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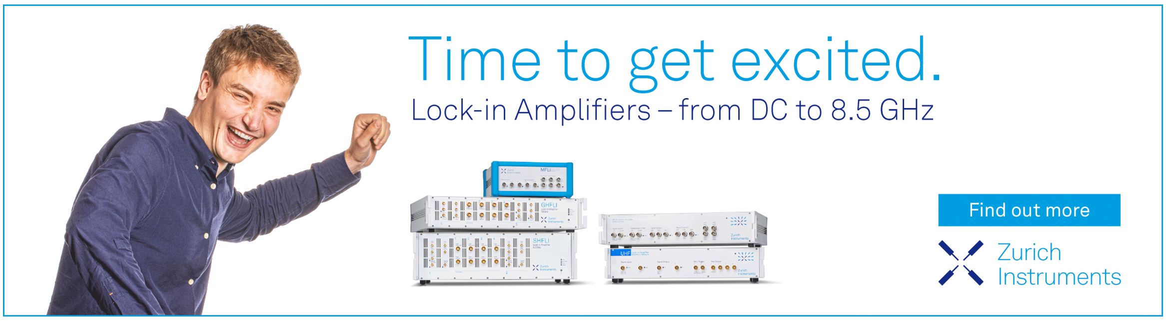

Optimization of Wind-Turbine Control Using the Hybrid ANFIS-PID Method Based on Ant Colony Optimization

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Abstract. The Permanent Magnet Synchronous Generator (PMS) be coupled with a wind turbine to produce electricity. The PMSG has very little efficiency to produce electrical power. This characteristic is influenced by wind speed, pitch angle, and others. Therefore, wind turbines need to be controlled to produce optimal electrical power. In this paper, a combination of Adaptive Neural Fuzzy Inference System (ANFIS) and Proportional Integral Derivatives (PID) was combined with the artificial intelligence of Ant Colony Optimization (ACO) to control the pitch angle. The combining ANFIS, PID, and ACO will be compared to control the pitch angle which to produce the optimal PMSG output power. The simulation results show that the three models tested have been covered for the ANFIS-PID-ACO model while the best model performed. The ANFIS-PID-ACO model was the best model whit the highest maximum active power obtained at wind speed t1= 3.7075 Watts, t2 = 2.188 Watts, t3 = 3.9199 Watts, t4 = 2.6086 Watts, and t5 = 5.0338 Watts. The ANFIS-PID-ACO method is proven to be able to optimize wind energy better than the previous method. However, this research will be developed using other methods to obtain the best optimization method.

INTRODUCTION

The potential energy in the wind can rotate the blades of the windmill. The blades are connected to the shaft and rotate the shaft which is connected to the generator. The windmills, together with wind energy, will provide power to the electrical system. As long as technological progressing develops and the increasing population, electric energy usages will also increase to support all activities for daily living, industrial processes, economic trading, and others. In line with this condition, the electricity load will also be increased following the energy usages. It is necessary to provide sufficient electricity supply to consumers so that the power released by the generator becomes larger and more stable. It means that all possible power plants should be activated to produce power through a joined produced power output. Technically, the power plant is constructed using a generator which is commonly built based on a PMSG as the main key to produce electricity[1]. In general, the PMSG can be coupled with wind turbines to produce electricity which is subjected to reduce expensive expenditure. The PMSG has less optimal efficiency to produce electrical power controlled by the wind speed and pitch[2][3].

PMSG needs to be controlled to produce optimal electrical power based on the appropriate rotation parameters. Currently, artificial intelligence was often used to develop various methods including wind turbine blade controls, wind-diesel controls. Moreover, an ACO method is also applied to similar problems[4][5][6]. This paper discusses a combination of Adaptive Neural Fuzzy Inference System (ANFIS) and Proportional Integral Derivatives (PID) controllers which are tuned using ACO to control the pitch angle. The combining PID, ANFIS, and ACO will be

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compared in its performances during searching the pitch angle to produce the optimal PMSG output power in various scenarios based on the technical parameters.

WIND TURBINE MODEL

This section consists of the brief essential material and methods or procedures used in a research study. As mentioned before that the PMSG roles in the power plant and can be modeled using the transformation park equation to present its characteristics[7][8]. These performances are very important as the mechanical machinery during the running time of the operation. In general, the PMSG can also be approached using the following equations.

$$v_{sd} = R_s\, i_d + \frac{d\lambda_d}{dt} - \omega_e\, \lambda_d \tag{1}$$

$$v_{sq} = R_s\, i_q + \frac{d\lambda_q}{dt} - \omega_e\, \lambda_q \tag{2}$$

$$\lambda_d = L_{sd} i_d + \lambda_m \tag{3}$$

$$\lambda_q = L_{sq} i_q \tag{4}$$

$$T_e = \frac{3}{2} p \; [\lambda_m i_q - (L_{sq} - L_{sd}) i_q\, i_d] \tag{5}$$

Where v_{sd} and v_{sq} are stator voltages, i_d and i_q are stator currents, R_s is stator resistance, λ_m is magnetic flux, L_{sd} and L_{sq} are stator inductances, and p is a magnetic pole.

Wind energy comes from natural air velocity. The aerodynamic wind turbine will convert wind energy into kinetic energy. Kinetic energy is used to drive the rotation of the generator shaft. The equation can be formulated as follows.

$$U = \frac{1}{2} (\rho A x) V^2 \tag{6}$$

$$P_w = \frac{1}{2} \rho A V^3 \tag{7}$$

$$P_r = P_w\, C_p = \frac{1}{2} C_p\, (\beta, \lambda) \rho \pi R^2\, V^3 \tag{8}$$

$$T_r = \frac{1}{2} C_T\, (\beta, \lambda) \rho \pi R^3\, V^2 \tag{9}$$

$$\lambda = \frac{\omega R}{V} \tag{10}$$

$$C_p\, (\lambda, \beta) = \lambda C_t\, (\lambda, \beta) \tag{11}$$

U is kinetic energy (joule), ρ is air density (kg/m3), A is area (m2), x is thickness plate (m), V is airspeed (m/s), C_t is ration constant, β is blade pitch angle, P_w is wind power, C_p is constant speed, λ is speed ratio, ωR is pole ratio, V is wind speed.

The operating characteristics of wind turbine speed concerning the variable pitch can be described from the power curve. The Power Curve provides an overview of the power output as a function of wind speed. This characteristic is commonly used to plot the possible potential wind energy sources. The operation of the wind turbine can be shown in Figure 1.

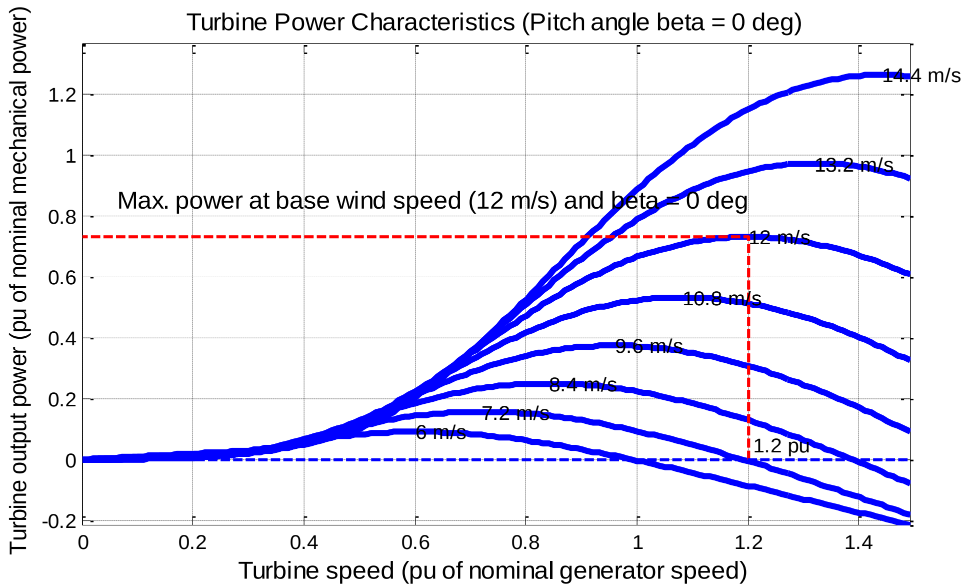


FIGURE 1. Wind turbine characteristic

MPPT is one of the methods used to convert maximum power. The maximum power of the wind speed follows the value of the power coefficient. Blade Pitch Control is a control method when the wind speed is outside the average value. With insufficient electromagnetic torque to control the rotor speed, the generator will be overloaded. To avoid this condition wind turbine power conversion must be limited. In a smaller torque state, it is done by lowering the wind turbine power coefficient.

Power Regulation is applied with the increasing amount of wind power entering the system. It is not possible to keep the power generated constantly. Therefore, voltage and frequency settings are needed so that the electrical power produced is following the load demand.

OPTIMIZATION APPROACH

1.1. PID Controller

In these works, selected controlling methods will be applied in the system. The controller in this method is limited by the value of the constant Kp between 0 and 100, the constant Ki between 0 and 50, and the constant Kd between 0 and 50, so that the output continues to oscillate with the same amplitude. In addition, the value of Kp is referred to as the ultimate gain. The output response generated in the three gain conditions is shown in Figure 2. The system can oscillate stably when Kp = Ku[9].

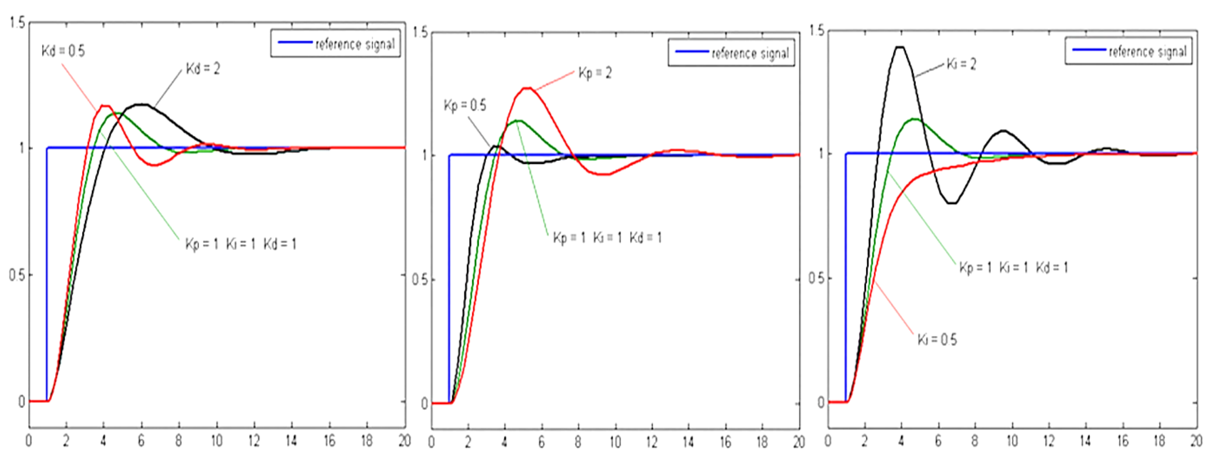


FIGURE 2. Characteristics based on PID

1.2. ACO

In particular, Ant Colony Optimization (ACO) is adapted to these works which are classified as one of the smartest animals, they can reach their food with the shortest and fastest paths. Ant behavior is the inspiration for this Colony Optimization ant algorithm. At first, it runs randomly, after regaining food for the colony they also put pheromones or traces. If other ants find such a road, they will not travel randomly, but ants do not follow the trail again if, in the end, they find new food. The ant finds the shortest path of the pheromone odor left behind. This pheromone gives the colony the shortest path to the food source, so other ants will follow that path[10][11]. The computing completion steps in the ACO are shown in Figure 3.

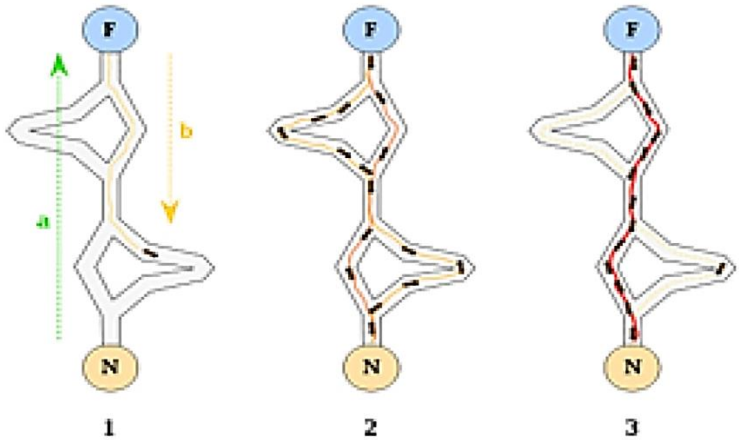


FIGURE 3. ACO steps

The ACO mechanism is adapted from the limited ability of individual ants which has been able to find the shortest path between food sources and nests. From Figure 3, it is known that the ant first finds the food source(F), then returns to the nest(N), leaving a trace, as presented in section 1. Furthermore, the next and follows four possible ways, but yes choose the path as the shortest route as shown in section 2. The last section is 3 which is presented for Ants taking the shortest route, and long route trails will disappear.

1.3. ANFIS

ANFIS is used for systems with a combination of FIS and NN. The FIS used is the FIS "Takagi Sugeno Kang" with consideration of convenience[12]. TSK fuzzy inference mechanism with two inputs x and y is performed in Figure 4 following role 1: if y is A1 and x is B1 then f1 = p1y + q1x + r1, and the role 2: if y is A2 and x is B2 then f2 = p2y + q2x + r2, with Input: y and x[12].

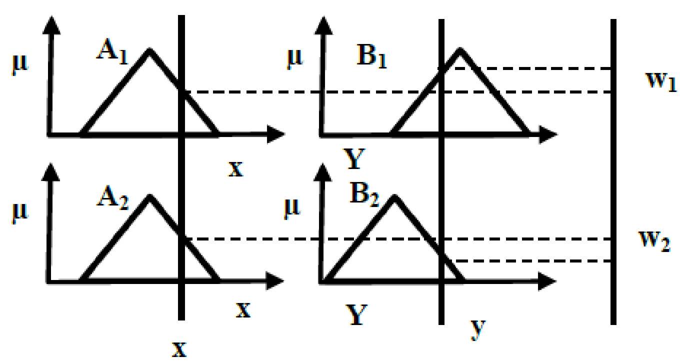


FIGURE 4. The TSK fuzzy inference system

1.4. PID-ACO-ANFIS

PID input and output data, which are tuned by ACO, will be entered into simout (To Workspace). Simout data is used as ANFIS input in the FIS Sugeno editor. The data is entered, load data in the ANFIS editor, generate FIS, replace

Epochs with 100, trained, and test. The data is exported to a workspace or file to be used for the ANFIS controller[9]. The image of the process of entering the train data into the simout can be seen in Figure 5 and Figure 6.

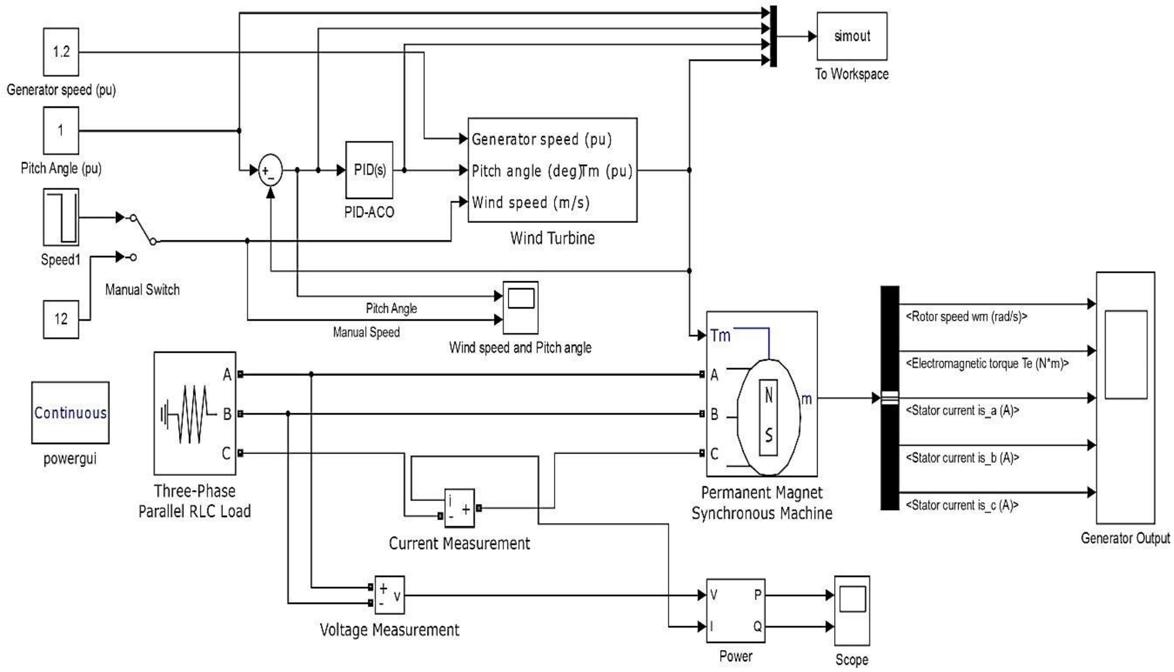


FIGURE 5. The process of entering the train data into the simout

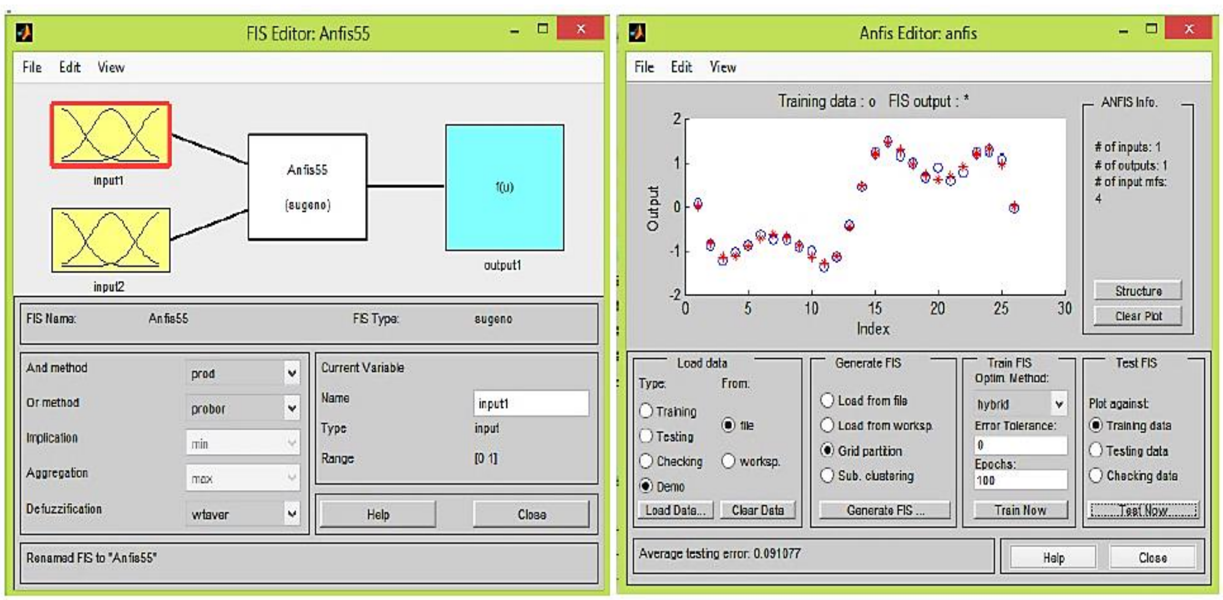


FIGURE 6. ANFIS process

RESULT

In this research, the wind turbine system has three kinds of inputs, namely; from the generator speed source, from the wind speed source, and the pitch angle source. The wind turbine with a pitch angle is controlled as shown in Figure 7.

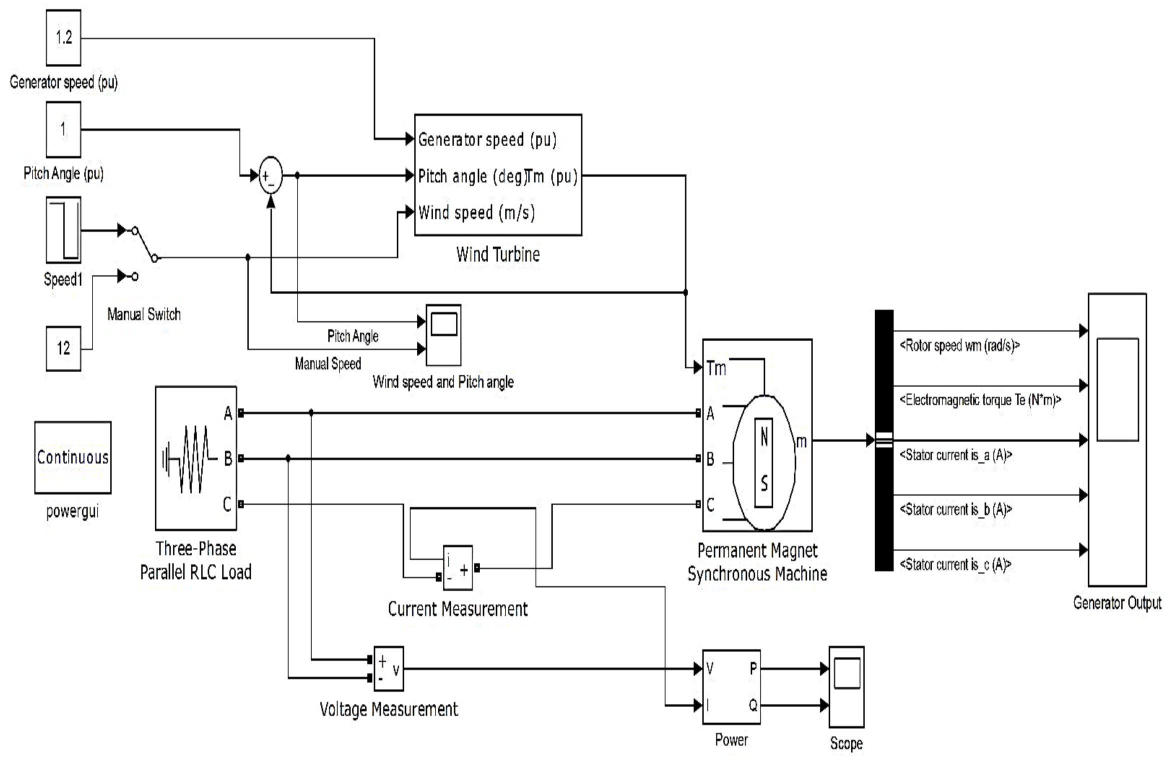


FIGURE 7. Wind Turbine System

This simulation is given a wind speed reference as presented in Figure 8.

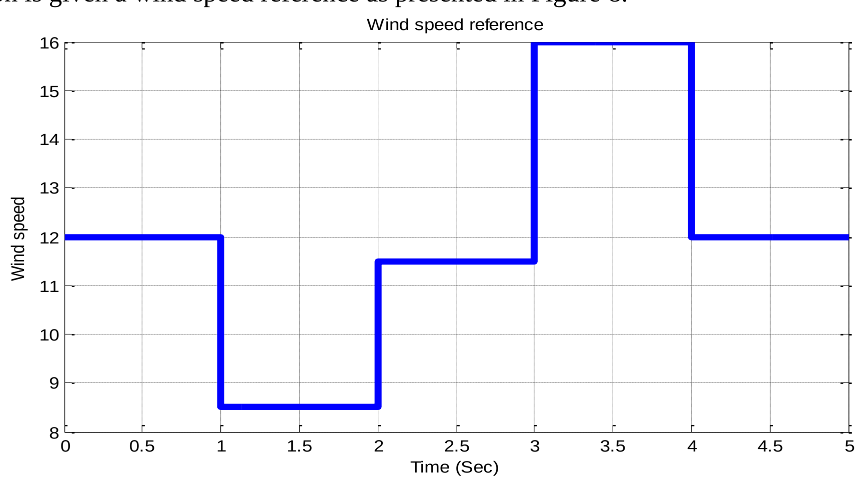
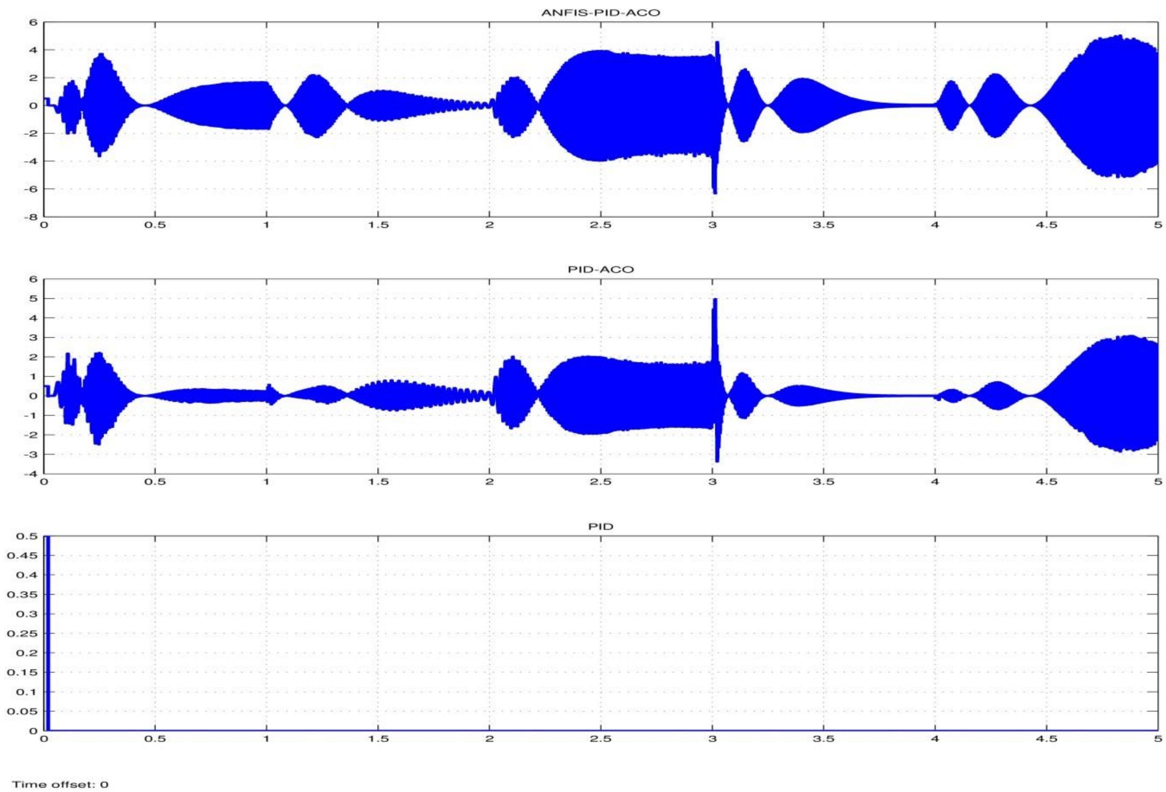


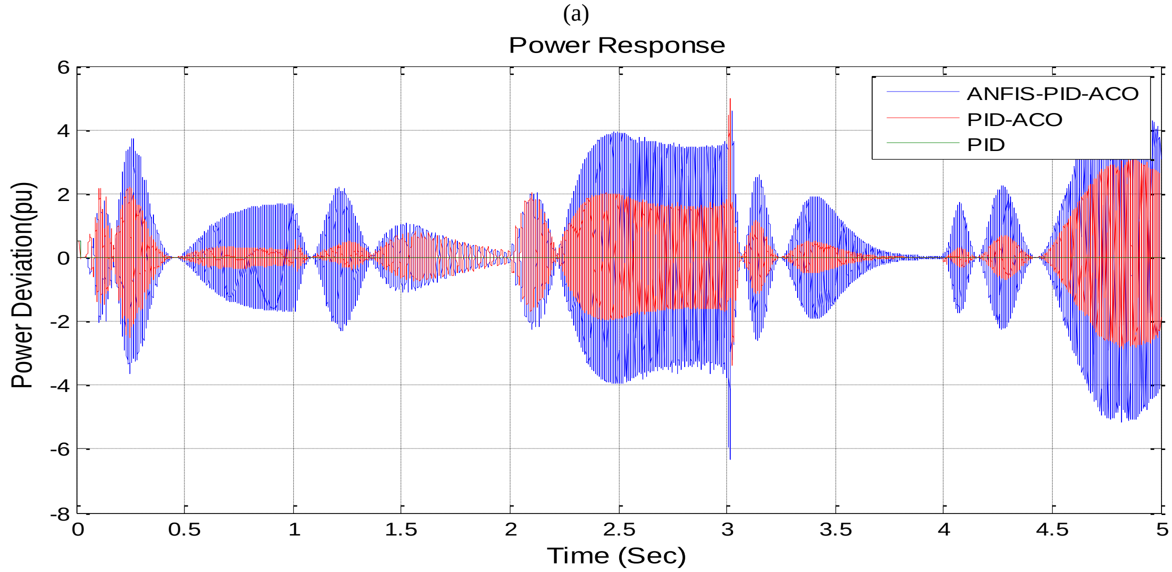
FIGURE 8. Wind speed reference

Figure 8a and Figure 8b show that the Active power profile on ANFIS-PID-ACO produces the best Active power. Based on the wind speed reference, the speed has been applied at t0 = 12, t1 = 8.5, t2 = 11.5, t3 = 16, t4 = 12, and t5 = 12.

In particular, the system has been also tuned to a certain point to find better results of the running program. The PID-ACO constant value is obtained in Kp = 8.640112, Ki = 1.501074, and Kd = 0.360264. in detail, the system control model can be seen in Figure 8. Three control models are also arranged in the parallel form, namely the PID model, PID-ACO model, and ANFIS-PID-ACO model considering the same input and load. In these cases, each impact in the active power output of the three models can be seen in figures 9 (a) and 9 (b).



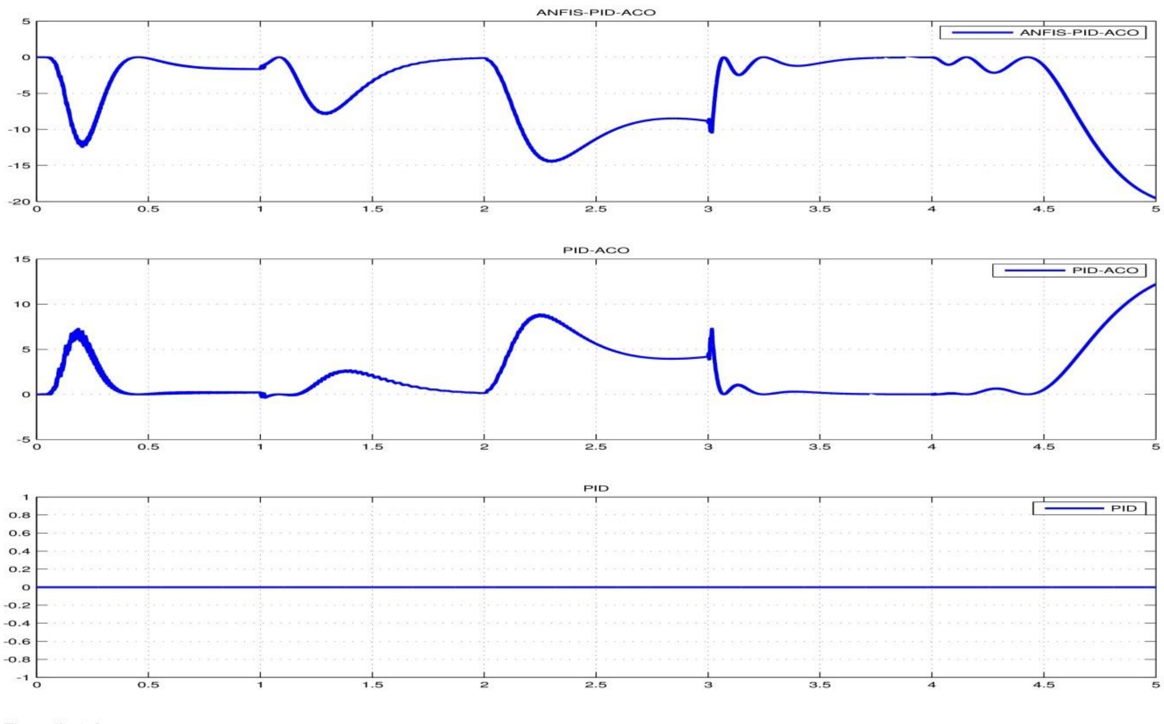
(a)



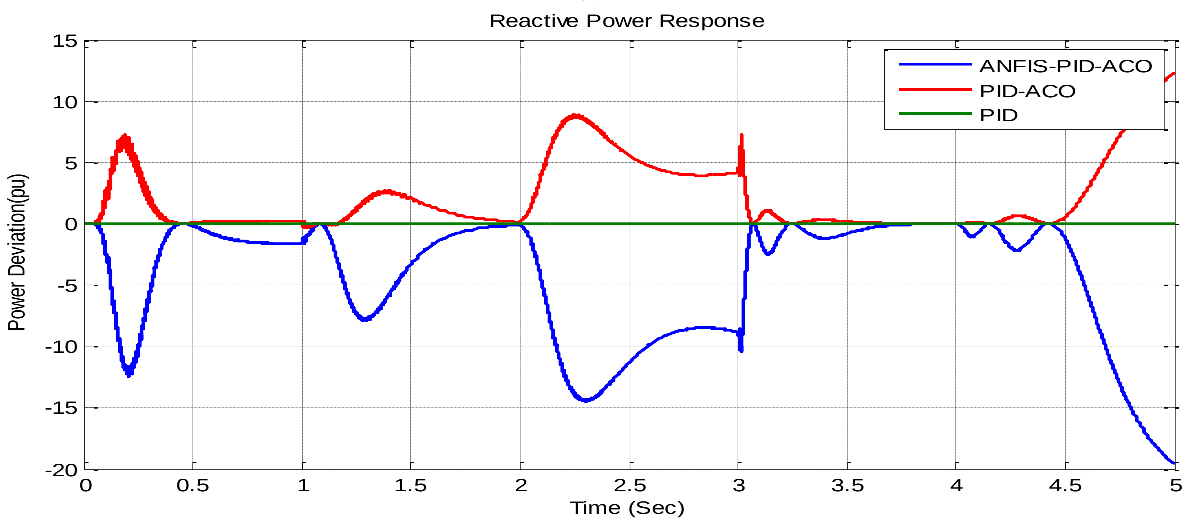
(b)

FIGURE 9. Active power output performances

As the wind speed changes, the active power output shows that the ANFIS-PID-ACO (blue) model has the highest maximum power (3.7075, 2,188, 3.9199, 2.6086, 5.0338), the PID-ACO model (red) has maximum power (2.2092, 0.8072, 0.8072, 1.1635, 3.0805), and the PID model (black) has maximum power (0.4975, 0.0085, 0.0172, 0.0078, 0.0265), while the reactive power Q (var) can be seen in figure 10 (a) and 10 (b). Figure 10a and Figure 10b show that the reactive power profile on ANFIS-PID-ACO produces the best reactive power. From the simulation results obtained that the reactive power output is presented from the ANFIS-PID-ACO between 0,000 to -19,353, PID-ACO between 12,251 to -0,381, and PID stabled at 0,000. The voltage output is presented in Figure 11. According to Figure 10, it is known that the output voltage of the three models is the same, with a voltage profile that coincides while the output of current can be seen in Figure 12.

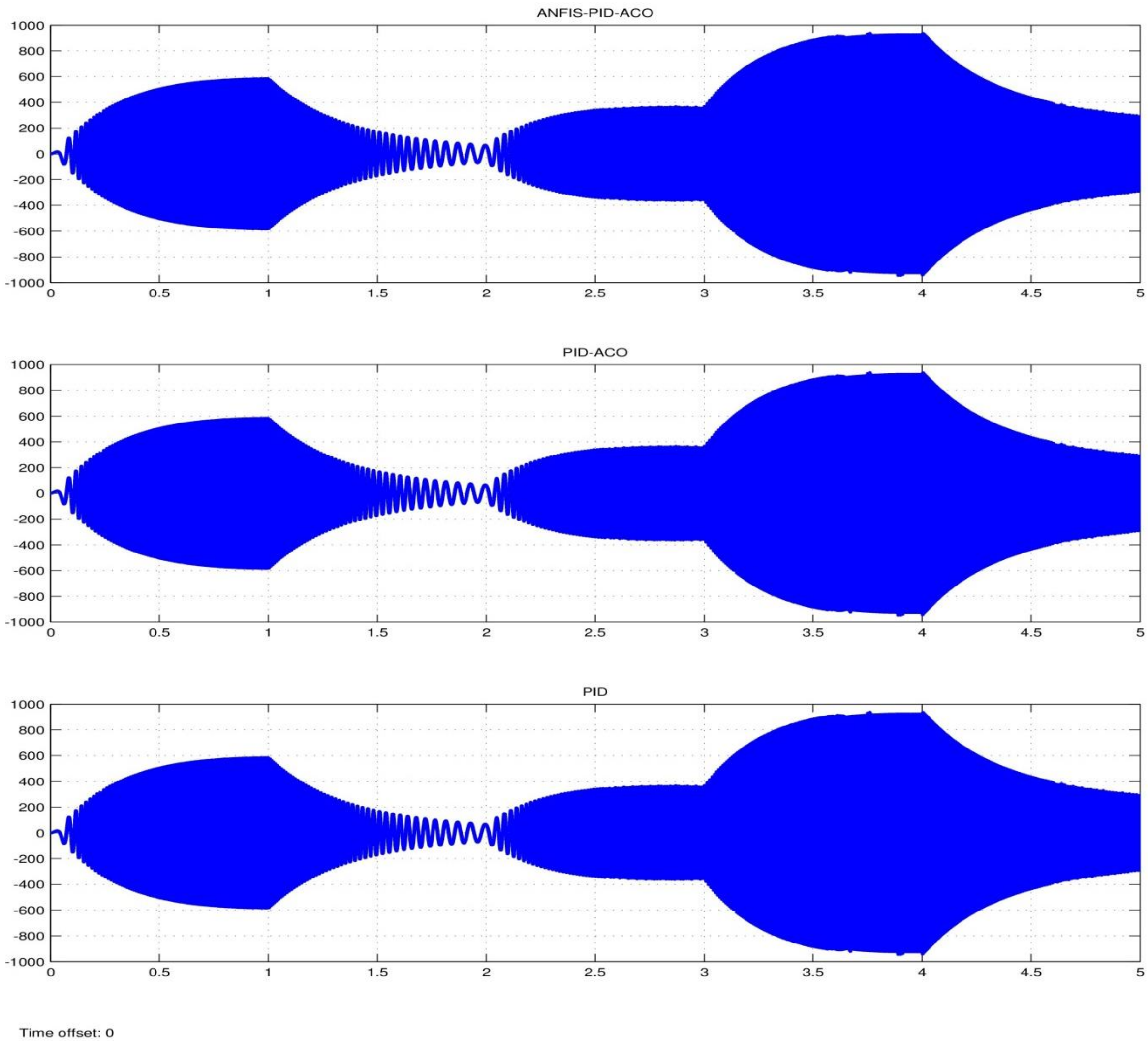


(a)

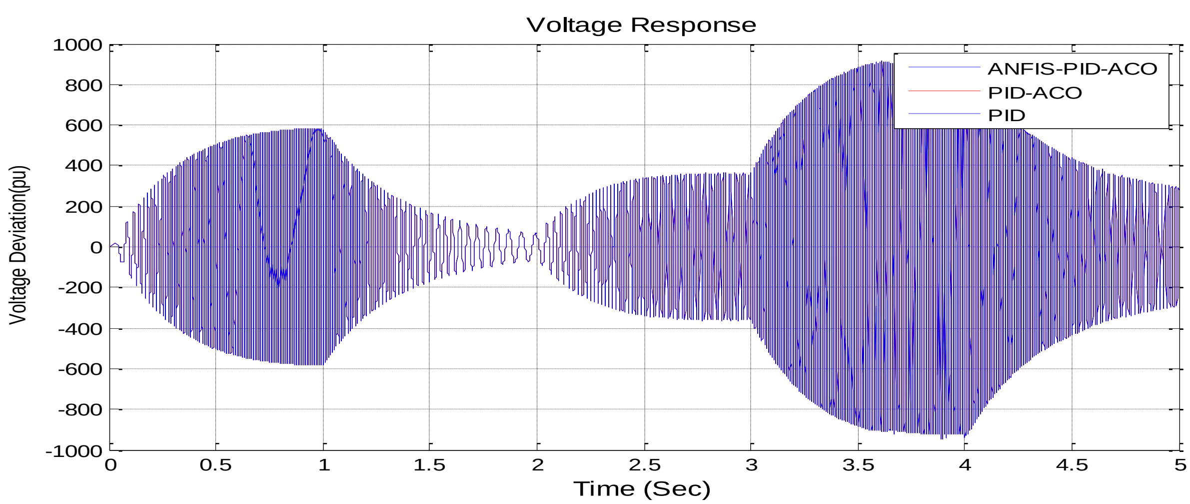


(b)

FIGURE 10. Reactive power output

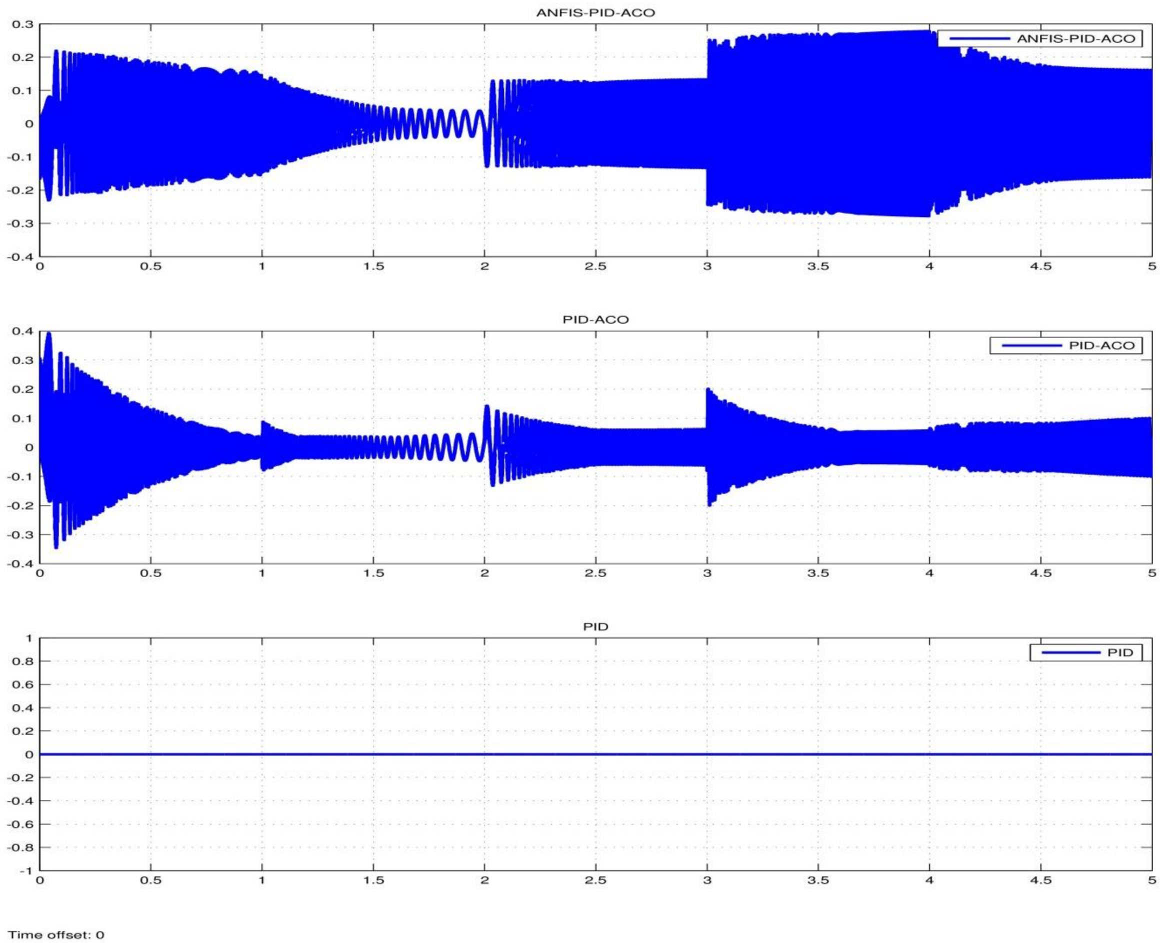


(a)

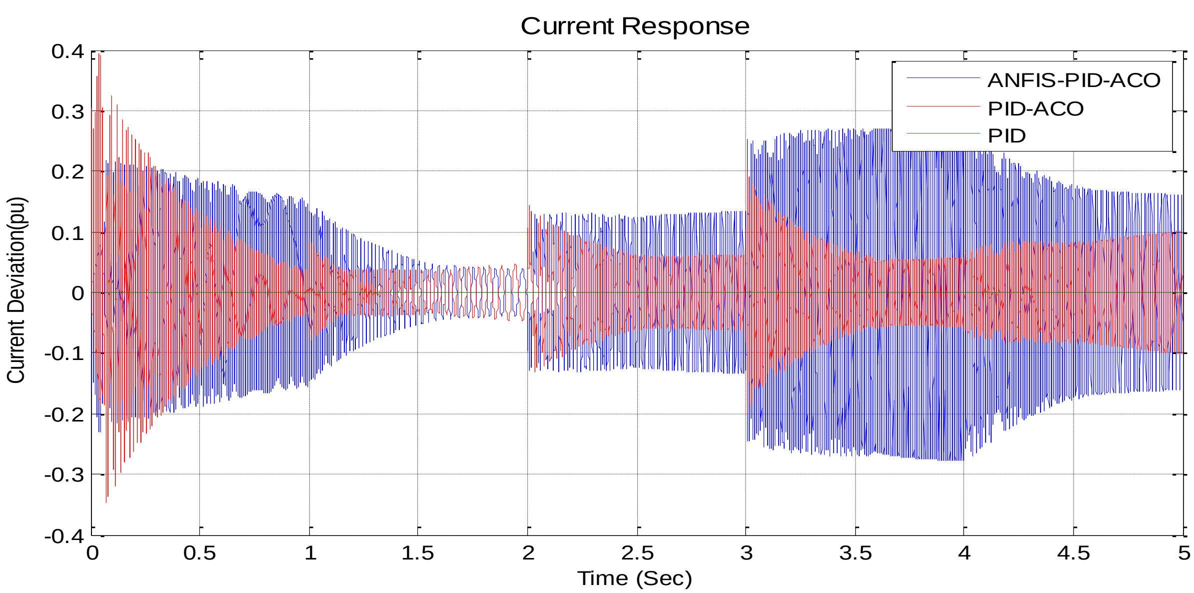


(b)

FIGURE 11. Voltage output condition



(a)



(b)

FIGURE 12. Current output flows

Moreover, the current output is also found in PID-ACO for the largest current at $0 \leq t \leq 0.302$ and $2{,}006 \leq t \leq 2{,}056$ as similar as the ANFIS-PID-ACO. The best current average is obtained from the ANFIS-PID-ACO model while the output of the PID, PID-ACO, and ANFIS-PID-ACO generators can be shown in Figure 13-15.

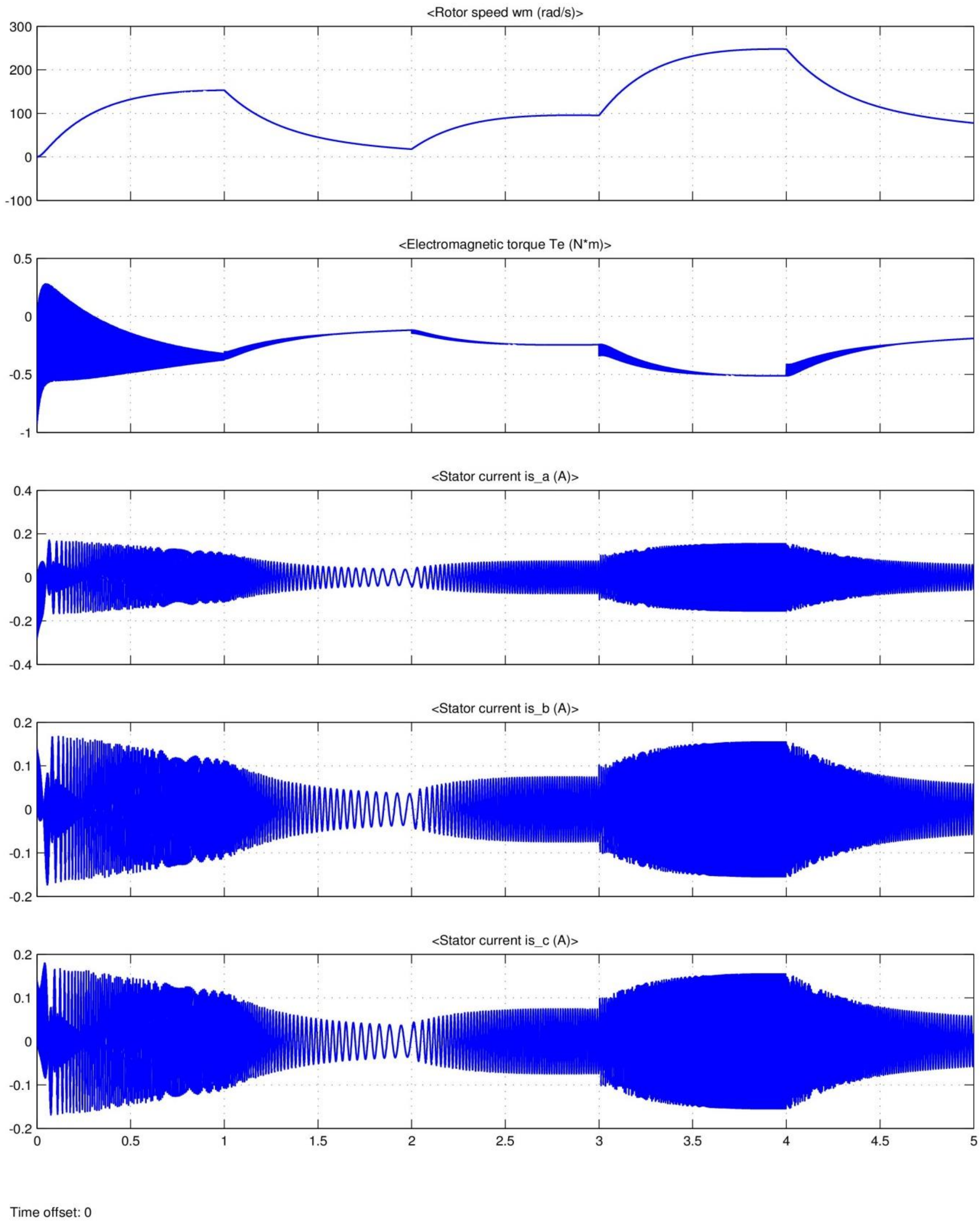


FIGURE 13. Generator Output using PID

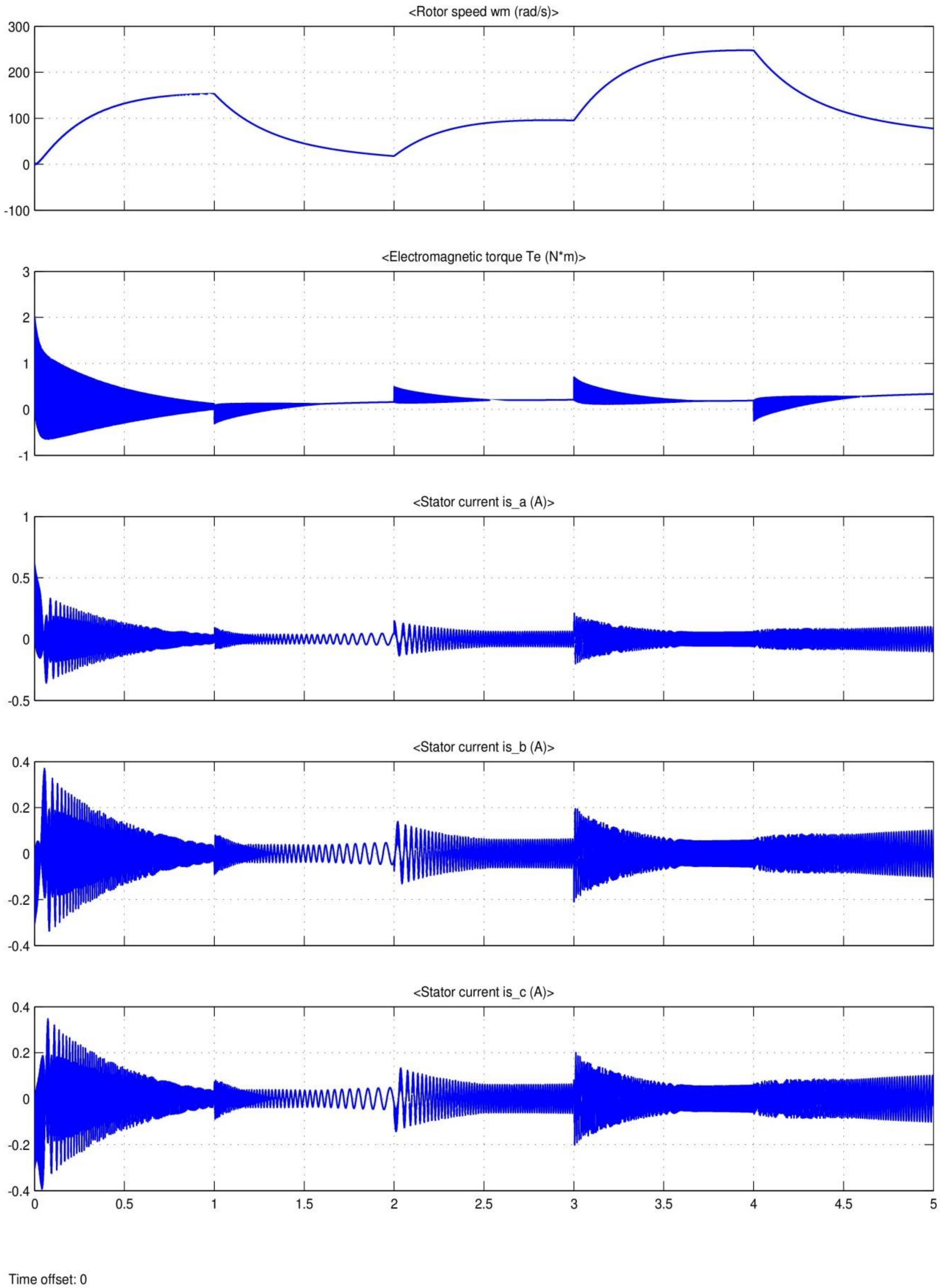


FIGURE 14. Generator Output using PID-ACO

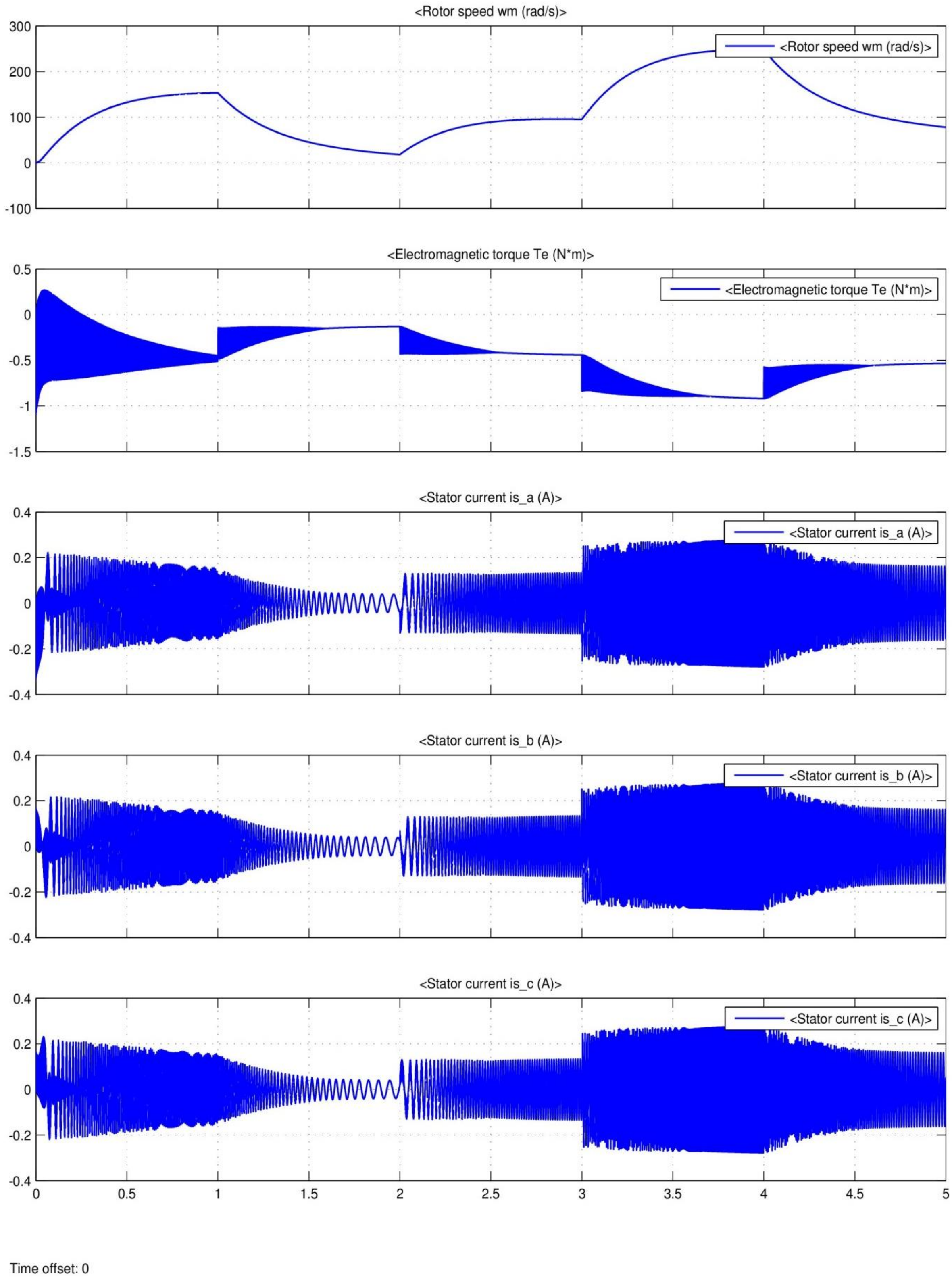


FIGURE 15. Generator Output using ANFIS-PID-ACO

The three output generator images show that the ANFIS-PID-ACO model has the best generator output on the rotor speed maximum of 247.7, electromagnetic torque between 0.269 and -0,965, and stator current maximum of 0.2786.

CONCLUSION

From these works, it can be concluded that the three models tested has different performances. The ANFIS-PID-ACO model is the best model whit the highest maximum active power is obtained at wind speed t1= 3.7075 Watts, t2 = 2.188 Watts, t3 = 3.9199 Watts, t4 = 2.6086 Watts, and t5 = 5.0338 Watts. In addition, the largest electromagnetic torque is determined between 0.269 to -0.965 while the stator current a, b, c maximum is given in 0.2786 Ampere. For further studies, it can be concerned with the blade wind controlling position and auto pitch set up. The ANFIS-PID-ACO method is proven to be able to optimize wind energy better than the previous method. However, this research will be developed using other methods to obtain the best optimization method.

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