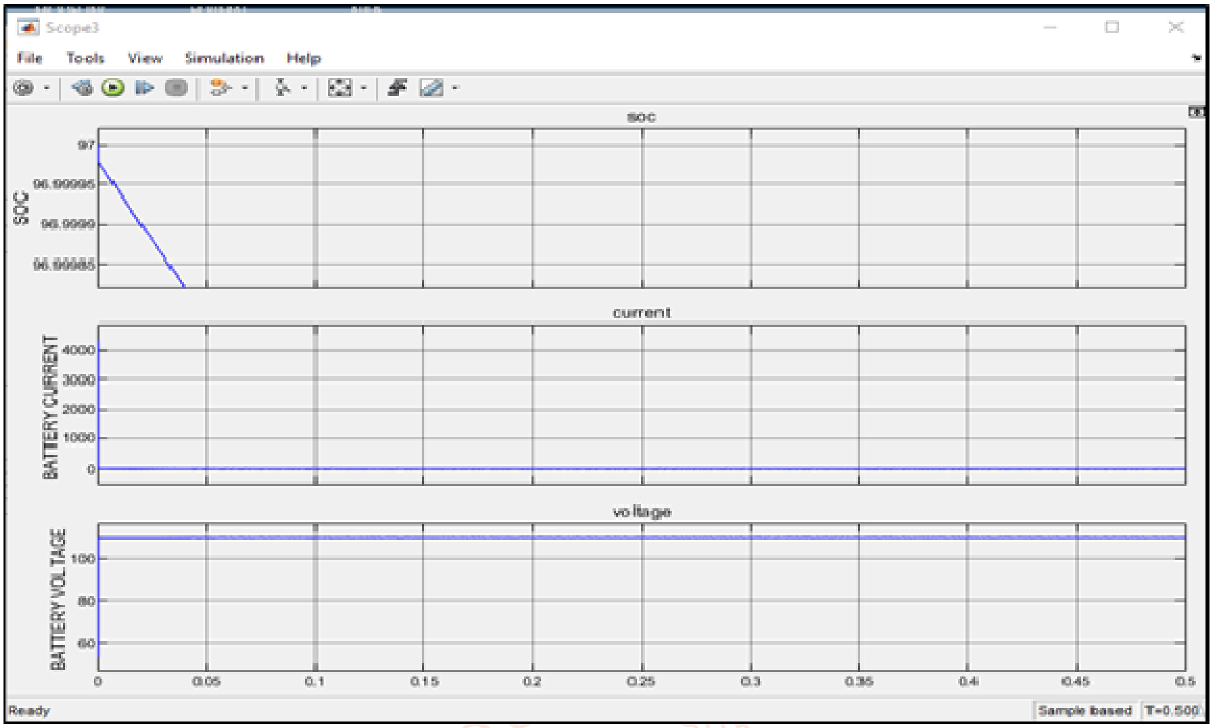


Figure 4: Battery Output

Figure 5: Battery Output showing with soc and battery voltage and current waveform ,battery charge upto 97 % at discharge after 97%, State of charge (SoC) is **the level of charge of an electric battery relative to its capacity**. The units of SoC are percentage points (0% = empty; 100% = full).

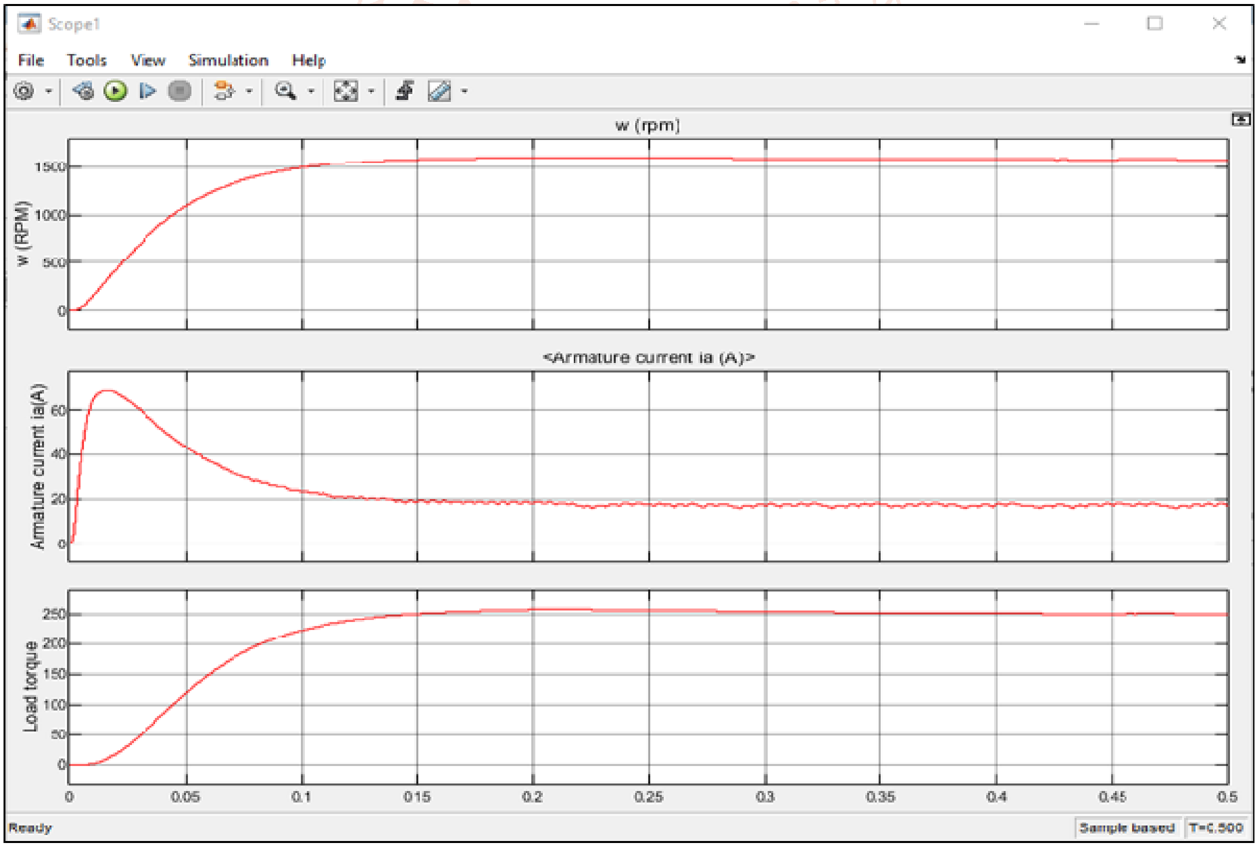


Figure 5: DC Machine Output

Figure 6: DC Machine Output rpm, armature current and load voltage, the stator consists of field windings while the rotor (also called the armature) consists of an armature winding. When both the armature and the field windings are excited by a DC supply, current flows through the windings and a magnetic flux proportional to the current is produced

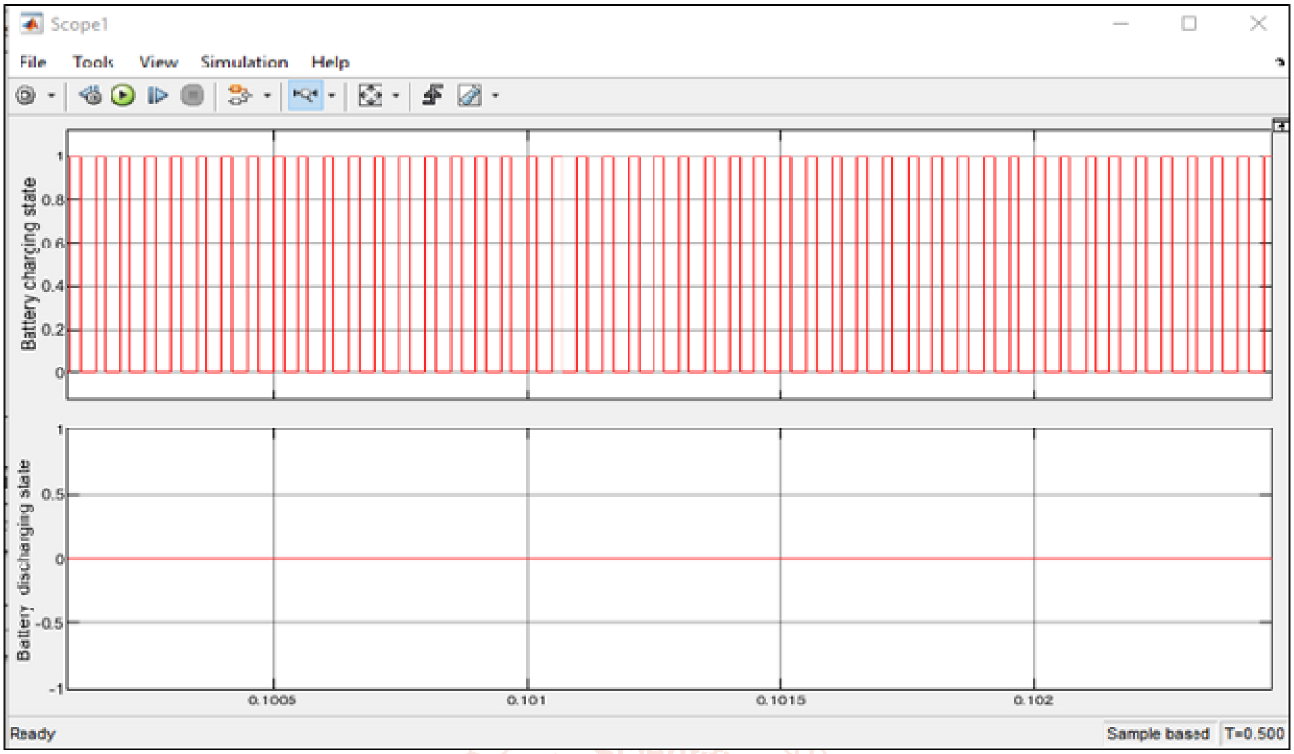


Figure 6: Battery Charging and Discharging States

Figure 7 showing the Battery Charging and Discharging States ,battery discharge at 0% and charging at 100%, The direction of current through the battery determines whether it is charging or discharging. The battery is trying to push current in a particular direction. If the current flows in that direction, the battery is discharging. If the current flows in the other direction, the battery is charging.

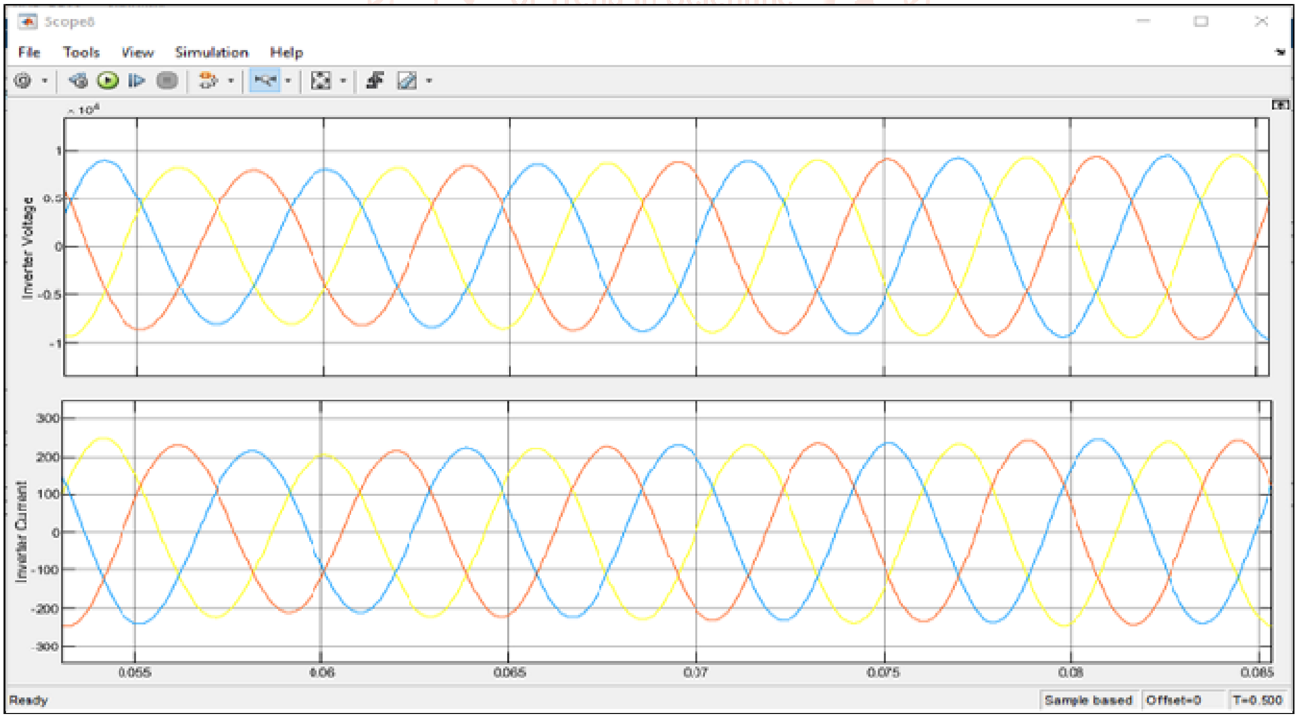


Figure 7: Inverter Current and Voltage

Figure 8 showing the three phase Inverter Current and Voltage, A three-phase inverter converts a DC input into a three-phase AC output. Its three arms are normally delayed by an angle of 120° so as to generate three-phase AC supply. The inverter switches each has a ratio of 50% the maximum power point tracker is an electronic DC to DC converter that optimizes the match between the solar array (PV panels), and the battery bank or utility grid.

Simulation Result with Solar and DFIG

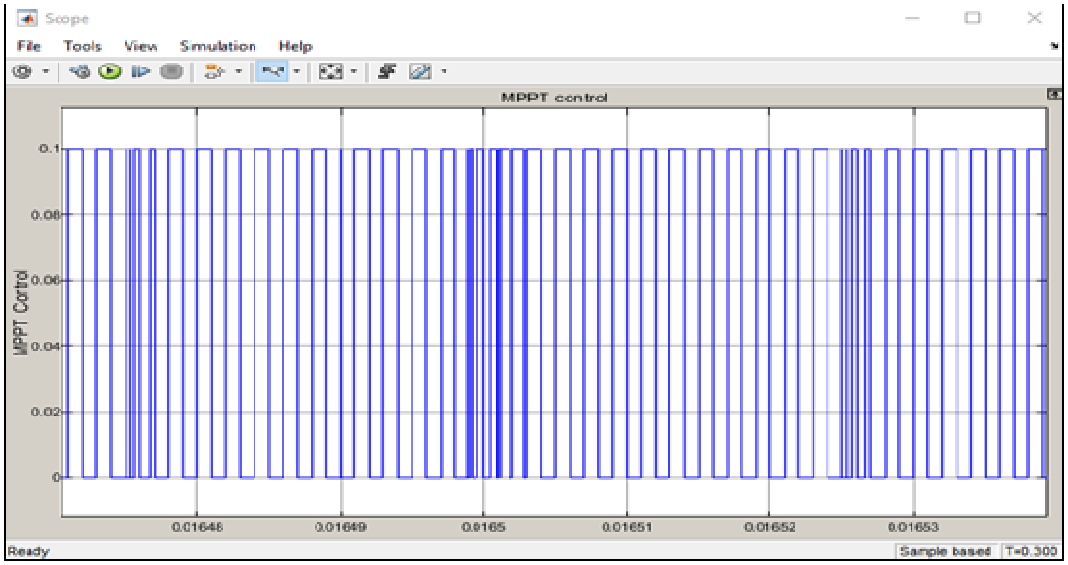


Figure 8: MPPT Control

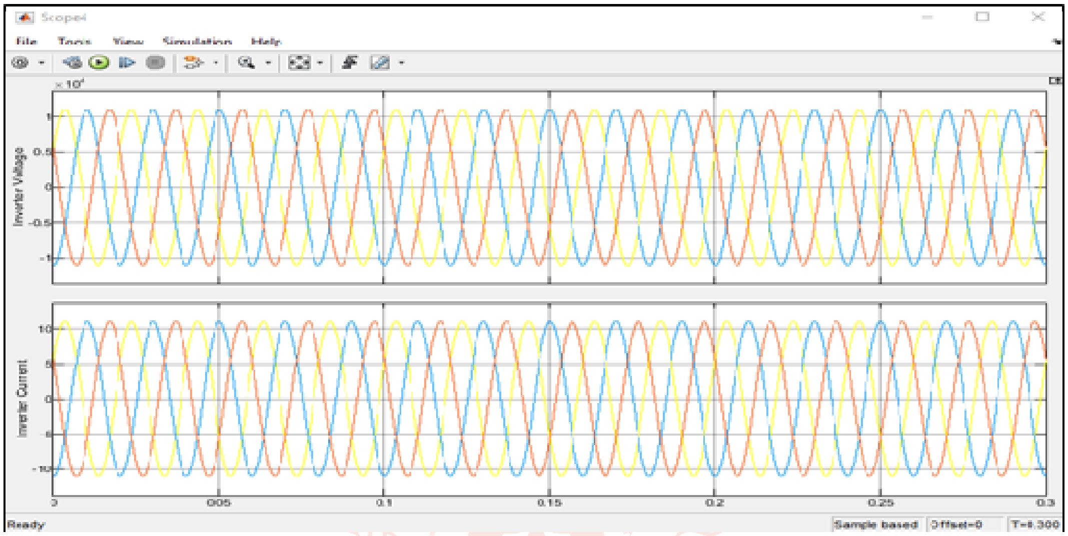


Figure 9: Input Voltage and Current

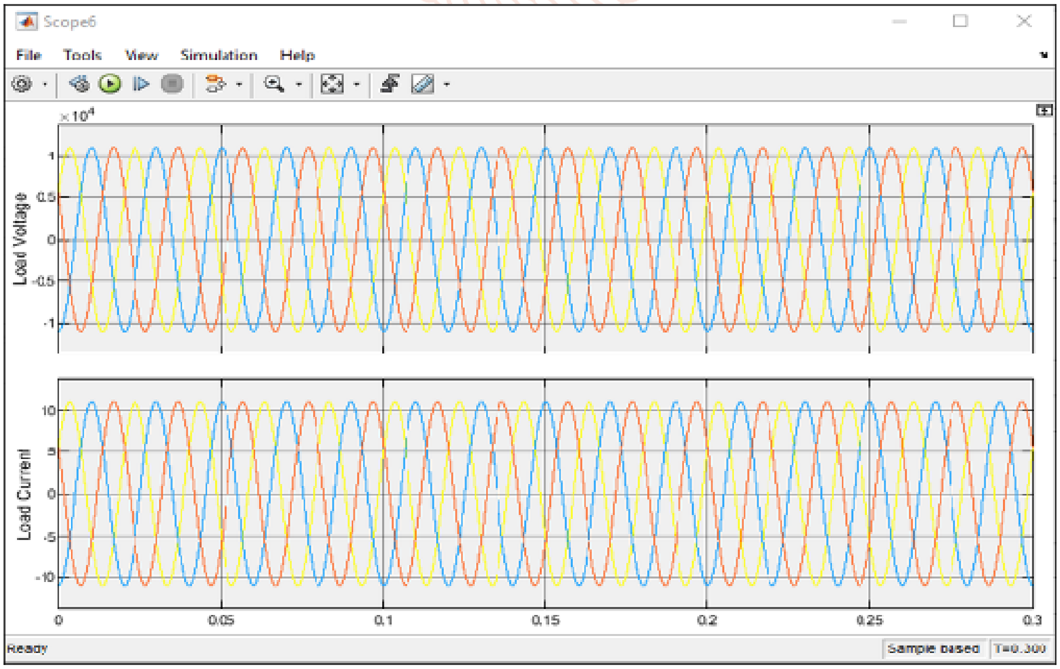


Figure 10: Load Voltage and Current

the amount of current" drawn by the thing that is connected to the output of the circuit. The actual power supply voltage that can be used when switching a load or continuously in an OFF state. The actual power supply voltage that can be used when switching a load or continuously in an OFF state.

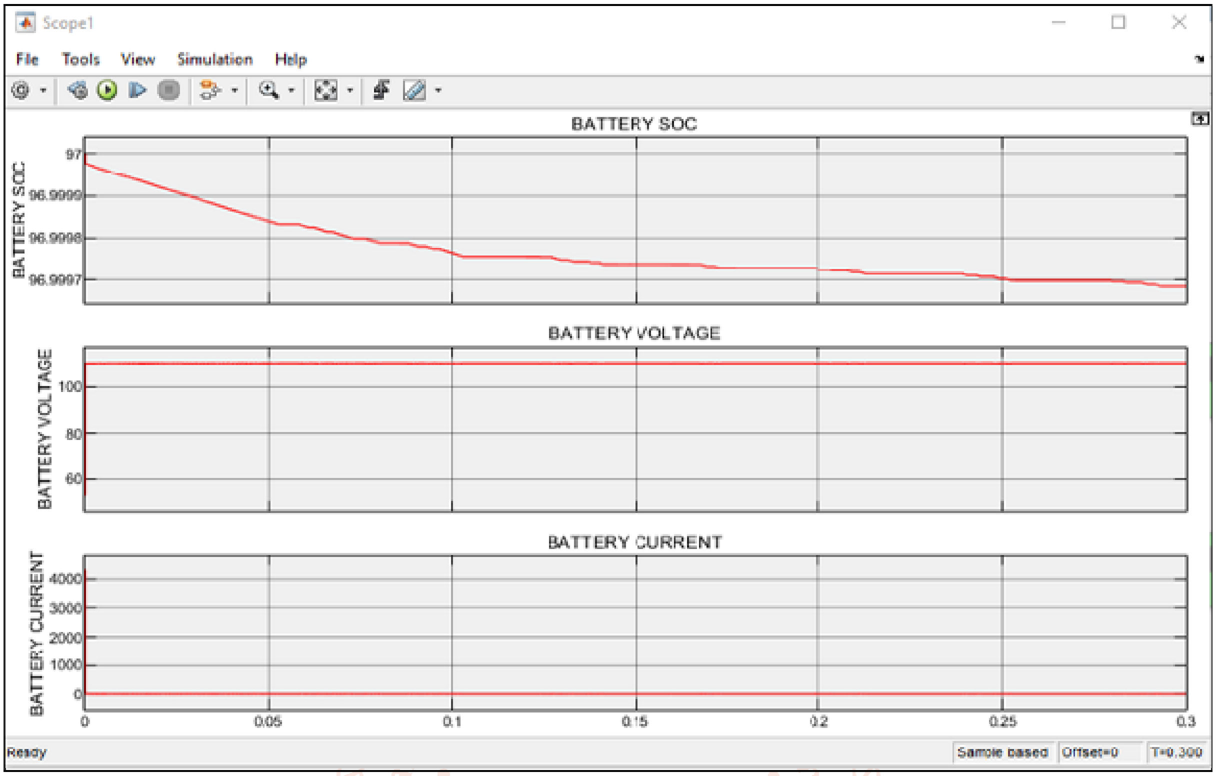


Figure 11: Battery Output

Fig 11 showing the battery output ,Power capacity is how much energy is stored in the battery.

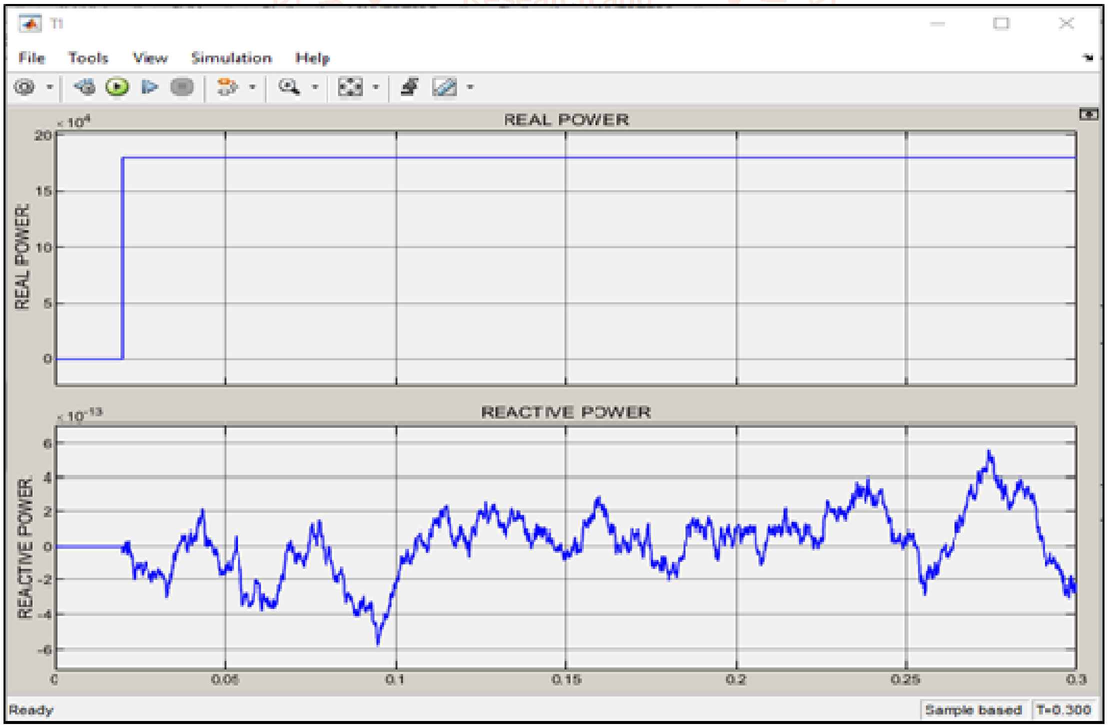
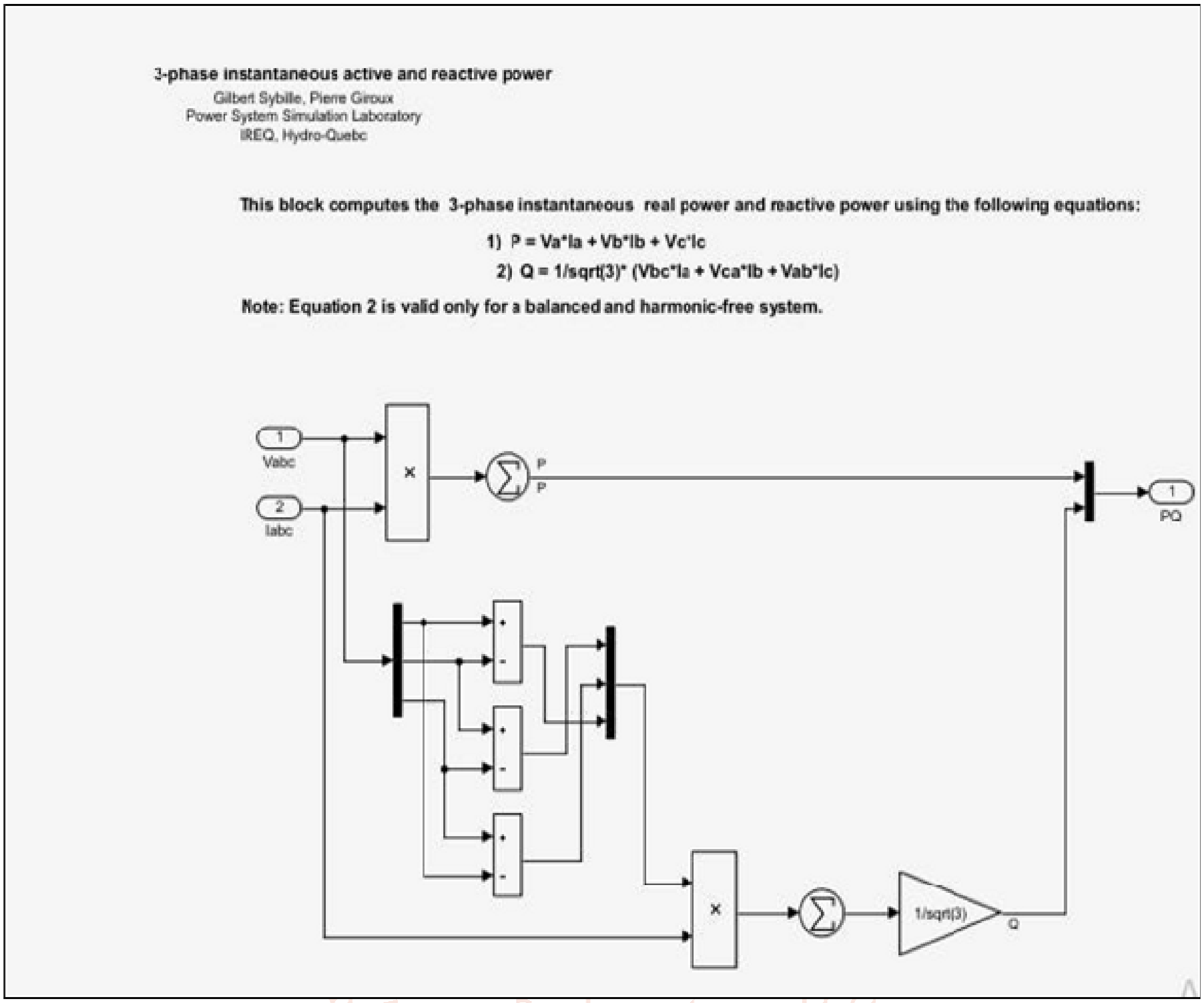


Figure 12: Real Power and Reactive Power

The active power is the real power consumes by the load. Whereas, the reactive power is the useless power. The active power is the product of the voltage, current and the cosine of the angle between them. Whereas, the reactive power is the product of voltage and current and the sine of the angle between them.



3-phase instantaneous active and reactive power
Gilbert Sybille, Pierre Giroux
Power System Simulation Laboratory
IREQ, Hydro-Quebc

This block computes the 3-phase instantaneous real power and reactive power using the following equations:

1) P = Va*Ia + Vb*Ib + Vc*Ic

2) Q = 1/sqrt(3)* (Vbc*Ia + Vca*Ib + Vab*Ic)

Note: Equation 2 is valid only for a balanced and harmonic-free system.

Figure 13: Phase Instantaneous Active and Reactive Power

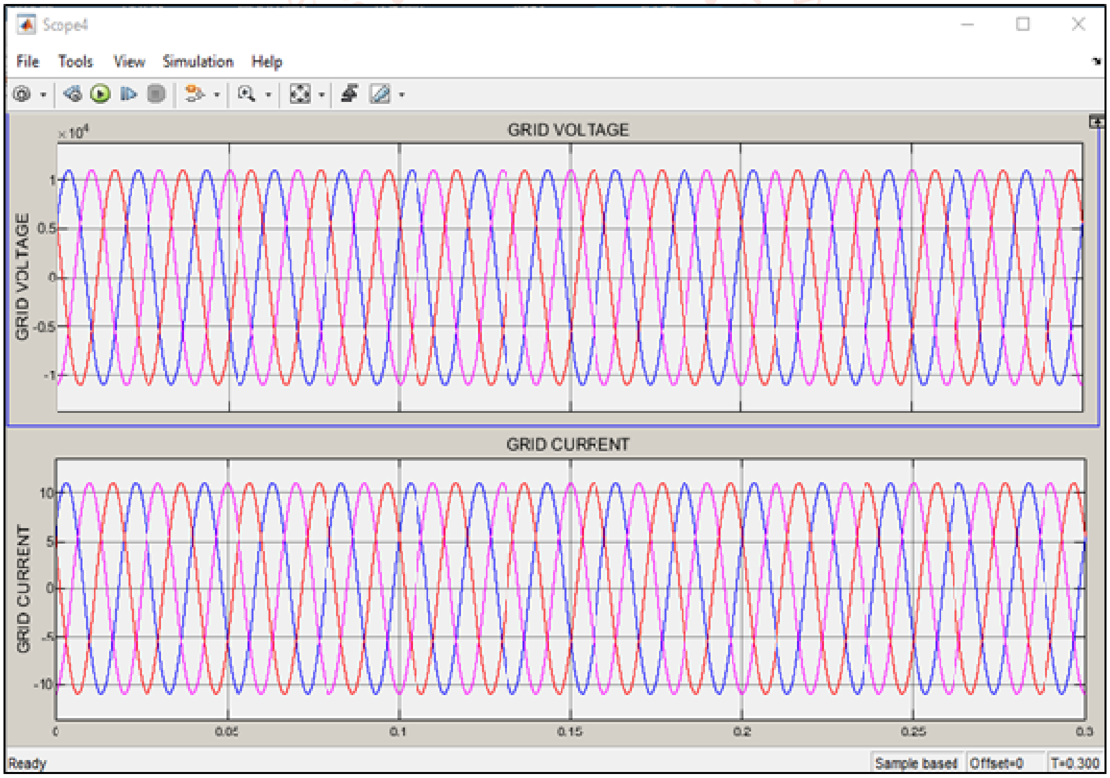


Figure 14: Grid Voltage and Current

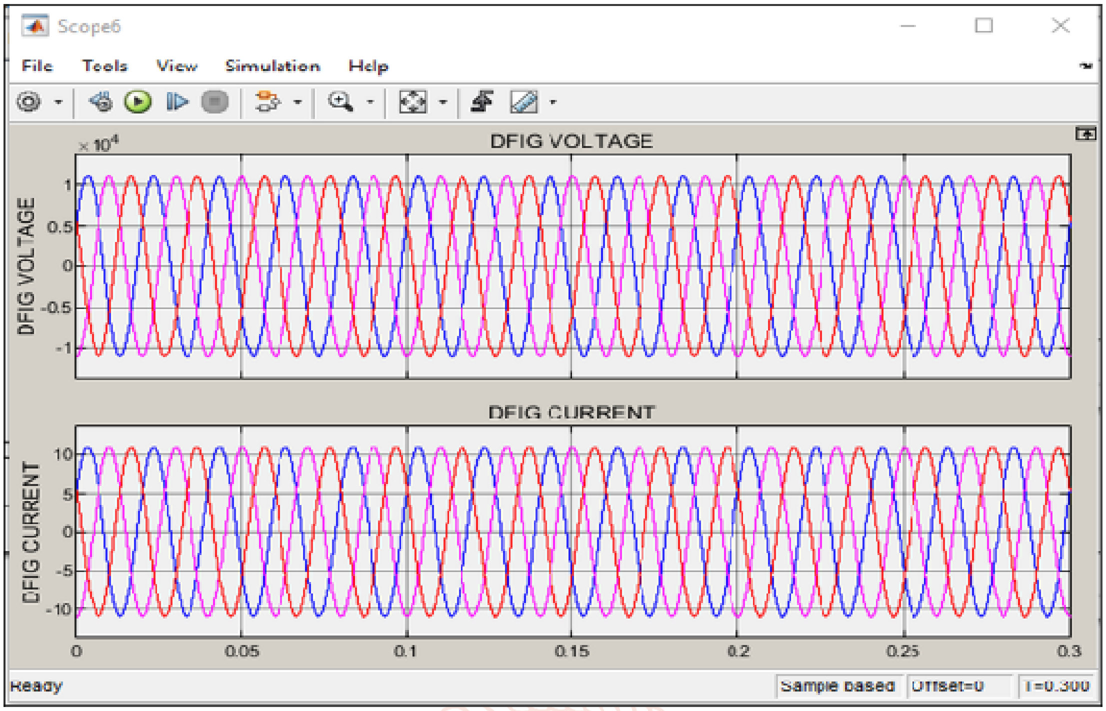


Figure 14: DFIG Voltage and Current

The DFIG consists of a 3 phase wound rotor and a 3 phase wound stator. The rotor is fed with a 3 phase AC signal which induces an ac current in the rotor windings.

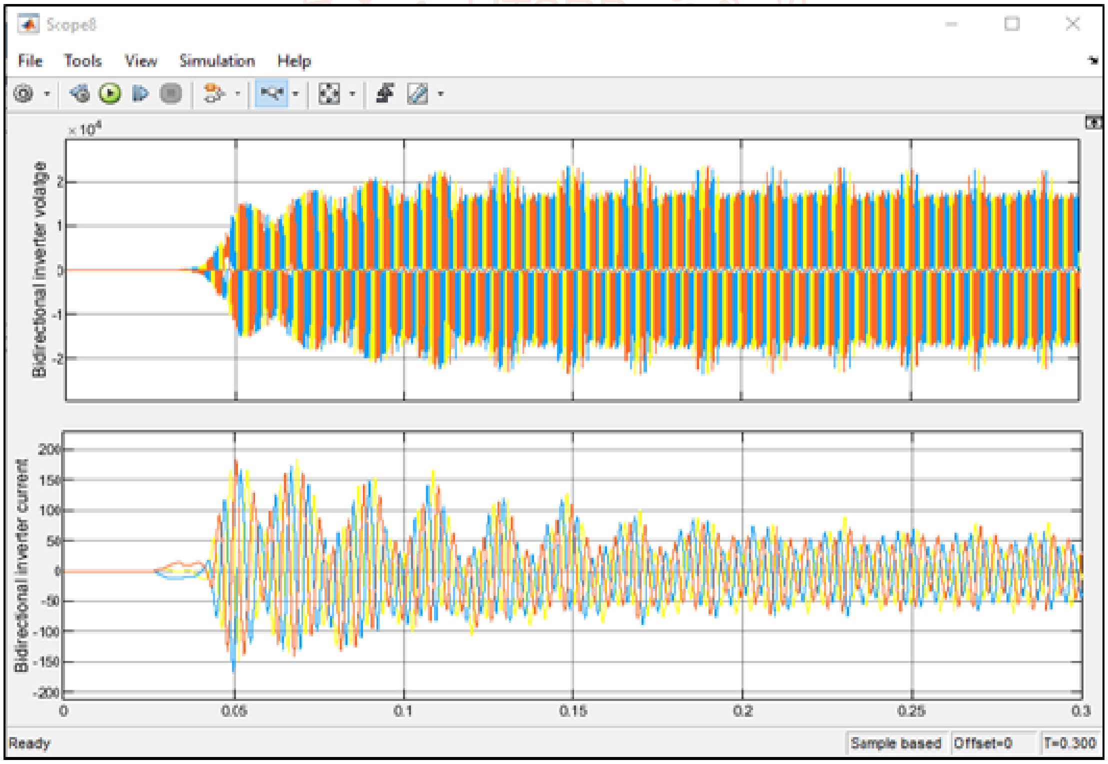
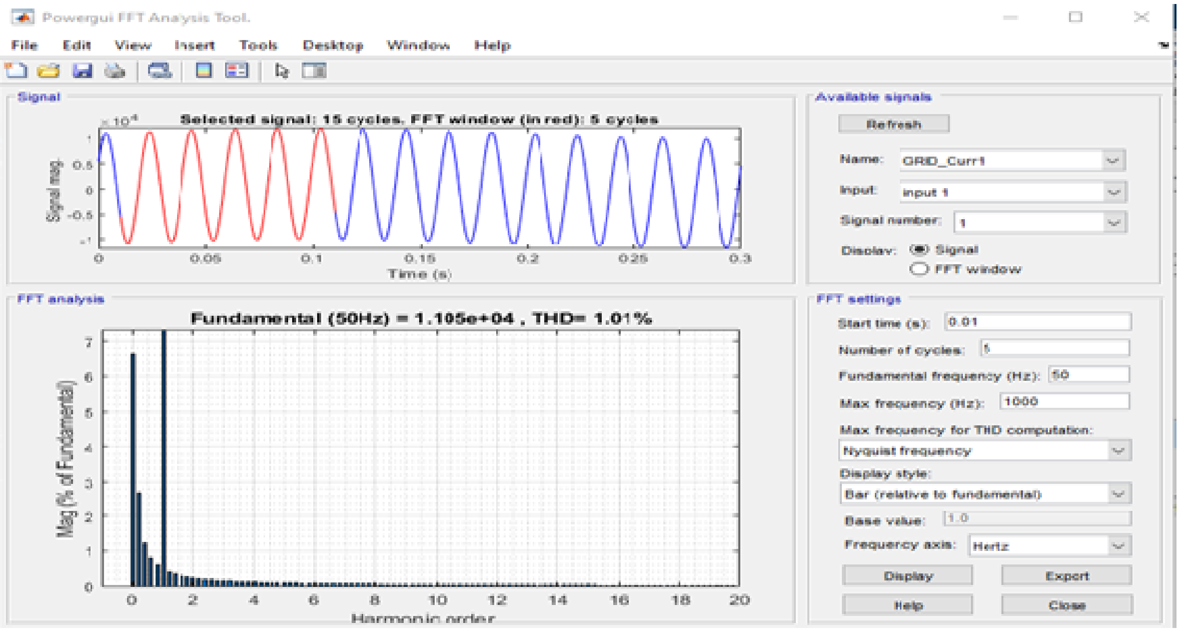


Figure 16: Bidirectional Inverter Current and Voltage

The bidirectional DC-AC inverter transfers power from the DC stage to the connected AC grid while the DC loading requirement is small. Or, the inverter transfers the power from the connected AC grid to the DC stage if the DC energy is insufficient for the DC loading requirement.

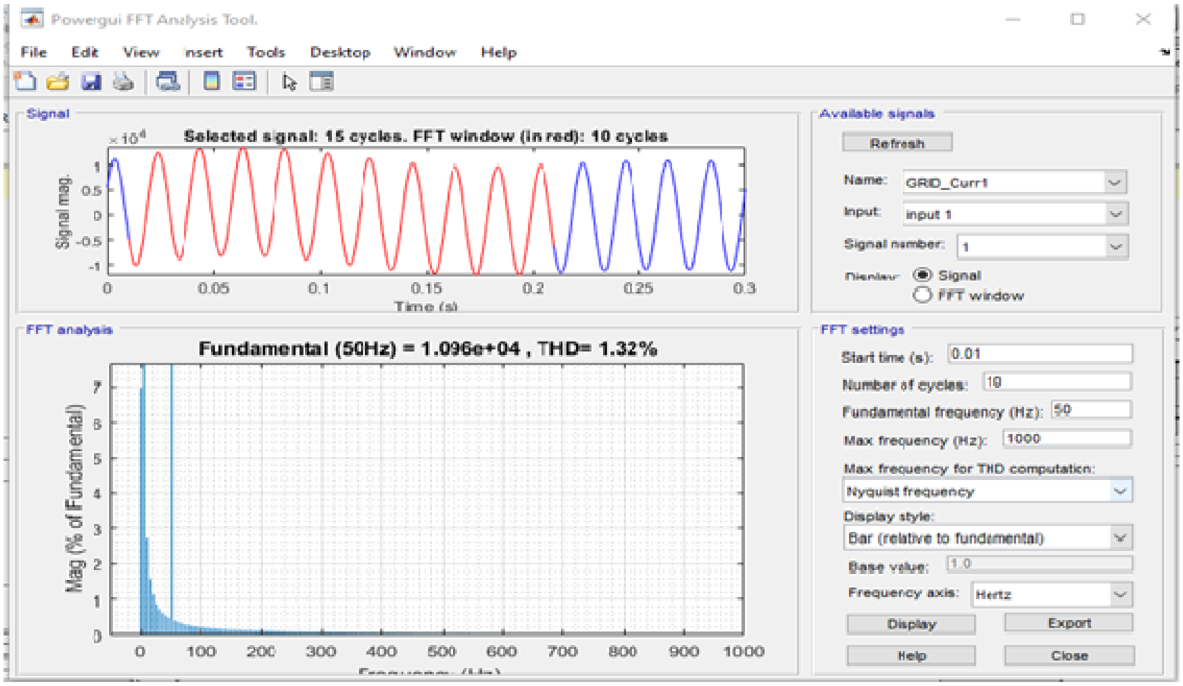


Selected signal: 15 cycles. FFT window (in red): 5 cycles

Fundamental (50Hz) = 1.105e+04 , THD= 1.01%

Name: GRID_Curr1
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.01
Number of cycles: 5
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 17: with solar thd



Selected signal: 15 cycles. FFT window (in red): 10 cycles

Fundamental (50Hz) = 1.096e+04 , THD= 1.32%

Name: GRID_Curr1
Input: input 1
Signal number: 1
Display: ● Signal ○ FFT window
Start time (s): 0.01
Number of cycles: 10
Fundamental frequency (Hz): 50
Max frequency (Hz): 1000
Max frequency for THD computation: Nyquist frequency
Display style: Bar (relative to fundamental)
Base value: 1.0
Frequency axis: Hertz

Figure 18: Without solar THD

Table 1 showing the comparison result in between proposed wok and exiting work, solar irradiance and grid power compare with the existing work, in the proposed work grid power showing higher as compare to existing work

Table 1 Power comparison with existing work

	Technique	Solar Irradiance	Grid power
Proposed system	MPPT, P& O	1000 rad/S	20 KW
Existing system	Predictive MPPT	1000 rad/S	15 W

Table 2 THD comparison With Solar and without solar

MODEL	THD
With Solar	**1.01**
Without Solar	**1.32**

Table 2 Showing The THD Comparison With And Without Solar, In The Proposed System Two Model Designed As DFIG With Solar And DFIG Without Solar, With Solar THD Showing Better As Compare To Without Solar.

IV. CONCLUSION

This research presents an effective approach for frequency regulation in a microgrid using a Doubly Fed Induction Generator (DFIG)-based hybrid renewable energy system. An adaptive droop control strategy is implemented in the Grid Side Converter (GSC) in coordination with a Battery Energy Storage System (BESS) connected to the DC link of the back-to-back converter.

The proposed control strategy successfully maintains system frequency under disturbance conditions while ensuring maximum power extraction from the wind turbine. The integration of BESS provides fast dynamic support, enabling improved frequency regulation, reduced response time, and enhanced frequency stability in both super-synchronous and sub-synchronous operating modes.

Furthermore, the BESS contributes to DC-link voltage regulation and efficient energy management. During super-synchronous operation, excess energy is stored in the battery, while during sub-synchronous operation, the stored energy is supplied to maintain system stability.

Overall, the simulation results demonstrate that the proposed adaptive droop control strategy significantly improves system stability, frequency regulation, and overall performance of grid-connected DFIG-based hybrid wind-PV microgrid systems.

REFERENCES

[1] Z. Liu, Y. Chen, J. Ma, and Z. Zhang, “Adaptive control strategy for improving small-signal stability of multiple grid-connected converter systems,” J. Mod. Power Syst. Clean Energy, vol. PP, no. 99, pp. 1-11.

[2] Dan Wu; Gab-Su Seo; Lie Xu; Chi Su, “Grid integration of offshore wind power: Standards, control, power quality and transmission,” IEEE Open J. Power Electron., vol. 5, pp. 583-604, 2024.

[3] K. Rajkumar, K. Ambika, K. Abhinaya, A. Nafeeza Begum, K. Teena, and U. Viveka, “Hybrid solar and wind power generation system using ANFIS algorithm,” in 2023 Intelligent Computing and Control for Engineering and Business Systems (ICCEBS), 2023, pp. 1-6.

[4] Z. Li, H. Xu, Z. Wang, and Q. Yan, “Stability assessment and enhanced control of DFIG-based WTs during weak AC grid,” IEEE Access, vol. 10, pp. 41371-41380, 2022.

[5] Youssef Moumani, Abdeslam Jabal Laafou, Abdessalam Ait Madi Modeling and Backstepping Control of DFIG used in Wind Enegry Conversion System 2021 7th International Conference on Optimization and Applications (ICOA) Year: 2021 | Conference Paper | Publisher: IEEE DOI:10.1109/ICOA51614.2021.9442625.

[6] Abdeslam Jabal Laafou; Abdessalam Ait Madi; Adnane Addaim Dynamic Control of DFIG used in Wind Power Production, based on PI regulator 2020 IEEE 2nd International Conference on Electronics, Control, Optimization and Computer Science (ICECOCS) Year: 2020 | Conference Paper | Publisher: IEEE DOI:10.1109/ICECOCS50124.2020.9314563.

[7] Jitheesh P Gopalan, Binitha Joseph Mampilly, “A Versatile STATCOM for SSR Mitigation and Dynamic Reactive Power Management in DFIG Based Wind Farm Connected to Series Compensated Line 2020 IEEE International Power and Renewable Energy Conference Year: 2020 | Conference Paper | Publisher: IEEE DOI:10.1109/IPRECON49514.2020.9315202.

[8] Pandian, Ch. Rami Reddy Cuckoo Search Optimization based MPPT for Integrated DFIG-Wind Energy System B. Srikanth Goud; P. Srinivasa Varma; B. Loveswara Rao; M. Sai Krishna Reddy; A. 2020 International Conference on Decision Aid Sciences and Application (DASA) Year: 2020 | Conference Paper | Publisher: IEEE DOI:10.1109/DASA51403.2020.9317072.

[9] Youssef Baala, Seddik Bri DFIG-Based Wind Turbine Control Using High-Gain Observer 2020 1st International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET) Year: 2020 | Conference Paper | Publisher: IEEE DOI:10.1109/IRASET48871.2020.9092280.

[10] Subinay Vajpayee, Nihar Ranjan Panda, Prasanajit Behera, Sarat Chandra Swain “Implementation of PLL algorithm in DFIG based wind turbine connected to utility grid 2020 Second International Conference on Inventive Research in Computing Applications” (ICIRCA) Year: 2020 | Conference Paper | Publisher: IEEE DOI:10.1109/ICIRCA48905.2020.9182961.

[11] Md Aktarujjaman, M. E. Haque, S. Saha, M. Negnevitsky “Impact of DFIG Based Wind Generation on Grid Voltage and Frequency Support” 2020 International Symposium on

Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM) Year: 2020 | Conference Paper | Publisher: IEEE DOI:10.1109/SPEEDAM48782.2020.9161867.

[12] Răzvan Beniugă, Oana Beniugă, Dragoç Machidon Assessment of DFIG wind turbine overvoltage protection system for grid stability 2019 8th International Conference on Modern Power Systems (MPS) Year: 2019 | Conference Paper | Publisher: IEEE DOI:10.1109/MPS.2019.8759781.

[13] Jinxin Ouyang; Ting Tang; Jun Yao; Mengyang Li Active Voltage Control for DFIG-Based Wind Farm Integrated Power System by Coordinating Active and Reactive Powers Under Wind Speed Variations IEEE Transactions on Energy Conversion Year: 2019 | Volume: 34, Issue: 3 | Journal Article | Publisher: IEEE.

[14] Anjali V. Deshpande, V. A. Kulkarni Simplified Model of DFIG in Wind Integrated Power System 2019 3rd International Conference on Computing Methodologies and Communication (ICCMC) Year: 2019 | Conference Paper | Publisher: IEEE DOI:10.1109/ICCMC.2019.8819670.

[15] Sobhy S. Dessouky, Walid S. E. Abdellatif, Saad A. Mohamed Abdelwahab, Marwa A. Ali, “Maximum Power Point Tracking Achieved of DFIG-Based Wind Turbines Using Perturb and Observant Method” 2018 Twentieth International Middle East Power Systems Conference (MEPCON) Year: 2018 | Conference Paper | Publisher: IEEE DOI: 10.1109/MEPCON.2018.8635206.