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Application of artificial bee colony-based optimization for fault section estimation in power systems

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ABSTRACT

This paper presents an artificial bee colony algorithm to enhance the fault section estimation performance in power systems. Through mimicking the foraging behaviors of honeybee swarms, the algorithm owns exploitation and exploration procedures to constitute an effective near-optimal search mechanism. This proposed method excels at saving decision on external parameters such as crossover and mutation rates, facilitating the improvement of computation performance. Meanwhile, the method has added a random selection scheme to look for a new source, by which the probability of being trapped into local minimum can be largely reduced, hence serving as beneficial aids of grasping the faulted section more effectively. Through this proposed approach, it benefits the engineers to find the accurate fault section among voluminous alarms, and reduces the possibility of inaccurate diagnosis. To validate the effectiveness of the method, it has been tested on practical power systems with comparisons to published techniques.

1. Introduction

Fault section estimation identifies the fault section in power systems by using the protective status of relays and circuit breakers acquired from supervisory control and data acquisition (SCADA) systems. Through the messages provided by protective devices, the operators would be able to justify and isolate the fault sections such that the affected duration and level of services can be minimized. From perspectives of both system operators and customers, the fault section diagnosis is always a vital task, yet some factors may still bring difficulties such as the information of relays and circuit breaker failures as well as multiple faults are hard to grasp. The stress encountered under voluminous alarms and insufficient experiences to interpret are also challenging burdens [1]. Numerous papers such as expert systems (ESs) [2], artificial neural networks (ANNs) [3–5], cause-effect networks (CE-nets) [6,7], Petri-nets [8,9] and Bayesian networks (BNs) [10] have been proposed to solve this problem. Although the expert system based approach offers expertise to the diagnosis, the procedure of knowledge acquisition along with the achievement of knowledge sufficiency is yet burdensome. Such a situation is also faced by using artificial neural network techniques. Without the extensive confirmation of the quality of training process and the quantity of training data, the performance is highly restricted. Next, considering the CE-nets, Petri-nets and BN, the completeness of causal relationships and the reasoning model are also laborious to form up.

Over the last few decades, several biological intelligence approaches based on emulating the intelligent behaviors of real organisms have been developed. The biological intelligence based clustering concepts such as genetic-based algorithms [11–15] and swarm intelligence algorithms [16,17] were both applied to estimate the fault section with great appreciation. Among these techniques, the swarm intelligence usually embeds with characteristics of positive feedback, negative feedback, randomness, and synergy to develop a powerful and efficient mechanism [18–21]. Based on a well contemplated design, the computation process is anticipated to evolve on the optimal tracks. By imitating the bee forage behaviors and formulating the relationships among food source, employed bees, onlookers and scout bees, an artificial bee colony algorithm (ABC) was proposed. Such a method has been also suggested to solve multi-dimensional and multimodal numeric problems [22–24] as well as power system problems [25–31]. In the method, the food selection process takes two important schemes into account [22]. The first one is greedy-selection scheme, in which the employed bees memorize the food source information and share with onlookers. The intensification process managed by employed bees and onlookers is found to be efficient for local optimization. The other one is the random selection scheme, by which the employed bee becomes the scout one to look for a new source until the nectar is exhausted. Through these two schemes, the algorithm not only enhances with local and global search, but also reinforces with information exchange and memorization capability.

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Based on aforementioned features, we have discussed with utility engineers to apply this ABC method to the real system. The method starts with representing the control variable of problem and fitness by food position and the amount of nectar. Then, with the aid of foraging search, the optimal amount of nectar is expected to be better localized, implying that the fault section diagnosis can be accomplished more effectively. This paper will apply the method on the sample system and the real system. The test results will be reported, evaluated, and compared to other methods.

The organization of this paper is made as follows. Section 2 formulates the fault section estimation problem, Section 3 describes the method with its application, Section 4 delineates the computation procedure, Section 5 discusses the test results, and Section 6 draws the conclusions.

2. The paradigm

2.1. Problem analysis

In power system protection, protective relays and circuit breakers are required to remove faults cooperatively as fast as possible. When a fault happens, it is vitally important that the on-off status of associated relays and breakers should inform engineers in a shortest time. To mimic the method, the study first formulates each protective section with a food source position, where three types of protective sections (busbar, transformer, and line section) are all considered [32,33]. With each section deemed as a food source position in the algorithm, its corresponding nectar amount is regarded as the fitness to the problem that is investigated.

Given an example for a preliminary analysis, Fig. 1 shows a sample system consisting of five busbar sections (B_1–B_5), one transformer section (TR), and four transmission line sections (L_1–L_4). The protective relays are classified into main, primary backup and remote backup relay. For each section, a circuit breaker is accompanied to distinguish from the neighboring zone. All three types of relays are installed at transformer sections and line sections, but only main relay is installed at each busbar section. When a fault occurs at any section, its main protective device is activated to isolate the fault; yet if there comes with any failure during the fault-clearing process, the primary and remote backup relay will be activated instead.

Now, assume that a fault happens at the transformer section TR, and the circuit breakers CB_2 and CB_3 are triggered by the transformer's main protective relay. If the main relay fails at this time, it will activate the primary backup relay. Yet, for a fault occurring near the neighboring B_1 or B_2 of TR when the main relay of B_1 or B_2 does not work appropriately, the remote backup relay of TR will activate for the protection. Similarly, suppose a fault occurs in L_1, then the main protective relays at two ends of L_1 will send the signal to activate the circuit breakers CB_4 and CB_5. Once any main relay fails to trip, the primary backup relays at two ends of L_1 will work right away. It is noted that if a fault occurs in B_2 or TR with failed main relay, the remote backup relay will trip CB_5. This can be inferred that when a fault occurs in B_3 with a failed CB_5, or if a fault occurs in L_2 or L_4 with failed CB_6 and CB_{11}, then the remote backup relay will trip CB_4 as well. From these operations and descriptions, mathematical model of fault section estimation is derived and detailed below.

2.2. Mathematical model formulations

The fault section estimation problem is to find the most probable fault section based on the reported alarm information [16,17]. From aforementioned discussions, mathematical terms of protective device are derived as follows:

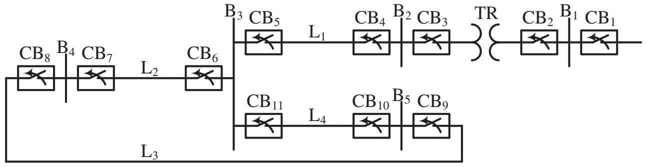

Fig. 1. Simple power system.

$$\mathbf{Min} J_{obj}(\boldsymbol{S},\boldsymbol{U}) = \exp\Bigg\{\sum_{b=1} F^{bus}_{m,b}(\boldsymbol{S},\boldsymbol{U}) + \sum_{t=1}\Big[F^{TR}_{m,t}(\boldsymbol{S},\boldsymbol{U}) + F^{TR}_{p,t}(\boldsymbol{S},\boldsymbol{U}) + F^{TR}_{s,t}(\boldsymbol{S},\boldsymbol{U})\Big] + \sum_{l=1}\Big[F^{line}_{send,m,l}(\boldsymbol{S},\boldsymbol{U}) + F^{line}_{rec,m,l}(\boldsymbol{S},\boldsymbol{U}) + F^{line}_{send,p,l}(\boldsymbol{S},\boldsymbol{U}) + F^{line}_{rec,p,l}(\boldsymbol{S},\boldsymbol{U}) + F^{line}_{send,s,l}(\boldsymbol{S},\boldsymbol{U}) + F^{line}_{rec,s,l}(\boldsymbol{S},\boldsymbol{U})\Big]\Bigg\} \tag{1}$$

where $J_{obj}(\cdot)$ is the objective function, and $\boldsymbol{S}$ is a set of the control vectors that decide the probability of a fault occurring at each section. In the expression, $\boldsymbol{S}$ is composed of the set of the probabilities B_b, TR_t and L_l of a fault occurring at busbar, transformer and line sections, respectively. In other words, by expressing $\boldsymbol{S} = [B_b\ TR_t\ L_l]$, its suffix b, t and l would individually stand for the serial number of busbar, transformer and line sections. The set of $\boldsymbol{U}$ stands for the protective status of busbar, transformer and line section, namely, $\boldsymbol{U} = [R^{bus}_m R^{TR}_m R^{line}_{send,m} R^{line}_{rec,m} R^{TR}_p R^{line}_{send,p} R^{line}_{rec,p} R^{TR}_s R^{line}_{send,s} R^{line}_{rec,s} CB]$, where the suffix m, p and s represent the main, the primary, and the remote backup relays. The suffix *send* and *rec* denotes sending and receiving ends of line section. Note that the value of 0 for non-operation and 1 for in-operation is used in this study. In(1), $F^{bus}_{m,b}(\cdot), F^{TR}_{m,t}(\cdot), F^{line}_{send,m,l}(\cdot)$ and $F^{line}_{rec,m,l}(\cdot)$ are functions of main protective relay for busbar, transformer, and the sending and receiving ends of line. They can be formulated by

$$F^{bus}_{m,b} = (1 - 2R^{bus}_{m,b})B_b \tag{2}$$

$$F^{TR}_{m,t} = \Big(1 - 2R^{TR}_{m,t}\Big)TR_t\Big(1 - R^{TR}_{p,t}\Big) \tag{3}$$

$$F^{line}_{send,m,l} = \Big(1 - 2R^{line}_{send,m,l}\Big)L_l\Big(1 - R^{line}_{send,p,l}\Big) \tag{4}$$

$$F^{line}_{rec,m,l} = \Big(1 - 2R^{line}_{rec,m,l}\Big)L_l\Big(1 - R^{line}_{rec,p,l}\Big) \tag{5}$$

While the modeling of primary backup relay $F^{TR}_{p,t}(\cdot)$, $F^{line}_{send,p,l}(\cdot)$ and $F^{line}_{rec,p,l}(\cdot)$ are expressed as

$$F^{TR}_{p,t} = \Big(1 - 2R^{TR}_{p,t}\Big)TR_t\Big(1 - R^{TR}_{m,t}\Big) \tag{6}$$

$$F^{line}_{send,p,l} = \Big(1 - 2R^{line}_{send,p,l}\Big)L_l\Big(1 - R^{line}_{send,m,l}\Big) \tag{7}$$

$$F^{line}_{rec,p,l} = \Big(1 - 2R^{line}_{rec,p,l}\Big)L_l\Big(1 - R^{line}_{rec,m,l}\Big) \tag{8}$$

the modeling of remote backup relay $F^{TR}_{s,t}(\cdot)$, $F^{line}_{send,s,l}(\cdot)$ and $F^{line}_{rec,s,l}(\cdot)$ are accordingly derived

$$F^{TR}_{s,t} = \Big(1 - 2R^{TR}_{s,t}\Big) \times \Big\{1 - \prod_{h=1}[1 - Z_{t,h}(1 - R_{m,h})(1 - R_{p,h})CB_h]\Big\} \tag{9}$$

$$F^{line}_{send,s,l} = \Big[\Big(1 - 2R^{line}_{send,s,l}\Big) \times \Big\{1 - \prod_{c=1}[1 - Z_{l,c}(1 - R_{m,c})(1 - R_{p,c})(1 - CB_c)CB_{send,l}]\Big\}\Big] \tag{10}$$