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Optimal allocation of FACTS devices for static security enhancement in power systems via imperialistic competitive algorithm (ICA)

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ABSTRACT

The problem of optimal allocation of flexible AC transmission systems (FACTS) devices is deemed as a formidable optimisation problem. Metaheuristics are the common approaches for solving FACTS allocation problems. Imperialistic competitive algorithm (ICA) is a well-established optimisation algorithm which has been successfully employed for solving complex optimisation problems in different fields. It is inspired by imperialistic competition and socio-political evolution of human beings and offers appropriate exploration and exploitation capabilities during the search for global optima. This paper employs ICA for solving FACTS allocation problem in a way that low values of overloads and voltage deviations are resulted both during line outage contingencies and demand growth. Thyristor-controlled phase shifting transformers (TCPST's) and thyristor-controlled series compensators (TCSC's) have been used as FACTS devices. The results of employing ICA for FACTS allocation problem indicate that ICA Offers better results than artificial bee colony (ABC), gravitational search algorithm (GSA), evolutionary programming (EP), bat swarm optimisation (BSO), nonlinear programming (NLP), pattern search (PS), asexual reproduction optimisation (ARO) and backtracking search algorithm (BSA).

1. Introduction

In electric power systems, the demand is continually increasing which may lead to voltage depressions in buses and excessive power flows in branches. Moreover, power systems may face challenges due to the outage of their components [1]. Using FACTS devices is a very popular and common approach for addressing the mentioned issues [2–7]. Through controlling power systems' parameters, FACTS devices can improve different characteristics of power systems [8–10]. Thyristor-controlled phase shifting transformer (TCPST) is a commonly used series FACTS device.

In a power system, the power flow of a branch can be controlled by controlling the voltage angle difference of its connecting buses. Through controlling the voltage phase angle, TCPST controls the power flow of the branch where it is located. It adds a quadrature component to the existing voltage in order to increase/decrease its phase angle [11].

TCPST is an effective device for power flow control in transmission systems [12]. However, in order to get maximal benefit from TCPST units, their optimal phase angles should be determined. This represents an optimisation problem with highly multimodal landscape. For solving this problem, different optimisation schemes have already been utilised which can be classified into 3 groups; classical approaches, technical approaches and metaheuristic approaches [13]. As an example of the applications of classic optimisation schemes, in [14], mixed integer linear programming (MILP) has been assisted to determine optimal number, location and setting of TCPST's in a way that power system loadability is maximised. Generally, classic optimisation algorithms are not flexible and in particular, handling constraints in those approaches is difficult. In technical approaches, a sensitivity index is introduced based on a technical criterion. Then, different locations of power system are ranked and the best locations are determined for placement of FACTS devices. As an example of the application of technical-based schemes, in [15], a technical approach is utilised for optimal allocation of phase shifter units in order to minimise copper losses. The change in power loss with respect to the location of phase shifter is defined as a sensitivity index. This sensitivity index is computed for all possible locations of phase shifters and the phase shifter is installed in branch with the highest sensitivity index. The proposed technical-based optimisation scheme has been simulated on a simple 5 bus power system. A salient drawback of technical approaches is that the degree of optimality of found solutions is not known.

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Metaheuristics are very flexible and efficient approaches [16]. They can easily handle discrete and constraint optimisation problems. They are the most common and efficient approaches for solving TCPST allocation problems [13,17–19]. In [20], GA is used for optimal allocation of phase shifters for minimisation of voltage deviations and minimisation of excessive power in branches in IEEE 118 bus system. In [21], first, a sensitivity analysis is conducted wherein the changes of power flow of different branches with respect to their phase angle are computed as a performance index. Based on such a performance index, some branches of the power system are nominated as candidates of TCPST installation, then GA is used to find optimal location of TCPST. Optimal setting of TCPST is found by OPF. The objectives are minimisation of installation costs of TCPST's and minimisation of excessive power flows in branches.

In [22], DE has been used for optimal allocation of TCPST's in order to minimise generation cost. The simulations on modified IEEE 30 bus system show the outperformance of DE over EP and PSO. In [11], an improved DE variant, named composite DE has been proposed for allocation of TCPST units. The objective is to maximise loadability. The simulation results confirm that in all terms of achieved loadability, computational time and convergence characteristics, composite DE outperform conventional DE and PSO.

In [23], gravitational search algorithm (GSA) is utilised to find optimal location and setting of TCPST's in order to minimise power losses. The simulations on Java-Bali 500 KV system of Indonesia shows that using four TCPST's, power loss is decreased from 297.607 MW to 234.88 MW. Main features of existing research works in FACTS allocation have been tabulated in Table 1. Although metaheuristic optimisation techniques are considered superior to classic and technical approaches, they may converge into local optima instead of global one. This issue is referred to as premature convergence. Based on review of the existing works, in most of the research works, the performance of the proposed optimisation approach has not been validated by comparison with a diverse set of state of the art optimisation techniques.

The drawback of existing optimisation schemes applied to TCPST allocation problem is that they cannot offer an appropriate tradeoff between their explorative and exploitative abilities, so they tend to converge into local optima instead of the global optimum. The imperialist competitive algorithm (ICA) is a metaheuristic optimization algorithm. It was developed by Atashpaz-Gargari and C. Lucas based on a socio-politically motivated strategy [34]. The ICA is a population-based algorithm wherein each individual is a country. Each country can be either a colony or an imperialist [34]. It takes inspiration from imperialistic competition and socio-political evolution of human beings. Due to its appropriate explorative and exploitative capabilities, ICA has been successfully employed for solving various complex optimisation problems in power systems [35–38]. However, to the best knowledge of the author, ICA has not yet been utilised for allocating FACTS devices. The contribution of this paper is to utilise high potential of ICA for solving TCPST allocation problem. Actually, the strong exploitation and exploration capabilities of ICA is utilised for solving TCPST allocation problem. It should be noted that the main objective of this paper is optimal allocation of TCPST's via ICA, however, after applying ICA for TCPST allocation, in order to corroborate the strength of ICA, it will be also applied for allocation of another prevalent FACTS device (TCSC). It should also be noted here that in this work, the performance of ICA is compared with gravitational search algorithm (GSA) [39], artificial bee colony (ABC) [40], adaptive evolutionary programming (EP) [41], bat swarm optimisation (BSO) [42], asexual reproduction optimisation (ARO) [43], nonlinear programming (NLP), pattern search (PS) and backtracking search algorithm (BSA) [44].

The remainder of the paper is structured as follows; in Section 2, the overview of ICA is given. In Section 3, FACTS allocation problem is formulated. In Section 4, the procedure of applying ICA to FACTS allocation problem is explained in details. The results and analysis will be presented in Section 5. Finally, the conclusions are drawn in Section 6.

2. ICA overview

The imperialist competitive algorithm (ICA) is a fairly novel metaheuristic optimization algorithm. It was developed by Atashpaz-Gargari and C. Lucas based on a socio-politically motivated strategy [34]. The ICA is a population-based algorithm wherein each individual is a country. Each country can be either a colony or an imperialist [34]. The stages of ICA are described below.

2.1. Initilisation

ICA is launched by an initial population of countries. Some of the best countries are as imperialists and the rest countries form the colonies of imperialists. All the colonies are divided among the imperialists based on the total power of the imperialists. Total power of an imperialist is computed via adding its fitness and a percentage of the mean value of its colonies' fitness [34].

To divide the colonies among imperialists, the normalized cost of an imperialist is defined as Eq. (1).

$$C(i) = c(i) - max(c(j)) \tag{1}$$

where $c(i)$ represents the cost of ith imperialist and $C(i)$ represent the normalized cost of ith imperialist [34].

Then, based on normalized costs of all imperialists, normalized power of each imperialist is computed by Eq. (2).

$$P(i) = \left| \frac{C(i)}{\sum_{j=1}^{j=N_{imp}} C(j)} \right| \tag{2}$$

where N_{imp} represents the number of imperialists.

Then, the number of colonies for ith imperialist is computed by Eq. (3).

$$N_{col}(i) = round(P(i).N_c) \tag{3}$$

where N_c represents the number of all countries and "round" is the function that rounds its arguments to the nearest integer [34].

After dividing all colonies among imperialists, each colony is attracted toward its relevant imperialist.

2.2. Moving colonies toward their corresponding imperalists (assimilation)

This movement is inspired from assimilation policy in politics wherein colonies are attracted toward their corresponding imperialist and make themselves similar to their imperialist [34]. In ICA, assimilation is done in two stages. In first stage, the colony moves toward the imperialist by Y units. The direction of the movement is the vector from colony to its corresponding imperialist. In this movement, Y is a random variable as following equation [34]:

$$Y \sim U\left(0, \beta.d\right) \tag{4}$$

where β is a control parameter called assimilation coefficient and d represents the distance between the colony and imperialist.

In the second stage of assimilation process, in order to add to the explorative capability of ICA, a random amount of deviation (θ) is added to the direction of movement. The deviation θ is computed by following equation.

$$\theta \sim U(-\gamma, \gamma) \tag{5}$$