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Tracking the maximum power point of a combined wind and solar power plant with the help of a colonial competition algorithm

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Abstract

Due to the pollution of energy related to fossil fuels and the cost of production and consumption, today most developed countries are moving towards the use of renewable energy such as wind and solar energy through wind turbines and photovoltaic systems. Solar energy tends to be a global phenomenon. They have clean and effective modern technology that provides a beacon of hope for a future based on sustainable and pollution-free technology. One of the leading challenges in using these resources is energy source changes, in other words, the wind and flux of the sun change during the day and seasons. If it is possible to find the maximum power and extract the appropriate commands for each of the mentioned power plant units, the maximum power can be extracted according to temporal and spatial changes. For this purpose, in this article, in the beginning, in the first part, the problem and the activities taken are described. Then, in the second part, the required formulations and relations are expressed according to the production power in terms of wind, radiation intensity, environmental conditions, and the characteristics of turbines and solar arrays. Then, considering that the pursuit of maximum power requires the use of optimization algorithms, in the third part, the formulation and implementation process of the colonial competition algorithm is fully described. Section 4 presents the results of implementing the algorithm and solving the model in MATLAB. In the simulation section, the solar position for the province of Khorasan Razavi - Iran is considered. Then, using the information of the Meteorological Organization, the average wind speed is approximated. In wind speed modelling, wind speed information of Khorasan Razavi province - Iran has been used for a period of 72 hours. Also, modelling for a combined power plant with a maximum capacity of 225 has been modelled. For the required power, 200 kW is considered in relation to the capacity of power plants, and it also has the ability to be stored in the home battery, which can be used as a storage power plant. Which a good proposed approach has been able to provide the required power in a 24-hour period based on weather and solar conditions. Also, control variables such as the amount of screw angle, torque and rotor to the generator as well as voltage-current at both ends of the cells are optimally obtained. The results during the simulation indicate the achievement of maximum power based on the required power and atmospheric conditions and solar radiation.

Keywords: Wind Turbine, Photovoltaic System, Maximum Power Pursuit, Colonial Competition Algorithm
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1 Introduction

Renewable energy from wind turbines (WTs) and solar photovoltaic systems (PV) is the most suitable type of energy for use in the environment. These energy sources are a global phenomenon. They have the fastest growing energy in the world and are a clean and efficient modern technology that provides a beacon of hope for a future based on sustainable and pollution-free technology. Today's WTs are the most advanced modern technology and their installation is very fast [3].

Variable wind speed control (WS) shows the optimal power curve, which shows the relationship between the generator speed and the maximum output power of the system. Variable wind speed or generator speed control is essential for time-varying wind turbines. A wind turbine produces mechanical power at a specific variable wind speed that is a function of its shaft speed. To get the power tracker from the wind, the shaft speed must be controlled. At a given shaft speed, turbine power increases by increasing the variable wind speed. Also, the maximum power point (MPP) of the turbine occurs at different turbine speeds and variable wind speeds corresponding to the maximum power, which increases with increasing variable wind speed. [1] The conventional method is to create a control law to generate generator torque (T_e), which allows the wind turbine to reach the maximum power point by accelerating torque or decelerating to achieve a certain angular velocity. Regardless of the generator used for the variable speed-based wind energy conversion system (WECS), the output energy of the wind turbine system depends on the maximum power point tracking technique on the turbine characteristics due to the variable wind speed. Maximum power point tracking methods can be divided into two categories [4]:

1. Methods of tracking the maximum power point based on the sensor
2. Maximum power point tracking algorithms without sensor, based on the sensor required to calculate variable wind speed.

Sensor-based maximum power point tracking algorithms consist of maximum power point tracking techniques that use an anemometer to measure actual wind speed in an instant, such as a method of measuring wind speed or speed-to-tip ratio (TSR). Sensorless maximum power point tracking algorithms include techniques that do not use any system such as an anemometer to measure wind speed to extract maximum power. These control methods use indirect methods or may use a variety of techniques that do not require information or knowledge of wind turbine systems, such as fuzzy logic (FL), neural network (NN), and ANFIS-based techniques. Maximum power point tracking techniques are usually integrated into an electrical converter framework that converts voltage or current, filters, and adjusts for different loads, including power grids, batteries, and motors. Due to the complementarity of wind and solar energy, the combination of the two can be used to achieve more and more appropriate energy production [9]. In a hybrid system, the maximum power point tracking technique of the I-V characteristics of solar systems is provided by wind turbines. Clearly, there is only one point at which the hybrid system provides maximum power. To extract the maximum power from the cell, the working voltage or current must be according to the maximum power point, which is determined by V and I, respectively, under temperature and sunlight. Performance indicators for maximum power point tracking strategy for specific applications are an important design factor and should be based on the effectiveness of maximum power point tracking, response time [6].

Maximum power point detectors use a variety of methods to find the maximum power point and keep the efficiency of solar cells and wind turbines at the maximum. Given that maximum power is a kind of optimization, these methods seek optimization. One of the algorithms used for this purpose is the colonial competition algorithm. The colonial competition algorithm has become very popular among researchers in recent years due to its high speed and accuracy; Like other evolutionary algorithms, it starts with an initial random population, and each member of that population is called a country. Some of the best members are considered imperialists and others are colonies. The imperialists absorb a colony or a colony in a special way. In an optimization problem, the main goal is to find the best optimal answer to the problem. For this purpose, it is formed with a set of optimized variables [10].

A maximum power tracking algorithm, in addition to simplicity and low cost in implementation, should be able to track accurately and adapt quickly to environmental conditions. In this research, an optimization-based approach will be used to achieve the above goal. Optimization algorithms can be a good option for this challenge due to their high speed of action in finding optimal answers. In order to study the process of pursuing maximum power with an optimization-based approach, we must first mathematically model the intensity of solar radiation and the array of solar cells. Then, the relationship between the solar cell array model and radiation intensity with the optimization algorithm is determined and finally, using the simulation technique, the mentioned approach is evaluated.

2 Mathematical modeling of wind turbine and photovoltaic system

Due to the nature of this research, in this section, two parts of modelling the photovoltaic system and wind turbine will be described. First, the relationships and formulations of photovoltaic systems and power output and effective parameters in power will be expressed. Then, in the second part, the required relations for the wind turbine are described.

2.1 Modeling of photovoltaic systems

A solar cell acts as a p-n junction with nonlinear properties that express the response to the electrical behaviour of the system. In order to analyze these properties, a mathematical model of solar arrays has been developed that is defined based on the relationships between the inputs and outputs of the solar array. A photovoltaic array consists of a set of solar cells connected to a diode (D) by parallel or series arrays. Figure 1 shows the equivalent electrical circuit for a solar cell. As shown in Figure 1, this circuit contains a current source that depends on the intensity of the sun's radiation and the cell's temperature. In other words, this approach is used to equate the light output produced [5].

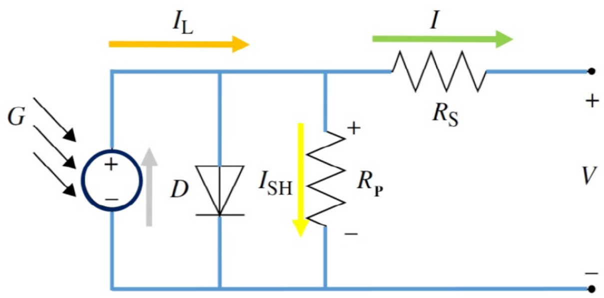

Figure 1: Equivalent electrical circuit for a solar cell

The output of the current source is proportional to the mass and intensity of the light beam that shines directly into the cell. In the dark (no light), the solar cell is inactive and acts as a diode, so it produces neither current nor voltage. If light shines on the surface of the solar cell, it creates a diode current. Diode D determines the current-voltage (I-V) characteristics of the cell. The series resistance, R_s, represents the resistance inside each cell, while the shunt resistance, which is modelled as a parallel noise resistance (R_p) in the circuit, is ignored due to its high resistance value [8].

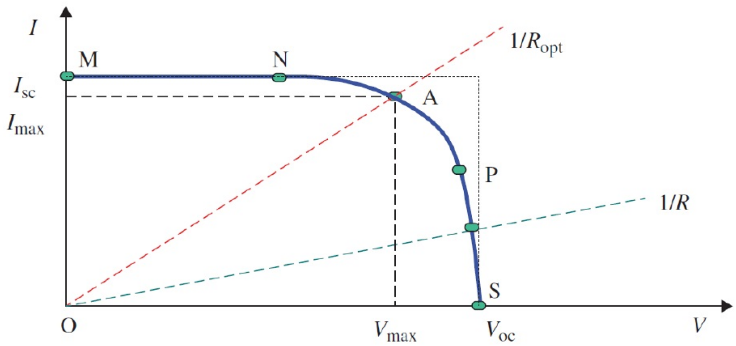

Figure 2: Characteristic curve V-I of a solar cell for a specific radiation intensity

Short circuit current, I_{sc}, is the maximum amount of current produced by a solar cell. This condition occurs in the case of a short circuit where $V = 0$. Open circuit voltage is related to the voltage drop across the diode when the light current is zero.

2.2 Modeling of time-varying wind turbines

The wind turbine considered in this research is a three-rotor horizontal wind turbine with an asynchronous generator, which is shown in Figure 3. The characteristics considered in the dynamic modelling section are:

- Turbine aerodynamics
- Turbine mechanics
- Generator dynamics
- Dynamics of operators

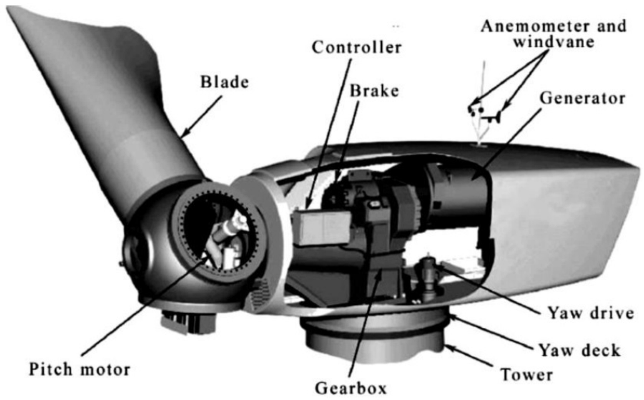

Figure 3: Horizontal axis wind turbine

The efficiency coefficient for wind turbines is done through wind tunnel calculations and is presented as a table, and in some cases, such as this research, it is also described as a nonlinear function. The three-dimensional drawing of the efficiency coefficients for the specified range is shown in Figure 4.

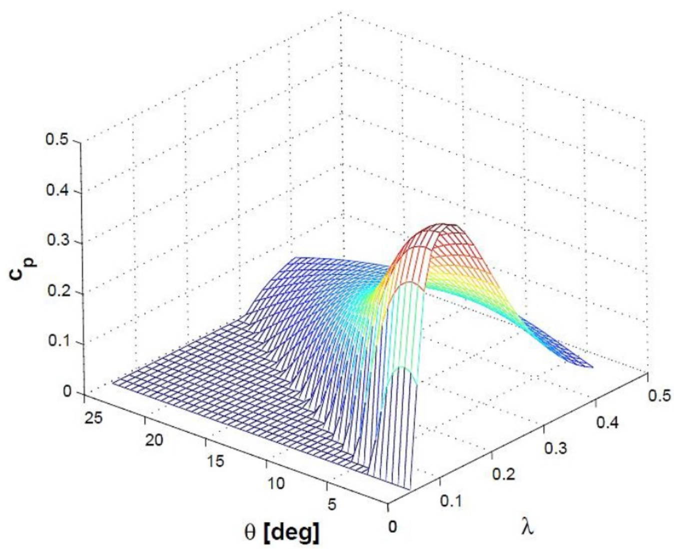

Figure 4: Three-dimensional view of efficiency coefficient

Figure 4 According to the power factor in Figure 2, the constant power curves (I_{sc}-power), the power extracted from the turbine, shows the nominal speed of the rotor. The figure shows that it is necessary to reduce the efficiency of the blades when the effective wind speed exceeds the allowable range, for example, about $V = 11$ meters per second (i.e. work in zone IV).

The curves shown in the figure above are plotted as functions of winding angle and wind speed. It is observed that the wind speed must be greater than 11m/s to extract the rated power. Interesting features are published by constant power curves, in which turbine power can be extracted by two values of screws. Power can be limited by both blades in positive and negative directions. In other words, negative pitching is called active steel control and positive pitching is called screw control.

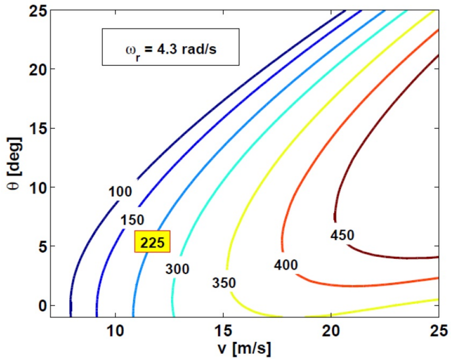

Figure 5: Constant power curves

One of the important factors in modelling wind turbine behaviour in the discussion of maximum power pursuit is the effect of effective wind speed (V_{wind}). Awareness of effective wind speed (V_{wind}), and its extreme fluctuations can also be effective in preventing damage to the turbine. However, effective wind speed is an abstract concept and is described as a wind field that is applied to the entire rotor disk and experienced by the rotor disk. Therefore, V_{wind} cannot be obtained directly from measurements [7].

The effect of effective wind speed can be considered as a random process and it can be modelled using random functions and a combination of oscillating functions such as trigonometric functions.

3 Colonial competition algorithm

In discussing the colonial algorithm, it should be noted that some optimization algorithms are inspired by natural and biological phenomena, but this algorithm has been proposed and invented inspired by a historical course. The phenomenon of colonialism is a historical event that has led countries that have been more powerful in terms of military power and economic knowledge to meet some of their needs for countries with strong but weak military and economic resources. Dominate and thus create a central government to control those countries and consequently have access to its resources [2].

4 Simulation results

In this section, the results of the implementation of the colonial competition algorithm on the problem of tracking the maximum power point of a combined wind and solar power plant in MATLAB software will be presented. First, the model specifications for the photovoltaic system and wind turbine are presented. It will then be expressed with a Spatio-temporal position to calculate the intensity of solar and wind radiation.

In the discussion of the desired geographical location, the province of Khorasan Razavi-Iran was adopted. Therefore, the length and width of the geographical area are 59.6057 and 36.298, respectively. The desired time was 230 equal to the 18th of August 2021. The average local temperature of the day was 35 degrees Celsius. In other words, the intensity of radiation during the day and the maximum power for the photovoltaic system for a period of the day will be as follows:

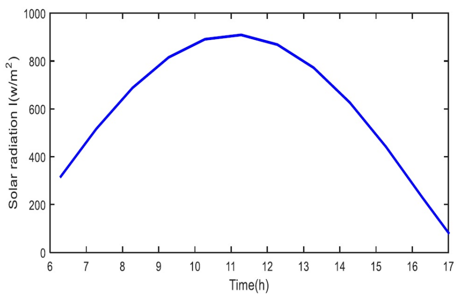

Figure 6: Curve of solar radiation intensity over a period of one day

In the following one-day period, the current-voltage and power-voltage curves are plotted, and the process of power optimization with a colonial algorithm for each hour is shown. Results are for 7am.

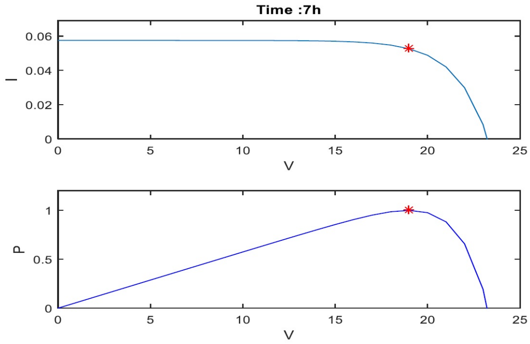

Figure 7: V-I and V-P curves and point points obtained from the colonial competition algorithm for 7 o'clock

Figure 7 shows the voltage value of the horizontal axis and the amount of power and current on the vertical axis. The maximum amount of power and current corresponding to the maximum power of the optimization algorithm is indicated in red for a photovoltaic cell.

As can be seen from Figure 7, the algorithm was able to extract the maximum power at any time of the day and calculate the appropriate control commands to achieve the desired power. The following results will be shown to follow the power and obtain the optimal power for the wind turbine.

It should be noted that in reality, the wind turbine control commands do not change moment by moment because this increases the failure of the operators and consequently increases the maintenance costs. If the average has to change over a period of time, for example half an hour or an hour, the control algorithm calculates the required control commands and transmits the operators. Here the simulation is performed for a period of 25 minutes from 7 to 7:25.

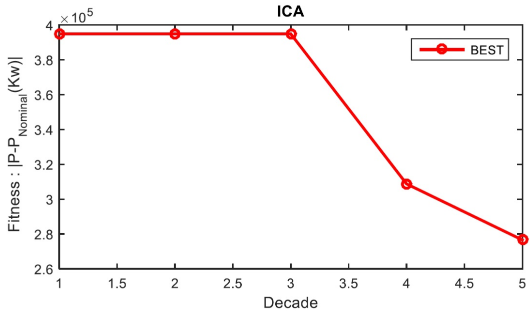

Figure 8: Curve of the maximum power pursuit criterion function (absolute value of the difference between the output power and the desired power) during the optimization process

Figure 8 shows the number of decades of optimization on the horizontal axis and the value of the cost function for the wind turbine on the vertical axis.

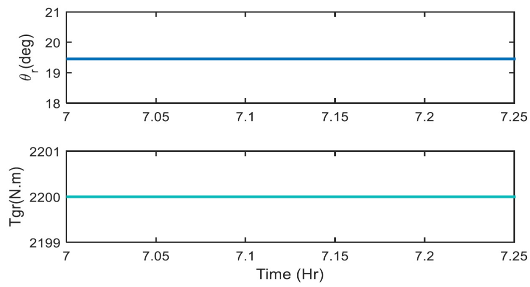

Figure 9: Commands of control operators

Figure 9 shows the commands of the control operators related to the screw angle and the torque transmitted from the rotor to the generator over time.

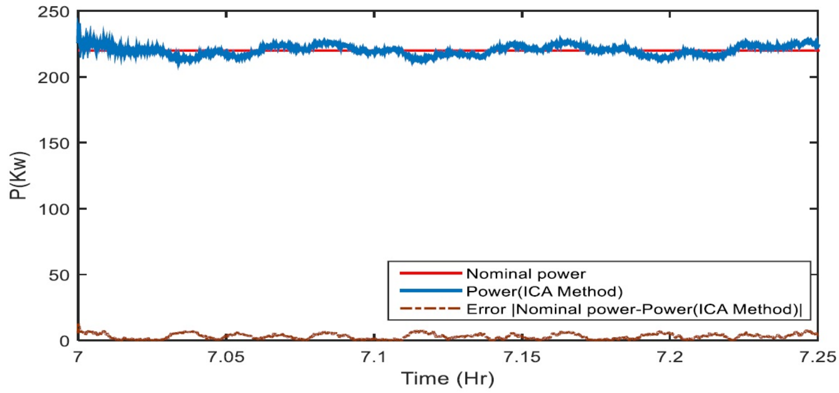

Figure 10: Curve of power output from wind and maximum power and power difference of nominal value

Figure 10 shows the power output from the wind turbine with a blue line and the power required by the red line and the error between the power output from the wind turbine and the power required by the brown line over time.

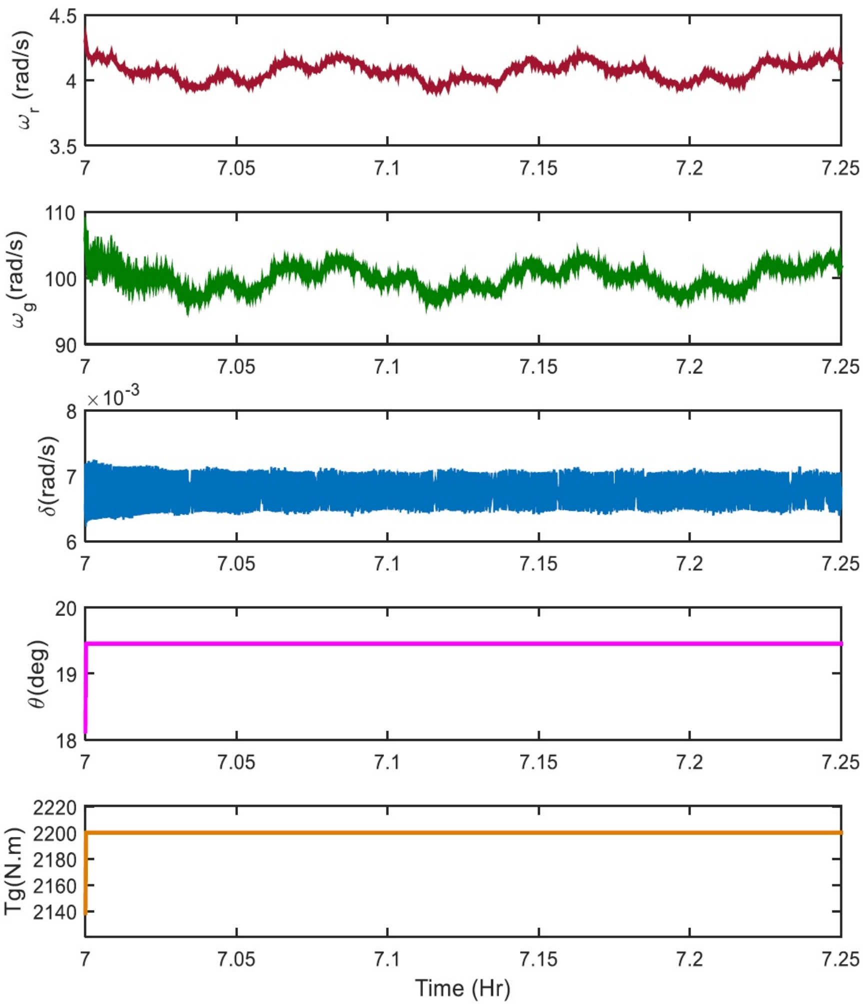

Figure 11: Curve of changes in system mode variables (wind turbine) over time

Figure 11 shows the change curve of wind turbine mode variables over time. From top to bottom, respectively, the rotor rotational speed curve, generator rotational speed, shaft torsion, blade angle (screw) and finally generator torque are shown in terms of time for the wind turbine.

Figure 12 shows the simulated wind speed curve over time. As can be seen in Figures 7 to 11, the colonial algorithm

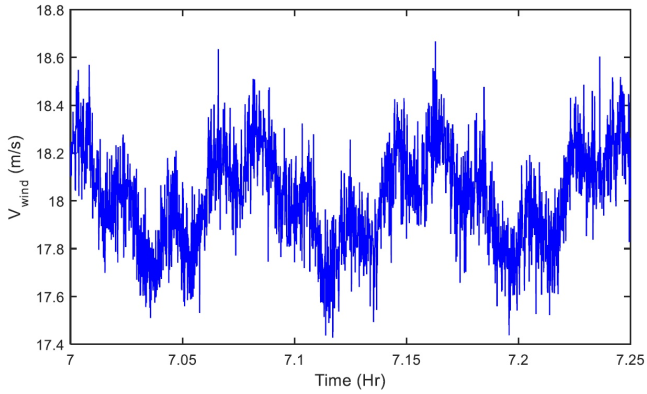

Figure 12: Variable wind curve

has been able to extract control commands well so that the maximum power is tracked over time due to the variable wind.

Power tracking of combined wind and solar power plant (PV)

First, before dealing with the power diagrams of wind and solar power plants, we examine the number of turbines in wind farms and the number of photovoltaic arrays in solar power plants and how they are calculated in relation to the power of power plants. As shown in Table 1.

Table 1: Maximum production capacity of solar power plants

The maximum output power of each module is 200w				
Power plant number	Number of modules	Number of panels	Number of arrays	Maximum power output of the power plant (kw)
1	1125	225	45	225

Table 2: Maximum production capacity of wind farms

The maximum power output of a wind turbine is 225w		
Power plant number	Number of turbines	Maximum production capacity power plant (kw)
1	1	225

The simulation results of the wind power plant and solar power plant with a power of 225 to the required power of the network, which is 200 kW and also has the ability to store in the home battery, are presented below.

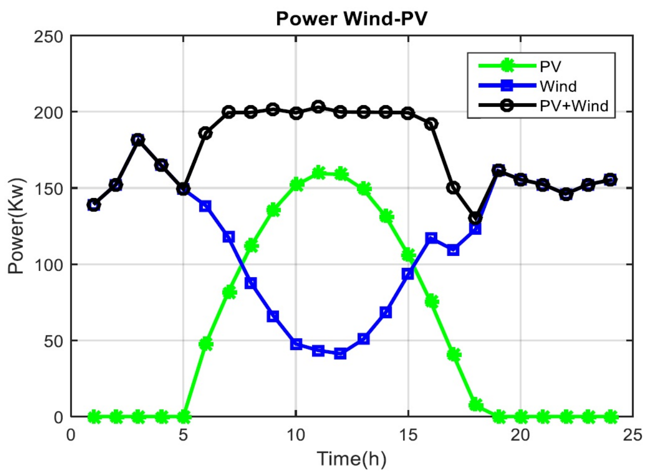

Figure 13: Total power-power generation curve by solar power plant - wind power plant

In Figure 13, the green curve corresponds to the maximum power of the solar power plant 225 kW and the blue curve corresponds to the maximum power of the 225 kW wind power plant and the black curve corresponds to the maximum power of the combined wind and solar power plant during 24 hours with the maximum power output from the solar power plant. And the rest is shown by the wind farm. As it is known, from 00:00 to near sunrise, that is, around 5:30 in the morning, which is the absence of the sun, the solar power plant does not receive power, which is according to the green chart of the clock. 00:00 to 5:00 has a value equal to zero. After the sun begins to rise and reaches its peak in the sky in the middle of the day, at the same time the production capacity of the solar power plant increases and reaches its maximum production point in the middle of the day. After this stage, with the arrival of the sunset moments, the production capacity of the solar power plant is reduced, and after the sunset, which is about 18:00, the production capacity of the solar power plant will reach zero point. As can be seen, the blue wind farm is clear that with the rising of the sun and the moderation of the weather, the amount of wind decreases dramatically and this decrease continues until the end of the day and at the end of the day with the setting of the sun, regional winds intensify. The result of combining these two power plants is shown in black in Figure 13, which indicates that on average in the total time interval of the combination of these two power plants, the average power output of the power plant is The average is between 150 and 200 kW, which is much more efficient than if each power plant operated alone.

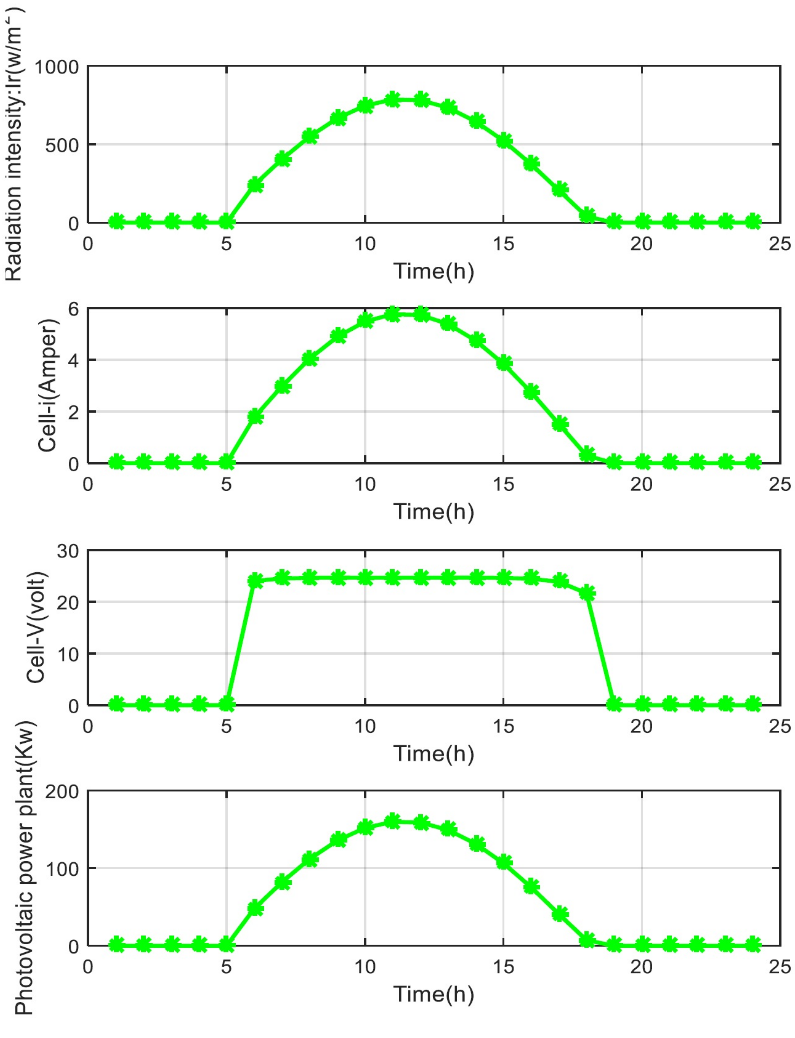

Figure 14: Curve of solar radiation intensity, current and cell voltage of a solar cell and power output by a solar power plant

Figure 14 shows the intensity of sunlight over 24 hours. The voltage and current curves of a single cell of the solar panel module are also shown. The maximum production capacity is shown by the solar power plant during the day and night. As can be seen. Figure 14 in the first diagram shows the intensity of sunlight, which, as previously described, is from 00:00 to early morning, which is approximately equivalent to 5:00 and is a trace of It is not the sun, it is expected that the graph of the intensity of sunlight shows a value equal to zero, which is quite clear in the graph. In mid-day, the intensity of sunlight increases, which can be seen in the diagram. As the sun sets, the graph assumes a value equal to zero, which is quite obvious. The sun sets at about 18:00, and the graph shows this.

Figure 14 of the second diagram shows the amount of current generated, which is directly related to the amount of direct sunlight that the first and second diagrams are expected to match, which, as can be seen, has been met. In the third part of the diagrams, the voltage-cell diagram is shown that by starting the day and creating an acceptable radiation intensity, it has created a constant amount of voltage during the day and in the dark hours such as 00:00 to 6:00 or 18:00: 00 to 24:00, which is the absence of the sun and its radiation, the amount of voltage generated is equal to zero.

In the final diagram, which is the output power diagram, it is expected that the output power diagram corresponds to the output current diagram because the power is proportional to the amount of current in the voltage, given that the voltage diagram is almost constant and the current diagram is a diagram. The share is of the quadratic function, the power diagram must also be of the quadratic function, which has met our expectations.

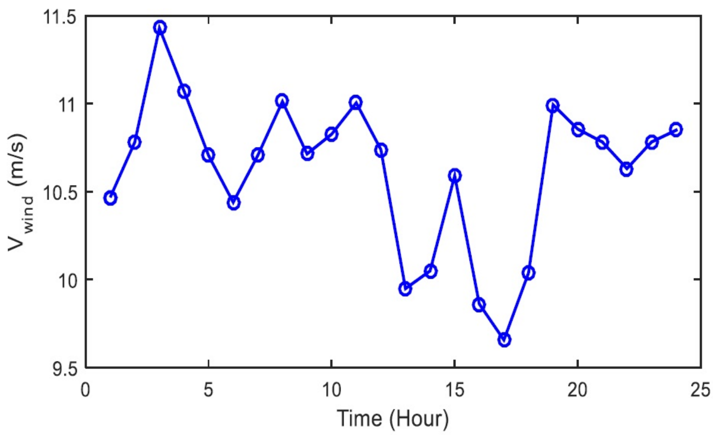

Figure 15: Wind speed curve overnight (24 hours)

In Figure 15, the simulated wind speed is 24 hours, and it goes without saying that due to the momentary change in wind speed, Figure 15 shows the average wind speed, and we have therefore used this method to use in the research method related to this research. As can be seen, the average wind speed decreased from the beginning of 00:00 to hours after half a day, and then with the approach of sunset, the regional winds intensified again.

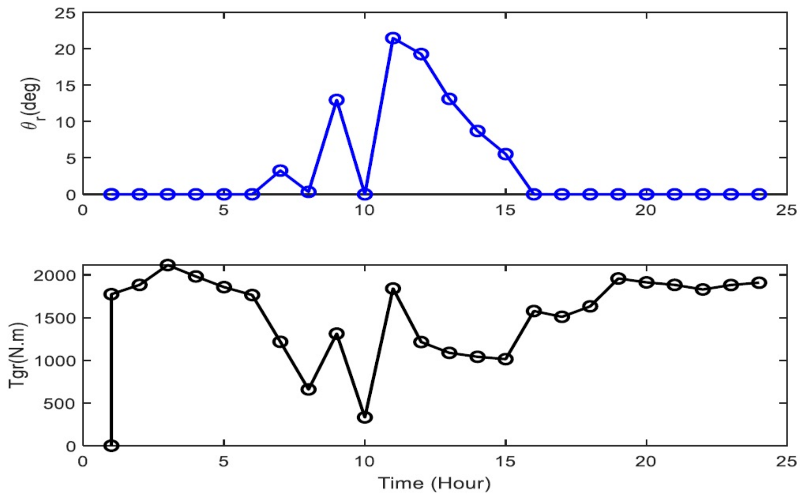

Figure 16: Curve of wind turbine control actuators to supply the required power

Figure 16 shows the command curves of the control operators related to the screw angle and the torque transmitted from the rotor to the generator during the simulated time.

Figure 17 shows the curve of changes in wind turbine state variables over a 24-hour period. From top to bottom, respectively, the rotational speed curve of the rotor, which as it is known has a constant rhythm in the hours of the

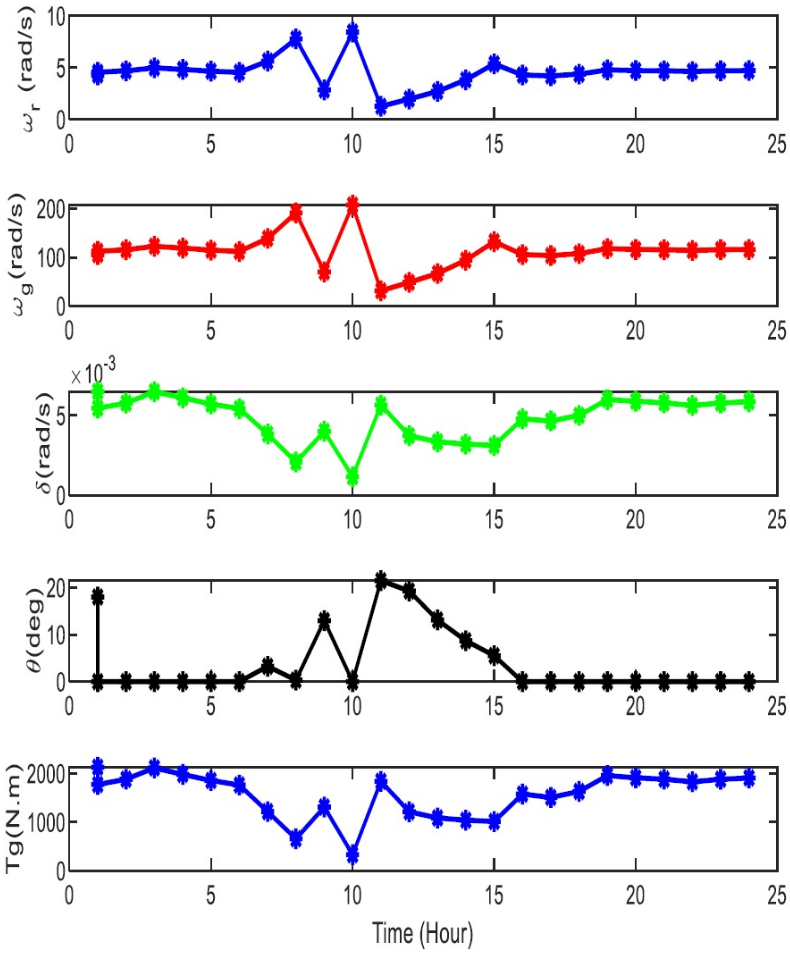

Figure 17: Curve of changes in wind turbine mode variables

absence of the sun and related radiation, this value has changed in the daily hours and solar radiation, which until the end The day has continued, in the next part, the second diagram, we see the rotational speed of the generator, which has a constant rhythm of operation at night and in the absence of the sun, and this constant value has changed during the day and the change of weather and sunlight. And then in the evening hours onwards until the end of the night, it has reached its same night rhythm again. The third diagram shows the shaft rotation, the next diagram shows the angle of the rotor blade (screw) and finally the generator torque in terms of time.

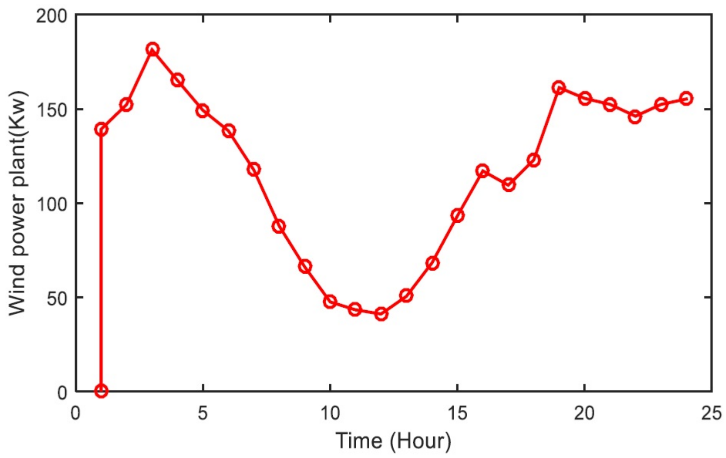

Figure 18: Power curve from a wind farm over a 24-hour period

Figure 18 shows the maximum power curve by the wind farm during a 24-hour period. On the contrary, in the hours when we see the absence of the sun, the production capacity of the wind farm has increased.

5 Conclusion and Recommendations

Due to the pollution of energy related to fossil fuels and the cost of production and consumption, today most developed countries have turned to the use of renewable energy such as wind and solar energy through wind turbines and solar photovoltaic systems. These energy sources are a global phenomenon. They have clean and effective modern technology that provides a beacon of hope for a future based on sustainable and pollution-free technology. One of the leading challenges in using these resources is energy source changes, in other words, the wind and flux of the sun change during the day and seasons. If it is possible to find the maximum power and extract the appropriate commands for each of the mentioned power plant units, the maximum power can be extracted according to temporal and spatial changes. For this purpose, in this article, in the beginning, in the first part, the issue and the activities taken are discussed. Then, in the second part, the required formulations and relationships were expressed according to the production power in terms of wind, radiation intensity, environmental conditions, and the characteristics of the turbine and solar array. Then, considering that the pursuit of maximum power requires the use of optimization algorithms, in the third part, the formulation and implementation process of the colonial competition algorithm were fully explained. In the fourth section, the results of algorithm implementation and model solving in MATLAB were presented. In the simulation section, the solar position was considered for Khorasan Razavi province-Iran. Then, using the information of the Meteorological Organization, the average wind speed was modelled approximately. In wind speed modelling, wind speed information of Khorasan Razavi province - Iran has been used for a period of 72 hours. Also, modelling for a combined power plant with a maximum capacity of 225 was modelled. For the required power, 200 kW is considered in relation to the capacity of power plants, and it also has the ability to be stored in the home battery, which can be used as a reserve power plant. The proposed approach has been able to provide the required power in a 24-hour period based on weather and solar conditions. Also, control variables such as the amount of screw angle, torque and rotor to the generator as well as voltage-current at both ends of the cells are optimally obtained. The results during the simulation indicate the achievement of maximum power based on the required power and atmospheric conditions and solar flux.

Given the position and practical importance of issues related to tracking the maximum power point of a combined wind and solar power plant with the help of a colonial competition algorithm, systematic determination of approaches and strategies related to this field can solve current and related challenges. It will be in the new energy industry. According to the results of the research work of this research and in order to deepen and expand the results of this research, some additional suggestions can be considered as follows:

1. Provide a new solution to improve the speed of solving the maximum power point tracking problem using the colonial competition algorithm.
2. Investigating the effect of control variables on maximum point tracking.
3. Investigation of the effect of dynamic correlation of maximum power point tracking in the wind and photovoltaic turbines.
4. Investigation of the effect of disturbances on tracking the maximum power point of a combined wind and solar power plant.
5. Intelligent maximum power point tracking system intelligent by algorithms based on artificial intelligence.

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