1. Wipobh JAIKHANG[1], 2. Puchong CHANJIRA[2]

Faculty of Industrial Technology Chiang Rai Rajabhat University (1),
Faculty of industrial education, Srinakharinwirot University (2)
ORCID: 1. 0000-0001-9785-1917; 2. 0000-0002-4842-3876

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Optimization of PI Controller Using Ant Colony Algorithm for Wind Turbine System

***Abstract**. The classical PI controller is applied for wind turbine, however it is the more concrete and specific algorithm. An ant colony optimization (ACO) is one of a modern metaheuristic for optimal tuning the gain of the controller. This paper designs and investigates the wind turbine system which is connected to grid system through the boot converter circuit driven by permanent magnet synchronous generator (PMSG) By regulating PI controller, ACO is used to optimize the gains. The simulation results show that an overshoot and lifetime of design is less. As a results, ACO method is able to optimize the gain of PI controller to regulate the active power and reactive power for booting up the high DC voltage of the wind turbine for grid connected, effectively.*

***Streszczenie.** Klasyczny regulator PI jest stosowany do turbin wiatrowych, jednak jest to bardziej konkretny i szczegółowy algorytm. Optymalizacja kolonii mrówek (ACO) jest jedną z nowoczesnych metaheurystyk do optymalnego dostrojenia wzmocnienia regulatora. W tym artykule zaprojektowano i zbadano system turbiny wiatrowej, który jest podłączony do sieci za pośrednictwem obwodu przetwornicy rozruchowej napędzanej przez generator synchroniczny z magnesami trwałymi (PMSG). Poprzez regulację regulatora PI, ACO jest używane do optymalizacji wzmocnień. Wyniki symulacji pokazują, że przeregulowanie i żywotność projektu są mniejsze. W rezultacie metoda ACO jest w stanie zoptymalizować wzmocnienie regulatora PI w celu regulacji mocy czynnej i biernej w celu uruchomienia wysokiego napięcia stałego turbiny wiatrowej podłączonej do sieci, skutecznie. (**Optymalizacja regulatora PI przy użyciu algorytmu kolonii mrówek dla systemu turbin wiatrowych**)*

Keywords: PI Controller; Ant Colony; Wind Turbine; PMSG
Słowa kluczowe: sterownik PI; Kolonia mrówek; Turbina wiatrowa; PMSG

Introduction

In recent, wind and solar energy is transformed to electrical energy. They are clean and sustainable energy. In order to transform kinetic energy to electrical energy a generator is applied. One of the generator is permanent magnet synchronous generator (PMSG) can produce pulse width modulator (PWM). The PWM is passed into rectifier circuit. It is converter connected as direct current voltage. Then, the boot converter adjusts the dc voltage to high dc voltage. During low wind speeds, the diode rectifier output voltage becomes significantly to lower. As discussed earlier, to transfer the generated power to grid, the dc-link voltage must be higher than the grid line-line voltage. In following to connect the grid system, thigh voltage in increase by the boot converter. Itoh and Fujii (2008) proposed the circuits can decrease losses by 2/3 in comparison with a conventional buck-boost converter [1]. The high dc voltage is approached to the inverter and transferred to the grid system. In case of power wind speed, the grid system supplies the voltage to the wind turbine system. The voltage from the grid connected is transformed by Clark transformation. In the Clark transformation of d-q system, the current is controlled by PI controller. The gains of PI controller can be tuned by optimization algorithms. Ant colony optimization (ACO) is one of the modern mutaheuristic optimization. It is able to optimize the gains of PI controller. Errouissi, R., Al-Durra, A., Muyeen, S.M., (2016) The effectiveness of the proposed controller was tested numerically and validated experimentally with the consideration of the grid-connected PV inverter system and its controller [2]. Manoharan, M.S., Ahmed, A., Hu Park, J., (2016) The proposed PCS with the control scheme is analyzed and verified using hardware results in a grid connected mode of operation [3]. Kuo-Yuan, L., Yaow-Ming, C., Yung-Ruei, C., (2017) shown to verify the performance of the proposed BSG-inverter [4]. Muhammad Ibrahim, M., Tasneim, A., Khalifa Hasan, A.H., This will be followed by a detailed mathematical and engineering analysis for the simulated results. The validity of the proposed scheme will be verified by simulation using the PSIM software [5].

In this paper, the aim is to tune optimal gains of PI controller for the wind turbine based on PMSG with grid connected system using ACO. There are five sections. Firstly, introduction. Secondly, a metaheuristic optimization method. Thirdly, the design system. Fourthly, the results and discussions. Finally, the conclusions.

Metahuristic optimization methos

A. Ant colony optimization

In 1990s, the ant colony optimization (ACO) was proposed by Dorigo. ACO is one of the modern metaheuristic approach to solve the diverse set of optimization problems. The inspiration of ACO is based on the foraging behavior of the real ant colonies which are used to solve discrete optimization problems. [6] The real ants are almost blind animals. They gather in a colony. To understand how ants can find a source of food in the shortest path between the nests. Fig. 1 shows the behavior of real ant. They go through the food while laying down pheromone trails. The shortest path is discovered via pheromone trails. Each ant moves at random. The pheromone is deposited on path. The real ants follow the intense pheromone trails. The more ants follow a trail, the more attractive that trail becomes for being followed. The process is therefore characterized by a positive feedback loop, where the probability of a discrete path choice increases with the number of times the same path was chosen before. Collective system capable of accomplishing difficult tasks in dynamic and varied environments without any external guidance or control and with no central coordination.

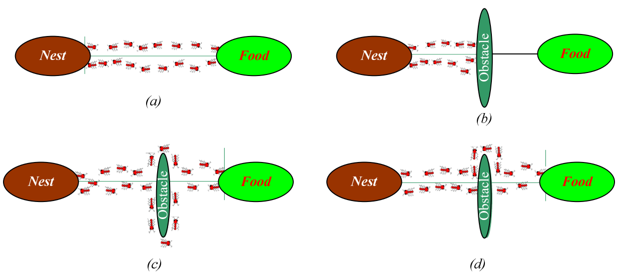

Fig.1 The diagram of behavior of real ant. [6]

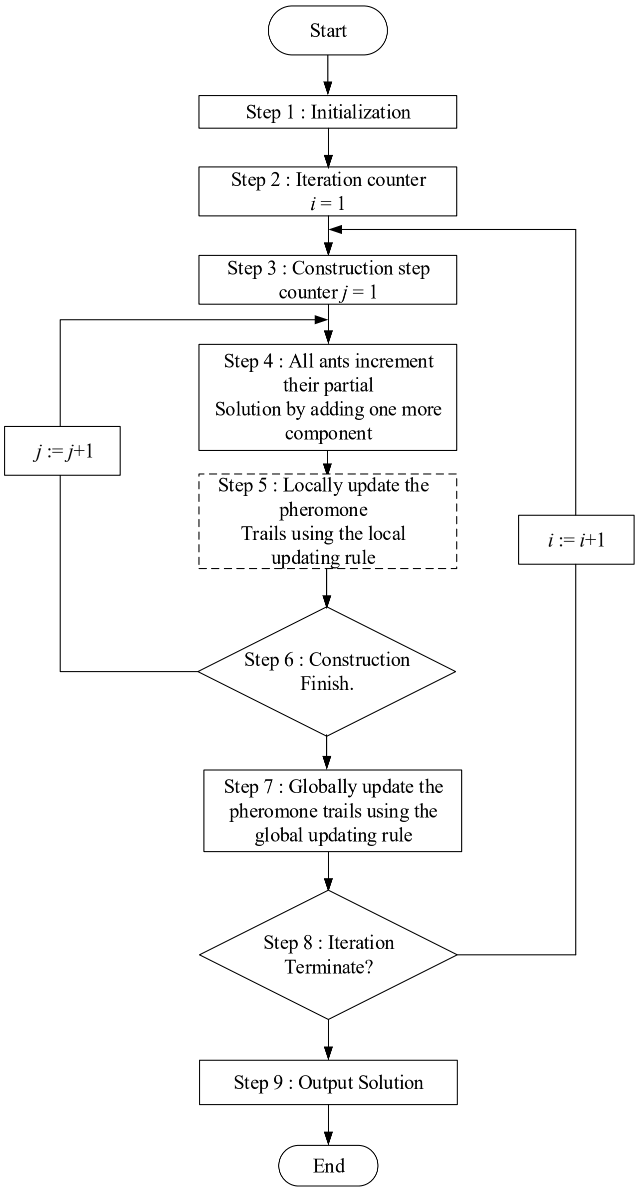

Fig 2. The diagram of ACO. [6]

The main steps of the ACO metaheuristic are explained in more detail in Fig.2. A general outline of the ACO metaheuristic for applications to static combinatorial optimization problems is given after initializing parameters and pheromone trails, the main loop consists of three main steps. First, m ants construct solutions to the problem instance under consideration, biased by the pheromone information and possibly by the available heuristic information. Once the ants have completed their solutions, these may be improved in an optional local search phase. Finally, before the start of the next iteration, the pheromone trails are adapted to reflect the search experience of the ants. The choice of the solution component to add is done probabilistically at each construction step. Various ways for defining the probability distributions have been considered. The most widely used rule is that of Ant System (AS) as shown in Equation (1) [7].

(1) $$p_k(t) = \frac{[\tau(i,j)]^{\alpha}[\eta(i,j)]^{\beta}}{\sum_1^t[\tau(i,u)]^{\alpha}[\eta(i,u)]^{\beta}} \quad j,u \in N_k, i$$

Where $\tau(i,j)$ represents the pheromone trail associated with li, j, which is the connection between vertices i and j, $\eta(i,j)$ is a heuristic value, called the desirability of adding connection.

The pheromone update is intended to make solution components belonging to good solutions more desirable for ants operating in the following iterations.The pheromone update is commonly implemented as:

(2) $$\tau(i,j) \leftarrow (1-\alpha)\cdot\tau(i,j) + \sum_{k=1}^{m}\Delta\tau_k(i,j)$$

Where α is a pheromone decay parameter with $0 < \alpha \le 1$, and

(3) $$\Delta\tau_k(i,j)\{_0^{1/j_{i,j}} \quad \begin{matrix} (i,j)\in\varphi ij \\ otherwise, \end{matrix}$$

Where φ being the set of moves done by the k the ant.

B. Cost function

Root mean square error (RMSE), the standard deviation of the residuals, is very commonly used and measured of the differences between the reference and the value actually output from the plant. In formulating the optimization problem, the RMSE is used as the objective of the ACO simulation. It can be defined as [8].

(4) $$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}e_i^2}$$

Where e_i is an error (i = 1, 2,..., n)

DESIGN SYSTEM

A. PI controller

Proportional-Integral (PI) control is a general control algorithm. It is used in industry and has been widely accepted in industrial control. The theory of classical PI and the effects of tuning a closed loop control system can account for in the block diagram of Fig 61

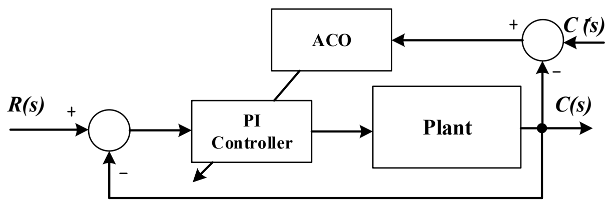

Fig 3. ACO - based PI controller design.

In a proportional controller, PI is given by the expression [9].

(5) $$PI = K_P e(t) + K_i\int_0^t e(t)dt$$

Where the output $C(s)$ is the average current and the input $R(s)$ is the average current set point.

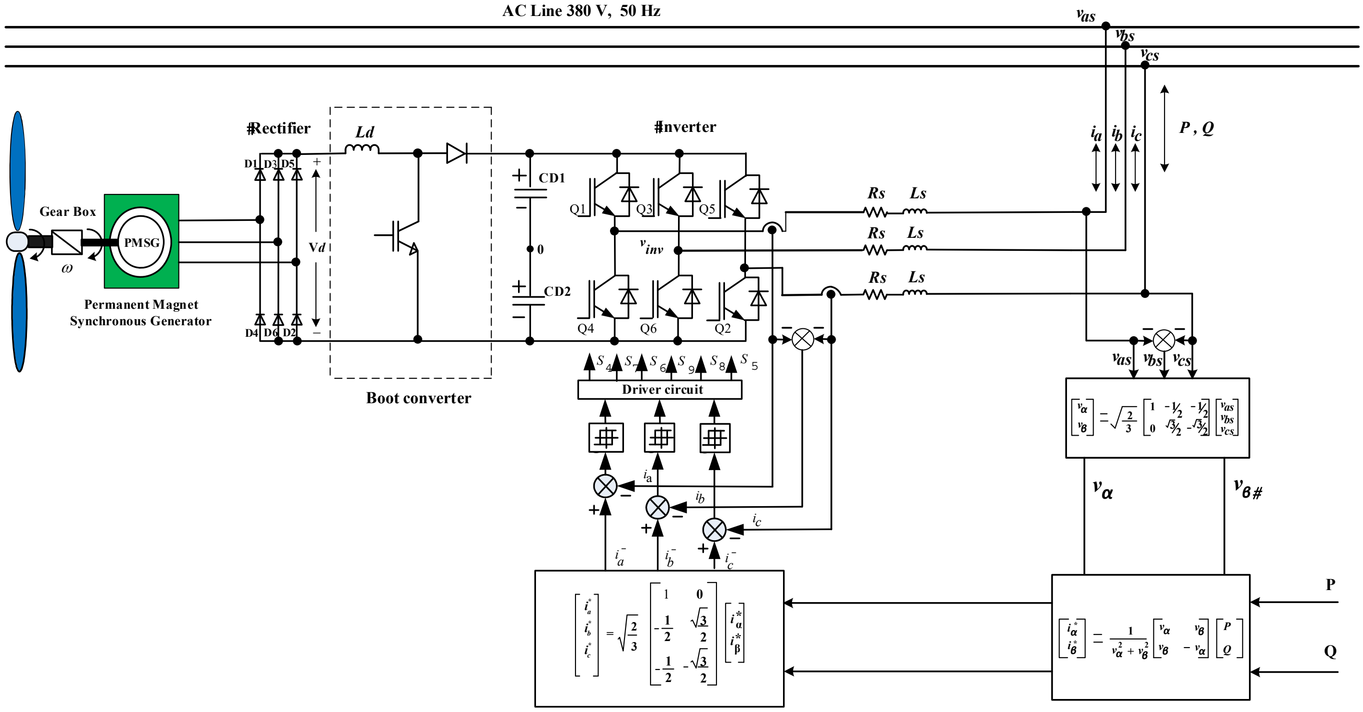

Fig. 4 The design system of wind turbine with PMSG by boot converter

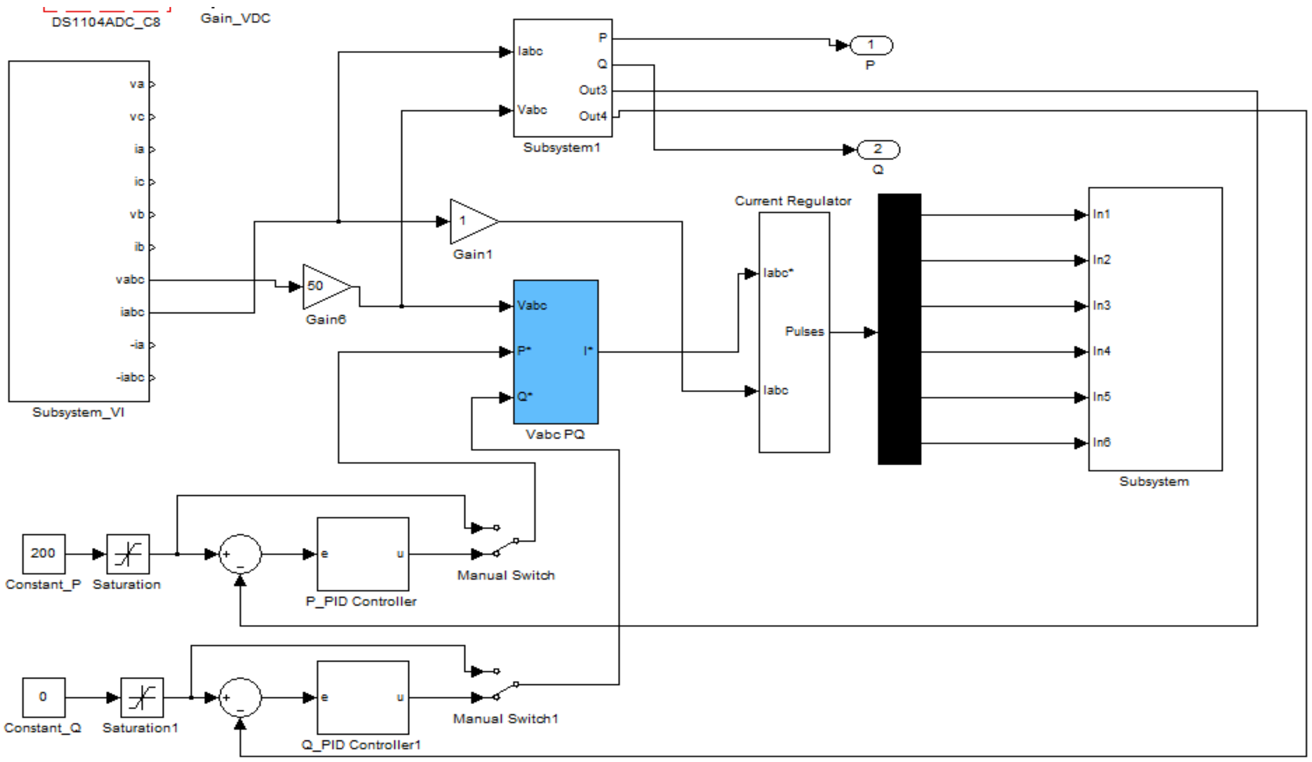

Fig. 5 Schematic of Simulation

B. Simulation experiment

In this section, a wind turbine with PMSG by boot converter of the control system is presented. A boot converter is very significant to adjust the dc voltage to high dc voltage at while wind speeds is low. It can boot up the voltage to high DC voltage. In this paper

Clark transformations is used to transform the 3-phase to 2-phase between the design and the grid connected system. Mathematically to convert the frame from stationary a-b-c to stationary $\alpha-\beta$, the Clark transformation of d-q system is given by [10].

(6)
$$\begin{bmatrix} v_\alpha \\ v_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v_{as} \\ v_{bs} \\ v_{cs} \end{bmatrix}$$

In stationary $\alpha-\beta$, the instantaneous power of the $P(t)$ and $Q(t)$ can be written as

(7) $$\begin{bmatrix} P \\ Q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix}$$

Where v_α is the real voltage, v_β is imaginary voltage, i_α and i_β are command currents in stationary $\alpha-\beta$ frame.

Such that, the instantaneous currents can be defined as

(8) $$\begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix} = \frac{1}{v_\alpha^2+v_\beta^2} \begin{bmatrix} v_\alpha & v_\beta \\ v_\beta & -v_\alpha \end{bmatrix} \begin{bmatrix} P \\ Q \end{bmatrix}$$

Where i_α^* and i_β^* are reference currents in stationary $\alpha-\beta$ frame. In inverse Clark transformation, the command currents, i_a^*, i_b^*, i_c^* in stationary *a*,*b*,*c* frame are expressed as

(9) $$\begin{bmatrix} i_a^* \\ i_b^* \\ i_c^* \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{bmatrix} 1 & 0 \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} i_\alpha^* \\ i_\beta^* \end{bmatrix}$$ ########

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C. Experimental setup

Table 1 shows the setting parameters of the proposed system as shown in Table 1.

Table 1. Various parameters for power circuit.

Parameters	Values
Roh	0.005
Alpha	0.003
Beta	0.005
Node	990
P	-1,800 – 1,800 watt
Q	0
$R(\Omega)$	20
$L(mH)$	200

The design system is simulated as block diagram in Fig.5 by the MATLAB/Simulink. The initial condition consists of the permanent magnet synchronous generator which is rated at 1 kW, 4 poles with 380 V and 50 Hz. The simulated output phase voltage of converter is from the dc-link voltage (VDC), the supply phase voltage (Van) and current (ian). Q is set to zero to operate at unity power factor. The simulation experiment results showed that the dynamic response of the converter can control voltage source inverter which operate under rectifying mode and inverting mode condition by setting active power reference control with active power between +1,800 watt to -1,800 watt.
Figure 6 the control of the power flow of -1,800 watts to 1,800 watts of the PI controller using the ant colony algorithm. where the red line is given is the reference power and the black line is the behavior of the PI controller. As shown in Figure 6 (a), the response speed of the system is 1.80 seconds without overload. The system has the optimal value.
In this research It is a good and acceptable control. and is stable. Figure 6(b) shows the virtual power flow. According to the control of the system here, where the system control requirement is zero. Figure 6 (c) shows the actual power flow. According to the control of the system from the grid system of the Provincial Electricity Authority, it enters the load and flows from the inverter mode into the grid system.

D. Results and Discussion

Table 2. K_P, K_I Constant values for various methods.

Iteration	Number of ant	K_P	K_I	RMSE
50	30	25.435	27.530	3.248
50	40	25.541	28.650	3.981
50	50	25.643	29.788	4.007
50	60	25.853	30.855	4.638
100	30	16.893	23.065	2.671
100	40	17.890	24.671	3.128
100	50	19.073	25.677	3.900
100	60	20.561	26.543	4.463
200	30	9.561	11.108	1.988
200	40	10.105	12.842	2.056
200	50	11.290	13.592	2.980
200	60	12.393	14.395	3.300
500	30	0.341	0.554	0.361
500	40	0.453	0.691	0.476
500	50	0.586	0.725	0.541
500	60	0.632	0.841	0.932
1000	30	0.003	0.005	0.024
1000	40	0.004	0.006	0.072
1000	50	0.005	0.007	0.061
1000	60	0.006	0.008	0.083

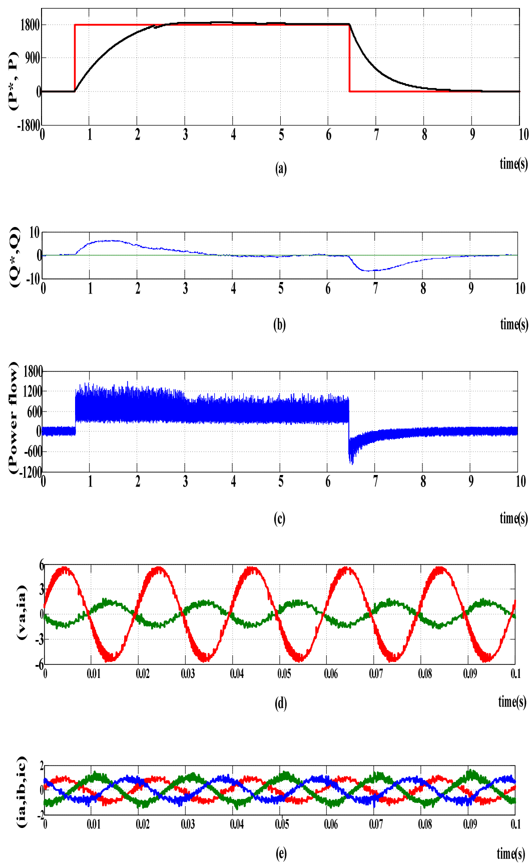

Figure 6. Signal response for various values

Figure 6 (d) is the steady state load current and voltage waveforms. It is found that the current has a phase angle that lags slightly behind the voltage. Figure 6 (e) the actual working current value of the three-phase power system, that is, phase A, phase B and phase C with a voltage level of 380v and a frequency of 50 Hz.

Conclusions

The wind turbine based on PMSG can generate the clean energy to grid connected system. The objective of this paper is to optimize the gains of PI controller by ACO. The design system is simulated by MATLAB/Simulink. To boot up the high DC voltage, the boot converter is applied. In regards to ACO, it can search the optimal gains for tuning PI controller. The interval of lower and upper bounds of gains are 0.003 and 0.005, respectively. The simulation results show that the overshoot and life time of the design system is very low. Therefore, ACO can provide the optimal gains for PI controller to boot the voltage for the wind turbine system with PMSG using boot converter.

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