International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

Design and Simulation of Solar-wind Hybrid Energy System with Trapezoidal MPPT Control for AC load Applications

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***Abstracts* - This article includes the modeling and simulation of a hybrid wind-solar power system that features an improved MPPT algorithm termed by trapezoidal perturb and observe algorithm. The suggested algorithm employs a variable step-size to obtain faster convergence and eliminate vibrations around the point of operation. The wind and the solar resources are interconnected via a simple DC-link to provide power at all times at different environmental conditions. Wind side, PMSG is applied and power electronic converters are applied to control system operation. Mathematical simulations conducted in MATLAB/Simulink have shown that simulation exhibits a better dynamic response and voltage stability and remains minimally distorted to showing less harmonic distortion, when compared to the traditional MPPT techniques. Proposed system is to improve its overall efficiency and reliability, thus it can be adopted in the grid-connected and sustainable applications of RES.**

Keywords - Solar Photovoltaic, Wind Energy Conversion, Maximum Power Point Tracking, Trapezoidal P&O Algorithm, DC-Link Voltage Stability, Power Quality, Total Harmonic Distortion.

I. INTRODUCTION

Increasing need of electrical power, combined with exhaustion of traditional sources of fossil fuels has promoted the use of sources of renewable energy. These include solar photovoltaic, wind energy systems which are mostly used as they are clean, sustainable. Nonetheless, the performance of these sources is very sensitive to the weather conditions including solar irradiance and speed of the wind resulting in variations in energy production and lowered dependability [1].

Researchers have investigated various control strategies and system designs as a way of enhancing the performance of the systems. Hybrid power generation of solar and wind has been found to be a viable way of addressing the shortcomings of either wastes [2], [3]. These hybrid systems utilize the complementary nature of solar and wind resources, and hence it improves energy supply and makes the power supply more reliable [4].

In the renewable systems, especially photovoltaic applications, efficient energy harnessing is one of the prerequisites. PV systems are normally operated under MPPT techniques. One of them is P&O technique which is frequently used due to its simplistic design and ease of application [5], [6]. Nevertheless, the traditional P&O techniques tend to generate the oscillations around the peak operating point and cannot effectively be used in highly variable conditions [7].

In order to overcome these shortcomings, a number of enhanced methods of MPPT have been proposed such as methods based on hybrid and optimization [8], [9]. Although these techniques improve the performance of tracking systems, they may increase the complexity and computational overhead of a system. Thus, creating an MPPT method which reaches superior results with the same amount of complexity increment is a research problem of significance [10].

Present research has also incumbent studies of enhancing the renewable energy systems by using hybrid systems through implementing the modern control strategy and power conversion methods [11], [12]. Algorithms of MPPT have been modified to improve the speed of tracking and minimize steady-state oscillation [13]. Moreover, it has been investigated that optimization and smart control techniques will enhance overall efficiency and power quality of RES [14], [15].

In addition, modeling and simulation environment, including MATLAB/Simulink, is important to study the dynamics of hybrid system and testing control methods before actual one can be implemented [16], [17]. These researches confirm the importance of sound system design and effective control systems to attain sustainable and stable generation of energy.

In this respect, the current paper suggests a hybrid powered system of energy alongside trapezoidal perturb and observe MPPT method with an advanced design. The suggested solution will accomplishment the aim of increasing the accuracy of tracking, decreasing oscillations, and increasing the stability of the system without having to complicate and make the proposed implementation more complex.

The rest of the paper is organized in subsequent way. Section II outlines the overall design of the proposed wind solar hybrid energy system and how it works. Section III shows the control topology with the application of the trapezoidal

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

perturb and observe MPPT strategy. The proposed system is discussed in Section IV, paying attention to the implementation of renewable sources and the improvement of the control approach. Section V presents simulation results and the performance analysis such as voltage, power output, and stability of the DC-link and a comparison of harmonic distortion. Both sections V and VI conclude the paper with major findings and contributions. Lastly, the sources used in the paper have been mentioned at the end.

II.SYSTEM DESCRIPTION

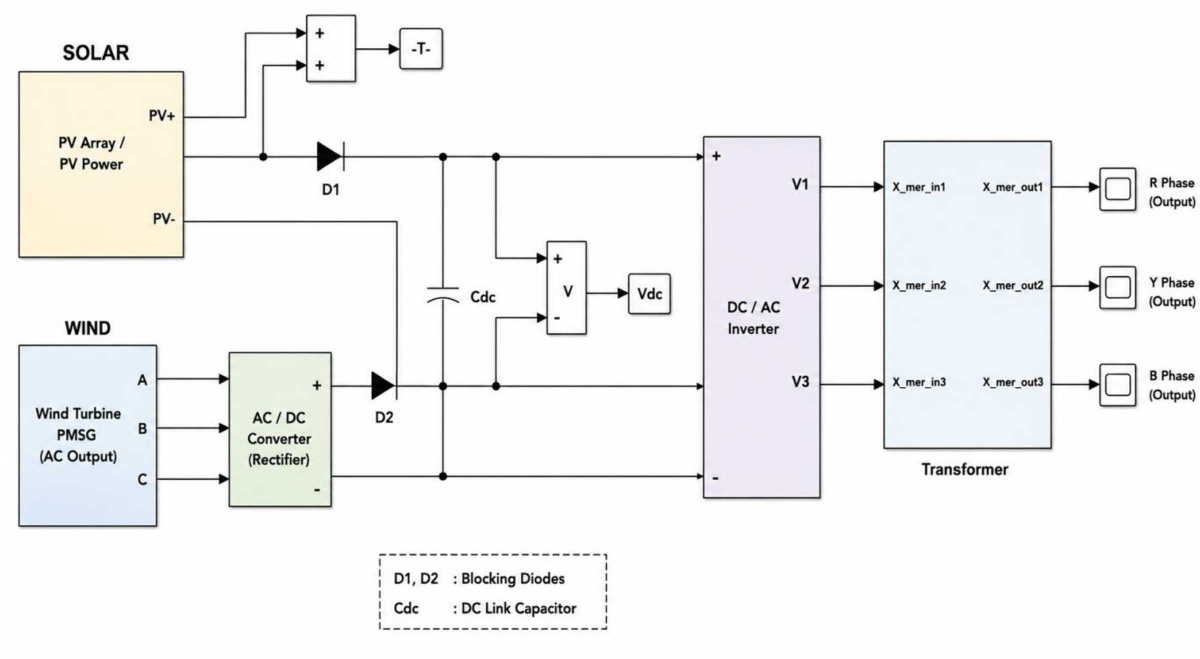

Fig.1.Block Diagram of Hybrid Power System through Power Conditioning Units

Fig. 1 shown the proposed system, which is a hybrid system comprising a combination of solar photovoltaic and wind energy sources coupled together in a common power conversion system. The architecture is also meant to provide a sustained and reliable power generation through the complementary nature of the two renewable sources.

The solar unit transforms the incident solar radiation into electrical energy through the use of DC power, whereas wind produces electrical energy by capturing the energy available from moving wind through turbine generator arrangement. It is important to note that the abiotic portions of the two sources are variable in nature and as such, their outputs vary according to the environmental conditions.

A.Power Conversion Stage

Comparing Fig. 1, the results of a solar and a wind subsystem are inputted into a common inverter with a proper interfacing stage. Inverter is also a useful item that converts the blended DC power in three-phase AC. It also provides controlled switching in order to keep the quality of the waveforms intact and minimizes distortions of the output signal.

Having a single inverter on both sources makes it easier to combine the systems and allows to use the power produced productively. Three-phase (ABC) signals are the inverter output and are further operated on in the system.

B.Output Monitoring and Traffic Control

The voltage level adjustment and electrical isolation are executed by a transformer as shown in Fig.1, and the inverter output is fed to it. This step is used to make sure that the power generated is of the needed voltage to be used in the load or in the grid.

Transformed output is then achieved as an interconnection with measurement blocks (scopes), at which important electrical parameters are measured: voltage and current. These outputs are handy in studying the performance of the system, such as stability as well as power quality.

C.System Operation

According to the design presented in Fig.1, the hybrid system will operate by utilizing power from solar and wind systems. The PV system would add substantially to the overall power output in periods that have a lot of solar irradiance. On the other hand, the wind subsystem supplements energy when the speed of the wind increases.

This synchronized operation eliminates dependence on one source of energy and enhances the reliability of the whole system. This interconnection by way of shared conversion phase enables a good use of the available renewable energy to ensure consistency and uninterrupted supply of power.

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III.CONTROL TOPOLOGY

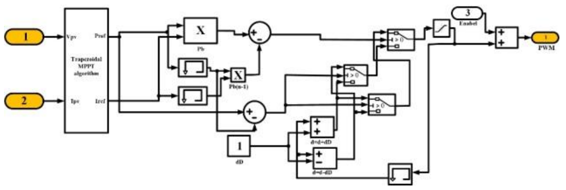

Fig.2.Control Topology of Trapezoidal P&O MPPT Algorithm for Hybrid System

The proposed system has a control structure that builds up on an improved MPPT method that utilises trapezoidal Pando method. As shown in Fig.2, control topology is used to process the real time voltage and current signals recorded by the photovoltaic system and identify the optimal operating point.

The inputs to this control block are PV voltage (V_{pv}) and PV current (I_{pv}) and these inputs are constantly monitored. The instantaneous power of the system is calculated using these signals and it forms the foundation of the MPPT operation.

1. Calculation and Comparison of Power.

Based on Fig.2, the current signal multiplied by the voltage signal is instantaneous power (P). This value is compared against the previous power sample (P_{n-1}) to obtain the direction of movement to the maximum power point. The successive values of power can be used to determine whether an operating point is approaching or reaching away the optimal point.

In comparison with the traditional P&O procedures, the suggested one involves the use of a trapezoidal concept in order to enhance the decision-making process. The controller minimizes the unwanted oscillations and the tracking accuracy by taking into account the difference in power within a specified period of time.

2. Adjustment Mechanism of Duty Cycle

As revealed in Fig.2, the control algorithm produces a new duty cycle using the results of the comparison. A variable step-size mechanism changes the duty cycle, which is denoted as (ΔD). Two potential adjustments are done:

- Increase in duty cycle ($D + \Delta D$)
- Decrease in duty cycle ($D - \Delta D$)

With this adaptive adjustment, the optimality toward the maximum power point can be achieved at a faster rate without disturbing the System stability. A variable step size will also help increase the dynamic response of the system to varying environmental conditions.

Switching and PWM Generation It plays a role in modulating the domains of power generation and manufacturing Switching and PWM Generation It is involved in switching the areas of power generation, and manufacturing.

The new duty cycle is then operated on logical switching blocks as shown in Fig.2 to decide on the right action to control. To control the operation of the switching, an enable signal is circulated such that there is a due synchronization within the control loop.

A pulse width modulation (PWM) generator is finally connected with the processed signal and generates the gating pulses needed by the DC-DC converter or inverter switches. These PWM signals have a direct effect on the operating point of the photovoltaic system and hence optimum power extraction is delivered.

3. Control Performance

Control topology Fig.2 shows that the use of control topology leads to a better performance of the MPPT system in terms of steady-state oscillations and tracking speed. The addition of the trapezoidal method allows to estimate the maximum power region more precisely, which leads to the better control of the voltage and the increased efficiency.

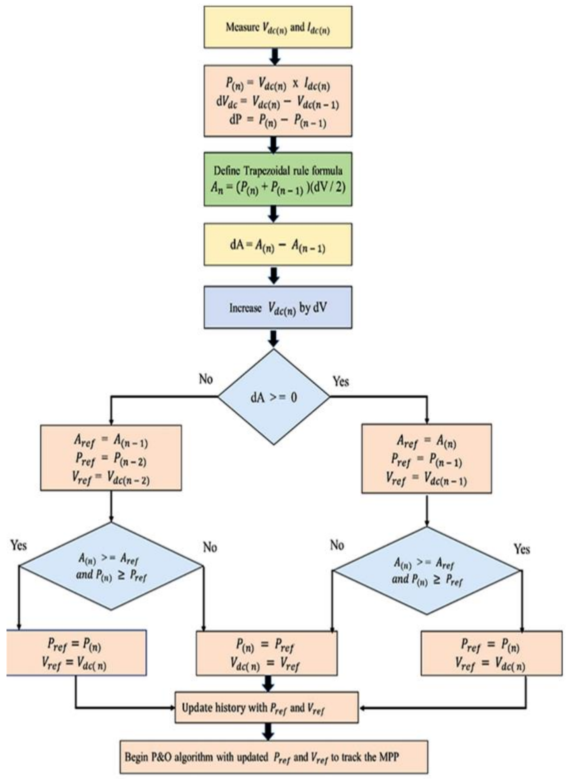

Fig.3.Flowchart of Trapezoidal-Based Perturb and Observe MPPT Algorithm for PV System

The flow chart of the series of functioning of the proposed trapezoidal-based perturb and observe MPPT method is illustrated by Fig.3. The algorithm uses the instantaneous DC voltage and current of the photovoltaic system which the algorithm uses to calculate the output power. The difference between the voltage and power of on consecutive samples is then acquired to assess an operating trend of the system.

Unlike traditional perturb and observe algorithm, the suggested method uses a trapezoidal formulation to best estimate the change in power within a specified period of time. This enables the controller to measure the direction of movement to the maximum power point with greater accuracy. Depending on the difference between the computed

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

areas, one decides whether to go on with the perturbation direction or not.

The algorithm also dynamically changes reference values of voltage and power used to change the duty cycle of the converter. Such a regulation mechanism minimises superfluous vibrations and increases the rate of convergence. This is done repeatedly, and the system can keep monitoring the maximum power point in different environmental parameters. Consequently, the suggested technique is stabilized better, has a higher tracking, and a general superior performance over the traditional approaches to MPPT.

IV.PROPOSED SYSTEM

The suggested work proposes the development of hybrid renewable energy system which is a combination of solar photovoltaic and wind energy to attain power generation that is reliable and efficient. The system takes a DC-coupled layout where the two energy sources are merged at a single DC-link which allows power to be shared intelligently across different environmental situations. Photovoltaic unit transforms solar energy into electricity depending on the irradiance and temperature, and the wind energy conversion system produces the electrical energy with the help of the turbine and the electrical generator. The combination of the two given sources in their varying operation allows to provide a more stable and reliable power supply as they are inherently variable.

In order to increase the effectiveness of the photovoltaic subsystem the more efficient maximum power point tracking design, which is based on trapezoidal perturb and observe approach is used. Unlike the traditional methods which use the predetermined perturbation steps, the proposed method automatically changes the size of the step based on the change in the operating conditions. The controller can identify the direction to the optimum operating point with increased precision by examining variation of power over a specified range of voltage. It leads to a decreased oscillatory behavior and a faster stabilization about the maximum power point particularly when there are fast environmental variations.

This DC of the two sources is added together to the power conversion stage where inverter is utilized in the production of three phases that are alternating current that can be used in real life. The inverter switching signals are produced by the pulse width modulation, controlled by the control algorithm. This provides a means of proper control of voltage and current as well as stability of the system. The control strategy is adaptive and hence the system can effectively cope with changes in input conditions.

All in all, the suggested system promises a higher level of operational performance in terms of the increased capacity of energy extraction as well as minimizing power variability. The add-on of the trapezoidal-based MPPT method helps in enhancing the stability of the voltages operated at the DC-link and enhancing the response. Moreover, hybrid set-up enhances the reliability of the system as it exploits more than one energy sourcing, so it is an appropriate solution to the contemporary renewable energy application, both grid-connected system and standalone ones.

V.SIMULATION RESULTS AND DISCUSSION

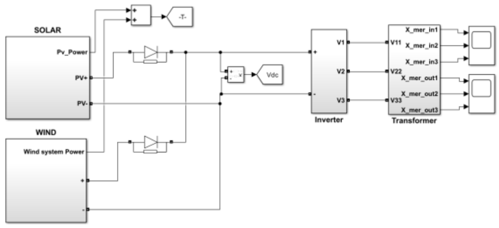

Fig. 4 Simulink model of the proposed System

Parameter	Symbol	Value
Wind Output Voltage	V_{wind}	450V
Wind Output Current	I_{wind}	15 A
Wind Power	P_{wind}	6.5kW
PV Output Voltage	V_{pv}	200v
PV Output Current	I_{pv}	26A
PV Power	P_{pv}	5 kW
Load Resistance	R_{load}	1 KΩ
Load Voltage	V_{load}	50 V

Table 1. Key System Parameters of the Proposed System

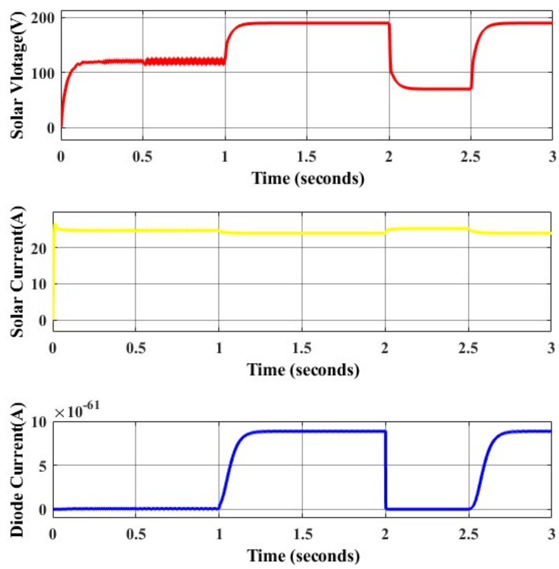

Fig. 5 Solar Voltage, Current, diode Current

The behavior of the photovoltaic subsystem is also depicted in Fig.5 where the variation of the solar voltage, current and diode current was plotted under varying operating conditions. This voltage signal indicates an initially rapid spike in the voltage and then constant operation at small amplitude variations with irradiance changes. The present profile is complementary in nature, constantly stable and changes depending on the voltage changes. The diode current is an

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International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 08 , August - 2026

indicator of the internal action of the PV model and suggests the normal operation of the nonlinear dynamics of the solar cell. The oscillations and smooth changes in the waveforms also confirm that the MPPT method whose implementation is proposed is effective in ensuring that the operation remains stable around the peak power point.

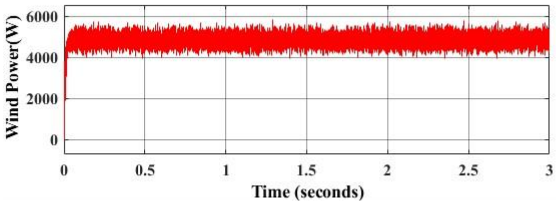


Fig. 6

Wind Turbine PMSG Output

Fig.6 indicates the output of wind energy conversion system which is the electrical output of permanent magnet synchronous generator (PMSG). The waveform shows fluctuating in nature because of variations in the wind speed which directly influences the generated power. These changes do not pose a serious problem as the output is controlled over a manageable range, implying that the system can cope with fluctuating amount of input conditions. The ability of the wind subsystem to add value to the hybrid system is evidenced by the steady average power level.

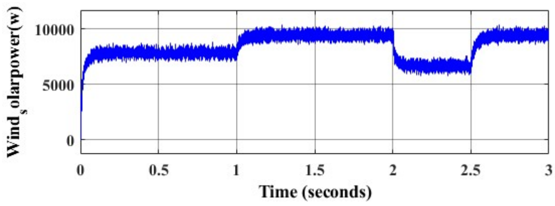
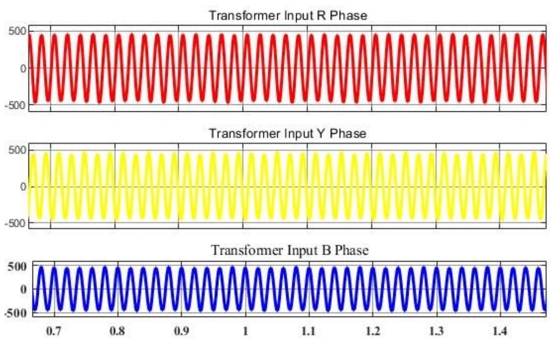


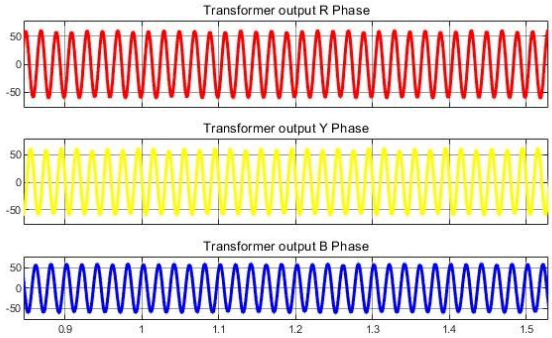
Fig.7

Combined Wind–Solar Power Output

The integrated performance of the hybrid system is illustrated in Fig. 7 where the combination of solar and wind sources gives a more steady power performance than the individual sources. This waveform shows that a variation in one generator is countered by the other and therefore, gives better continuity in generating power. The hybrid design will lessen the effect of intermittency and guarantee greater average power generation. This shows that there is efficiency in combining various sources of renewable energy to increase efficiency and reliability.



(a)



(b)

Fig. 8 (a), (b). Transformer Input and Output Waveforms

Fig. 8 (a, b) shows the three phases of input and output of the transformer. The input waveforms have equal sinusoidal waveforms with respect to the inverter output, which points to optimal conversion of DC to AC. The adjustment of the voltage level is done by the transformer output waveforms as they keep this balance. Three-phase (R, Y and B) signals, which have constant amplitude and phase shift, is the evidence of stable system operation and the performance of power delivery. The fact that these waveforms are smooth and consistent is also an indication of less harmonic distortion and better power quality.

The simulation experiments provide a clear illustration of the efficiency of the suggested hybrid system and controller approach. These are because the solar subsystem works efficiently with constant voltage and current characteristics whereas wind subsystem works continuously regardless of changes in wind conditions. The total production reveals that there is a greater stability in output as well as lesser changes of power, which justify the benefit of hybrid integration. Besides, the fact that the transformer output contains balanced three-phase waveforms is evidence that the power quality is good. The use of the trapezoidal MPPT technique is also relevant in reducing oscillations and maximizing the system performance and this is why the proposed system is applicable to practical application of renewable energy.

A.COMPARISON RESULTS

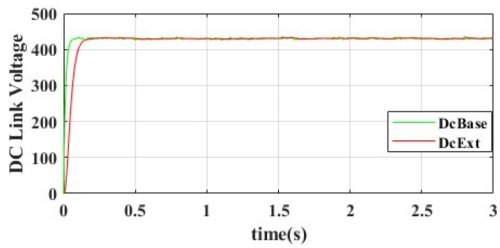


Fig. 9 DC-Link Voltage Comparison between Conventional and Trapezoidal P&O MPPT

The DC-link voltage characteristics between the traditional and proposed MPPT methods are shown in Fig. 9. The plot about the traditional P&O technique shows some observable changes and sporadic deviation around the reference operating point. Conversely, the P&O trapezoidal MPPT distribution demonstrates a much less jagged voltage profile with considerably smaller proportions of ripple. Such

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advancement implies that the suggested algorithm offers a more optimal control over the DC-link voltage due to the reduction of redundant perturbations. This increase in stability in the DC-link voltage is directly related to the resultant increase in the overall performance of the system since it leads to a stable input to the inverter stage and less stress on power electronics.

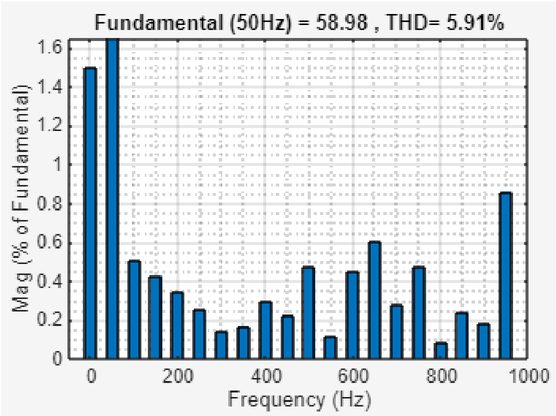

Fig. 10 THD of Output Voltage using Conventional P&O MPPT

The results of system harmonic operation under the conventional P&O MPPT technique are shown in Fig. 10 FFT analysis of the output voltage indicates that there are major components of harmonic values which leads to total harmonic distortion of about 5.91. The elevated degree of distortion response shows that the traditional technique injects variations in the procedure of switching, which adversely impacts the risk of the output signal. This distortion may result in further losses and low efficiency in normal power systems.

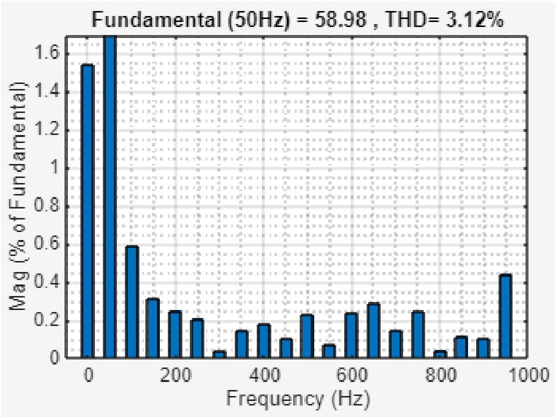

Fig. 11 THD of Output Voltage using Trapezoidal P&O MPPT

Table 2 Voltage THD Comparison

Parameter	P AND O THD	Trapezoidal P and O THD
Voltage	5.91	3.12

The FFT result of the trapezoidal P&O MPPT technique proposed is presented in Fig.11. The outcomes show that there is a substantial decline in harmonic content, where the THD value reduces to about 3.12%. The quality of the waveform is positively correlated with the ability to have a smoother duty cycle variation and smaller oscillations in the control algorithm. Less harmonic distortion will also increase the effectiveness of power conversion as well as compatibility with the grid and load requirements is improved.

The fact that the trapezoidal P and O method is better than the conventional one is easy to identify in its comparison with the proposed ones. The fact that DC-link voltage variability is decreased and that the harmonic performance level improves significantly proves that the suggested control strategy promotes the stability and power quality. The reduction in THD between 5.91 percent and 3.12 percent is indicative of the algorithm in reducing distortion and enhancing the waveform properties. On balance, the results of the simulation prove that the suggested system will offer a more effective and accurate solution to be applied in hybrid renewable energy.

VI. CONCLUSION

In this work, the modeling and simulation of a hybrid wind-solar energy system using an improved approach of trapezoidal perturb and observe maximum power point tracking strategy were presented. The combination of solar and wind resources with the help of a common DC-link enhanced the continuity and reliability of power generation in the presence of different environmental conditions. It was found that the proposed MPPT technique performs better than the traditional one because it has faster convergence, lower oscillations around the operating point. The results of the simulation proved that the proposed system offers better DC-link voltage stability and better dynamic response. In addition, the harmonic analysis revealed that the total harmonic distortion has been minimized with the percentage decreasing to 3.12 in the proposed method as compared to 5.91 in the conventional approach. This increase in the quality of power can point to the success of the trapezoidal MPPT algorithm in the reduction of distortion and in providing improved system performance. On the whole, the hybrid system proposed can be claimed as a stable and efficient system in the field of renewable energy use. The enhanced control strategy increases the energy extraction, stability of the system and power quality, hence, it is applicable to both grid-connected and standalone systems.

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