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Optimization of Permanent Magnet Synchronous Generator Output Power in Wind Power Plants Using the Gray Wolf Optimization Method

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Abstract

Renewable energy, the wind is anticipated to supplement other energy sources as needed. Low wind speeds of only 2.5 to 6 m/s have an impact on the electrical output generated by the Permanent Magnet Synchronous Generator at Wind Power Plants in Indonesia. The Gray Wolf Optimization (GWO) method, which is based on the social stratum that wolves use to pursue their food, will be used to optimize the output voltage so that it can produce the most power with a low and fluctuating average wind speed. In order to obtain the best power and maximize the extraction of the already available power, this method measures the wind power plant's performance, such as voltage and current at the load. According to the results, when the wind speed is 4 m/s, it takes 0.04 seconds for trials without the GWO technique to reach a stable value, but when the wind speed is 12 m/s, it only takes 0.011 seconds. So, the faster the wind speed enters the wind turbine, the quicker it will be to determine a stable output value. There was a surge at the start of the generator operation in studies using the GWO technique, but it took 0.2 seconds for the value to stabilize at 4 m/s and 0.18 seconds at 12 m/s.

Keywords

Wing, Tracking, Generator, Optimization

INTRODUCTION

The escalating population increase and new developments in electricity-based technologies both have an impact on the rising energy demand. Up until 2050, Indonesia's electrical energy consumption in a variety of sectors is anticipated to increase by an average of 5.9 percent annually. Due to the rising trend in the production of fossil fuels, the restricted and falling development of various energies, including natural gas, oil, and coal, will eventually run out [1], [2]. Maintaining energy security and independence has become a high issue due to worries about the rise in fossil fuel prices and the environmental effects of using fossil fuels. In locations where there is a chance of strong wind gusts, one of the renewable energy sources is the wind. Wind energy must be transformed into electricity using wind turbines, windmills, and generators to be used in wind power plants. Electric generators come in a variety of designs for the energy conversion system, including synchronous generators, double-fed induction generators, and squirrel cage induction generators [3].

Wind energy resources in various parts of Indonesia according to the Ministry of Energy and Mineral Resources of the Republic of Indonesia range from 2.5 to 6 m/s at an altitude of 24 meters above ground level [4]–[6]. Given that Indonesia is an equatorial region with the potential for variable winds, the development of wind power facilities also faces several difficulties. According to data on wind energy resources, Indonesia is considered to have low to medium wind speeds. Given that only 1.96 MW of Indonesia's projected 970 MW total wind energy potential has been used, there is still a very high chance that wind power plant technology may advance. Variable wind conditions have an impact on wind energy conversion systems. Changes in wind speed have an impact on the Permanent Magnet Synchronous Generator's (PMSG) output power [7]–[9]. As a result, modeling is required to assess wind turbine output power, system stability, and turbine optimization. To control Maximum Power Point Tracking (MPPT), several models have been created. GWO is utilized in this paper for wind turbine optimization. In other words, this study will apply the GWO method to regulate the output power of the wind turbine to the load using a PMSG to optimize the output power of a wind energy conversion system. A powerful tool for determining the best answer to an optimization problem is the GWO [10], [11]. The GWO algorithm draws inspiration from how wolves attack their prey according to their social standing. The PMSG output power should be optimized by the very effective GWO algorithm. In this study, the wind power plant system is represented by a Simulink MATLAB model based on the wind turbine concept during the GWO implementation.

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RELATED THEORY

According to research on GWO for Optimum Parameters of Multiple Controllers of a Grid-Connected PMSG Driven by Variable Speed Wind Turbine, GWO offers the best convergence at the smallest value and delivers a better response than MPPT and its capabilities during symmetrical and asymmetrical failures [10], [12]–[14]. The output power produced will be higher when employing MPPT, according to research on optimizing the output power of a wind power production system using a permanent magnet synchronous generator based on a neural network. Synchronous generators are frequently utilized in wind energy conversion systems to transform mechanical energy into electrical energy. Wound-Rotor Synchronous Generator (WRSG) and PMSG are the two types into which synchronizing generators can be divided. In WRSG, rotor flux is produced by rotor field winding, but in PMSG, rotor flux is produced by permanent magnets. Synchronous generators can be divided into salient-pole and non-salient-pole varieties based on the rotor's design and the placement of air gaps around its perimeter. A stator and a rotor make up a PMSG, a type of synchronous generator. The generator's stator, which is a fixed component, is made up of several coils of conductor wire and is shaped like a cylindrical frame [7], [8], [15]. A location for magnetic flux induction is the stator. The generator's rotor rotates because a shaft is directly attached to it, making it a rotating component. A permanent magnet can be mounted on the PMSG's rotor to serve as a source of magnetic flux that travels to the stator. Because a permanent magnet produces the excitation field and there are no excitation losses, PMSG has a high level of efficiency. Due to this, PMSG is frequently employed in wind power plants.

GWO is inspired by the social strata of a pack of wolves hunting their prey in nature. So that hunting techniques and social hierarchy of wolves are modeled mathematically to design the GWO for optimization [10]. Prey tracking, prey encirclement, and prey attack are all carried out using the GWO algorithm. When creating the GWO algorithm, the life of a wolf population is separated into groups to reflect the leadership hierarchy. This helps to build the social hierarchy of wolves. The highest caste wolves in the optimization process for hunting decide the best solutions and keep variables until they force the wolves in the lowest caste to be the last solution and have to update their position after the other best wolves.

PROCEDURE

This segment of the theme will cover the use of artificial intelligence to optimize the maximum power extraction from wind turbines connected to loads. By applying the GWO method, the applied algorithm will operate the wind turbine system to produce the most electricity possible. Using MATLAB, the MPPT on the wind energy conversion system will be simulated. The Wind Energy Conversion System will power an electric generator to produce electricity. The generator rotor moves because of the mechanical energy that the wind turbine rotor transforms from the wind's movement on the rotating blades. The generator will then transform mechanical energy into electrical energy. Wind speed, pitch angle, and generator speed are the wind turbine's inputs in this study. where the generator speed is modified following the wind turbine's characteristics while the pitch angle is kept fixed. Figure 1 below depicts the total wind power generation system modeling used in this study. Furthermore, Figure 4 describes the GWO procedure in full. The purpose of this study is to demonstrate how to boost a wind power producing system's output power. To achieve the best results, a design and assessment approach will be used as the methodology. The relevant results to evaluate the optimization of the Wind Power Plant system will be obtained by comparing the outcomes between systems utilizing the GWO approach and without GWO; this model is described in more detail in Figure 2 and Figure 3.

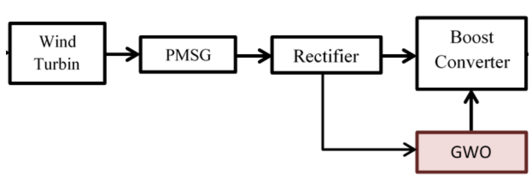

Figure 1. Wind energy model with GWO

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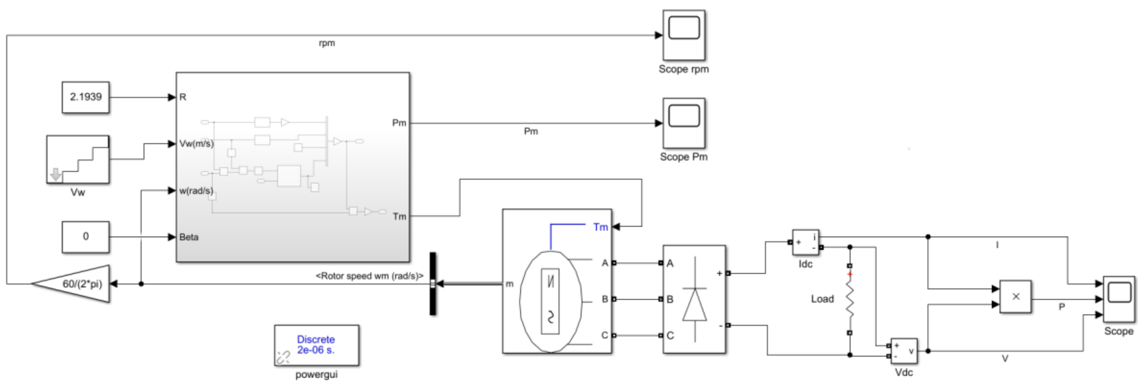

Figure 2. Wind power plant model without GWO

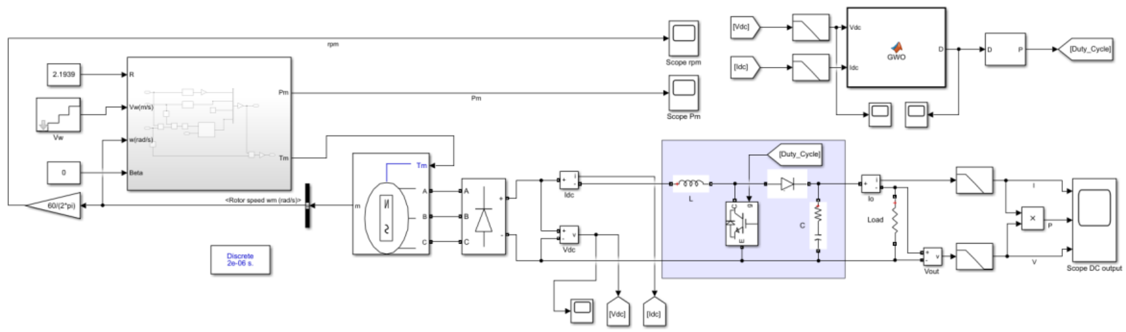

Figure 3. Wind power plant with GWO

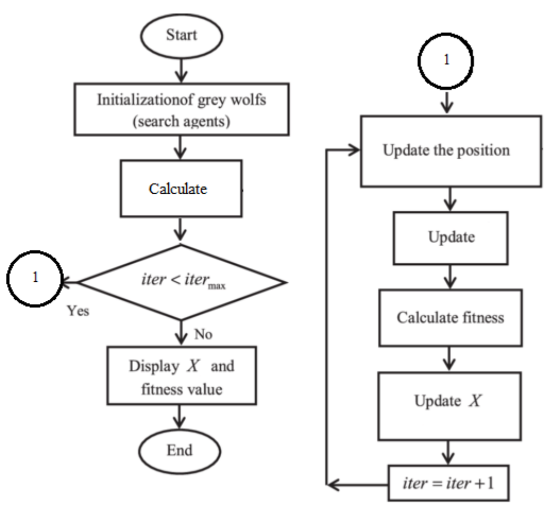

Figure 4. GWO process

Three aspects are used in the GWO approach. The alpha and beta wolves in the wolf social order were chosen as the decision-making group. The two major wolves are alpha and beta, and because they are considered to be equal competitors, beta wolves do not need to respect the alpha. To find possibly better prey and prevent local

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optimization, alpha and beta wolves alter their placements. The location of the gray wolf has been modified, however, the location of the omega wolf has not altered. According to the equation, the alpha and beta wolf locations are updated. After several decision-making comparisons, the executive team will seek agreement with leaders to update the position of the delta and omega wolves on the execution process, ensuring the accuracy of decision-making and boosting hunting effectiveness.

RESULT

The GWO is used in this chapter to simulate a wind power plant. The generator is viewed as perfect in this thesis research without accounting for power losses and environmental considerations. MATLAB software was used to run the simulation's two distinct tests. The specified wind speeds are 4, 6, 8, 10, and 12 m/s. The rotor speed and mechanical power values at particular wind speed situations vary depending on the wind turbine parameters owned, as indicated in Table I. This test specifically seeks to identify a system's properties.

TABLE I
SPEED AND POWER

Wind Speed	Rotor Speed (rpm)	Power
4 m/s	231	315 W
6 m/s	347	1063 W
8 m/s	463	2520 W
10 m/s	579	4920 W
12 m/s	695	8500 W

TABLE II
TEST RESULT WITHOUT GWO

Load (Ω)	Wind Speed	I_{output}	V_{output}	P_{output}
25	4 m/s	1.25 A	31 V	39 W
	6 m/s	1.92 A	48.2 V	93.4 W
	8 m/s	2.6 A	65 V	170.2 W
	10 m/s	3.27 A	81.95 V	269.9 W
	12 m/s	3.95 A	98.76 V	392.1 W
50	4 m/s	0.65 A	32.4 V	21.1 W
	6 m/s	0.99 A	49.7 V	49.6 W
	8 m/s	1.33 A	66.91 V	89.91 W
	10 m/s	1.68 A	84.14 V	142.2 W
	12 m/s	2.02 A	101.4 V	206.4 W
100	4 m/s	0.33 A	33 V	10.94 W
	6 m/s	0.5 A	50.42 V	25.5 W
	8 m/s	0.67 A	67.87 V	46.2 W
	10 m/s	0.85 A	85.32 V	73.07 W
	12 m/s	1.028 A	102.8 V	106 W
200	4 m/s	0.166 A	33 V	5.57 W
	6 m/s	0.25 A	50.8 V	12.96 W
	8 m/s	0.34 A	68.37 V	23.46 W
	10 m/s	0.42 A	85.92 V	37.05 W
	12 m/s	0.517 A	103.5 V	53.7 W

By calculating the mechanical power of the wind turbine, the wind's rate of rotation in revolutions per minute, and the output power of the rectifier placed in various load changes, the test is computed based on the electrical power produced by the generator. Based on the current and voltage measurements, the output power is determined.

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The installed voltmeter and ammeter show the current and voltage readings. The outcomes of the current and voltage multiplication are then presented in a graph to show the characteristics of the load's influence on the system output power. The test results from Table II are shown in the result without the GWO. Additionally, the purpose of this test is to identify the system's features when applying the GWO approach. A DC-DC Boost Converter is used in the circuit to obtain a high output voltage from a low input voltage. The test is administered in the same manner as the prior test. The test results with GWO are shown in Table III.

TABLE III
TEST RESULT WITH GWO

Load (Ω)	Wind Speed	I_{output}	V_{output}	P_{output}
25	4 m/s	1.95 A	48.7 V	94.8 W
	6 m/s	3.07 A	76.8 V	236.5 W
	8 m/s	4.2 A	105 V	441 W
	10 m/s	5.3 A	132.9 V	706 W
	12 m/s	6.42 A	160.6 V	1032 W
50	4 m/s	1.07 A	53.8 V	57.9 W
	6 m/s	1.67 A	83.86 V	140.7 W
	8 m/s	2.27 A	113.9 V	259.6 W
	10 m/s	2.87 A	143.8 V	413.6 W
	12 m/s	3.47 A	173.6 V	602.5 W
100	4 m/s	0.56 A	56.88 V	32.3 W
	6 m/s	0.88 A	88 V	77.50 W
	8 m/s	1.19 A	119.1 V	141.9 W
	10 m/s	15 A	150.2 V	225.5 W
	12 m/s	18.1 A	181.1 V	328.1 W
200	4 m/s	0.29 A	58.58 V	17.16 W
	6 m/s	0.45 A	90.29 V	40.76 W
	8 m/s	0.6 A	122 V	74.39 W
	10 m/s	0.768 A	153.6 V	118 W
	12 m/s	0.92 A	185.2 V	171.6 W

When the wind is blowing at 4 m/s, experiments without the GWO approach take 0.04 seconds to get a stable value, but at 12 m/s, it only takes 0.011 seconds. Thus, it can be inferred that the finding of a stable output value will proceed more quickly the faster the wind speed enters the wind turbine. In experiments utilizing the GWO approach, there was a spike at the beginning of the generator operation, but it took 0.2 seconds for the value to stabilize at 4 m/s while it took 0.18 seconds at 12 m/s. Although the difference is not large enough to conclude, it can nonetheless be said that the wind turbine determines a stable output value more quickly the higher the wind speed entering the device. According to the results of this test, any variations of the specified wind speed will result in a voltage that rises steadily as more wind enters the turbine. When the condition is stable, the output power value is determined by multiplying the current and voltage values. The installation of an RMS signal to obtain a steady value or minor ripple has also contributed to the resultant voltage's stability. The generator has been linked to the rectifier and the boost converter to adjust the voltage based on the results of this test. GWO monitors the output power and voltage of the converter and rectifier. To obtain a Root-Mean-Square signal and obtain a genuine value by eliminating ripple, the output current and voltage are multiplied to obtain the output power value. The GWO approach has been tested in a wind power generation system, and the results are promising. demonstrating the ability of the GWO approach to maximize the generator's output power value. Here are some factors to keep in mind to understand how GWO resolves optimization issues: In running iterations of a system, GWO stores the best solution; its circular mechanism displays solution areas that can be extended to greater dimensions, and its hunting techniques allow solutions to locate prey places.

CONCLUSION

This study explains the technology of a horizontal axis wind turbine for the generation of wind power and a generator in the form of a Permanent Magnet Synchronous Generator, based on the results of the simulation and analysis that has been done (PMSG). A rectifier and boost converter are necessary for a wind energy conversion system using PMSG to function effectively and produce the best output power. The Gray Wolf Optimization (GWO) approach is used to maximize the wind power plant's output power. The results of experiments with and without the use of Maximum Power Point Tracking with GWO show that the output power increases with increasing wind speed entering the wind turbine. Trials in various wind speed variations have proven this. The simulation results demonstrate that the GWO approach can successfully optimize the output power of a wind power facility. The GWO algorithm optimizes the output power at varying wind speeds and load fluctuations, as shown by a comparison of using GWO and without GWO. Future study ideas in the area of improving the performance of electric power networks by talking about variables related to wind speed with more variations and different kinds of generators.

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