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MINIMIZING OF POWER RIPPLES IN SOLAR-WIND HYBRID SYSTEM USING FRACTIONAL ORDER PID CONTROLLER

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Abstract

This research investigates the application of a Fractional Order Proportional-Integral-Derivative (FOPID) controller in a solar-wind hybrid system to minimize power fluctuations. The integration of solar and wind energy sources has gained significant attention due to their complementary nature, providing a more reliable and continuous power supply. However, the inherent fluctuations in these renewable sources can lead to power ripples, affecting the stability of the hybrid system. In this study, we propose the use of a FOPID controller, which offers enhanced flexibility in addressing the non-linear characteristics of the hybrid system. The controller is designed to optimize the power output by efficiently regulating solar and wind energy conversion and utilization. The proposed FOPID controller's ability to adjust parameters in real time contributes to the reduction of power ripples, ensuring a smoother and more stable energy output. The simulation results provide evidence of the FOPID controller's efficacy in reducing power fluctuations, as compared to conventional PID controllers.

Keywords: Renewable energy integration, Power management, Controller optimization, System stability.

I. INTRODUCTION

In the quest for cleaner and more efficient energy sources, the combination of solar and wind power in Hybrid Renewable Energy Systems (HRES) has gained prominence. This paper focuses on a crucial aspect of HRES performance—minimizing power ripples—by employing advanced control strategies.

As solar and wind sources bring diverse challenges such as intermittent power supply and changing environmental conditions, recent literature has extensively explored the optimization of power architectures, modeling, converters, and algorithms for HRES [1].

This work is divided into five pieces, with section I serving as an Introduction. Section II is dedicated to a comprehensive examination of prior research, while section III outlines the strategy that is being presented.

The results collected are provided in section IV. Section V provides a concise overview of the main ideas discussed in the study, as well as suggestions for future research.

II. LITERATURE REVIEW

Several studies have contributed to this field, each focusing on specific aspects and employing different models and techniques. Ali et al. [2], utilized a Simulink model of Voltage Source Converter (VSC) and current control.

The Adaptive Sine Cosine Algorithm (ASCA) was employed to optimize PID controller parameters and enhance system performance. K. Aseem and S. Selva Kumar [3] modified the mathematical model to estimate energy production in a Photovoltaic (PV) system using a single diode model. Simulink models for PV-wind Maximum Power Point Tracking (MPPT) and energy management are presented.

A STATCOM model based on a quasi-Z-Source Inverter (qZSI) was presented by N. KANAGARAJ [4]. As part of its control strategy, this model incorporates a qZSI and a PV system for switching. To reduce Total Harmonic Distortion (THD), S. Ravikumar et al [5] suggested a model that employs the FO-ROA method for optimization, specifically targeting the integral and proportional gain parameters of a PI controller. Another approach involves a Linear Quadratic Regulator (LQR) based controller was proposed by Sridevi Sukumaran et.al [6].

This controller aims to improve the power quality of a Micro-Grid inverter, incorporating a maximum power point tracking (MPPT) actuator. Based on simulation results, the controller shows a decrease in both harmonic spread factor (HSF) and total harmonic distortion (THD). In a different context, Sameh EL Mahjoub et.al [7] model a Permanent Magnet Synchronous Generator (PMSG) in the reference park and a lead acid battery with internal resistance and controlled voltage source. This work contributes to understanding the dynamics of these components in hybrid systems.

The complexity and non-linearity of the mathematical model of a Wind Energy Conversion System (WECS) are addressed by Abdelkader Mostefa et.al [8]. The model considers strong coupling between input, output, and internal variables, accounting for disturbances such as wind speed fluctuations and parametric variations.

A Maximum Power Point Tracking (MPPT) controller for a hybrid solar-wind system based on the Rain Optimization Algorithm and Bi-directional Long Short-Term Memory (ROA Bi-LSTM) was given by Dharma Raj T et al. [9]. This controller seeks to extract maximum power under variable climate circumstances by merging a doubly fed induction generator and a DC-DC boost converter.

Modeling of a solar PV panel with a Battery Energy Storage System (BESS) connected to a DC microgrid is discussed in [10]. The paper mathematically describes the block diagram representation of the system, including subsystem components, switching design, and dynamic equations. It also explores the operation of the buck-boost converter based on transfer function modeling.

The dynamic model of a Permanent Magnet Synchronous Generator (PMSG) in Park's (d, q) system is presented, along with the equivalent circuit modeling of a storage battery by F. E. Tahiri et.al [11].

The Integrated Hybrid Power System (IHPS) model is designed and simulated using the Matlab/Simulink platform.

An Energy Management System (EMS) was created by R.S.R. Krishnam Naidu et al. [12] by combining the Modified Flower Pollination Algorithm (MFPA) with the Modified Perturb and Observe (MP&O) technique.

This paper explores ways to minimize power ripples in a solar-wind hybrid system by employing a fractional order PID controller.

III. PROPOSED SYSTEM DESCRIPTION AND MODELLING

There are several types of hybrid renewable energy systems. As demonstrated in this research, a portion of these systems rely only on solar and wind energy to power them. Others connect a diesel generator to the grid in addition to a hybrid renewable energy system. The block diagram of the suggested system is shown in Figure (1).

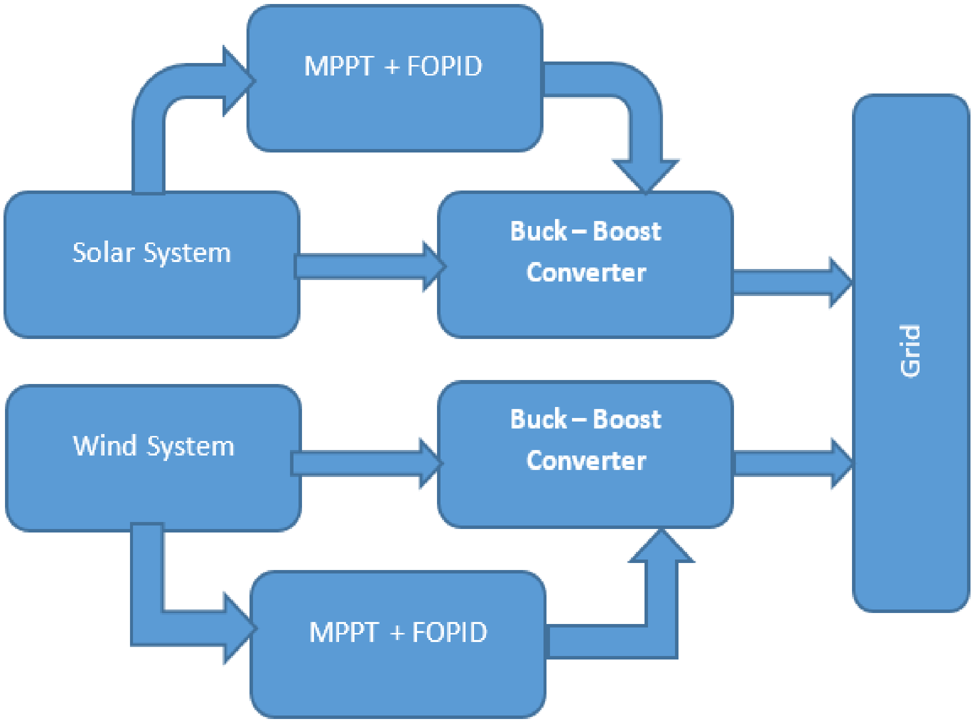


Figure 1: The system’s block diagram

A. Photovoltaic (PV) Model:

The photovoltaic (PV) system is typically represented as a single diode, as seen in Figure 2.

Hence, the mathematical representation of the PV system can be formulated as follows [13-15]:

$$I_{pv=} I_{ph} - I_s \left(e^{\frac{V_{pv}+ I_{pv}\ R_s}{a}} - 1 \right) - \frac{V_{pv} + I_{pv} R_s}{R_{sh}} \quad (1)$$

Where:

Ipv: The PV cell's output current.

V_{pv}: Output voltage of the PV cell

I_{ph}: Photocurrent

V_{ph}: Photo-voltage

I_s: Saturation current

R_s: The series resistance

R_{sh}: The shunt resistance

$a = \frac{N_s n K T}{e}$; Ns is the number of PV cell in series, n is the ideality factor of PV cell, and k is the Boltzmann constant, T is the Temperature, and e is the electron charge.

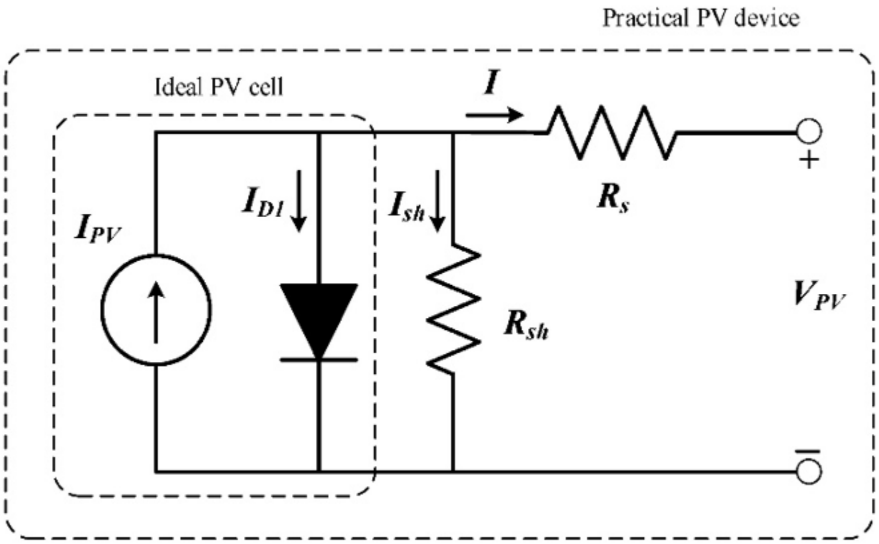


Figure 2: Practical PV model

B. Buck-Boost Converter Model:

The Buck-Boost Converter, a dynamic power electronics tool, plays an important role in solar systems by efficiently adjusting voltage levels to match the varying output from solar panels. This adaptability ensures that the energy harvested from fluctuating sunlight conditions can be optimally used, enhancing the overall efficiency and reliability of solar power generation [16,17].

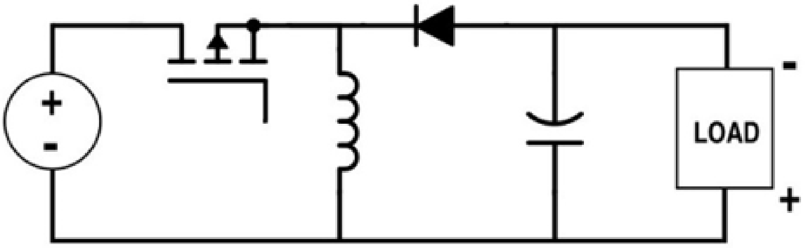


Figure 3: Buck-Boost Converter Circuit

C. FOPID Model:

The Fractional-Order PID Controller is an advanced control system component that introduces fractional calculus principles into the traditional Proportional-Integral-Derivative (PID) framework. By incorporating fractional derivatives and integrals, this controller offers enhanced flexibility in tuning and response, enabling more precise and adaptable control in complex systems, such as those found in renewable energy systems, robotics, industrial processes, and advanced engineering applications [18-20].

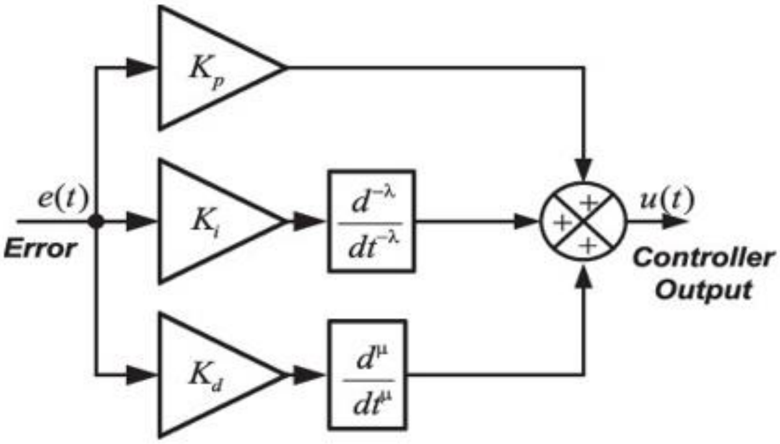


Figure 4: FOPID Block Diagram

The transfer function of this controller is as follow:

$$C(s) = K_P + K_D S^{\mu} + K_I S^{-\lambda} \qquad (2)$$

Where:

K_P, K_I, K_D are the proportional, integral and derivative gains of the controller.

μ : The order of the differential controller

λ: The order of integration controller

D. Maximum Power Point Tracking (MPPT):

One technique used in solar energy systems is Maximum Power Point Tracking (MPPT), which involves continuously adjusting operating parameters to increase the output power of solar cells.

This technology ensures efficient and optimal energy extraction from different environmental situations [21].

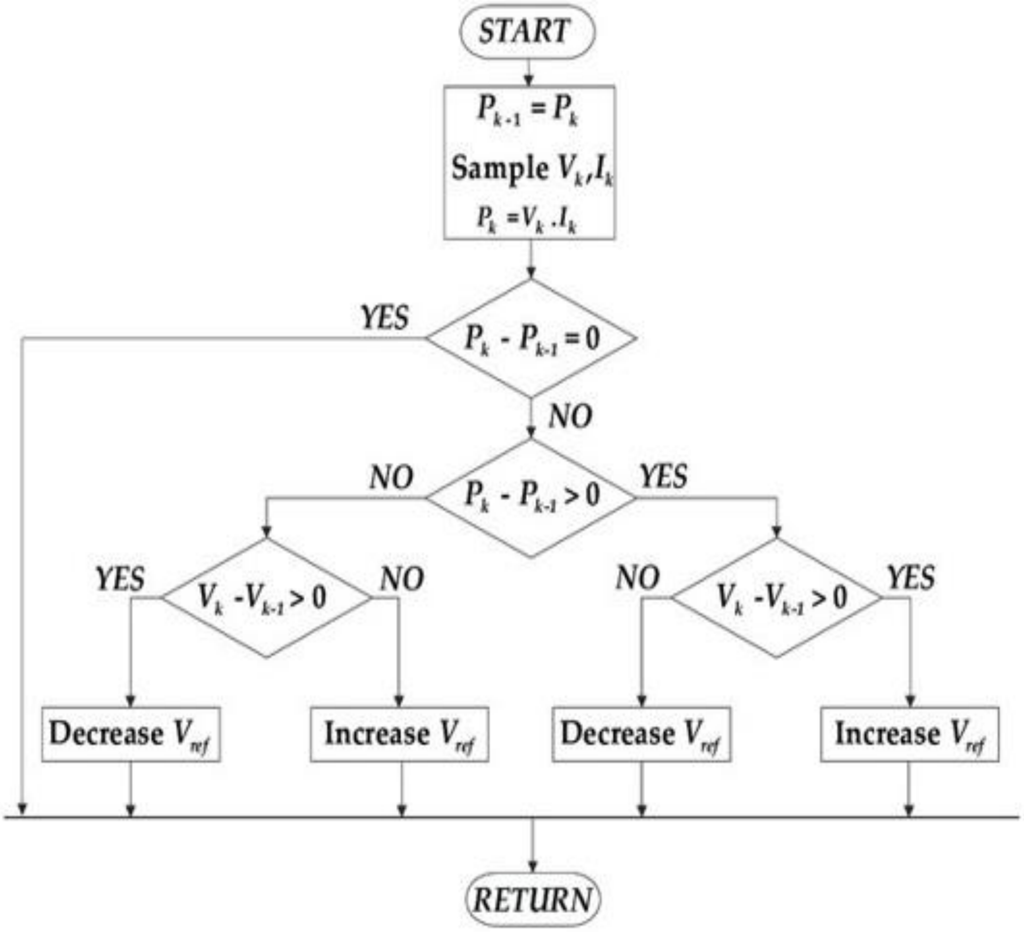
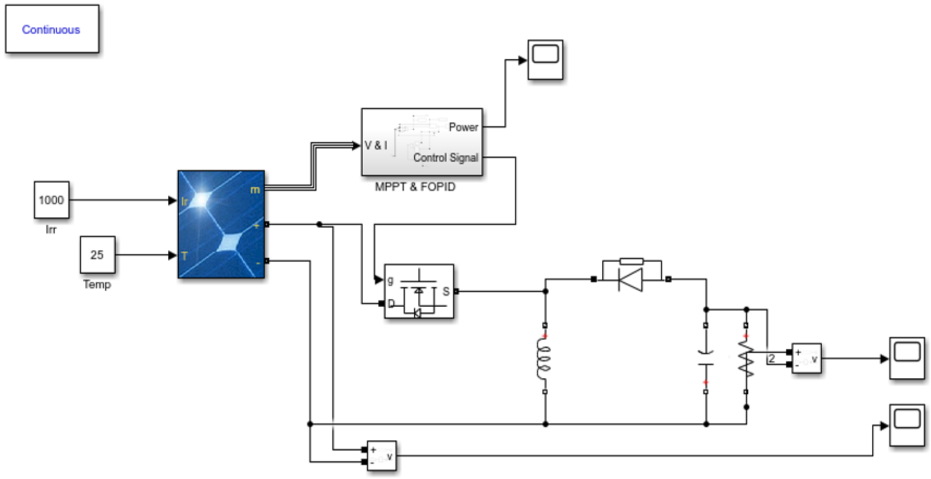


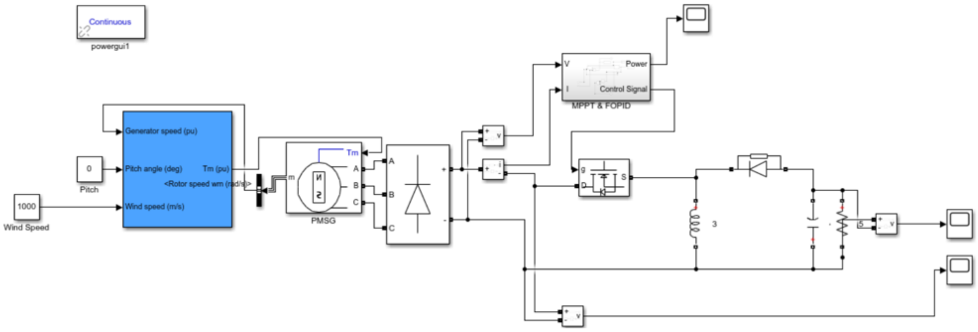
Figure 5: MPPT Flowchart

E. The Simulink Model

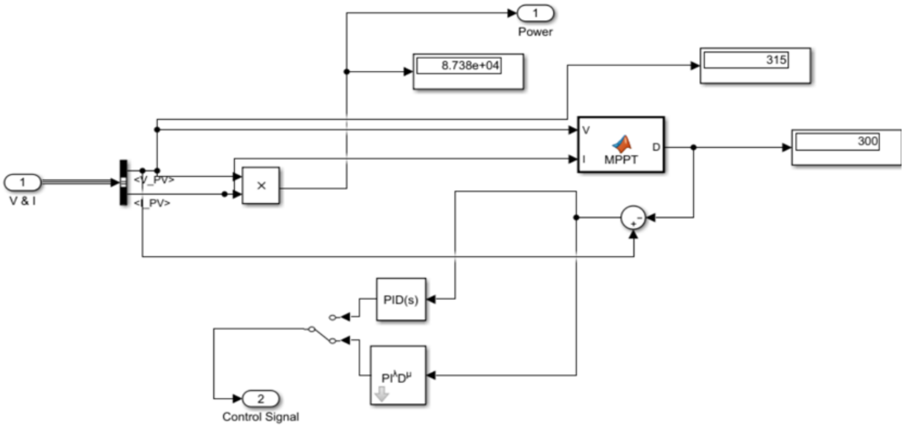
The suggested system is modeled using Matlab® Simulink, as depicted in Figure 6



(a) Solar Model



(b) Wind Model



(C) Control Model

Figure 6: The Proposed Model

III. RESULTS AND DISCUSSION

The proposed solar-wind hybrid system has the following parameters settings:

Power: 100.12e3 W

No. of solar cell: 470 (47 parallel strings × 10 series modules) cells

Irradiation: 1000

Temperature: 25 ^{0}C

Wind speed: 12 m/s

Pitch: 3

Figure 7 shows the maximum power that can be obtained at each value of the Irradiances in 25 ^{0}C.

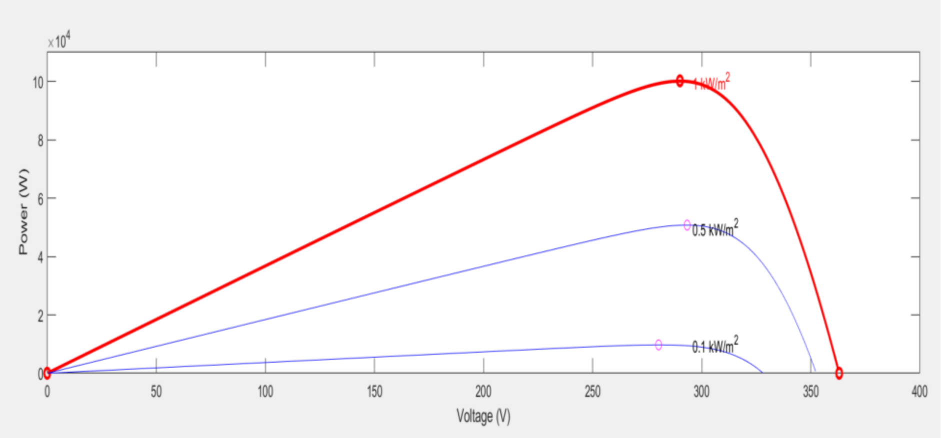


Figure 7: Maximum power in different irradiances values

Figure 8 shows the wind turbine characteristics.

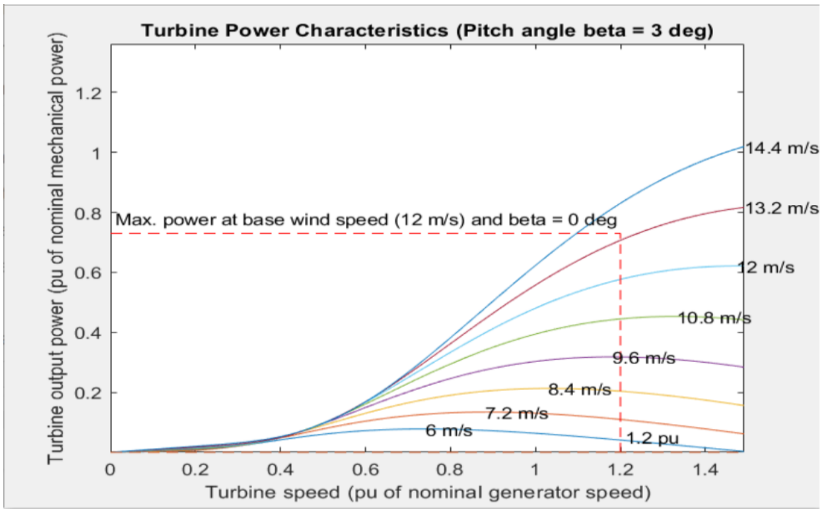


Figure 8: Wind turbine characteristics

The MPPT algorithm and the FoPID controller collaborate to optimize the duty cycle of the buck-boost converter, thereby reducing oscillations in both the output voltage and the generated power. Figures 9 and 10 depict the results of the system utilizing a PID controller, while Figures 11 and 12 illustrate the outcomes of the system when a FOPID controller was employed.

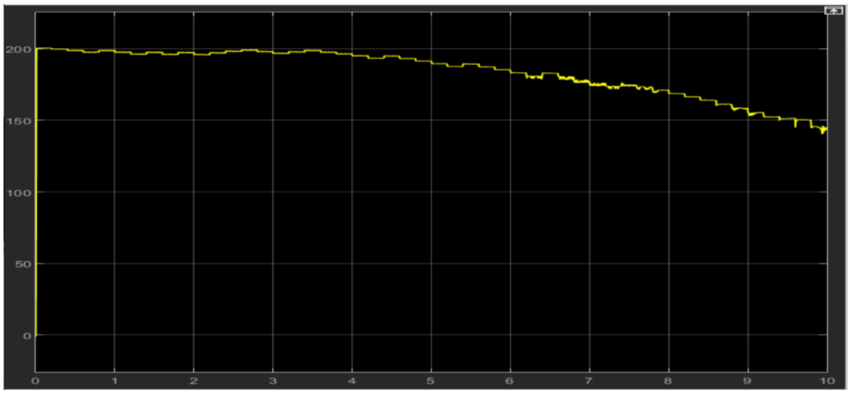


Figure 9: Output voltage of the system using PID

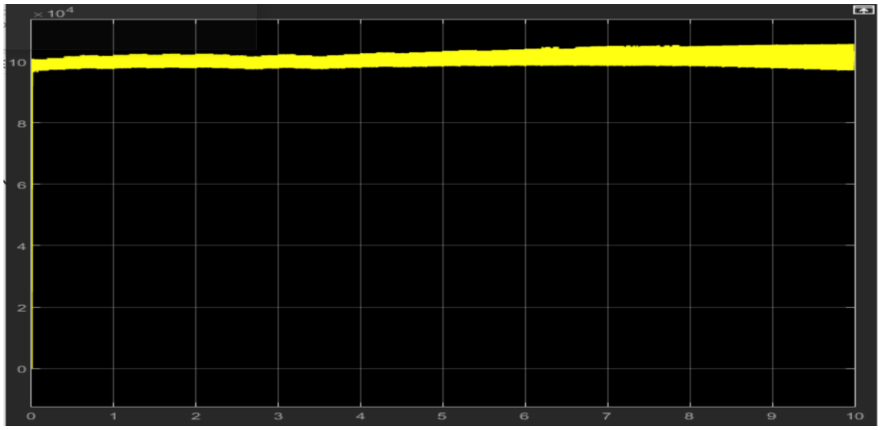


Figure 10: Power of the system using PID

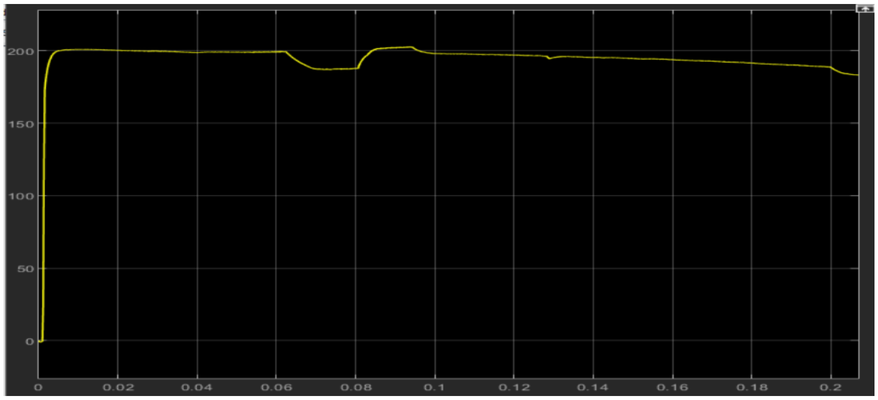


Figure 11: The system's output voltage when employing FOPID

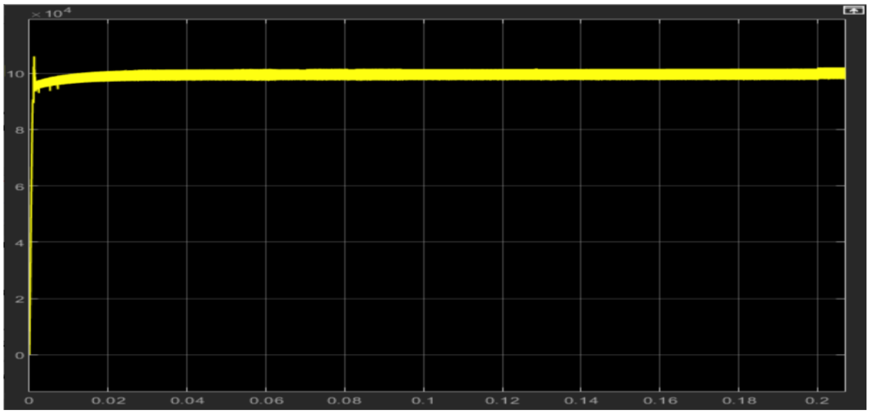


Figure 12: PID-based system power

The FOPID controller system effectively mitigated oscillations and ripples in power and voltage, as illustrated in Figures 11 and 12. Moreover, the output power of the FOPID controller system approximated the maximum power point target (MPPT) with considerable proximity.

IV. CONCLUSION

This research was conducted with the primary purpose of reducing the amount of fluctuations that occur in the power output of hybrid solar-wind systems. The study specifically investigated the efficacy of a Fractional Order PID (FOPID) controller in achieving this goal. Our findings reveal that employing this controller significantly improves the stability and reliability of the system. The use of a FOPID controller allows for better adjustment to the complex and changing nature of solar and wind energy. Our simulations demonstrated a clear reduction in power fluctuations compared to traditional PID controllers, indicating the practical benefits of adopting fractional order control.

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