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Optimizing power flow of AC–DC power systems using artificial bee colony algorithm

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ABSTRACT

Optimal power flow (OPF) is one of the known problems of the power systems. Many numerical and heuristic methods were used to solve this problem so far. As seen from these studies in literature, heuristic methods are more effective and faster than numerical methods. This case is to make more attractive and mandatory the using of heuristic methods in optimal power flow solution of high voltage direct current (HVDC) systems. In this study, the optimal power flow solution of alternating current–direct current (AC–DC) power systems is firstly accomplished by using the artificial bee colony (ABC) algorithm that is one of the heuristic methods. The proposed method is tested on two different test systems. The obtained results are compared to that of genetic algorithm (GA) and a numerical method in literature. In this study, the real transformer representation is also used for the transformers in the power systems.

1. Introduction

Many studies were performed for the stability and power flow solutions of HVDC systems so far [1–14]. All of them use the numerical methods. There are two basic approaches for solving the power flow equations of AC–DC power systems in literature. The first is the sequential approach [15–17]. In this method, the alternating current (AC) and direct current (DC) equations are solved separately by successive iterations. Although the implementation of the sequential method is easy, it has convergence problems associated with certain situations and are the state vector does not contain explicitly the dc variables. The second approach is known as the unified approach [18].

The scientists have used many different methods for solving OPF problem of purely AC power systems so far [19–25]. These methods are numerical and heuristic methods. According to the results reported in literature, it can be seen that heuristic methods are superior from the numerical methods [21–25]. The important one of the advantages of heuristic methods is that they convergence to the optimum solution in more short time than others and convergence fewer local minimum.

ABC algorithm is a new population based heuristic optimization method proposed by Karaboga [26]. Recently, successful applications of ABC algorithm to the power systems attract attention [27–29], because ABC algorithm is an efficient and effective algorithm in order to determine the global minimum points of nonlinear and non-convex problems.

In this study, the real model for the transformers is used. In the real model of transformer, also the impedance values of the transformers vary as the tap ratios of the transformers vary, and thus the bus admittance matrix of the power system also varies. The power system calculations are accomplished without inclusion the impact of the transformers to the Jacobian matrix. Thus, the transformers in the power system can be selected as the control variables. In heuristic method, each individual select a different tap ratio change of for each transformer and the bus admittance matrix of the power system is calculated uniquely for each individual. This process increases computational time of the software.

After this introduction, the modeling of DC transmission link is represented in Section 2. The ABC methodology is explained in Section 3. ABC algorithm based optimal power flow solution of AC–DC power system is explained in Section 4. In Section 5, to demonstrate validity, the efficiency and the effectiveness of the proposed method, simulation results of the modified 5-node test system and the New England 39 bus test system with an HVDC link is given and the obtained results are extensively evaluated and compared to those obtained by other methods. Finally, the conclusions and discussions are represented in Section 6.

2. The modeling of DC transmission link

Before analyzing DC transmission system, it is necessary to model the converters for two sides of DC links. The modeling is

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made based on widely accepted assumptions in the literature. The assumptions are as follows [18]:

- The main harmonic values of current and voltage in AC power system is balanced.
- The other harmonics except the main harmonic are ignored.
- The ripples in the current and voltage wave form of DC link are ignored.
- The thyristors used in the converters are accepted as ideal switch and it is supposed to be short circuit in the direction of transmission and open circuit in the direction of plugging.
- No load current of the converter transformers and the losses are ignored.

AC bus representation which is connected to DC transmission link is shown in Fig. 1 [30] and the equalities related to the kth bus are given by Eqs. (1), (2).

$$p_{gk} = p_{lk} + p_{dk} + p_k \quad (1)$$

$$q_{gk} + q_{sk} = q_{lk} + q_{dk} + q_k \quad (2)$$

In the equalities above; p_{gk} is the active power generation of the kth bus; p_{lk} is the active load of the kth bus; p_{dk} is the active power transferred to dc line from the kth bus; p_k is the active power transferred to ac line from the kth bus; q_{gk} is the reactive power generation of the kth bus; q_{lk} is the reactive load of the kth bus; q_{dk} is the reactive power absorbed by the converter connected to the kth bus; q_k is the reactive power transferred to ac line from the kth bus and q_{sk} is the shunt compensator in the kth bus

For rectifier bus,

$$p_{dk} = p_r \quad (3)$$

$$q_{dk} = q_r \quad (4)$$

For inverter bus,

$$p_{dk} = -p_i \quad (5)$$

$$q_{dk} = q_i \quad (6)$$

A basic schematic diagram of a two-terminal HVDC transmission link interconnecting buses "r" (rectifier) and "i" (inverter) is illustrated in Fig. 2. The basic converter equations describing the relationship between the AC and DC variables were expressed in Ref. [31].

The variables shown in Fig. 2 are defined as follows: v_r is the primary line-to-line ac voltage (rms) of the rectifier side; v_i is the primary line-to-line ac voltage (rms) of the inverter side; φ_r is the phase angle of the rectifier side; φ_i is the phase angle of the inverter side; i_r is the AC line current of the rectifier side; i_i is the AC line current of the inverter side; v_{dr} is the rectifier side voltage of DC link; v_{di} is the inverter side voltage of DC link; i_d is the direct current; t is the transformer tap ratio.

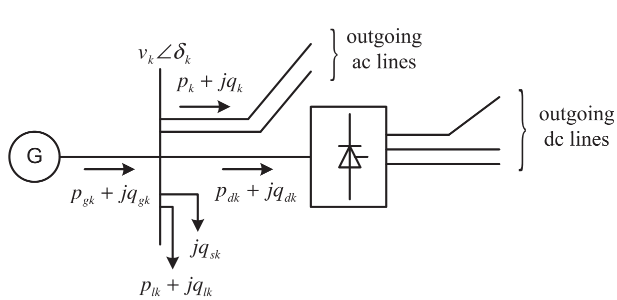

Fig. 1. AC bus representation which is connected to DC transmission link [30].

2.1. The equations of rectifier side for DC transmission link

The equivalent circuit of a two-terminal HVDC link is shown in Fig. 3 [32]. The equations related to the rectifier operation of a converter can be expressed as follows:

$$v_{dor} = kt_r v_r \quad (7)$$

$$v_{dr} = v_{dor} \cos \alpha - r_{cr} i_d \quad (8)$$

where v_{dor} is the ideal no-load direct voltage, $k = 3\sqrt{2}/\pi$ and α is the ignition delay angle. r_{cr} is the so called equivalent commutating resistance, which accounts for the voltage drop due to commutation overlap and is proportional to the commutation reactance, $r_{cr} = \sqrt{3}x_{cr}/\pi$. The active power on the rectifier side is determined by:

$$p_r = v_{dr} i_d \quad (9)$$

Since losses at the converter and transformer can be ignored ($p_r = p_{ac}$), the reactive power on the rectifier side is determined as follows:

$$q_r = |p_r \tan \phi_r| \quad (10)$$

where ϕ_r is the phase angle between the AC line voltage and the fundamental AC line current and is calculated by neglecting the commutation overlap as follows:

$$\phi_r = \cos^{-1}(v_{dr}/v_{dor}) \quad (11)$$

2.2. The equations of inverter side for DC transmission link

The equations related to the inverter operation of a converter can be expressed as follows:

$$v_{doi} = kt_i v_i \quad (12)$$

$$v_{di} = v_{doi} \cos \gamma - r_{ci} i_d \quad (13)$$

$$p_i = v_{di} i_d \quad (14)$$

$$q_i = |p_i \tan \phi_i| \quad (15)$$

$$\phi_i = \cos^{-1}(v_{di}/v_{doi}) \quad (16)$$

where γ is the extinction advance angle.

2.3. DC link equation

The relationship between the voltages in two sides of DC link can be given as follows:

$$v_{dr} = v_{di} + r_{dc} i_d \quad (17)$$

where r_{dc} is the resistance of DC transmission link.

3. Illustration of ABC algorithm

The ABC algorithm was proposed by Karaboga in 2005 [26]. The algorithm has been successfully applied in distinct fields of science such as electrical engineering, mathematics, mechanical engineering and civil engineering since 2005 [33–36].

The ABC algorithm is a population based algorithm created by the inspiration from the food pursuit of honey bees. In the algorithm the bees are divided into two groups: the worker bees and non-worker bees. The non-worker bees consist of onlooker and scout bees.

The each iteration of the ABC algorithm consists of five steps after initialization step:

Step 1: Moving the worker bees onto the food sources and calculating their nectar amounts.

Step 2: After the onlooker bees take all of the information about the food sources from the worker bees, placing they onto the new food sources and calculating the nectar amounts.