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Enhancement of ATC by Optimizing TCSC Configuration using Adaptive Moth Flame Optimization Algorithm

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Abstract: Generally, the Flexible AC Transmission System (FACTS) devices are recognized as capable solutions to gather the increased demand and to balance with the restructured transmission systems. Nevertheless, to attain the objective at a sensible cost, the optimal sizing and positioning of the FACTS devices can lead the system. In this paper, an Adaptive Moth Flame Optimization algorithm (A-MFOA) is developed to decide the optimal location and compensation level for the FACTS device. Moreover, this article subjects to the Particle Swarm Optimization (PSO) and, Bacterial Swarm Optimization (BSO) and Evolutionary Algorithm (EA) to precise simulation analysis to make sure fair comparison among the methods on FACTS sizing and localization. Additionally, this article is simulated on MATLAB 2018a. Finally, three benchmark bus systems, like IEEE 24 RTS, IEEE 30 and IEEE 57 bus systems are exploited to recognize the performance of the methods and sufficient statistical analysis is performed on the experimental outcomes.

Keywords: ATC; FACTS; Sizing; Localization; TCSC

Nomenclature

Abbreviations	Descriptions
ATC	Available Transfer Capability
ISO	Independent System Operators
ETC	Existing Transmission Commitments
PSO	Particle Swarm Optimization
OASIS	Open Access Same Time Information System
SVC	Static Var compensator
PF	Power Flow
TTC	Total Transfer Capability
FACTS	Flexible AC Transmission System
ULTCs	Under Load Tap Changers
GWO	Grey Wolf Optimization
DE	Differential Evolution
CBM	Capacity Benefit Margin
WOA	Whale Optimization Algorithm
QOGWO	Quasi-Opposition based GWO
CPF	Continuation Power Flow
UPFC	Unified Power Flow Controller
CSA	Cuckoo Search Algorithm
TRM	Transmission Reliability Margin
SMIB	Single Machine Infinite Bus
PTDF	Power Transfer Distribution Factors
TCSC	Thyristor-Controlled Series Compensation
SAPSO	Self-Adapted PSO
IHSA	Improved Harmony Search Algorithm
OPF	Optimal Power Flow
BSO	Bacterial Swarm Optimization
QODE	Quasi-Opposition based Differential Evolution

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1. Introduction

Currently, the power system comes across numerous novel confronts in accordance with the energy conversion of a few countries from regulating power system structure into deregulating structure in an economical and reliable power supply perception [1]. It is idea that the heightened number of possible producers frequents is considered by the consumers as a main important role for the achievement of a competitive market. On the other hand, with this better conversion, in an open market in the power system, the transmission lines have undergone definite limitations to set up the development of transmission grids which will be undergoing essential factors like a right of way, environment concerns, and cost utilizing time and so forth [19]. As electricity serves as a vital commodity, the markets were adopted to increase a form of enhancement termed ATC that is computed by means of the ISO and posted on OASIS [2]. It must control the PF parameters via FACTS to improve ATC.

Using different methods and tools ATC enhancement, and assessment, is examined [1]. The problem of ATC enhancement and assessment in addition to it is revolving to be an area of attention to the research organization because of the alteration in the techniques of Power Transmission, Distribution, and Generation. Usually, Power Transmission, Generation, and Distribution were vertically incorporated however at present they are horizontally incorporated and stipulation of open access for generation distribution and transmission is developed into the grid. Open access entails that any suitable costumer can withdraw/inject power from the grid. The problem of ATC enhancement and assessment these supplies although difficult; the mains confronts were thus far to become across regarding augmenting in renewable sources of generation both in distribution and transmission levels. Additionally, the issues in electric vehicles as virtual power plants that might act as both source and sink turned on the grid and market operating circumstances would as well affect the ATC [1].

For electric power trading, the objective of electric industry restructuring is to endorse competitive markets. The ATC of a transmission network is the unutilized transfer capabilities of a transmission network for the power transfer for additional commercial activity, over and above previously committed practice. Sufficient ATC is required to make sure all economic transactions, and to make easy electricity market liquidity [3]. Utmost employ of conventional transmission possessions will be high gainful for transmission system customers and owners will obtain superior services with minimized price. Several ATC boosting algorithms were recommended altering terminal voltages via rescheduling generation and ULTCs [20].

For ATC enhancement, productions are considered as main control measures. FACTS devices were developed that have their individual effect on the load flow, hence affecting the power system operational case [6]. The practice of Unified UPFC was performed in the AEP system whereas it has demonstrated noteworthy enhancements [5]. Generally, FACTS devices were effectively exploited to enhance the stability and loadability of the maximum voltage transmission network. In the line, the standard has been to recompense inductive voltage drop using an inserted capacitive voltage or that is to say, to minimize the effectual reactance of transmission line to enhance the ATC network. ATC is based upon other parameters like CBM, ETC, TTC, and TRM [3].

The main aim of this article is to contribute the precise simulation analysis to assure fair comparison among the proposed A-MFOA and conventional PSO, BA, and EA methods on FACTS sizing and localization. Here, three different benchmark bus systems are exploited to perceive the performance of the methods and adequate evaluation is done on the noticed outcomes. Here, the main objective function is to concentrates on the enhancement of ATC in order to optimize the TCSC configuration. Moreover, this work tries to present the proposed method to accurate experimental evaluation on three benchmark bus systems.

2. Literature Review

In 2020, Vladan Durkovic and Aleksandar S. Savic [1], worked on formative of the optimal positioning and the TCSC device parameter was considered to increase ATC in the event of one out of two introduced concurrent transactions were abandoned. The issue stated in the mode of two principle models, which was resolved because of an evolutionary NSGA-II method, in contrast, the predictive value of ATC for considered transactions was computed based on the DC power flows. At a planning level as the issue was resolved, the uncertainty with respect to the transmission lines, generators, and active power load variations was evaluated by exploiting the Monte Carlo experimentation. The final chosen from the set of best solutions was attained with regard to reactive power loads by means of Grey Relation Analysis in the power system.

In 2016, K. Bavithra et al [2], worked on the integration of FACTS, a semiconductor-based control device to improve the ATC of the transmission system. Several FACTS devices such as SSSC, STATCOM, and UPFC were designed using power flow equations and optimally set the FACTS parameters exploiting the PSO model in that manner in order to improve ATC in the deregulated electricity surroundings. This substitutes the impudent task of vertical novel transmission system or increasing the conventional one. The non-iterative, easy and rapid PTDF based sensitivity algorithm was developed in order to decide and improve ATC on sample 6 bus systems to show the viability of the ATC enhancement for multilateral and bilateral transactions.

In 2018, Naresh Kumar Yadav and Anju Bala [3], worked on ATC which was considered as the challenging criterion in the implementation of the deregulated power system. For enhancing ATC the maximum demand was usually convened by exploiting FACTS devices in the power system. Nevertheless, it undergoes a solemn crisis while determining the optimal positioning and compensation phase of FACTS. The current study exploits TCSC devices to recompense for the restriction of FACTS. In this paper, for ATC enhancement, a new SAPSO method was developed.

In 2019, Zora Luburic and Hrvoje Pandzic [4], developed FACTS devices and energy storage present advantages of the power system. For instance, enhanced system stability, minimized transmission losses, voltage regulation and minimized congestion were presented. Hence, FACTS devices were lesser value for the installed energy storage and vice versa. To evaluate their effect on each other, it prepares a unit commitment method which involves FACTS devices and generic energy storage and to examine features of their joint operation evaluate. The outcomes of four unit commitment methods were developed such as with energy storage only; with no storage or FACTS devices with FACTS devices only; with both energy storage and FACTS devices.

In 2018, Bibhu Prasad Ganthia et al [5], worked on the major contact of the power segment engineers was to increase the capability and durability of the present power section. Moreover, the pretty system dependable and presentation procedure was exploited and this directs to the development of FACTS technology. FACTS controllers increase power suggests constancy and capability. This paper indicates the representing and experimentation of the SMIB system with the TCSC controller. TCSC controller was worked out to enhance transient constancy of the SMIB system. Moreover, this paper suggests a TCSC controller which was projected.

In 2016, G. Naresh et al [6], developed Improved IHSA for the corresponding model of numerous TCSC and PSS to efficiently damp the oscillations. The outcomes attained by exploiting IHSA on WSCC 3-machine, 9- bus systems were established to be better when compared with the outcomes attained by exploiting the BSO method. Additionally, the damping performance of existing TCSC and PSS controllers was compared with the coordinated design of IHSA on the basis of the TCSC and PSS on the 39-bus system, New England 10-machine, over an extensive range of operating circumstances and contingency.

In 2017, Saurav Raj and Biplab Bhattacharyya [7], worked on WOA, DE, GWO, QOGWO and QODE method was exploited for the resolution of reactive power planning with FACTS devices i.e., TCSC and SVC. Generally, WOA was a lately presented nature-inspired meta-heuristic method on the basis of the hunting behaviour of Humpback Whales; DE was a stochastic real-parameter optimization model encompassing of genetic parameters such as cross-over and mutation. Additionally, GWO was a nature-inspired metaheuristic method on the basis of the hunting behaviour of the Grey wolf.

In 2019, Akanksha Sharma and Sanjay K. Jain [8], worked on the congestion, which was a fundamental problem in the deregulated energy market for the independent system operator. Since it involves extra cost and facades a threat to power system security. It introduces OPF and ATC based algorithms to alleviate congestion, in order to allocate TCSC by exploiting the congestion rent contribution method on the basis of the location marginal price. In the bilateral transaction environment, the dc power transfer distribution factors were exploited to calculate ATC. In a pool electricity market, the gravitational search aided method was used to control congestion.

3. Enhancement of ATC model

3.1 Fundamentals of ATC

The power transmission system of the customers and generators, who subsist in a deregulated electrical market, is usual. Therefore, power transfer among the consumer side and generator side exploits merely one power transmission system. In a deregulated electric market, there can be any number of producers, who are unavailable in tough conflicts. Hence, overloading and congestion would definitely occur. Because of congestion and overloading the contravention in voltage limits, line flow, and stability limits would subsequently appear, which leads to a system with a maximized level of unreliability and insecurity. ATC determination would possess a great impact on systems of that sort due to the determination of ATC aids such systems in controlling their reliability and security to a higher range. Determination of ATC is an important area that the countries all around the world motivate the knowledge in terms of the ATC to be retained updated in systems such as OASIS [9]. Generally, ATC can be stated as a measure of the ATC. ATC is a measure of the transfer capability remaining in the physical transmission network for further commercial activity over and above already committed uses. Eq. (1) denotes the mathematical formulation of ATC. The link that subsists between TTC, ETC, CBM, TRM, and ATC [13] are shown in Fig. 1.

$$ATC = TTC - TRM - (ETC + CBM) \tag{1}$$

The explanations of each parameter are explained as below:

1) TTC: It indicates the quantity of electric power that can be reliably transmitted via the connected transmission network so that the complete set of stated post-contingency and pre-contingency system states are fulfilled.

2) TRM: It states the quantity of transmission transfer capability which is required to discover the security of the connected transmission network, while presented a rational set of uncertainties which superior in the states of the systems.

3) CBM: It is the quantity of transmission transfer capability that the load-serving components reserve to assure access to generation from connected systems so that the generation reliability needs get fulfilled.

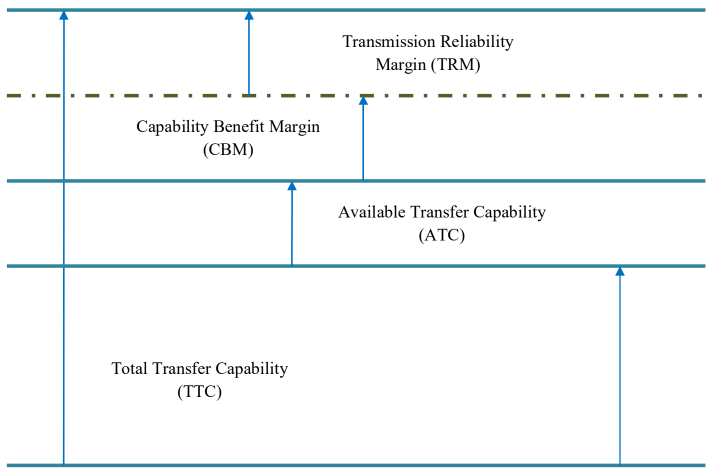

Fig. 1. *Diagrammatic representation of ATC estimation*

3.2 Determination of ATC

In the past, numerous research works were performed in linked with the ATC determination of [10] had suggested a novel algorithm that gets the shape of the security boundary on account of performing the calculation of ATC. In [11], ATC with the aid of SVM had evaluated. Although there are various advanced methods to perform estimation of ATC, the basic literary algorithms are categorized into two categories such as distribution factors on the basis of the estimation of ATC [12] and CPF based ATC estimation [13]. In the past years, the applications that were used as either AC or DC power flows. Hence, those algorithms were not much complex and the capability to do calculations was also not unsuccessful [12]. Nevertheless, the disadvantage of aforesaid algorithms is the non-success to generate the best outcomes. Hence, the CPF algorithms had received much attention. In CPF algorithms, the utmost probable value of a scalar function could be attained with the injection of linear variation at a class of buses [14]. It implicates the CPF is able to increase the controlling parameter value in a linear manner, hence that the problems in power flow could be corrected in each iteration. The procedure will be done without an interception until the voltage instability is obvious.

3.3 Objective Model

Consider a common bus system for that the enhancement of ATC must be done with a minimum number of external resources (implicit the FACTS devices being presented). This work pays more interest to TCSC and therefore, the issue can be formulated as the increase of ATC according to the provided TCSCs. The resources are restricted due to the number of TCSCs to be exploited is depends on what we present. Therefore, eq. (2) denotes the problem model.

$$\left[I_t^*, Y_t^*\right] = \underset{[I_t, Y_t]}{\arg\max}\, ATC; 0 \le t \le N_T - 1 \tag{2}$$

In eq. (2), Y_t indicates the compensation level and I_t indicates the set of line indices of t^{th} TCSC in the bus system. Moreover, $\left[I_t^*, Y_t^*\right]$ denote the optimal connections in the set. Nevertheless, the final objective is to attain the enhancement of ATC. Therefore, the formal explanation and the equivalent representation can be explained again in the forthcoming sections.

The fitness calculation C_p is considered in this paper, which involves an iterative process that creates a module of the estimation of the ATC procedure. It discloses the system data that is nothing however the line data and the bus data of the system in the investigation. The compensation level which correlated with a particular line index that is indicated as C_p is provided to the line data. Initially, the lambda value λ is fixed at the minimum probable value. Let us assume the value of lambda at the starting phase as ($\lambda = \lambda_i$), whereas $\lambda_i = 0.1$. Once the compensation reactance is integrated as well as the bus voltages are recorded, the continuous power flow evaluation is subsequently performed. If any sort of voltage limit violations is discovered, the procedure gets halted. Subsequent to the procedure, the ATC is calculated, which has halted is presumed to be the fitness of the equivalent solution. Although, the procedure is repeated with the lambda value being maximized at each of the iterations until no violations in voltage limits happen. The entire mathematical formulation for the estimation of the ATC process is being stated in [15].

4. Proposed methodology For ATC enhancement

4.1 Motivation of AMFO Algorithm

As similar to the family of butterflies, moths are small insects. During the night the sheer promoting reality regarding moths is their well-defined steering algorithms. Over a straight line, they uphold a fixed angle regarding the moon to travel extensive areas. Because of the additional considerable distance between the moon and the moth, such a model assures flying in a straight line. Artificial lights ploy moths, and therefore, moths fly spirally approximately the human-made lights. In a straight line, a moth tries to keep as same as incline for artificial light to fly. Since artificial lights are extremely near to the moth, possession same angle triggers a menacing spiral route for moths. Finally, the moth eventually converges on the artificial light.

4.2 Conventional MFO Approach

MFO method states the spiral movement of moth toward the flame (light). In the current method, moths and location of moths correspond to the problem's variables and candidate solutions, correspondingly. In the eq. (3), the set of moths O is indicated.

$$O = \begin{bmatrix} o_{11} & \cdots & o_{1d} \\ \vdots & \ddots & \vdots \\ o_{n1} & \cdots & o_{nd} \end{bmatrix} \tag{3}$$

In eq. (3) d indicates the number of variables and n indicates the number of moths correspondingly. Eq. (4) denotes the array available in sorted fitness values.

$$AM = \begin{bmatrix} AM_1 \\ AM_2 \\ \vdots \\ AM_n \end{bmatrix} \tag{4}$$

Through the fitness function, all moths are passed, and their return value is considered as the fitness value of the objective model. AM indicates the array, which is similar to the fitness model result. Flames indicate a basic matrix of MFO. Eq. (4) denotes the flames matrix.

$$Fl = \begin{bmatrix} f_{11} & \cdots & f_{1d} \\ \vdots & \ddots & \vdots \\ f_{n1} & \cdots & f_{nd} \end{bmatrix} \tag{5}$$

The dimension of the moth's matrix and flames matrix is equivalent. As stated in eq. (6), on the basis of the fitness value, the flames are sorted.

$$AF = \begin{bmatrix} AF_1 \\ AF_2 \\ \vdots \\ AF_n \end{bmatrix} \tag{6}$$

In the recommended algorithm, another condemnatory module is flames that develop the optimal location of moths. Therefore, each moth searches regarding the flame as well as amends itself in the matter of attaining a better solution. Such a model guarantees it never misplaces its optimal location. Using eq. (7), the location of every moth regarding flame is updated.

$$A_m = SF(A_m, Fl_n) \tag{7}$$

In eq. (7), SF indicates the spiral function, A_m indicates the m^{th} moth and Fl_n indicates the n^{th} flame. Eq. (8) denotes the spiral model.

$$SF(A_m, Fl_n) = Ds_m e^{at} \cos(2\pi t) + Fl_m \tag{8}$$

Where, Ds_m demonstrates the distance among m^{th} moth and n^{th} flame, a represents a constant recognizing the shape of a spiral, and t is an random number among [−1, 1].

$$Ds_m = |Fl_n - A_m| \tag{9}$$

Eq. (8) indicates the spiral search path for the flying moths when updating their location regarding flames. Parameter t shows the nearness of moth with flame. While $t = -1$, the moth is in the neighbourhood of the flame, while $t = 1$, the moth is farthest from the flame. To improve the search around the superior solutions, flames are contemplated as optimal solutions. According to eq. (7) and (8), moths update their locations regarding flames.

In eq. (8) the location updating entails the moths to goes toward a flame, however, it reason the MFO method to be trapped in local optima quickly. To shun this, each moth amends its location using merely one of the flames in eq. (8). Here, one more concern is that the location updating of moths regarding the number of different flames in the search space can damage the exploitation of the optimal able outcomes. An adaptive method is developed for the number of flames to resolve this problem. As per eq. (10), the number of flames minimizes with maximizing the number of iterations.

$$\text{flame no} = N - c * \left(\frac{N-1}{T}\right) \tag{10}$$

In eq. (10), N indicates a maximum number of flames, c indicates the current iteration and T indicates the maximum number of iterations. In the number of flames, the continuing minimization during iterations balances between exploitation and exploration within the search space.

4.3 Adaptive MFO Algorithm

Establishing randomization plays a fundamental role in stochastic metaheuristics algorithms. In [16], different variants of MFO exploiting Cauchy operators and Levy flight and are presented.

The MFO updates its agents toward the candidate solution on the basis of the eq. (8) with the traditional circumstances. The effectiveness of the traditional MFO [17] is indisputable, a sense that while supposed sufficient calculation period, and it is definite to converge to the best counter at last. On the other hand, the search procedure may be slow. To enhance the convergence rate whereas maintenance of the obvious physiognomies of the MFO, an improved searching process that is, similarly to the adaptive CSA [18] is introduced. Fig. 2 exhibits a flowchart of the proposed A-MFO approach.

The traditional MFO method updates the moth location on the basis of the distance of moth regarding the flame. Moreover, to comprise the step size based on the optimal and worst moth location and current moth location.

The step size decides how distant a novel moth location is positioned from the current location. As stated in eq. (11), step size differs inversely with a generation that is with a raise in the iteration, step size minimizes. As demonstrated in eq. (12), the computed step size is along with the current moth location to attain a new moth location. In eq. (12), is an arbitrary number among [0, 1] begins random module in location update equation.

$$Y_m^{t+1} = \left(\frac{1}{t}\right)^{\left|\frac{best(f(t) - f_m(t))}{best\, f(t) - worst\, f(t)}\right|} \tag{11}$$

$$Moth\_pos(t+1) = Moth\_pos(t) + p * Y_m^{t+1} \tag{12}$$

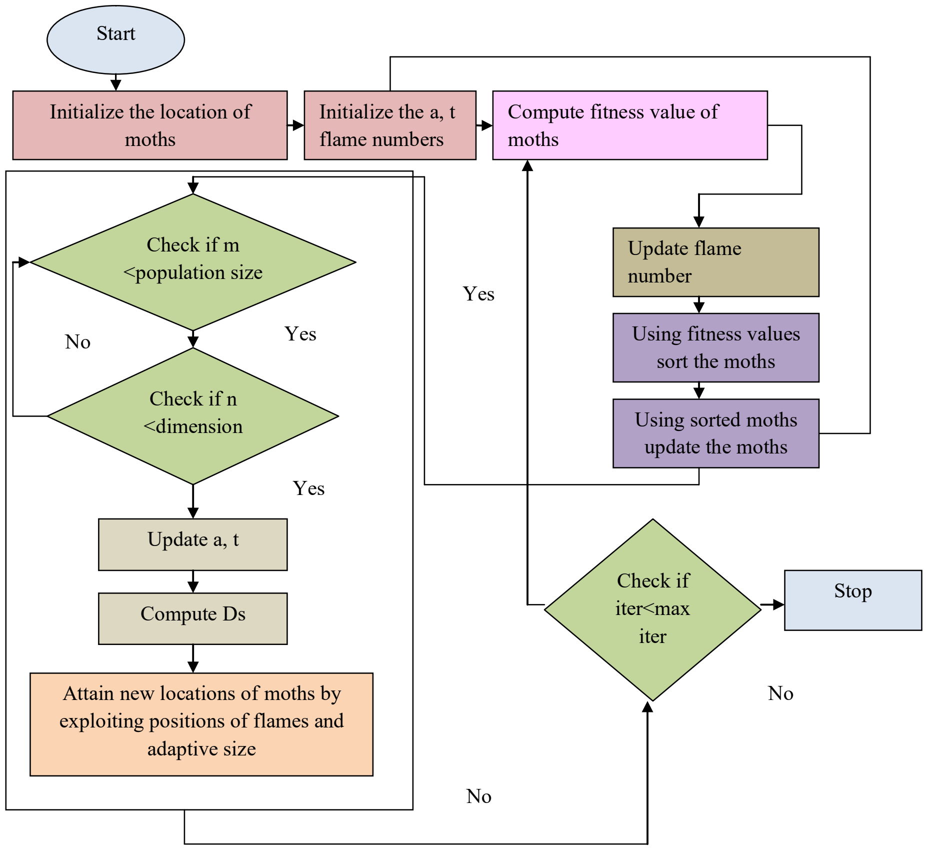

Fig. 2. *Flow chart of the proposed A-MFOA algorithm*

5. Results and Discussions

5.1 Simulation Procedure

The performance of the proposed method was shown by exploiting 3 benchmark bus systems like IEEE 24 RTS system, IEEE 30 bus system, and IEEE 57 bus system. It was simulated in MATLAB 2018a, the advantage of the outcomes was compared over the PSO, BSO, and EA. To guarantee better outcomes, the methods were operated in handling multiple TCSCs. For ATC enhancement, in [21] only 2 TCSCs were exploited for that the best positioning, as well as the compensation levels, was determined. In this paper, the investigational case of 5 TCSC connections was used. The outcomes for such varying scenarios were shown for the individual benchmark system.

5.2 Performance Analysis

In Fig. 3, analysis of the proposed and existing techniques for increasing TCSC configurations in IEEE 24 RTS is shown. Here, the proposed method is 24% better than the conventional PSO, 27% better than the conventional BSO, and 29% better than the conventional EA. Fig. 4 exhibits the analysis of the proposed and existing methods for increasing TCSC configurations in IEEE 30. Here, the proposed method is 32% superior to the conventional PSO, 15% superior to the conventional BSO, and 19% superior to the conventional EA. Fig. 5 exhibits the analysis of the proposed and existing methods for increasing TCSC configurations in the IEEE 57 bus system. Here, the proposed technique is 18% superior to the conventional PSO, 21% superior to the conventional BSO, and 26% superior to the conventional EA.

The overall analysis shows that the proposed technique outperforms conventional techniques such as PSO, BSO, and EA with respect to the ATC enhancement.

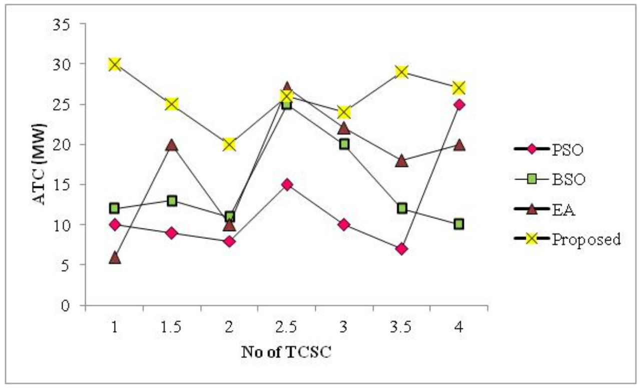

Fig. 3. *Analysis of proposed and existing methods for increasing TCSC configurations in IEEE 24 RTS*

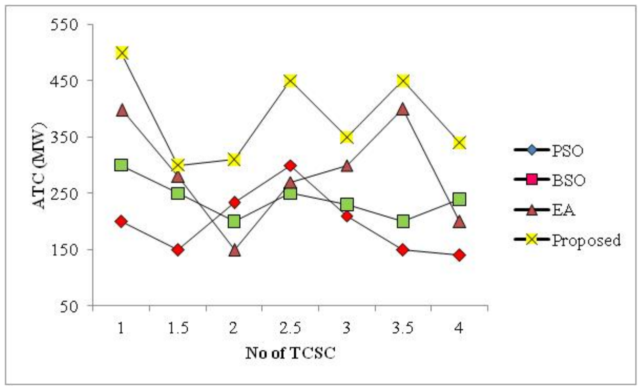

Fig. 4. *Analysis of proposed and existing techniques for increasing TCSC configurations in IEEE 30*

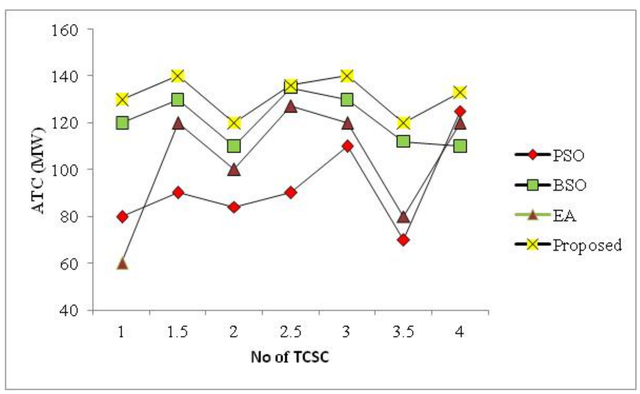

Fig. 5. *Analysis of proposed and existing techniques for increasing TCSC configurations in IEEE 57*

6. Conclusion

In deregulated power market, the main concerns are transmission pricing, congestion management and ATC, which required to determined. Amid these interesting challenges, one that requires to be interrogated to offer guaranteed open access transmission service is ATC. The manner of enhancing ATC is either adding transmission facilities or exploiting several FACTS devices. In this work, the simulation related to ATC enhancement by exploiting an Adaptive Moth Flame Optimization Algorithm was presented. Here, a rigorous evaluation was performed by exploiting the developed algorithm this was the adaptive version of the existing Moth Flame algorithm. Subsequent to the experimentation of developed enhancement of the ATC model, and the performance evaluation was performed regarding the maximized number of TCSCs. Moreover, the effectual performance analysis of the developed method was evaluated by analyzing the existing algorithms such as PSO, EA, and BSO. In the first scenario, the proposed model was offered a better response regarding the enhancement of ATC against the maximized TCSC associations than the PSO, EA, and BSO.

Compliance with Ethical Standards

Conflicts of interest: Authors declared that they have no conflict of interest.

Human participants: The conducted research follows the ethical standards and the authors ensured that they have not conducted any studies with human participants or animals.

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