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Performance Analysis of MPPT-Based Grid-Connected Hybrid Renewable Energy Systems

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ABSTRACT

The increasing demand for clean and sustainable energy sources has driven the development of hybrid renewable energy systems that integrate multiple sources such as solar and wind. To optimize the performance of these systems, advanced control techniques such as Maximum Power Point Tracking (MPPT) algorithms are crucial. This research presents a performance analysis of MPPT-based grid-connected hybrid renewable energy systems. The study begins with a comparative analysis of various MPPT algorithms, including Perturb and Observe (P&O), Incremental Conductance (IC), and Fuzzy Logic Control (FLC). Factors such as accuracy, convergence speed, computational complexity, and robustness to varying environmental conditions are considered to determine the most suitable algorithm for the hybrid system. The analysis then focuses on evaluating the power generation capabilities and grid integration challenges of the hybrid system. Energy output characteristics, power quality, and grid stability are investigated under different operating conditions to ensure reliable and consistent power supply to the grid. the research explores system efficiency and energy management strategies. Energy conversion efficiency, power loss analysis, and advanced control techniques are examined to optimize power flow and enhance overall system performance. The aim is to minimize energy wastage and optimize energy storage and distribution.

INTRODUCTION

The urgent need to address climate change and transition towards a sustainable energy future has fueled the adoption of renewable energy sources. Hybrid renewable energy systems, which combine multiple sources such as solar and wind, have gained significant attention due to their potential for enhanced energy generation, improved reliability, and reduced environmental impact. To maximize the efficiency and effectiveness of these systems, advanced control techniques such as Maximum Power Point Tracking (MPPT) algorithms play a crucial role.

MPPT algorithms are employed to optimize the energy conversion process and ensure that renewable energy systems operate at their maximum power points. By continuously tracking and adjusting the operating conditions of the energy sources, MPPT algorithms enable optimal power extraction and improve overall system performance. This is particularly important in grid-connected hybrid renewable energy systems, where the generated energy needs to be efficiently integrated into the existing power grid.

The performance analysis of MPPT-based grid-connected hybrid renewable energy systems holds great significance for several reasons. Firstly, it enables the identification and selection of the most suitable MPPT algorithm for a given hybrid system. Different algorithms, such as Perturb and Observe (P&O), Incremental Conductance (IC), and Fuzzy Logic Control (FLC), offer varying levels of accuracy, speed, and adaptability to changing environmental conditions. Evaluating their performance will facilitate informed decision-making during system design and implementation.

Secondly, analyzing the power generation capabilities and grid integration challenges of hybrid renewable energy systems provides insights into their operational characteristics. Understanding the energy output, power quality, and stability of the system under different operating conditions is essential to ensure reliable and consistent power supply to the grid. This analysis will aid in optimizing the system's performance and minimizing disruptions or fluctuations in power generation. investigating the overall system efficiency and energy management strategies is crucial for maximizing the utilization of renewable energy sources. By assessing energy conversion efficiency, identifying power losses, and exploring advanced control techniques, researchers can develop strategies to improve system efficiency, minimize wastage, and optimize energy storage and distribution. assessing the economic viability of MPPT-based grid-connected hybrid renewable energy systems is paramount for wider adoption. Understanding the costs involved, including initial investments, maintenance expenses, and payback periods, will enable stakeholders to make informed decisions regarding the feasibility and long-term benefits of implementing such systems. this research aims to perform a comprehensive performance analysis of MPPT-based grid-connected hybrid renewable energy systems. By addressing key aspects such as MPPT algorithm comparison, power generation and grid integration, system efficiency and energy management, and economic viability, the findings of this study will contribute to the advancement and optimization of hybrid renewable energy systems, promoting a sustainable and greener energy future.

METHODOLOGY

Mppt Algorithm

Maximum power point tracking (MPPT) is an algorithm that is used in photovoltaic (PV) systems to change the impedance measured by the photovoltaic system so that the photovoltaic system stays close to the photovoltaic system even when things like sunlight, temperature, and load change. This makes it possible for the solar system to stay as close as possible to it. Engineers use the maximum power point tracking (MPPT) method to increase the amount of power that solar systems produce. The programme keeps track of how much power is used to make sure that the system is always running at the "maximum power point" (also called the "maximum load") on the power processing line. The next line shows how this is true. Maximum Power Point Tracking (MPPT) is a method that is often used to build controls for solar systems. The algorithm takes into account the different amounts of radiation (sunlight) and temperature to make sure that the solar system makes the most electricity possible. Maximum voltage control is a method that is often used in wind turbines and solar (PV) systems to get more power out of them in any situation. This idea is about solar energy, but it can also be applied to light sources that change often, like optical power transfers and thermal solar cells. In terms of how the solar system is connected to the inverter, the external network, the battery pack, or any other loads. But no matter what the end goal of solar energy is, MPPT solves the main problem that the efficiency of solar cell transmission depends on the amount of sunlight that hits the solar panels and the features of the load. This is the problem that MPPT helps fix. When there is a change in the way the sun shines, there will also be a change in the way power can be sent so that it is as efficient as possible. When there is a change in the way the load works, the system will become more efficient to keep the power transfer as efficient as possible. The word "most vital point" refers to this part of the load, and "most productive point technique" (MPPT) is the process of finding the most productive point and keeping the load-carrying part there. Maximum power point tracking (MPPT), which can be built into the circuitry so that it puts all the loads on the solar cell and turns the power, current, and frequency to other devices or systems, solves the selection problem. The best amount of weight that the battery can carry at any given time. The link between temperature and absolute resistance in solar cells is complicated. This leads to the production of a non-volatile product that can be studied using the IV cycle. This product can be looked at to see if the solar cell is working properly or not. The MPPT system checks the output of the solar cell and then uses the level of resistance (load) that, given the conditions, will make the solar cell produce the most electricity. In power converter systems, it is common to find devices that track the highest power point. These systems can automatically convert, filter, and control the flow of power to different loads, like the grid, a battery, or an engine.The sun converter can change direct current to

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alternating current and may have MPPT: This type of inverter checks the power output (curve IV) of the solar model and uses a load (resistor) that is meant to get the most power possible.

• MPP power (Pmpp) is the product of MPP voltage (Vmpp) and MPP current (Impp).

Boost Converter

The voltage coming out of a switch-mode DC-to-DC converter with a boost converter is higher than the voltage going in. A boost rectifier is another name for the boost converter. This thing is also called a boost converter. The Boost converter gets its name from the fact that the input voltage is raised to a higher level than the input voltage. This is similar to how the boost transformer works. In order to follow the law about energy conservation, the amount of power put in must be equal to the amount of power taken out (assuming there is no loss in the circuit).

$$\text{Input power } (P_{in}) = \text{output power } (P_{out})$$

Since $V_{in} < V_{out}$ in a boost converter, it follows then that production current is less than the input current than in boost converter

$$V_{in} < V_{out} \text{ and } I_{in} > I_{out}$$

Principle of operation of Boost converter: The basic way a booster converter works is that the inductor in the input circuit can handle sudden changes in the input current. When the switch is open, energy can be saved as magnetic power in the inductor. When the switch is closed, the energy can be released. If the capacitor in the output circuit is thought to be big enough, the time constant of the RC circuit in the output step is thought to be bigger. A longer time constant compared to the change period can help make sure that the production voltage stays the same. Vo (t) = Vo (constant)

Circuit diagram of Boost converter: The circuit diagram of the boost converter is shown in the figure below

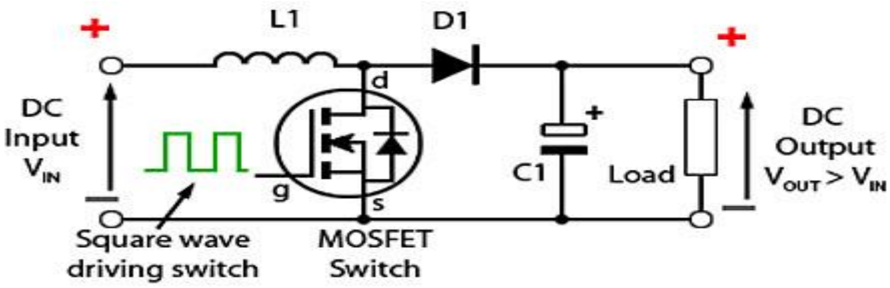

Figure 1: Boost Converter

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Operation:

Step 1

If the switch is in the closed position, one of two things will happen: either the current will run through the inductor anticlockwise, or the inductor will save energy by making a magnetic field. On the left side of the inductor, you can see that the voltage is going up.

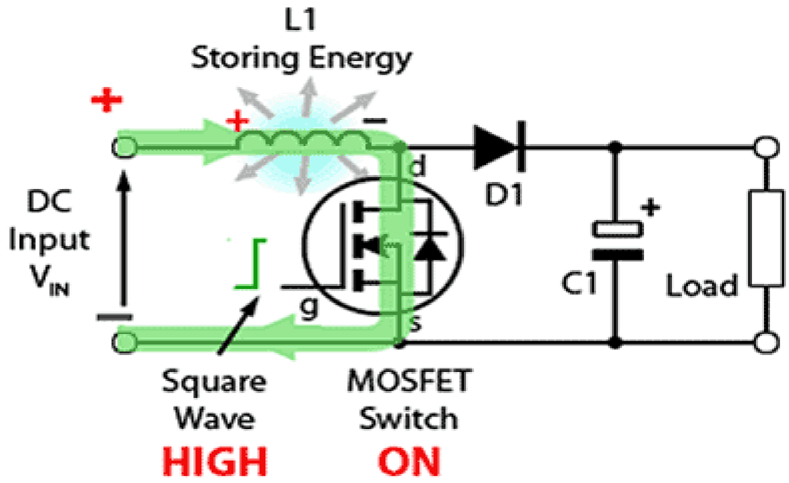

Figure 2: Boost Converter Switch Close

Step 2

When the switch is off, the current goes down and the resistance goes up. This gets rid of the magnetic field that was there before, letting the current keep going to the load. Because of this, the polarity has changed, which means that the negative charge will now be on the left side of the inductor. Because of this, the two power sources will be connected in series, which will make the capacitor get a higher voltage through diode

D.

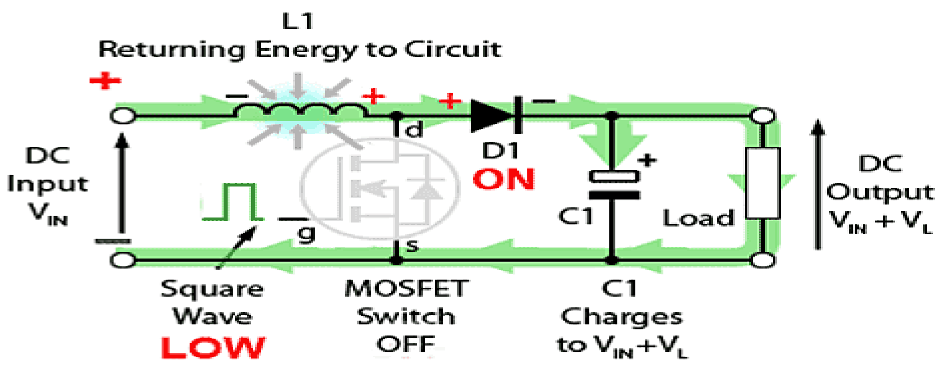

Figure 3: Boost Converter Switch Open

Working mode for boost converter

The boost converter can operate in two modes

a) In a state of continuous conduction, the flow of current into the inductor never stops. This means that the inductor is only partly charged before the button turn starts.

b) When the switching cycle is over and there is no current going through the inductor, the wire is said to be "disconnected." This means the inductor has lost all of its charge.

Circuit analysis of boost converter

During the analysis process, it is assumed that the actual oscillation (at least to a minimum) through the input and the volt oscillation through the capacitor is very small, so they change lines. To facilitate analysis and compare it to its actual value. The results we obtained from this study were very accurate

Case 1: When switch S is on

When the switch is turned on, the diode conducts because the n-terminal voltage of the diode is higher than the voltage of the p-terminal, which is short-circuited to ground through the switch.

In this mode, the inductor is charged, and the inductor current increases. The current flowing through the inductor is

$$I_L=(1/L)*\int V * dt \qquad \text{eq.4.1}$$

Assume That Prior To The Opening Of Switch The Inductor Current Is $I'_{L,\ Off}$. Since The Input Voltage Is Constant

$$I_L,Off=(1/L)*\int (vin) * dt + I'_{L_{off}} \qquad \text{eq.4.2}$$

Assume that the switch will stay open for the given number of seconds, which can be found by multiplying the duty cycle, D, by the switching time period, Ts. When the switch is in the "on" position, the amount of current passing through the inductor is given as

$$I_L,on=(1/L)*V_{in}*D * TS+I'_L \qquad \text{eq.4.3}$$

$$\text{Hence } \Delta I_L = (1/L)*V_{in}*D*T_s. \quad \text{eq.4.4}$$

Case 2: When the switch is off

When off, the diode will short circuit, and the boost converter circuit can be drawn as follows: The inductor is now discharged through the diode and RC combination. Assume that before the voltage switch is turned off, the inductor current is I and turns off. The current flowing through the inductor

$$\text{is } I_{L,OFF}=-(1/L)*\int(Vin-out)*dt+I_L'',off \quad \text{eq.4.5}$$

Note that the negative sign means that the inductor is discharged. Assume that the switch-off time is (1-D) * Ts, where D is the operating cycle, and Ts is the switch-on time. The current flowing through the inductor at the end of off mode is

$$I'''_{L,\,off} = -(1/L)*(V_{in}-V_{out})*(1-D)*T_s + I''_{L,\,off} \quad \text{eq. 4.6}$$

Since the current flowing through the inductor does not change suddenly, under steady-state conditions, the current at the end of the on-state must be equal to the current at the end of the off-state. In addition, the current at the beginning of the closed state must be equal to the current at the end of the open state. Therefore

$$I'''_{L,\,off} = I_{L,\,on}, \text{ also } I''_{L,\,off} = I''_{L,\,off} \quad \text{eq. 4.7}$$

Using the equations 4.1 and 4.2 we get

$$(1/L)*V_{in}*D*T_s = (1/L)*(V_{in}-V_{out})*(1-D)*T_s \text{ (re-insert properly)}$$

$$V_{in}*D=-(V_{in}-V_{out})*(1-D)$$

$$V_{in}*(D-1+D) = V_{out}*(1-D)$$

$$V_{out}/V_{in} = 1/(1-D)$$

Since $D < 1$ $V_{out} > V_{in}$. Assuming , losses in the circuit and applying the law of protection of energy

$$V_{out}*I_{out} = V_{in}*I_{in}$$

This means I_{out} / I_{in} = (1-D), so Iout <Ii .As the operating cycle increases, the output voltage increases, and the output current decreases. However, due to lumpy element resistance, inductors, and parasitic elements in capacitors, the boost ratio Vout / Vin decreases at higher operating cycles and approaches zero at unit operating cycles.

Discontinuous condition mode

As previously mentioned, when the converter operates in a discontinuous state, the inductor completely deplete its stored energy before the switching cycle is completed. The figure below shows the current and voltage waveforms of the boost converter in discontinuous mode. The inductor consumes all accumulated current during the charging interval for the same changeover cycle in discontinuous mode. The current flowing through the inductor is

$$I_L=(1/L)*\int V * dt$$

(1/L)*area under the curve of voltage v/s time. Hence from the waveforms shown in the

$V_{in}*D*T_s = -(V_{in}-V_o)*\delta*T_s$(negative sign signifies that the inductor is discharging)

$$V_{out}/V_{in} =(D+ \delta)/ \delta$$

and the ratio of output to input current from law of conservation of energy is $I_{out}/I_{in} =\delta/ (D+ \delta)$.

Battery

A battery is a piece of equipment that has one or more electrical cells. The battery can send energy to things like lights, cell phones, and electric cars because it can connect to the outside world. When the battery is being used, the cathode is the positive terminal and the anode is the negative terminal. The electrons that make their way to the positive electrode through an external circuit come from the negative terminal, which has a mark on it to show that it is negative. When the battery comes into touch with a load from the outside, the redox process turns the energy reactant into a product with less energy. The loss of free energy is shown by an increase in the amount of electrical energy in the area that is open to the environment. Before, the word "battery" was used to describe a device with more than one battery. Now, it's more common to use it to describe a device with only one battery.

RESULT AND IMPLEMENTATION

MATLAB Simulink makes it possible to use the Maximum Power Point Tracking (MPPT) method for wind and solar power systems. Both the solar panel and the wind machine have been modelled in MATLAB. The solar panel gets readings of the temperature and amount of light shining on it. The main things that affect the voltage between the solar panel's output ports are the temperature and the amount of light hitting the panel. Between the solar panel and the boost converter, a link has been made. The converter changes the solar panels' impedance so that it matches the impedance of the load. This makes it possible for the solar photovoltaic system to send as much power as possible to the load. The boost converter is what takes care of the load. The solar screen works as a power source that sends out power whenever the load changes. The solar panel's maximum power point tracking (MPPT) can be done by using both the incremental conductance method and the perturb and observation technique.

Simulation results of Incremental Conductance Method

People often think of getting power from the sun and wind as an alternative way to make power that is better for the world and could help solve problems caused by the need for power. The goal of this study is to come up with a standalone hybrid power-generating system made up of a solar power source, a permanent magnet synchronous generator (PMSG), and an AC load. A maximum power point tracking (MPPT) supervisory control unit has been put in place to make the most of the simultaneous energy harvesting from the total power production in different climates. The amount of power that can be made from each source of energy and the amount of power that is needed are both taken into account and put into different categories. To get the most out of a photovoltaic (PV) system, the Maximum Power Point Tracking (MPPT) controller uses the Perturb & Observe (P&O) method as its control logic. On the other hand, a wind power system uses the Hill Climb Search (HCS) algorithm as MPPT control logic.

By comparing the incremental conductance to the instantaneous conductance, one can use the incremental conductance method to find out what the output voltage of the PV module is. When the instantaneous conductance is the same as the gradual conductance, the power output is at its highest level. The PV module's terminal voltage is changed all the time and at regular intervals so that the incremental conductance gets closer to being the same as the immediate conductance.

This is represented in the following equation (Ting-Chung & Yu-Cheng 2012).

In the voltage source region,

$$\frac{\partial Ipv}{\partial Vpv} > -\frac{Ipv}{Vpv} \rightarrow D = D + \Delta D \text{ (Increment D)}$$

In the voltage source region,

$$\frac{\partial Ipv}{\partial Vpv} < -\frac{Ipv}{Vpv} \rightarrow D = D - \Delta D \text{ (Decrement)}$$

At MPP $\frac{\partial Ipv}{\partial Vpv} = -\frac{Ipv}{Vpv}$ $D = D$ (retain D)

The incremental conductance method is explained in detail in chapter 4 for the maximum power point tracking for solar PV energy conversion system. The algorithmic steps are given below:

Algorithmic steps:

Step 1: Sense the two consecutive voltages and current of solar PV

Step 2: Calculate the dI/dV.

Step 3: If dI/dV >0, the operating point is on the left of MPP. Increment the voltage.

Step 4: If dI/dV <0, the operating point is in the right of MPP. Decrement the voltage.

Step 5: Go to step 1.

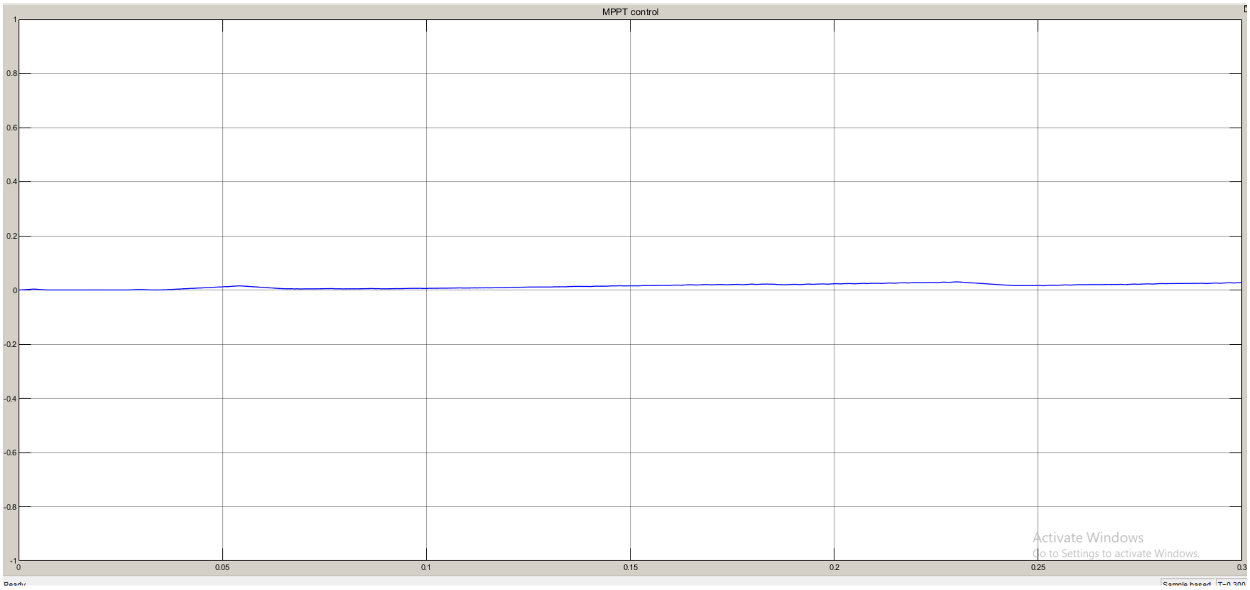

Figure 4 MPPT Output

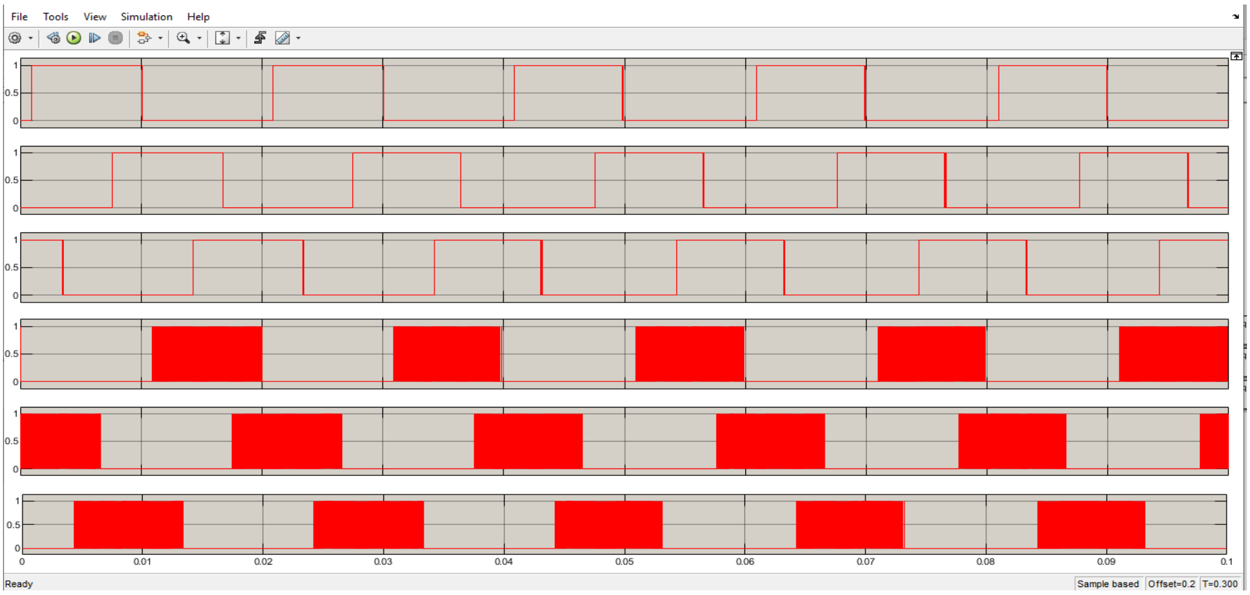

Figure 5: Switching Pulse

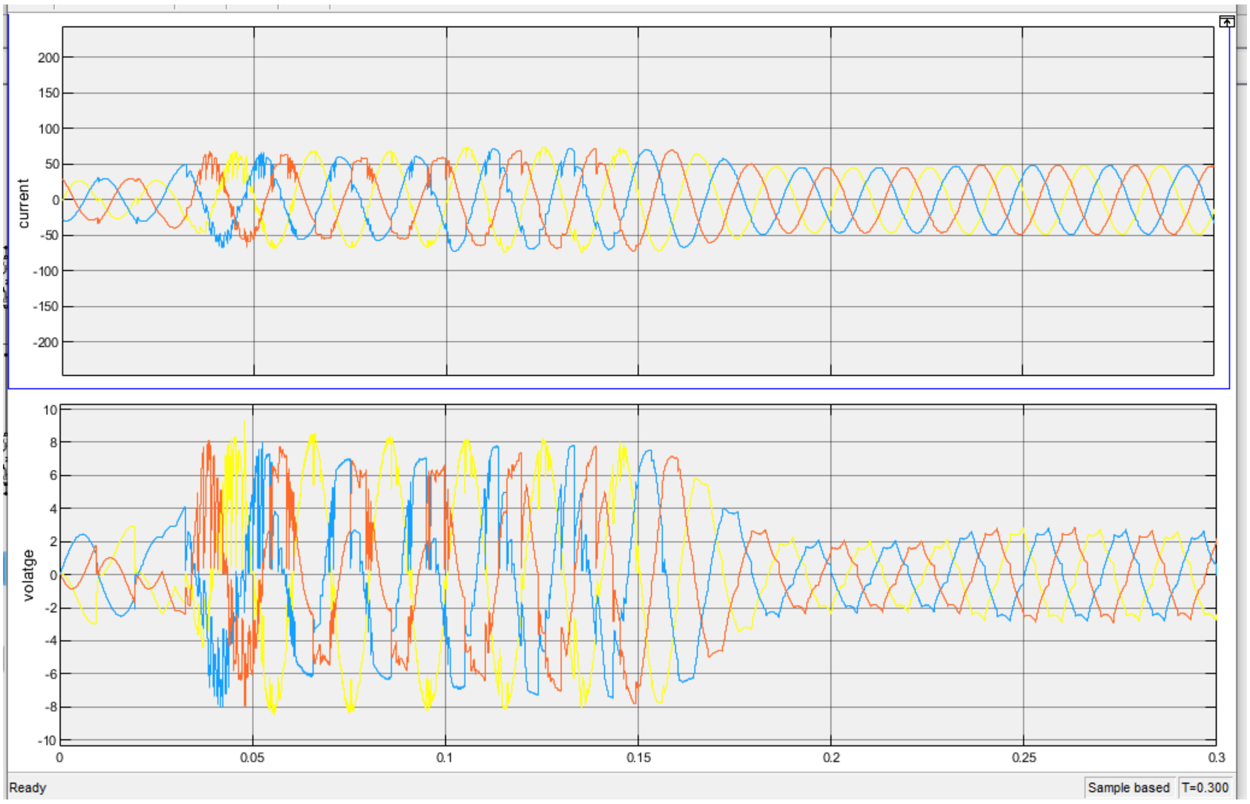

Figure 6 Grid Voltages and Current

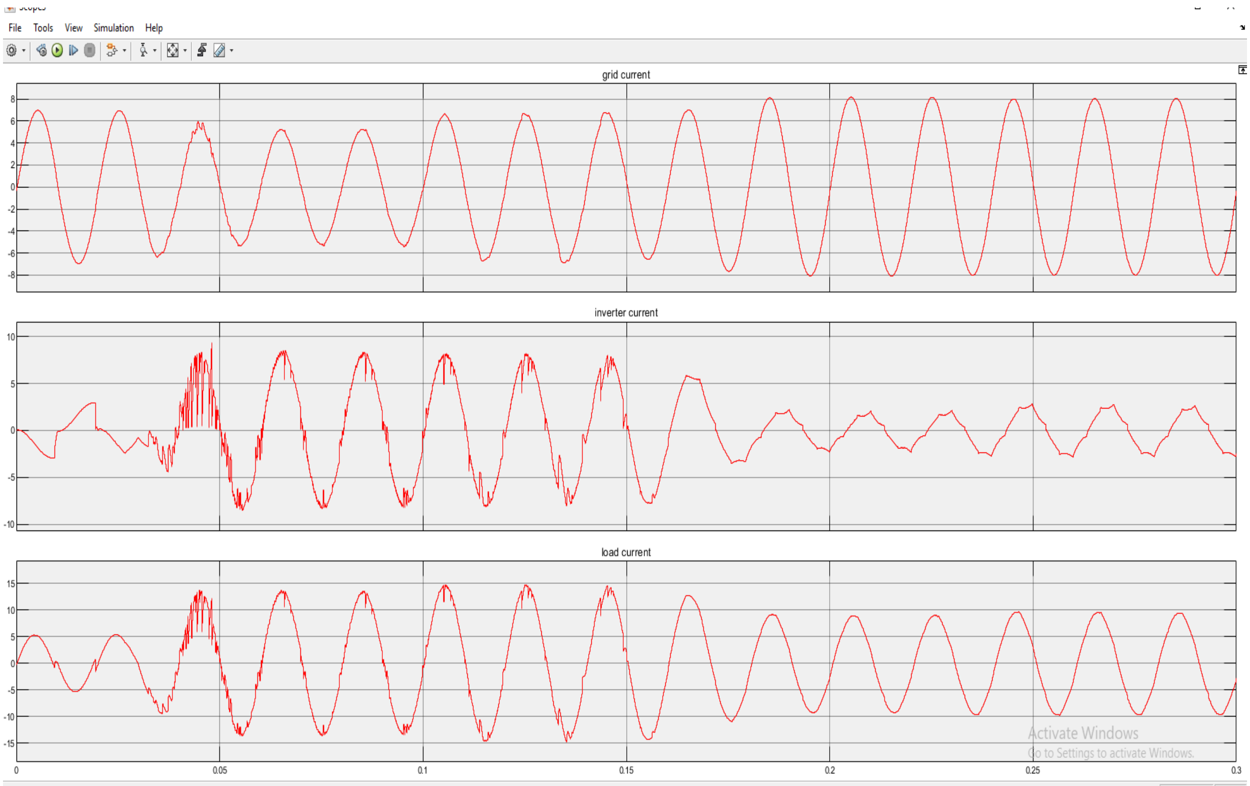

Figure 7 Grid, Load and Inverter Current

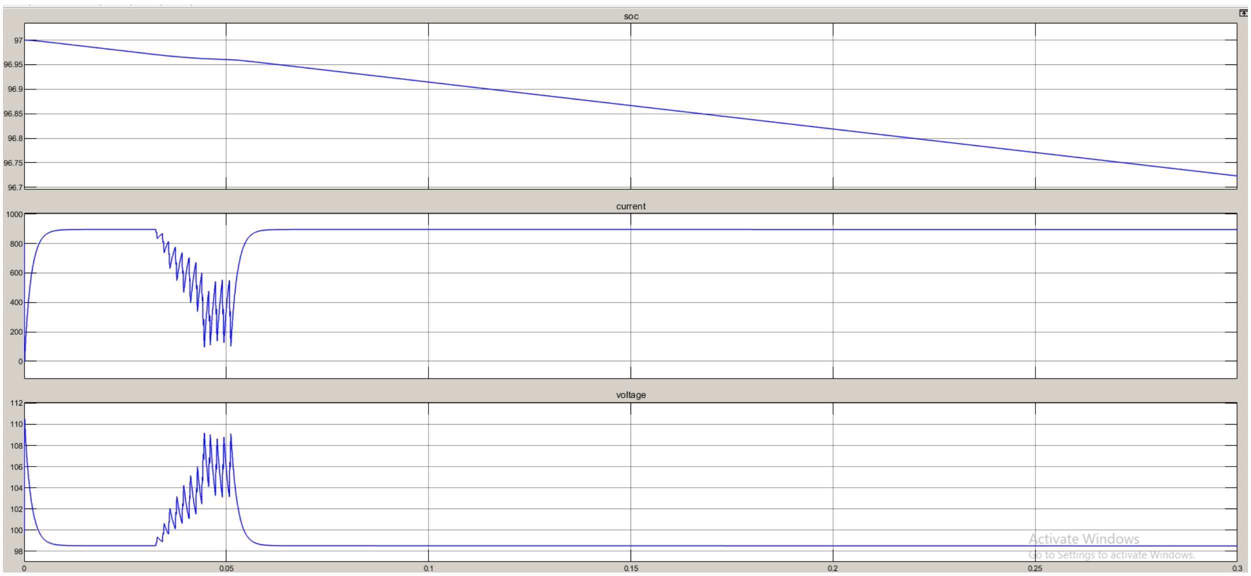

Figure 8 Battery Output

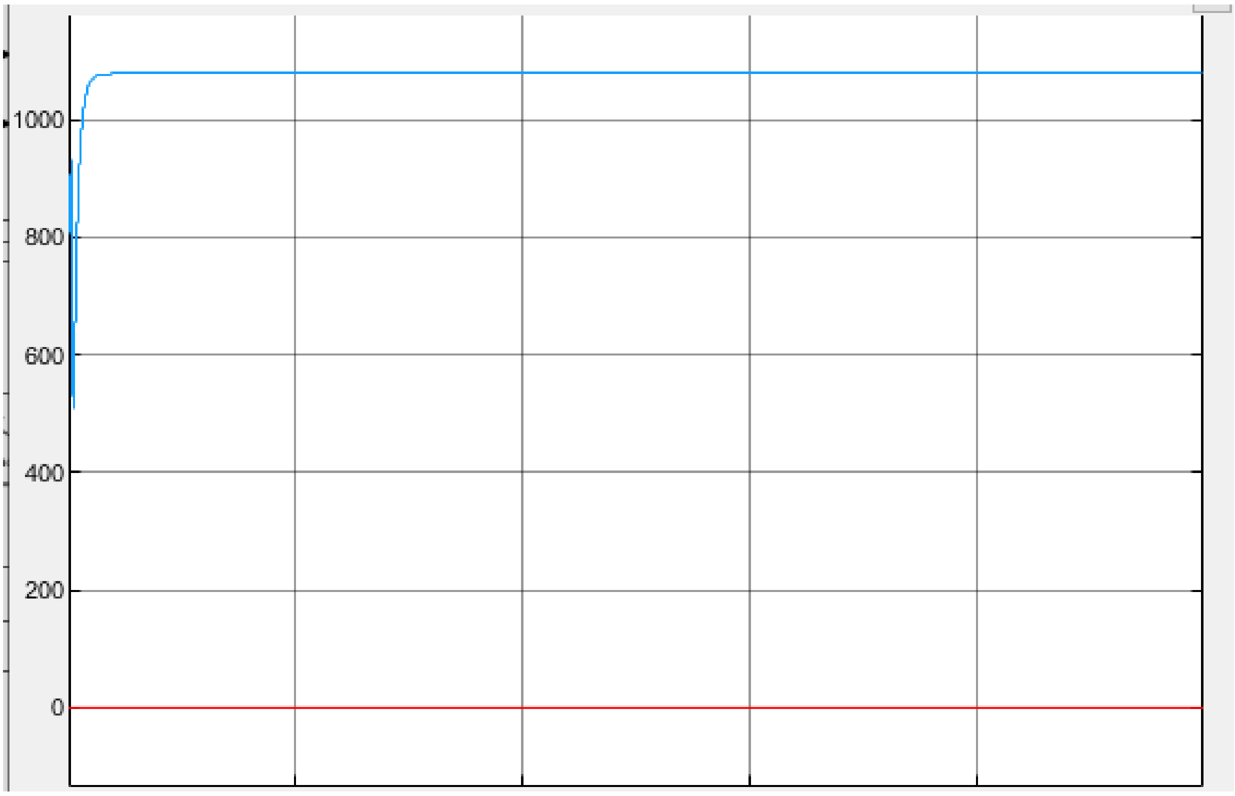

Figure 9 : Solar Output

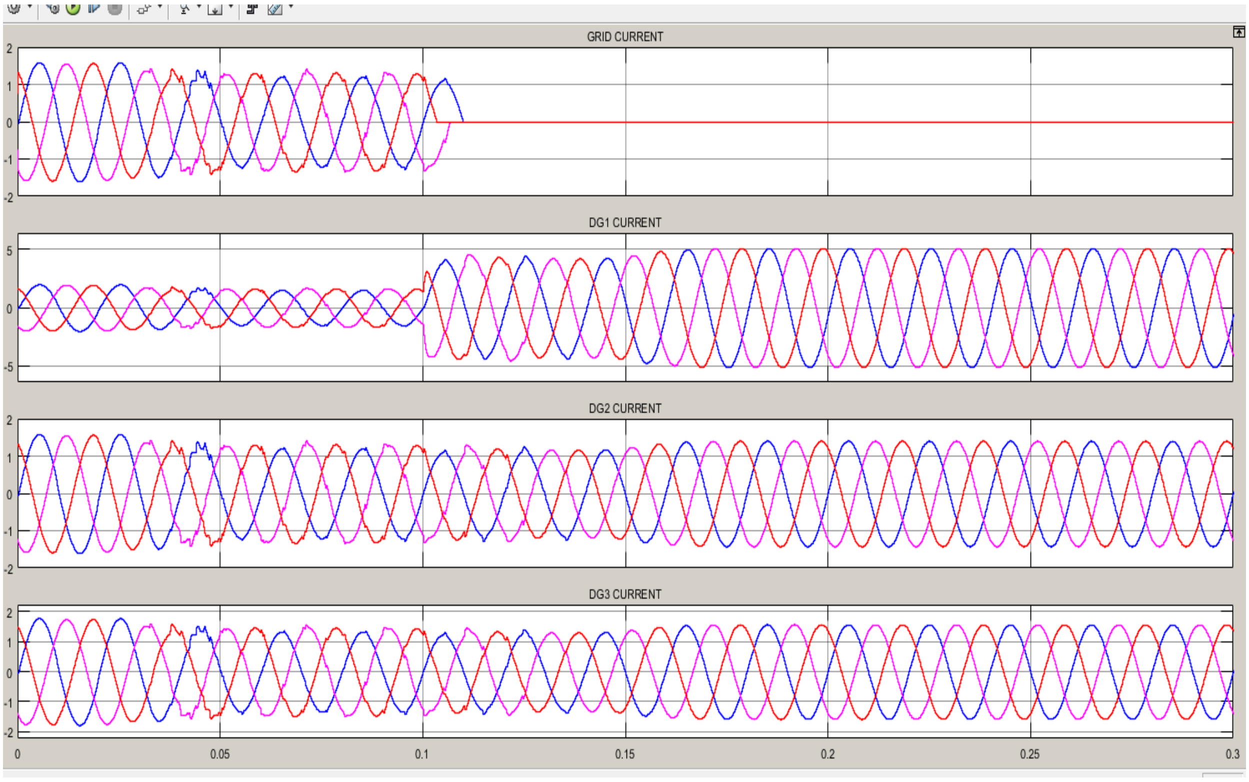

Figure 10 Grid, DG1, DG2, DG3 Current

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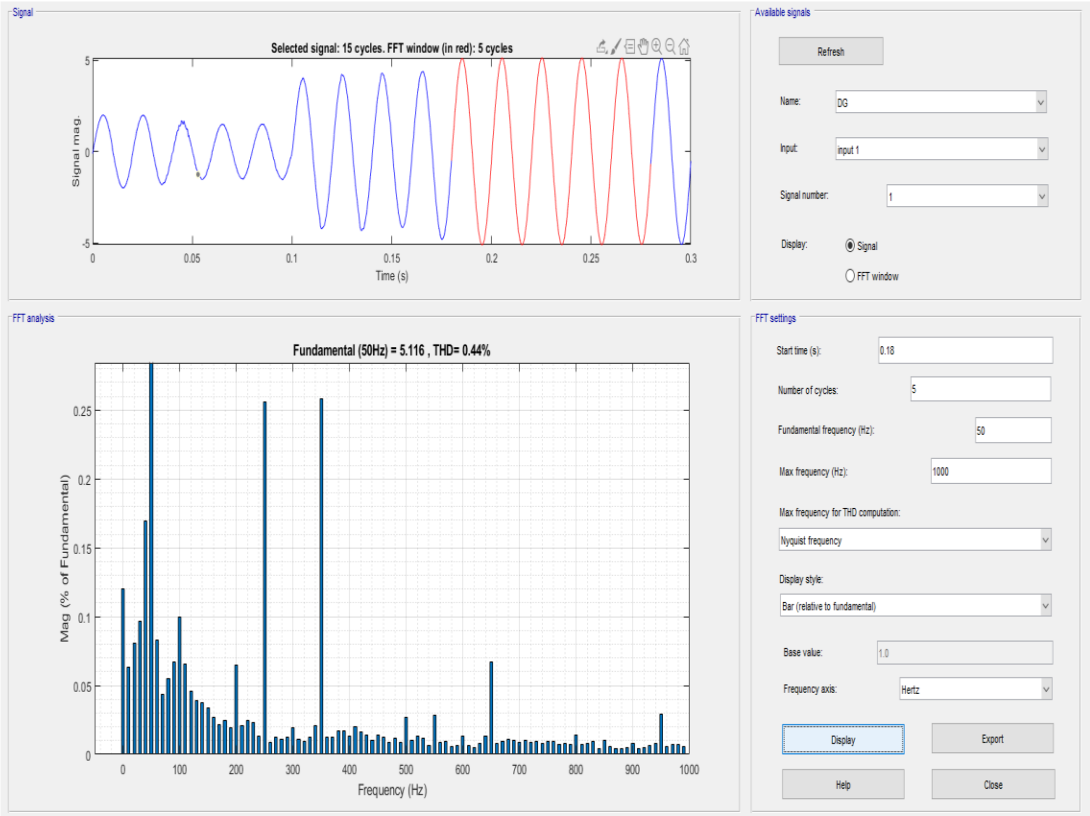

Fig 11 THD performance of incremental and conductance MPPT

MPPT Simulation Result of Perturb and Observation

Most of the time, the Perturb and Observe method is used to turn energy from sun and wind sources into something else. In a solar PV system, the voltage and current of the PV output are measured at two different but close together times. The power is worked out for two different times that come after each other. dP/dV stands for the ratio between the change in power and the change in voltage. The positive and negative values of the slope dP/dV determine how much the duty cycle is raised or decreased. Because of this, the voltage and power are changed to match the highest powerpoint. If the slope (dP/dV) is equal to zero, the highest power point has been reached for the current conditions in the environment. This is a process that will keep going on forever. Continuous measurements must be taken, and changes in power and voltage must be found so that the best way to handle the problem can be chosen. Matching the impedance of the load side with that of the solar PV grid is how the MPP is done. The duty cycle is changed so that it matches the resistance better. The part before this one talks about this MPPT algorithm and shows a flow chart and the algorithm itself. Listed below are the steps of the programme.

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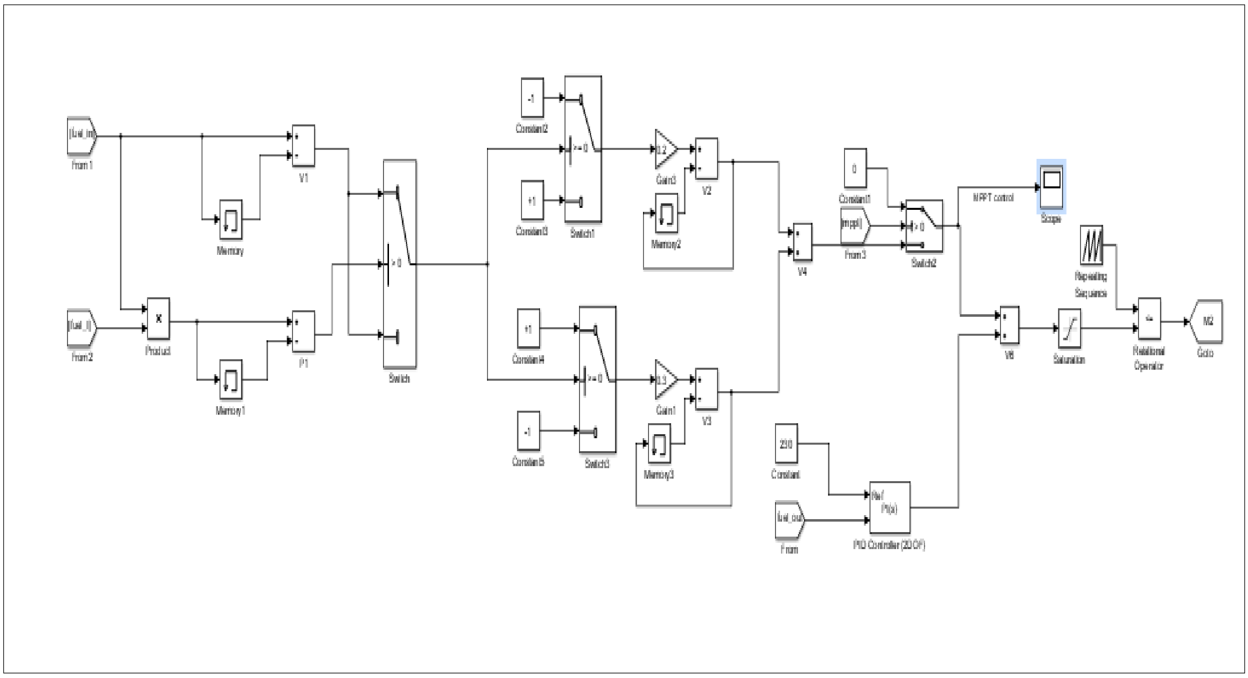

Figure 12 Perturb and Observation Block

CONCLUSION

The performance analysis of MPPT-based grid-connected hybrid renewable energy systems has provided valuable insights into their efficiency, reliability, and economic viability. Through the evaluation of various MPPT algorithms, the most suitable algorithm for the hybrid system can be selected, considering factors such as accuracy, convergence speed, and adaptability to varying environmental conditions. The assessment of power generation and grid integration has highlighted the system's operational characteristics, including energy output, power quality, and grid stability. This analysis is crucial in ensuring a reliable and consistent power supply to the grid, optimizing the system's performance, and minimizing disruptions. The investigation into system efficiency and energy management strategies has contributed to maximizing the utilization of renewable energy sources. By evaluating energy conversion efficiency, identifying power losses, and implementing advanced control techniques, the overall system performance can be enhanced, leading to reduced energy wastage and improved energy storage and distribution. The economic viability analysis has demonstrated the financial benefits of MPPT-based grid-connected hybrid renewable energy systems compared to conventional energy systems. Considering factors such as initial investment, maintenance costs, and payback period, stakeholders can make informed decisions regarding the feasibility and long-term benefits of implementing these systems.

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