Control of a stand-alone variable speed wind turbine generator system

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ABSTRACT

The focus of the work is on optimizing the wind power system to generate high-quality power from renewable energy sources. This article describes how to control a stand-alone PMSG wind turbine system using perturb and observe (P&O) maximum power point tracking (MPPT) controller. This aids in the regulation of output voltage levels and the maximum power provided to the load. The present study employs P&O MPPT control algorithm to optimize energy extraction from the wind resource, while simultaneously ensuring a stable voltage throughout the load. The goal of MPPT approaches is to establish a reference speed so that the wind energy conversion system (WECS) control system can follow the MPPT trajectory. The MPPT controllers can keep the system running smoothly irrespective of the wind speed fluctuations. There is a significant power output improvement over conventional controllers when using the proposed MPPT controller, according to the comparison results. The DC-DC boost converter was implemented for enhancing the low AC voltage given by the permanent magnet synchronous generator (PMSG).

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1. INTRODUCTION

A phenomenal expansion in the renewable energy sector has been fueled by the growing demand for renewable energy technologies as environmentally friendly alternatives or as supplements to conventional methods of electricity generation. Wind energy is a strong contender among the many renewable energy sources. It is well-known for its inexhaustible nature, safety, environmental friendliness, and large power generating potential. Wind energy is a renewable energy source [1].

A substantial amount of research and development work has been done in both the academic world and the business world in conjunction with the rapid spread of wind power generation systems in renewable energy applications. Wind turbines may be broken down into two basic categories: fixed speed and variable speed [2]. These two categories are taken into consideration to be the most prevalent sorts of wind turbines that are currently available on the market. Fixed-speed wind turbines, which are often fitted with induction generators that are directly connected to the grid, have seen widespread adoption; nonetheless, they have a number of drawbacks, including a lack of control over reactive power and grid voltage levels which can be problematic.

Variable-speed wind turbines, on the other hand, exhibit a multitude of benefits in comparison to their fixed-speed counterparts. These systems provide benefits such as enhanced energy capture, operation at the maximum power point, increased efficiency, and enhanced power quality. In order to convert alternating current (AC) voltage at the generator side into direct current (DC) voltage, these systems make use of power electronics that employ AC-DC converters. As a result of its straightforward construction, capacity to function at low speeds, capacity for self-excitation, and high efficiency, permanent magnet synchronous generators (PMSGs) have emerged as the most popular option among the several types of generators that are utilized in wind energy conversion system [3].

When it comes to variable speed wind energy systems, controlling the speed of PMSGs is crucial for optimizing the amount of electricity generated. The rotor speed of PMSGs needs to be adjusted accordingly in order to achieve the maximum amount of power extraction from the different wind speeds that occur during the day [4]. Since the amount of power produced by variable speed wind energy systems fluctuates with the actual wind speed, it is critical to have effective energy storage technologies available in order to keep power balance.

Maximum power point tracking (MPPT) controllers play an essential role in the overall operation of the system. By adjusting the speed of PMSGs, MPPT controllers make it possible to capture the greatest amount of power from available wind power without the use of specific sensors [5]. MPPT controllers provide enhanced efficiency and increased output power in comparison to conventional control approaches like proportional-integral (PI) and proportional-integral-derivative (PID) controllers. By exploring into the technical challenges of managing PMSG in variable speed wind energy systems using MPPT controllers, the purpose of this article is to highlight the superiority of MPPT controllers in terms of maximizing power production and optimizing system performance [6]. This paper's objective is to provide an explanation of why MPPT controllers are superior.

2. LITERATURE SURVEY

Using standalone PMSG wind energy conversion system the control technique aims to regulate the load voltage in different operational conditions, including variations in windspeed, load, and imbalance, by adjusting its magnitude and frequency. The wind turbine, PMSG, uncontrolled rectifier, and DC-DC boost converter are the components of the wind generating system that is being tested. The duty cycle of the boost converter is the primary control variable in the given control strategy. This study was conducted by Venkataraman *et al.* [7], "An efficient UPF rectifier for a stand-alone wind energy conversion system”. It is connected to a permanent magnet synchronous generator (PMSG) which in turn powers a wind turbine with a set pitch. To evaluate how well the converter works, it compared it to a standard diode bridge rectifier that does not have current regulation.

Izumi *et al.* [8] for a PMSG-based WECS, "a control method for maximum power point tracking of a wind turbine using online parameter identification". It uses an AC-DC-AC converter system. The generator-side converter optimizes the PMSG's torque regulation to maximize wind power generation. Singh *et al.* [9] “control of PMSG based variable speed wind-battery hybrid system in an isolated network”. It consists of a chopper-based speed control system for the generator, which operates effectively under different wind conditions.

Ackermann *et al.* [10] “wind energy technology and current status: a review, renewable, and sustainable energy reviews”. It is primarily focused on grid-connected wind capacity quadrupled every three years in the last decade of the 20th century. Due to rapid industry growth, wind turbine technology has evolved. Hussein *et al.* [11] “simple maximum power extraction control for permanent magnet synchronous generator-based wind energy conversion system,” It carries a work for betterment of the efficiency of the goal function in the optimization technique and improve the controller's capability to address system issues.

3. PROPOSED WORK

Wind energy employs various generator types, including the doubly fed induction generator (DFIG), wound rotor induction generator (WRIG), squirrel cage induction generator (SCIG), and permanent magnet synchronous generator (PMSG). The selection of PMSG for this study was based on its outstanding attributes, including its high efficiency, enhanced power factor control, and compact dimensions. Before connecting to the main load, the PMSG is the primary energy source and is interfaced with an unregulated rectifier-inverter combination [12].

An AC-DC rectifier is a key component in wind energy conversion systems (WECS) that converts the alternating current (AC) generated by the wind turbine into direct current (DC) for further processing, storage, or transmission. A PMSG generator and controller are used to extract the most attainable energy from the wind. To maximize energy extraction from the wind while minimizing voltage drop across the load, the present work employs the perturb and observe (P&O) MPPT control algorithm. Wind turbines generate variable-speed AC power, and this power needs to be converted to a stable DC output for integration into the grid or for charging energy storage systems. DC-DC voltage converters in WECS serve as crucial components for optimizing energy conversion, storage, and utilization [13].

The choice of DC-DC converter design depends on the specific requirements of the wind energy system and the intended applications. Wind turbines, especially those with variable-speed capabilities, can generate different power levels based on the wind conditions. A DC-DC converter with maximum power point tracking functionality optimizes the power extraction from the wind turbine by adjusting the voltage and current levels to match optimal operating point of the turbine.

MPPT is particularly important because the power output of renewable energy sources like solar panels and wind turbines can vary due to changes in environmental conditions, such as sunlight intensity, wind speed, and temperature. Implementing MPPT on the source side of a wind turbine involves sophisticated control algorithms and real-time monitoring to ensure that the turbine operates at or near its maximum power point while adhering to safety and operational limits. This approach contributes to the overall efficiency and effectiveness of the WECS [14]. The MPPT system on the source side monitors wind conditions (source information) and optimizes the operating parameters of the wind turbine (source) to maximize the energy extracted from the wind. This includes adjusting blade pitch, generator load, and other control parameters for working of the turbine at its maximum power point for varying wind conditions. The P&O algorithm is widely employed in renewable energy systems, namely in the environment of solar PV system and wind turbines, with the purpose of effectively monitoring and optimizing the maximum power point [15]. The schematic diagram in Figure 1 shows the wind energy conversion system, rectifier, and DC-DC converter. Wind energy is directed towards the rectifier convert AC to DC. The DC-DC converter amplifies the DC current from the DC. The DC goes to the load. For load control, switch mode rectifier control in conjunction with MPPT controller are used.

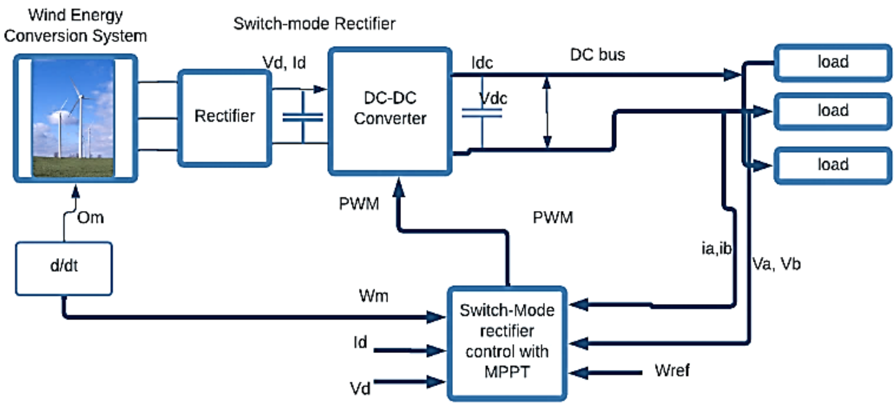

Figure 1. Schematic representation of the WECS

4. METHODOLOGY

The energy received from the wind turbine. Wind speed air density is directly proportional to the coefficient of power in a wind turbine [16]. PMSG is an essential component in wind energy systems. Its primary function is to transform the mechanical energy that is generated by wind turbines into electrical energy in the form of alternating current (AC). Under the influence of an unregulated rectifier, the alternating current (AC) is converted into direct current (DC) in order to promote the efficient utilization of stored energy [17]. In spite of their ease of use, versatility, and cost-effectiveness, unregulated rectifiers have a number of downsides, including a poor power factor and distorted DC output voltage.

The utilization of control strategies is absolutely essential in order to effectively address these problems and get the most of the quantity of energy that can be extracted from the wind. The first step in this process is to generate pulse for the DC-DC boost converter that is contained within the switch mode rectifier [18]. Due to the fact that this converter is responsible for regulating the input DC voltage under a wide range of conditions, it guarantees that the DC-link voltage will remain stable and constant.

Stabilization of the DC-link voltage is made possible by ensuring that the reference value for the converter's duty cycle remains consistent. The firing pulses of the DC-DC converter are generated by a MPPT controller in order to further optimize the power output of the converter. Its primary objective is to maximize the amount of power produced by wind turbines by precisely tracking the highest power point, regardless of fluctuations in wind pressure [19].

MPPT controller makes it possible to optimize power tracking by dynamically adjusting the operating point of the turbine. This results in improved energy capture and overall system efficiency. Given the frequent changes in wind conditions that lead to variations in wind speed and power output, the adaptability of the minimum power point tracking controller is of the utmost importance. It does this by continuously monitoring the fluctuations in wind speed and adjusting the operating point of the turbine appropriately. This ensures that the turbine operates at the maximum power point, which allows it for capturing maximum amount of energy possible that it can.

In essence, exact power optimization can be achieved by integrating MPPT controller into the wind energy system. This minimizes the impact of varying wind conditions and maximizes the amount of energy that can be extracted from the available wind resource. This approach enhances the overall efficiency and profitability of variable speed wind turbine generating systems, hence rendering these systems more competitive and sustainable in the realm of renewable energy.

5. PROPOSED ALGORITHM: ENHANCING WIND POWER GENERATION EFFICIENCY WITH ADAPTIVE MPPT CONTROL

MPPT is a widely employed technology in wind turbines and photovoltaic (PV) solar systems in order to optimize power extraction across various operating circumstances. In order to optimize power output, The DC-DC converter's firing pulses are produced with the use of MPPT controller. However, it is designed to maximize wind turbine power production by measuring the maximum power point while accounting for wind speed fluctuations [20]. In contrast, the MPPT controller is specifically tailored for power optimization. The operating point of the turbine is adjusted in order to optimize power tracking, resulting in enhanced energy capture and higher overall efficiency. Wind conditions can change rapidly, resulting in variations in wind speed and power output. It is designed to adapt to varying conditions and adjust the operating point accordingly, ensuring the turbine operates at the maximum power point and captures as much energy as possible. Due to its focus on power optimization, an MPPT controller has the prospective to significantly enhance the overall efficiency and energy production of the windmill system. At the maximum power point, the derivative of the output power (P) with respect to the panel voltage (V) is zero, which is the foundation of the maximum power point tracking technique. This algorithm monitors the peak power level in order to optimally distribute the available power [21]. The MPPT algorithm is depicted in Figure 2. Complex algorithms used in MPPT controllers necessitate special attention during implementation.

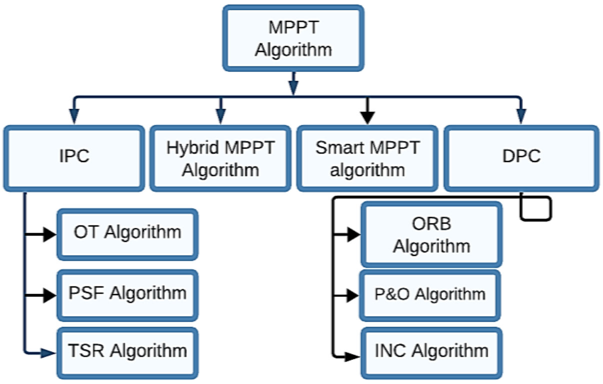

Figure 2. Methods for MPPT classification

5.1. Perturb and observe (P&O) method

Perturb and Observe algorithm is often referred to as a hill climbing quest and is significantly used to make changes to variable control during wind speed conditions [22]. Figure 3 depicts the P&O algorithm, which is the main sensor-less mathematically better approach to the maximum power point, as it provides a robust tracking procedure among control variables. Lately, several researchers have chosen the P&O algorithm from the multiple MPPT algorithms which enhances the power technique on the WECS. The output is measured in this P&O algorithm. The power that has been calculated and the differentiation between recently calculated power and before acquiring the output power ΔP is calculated. By applying the computed ΔV the duty cycle is being modified to acquire the new V and I values. When ΔP is negative, the perturbation is self-controlled, causing ΔP to swing until the ultimate power point on the power curve is reached.

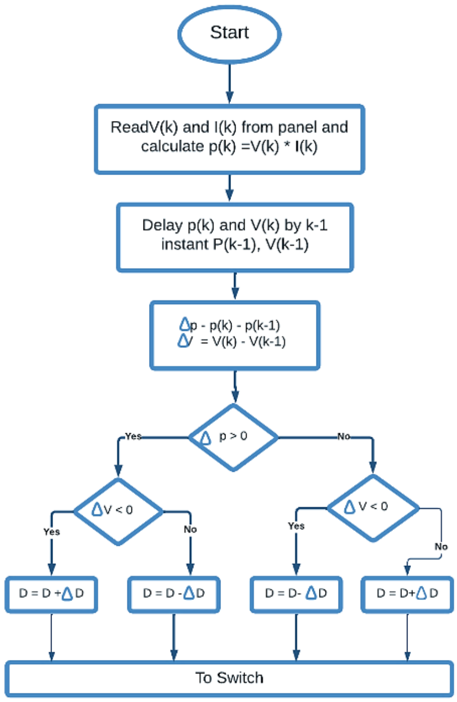

Figure 3. P&O algorithm flow diagram

6. SIMULATION RESULTS FOR MPPT CONTROLLER

In wind turbine generators, MPPT algorithm is dependent on the algorithm design, turbine parameters, wind conditions, and simulation configuration, as shown in Figure 4. Simulated studies have demonstrated that the implementation of MPPT techniques in wind turbine generators can result a number of benefits, one of which is an improvement in energy capture even when the wind conditions are variable [23]. Because of this, overall power output is enabled.

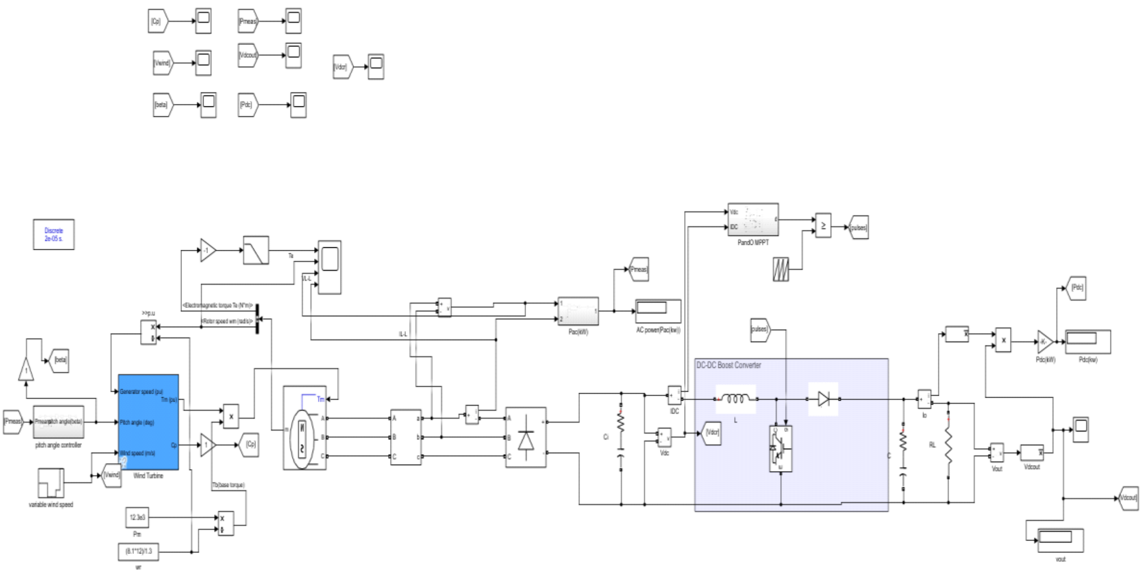

Figure 4. Simulation model of a WECS using MPPT controller

MPPT algorithms make it possible for the wind to adjust the turbine to wind speeds that are different from one another and modify its operating parameters in accordance with the differences in wind speed. It demonstrates that the turbine is able to continue functioning at its best position even when the wind speed is too low, and that it is able to sustain stable operation even when the wind speed is high without exceeding its power constraints. In other words, the turbine is able to continue operating at its optimal location whenever the wind speed is low [24]. MPPT controllers have the capability of including a wide range of control strategies, which can be utilized to protect the wind turbine from any potential harm. MPPT controllers in wind turbines have the potential to facilitate grid integration [25].

Ensuring that the power production is both consistent and as efficient as possible. They are able to make adjustments to the parameters of the power supply provided by the generators in order to make it conform to the requirements of the load. To make the most of the fact that the particular simulation results, it is vital to take advantage of the situation. Figure 5 illustrates a step-by-step change in wind speed, beginning at 12 metres per second and progressing to 8 metres per second, 10 metres per second, 14 metres per second, and then returning to 12 metres per second. Figure 6 illustrates the efficiency of a wind turbine in terms of its turbine efficiency. Figure 7 demonstrates that PMSG is able to generate electrical power with the variations in wind speed. This is something that can be seen directly. After that, the converters are utilised to transform this power into direct current (DC), and it is then distributed to loads; the maximum amount of power that can be generated throughout the load is eight kilowatts (KW). See Figure 8 for an illustration of the direct current voltage that is present across the rectifier. Figure 9 depicts the voltage that is distributed over the load by the direct current (DC) output supply. Figure 10 shows a representation of the direct current (DC) power that is measured throughout the load. The amount of power changes according to the speed of the wind. It is at a particular instant that the load produces the maximum power of 8 KW.

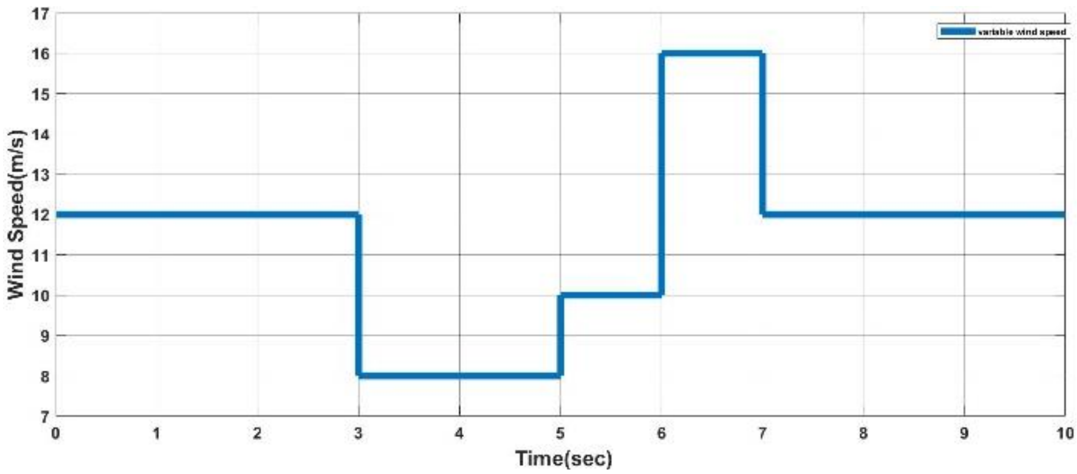

Figure 5. Step change of wind speed

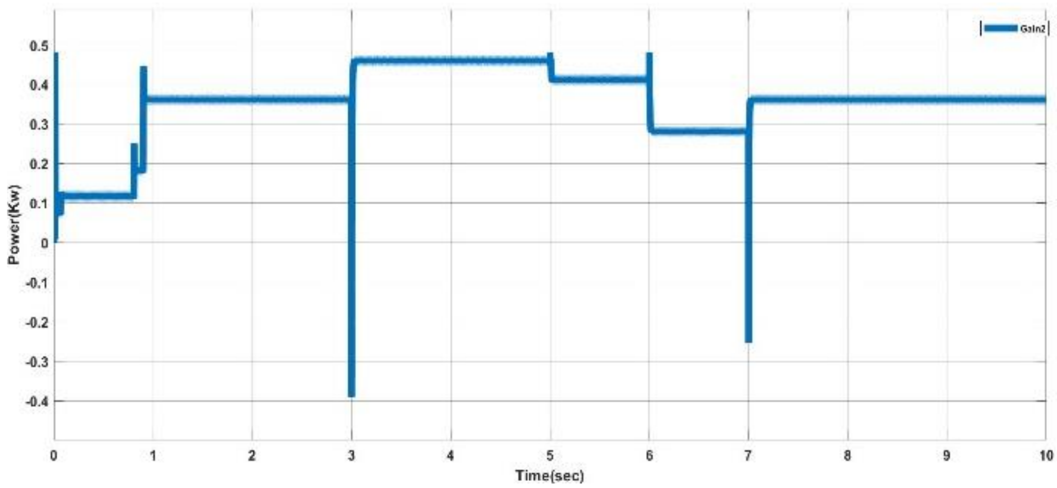

Figure 6. Turbine coefficiency

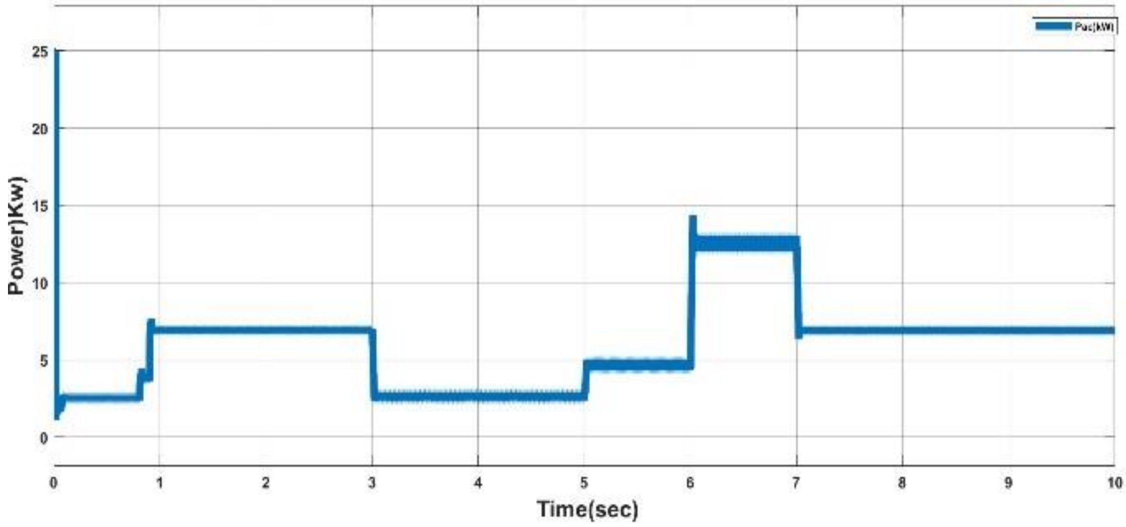

Figure 7. AC power across the generator

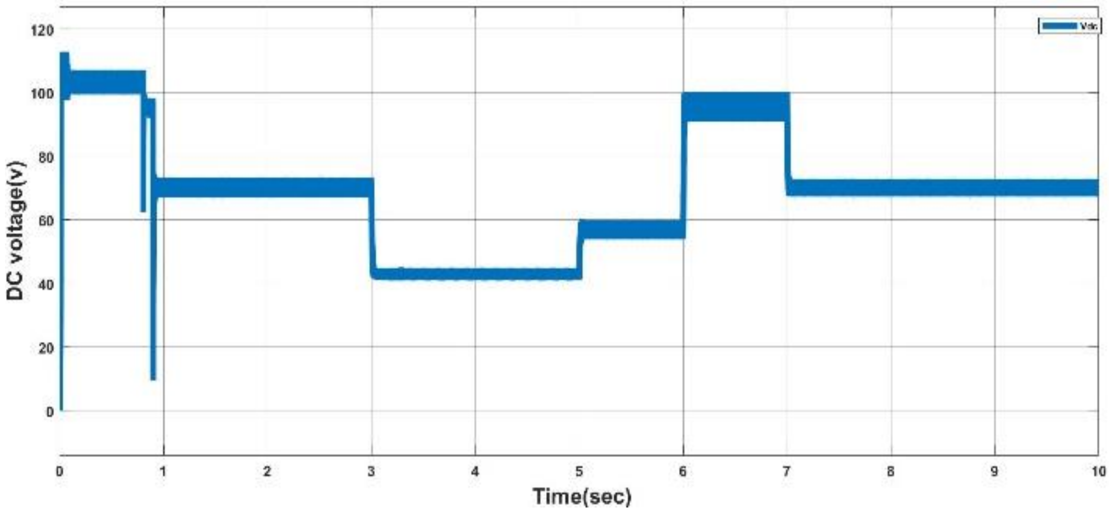

Figure 8. Output DC voltage across the bridge rectifier

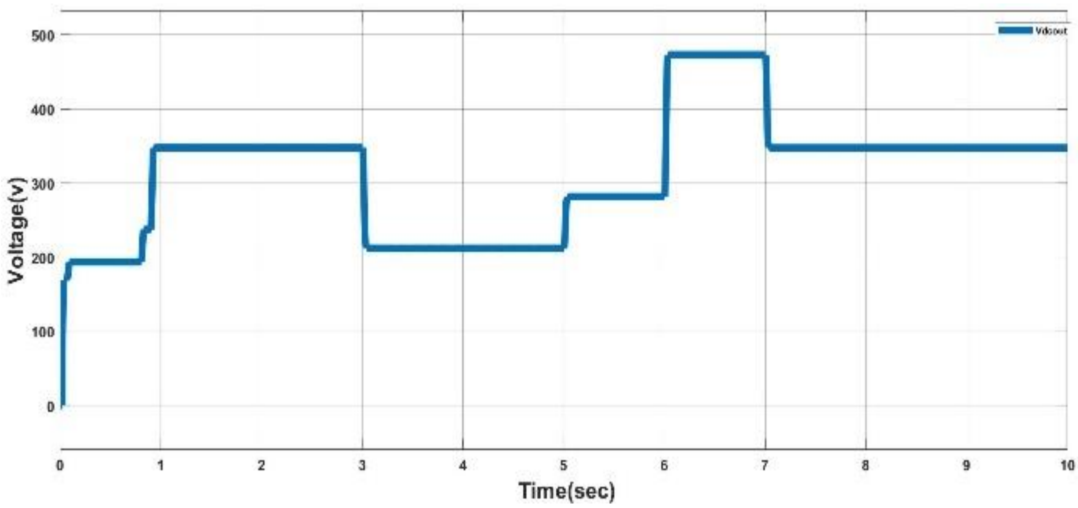

Figure 9. DC voltage across the load

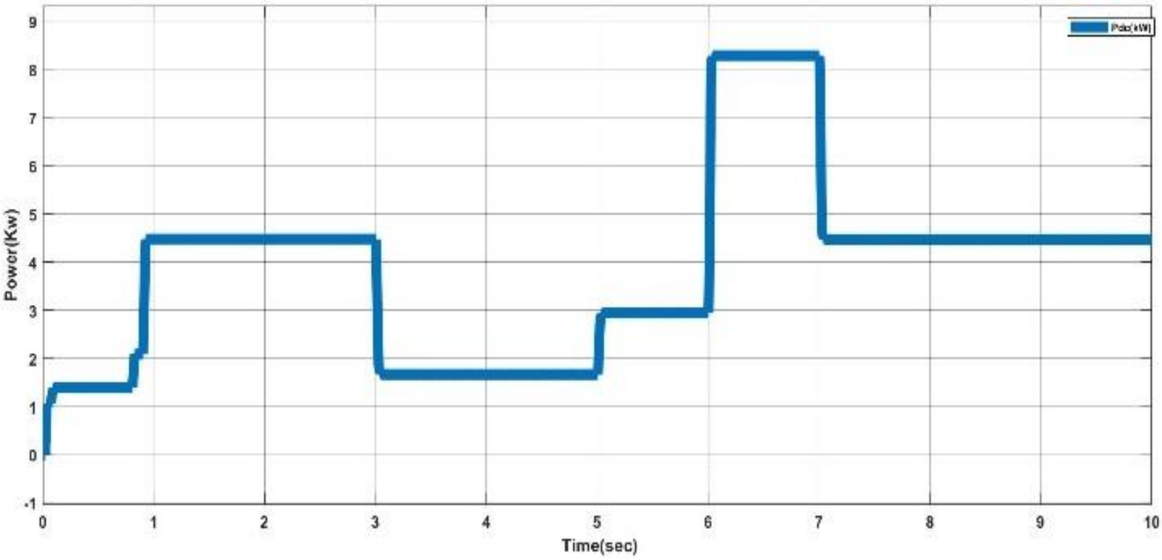

Figure 10. DC power across the load

7. CONCLUSION

An easy control strategy was built on the source side converter by making use of the simulation software MATLAB. This was done in order to generate the highest amount of power possible. It has been observed that the controller consistently supplies the load with adequate voltage and frequency, irrespective of whether the load is steady or fluctuating. The outcome of the simulation demonstrates that the P&O MPPT controller is acting in a manner that is compatible with the requirements. The simulation's findings indicate that the controller is effective in both dynamic and steady-state settings, demonstrating its performance capability. The MPPT method is capable of calculating both the wind speed and the power. As a result of the implementation of MPPT, it has been found that the maximum power output of the model is maximized to the greatest extent possible across the load. It is only possible to reap the benefits of successfully utilizing the P&O MPPT controller in a system that is stable and has low variance. The results of the simulation demonstrate a satisfactory behavior when the P&O MPPT controller is used.

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