An Optimal Control Strategy for Improving the Output Power of a Standalone Wind Energy System

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***Abstract*— This research provides an optimal control technique for increasing a solitary wind energy system's output power. Because of the potential for strong winds, the use of renewable energy, particularly wind turbines, is becoming more popular in Indonesia. In general, the wind turbines deployed in Indonesia are small-scale, based on the existing wind potential. A permanent magnet synchronous generator (PMSG) type generator is best suited for this tiny scale wind turbine. Because it adapts the very unpredictable wind speed, the wind turbine system implements the off-grid system. This work used a method based on maximum power point tracking (MPPT) control to increase the performance of this wind turbine system. Converters connected to PMSG generators use an MPPT control-based control technique. The perturbing and observing (PO) algorithm support this MPPT control technique. A characteristic test on a 1000-watt wind power plant running at wind speeds ranging from 3 to 10 m/s is carried out in this study. Simulink-MATLAB software is used to simulate this performance test. The results revealed that using MPPT control on wind turbine systems can greatly increase power output.**

Keywords—control strategy, MPPT, PMSG, wind turbine, output power

I. INTRODUCTION

A wind power plant is a power station that generates electricity using wind as a source [1]. Wind turbines or windmills are used at this factory to transform wind energy into electrical energy. Because wind is one of nature's limitless energies, this power generation system employing wind as an energy source is becoming increasingly popular. In concept, the fundamental benefit of employing wind power plants is that they are renewable [2]. This means that, unlike the use of fossil fuels, development of this energy source will not result in the decrease of wind resources. As a result, wind power has the potential to contribute to global energy security in the future [3]. The wind energy is also an environmentally benign energy source, as it produces no major exhaust emissions or pollution in the environment when used.

The component manufacturing process at the site where the wind power plant will be erected are both sources of carbon emissions in wind power. This wind power plant, on the other hand, does not produce considerable emissions when it generates electricity. The carbon dioxide emissions of these wind power plants are a hundredth of those of coal-fired power plants. In addition to carbon dioxide, wind power facilities emit less sulfur dioxide, nitrogen oxides, and other pollutants into the atmosphere than coal or gas-fired power plants [4]. This wind power facility, however, is not completely environmentally benign. Visual impacts, acoustic noise, some ecological issues, and aesthetics are all issues that arise when wind energy sources are used as power plants.

In operation, wind turbines can generate electricity if they are exposed to sufficient wind speed. Wind turbines are directly connected to generators in wind power generation systems, which may transform the motion energy from the wind turbine into electrical energy [5]. The Permanent Magnet Synchronous Generator (PMSG) type generator is utilized for small to medium capacity [6]. PMSG produces a wide range of output power depending on wind speed. Turbine rotation can be continuously conditioned with the newest control technologies as technology advances [7]. A Maximum Power Point Tracking (MPPT) controller is used to maximize the generator output power even when the wind speed fluctuates. To extract the most power out of this wind power plant, MPPT is employed [8].

Fuzzy logic-based approaches, artificial neural network (ANN) methods, gradient approach methods, ant colony optimization (ACO) methods, particle swarm optimization (PSO) methods, and perturb and observe (PO) methods have all been employed for MPPT in wind energy systems [90] - [11]. The gradient approach MPPT method measures the voltage and current at the load, then changes the duty cycle of the DC-DC converter to get maximum power [12]. A single-phase bridge inverter is used to generate the AC output voltage. The average power ratio without MPPT to maximum power is 79 percent, but using MPPT can boost it to 95 percent, according to simulation data. According to the findings of this study, wind turbines that use MPPT have a considerable boost in performance.

The MPPT is controlled using a FLC algorithm in wind plant system in [13]. Through Chuck Converter's DC-DC Converter circuit, the technique is tasked with regulating the generator's output voltage. By altering the duty cycle, the switching mechanism uses PWM (Pulse Width Modulation). The duty cycle value changes as the wind speed changes. A FLC algorithm is used to set the duty cycle value and accelerate the switching response of PWM control. The results revealed that using FLC-based MPPT technology, the system's efficiency may be increased from 46% to 87 percent.

In solar power facilities, the PO method is used to determine maximum power values. This method has various advantages over other MPPT methods, including straightforward feedback and a variety of measuring settings. The PO method is a simple methodology that can be applied to solar power facilities. The PO approach was used to analyze small-scale wind power installations in our research. This generator can be used to generate power for home requirements on its own. A freestanding system is the name given to this type of power plant. Because of its simple approach, the PO method may be applied to wind turbine systems. Because the PO technique does not require knowledge about turbine specifications or wind speed, finding the maximum power point is more efficient and faster. This approach, however, has a flaw in terms of producing oscillations under steady conditions. As a result, improvements were made in our study by combining the PO approach with the predictive method. Both of these strategies alternate depending on the current and voltage circumstances on the converter's input side. The magnitude of the step shift in the PO algorithm is determined using the predictive technique. A large step size will be used if the voltage shift is large, whereas a small step size will be used if the voltage change is minor.

II. WIND TURBINE CONTROL SYSTEM

A. Representaion of Wind Plant

Figure 1 depicts a diagram of a wind power system. In Figure 1, it can be seen that main components of a wind power system, which include a wind turbine, PMSG type generator, three-phase rectifier, dc-dc converter, MPPT system, PWM, and resistive load [14].

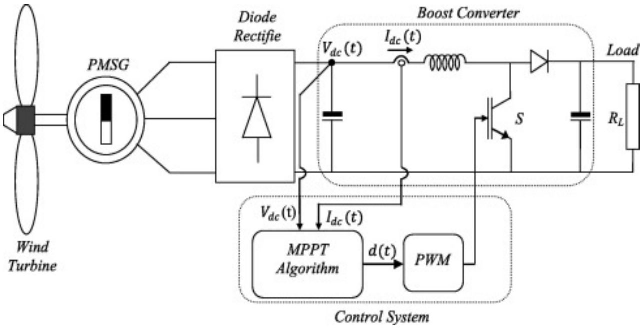

Fig. 1. Representation of a wind power plant with MPPT model

The parameters of the wind power plant used in this study are described as follows. The turbine model used is AF 1-24-0125 (406 PMG). The turbine blade consists of 3 pieces with 28 degrees of blade pitch. The initial wind speed used is two m/s, with the charging initiation of wind being three m/s. The charging initiation of RPM is set at 258 rpm. The generator's output power at 24 volts is 1000W at a rated wind speed of 10 m/s. The rotor diameter used is 1.8 m, with a rotation of 200-800 rpm. The type of generator that produces electricity is a 3 phase permanent magnet synchronous generator. A DC rectifier rectifies the output voltage of the generator.

By harnessing wind gusts, the wind turbine rotates the generator. A horizontal wind turbine with a blade-shaped drag-style wind turbine blade was used in this study. The generator rotor is linked to the rotor of the wind turbine. The generator rotor turns automatically when the wind turbine spins. A permanent magnet synchronous generator (PMSG) is the type of generator employed. This generator is widely utilized in small and medium-sized wind power systems. This turbine turns a generator that generates three-phase ac voltage. The rectifier then rectifies the three-phase electric voltage to produce dc voltage. A boost converter is used to convert the dc voltage into the required voltage for the system. The MPPT controller is used to maximize generator power generated. MPPT is used in this study, and it is based on the PO technique.

B. Control of Wind Turbine Output Power

The wind power generating system finds an optimal point through a boost converter fitted with MPPT based on the PO approach to produce the best output power. The input voltage and input current from the wind generator are necessary for the operation of this approach. Multiplying both parameters yields the output power of P. The slope is calculated as the method's tracking core. Figure 2 depicts a graph of the MPPT determination mechanism on a wind power facility. The three types of points are explained in three spots in that diagram. dP/dV>0 is to the left one, dP/dV=0 is to the top one, and dP/dV=0 is to the right one.

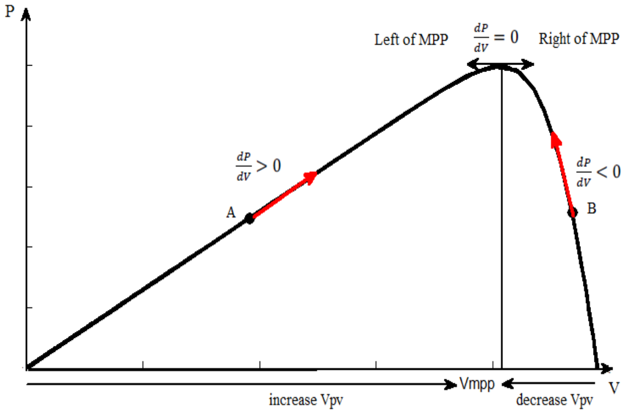

Fig. 2. MPPT procedure in wind power system

In operation, the higher the wind speed it will increase the more turbine rotation, which at the same time increases the rotation of the PMSG generator rotor. The higher the generator rotor rotation, the higher the generator output power as well. However, if the generator serves an electrical load, a high load current will be generated. This high load current causes the generator output power converted by the dc-dc converter not to be fully detected, so the generator output power is not maximum. In this case, the role of MPPT is significant in making the duty cycle of the boost type dc-dc converter always at the full power position. A reliable method is needed to control the duty cycle work of this boost type dc-dc converter, which is the perturb and observe (PO) method in this research. Flowchart of the PO algorithm can be seen in Figure 3.

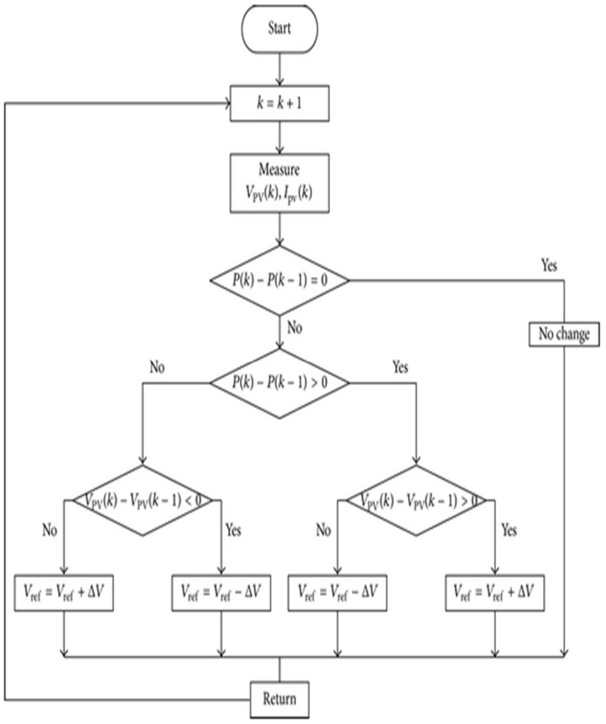

Fig. 3. Flowchart of the PO algorithm

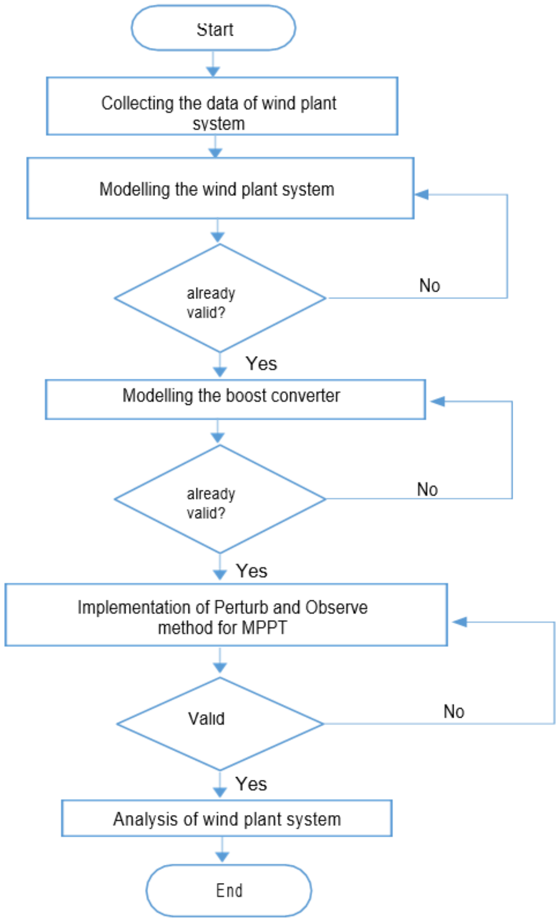

Fig. 4. Flowchart of this research steps

III. METHODOLOGY

Figure 4 depicts a flowchart of the research steps. The initial step of the research, as shown in the diagram, is to collect data on wind power systems. The information gathered includes data on wind power system specifications and wind characteristics in Indonesia, particularly in the southern part of the Java Islands. Modeling wind power systems is the next step. A wind turbine system is modeled in a block diagram in this modeling, and the block diagram system is then implemented in MATLAB/Simulink software. The system validation was performed to confirm that the block diagram was correct. If the system is correct, the boost converter was modelled and a validation test was run. The implementation of the perturb and observe approach in MPPT, as well as the validation test, are the most important steps. If the system is complete, the wind power plant's analysis system can be used. A comparison of the system without MPPT and the system with MPPT was conducted in this study. This analysis is helpful in determining the performance of the perturb and observe method when it is applied to MPPT.

IV. RESULTS AND DISCUSSION

The study's findings, as well as the analysis, are detailed in this section. The study's findings include a test of a wind power system without MPPT and a comparison of a wind power system with MPPT. The PO method is used to calculate MPPT in this study. Figure 5 shows how to evaluate a wind power system using MATLAB/Simulink software. The system is supposed to transport 200 ohm and 400 ohm resistive loads, respectively. Wind speeds from 3 to 10 m/s are received by the wind power system in the scenario at each load. The observed outcomes are the generator's output voltage and the current entering the resistive load. The outcomes are depicted in Figures 6 and 7.

The results showed that the higher the wind speed, the higher the PMSG generator output power. The PMSG generator output is connected to a boost type dc-dc converter to support system performance. The placement of this converter is intended to produce a dc output voltage that can be stored in the battery. The use of converters also has the advantage of being able to control the output voltage and current using an appropriate control strategy. The boost type dc-dc converter with duty cycle controlled by MPPT based on the PO method in this study shows promising performance. Simulation tests have been carried out for resistive loading of 200 and 400 ohms. Each of these loadings was observed for conditions without MPPT controller and with MPPT controller. Simulation on resistive loading of 200 ohms with the lowest wind speed of 3 m/s produces a converter output voltage of 106 volts, where the load current is 0.51 amperes. In this condition, the output power produced is 54 watts. This condition is the wind power plant with the lowest power output in this simulation because the simulated wind speed is also the lowest and is the cut-in limit of the system.

The following simulation is the application of the MPPT optimal controller on a boost type dc-dc converter. The MPPT application on the system succeeded in increasing the converter output voltage to 224 volts with a load current of 0.51 amperes. Thus, the generator output power through the converter is 115 watts. This output power is more than double that of the system without MPPT, which is 54 watts. In this simulation, it can be seen that the MPPT controller is able to make the duty cycle of the converter work optimally.

The simulation is continued with a higher wind speed to see variations in the generator's voltage, current, and power through a boost type dc-dc converter. The highest wind speed that is simulated is a wind speed of 10 m/s. In conditions without MPPT with a resistive loading of 200 ohms, the system's output voltage on the converter is 588 volts with a load current of 0.91 amperes. Thus, the output power of the wind power plant is 535 watts. The power generated is still not optimal because the actual power generation capacity is 1000 watts. The MPPT controller application in this study is able to produce a higher generator output power through a converter. This condition with MPPT produces a converter voltage of 1090 volts, with a resistive load current of 0.91 amperes. The system output power is 992 watts. The output power with MPPT is almost twice as high as without MPPT. This significant increase in power is because the PO-based MPPT controller can control the converter's duty cycle so that it works at maximum power.

Simulation on resistive loading of 400 ohms with the lowest wind speed of 3 m/s produces a converter output voltage of 126 volts, where the load current is 0.57 amperes. In this condition, the output power produced is 72 watts. This condition is the wind power plant with the lowest power output in this simulation because the simulated wind speed is also the lowest and is the cut-in limit of the system.

The following simulation is the application of the MPPT optimal controller on a boost type dc-dc converter. The MPPT application on the system succeeded in increasing the converter output voltage to 236 volts with a load current of 0.57 amperes. Thus, the generator output power through the converter is 135 watts. This output power is about double that of the system without MPPT, which is 72 watts. In this simulation, it can be seen that the MPPT controller is able to make the duty cycle of the converter work optimally.

The simulation is continued with a higher wind speed to see variations in the generator's voltage, current, and power through a boost type dc-dc converter. The highest wind speed that is simulated is a wind speed of 10 m/s. In conditions without MPPT with a resistive loading of 400 ohms, the system's output voltage on the converter is 604 volts with a load current of 0.96 amperes. Thus, the output power of the wind power plant is 580 watts. The power generated is still not optimal because the actual power generation capacity is 1000 watts. The MPPT controller application in this study is able to produce a higher generator output power through a converter. This condition with MPPT produces a converter voltage of 1039 volts, with a resistive load current of 0.96 amperes. The system output power is 998 watts. The output power with MPPT is almost twice as high as without MPPT. This significant increase in power is because the PO-based MPPT controller can control the converter's duty cycle so that it works at maximum power.

In the simulation carried out in the Simulink-MATLAB environment, it has been proven that the PO method applied to the MPPT controller can maintain the duty cycle of the boost type dc-dc converter to remain at maximum power condition. The duty cycle is maintained by increasing the converter output voltage level. Increasing the resistive load served will cause the load current to increase and reduce the output voltage level. At this time, the MPPT controller controls the output voltage so that the output power remains maximum.

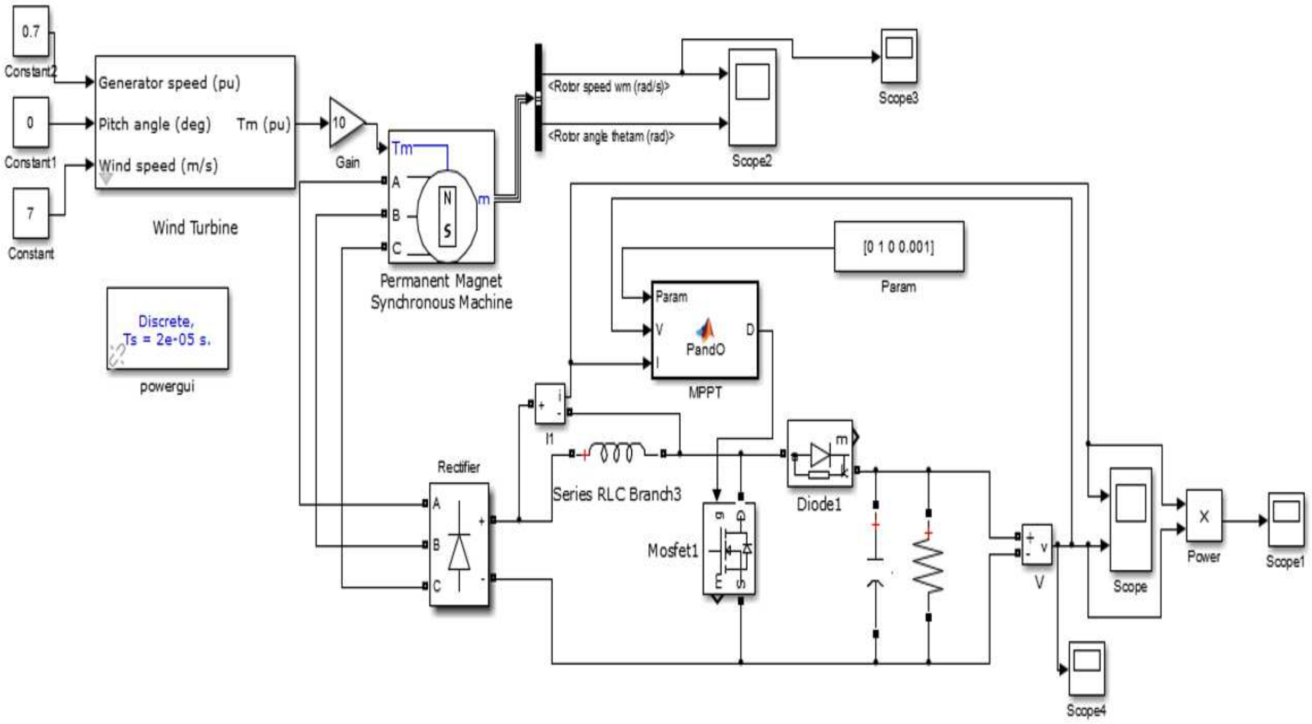

Fig. 5. Wind power system with PO-based MPPT model in MATLAB/Simulink

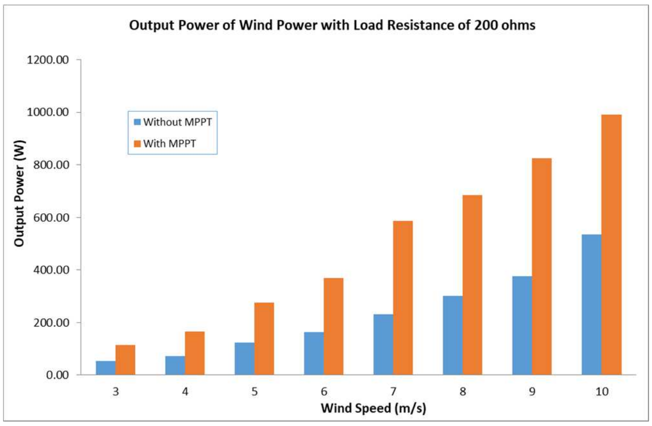

Fig. 6. Simulation for the resistance of 200 ohms

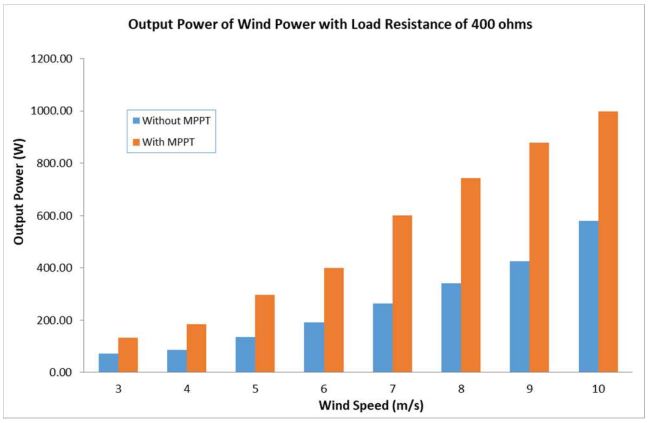

Fig. 7. Simulation for the resistance of 400 ohms

Figures 6 and 7 illustrate the overall performance of MPPT using the PO approach in this study. Figure 6 depicts the wind power system's output power with a load resistance of 200 ohms. The wind speed fluctuations used in the wind power system range from 3 to 10 m/s, with a 1 m/s increased interval. We concluded from all of the test findings that MPPT was successful in greatly improving the generator output power of the wind power system. When the wind speed reaches 10 m/s, the most power is generated. The generator output power for wind power systems with MPPT is 992 watts at this speed, while it is 535 watts for wind power systems without MPPT. With the implementation of this MPPT, the generator output power was increased by 86 percent to 457 watts. When considering the success of increased power, the wind speed of 7 m/s produces the highest percentage. In this case, the system with MPPT has a generator output power of 589 watts, while the system without MPPT has a generator output power of 232 watts. This translates to 357 watt increase, or a 155 percent increase in power.

In order to analyze more comprehensively, the simulation data for the performance of wind power plants at various wind speeds from 3 m/s to 10 m/s with a pure resistive loading of 400 ohms are shown in Figure 7. the converter cannot carry out its duties properly, where the higher load current holds back the duty cycle due to the larger load. We concluded from all of the test findings that MPPT was successful in greatly improving the generator output power of the wind power system. When the wind speed reaches 10 m/s, the most power is generated. The generator output power for wind power systems with MPPT is 998 watts at this speed, while it is 580 watts for wind power systems without MPPT. With the implementation of this MPPT, the generator output power was increased by 73 percent to 419 watts. When considering the success of increased power, the wind speed of 7 m/s produces the highest percentage. In this case, the system with MPPT has a generator output power of 599.68 watts, while the system without MPPT has a generator output power of 265 watts. This translates to 336 watt increase, or a 127 percent increase in power. Finally, the average increase in generator output power with the application of MPPT based on PO technique is 114 percent when regarded as a whole.

V. CONCLUSION

This research looks at an optimal control method for wind power generation utilizing the MPPT technology. The MPPT approach is based on the PO method. The load served by the wind power plant through the converter dramatically affects the output power generated by the generator. The greater the load carried, the greater the load current, which causes the converter's duty cycle to be unable to read the actual voltage from the generator. This condition causes the generator output power to be small. Therefore, the MPPT controller application based on the PO method has succeeded in tracking the converter's duty cycle so that the output voltage is maintained correctly and the result is optimally maintained power. The performance of the PO method for the MPPT controller has been demonstrated by loading 200 and 400 ohms on a wind power plant. With the use of MPPT based on the PO technique, the generator's output power increased by an average of 113.90 percent. Furthermore, wind speeds of 10 m/s produce the maximum wind power efficiency.

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