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Brainstorm optimisation algorithm (BSOA): An efficient algorithm for finding optimal location and setting of FACTS devices in electric power systems

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ABSTRACT

In electric power systems, finding optimal location and setting of flexible AC transmission system (FACTS) devices represents a difficult optimisation problem. This is due to its discrete, multi-objective, multi-modal and constrained nature. Finding near-global solutions in such a problem is very demanding. Brainstorm optimisation algorithm (BSOA) is a novel promising heuristic optimisation algorithm inspired by brainstorming process in human beings. In this paper, BSOA is employed to find optimal location and setting of FACTS devices. Static var compensators (SVC's) and thyristor controlled series compensators (TCSC's) are used as FACTS devices. FACTS allocation problem is formulated as a multi-objective problem whose objectives are voltage profile enhancement, overload minimisation and loss minimisation. The results of applying BSOA to FACTS allocation problem in IEEE 57 bus system demonstrate its high efficacy in solving this problem both with TCSC and SVC units. BSOA leads to better voltage profile and lower losses than particle swarm optimisation (PSO), genetic algorithm (GA), differential evolution (DE), simulated annealing (SA), hybrid of genetic algorithm and pattern search (GA–PS), backtracking search algorithm (BSA), gravitational search algorithm (GSA) and asexual reproduction optimisation (ARO). The findings of this research can be used by power system decision makers in order to establish a better voltage profile and lower voltage deviations during contingencies.

Introduction

In power systems, factors like continual load growth, outage of components and deregulation policies may lead to issues such as power congestion, static and dynamic instabilities [1–4]. For tackling such consequences, using flexible AC transmission system (FACTS) devices is the most commonplace strategy [5]. However, such expensive devices should be placed in optimal location with optimal setting, so that the most potential benefit can be extracted.

From optimisation perspective, optimal allocation of FACTS devices is a very complex optimisation problem, because it is highly multi-modal, multi-objective and constrained [6–10]. The approaches for solving FACTS allocation problems can be classified into 3 categories; classical approaches, technical approaches and heuristic approaches [11–17]. Heuristic approaches are the most common and efficient approaches for solving FACTS allocation problems [6,11,18,19]. In [20], real coded genetic algorithm (GA) is applied to maximise available transfer capability (ATC) of power systems with static var compensator (SVC) and thyristor controlled series compensator (TCSC). In [21], bacterial foraging optimisation algorithm (BFOA) is applied to maximize power system damping with TCSC. The results show that BFOA outperforms GA. In [22], teaching learning based optimisation algorithm (TLBO) has been utilised to minimise voltage deviations, overloads and losses of power system with TCSC units.

In [23], artificial bee colony (ABC) as a heuristic algorithm with strong exploration capability is hybridised with sequential quadratic programming (SQP) as an algorithm with strong exploitation capability. This is to benefit from the advantages of both algorithms. The hybrid ABC–SQP is applied to maximize damping of power system with SVC devices. The results showed the superiority of the hybrid ABC–SQP over ABC and GA. In [24], a harmony search algorithm is applied to find optimal location and setting of SVC's and static synchronous compensator (STATCOM) units. The objective is to maximize voltage stability and minimise power losses.

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In [25], differential evolution (DE) is used to find optimal location and setting of unified power flow controller (UPFC) devices in order to maximize power system security during single contingencies. In [26], gravitational search algorithm (GSA) is used to find optimal setting of UPFC devices in order to minimise fuel cost of generating units. In [27], evolution strategy (ES) is applied to find optimal setting of SVC, static synchronous series compensator (SSSC), STATCOM and UPFC devices in order to minimise power losses. In [28], simulated annealing and Tabu Search are applied to find optimal setting of SVC in order to maximize power transfer capability in power system.

In [29], optimal location and setting of SVC and TCSC devices are determined via particle swarm optimisation (PSO). The objective is to maximize small signal stability. In [30], PSO is utilised to find optimal location and setting of SVC, TCSC and UPFC devices. The objective is to maximise power system loadability and minimise installation cost of FACTS devices. In [9], a new particle swarm optimisation variant, named as "Enhanced leader PSO (ELPSO)" has been introduced for mitigating the consequences of line outage contingencies via TCSC units. ELPSO is mainly based on a five successive mutation strategy that significantly decreases the probability of being trapped in local optima. The results indicated that ELPSO leads to lower objective values than some other heuristic optimisation algorithms [9]. The features of some of approaches applied to FACTS allocation problems have been tabulated in Table 1.

BSOA is a novel heuristic optimisation algorithm that takes inspiration from brainstorming process of human beings [31]. To date, BSOA has been applied to few optimisation problems and its capability in solving complex optimisation problems has not been investigated enough [32–34]. In this paper, BSOA is utilised to find optimal location and setting of TCSC's and SVC's during line outage contingencies.

The remainder of the paper is organised as follows; in Section 'Overview of BSOA', an overview of BSOA is provided. In Section 'Problem formulation and model of FACTS devices', FACTS allocation problem is formulated and models of SVC and TCSC are presented. In Section 'Procedure of BSOA application', the detailed procedure of applying BSOA for finding optimal location and setting of FACTS devices is presented. The results and analysis of results will be presented in Section 'Results and analysis'. Finally, the conclusions are drawn in Section 'Conclusions'.

Overview of BSOA

Human being is the most intelligent creature in the world. Intuitively, the optimisation algorithm inspired of human being creative problem solving process should be superior to the optimisation algorithms inspired from collective behavior of animals, birds, ants, bees, etc. [31]. Brainstorming optimisation algorithm (BSOA), inspired by brainstorming process in human beings, was developed by Shi in 2011 [31]. The notion of brainstorming was first developed by Osborn in 1939. Brainstorming process is defined as a group or individual creativity technique by which efforts are made to find a conclusion for a specific problem by gathering together a group of people, especially with different backgrounds [33,35]. The steps of brainstorming process in human being are as follows [31].

1. Some people with as diverse background as possible are gathered.
2. The people create new ideas according to 4 rules called Osborn's rules.
3. Three or five clients act as the problem owner and one idea per owner is selected as good solution for the problem.
4. The ideas selected in step 3 are used as clues for generating more ideas.
5. Some ideas are randomly selected to be used as clues for generating more ideas.
6. Better ideas are selected.
7. Steps 2–6 are repeated till a good enough solution for the problem is found.

Four general rules of brainstorming named as Osborn's rules that make it so efficient are as follows [33,35]:

- *Focus on quantity*: This rule is based on the fact that the greater the number of ideas generated, the higher the chance of generating a good solution. This rule aims to facilitate problem solving through quantity breeding quality [33,35].
- *Avoid criticism*: Rather than criticising ideas generated, participants of brainstorming should focus on adding to ideas and reserving criticism for a later stage, by which participants will be unrestricted to generate unusual and creative ideas, with a higher probability [33,35].
- *Welcome unusual ideas*: By viewing problems from different perspectives and suspending assumptions, participants can generate unusual ideas. These solutions are welcomed to get a good and long enough list of ideas [33,35].
- *Cross-fertilize*: By simulating the building ideas with a process of association, this rule believes that better ideas are obtained by combing through good ideas [33,35].

Brainstorm optimisation algorithm (BSOA)

Based on brainstorming process in human being, Shi proposed BSOA for solving optimisation problems. In BSOA, individuals are analogous to ideas in brainstorming, clusters are analogous to brainstorming groups and cluster centers are analogous to best

Table 1
Features of some approaches used for solving FACTS allocation problem.

Ref.	FACTS device	Approach	Objective
[20]	SVC and TCSC	Real coded GA	Maximisation of available transfer capability
[22]	TCSC	TLBO	Minimisation of overloads, voltage deviations and losses
[21]	TCSC	BFOA	Maximisation of damping
[23]	SVC	Hybrid ABC–SQP	Maximisation of damping
[24]	SVC and STATCOM	HS	Voltage stability enhancement and loss minimisation
[25]	UPFC	DE	Minimisation of voltage deviation and line overloads during contingencies
[26]	UPFC	GSA	Fuel cost minimisation
[27]	SVC, SSSC, STATCOM and UPFC	ES	Power loss minimisation
[28]	SVC	SA	Maximisation of power transfer capability
[28]	SVC	TS	Maximisation of power transfer capability
[29]	SVC and TCSC	PSO	Maximisation of small signal stability
[30]	SVC, TCSC and UPFC	PSO	Loadability maximisation, minimisation of installation costs
[9]	TCSC	ELPSO	Minimisation of overloads, voltage deviations and power losses