Pamukkale Univ Muh Bilim Derg, 31(1), 73-78, 2025

Pamukkale Üniversitesi Mühendislik Bilimleri Dergisi

Pamukkale University Journal of Engineering Sciences

Adjustment of variable speed wind turbine blade angle with Modified PSO

Modifiye PSO ile değişken hızlı rüzgâr türbini kanat açısının ayarlanması

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Received/Geliş Tarihi: 11.12.2023 Revision/Düzeltme Tarihi: 27.02.2024 doi: 10.5505/pajes.2024.99399
Accepted/Kabul Tarihi: 22.03.2024 Research Article/Araştırma Makalesi

Abstract

The main motivation of this study is to adjust the blade angle (β), which affects the mechanical output power of wind turbines (WTs), by particle swarm optimization (PSO). For this purpose, the standard PSO structure has been modified. Thus, the modified PSO algorithm has become capable of updating itself depending on the change of wind speed. In this study, the blade angles of wind turbines operating at variable wind speeds were controlled and adjusted using an optimization algorithm based on swarm intelligence. Within the scope of the study, a variable speed wind turbine was operated in two different simulation environments. In the first case, the values were obtained by keeping the wing angle constant (for β=0). In the second case, the proposed modification was operated by adjusting the blade angle with the angle produced by PSO, and the results of both cases were discussed.

Keywords: Wind turbine, Modified PSO, Pitch angle.

Öz

Bu çalışmanın ana motivasyonu, rüzgar türbinlerinin (RT) mekanik çıkış gücüne etki eden kanat açısının (β) parçacık sürü optimizasyonu (PSO) ile ayarlanmasıdır. Bu amaca yönelik olarak, standart yapıdaki PSO modifiye edilmiştir. Böylece modifiye edilmiş PSO algoritması rüzgar hızının değişimine bağlı olarak kendini güncelleyebilen bir duruma getirilmiştir. Yapılan çalışma da, değişken rüzgar hızlarında çalışan rüzgar türbinlerinin kanat açılarının kontrolü sürü zekasına dayalı bir optimizasyon algoritması kullanılarak ayarlanması sağlanmıştır. Çalışma kapsamında değişen hızlı rüzgar türbinini iki farklı şekilde benzetim ortamında çalıştırılmıştır. Birinci durumda kanat açısı sabit tutularak (β = 0° için) değerler elde edilmiştir. İkinci durumda ise önerilen modifiye PSO'un ürettiği açı ile kanat açısı ayarlanarak çalıştırılmıştır ve her iki durumun sonuçları tartışılmıştır.

Anahtar kelimeler: Rüzgâr türbini, Modifiye PSO, Kanat eğim açısı.

1 Introduction

Wind energy is one of the most modern forms of renewable energy sources (RESs), with high energy potential and promise for the future [1],[2]. However, the essential issue with wind energy conversion systems (WECS) is the large differentness among the inordinate form of the preliminarily source (wind power) (wind speed is a coincident, rather floating duration) and the immediate requisition on the quality of electric energy [3]. Wind energy source, which is an alternative to traditional sources of electricity production, is becoming increasingly popular because it is abundant in nature and does not create pollution [4]. Thanks to this structure, they can be designed for high powers, but as the size of the wind turbine increases, its transportation, installation and service costs also increase [5]. The optimum total energy output from a wind power plant may be achieved by the optimum geographical location of the wind turbines [6]. Wind turbines also take up less space than RES and can be placed on any terrain or offshore, in remote locations such as mountains or deserts [7]. Thanks to these features, wind turbines can produce energy almost anywhere on Earth and at any time of the day. In the 2013 Wind Report of the Global Wind Energy Council (GWEC), it is stated that wind energy is the second largest RES and will account for 25% of all renewable energy by 2035. [8]. A wind turbine is a type of power machine that produces mechanical energy from wind energy. The blades are one of the most important components of the wind turbine. Conversion efficiency of wind energy subject to the aerodynamic shape of the wing. [9]. To obtain maximum power from wind turbines operating in variable wind speed regions, the tilt angle of the turbine blades must be controlled by an appropriate control signal [10]. Wind turbine blade angle control (Pitch control) ensures that turbines operate efficiently above nominal wind speed. To hold WTs in a safe running zone as well as obtain stable power, the pitch control technique must also be intelligent and highly efficient [11]. PSO is a new algorithm developed in recent years, which has several advantages of easy use and high precision, fast convergence [12]. When related studies are analyzed, [13] With their study to increase the efficiency of wind turbines; They proposed a system in which mechanical energy may be reserved in an unloaded WT and occure a risk of the futurity system frequency falling to a level below the low frequency verge, the stored mechanical energy is then let off to promote the futurity frequency to a low level the lower frequency verge. In this purpose, time and maximum step angle related to the trapezoidal step angle command were determined using PSO. At the end of the study, the results obtained from simulations results indicate the accuracy of the aimed preventive frequency controller and the aim at analytical frequency estimator effectiveness in preventing future low-frequency load shedding.

The resoluteness of WT's output suffers from multifactor perturbations, which makes it difficult for the traditional proportion-integral-differential (PID) control technique to obtain. [14] With their study, they proposed a fuzzy adaptive particle swarm optimization PSO-PID control strategy. Within the scope of the study, a wind turbine model was created compose of a permanent magnet synchronous generator (PMSG) and pitch regulator. They then analyzed the effect of

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various disturbances for example installation errors, blade deformation, and external wind speed on the WT speed. Moreover, to achieve the targeted operation, a WT pitch control strategy has been designed, in which parameters of PID are firstly optimized by the PSO and adeptly adjusted by the fuzzy logic controller (FLC). Finally, they carried out simulations under turbulent and strong wind conditions. The results showed that compared with PID, fuzzy PID and fuzzy adaptable PSO-PID can effectively diminish the errors in WT's output power and wind wheel speed.

Wind speed and direction are fundamental parameters that affect the power generation by the WTs and are changing constantly. Optimal method of controlling the output power of a WT is to adjust the angle of the rotor blades. Based on this information, researchers [15] used an adaptive control technique to control the wind turbine tilt angle. They obtained the coefficients they needed with sliding mode control determined using the PSO-support vector machine (SVM) method. To assess the occasion of their aimed method, they compared it with the Model Reference Adaptive Controller (MRAC) running under uneasy. Their consequences showed that the aimed controller is preferable to MRAC in case of disturbance. Simulations have also shown that the power generated at variance wind speeds reaches the optimum value faster.

To obtain maximum power in variance speed wind regions of WTs, it is important to apply a control signal appropriate to the pitch angle of the rotor blades. According to the researchers, the current indefinite in modeling wind turbines makes calculating these signals difficult. To overcome this trouble, an optimal controller like PSO is suitable. In their study [16], researchers proposed and applied fractional order PSO (FPSO) to improve the performance of the controller. To create this approach for a two-mass WT. In particular, it has been observed that without attitude feedback, FPSO, CPSO and TSK fuzzy systems are unable to stabilize Wind turbines in tracking the wish for trajectory.

In this study, it is aimed to adjust the blade angle (β), which affects the mechanical output power of wind turbines, by PSO. For this purpose, the standard PSO algorithm is modified and given the ability to update itself depending on the change in wind speed. With this study, it is aimed to control and adjust the blade angles of wind turbines operating at variable wind speeds by using an optimization algorithm based on swarm intelligence. As a result, a variable speed wind turbine is operated in a simulation environment (Matlab/Simulink) over two different scenarios and the results of both cases are discussed. As a result of the study, it is aimed to bring a study to the literature that metaheuristic algorithms such as PSO can be used in the optimization of energy sources with nonlinear output characteristics such as wind turbines.

The proposed study consists of four main sections, accordingly, in the Introduction section, the information and literature review that may be the basis of the study are given. In the second section, the materials and methods necessary to achieve the objectives of the study are given. In the third section, Results and discussions, the outputs obtained within the scope of the study are discussed. The last section, Conclusions, evaluates the results of the entire study and includes the positive and negative aspects of the study.

2 Material and methods

2.1 Characteristic of the wind energy conversion systems

Wind power generation systems (WPGS) have become inviting and agonistical due to being inexhaustible and clean sources of power [17]. WTs are commonly used as wind energy transform systems. Renewable energy sources like wind, coal or diesel are more affordable and feasible than traditional non-renewable energy resources [18]. In the past, wind energy was used in drawing water from water wells, grain milling and some industrial processes. Nowadays, electrical energy is produced with modern wind turbines. WTs are mechanical structures that transform the kinetic energy of the wind into electrical energy. Thanks to the aerodynamic structure of the rotor wings, the wind hitting the wings produces a lift force (F_L) on the wings. A cross-sectional view of the WT's blade used in modern wind turbines is shown in Figure 1.

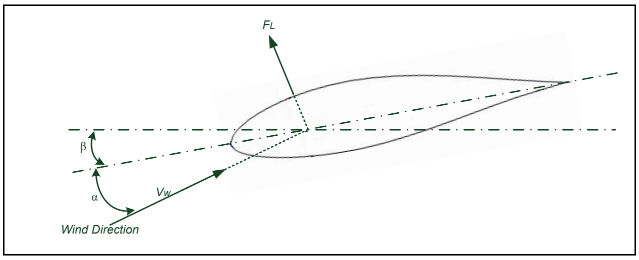

Figure 1. Sectional diagram of the turbine blade.

The main goal in the control tecnique of WT is to try to control the turbine at wind speeds where the generator speed of the wind turbine reaches its nominal value, and therefore the generator power reaches its rated value, based on a certain wind speed and named as nominal wind speed. When the wind speed is below the rated speed, torque control is employed to maximise the power coefficient of the WT so that the power from the wind is maximised.. When the wind speed higher than the nominal wind speed, slope control is used. Variable-speed wind turbines are the most used wind energy conversion system today [19]. Wind turbines with variable blade angle configuration, operating in variable speed winds, have three main operating zones as shown in Figure 2.

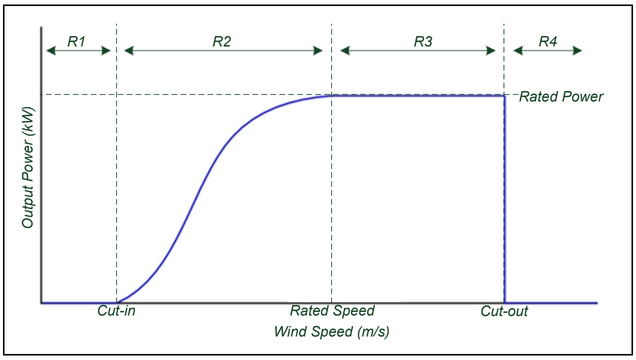

Figure 2. Main operating regions of wind turbines with variable speed and variable pitch angle configuration.

In zone 1, the wind speed is lower than the turbine cut-in speed (V_{cut-in}) and the WT is not activated; In zone 2, the wind speed is between the cut-in speed (V_{cut-in}) of the WT and the nominal wind speed (V_{rated}), and the maximum wind power must be achieved by the rotor speed control; In zone 3, the wind speed is between the nominal wind speed (V_{rated}) and the cut-out speed ($V_{cut-out}$). The goal of the control technique to be applied in this region is to obtain the nominal output power of the turbine from wind power through blade pitch control and electromagnetic torque control.

2.2 Mathematical explanation of wind turbine and PSO algorithm

WTs are mechanical structures that transform the kinetic energy of the wind into electrical energy. Thanks to aerodynamic structure of the rotor wings, the wind hitting the wings produces a lift force on the wings. With the rotatable structure of the wings from the rotor shaft, this lift force turns into rotational motion. The rotational motion produced can be easily converted into electrical energy via electrical generators. Thus, electrical energy is produced from wind energy. The mechanical output power produced from wind turbines is expressed by equation (1). In wind turbines, wind turbine efficiency depending on blade angle is calculated with Equation (2).

$$P_m = \frac{1}{2} C_p(\alpha,\beta)\rho A V_w^3 \qquad (1)$$

$$C_p(\alpha,\beta) = t_1\left(\frac{t_2}{\lambda_i} - t_3\beta - t_4\beta^x - t_5\right)\exp(-\frac{t_6}{\lambda_i}) \qquad (2)$$

Where:

P_m	:	Mechanical output power of wind turbine
ρ	:	Air density (kg/m^3)
V_w	:	Wind speed (m/s)
A	:	Turbine swept area (m^2)
$C_p(\alpha,\beta)$	:	The coefficient of the wind turbine
β	:	Pitch angle of blades (°)
λ	:	TSR of rotor blade

Where the t_1 to t_6 are constant of the wind turbine model. The PSO algorithm has attested to be a robust tool for solving optimization-based non-linear problems [20],[21]. PSO, first introduced by J. Kennedy, Y. Shi and R. Eberhart in 1995, is a stochastic optimization method that emerged by describing the social behavior of flocks of birds or fish [22]. Unlike traditional optimization approaches, PSO endures trajectories of a cluster of possible settlement, it is known as "particles", in its search for the optimum [23]. PSO has few parameters to update and is also simple to perform. The idea of PSO is widely used happily in many industrial process [24]. The PSO algorithm can be explained with the following steps:

Step I: It starts with an inceptive arrange the particles that are generally distributed randomly along with the design space.

Step II: Each particle's velocity (v) is determine on Equation (3):

$$v_{k+1}^i = K[w v_k^i + c_1 r_1(p^i - x_k^i) + c_2 r_2(p_k^g - x_k^i)] \qquad (3)$$

Where (x) is the position, (K) is the contraction parameter, (w) is called the inertia weight, (P_k^g) is the present global optimum in the swarm at iteration (k) and (P^i) is the current local optimum of the particle (i). The coefficients (C_1) and (C_2) are called social and cognitive variance, (r_1) and (r_2) are are random numbers of odd form, ranging from 0 to 1.

The x position of particle (i) is updated with Equation 4:

$$v_{k+1}^i = v_k^i + v_{k+1}^i \qquad (4)$$

Step III: Return the step II and repeat the process till some overlap criteria is provide your requirement or all iterations are finished off. In order to develop the performance of PSO, Shi and Eberhart recommend that the inertia weight which linearly rates between 0.4 to 0.9. The inertia weight may be determined from Equation 5.

$$w = w_{max} - k(w_{max} - w_{min})/k_{max} \qquad (5)$$

Where w_{min} and w_{max} indicate the minimum and maximum of w, k is the current iteration and k_{max} is the maximum number of iterations. The constriction constant K can be determined as:

$$K = \frac{2}{\left|2 - \varphi - \sqrt{(\varphi^2 - 4\varphi)}\right|}, \qquad \varphi = C_1 + C_2 > 4 \qquad (6)$$

K is broadly evaluated to be 0.729 and $C_1 = C_2 = 2.05$ [23].

2.3 Active pitch control based on the modified PSO algorithm

Wind energy conversion systems necessitate appropriate control to maximize the power produced by WT regardless of wind conditions [25]. The basic motivation of PSO is to reach the ideal solution to a complex issue by initializing a group of random particles and performing iterations in a given loop. Particles reform himself by following two extremes in each iteration. One is the ideal solution obtained by the self-repetition of the particles, that is, the individual extremum *pbest*, and the other is the global ideal solution, that is, the global extremum *gbest* [26]. The flow chart of the Modified PSO, which was created by modifying the traditional structured PSO, is given in Figure 3.

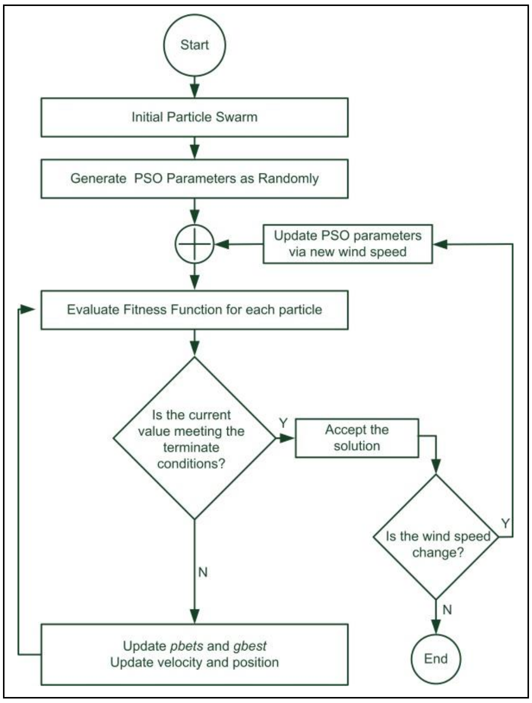

Figure 3. Modified PSO algorithm flow chart.

PSO algorithm in standard structure; the proposed algorithm starts optimization based on the wind speed applied to the turbine and random particles. The algorithm tries to reach the most suitable function and when the desired iteration is reached, it checks whether the values reached meet the need. If the conditions are met, updates are made and the process is terminated. However, if the wind speed changes, the algorithm cannot update the optimum values. According to the flow chart given in Figure 3, when wind speed changes, the algorithm goes back to the beginning and tries again and calculates new appropriate values for the new wind speed. These two described cases are shown in Figure 4.

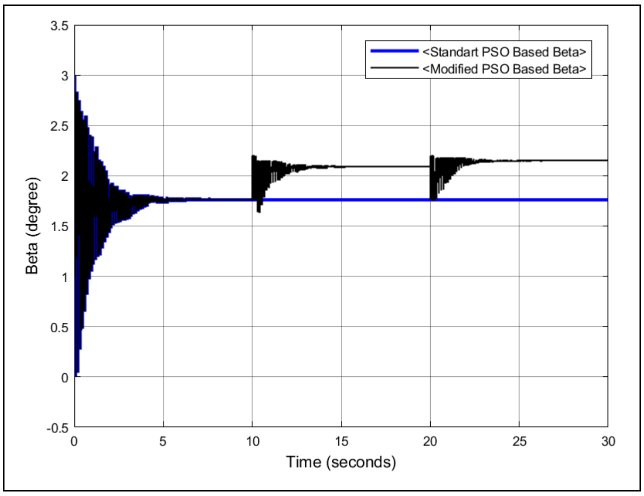

Figure 4. Effect of Conventional PSO and Modified PSO on Beta value.

The model designed according to Figure 4 was operated under the same conditions with both standard PSO and modified PSO. It is understood that the standard PSO did not retry even if the wind speed changed after reaching the desired conditions and worked with the same angle β in all operating regions.

3 Results and discussions

The diagram of the suggested system created to run the modified PSO algorithm proposed within the scope of the study is given in Figure 5.

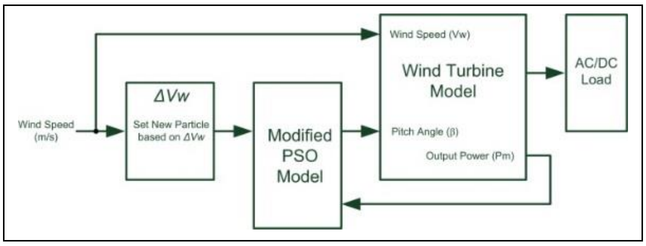

Figure 5. Block diagram of the wind energy conversion system designed within the scope of the study.

The proposed system includes a section (ΔVw) that detects the change in wind speed, determines the new particle swarms required for the PSO algorithm, and reruns the algorithm. This section ensures that the particles are distributed within a certain range rather than randomly, based on the previous optimal Beta value according to the amount and direction of change in wind speed, and restarts the algorithm. This situation can be explained through the graph given in Figure 6. According to the graph, the random particles vary between 0°-2.8° (y-axis) at the initial wind speed (6 m/s), while the particles vary between 1.6°-2.2° at the second wind speed (16 m/s), and 1.8°-2.2° at the final wind speed (23 m/s) can be seen to vary between.

The wind profile applied to the turbine is given in Figure 7. Accordingly, the wind turbine was activated with 6m/s, which is a value that can be considered as the initial wind speed for many wind turbines in the range of 0-10 seconds. The second wind speed was applied between 10-20 seconds, 16ms, which can be considered as the rated wind speed for many wind turbines and is a value at which the turbine starts to produce maximum power. Finally, the maximum power generation range (rated power) of the wind turbine and a slightly lower value than the cut-in speed is 23 m/s and was applied between 20-30 seconds. The selection of these values was created by examining the wind turbines that have been the subject of studies and taking into account the operating regions of variable speed wind turbines given in Figure 2.

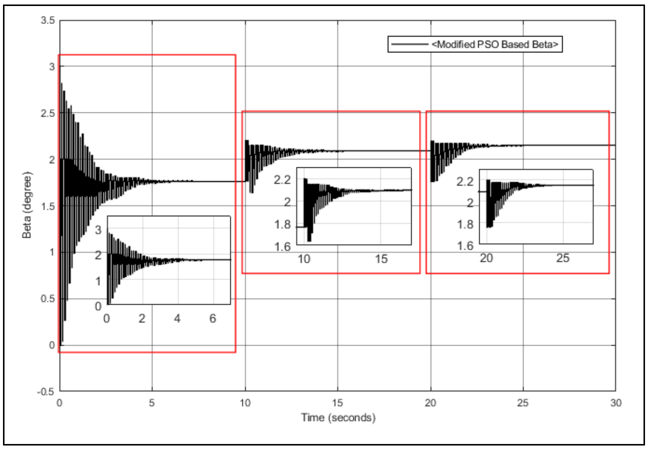

Figure 6. Effect of modified PSO on Beta at variable wind speeds.

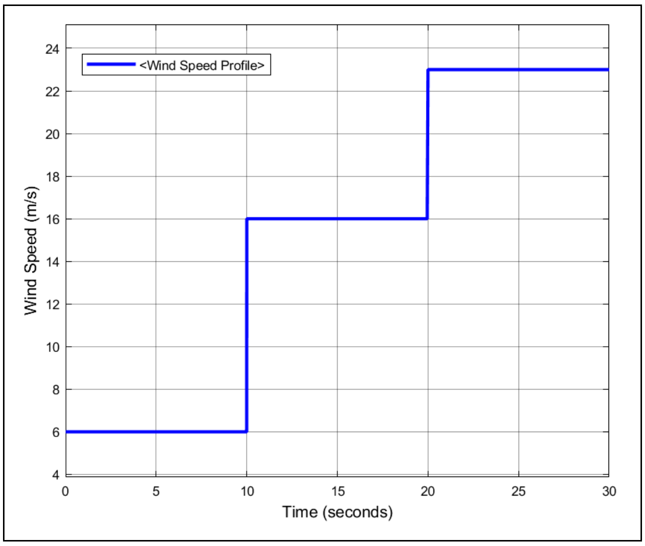

Figure 7. Variable wind speed profile used in the study.

The wind power conversion system designed within the scope of the study was operated both for a fixed angle ($\beta = 0°$) and under the same conditions with the variable (β) adjusted by the modified PSO, and the turbine rotor speed graph given in Figure 8 was obtained.

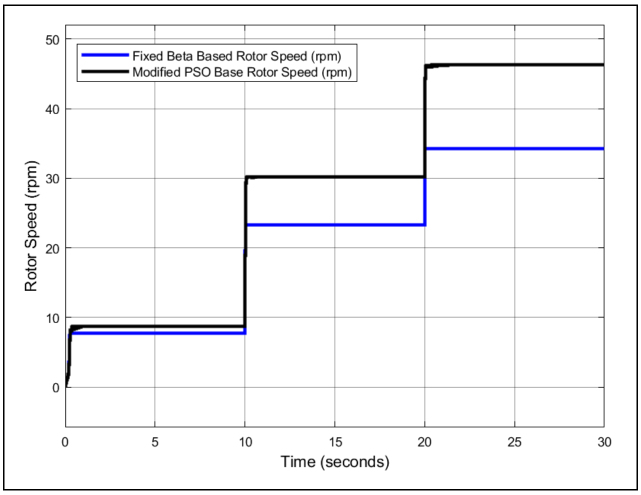

Figure 8. Wind turbine rotor speed graph obtained as a result of the simulation under $\beta = 0°$, and variable β.

It can also be understood from the turbine rotor speed chart that limited power values can be produced as a result of operating the wind turbine with a constant Beta value (for 0°) from start to finish. Although all conditions were the same, it was observed that the β value produced by the proposed modified PSO kept pace with wind speed changes. The graph showing the β value produced in response to the wind speed change and the constant value is given in Figure 9.

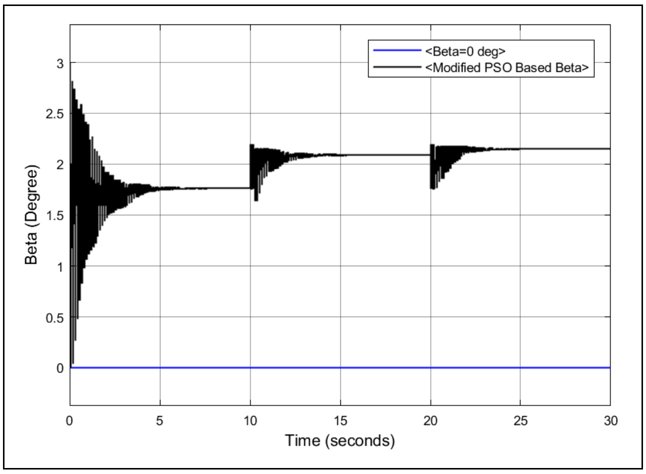

Figure 9. Change graph of Beta values applied to the wind turbine blade within the scope of the study.

4 Conclusions

Within the scope of the study, a different approach to blade angle control is aimed for wind energy conversion systems operating in regions with variable speed winds. Wind power conversion systems require an appropriate control strategy to maximize the power generated from these systems. For this purpose, the blade angle of wind turbines may be controlled by modifying the PSO, which imitates the behavior of bird and fish flocks, which can provide the optimum solution for complex systems. The desired operation aims to guarantee that wind turbines operate in safe areas and obtain the highest power value. A wind energy conversion system was designed for this purpose, and secondly, the PSO algorithm was modified to meet the needs. Finally, a wind temperature profile was created to suit the working regions of wind turbines encountered in literature studies. By operating the wind turbine in this wind speed profile, the change in turbine rotor speed was observed. The wind turbine was operated separately under the same conditions for both fixed angle ($\beta = 0°$) and variable Beta, and the results were analyzed. As a result of the study, it is aimed to bring a study to the literature that metaheuristic algorithms such as PSO can be used in the optimization of energy sources with nonlinear output characteristics such as wind turbines.

5 Author contribution statements

All processes and stages of the study were carried out by Göksel GÖKKUŞ.

6 Ethics committee approval and conflict of interest statement

"There is no ethics committee approval needed for this article". "In addition, there is no conflict of interest with any person or organisation in this article".

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