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ATC Enhancement in Power System: A Review on Research Methodologies

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Abstract—ATC is a new demanding task for the engineers of power system in dealing with the safety of the power system. The evaluation of ATC has to be performed to guarantee the economic, secure, stable and consistent functioning of power systems. Owing to power system intricacy and alterations in power transaction, ATC has to fulfill certain conditions to equilibrate both commercial and technical issues. Therefore, this survey intends to review various topics on ATC enhancement. Accordingly, the various algorithmic classifications attained from the surveyed papers were analyzed and portrayed. In addition, the performance measures and the maximum performance achievements are also analyzed and demonstrated in this survey.

Keywords— Available transfer capability; Power grid; FACTS; TCSC; Performance measures. Nomenclature

Acronyms	Description
Available Transfer Capability	ATC
Continuation Power Flow	CPF
Cat Swarm Optimization	CSO
Superconducting Magnetic Energy Storage	SMES
Integrated Energy Systems	IESs
Probabilistic ATC	PATC
Latin Hypercube Sampling	LHS
Natural Gas-Fired Power Plants	NGFPPs
Particle Swarm Optimization	PSO
Power Transfer Distribution Factors	PTDF
Real genetic algorithm	RGA
Analytical Hierarchy Process	AHP
Dynamic Available Transfer Capability	DATC
Support Vector Regression	SVR
Semiconductor dependent Control Devices	SCD
Multilayer Perceptron Neural Network	MLPNN
Support Vector Machine	SVM
Repeated Power Flow	RPF
Hybrid Mutation Particle Swarm Optimization	HMPSO
Genetic Algorithm	GA
Megavar-corrected Megawatt Limits	MCML
Independent Power Producers	IPPs
Under Load Tap Changers	ULTCs
Voltage Source Converter	VSC

I. INTRODUCTION

In the aggressive electrical environment, the power grid has been comprehensively exploited and activated adjacent to its bounds. These consequences a new demanding task for the engineers of power system in dealing with the safety of the power system. ATC [1] [2] is a representation of the anticipated transfer capacity lasting on the transmission network. ATC [25] [26] [27] [28] is described as “the additional power that can be transmitted through a specified interface over and above the already committed transactions”. The details regarding ATC [3] [4] of an interface facilitate the ISO to make a decision on possible transactions.

ATC could offer significant information for transmission consumers, power marketers and system operators in real power markets [5] [6] [7], for economy or reliability purposes. To provide open access to electric power transmission networks, generation competition is promoted, which offers the clients with new choices [8] [9]. In addition, the estimation of ATC has to be performed to guarantee the economic, secure, reliable and stable operation of power systems [10] [11]. Owing to the complexity of power system and alteration of the power transmission, ATC has to gratify certain norms to equilibrate both commercial and technical problems. The physical parameters namely, voltage, thermal, dynamic and stability limits forced on the system elements have to be considered in the assessment of ATC [12] [13].

Accordingly, conservative and over concern assessment of ATC [14] [15] consequences into poor consumption of transmission capacity, alternatively, an optimistic approximation of ATC may jeopardize the security of the system. Therefore approximation of ATC [16] [17] plays a significant role in the operation and planning of modernized power system. Numerous ATC boosting techniques have been adopted, which adjusts terminal voltages via rescheduling generation and ULTCs. Depending on the NERCs description of ATC [18] [19] and its purpose, transmission network can be constrained by voltage, stability and thermal limits. Anyhow, it is known that the establishment of FACTs devices into distribution network have consequence in rigorous effect in system exploitation [20].

This survey has reviewed various works related to the ATC enhancement. Here, various algorithmic classifications, which are adopted in the surveyed papers, are demonstrated along with their performance measures. Along with it, the maximum performances achieved by the various works are also portrayed by this survey. The paper is organized as follows. Section II analyzes the various related works and reviews done under this topic. In addition, section III describes the various analyses on ATC enhancement, and section IV presents the research gaps and challenges. Finally, section V concludes the paper.

II. LITERATURE REVIEW

*A. **Related works***

In 2016, Nireekshana *et al.* [1] have analyzed the exploitation of FACTS devices, namely, TCSC and SVC, to increase power transactions throughout contingency and normal circumstances. Here, ATC was evaluated by means of CPF scheme in view of both the voltage profile and thermal limits. CSO was deployed as an optimization parameter to define the controlling and location constraints of TCSC and SVC. The adopted method was analyzed for normal and diverse contingency cases.

In 2016, Rao *et al.* [2] have suggested a technique to raise the transfer capability by exploiting FACTS controllers. Accordingly, SSSC, UPFC, and STACOM were taken in to account to demonstrate the impact of such controllers in improving ATC of system. Hence, a novel technique depending on current and optimal location strategy of FACTS were implemented. Finally, the proposed technique was analyzed, and the outcomes were attained with associated graphical and mathematical outcomes.

In 2016, Saraswathi *et al.* [3] have deployed combination of STATCOM and SMES that were associated with prevailing power transmission line for improving the ATC. STATCOM was power electronic VSC that was linked to the transmission system. SMES was considered as a well-known energy storage scheme. Probability of the suggested power system could control the flow of power unconventionally among the STATCOM-SMES and transmission lines units. Furthermore, suggested power system was executed in Matlab and its performance was authenticated on the basis of attained examination outcomes.

In 2016,Wei *et al.* [4] have adopted a PATC design regarding the static security parameters of IESs. Accordingly, the inaccuracies of associated electricity / gas loads and wind power systems were considered that were represented by a mixture of Nataf transformation and LHS. In addition, the remedial modification in NGS's was implemented to guarantee the availability of fuel in NGFPPs. At last, simulation outcomes were offered to validate the applicability of the adopted technique.

In 2016, Bavithra *et al.* [5] have established a scheme based on the integration of FACTS, a SCD to improve the ATC of the system. Several FACTS namely, SSSC, UPFC, and STATCOM were demonstrated by power flow equivalences, and FACTS constraints were set by PSO method optimally in order to improve ATC in the electricity setting. This substitutes the risky job of intensifying the prevailing one. In addition, the non-iterative, fast and simple PTDF dependent sensitivity technique was implemented to define and improve ATC to demonstrate the probability of ATC development for bilateral and complex transactions.

In 2008, M.Rashidinejad [6] had offered a model to define the optimal capacity and location of TCSC so as to develop ATC in addition to the voltage profile. Here, RGA connected with fuzzy sets and AHP were employed as a hybrid empirical method to enhance such a complex issue. Finally, the effectiveness of the established methodology was scrutinized through diverse case studies.

In 2015,Srinivasan *et al.* [7] have offered DATC determination in power system surroundings by means of SVR. For minimizing the training period and develop accurateness of the SVR, kernel constraints were regarded. The offered SVR dependent technique and its simulations were authenticated by relating with MLPNN. Finally, investigations demonstrate that the SVR contributes quicker and more precise outcomes for DATC when distinguished with MLPNN.

In 2014,Srinivasan *et al.* [8] have presented a bi-level programming model for finding out the optimal generation distribution to increase the ATC by regarding Hopf bifurcation in multilateral / bilateral transaction. Accordingly, in this work, RGA was exploited as an optimization device to resolve the adopted methodology. Finally, the proposed method was compared with traditional schemes, and the results were attained.

In 2013, Vaithilingam and Kumudini [9] have presented a SVM dependent technique for ATC approximation. This was considered as the first work to exploit SVM for ATC approximation. In addition, two approaches were adopted in this paper. The initial technique exploits the real power demands as inputs to SVM design. The subsequent technique exploits certain indices as inputs to approximate ATC. Finally, the results were distinguished with RPF outcomes and the improved developments have been attained by the suggested scheme.

In 2013, Wei *et al.* [10] have proposed a scheme that deals with the approximation of ATC for incorporating HVDC link along with AC power system. The arithmetical design of ATC was also modeled in this paper. In addition, the uncertainties and time-varying features of the power system were regarded, and numerous arithmetical indices were offered to calculate ATC. Also, a statistical analysis was held to show the efficiency of the adopted scheme.

In 2012, Farahmand *et al.* [11] have suggested a HMPSO method for enhanced estimation of ATC as a decision principle. Primarily, this was achieved by distinguishing a typical application of PSO system with traditional GA approaches. Subsequently, a multi-objective optimization issue regarding the optimal capacity allocation of FACTSs devices was offered and confirmed.

In 2012, Nireekshana *et al.* [12] have analyzed the exploitation of FACTs devices, namely, TCSC and SVC, to increase transmissions of power throughout contingency and normal conditions. Accordingly, ATC was evaluated by means of CPF technique regarding both voltage profile and thermal limits. In addition, RGA was deployed as an tool for optimization to define the controlling factors of TCSC and SVC. Moreover, the modeled approach was analyzed for different and normal contingency cases.

In 2009, Jain *et al.* [13] have introduced sensitivity analysis in terms of controlling constraints of FACTS for their optimum location in network. Here, two kinds of FACTS devices, namely, STATCOM and UPFC have been taken into account. In addition, the capable energy, presented by the UPFC and STATCOM, was encompassed in the structure conserving energy task to involve its effect on transient stability.

In 2003, Xiao *et al.* [14] have adopted a scheme based on the assessment of the effect of FACTS on ATC development. Methodological advantages of FACTS devices on ATC boosting were also examined in this scheme. In addition, improved knowledge about the potential of FACTS control was also deployed. Finally, the simulation outcomes of the adopted technique exhibit the efficiency of FACTS control on development of ATC. In 2003, Grijalva *et al.* [15] have portrayed a fast algorithm to incorporate the effects of ATC enhancement. The approximation of the line post-transfer complex flow was dependent on MCML and circle equations. Moreover, the technique can be simply combined with prevailing linear ATC software since the calculation was dependent on active power distribution features. Here, the presented scheme was demonstrated with a sample, and the error correction was established for transmissions in large systems.

III. VARIOUS ANALYSES ON ATC ENHANCEMENT

*B. **Algorithmic Classification***

The algorithmic classifications of the reviewed works are portrayed by Fig. 1. The various papers that are reviewed in this survey include several models, such as CSO, FF, PSO, and RGA that comprises the met heuristics algorithms. In addition, linear algorithms such as Bootstrap model, SVM, and Linear programming were also adopted in certain papers. Other algorithms such as SMES-ATC, LHS, Golden bisection model were implemented in certain works. Accordingly, CSO was adopted in [1], FF was implemented in [2], PSO was suggested in [5] [11] and RGA was adopted in [6] [8] [12]. In addition, Bootstrap model was implemented in [10], SVM was adopted in [7] [9] and Linear programming was proposed in [14] and [15]. Other schemes like, SMES-ATC was deployed in [3], LHS was implemented in [4] and golden bisection based interpolation technique was presented in [13].

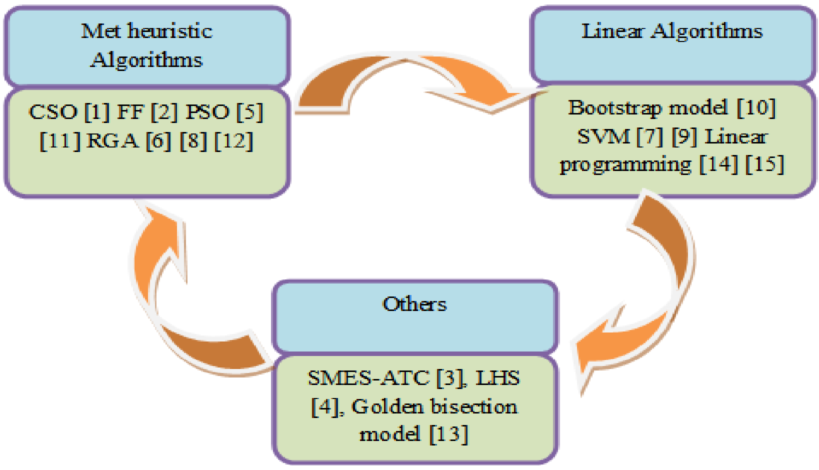

Fig. 1: Algorithmic classification of the reviewed models

C. *Performance Measures*

Numerous performance measures were evaluated in the reviewed papers, which comprises of ATC value, convergence rate, total power generation, computational time, error, Active constraint in EPSs, Identification accuracy, Transient energy, Confidence intervals, Length, Fitness Value, Load, Voltage, Compensation, Sensitivity, Dynamic ATC and Thermal burden. From the review, it was observed that ATC value has provided 70% of the total contribution and convergence rate has offered 10% of the entire contribution. In addition, total power generation has acquired about 10% of the total contribution and computational time has also attained 10% of the entire contribution. The error metrics has obtained 20% of the total contribution and the other performance measures such as, Active constraint in EPSs, Identification accuracy, Transient energy, Confidence intervals, Length, Fitness Value, Load, Voltage, Compensation, Sensitivity, Dynamic ATC and Thermal burden have offered about 80% of the entire contribution. The various performance measures are depicted in Fig.2.

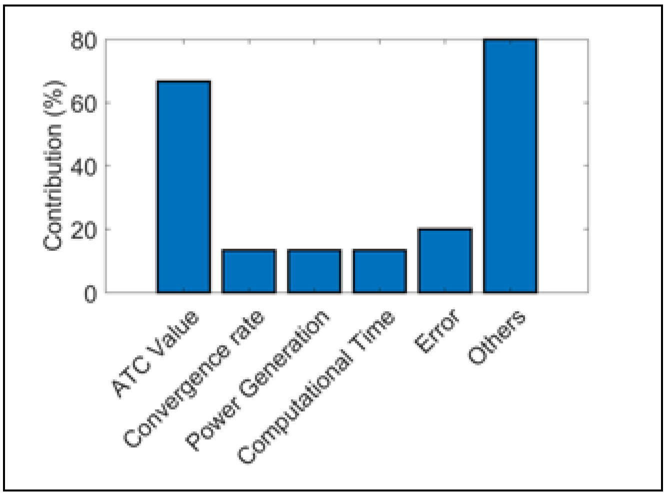

Fig. 2. Performance measures of the reviewed models

D. *Maximum Performance Achieved*

The maximum performance attained from the reviewed works is depicted by Table I. From the table, it was known that the ATC value has a maximum value of 962.4MW, which was determined in [4]. Accordingly, convergence rate was attained at a high rate in [5], i.e., 27.26 MW and total power generation have a maximum value of 120GW that was established in [15]. In addition, reduced computational time was attained as 0.02sec in [3], and error was extremely minimized, and it was adopted in [7] that have attained a percentage of 0.0025. Moreover, Active constraint in EPSs was adopted in [4] that had attained a value of 100%. Also, identification accuracy was found in [4], which was known to achieve 100%. In addition, transient energy was determined in [7], and it has acquired a value of 4.9p.u. Accordingly, confidence interval was achieved at 95%, and it was adopted in [10], and length parameter was attained at 470.78 that were determined by [10]. Fitness value and load was analyzed in [11], and it has achieved a value of 3 and 189.9MW respectively. In addition, voltage and compensation have been investigated in [6] and [12], which have attained a value of 1.05p.u and 0.070p.u correspondingly. Moreover, sensitivity, dynamic ATC, and thermal burden have been experimented in [13], and it holds a value of 0.442, 325MW and 49.43% respectively.

TABLE I. **MAXIMUM ACHIEVEMENTS ATTAINED FROM THE REVIEWED WORKS**

Sl. No	Performance measures	Maximum power attained	Citation
1	ATC value	962.4MW	[4]
2	Convergence rate	27.26MW	[5]
3	Total power generation	120 GW	[15]
4	Computational time	0.2 Sec	[3]
5	Error	0.0025	[7]
6	Active constraint in EPSs	100%	[4]
7	Identification accuracy	100%	[4]
8	Transient energy	4.9p.u	[7]
9	Confidence intervals	95%	[10]
10	Length	470.48	[10]
11	Fitness Value	3	[11]
1	Load	189.9MW	[11]
2	Voltage	1.05p.u	[6]
13	Compensation	0.070p.u	[12]
14	Sensitivity	0.442	[13]
15	Dynamic ATC	325MW	[13]
16	Thermal burden	49.43%	[13]

E. Chronological Review

The chronological reviews of the surveyed papers are demonstrated by Fig. 3.The numerous papers concerned in this review are taken from various years ranging from 2003 to 2016. The papers taken from 2016 have offered 33% of the entire contribution and the surveys taken from the year, 2008, 2015 and 2014 have offered 5.5% of the total contribution. In addition, the papers taken from 2013 and 2012 have presented 14% of the entire contribution. Accordingly, the surveys taken from the year 2009 and 2003 have offered about 7% and 14% of the entire contribution.

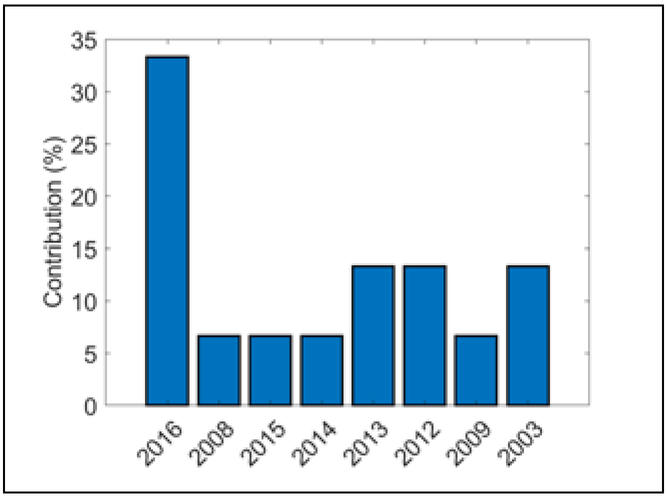

FIG. 3: CHRONOLOGICAL REVIEW OF THE REVIEWED MODELS

IV. RESEARCH GAPS AND CHALLENGES

ATC was considered as a major factor in real power markets. The key issues and challenges of ATC enhancement are depicted in this section. Deregulation of power systems not only offers inexpensive electricity and improved service for the consumers; nevertheless, it brings novel technological confronts to power industries. In an open transmission system, there was a requirement to enumerate the transmission transfer ability that paves the way to the concept of ATC. The most important conventional ways to improve the ATC were regulating terminal voltage of generators, rescheduling active power productions and varying taps of on load tap changers. Production of transmission lines was always been an alternative. However, it was subjected to environmental limitations and social issues. The reformation of the electric industry all through the world intends to generate competitive markets to distribute electricity, and it moreover produces a host of novel technical challenges to market contributors and power system analysts. ATC has to be assured to aid in free market dealing and to sustain a safe and cost-effective operation over numerous system conditions. Anyhow, tight constrictions on the production of new services owing to the rising complex economic, social, and environmental issues, have led to a much more rigorous exploitation of the traditional transmission services by IPPs and utilities.

V.CONCLUSION

ATC was considered as significant information to be available on the open-access for the market applicants to organize feasible power transactions in a secure way. As a result, a speedy and precise assessment of the ATC was more significant to give surety regarding the stable, secure, economic and consistent functioning of power systems. ATC of a transmission network enumerates the measure of unconsumed power left over in the transmission network for previously committed utilization. This paper has presented a survey on ATC enhancements in power markets. Accordingly, in this survey, various papers were analyzed, and the corresponding techniques adopted in each surveyed paper were described. In addition, the performance measures concerned in each paper were illustrated and along with it, the maximum performance measures attained were also illustrated. Thus the survey provides the detailed analysis of the ATC enhancement from the reviewed papers.

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