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Improving the Transient Stability of Power Systems Using STATCOM and Controlling it by Honey Bee Mating Optimization Algorithm

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Abstract

In this study, a new method for designing the damping controller was proposed to improve the transient power system stability in a single machine network connected to an infinite bus. The STATCOM controller problem in a wide area of the system function was considered as an optimization problem with multi-purpose objective function. Also, the Honey Bee Mating Optimization Algorithm was used to determine its parameters. In this paper, a new method for designing a damping controller was presented to improve the transient power system stability in a single machine network connected to an infinite bus. The STATCOM controller design problem in a wide area of system function was considered as an optimization problem with a multi-purpose objective function and the honey bee mating optimization algorithm was used to determine its parameters. As shown, STATCOM improved system stability. For a more comprehensive analysis, the results were tested in three different scenarios. Simulation of the STATCOM controller design for small signal stability was conducted in the MATLAB / SIMULINK environment. The tuning variables in designing the controller were variables c and φ that were used to adjust the modulation index and firing angle of switches. In order to achieve the best possible state, the artificial honey bee colony algorithm was used.

Keywords: Transient stability, Single-machine network, Honey bee mating optimization algorithm, the flexible AC transmission systems
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1. Introduction

Power system stability is one of the most important aspects of power networks' exploitation. By developing the interconnection of large electric power systems, low frequency oscillation becomes a serious challenge in power systems. This oscillation is as a result of a sudden increase in load, a sudden loss of one generator, or switching out of a transmission line during a fault [1]. Once started, low frequency oscillations (LFC) would continue over a long period of time, and in some cases, they continuously increase and can lead to the separation of sub-systems of a network. Thus, damping of low-frequency electro-mechanical oscillations is very important for the system secure operation [2]. Excessive power transmission in a transmission line causes over-voltage drop and reduces power transfer capacity to a given part of the power system. Consequently, it is attempted to refrain from constructing new lines as much as possible by taking into account the economic requirements of power systems using peripheral equipment such as FACTS devices and reactive power compensation techniques [3]. Today's manufacturing systems in the electric power industry usually work at their highest capacity levels. This issue lowers the stability of the system itself. FACTS devices in power systems release line capacities, through which it can prevent losses and voltage drop of the network. Parallel FACTS devices, such as TCRs and SVCs, by injecting or receiving reactive power and series FACTS devices such as TCSCs, by decreasing the reactance of the line, are the main cause of this issue. In order to demonstrate the improvement of the voltage profile in the network with the presence of FACTS devices during the steady state, the correct impact of these devices on the network equations to solve the load flow should first be considered [4-6]. Rapid changes in system parameters such as line impedances, power angle and line currents, transients introduced by the associated compensator 's control action, and the harmonics involved in the related system are all affected by the presence of these FACTS devices in the transmission lines at the time of fault incidence [7-9].

The conducted simulation in this paper is divided into two parts. The first simulation is based on the STATCOM's permanent and dynamic studies that are conducted in the MATLAB / SIMULINK environment. This simulation was performed to explore reactive power regarding fault incidence and then STATCOM's behavior was analyzed in dealing with fault incidence and its impact. The second simulation is the nonlinear network model and STATCOM for its designing with the goal of improving transient stability. To solve this problem, the honey bee mating optimization algorithm was applied.

2. Honey Bee Mating Optimization Algorithm

An artificial bee colony algorithm is a search algorithm that was first created in 2005 using the simulation of the food foraging behavior of honey bee colonies [10]. In the honey bee mating optimization algorithm, food sources are searched using three categories of honey bees, i.e., queen, drone (male bee), and workers (female). These bees are structurally similar, but each performs different actions. In this algorithm, the problem variables are considered as the source of the food. The nectar of the food source represents the probability function. Each food source is extracted by a worker bee, meaning that the numbers of the worker bees are equal to the number of the food sources around the hive. The general steps of the artificial bee colony algorithm are shown in Figure 1.

3. Simulation of Permanent and Dynamic Conditions of STATCOM

This section was simulated using MARLAB/SIMULINK software. STATCOM simulation was done by the 48 pulse inverter. Given the power ratio of a STATCOM, many different technologies are used for power converter. This model requires simulation in discrete time and fixed time steps (which is here 25 microseconds) and is used to study the STATCOM performance in a very short time (about a few seconds). In the simulated model, a 511 KV three-bus system and a STATCOM 110-Mvar voltage regulator were considered in B_1. The internal voltage of the connected equivalent system in B_1 can be changed by the three-phase voltage source block and the STATCOM dynamic response to changes the voltage of the system can be observed.

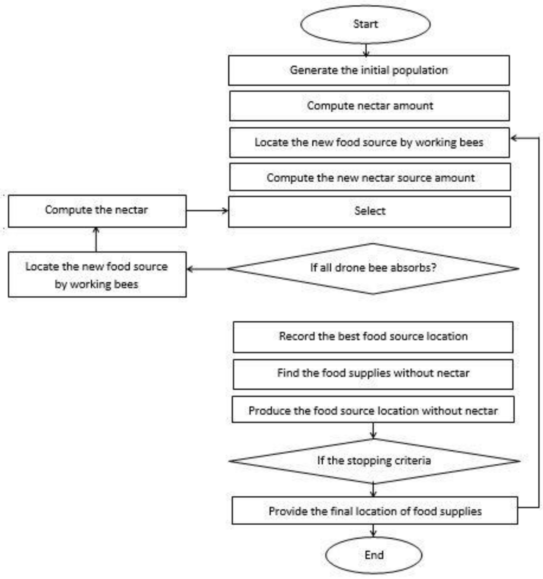

Fig. 1. The general steps of an HBMO algorithm
Fig. 2.

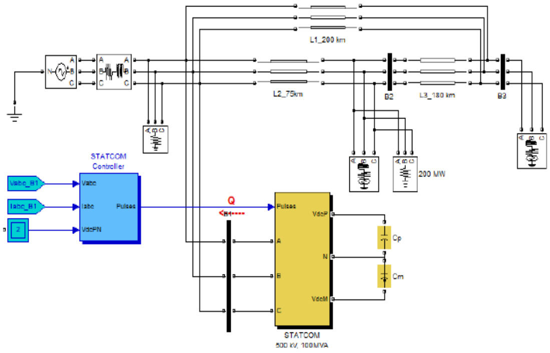

Fig. 3. A general model in MATAB/SIMULINK software

A) *The permanent and dynamic performance of STATCOM*

When the system voltage changes, it is possible to observe the permanent and dynamic performance of STATCOM. The simulation results are shown in Figures 3 and 4. The results were studied for B_1. The control circuit was designed by indirect control technique. First, the voltage source is set at 1pu. This voltage value remains constant for up to 0.1 seconds. In the first step of changes from 0.1 to 0.2 seconds, the voltage source is reduced to 0.955 pu and in the second step, from 0.1 to 0.2 seconds, the voltage source will be increased to 1.045 pu. Figure 3 shows the values of the STATCOM's output voltage and current. As shown in the figure, the current is injected into the network as inductors and capacitors from the 0.1 to 0.2 seconds and 0.2 to 0.3 seconds, respectively.

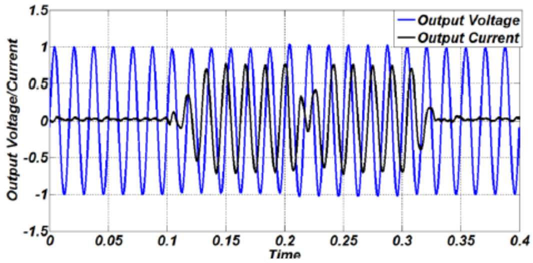

Fig. 4. The values of the STATCOM’s output voltage and current

In the first step of the changes, STATCOM reacts by generating reactive power (Q= +70Mvar) to keep the voltage at 1pu. In 95% of the time settling is approximately 47 ms, the DC voltage is increased to 20.4 KV. In the second step of the changes, STACTOM reacts by changing its operating point from capacitive to inductive in order to keep the voltage at 1pu. At this point, the STATCOM absorbs 72Mvar and DC voltage is lowered to 18.2 KV. These conditions and changing the operating point of the STATCOM lasted about a time cycle.

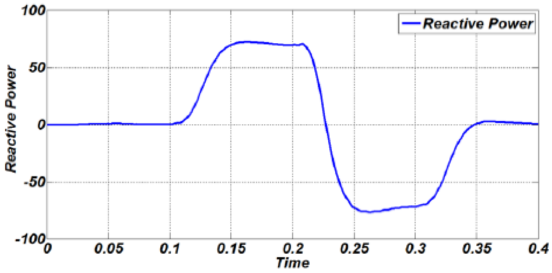

Fig. 5. STATCOM reactive power

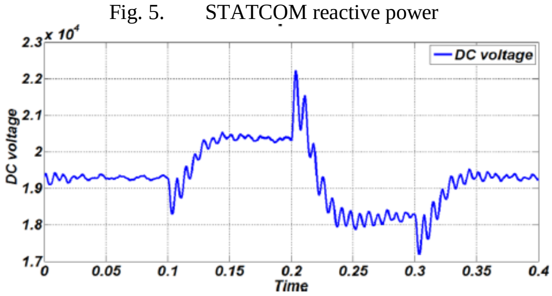

Fig. 6. DC voltage

4. Simulation of Nonlinear Dynamic Model of STATCOM

In this section, the simulation of the nonlinear dynamic model is presented. Initially, nonlinear model of the network in the presence of STATCOM is described and then the used method for designing and setting of STATCOM’s parameters is expressed.

A) *Evaluating power network model*

In this section, a single-machine system with STATCOM for the low frequency oscillation and transient stability is shown in Figure 6. The synchronous generator delivers the power to the infinite-bus through a double circuit transmission line and an STATCOM.

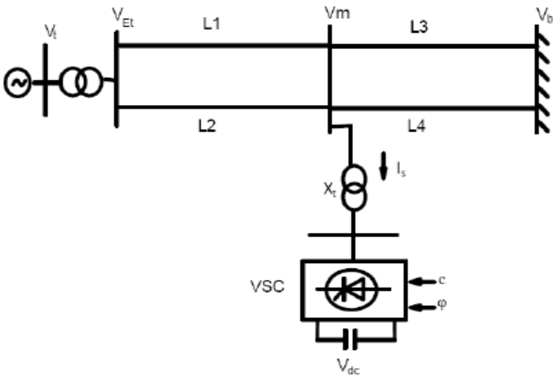

Fig. 7. A single-machine system equipped with STATCOM

The voltage source inverter (VSC) generates a controllable AC voltage source. The voltage differences between the system and STATCOM, $V_L(t)$ and $V_0(t)$ produces a reactive power exchange between STATCOM and the power system. The STATCOM voltage is set by the amplitude and the phase. The dynamic relation between the capacitor voltage and current in the STATCOM circuit is as follows [11]:

$$\bar{I}_{LO} = I_{Lod} + jI_{Loq} \tag{1}$$

$$V_o = cV_{dc}(\cos\varphi + j\sin\varphi) = cV_{dc-\varphi} \tag{2}$$

$$\dot{V}_{dc} = \frac{I_{dc}}{C_{dc}} = \frac{c}{C_{dc}}(I_{Lod}\cos\varphi + I_{Loq}\sin\varphi) \tag{3}$$

In which for the PWM inverter, we have c = mk and k is the ratio between AC and DC voltage. Depending on the inverter structure, m is the modulation ratio. The dynamic of the generator and the excitation system are expressed though a third order model as follows:

$$\dot{\delta} = \omega_0(\omega - 1) \tag{4}$$

$$\dot{\omega} = (P_m - P_e - D\Delta\omega)/M \tag{5}$$

$$E'_q = (-E_q + E_{fd})/T'_{do} \tag{6}$$

Considering the third order model of the power system, the amount of current flow through the capacitor is achieved by the following relations:

$$I_{Lod} = \frac{e'_q - (x'_d + X_{tL})I_{tLq} - mV_{dc}\sin\varphi}{X_{SDT}} \tag{7}$$

$$I_{Lod} = \frac{mV_{dc}\cos\varphi - (x'_d + X_{tL})I_{tLq}}{X_{SDT}} \tag{8}$$

$$I_{tld} = \frac{(1+\frac{X_{LB}}{X_{SDT}})e'_q - \frac{X_{LB}}{X_{SDT}} mV_{dc}\sin\varphi - V_b\cos\varphi}{X_{tL} + X_{LB} + \frac{X_{tL}}{X_{LB}} + (1+\frac{X_{LB}}{X_{SDT}})x'_d} \quad (9)$$

$$I_{tld} = \frac{\frac{X_{LB}}{X_{SDT}} mV_{dc}\cos\varphi + V_b\sin\varphi}{X_{tL} + X_{LB} + \frac{X_{tL}}{X_{LB}} + (1+\frac{X_{LB}}{X_{SDT}})x_d} \quad (10)$$

$$X_{tL} = X_T + \frac{X_L}{2};\; X_{LB} = \frac{X_L}{2} \quad (11)$$

$$\Delta\dot{\delta} = w_0 \Delta w \quad (12)$$

$$\Delta\dot{w} = (-\Delta P_e - D\Delta w)/M \quad (13)$$

$$\Delta E' = (-\Delta E_q + \Delta E_{fd})/T'_{do} \quad (14)$$

$$\Delta\dot{E}_{fd} = (K_A(\Delta u_{ref} - \Delta u) - \Delta E_{fd})/T_A \quad (15)$$

$$\Delta P_e = K_7\Delta\delta + K_8\Delta E'q - K_9\Delta u_{dc} + K_{dc}\Delta c + K_{d\phi}\Delta_\phi \quad (16)$$

$$\Delta P_e = K_1\Delta\delta + K_2\Delta E'q - K_{pdc}\Delta u_{dc} + K_{pc}\Delta c + K_{d\phi}\Delta_\phi \quad (17)$$

$$\Delta E'_a = K_4\Delta\delta + K_3\Delta E'q - K_{pdc}\Delta u_{dc} + K_{qc}\Delta c + K_{q\phi}\Delta_\phi \quad (18)$$

$$\Delta V_t = K_5\Delta\delta + K_6\Delta E'_q - K_{udc}\Delta u_{dc} + K_{uc}\Delta c + K_{u\phi}\Delta_\phi \quad (19)$$

Where k_1, k_2, k_3,… k_9, k_{pu}, k_{qu}, k_{vu} are linearization constants of dynamic model. The state space model and block diagram of the linearized dynamic model of a single-machine infinite bus power system with STATCOM is given by [12-19].

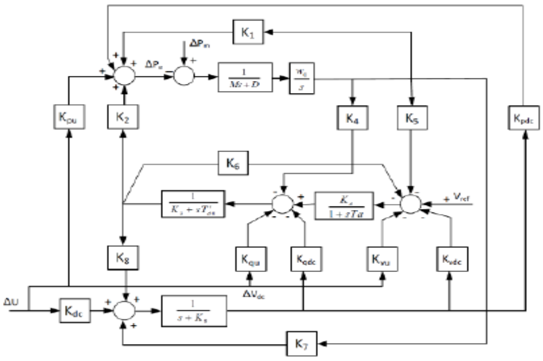

Fig. 8. Block diagram of the linearized dynamic model of a single-machine infinite bus power system with STATCOM

To evaluate the proposed simulation method, it was tested in three different scenarios. In each scenario, the network load is considered different and fault incidence is considered in the fifth seconds of the fault. Table 1 shows the amount of loads for different studies.

Table.1.
Different Loading Conditions

Loading condition	***XL***	***Qe(pu)***	***Pe(pu)***
Normal	0.3	0.15	0.8
Minimum	0.3	0.01	0.2
Maximum	0.3	0.4	1.2

The results for each scenario are as follows. The following figures illustrate the simulation results for normal, minimum, and maximum loading conditions.

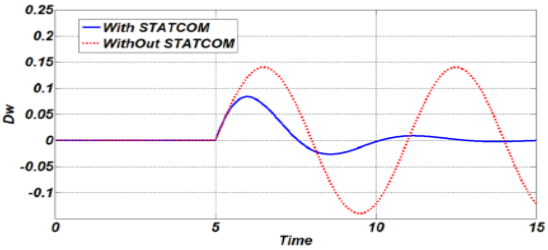

Fig. 9. The simulation results for normal loading condition

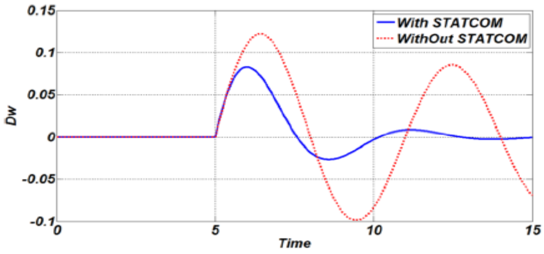

Fig. 10. Simulation results for minimum loading condition

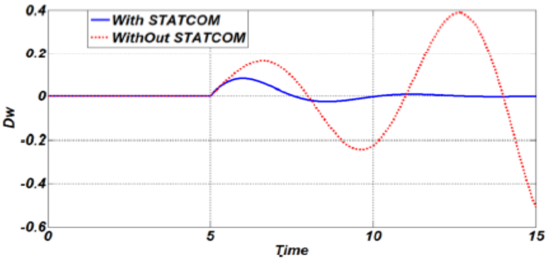

Fig. 11. Simulation results for maximum loading condition

5. Algorithm, Designing, and Adjusting Method of the STATCOM

In a network under a small signal interference, the rotor speed of the synchronous generator changes and consequently the power injection into the network decreases or increases. High power injection changes into the network can exacerbate the instability. Hence, to avoid instability and fault detection, the error signal around the rotor can be used. The simulation of the STATCOM controller design was done to improve the stability of the small signal in the MATLAB/SML environment. The tuning variables for designing the controller are c and φ that are used to adjust the modulation index and firing angles of switches. The honey bee optimization algorithm was used to achieve the optimal possible condition. The number of bees for searches and the number of algorithm's iteration were considered 20 and 50, respectively. The allowed limits for the variables are as follows:

1) For variable c, the permissible limit was considered from 0 to 1

2) For variable φ,the permissible limit was considered from 0 to 180.

Food source included two parts. The first part is the value of the variable c and the second part is related to the value of φ. The algorithm, in each iteration, calculates a value for each member and then outputs are given to MALAB/SIMULINK file as input and execute it with the sim command. The amount of speed deviation as the output of the MATLAB/SIMULINK file during the simulation is given to the program's main file, and the sum of these values is considered as the cost function of each member. The nonlinear model of the simulated system is shown in Figure 11.

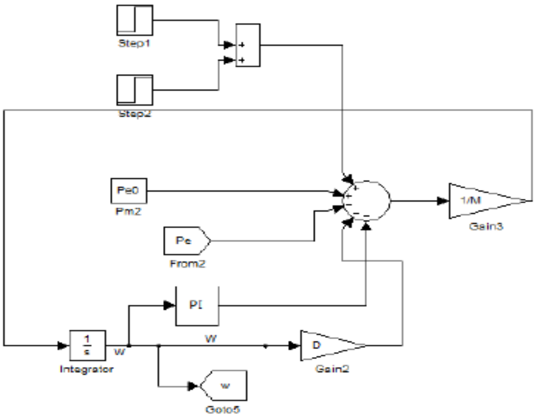

Fig. 12. The nonlinear simulated system (Rotor synchronous generator model)

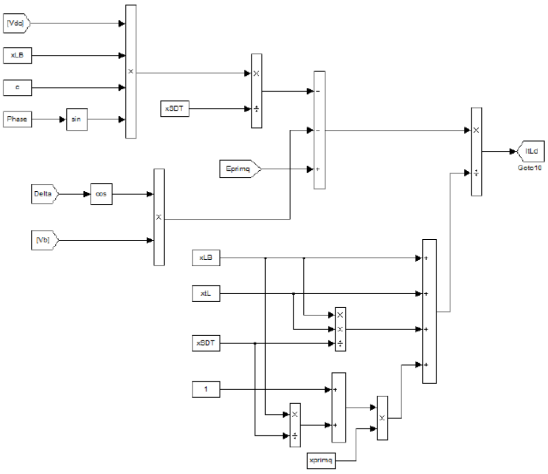

Fig. 13. The nonlinear simulated system (Network flow model)

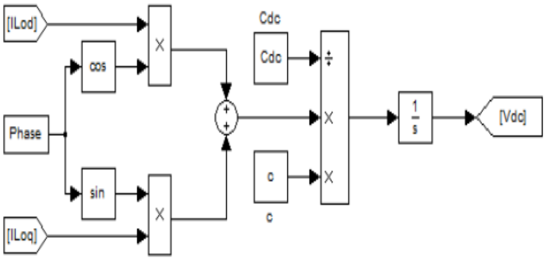

Fig. 14. The nonlinear simulated system (DC flow model)

Figure 14 shows the rotor speed deviation. As shown, after performing fault incidence at 5 seconds, the rotor deviates its synchronous speed and this speed deviation is compensated by the STATCOM controller and the rotor reaches to its synchronous value at 5 seconds. Hence, the dynamic stability of the system is maintained. In fact, STATCOM controller avoids transient instability by preventing the unnecessarily increasing rotor speed deviations.

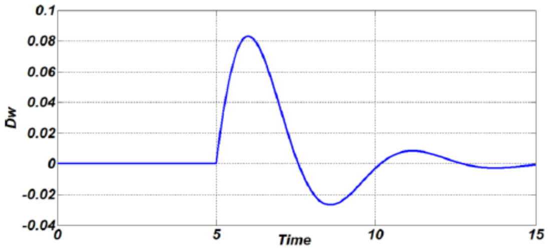

Fig. 15. Rotor deviation rate of simulated system

Fig. 16.

To test the designed model, the simulation time interval was increased (30 seconds) and fault was applied into the system at two different times. Figure 15 shows the rate of speed deviation in this test. As seen, after performing fault incidence at 2 seconds, the rotor deviates its synchronous speed and STATCOM controller compensates this speed deviation and the rotor reaches to its synchronous value within 15 seconds. At this time, a fault was applied to the system again and as can be seen from the results, this fault was also damped by STATCOM controller. Figure 16 shows the rate of the speed deviation for each test. Dash line is related to the results of the second test and the next line is the results of the first test.

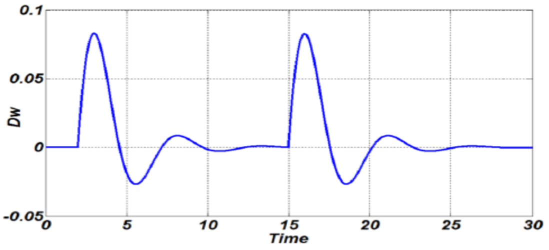

Fig. 17. Rotor speed deviation rate of the simulated system, Test1

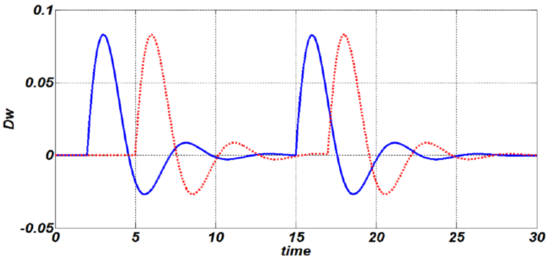

Fig. 18. Rotor speed deviation rate of simulated system, Test2

To test the optimal calculated value of the STATCOM parameters by the proposed algorithm, the system simulation was executed by optional values of STATCOM parameters. For example, the values of the variables c and φ was considered 0.1 and 30.34, respectively. As shown in Figure 17, after fault incidence on the system, the rotor speed increased and the deviation around the rotor is slightly positive.

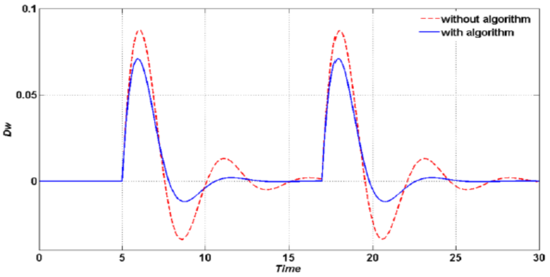

Fig. 19. The speed deviation rate of simulated system Test 1 and 2 with optional values.

6. Results

In this paper, a new method for designing a damping controller was presented to improve the transient power system stability in a single machine network connected to an infinite bus. The STATCOM controller design problem in a wide area of system function was considered as an optimization problem with a multi-purpose objective function and the honey bee mating optimization algorithm was used to determine its parameters. As shown, STATCOM improved system stability. For a more comprehensive analysis, the results were tested in three different scenarios. Simulation of the STATCOM controller design for small signal stability was conducted in the MATLAB / SIMULINK environment. The tuning variables in designing the controller were variables c and φ that were used to adjust the modulation index and firing angle of switches. In order to achieve the best possible state, the artificial honey bee colony algorithm was used.

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