# Optimal Power Generation Control of Wind Turbine by Using Different Meta-Heuristic Algorithms

Marwa Arabi(1)*, Lotfi Chetioui(2),Youcef Zennir(3)*, Hichem Bounezour(4), Jesus Anrique Sierra Garcia(5)

(1,3,4) Automation Laboratory Skikda (LAS). Université of 20 august 1955, 21000 Skikda, Algeria
(2) LRPCSI Laboratory, Université 20 Aout 1955, Skikda 21000, Algeria
(5) Digitalization Department (section in systems engineering and automation). Burgos University, Burgos, Spain

*m.arabi@univ-skikda.dz, y.zennir@univ-skikda.dz

**Abstract:** The modeling and control of a wind energy conversion system (WECS) that makes use of a permanent magnet synchronous generator (PMSG) are investigated in this work. It compares two methods—MPPT-PSO and MPPT-GA—with the aim of maximizing power extraction from the system in each case. The simulation results demonstrate that the use of these MPPT algorithms enables the system to reach the optimal mechanical speed necessary for maximum power output. All simulations were performed using Matlab/Simulink.

***Keywords:*** Wind turbine, Speed control, Optimization, GA, PSO, PI.

## 1. INTRODUCTION

In the recent past, there has been a surge in interest regarding wind energy. This particular form of energy is generated through the use of wind turbines [1] which work by using their structure to transform some of the kinetic energy of the wind into mechanical energy. An electric generator then uses this mechanical energy to create electrical energy.

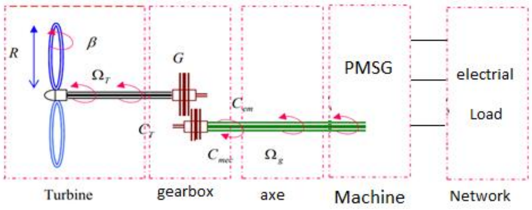

Fig. 1. Wind energy conversion principal.

Horizontal and vertical axis wind turbines are the two types of wind turbines. , in the immediate term, the horizontal axis one are the most common wind turbines on the market, and their success result from their very interesting production profile [4].

Wind turbines employ various generators, including squirrel-cage induction generator (SCIG), wound rotor induction generator (WRIG), doubly fed induction generator (DFIG), and Permanent Magnet Synchronous Generator (PMSG). Notably, the variable speed wind turbine (VSWT) with PMSG outshines others in terms of efficiency, reliability, compact size, and cost-effectiveness compared to WRIG, SCIG, and DFIG [2].

Wind speed and the mechanical output of the wind turbine are inextricably related. Even though wind speeds vary, there is a specific optimal operating condition that enables the turbine to get the most possible power. Attaining this condition requires fine-tuning the generator's speed, a method referred to as the Maximum Power Point Tracking (MPPT) technique [3].

To enhance the Proportional-Integral (PI) controller gains in the MPPT architecture, the Particle Swarm Optimization (PSO) algorithm and Genetic Algorithm (GA) will be applied and compared. This optimization process aims to maximize the power output of the WECS [5] and DFIM with HHO, PSO and SSA algorithms [6].

## 2. WECS MODELLING

### a) *Wind Turbine Modelling*

The generation of a wind turbine involves an aerodynamic torque $C_{aer}$ and mechanical power$P_t$, expressed as outlined in [7]:

$$P_t = 0.5C_p(\lambda,\beta)\rho\pi R^2V^3 \text{And } C_{aer} = \frac{P_t}{\Omega_t} \qquad (1)$$

Where $R$ is the diameter of the wind turbine rotor (m) $V$ represents wind velocity (m/s), ρ represents air density, and $C_p(\lambda,\beta)$ represents the wind turbine power coefficient, as defined below:

$$C_p = \left[0.5176\left(\frac{116}{\lambda'}\right) - 0.4\beta - 5\right]\exp\left(\frac{-21}{\lambda'}\right) + 0.0068\lambda \qquad (2)$$

$$\text{With:}\lambda' = \frac{1}{\lambda+0.08\beta} - \frac{0.035}{\beta^3+1} \qquad (3)$$

$$\lambda = \frac{\Omega_{mec}\,R}{V} \qquad (4)$$

Where: $\lambda$ is the tip-speed-ratio,$\Omega_t$is the mechanical speed of the turbine blades (in rad/s), and $\beta$ is the blade pitch angle. The char acteristics of the wind turbine are shown in Figure 1 [8].

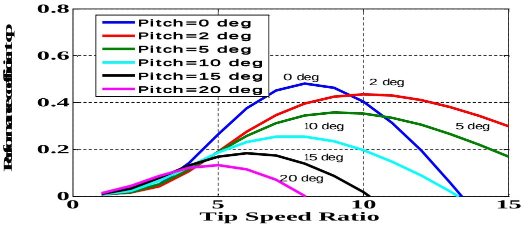

Fig. 2. Aerodynamic power coefficient $C_p$ variation as a function of tip speed ratio (λ\lambda) and pitch angle $\beta$.

The mechanical torque of the wind turbine is calculated as follows:

$$C_t = \frac{P_t}{\Omega_{mec}} = \frac{0.5C_p(\lambda,\beta)\rho\pi R^2V^3}{\Omega_{mec}} \qquad (5)$$

The expressions related to the gearbox are showcased as follows:

$$C_t = \frac{\Omega_{mec}}{G} \qquad (6)$$

$\Omega_{mec}$=G*$\Omega_t$
(7)

$G$ is the gear ratio coefficient, $\Omega_{mec}$ is the mechanical rotationel speed .
The illustration of the mechanical transmission is outlined as follows [5]:

$$J\frac{d\Omega_g}{dt} = C_{mec} = C_g - C_{em} - C_f \qquad (8)$$

Figure 3 visually presents the model of the wind turbine.

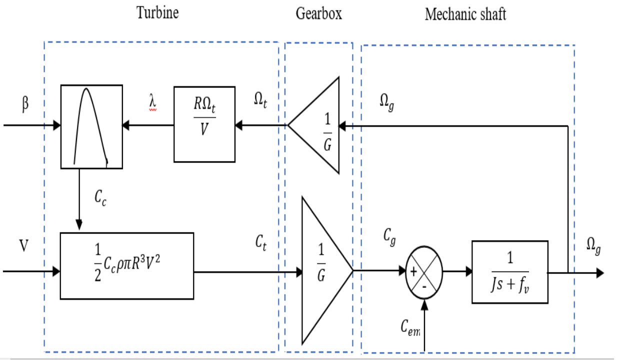

Fig. 3. Block diagram of a horizontal-axis wind turbine [5].

### b) *Permanent Magnet Synchronous Generator*

The PMSG generates electromagnetic torque, as indicated below[9]:

$$C_{em} = \frac{3P}{2(\lambda_r i_{qs} - (L_d - L_q)i_{ds}i_{qs})} \qquad (9)$$

Where, $L_d$(H) and $L_q$(H) are the dq-axis self-inductance of the synchronous generator, $\lambda\_r$ ($wb$(*rms*)) is the rotor flux linkages, P is the number of pole pairs, and $i_{ds}$ and $i_{qs}$ stand for the stator current along the dq-axis of the generator, as demonstrated in equation 10 :

$$\begin{cases} \dfrac{di_{ds}}{dt} = -\dfrac{R_s}{L_d}i_{ds} + \dfrac{L_q}{L_d}w_r\, i_{qs} - \dfrac{1}{L_d}v_{ds} \\ \dfrac{di_{qs}}{dt} = -\dfrac{R_s}{L_q}i_{qs} + \dfrac{L_d}{L_q}w_r\, i_{ds} - \dfrac{1}{L_q}w_r\,\lambda_r - \dfrac{1}{L_q}v_{qs} \end{cases} \qquad (10)$$

$R_s$ represents the stator winding resistance of the PMSG generator, while$v_{qs}$ and $v_{ds}$ denote he *dq-axis* stator voltage:

$$\begin{cases} v_{ds} = -R_s i_{ds} + L_q w_r\, i_{qs} - L_d\,\dfrac{di_{ds}}{dt} \\ v_{qs} = -R_s i_{qs} - L_d w_r\, i_{ds} + w_r\,\lambda_r - L_q\,\dfrac{di_{qs}}{dt} \end{cases} \qquad (11)$$

## 3. SPEED CONTROL TECHNIQUES FOR WIND TURBINES

To maximize the power extracted by the wind turbine, adjusting the power coefficient $C_p$ becomes crucial for enhanced power absorption from the uncertain wind speed. Numerous factors can affect the optimization of energy capture by wind turbines. The utilization of variable wind speed, considered a disturbance variable, in conjunction with other techniques, facilitates both the optimization of output and the fine-tuning of turbine speed to align with the specified reference value, modeled in equation (12), regardless of fluctuating wind speed readings. Controlling the Cp coefficient, which is reliant on the generator's velocity, allows for this adaption. Therefore, It is vital to design control systems that maximize the amount of the energy produced[10].

$$\Omega_{ref} = \frac{\lambda_{Cpmax}}{R} \cdot v \qquad (12)$$

The integration of the MPPT approach into the WECS is depicted in the figure below.

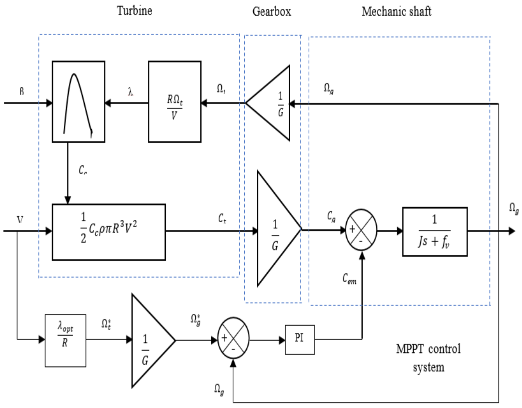

Fig. 4. The proposed MPPT principle for the wind turbine [10].

### c) Particle Swarm Optimization

Inspired by collective behaviors seen in fish and bird flocks, Particle Swarm Optimization (PSO) is an evolutionary computation-based optimization approach. A new version was proposed in 1998 to enhance the effectiveness of the initial approach, which was first introduced in 1995. In PSO, a mathematical equation that directs particles throughout their motion is used to simulate social behavior [7-8-11].

The particle's movement is impacted by three primary components: the inertial component, the cognitive component, and the social component. Refer to Fig. 5 for the flowchart illustrating the method.

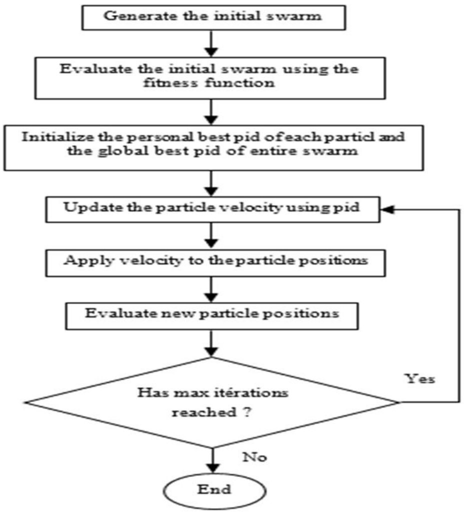

Fig. 5. PSO algorithm flowchart [5].

By using these techniques, the system's resilience to parametric fluctuations will be improved and the tracking of reference mechanical speed values will be ensured.

### d) Genetic Algorithm

The Genetic Algorithm stands out as a probabilistic optimization method, mirroring the principles of natural evolution with its core operators: selection, crossover, and mutation. Recognized for its effectiveness in solving optimization problems [12], this algorithm has proven to be an efficient strategy. For a comprehensive overview, consult Figure 6, presenting the flowchart that outlines the steps of the Genetic Algorithm.

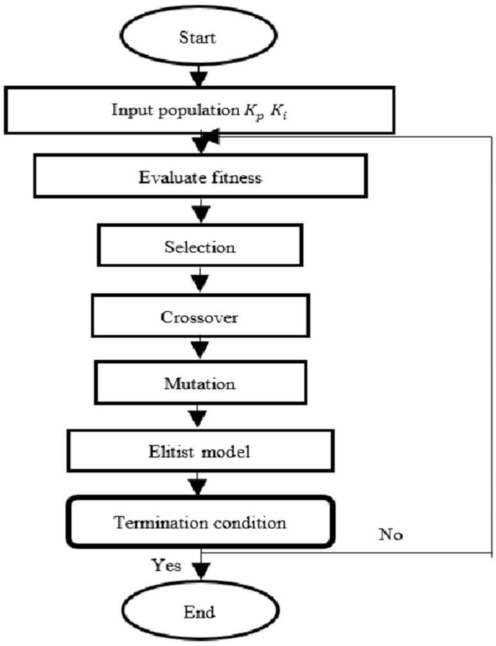

Fig. 6. GA algorithm flowchart

These strategies will be used to guarantee that the system is resistant against parametric fluctuations and that the reference mechanical speed values are tracked.

## 4. SIMULATION AND RESULTS

MATLAB/Simulink was used to obtain the simulation results for regulating a WECS's mechanical speed using a PMSG. In Figure 7, the simulation block is shown.

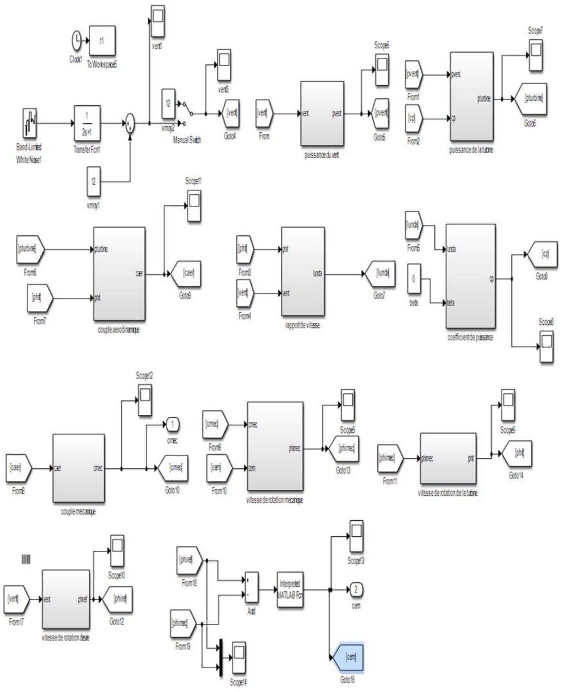

Fig. 7. Wind turbine simulation block

The results achieved for the Wind Turbine's mechanical speed control are shown. As shown in Figure 8, we optimized the speed controller's parameters using the PSO and GA algorithms. In order to assess the efficacy of PID controller design, drafts are frequently used in the literature [13–14]. We present a more efficient method for creating a shared objective [13]. Many researchers have embraced the approach we suggest. The following four indices are frequently used to indicate system performance: Square Temporal Integral Error (ITSE), Absolute Integral Error (IAE), Square Integral Error (ISE), and Absolute Temporal Integral Error (ITAE) [15–16]:

$$IAE=\int |e(t)| dt \quad (12)$$

$$ITAE=t.\int |e(t)| dt \quad (13)$$

$$ISE=\int e(t)^2 dt \quad (14)$$

$$ITSE=\int t.e(t)^2 dt \quad (15)$$

Figure 6 depicts the fundamental principle of the MPPT-PSO (GA) approach.

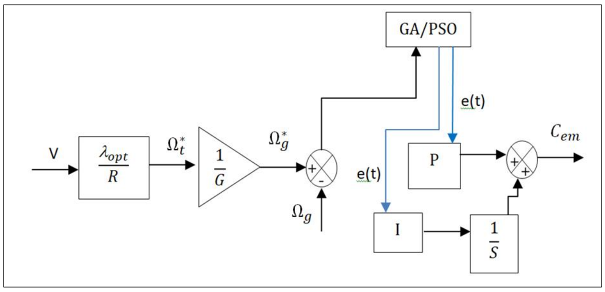

Fig. 8. Block diagram of the optimization approach for turbine speed control.

The table below displays various parameters derived from the optimization process. It is crucial to emphasize that the optimal results for each algorithm have been incorporated following extensive testing.

TABLE.I. various parameters acquired during the

| | IAE | ITAE | ISE | ITSE | Error |
|---|---|---|---|---|---|
| **PSO-kp** | 41.12 | 4.94 | 50.0 | 19.2 | $44.8*10^{-8}$ |
| **PSO-ki** | 4.73 | 20.53 | 5.6 | 25.5 | $44.8*10^{-8}$ |
| **GA-kp** | 10.00 | 56.52 | 12.1 | 1.4 | $0.32*10^{-7}$ |
| **GA-ki** | 43.75 | 53.10 | 30.5 | 51.0 | $0.32*10^{-7}$ |

optimization process.

Yellow highlights within each function denote the optimal values aimed at minimizing errors.By employing the PSO and GA Algorithms to fine-tune the PI controller parameters through the MPPT approach, aimed at maximizing wind turbine power generation under variable wind conditions, the following results were obtained:

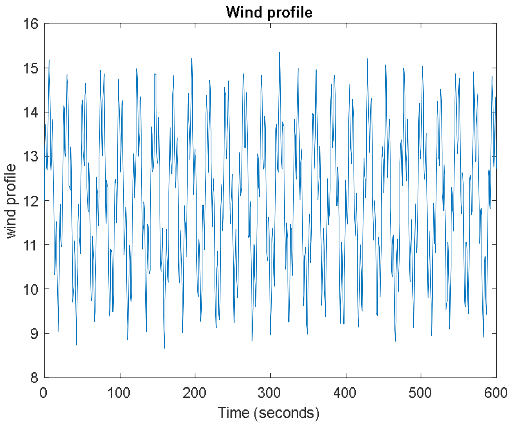

Fig. 9. Uncertain wind profile

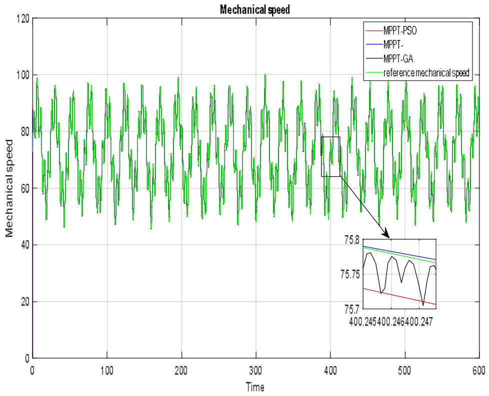

Fig. 10. Mechanical speed of the wind turbine

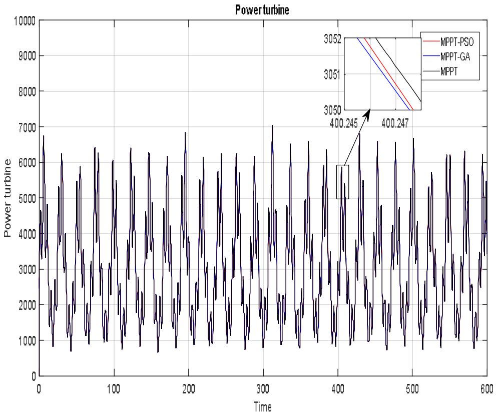

Fig 11. Power of the wind turbine

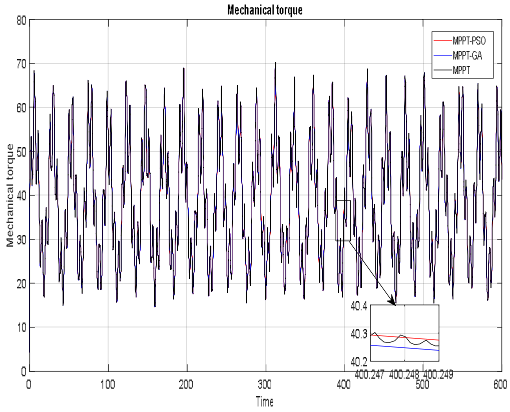

Fig. 12. Mechanical torque

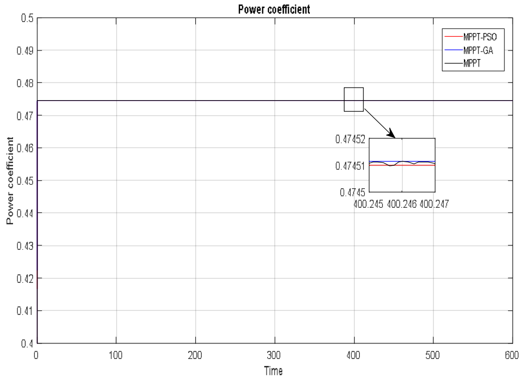

Fig. 13. Power coefficient

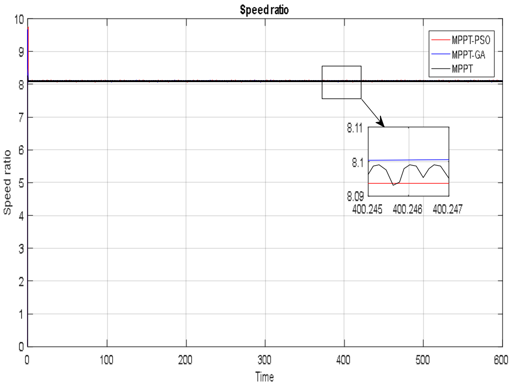

Fig. 14. Tip Speed ratio

Figures 10, 11, and 12 depict the differences in wind turbine power, torque, and mechanical speed, correspondingly, under different wind profiles. In terms of mechanical speed, the MPPT-PSO approach results in an overshoot of 23, a 1.05 s response time and a $44.8 * 10^{-8}$ error rate .Conversely, the MPPT-GA approach achieves an overshoot of 21.6, a response time of 0.22 s, and an error rate of $0.32 * 10^{-7}$.

Figures 13 and 14 depict the power coefficient (equal to 0.4745) for the applied approaches and the speed ratio, which stands at 8.1.

## 5. CONCLUSIONS

An analysis of wind turbine's mechanical speed equipped with a PMSG was carried out using an enhanced MPPT control strategy, utilizing particle swarm optimization (PSO) and genetic algorithms(GA).The aim was to maximize energy efficiency under random wind speeds simulating natural conditions. The MPPT-GA approach achieved a satisfactory response, while the MPPT-PSO approach achieved the reference mechanical speed with a high level of satisfaction. As part of future work, a hybrid MPPT-PSO-GA will be applied to the system for further optimization.

## *References*

[1] J.G. Njiri, D. Söffker, (2016). State-of-the-art in wind turbine control: Trends and challenges, Renewable and Sustainable Energy Reviews 60 (2016) 377–393.

[2] T.ahmed et A.abd el ,(2010), “active and reactiv power control of wind based on Synchronous generator,” ,” Revue of basic and applied Sciences, vol. 10, pp.327-335, 2010.

[3] T.Yacine, (2020). Contribution to the optimization of hybrid systems for the production of renewable energy. Doctoral thesis, University of Haute Alsace – Mulhouse, University of Mouloud Mammeri (Tizi-Ouzou, Algérie).

[4] P. M. Koumba, (2019). Contribution to the study and control of wind turbines with synchronous generators dedicated to autonomous electrical networks, university of québec a trois-rivières.

[5] Lotfi, Chetioui, Zennir Youcef, Arabi Marwa, Horst Schulte, Mechhoud El-Arkam, and Bendib Riad. (2023). "Optimization of a Speed Controller of a WECS with Metaheuristic Algorithms" *Engineering Proceedings* 29, no. 1: 7. https://doi.org/10.3390/engproc2023029007

[6] Lotfi, Chetioui, Zennir Youcef, Arabi Marwa, Horst Schulte, Bendib Riad, and Mechhoud El-Arkam. (2023). "Optimization of a Speed Controller of a DFIM with Metaheuristic Algorithms" *Engineering Proceedings* 29, no. 1: 13. https://doi.org/10.3390/engproc2023029013

[7] M. L. Conadini, G. Ippoliti, and G. Orlando, (2013). Fully sensorless robust control of variable-speed wind turbines for efficienry maximization, Automatica, Vol. 49:3023-3031,.

[8] H. K. Alaboudy , A. A. Daoud , S. S. Desouky , A. A. Salem, (2013). Converter controls and flicker study of PMSG-based grid connected wind turbines, Ain Shams Engineering Journal, vol. 4, pp. 75–91.

[9] B. Rim, SCH. Horst, M. Abdelkader, (2017). Modeling and Simulation of a small Wind Turbine system based on PMSG generator. Evolving and Adaptive Intelligent Systems (EAIS) Ljubljana, Slovenia, May 31 - June 2, 2017,pp.1-6.

[10] Nabil Derbel, Quanmin Zhu, (2019) "Modeling, Identification and Control Methods in Renewable Energy Systems" , Springer Science and Business Media LLC, pp. 1-374. https://doi.org/10.1007/978-981-13-1945-7

[11] D.R. Sulaiman, (2020). Multi-objective Pareto front and particle swarm optimization algorithms for power dissipation reduction in microprocessors’. International Journal of Electrical and Computer Engineering (IJECE), Vol. 10, No. 6, pp. 6549-6557.

[12] N.D. Pandey, P.Tiwari. (2017). Comparison betweenspeed control DC motor using genetic algorithm and PSO-PID algorithm. International Journal of ElectricalEngineering & Technology, 8(1): 17-25

[13] Z.-L. Gaing, (2004). A particle swarm optimization approach for optimum design of PID controller in AVR system. IEEE Trans. Energy Convers, vol. 19. no. 2, pp. 384–391

[14] S. Ekinci and B. Hekimoglu,(2019). Improved kidney-inspired algorithm approach for tuning of PID controller in AVR system. IEEE Access, vol. 7. pp. 39935–39947

[15] Z.-L. Gaing, (2004). A particle swarm optimization approach for optimum design of PID controller in AVR system’’, IEEE Trans. Energy Convers., vol. 19, no. 2, pp. 384–391.

[16] Ercan Kose. (2020). Optimal Control of AVR System with Tree Seed Algorithm-Based PID Controller’’, IEEE Access, pp. 89457-89467.