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Artificial Intelligence Techniques for Predicting Transmission Network Congestion: A Comprehensive Review

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ABSTRACT
One of the most significant factors that has contributed to the development of the electrical market is the deregulation of electricity transmission systems. This process is aimed at creating efficient markets and ensuring that the electricity supply is distributed fairly. However, open access can lead to system overload and can clog the network. It is essential to quickly determine the availability of a transmission network's transfer capability during a time-consuming activity in the system. This paper presents a variety of AI techniques that can help identify ATC, including deep learning, natural language processing, and machine vision. This study explores various methods and approaches that can be used to forecast the congestion in the transmission network. It also reviews the literature and examines the outcomes of different AI techniques when it comes to calculating ATC.

Keywords— Deregulation, Transmission Network, ATC, Congestion, Artificial Intelligence.

Abbreviations

ATC	Available Transfer Capability
TTC	Total Transfer Capability
TRM	Transmission Reliability Margin
CBM	Capacity Benefit Margin
ETC	Existing Transmission Commitment
PTDF	Power Transfer Distribution Factor
ACPTDF	AC Power Transfer Distribution Factor
DCPTDF	DC Power Transfer Distribution Factor
MEEPSO	Metaheuristic Evolutionary Particle Swarm Optimization
FACTS	Flexible A.C. Transmission Systems
SPCR	Sensitivity and Power loss-based Congestion reduction method
ANFIS	Adaptive Neuro Fuzzy Inference System
RBF	Radial Basis function
RTS	Reliability Test System
BPA	Back Propagation Algorithm
RBFNN	Radial Basis Function Neural Networks

ACLF	AC Load Flow
OASIS	Open Access Same Time Information System
SVM	Support Vector Machine
CPF	Continuation Power Flow
RPF	Repetitive Power Flow
SAP	Proposed Sensitivity Analysis
CNR	Conventional Newton Raphson
PWS	Power World Simulator
NRLF	Newton Raphson Load Flow

1. INTRODUCTION

The deregulation of the electric utility industry has allowed a large number of power producers to join the transmission system. This process is known as the deregulation of electrical systems research. It involves reforming the regulations and awarding incentives to encourage the responsible management of electric utilities. The goal of the deregulated framework is to create a more competitive electricity market. One of the main features of this system is its open access. This feature allows the transmission line to be operated without interference from other users. However, this can lead to system overload. One of the most effective ways to prevent this issue is by accurately calculating the availability of the transfer capability of the transmission network. This method can be used to predict the congestion in the system before it happens.

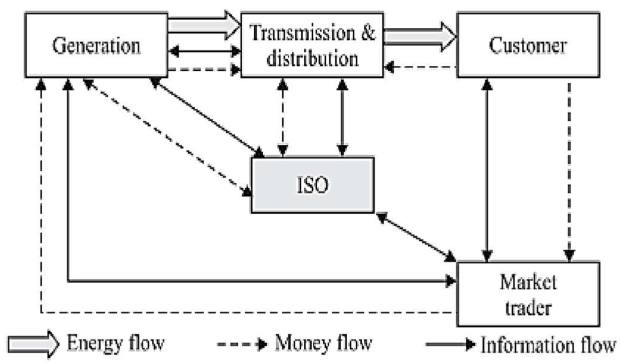

Fig.1. A typical deregulated power system's structure

1.1Available Transfer Capability-

According to NERC, the availability of transfer capability refers to the remaining capacity in the transmission system that can be utilized for commercial activities. This is referred to as the ATC. ATC is important in calculating the availability of open access and identifying congestion. This is because it allows the transmission system to safely transport power between regions. The concept of transfer capability differs from transfer's limit, which only takes into account the line specifications and temperature constraints.

$$ATC = TTC - TRM - (CBM + ETC) \quad (1)$$

where,

TTC –Total Transfer Capacity

TRM – Transmission Reliability Margin

CBM – Capacity Benefit Margin

ETC– Existing Transmission Commitments

1.2 Total transfer capability (TTC): The TTC is the maximum amount of electric power that the transmission system can safely transport over a reasonable range of contingencies and uncertainties. Its calculation is carried out by taking into account various factors such as system conditions, parallel path flows, and simultaneous and non-simultaneous transfers [1]. The TTC's reliability margin is a measure of the transmission system's ability to safely transport power over a certain range of uncertainties and contingencies. The capacity benefit margin is the amount of power that load-serving organizations reserve to guarantee the availability of electricity from their interconnected networks. It also helps fulfil generating standards and reduce the current load in plants. The availability of power transfer that is required to meet current processes is referred to as an existing transfer commitment.

The Power Transfer Distribution Factor is expressed as-

$$(\mathrm{PTDF})_{ij(mn)} = \frac{\Delta \mathrm{P}_{ij}}{\Delta\, \mathrm{T}_{mn}} \quad (2)$$

where,

ΔP_{ij} – Change in real power flow of line i-j for transaction between m-n

$\Delta\, T_{mn}$ – Change in transaction between m and n

Mathematical formulation of Total Transfer Capability at base case, between bus m and n is expressed as

$$TTC_{mn} = \min\left(\frac{P_{ij}^{max} - P_{ij}^{0}}{PTDF_{ij\ (mn)}},\, ij \in B\right) \quad (3)$$

where,

P_{ij}^{max} – MW power limit (thermal limit) of a line between i-j

P_{ij}^{0} - Base case power flow in the line between bus i-j

$PTDF_{ij\ (mn)}$ - Power Transfer Distribution Factor for line i-j for the real power transaction between the buses m and n.

B – Total number of branches.

ATC is the minimum of transfer capabilities of all elements [2-4].

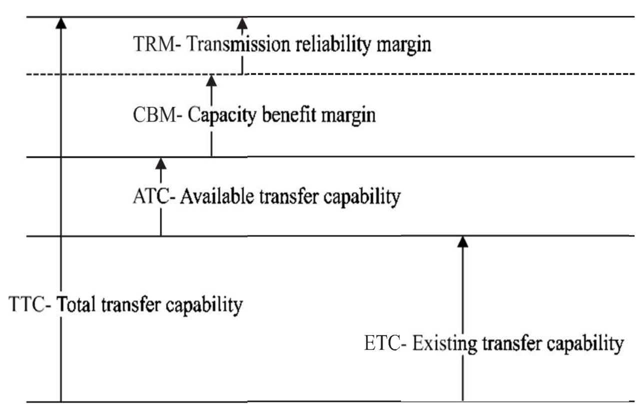

Fig.2 ATC visual illustration

The ATC varies depending on the situation of the system and the circumstances of operation. It shows the energy that can be transferred between the seller and buyer buses without putting the safety of the system at risk. Efficient computation of ATC is essential for carrying out transactions efficiently. In numerous research proposals, the transmission network's functioning is simulated to determine ATC. Research studies [3,5-9] on this strategy are presented in detail.

Linear Approximation Methods: The linear approximation method (LAM) is used to determine the transfer capacity of interconnected networks. It takes into account the networks' sensitivity measures [1].

DC Power flow: The DC PF formulation takes into account the following assumptions when calculating the AC PF. The reactive and declining PFs are excluded. The bus's voltage is set to one unit, and all control devices are stationary [1].

Power Transfer Distribution Factor (PTDF): The power transfer distribution factor (PTDF) is a calculation that takes into account the effects of a change in power injection or a transfer. It can be used to determine the overall impact of a particular modification on the transmission system [10].

Repetitive Power Flow (RPF) and Continuation Power Flow Methods (CPFLOW): The RPF technique is a method that takes into account the complex load conditions at different points in the transmission system. It then gradually increases the power injection at the source and the load buses in the sink zone until the limits are reached. This method can be used for performing non-simultaneous transfers [11].

The continuous power flow monitoring tool known as CPFLOW can be utilized to analyze a system's performance by keeping track of changes in generation and demand. It can also be used to determine the maximum power transfer limits. This tool has numerous applications, such as analysing voltage issues caused by changes in generation or load [12].

This method is also used to analyse the effects of cross-border transactions on the power flow. It then takes into account the changes in the power flow and the distribution factors to arrive at the appropriate transfer capacity [10].

1.3 Artificial Intelligence

The field of computer science is booming with the development of Artificial Intelligence, which is a type of machine that can perform various tasks and perform complex calculations. This technology is also referred to as "man-made intelligence."

The goal of this research is to develop a better understanding of human intelligence by studying how machines and computers simulate human beings to recognize and analyse information. AI techniques are not only more efficient than traditional methods, but they also avoid the local optimization issues encountered in complex systems [13-14].

Artificial Intelligence can be used in various applications. These include performing complex calculations and analysing information.

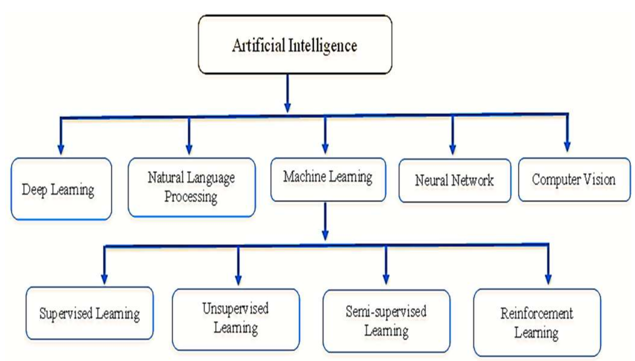

Fig.3: AI Techniques

Deep Learning- The deep learning technique is similar to machine learning in that it uses neural networks to learn about and classify data. It makes it easier to perform prediction and classification by transforming the original features into new ones [13].

Natural Language Processing- Computational linguistics is utilized in Natural Language Processing to develop applications that can work with various languages. It was able to interpret and understand human language.

Machine Learning- The technology known as machine learning involves training machines to perform various tasks, such as making recommendations or predictions based on past experiences.

Machine learning is categorized into four different types-

1. **Supervised Learning**: A supervised learning system provides a computer with a set of data that lets it learn how to perform a specific human task. This type of system can be utilized by a supervisor or teacher to help the computer improve its skills.
2. **Unsupervised learning**: The computer is unsupervised learning when it gets unlabelled data. It doesn't have labels or an output vector, and it extracts previously unknown insights from the data. The sample set is then categorized into distinct groups based on the similarity between the various pieces.
3. **Semi-supervised learning**: This type of system is commonly referred to as semi-supervised learning. It allows the computer to perform a specific task while using the data it has been provided with.
4. **Reinforcement learning**: The computer uses reinforcement learning to identify the ideal actions that will minimize its risk and maximize its reward. This type of learning is based on feedback.
5. **Neural Network**: A neural network is composed of algorithms that are designed to identify the underlying links in a collection of data. It mimics the way the brain functions. In terms of origin, these systems of neurons can be synthetic or organic.
6. **Computer Vision**: Researchers in the field of computer vision are focused on developing systems that can process and understand images and videos. It aims to make the machines behave like living beings.

The paper presents a review of the various techniques used to determine the air traffic control (ATC) status. When the ATC is zero, the transmission network will experience congestion. It is important to determine the ATC fast to predict this issue.

2. LITERATURE REVIEW

The study presented by the researchers thoroughly covered the different approaches for calculating the ATC [1]. It also highlighted the significant contributions made by the researchers. The review found that the methods used for calculating the ATC are prone to errors. In addition, the development of an accurate and fast algorithm is affected by system dynamics. The researchers presented an extensive study on the various aspects of the transmission network's ATC. They discussed the different methods that are used in this research, such as linear approximation, RPF, and OPF. They also highlighted the disadvantages and merits of these methods. In addition, this study highlighted the uncertainties that are associated with the computation of ATC.

On April 24, 1996, the US Federal Energy Regulatory Agency (FERC) issued final rules regarding the establishment of non-discriminatory access transmission services [2]. These services are designed to promote competition in the electricity market. The NERC report clearly states the available transfer capabilities. The Board of Trustees of the organization approved this report at its meeting in May 1996. The purpose of this report is to provide a framework for establishing and operating a commercially viable ATC system. The paper [2] also presents the ATC Principles that are required to be followed when calculating the ATC values. These principles are based on the characteristics of interconnected networks. The paper presents a framework that is in line with the main provisions of the regulations. It will most likely be modified or developed upon further study once more information about the electric power market is available. The paper presents a review of the various techniques used to determine the air traffic control (ATC) status. When the ATC is zero, the transmission network will experience congestion. It is important to determine the ATC fast to predict this issue.

The authors of the paper [3] presented an overview of the different methods used for calculating the ATC when a bus load is applied. The same approach is used for calculating the ATC in cases of bilateral transactions. However, the total change in load is then split into different transactions. The authors explained how the power transfer distribution and sensitivity factors are utilized in the computation of the ATC for individual transactions. The researchers noted that the changes in the load can increase the network ATC and provide the line-PTDFs. The researchers developed an algorithm that enables them to perform quick and accurate ATC calculations for different load patterns. It is used for hour-a-head market computation.

The researchers presented a new method to determine the changes in the reactance of the TCSC to improve its transfer capability in [4]. They used a sensitivity analysis to perform a computation on the changes in the line flow caused by the installation of the device. The suggested method is based on a mathematical model for reactance computation. The paper states that the installed TCSC can enhance the ATC value by reducing the line's reactance. Simulations show that an operational range can be obtained by observing a linear variation between the line flow and the reactance. The line reactance and the TCSC's performance are then computed to determine the appropriate ATC for the power transaction. It's also observed that the line operates in a different range when the base condition is changed.

The authors of the study [5] discussed the various aspects of the ATC's determination guidelines and definitions. They additionally highlighted the technical challenges that are involved in the computation of the ATC. Although the NERC's guidelines and methods provide a lot of guidance for calculating the ATC, I believe that the research community still needs to study the various aspects of this process. This paper also highlighted the possible solutions to the ATC computation problems.

The researchers presented a new method that allows them to perform full-featured ATC calculations in a power system using only three input variables [6]. The method is thoroughly validated through a variety of simulation tests. The researchers presented a support vector machine-based method for calculating the ATC in [7]. This is the first time that a SVM is used for this type of computation. The two methods are presented in this paper. One of these uses real power demands as its input, while the other uses the source bus injections. The results of the two methods are compared with the RPF results.

The researchers explained how the gross power flows and proportional sharing algorithm is utilized in the calculation of the IEEE 6-bus system in [8]. They also noted that a sensitivity analysis is performed to determine the changes in the power flow due to load. This method is useful in determining the nodal prices needed in the computation of congestion management and differential tariffs. The researchers found that the losses caused by the changes in the load are generally the same when compared to the conventional methods. They also noted that the modified algorithms are more appropriate for the situation where the losses are allocated properly. The researchers noted that their method can be used to modify the transfer capabilities of the system by controlling the generator involvement factors. It can also help manage the network congestion.

According to the researchers in [9], the ATC was efficiently computed by using three different methods. These include the Back Propagation Algorithm, the Radial Basis Function, and the Adaptive Neuro Fuzzy Inference System. The researchers will be presenting the ATC on the Open Access Same Time System, which is accessible to the public. The three different methods were evaluated by the researchers on an IEEE 24-bus reliability test system. They were compared with the traditional AC load flow method for different load scenarios, such as line outages and transactions.

The researchers presented a novel approach to calculating the ATC by utilizing the power transfer factor and sensitivity analysis [10]. They noted that the congestion in the transmission network is the biggest challenge faced by the deregulated environment. This study also discussed the various techniques used in the analysis of power flow sensitivity. These include the use of power-flow detectors and the installation of advanced devices. The findings of this study show that an accurate and fast ATC computation is needed to improve the transmission system's performance.

The authors of this paper [11] proposed the ACPTDF, RPF, and DCPTDF methods to calculate the maximum amount of electricity that can be transmitted from one end of the transmission line to another. These methods are used on different IEEE 6 bus systems and 14 bus systems. They were able to perform the analysis using the Newton Raphson NR method.

The researchers in [12] utilized a computer package known as CPFLOW to analyse the steady-state behaviour of the power system. They noted that this tool can be used to determine the variations in the load caused by different parameter changes. Some of these include the general bus real and reactive loads, as well as system-wide reactive and real generation. The main advantages of the CPFLOW method over the conventional power flow calculation are its reliability and speed. It can also be used to perform various parameterizations and step-size control. This paper presents an overview of the implementation of the CPFLOW method. The CPFLOW software can be used to model power systems up to 10,000 buses. For instance, it can be utilized to set operational limits for a 3,500-bus system.

The researchers in [13] concluded that the use of AI in the smart grid can provide valuable technical support to the digital power network. Artificial intelligence (AI) is expected to play a vital role in the development of smart grid applications, such as power supply optimization and consumer behaviour analysis. Although it can face various challenges, such as the lack of reliable data collection and the establishment of a proper infrastructure, AI is a powerful tool that can help improve the efficiency of the power system.

The authors of this paper [14] presented a framework that uses an artificial neural network to forecast the future market conditions. It is designed to provide a competitive advantage to the market participants by taking into account the available day-ahead data. After testing the algorithm, the researchers discovered that it was able to predict the majority of the transmission lines with good recall values and accuracy. This method is useful in addressing the congestion issue in Germany and other countries as they are implementing their energy transition. The suggested method can be used to reduce the conflicts between the market structure and the transmission infrastructure. It only uses publicly-available data and is completely transparent. The researchers were also able to provide the necessary data to the regulators and the TSOs to easily implement the suggested algorithm. Before the algorithm was evaluated, the researchers conducted a comprehensive evaluation of the various model configurations. The findings of the evaluation were encouraging, as they showed that the proposed approach was able to predict the absence of congestion in most cases. The researchers were also able to demonstrate that it was more accurate than the nave prediction. This method can be utilized immediately to address the issue of undetected congestion.

According to the researchers, various frameworks for managing the transmission system in deregulated environments have been established all across the world [15]. These include three distinct approaches to accomplishing the same task. The first strategy that is commonly used is the OPF model. It has been shown that this method can be applied to various contexts, such as Australia, the UK, and New Zealand, and it is also utilized in the US. The second strategy is the price area and point tariff control method that is commonly used in Norway and Sweden. These are not theoretical solutions, but they are practical implementations that have been tested. Each of these approaches has its own weaknesses and strengths. Although they all protect the electrical grid's safety, they have varying effects on how the electricity market operates. The authors of this study [15] extensively covered the various aspects of congestion-management. They also discussed the analytical foundations and strengths of the different strategies being used globally.

The researchers presented a framework for establishing and operating a deregulated electric power sector [16]. This system would allow the private sector to participate in the generation of electricity and increase competition in the market. It also supports the government's efforts to expand the generation-transmission capacity. The increasing number of electric power installations and the complexity of the electricity market are creating significant obstacles to the development of new generation-transmission facilities. This study [16] has shown that the government can stimulate the private sector's investment in these projects by providing adequate economic signals.

The researchers utilized a program known as a MATLAB to calculate the voltage magnitude, phase angle, reactive power, and active power at each of the IEEE 6 bus systems in [17]. They then used three different methods to perform load flow analysis. The researchers found that the Gauss-Siedel method is the most commonly used in the analysis of the power flow due to its multiple features. However, the other methods used in the study, such as the Fast-Decoupled method, require more iterations. The researchers found that the Newton Raphson method is better than the GS method when it comes to calculating the ATC. The Fast Decoupled method, on the other hand, provides the same results as the NR method.

The researchers then proposed the use of the power flow method to calculate the available transfer capability of a power system in [18]. They were able to implement this technique in their study using the Power World software and the Fuzzy Logic artificial intelligence framework. The researchers chose the 30 buses as the test system to analyse the ATC. They also utilized the 11 bus and 26 bus test systems for the medium and large-scale systems, respectively. The researchers' analysis included the calculations of the ATC without any contingency. The researchers opted to use the fast decoupled approach for calculating the power flow of the test system. This method can be used to decouple reactive and real power mismatches. They also explored the possibility of using AI in the power system.

The researchers presented a method in [19] that uses AI to maximize the available transfer capabilities of a power system by controlling the time series. They were able accomplish this through the use of several AI techniques such as deep reinforcement learning and supervised learning. In this study, the researchers utilized the imitation learning method to provide an AI agent with a good initial policy. They then trained it using a novel exploration technique that increases its efficiency. They also introduced an Early Warning mechanism that helps the agent identify the optimal control strategies during long testing periods. This method can help improve the system's robustness and error tolerance. An AI agent trained to master the optimal topology for a power grid can handle various practical constraints and uncertainties.

The researchers then proposed a method that uses AI to determine the optimal location and capacity of the transformer for improving the power system's voltage profile and ATC in [20]. They were able to accomplish this through the use of a hybrid algorithm that combines the real genetic algorithm and fuzzy sets. Through case studies, the researchers were able to analyse the proposed methodology's effectiveness. They were able to conclude that the use of TCSC can enhance the ATC.

The researchers in [21] presented a methodology that uses neural networks to solve the issue of calculating the power transfer capability of a power system. The suggested method takes into account the optimal flow formulation and outputs the transfer capability. In this paper, the researchers introduced a neural network training algorithm that can be used to improve the performance of a power system. They performed a case study on an IEEE 30-bus system to demonstrate the practicality of this approach.

The authors of this paper [22] analysed the various works presented in the literature on congestion management. They then discussed the key issues and challenges that are involved in implementing the algorithms for improving the system's efficiency. This paper provides an overview of the different techniques that are used to address this issue. The paper was thoroughly reviewed and updated. It delves into the most critical issues confronting congestion management.

The authors of this paper [23] thoroughly reviewed the various techniques used in congestion management. Some of these include load shedding, load balancing, and optimizing the distribution of generation. They also discussed the use of genomic algorithms, such as the GA, and particle swarm optimization. The authors of the paper also analysed the various studies that were published in the literature to review the significant factors that influence the development and implementation of efficient techniques for managing congestion.

According to the researchers in [24], in most cases, demand responses aren't considered when it comes to managing congestion. Instead, a congestion management strategy should take into account the total social welfare. A two-level approach can then be developed to address the issue. The researchers presented a variety of solutions that include the nodal demand and the nodal prices. They performed case studies on a three-bus network and an IEEE 30-bus system to demonstrate the practicality of this approach. The studies revealed that the demand elasticity can help decrease the impact of congestion.

The researchers in [25] were able to use the open-source software known as MATPOWER to perform a comprehensive analysis of the power flow in a power system. It was able to identify the congestion line in the network and its sensitivity factor. An illustration of a power flow using Newton Raphson's method was presented in this paper. The paper also highlighted the importance of the library known as MatPOWER in helping students and researchers study the power system problems.

The researchers in [26] presented the suggested location of the series FACTS devices, such as the TCSC, to eliminate congestion. They utilized a sensitivity factor-based approach to determine the optimal placement of the device. The researchers noted that the line's power capability can be enhanced through a reactance model of the TCSC. The researchers were able to use the congestion line's sensitivity factor to identify the optimal location of the TCSC in a power system. They were able to perform a test on a 33-bus network in Delhi, India.

According to the researchers in [27], the use of FACTS devices can help reduce the flow of electricity in the network. They noted that this method can improve the stability of the system and lower the cost of production. The suggested location of the TCSC would be determined by taking into account the reduction of total system voltage losses and the real power performance index. The results of the study revealed that the cost of TCSC and the sensitivity index can be used to determine the ideal location of the device. The researchers were able to study the effects of the TCSC on a line outage. They discovered that it can help alleviate congestion by setting up the installed TCSC.

The researchers in [28] concluded that using cost-free methods can help reduce the congestion. They noted that using the FACTS devices can help avoid economic issues. The paper presents the use of two emerging FACTS devices, namely the TCSC and the UPFC, to address the congestion issue. In the congestion management process, the objective function of the problem is nonlinear, which means that a global optimal solution can be obtained by using a genetic algorithm [28].

The researchers in [29] presented a comprehensive analysis of the optimal allocation and choice of the four different types of FACTS devices in a multi-machine power system using a genetic algorithm. They were able to achieve the dispatch and economic generation of electricity in a deregulated market. The researchers then performed a comprehensive analysis of the overall system cost, which includes the investment costs of the various types of FACTS devices and the bid offers made by the market participants. They were able to find a way to minimize the overall cost function. The researchers were able to optimize the various attributes of the FACTS devices, such as their ratings and locations. The suggested algorithm can be used for the allocation of the devices in an electricity market that is deregulated.

The authors of this study [30] talked about the various changes that have occurred in the electric power industry. They presented an overview of the procedures involved in the assessment of the ATC using the ACPTDFs in the CEED environment. The line flow limitations are then checked using the ACPTDFs. The researchers compared the results of the ATC computation with those of the Newton Raphson load flow method. They were able to perform concurrent wheeling transactions on three bus systems. The findings of the evaluation were favourable. The authors of this study tried to calculate the appropriate ATC using the distribution factors of AC power in an emissions and economic environment. They used three different test systems to analyse the established model for the determination of the ATC.

The researchers were able to develop the suggested method using the SPCR and MEEPSO methods in [31]. The findings of this study were then validated by the 30 and six bus cases of the IEEE. The researchers were able to take into account the various factors that affect the location of the transmission lines. The researchers used the MEEPSO method to calculate the ATC values, which were compared with those of the other methods, namely the ACPTDF, PWS, and DCPTDF. The results of the comparison revealed that the values of ATC were significantly improved by 25.85% compared to those of the DCPTDF. The system's effectiveness was demonstrated by the various transactions that were conducted using different buses. The researchers were able to demonstrate that the proposed method was able to improve the ATC values in six bus systems when the TCSC was placed at line 7 during the first transaction. The researchers were able to show that the maximum value of ATC was observed at lines 8 and 7 in the first transaction [31]. In the second and third transactions, the researchers were able to demonstrate the system's effectiveness by using the MEEPSO method. The results of the evaluation revealed that the proposed method was more accurate than the conventional methods. In the 30-bus system, the researchers were able to demonstrate a 34.8% improvement in the value of ATC [31]. The suggested method was able to produce promising results when compared to the conventional techniques.

3. RESULTS

The following table presents the literature review's results related to the various AI techniques that were utilized in the computation of ATC.

3.1- Result 1 (Comparing the DCPTDF, ACPTDF, and NRLF Methods)

The IEEE 6 bus system handles two types of bilateral transactions, namely T1 and T2. The value of ATC for these two transactions is shown in Table 1 with the help of ACPTDFs and DCPTDFs for power transfer [30].

Table 1: ATC (MW) – IEEE 6 bus system

Transaction	DCPTDF Method	ACPTDF Method	NRLF Method	Power World Simulator
T_1 (3-6)	40.3331	41.0374	41.00	40.34

T_2 (3-5)	43.6850	43.2484	43.00	43.62

The results of four different bilateral transactions are presented in Table 2 using the ACPTDF technique in the 30-bus system. The findings are supported by the results of the power world simulator and the Repetitive AC load flow method. The latter involves increasing the transaction's base value every time one of the line flows gets close to the limit.

Table 2: ATC (MW) - IEEE 30 bus system

Transaction	ACPTDF Method	NRLF Method	Power World Simulator
T_1 (8-25)	25.0025	25.20	17.02
T_2 (5-30)	11.4522	13.93	14.98
T_3 (11-26)	9.1861	11.80	12.744
T_4 (2-28)	21.94	23.555	27.165

The time it takes to calculate the ATC for a given transaction is shown in Table 5. The ACPTDF technique is faster than the other methods when it comes to performing the computation. The time it takes to calculate the ATC for three test systems is shown in Table 3. The researchers noted that the ACPTDF method is faster than the NRLF technique when it comes to performing the computation.

Table 3: Execution time in seconds for ATC determination of three test systems

Test System	ACPTDF Method	NRLF Method
IEEE 6 bus	7.7	10.4
IEEE 30 bus	55.89	64.01

3.2- Result 2 (comparison between ACPTDF, DCPTDF, PWS, SPCR and MEEPSO)

The available transfer capability statistics for the bus system of the IEEE 6 are shown in Figure 4. The base case's parameters are usually determined in lines 2, 2-5, and 2-6. In addition, the transaction T1 and T2 involve buses 2 and 3. The first values of the various scenario variables are then calculated using the Newton–Raphson method and the ACPTPDF. The latter is used to determine the ATC for every transaction. The two techniques are then compared and evaluated using the software known as MATLAB. The results of the ATC calculation are compared with those generated by the DCPTDF and ACPTDF techniques. The suggested methods were also able to demonstrate their effectiveness by setting the TCSC at lines 7, 8 and 11. The MEEPSO algorithm is utilized for calculating the ATC, and it has the lowest and highest compensation amounts [31]. It can run for up to 200 iterations with a particle density of 50. The parameters of the algorithm are also set to 1., 1.2, and 0.9.

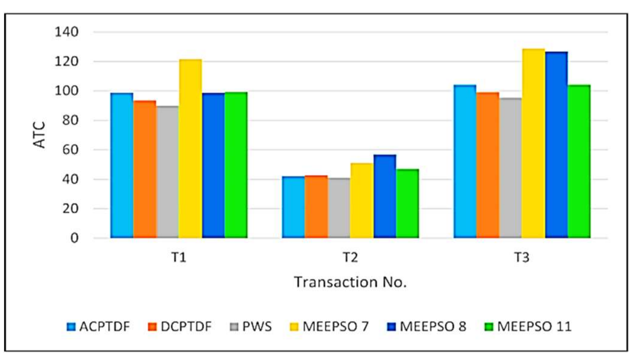

Fig.4: Available Transfer Capabilities (ATC) values Comparison at different transactions by various methods

(6 bus system)

The available transfer capability statistics for the 30-bus system are shown in Figure 5. The first values of the various transaction types are shown in the simplest case in lines 11-25 and 9-11. In the other case, the funds are transferred between buses 11 and 25. The parameters of the base case are then calculated using the Newton-Raphson method for estimating the load flow, and the ACPTDF technique for identifying ATC at each transaction. The two techniques' results are then compared and evaluated with those obtained through the Power Web Simulation.

Comparison of the ATC values of different transactions performed using different methods is shown in Figure 2.

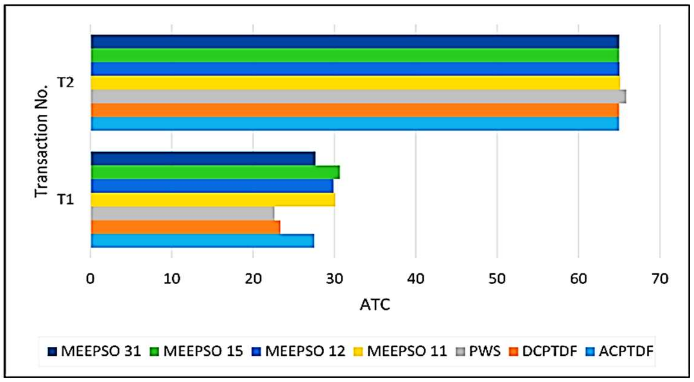

Fig. 5: Comparison of ATC values at different transactions by various methods

(30 bus system)

3.3- Result 3 (comparison between SAP, CNR, PWS Method)

The SENSTAC program, which is an IEEE 6 bus system analysis tool, is developed in MATLAB. It can perform sensitivity analysis on various transactions, such as line flows and PTDFs. It can also determine the ATC values for every transaction across the entire system. Since the program only has to be performed once, the sensitivity analysis can be justified when compared to the traditional approach to calculating the ATC values. The table 5 shows that the sensitivity analysis is capable of providing the appropriate accuracy and speed for power system applications.

This enhancement greatly improves the ATC computation results. It is also confirmed that the line PTDFs found in sensitivity analysis are almost identical to the ATC values in the same transaction. This means that the evaluation of these quantities can only be performed once, which can reduce the overall time spent on the evaluation.

The sensitivity analysis is used to determine the line flow PTDF and to analyse the ATC values. Comparison of the obtained values with those from different techniques is shown in Table 5 [10].

Table 4: Power Transfer Distribution Factors

Line	Method	Transaction No.				
		T_1	T_2	T_3	T_4	T_5
Line 1-2	SAP	-0.1114	-0.13	-0.045	-0.0568	0.0096
	CNR	-0.1104	-0.13	-0.043	-0.0557	0.0099
	PWS	-0.108	-0.129	-0.042	-0.054	0.006
Line 1-4	SAP	-0.0259	0.2161	-0.011	-0.0073	0.0077
	CNR	-0.025	0.2172	-0.01	-0.0062	0.0079
	PWS	-0.025	0.2063	-0.009	-0.006	0.006

Line 1-5	SAP	0.2271	-0.03	0.091	0.1411	0.0052
	CNR	0.2284	-0.029	0.093	0.1428	0.0055
	PWS	0.22	-0.03	0.089	0.139	0.004
Line 2-3	SAP	0.174	0.0452	0.263	-0.2454	-0.1568
	CNR	0.1704	0.0404	0.262	-0.247	-0.1562
	PWS	0.174	0.0413	0.265	-0.246	-0.158
Line 2-4	SAP	0.1985	0.684	0.079	0.1133	-0.0066
	CNR	0.2036	0.6911	0.08	0.1156	-0.0073
	PWS	0.201	0.6963	0.078	0.115	-0.006
Line 2-5	SAP	0.307	0.0744	0.126	0.1773	-0.0038
	CNR	0.3068	0.0736	0.126	0.1776	-0.0038
	PWS	0.31	0.0725	0.126	0.18	-0.004
Line 2-6	SAP	0.1965	0.0514	0.483	-0.1084	0.1779
	CNR	0.192	0.0455	0.482	- 0.1103	0.1787
	PWS	0.195	0.045	0.485	-0.109	0.178
Line 3-5	SAP	0.1897	0.0412	-0.077	0.3893	0.1222
	CNR	0.1882	0.0442	-0.085	0.4001	0.1271
	PWS	0.191	0.0438	-0.084	0.4	0.126
Line 3-6	SAP	-0.0202	-0.002	0.34	0.361	0.7206
	CNR	-0.019	-0.004	0.345	0.3542	0.7176
	PWS	-0.019	-0.004	0.345	0.354	0.718
Line 4-5	SAP	0.1709	-0.115	0.067	0.1051	0.001
	CNR	0.1659	-0.123	0.065	0.1027	0.0014
	PWS	0.165	-0.124	0.065	0.103	0.0016
Line 4-6	SAP	-0.1695	-0.042	0.196	-0.2578	0.1118
	CNR	-0.1593	-0.038	0.193	-0.2326	0.119
	PWS	-0.161	-0.037	0.191	-0.233	0.118

Table5: Available Transfer Capability

Method	Transaction No.				
	T_1	T_2	T_3	T_4	T_5
SAP	181.4	129.99	230.5	220.849	110.64
CNR	181.327	128.58	226.5	225.283	111.13
PWS	180.71	129.15	226.9	226.017	111.36

3.4- Result 4 (comparison with RPF and SVM Method)

The SVM model is used to estimate the ATC values of the various operational conditions of the 24-bus reliability test system. It can also perform the same calculations on the actual power loads and the injection of the source bus. The table 6 shows the percentage error in the ATC values that the model has generated [7].

Table 6: ATC values of the interfaces 23–3 obtained using RPF and SVM

Data Set	ATC for Normal Operating Condition		
	ATC using RPF (MW)	ATC using SVM (MW)	Error %
1	70	75	7
2	130	127	2
3	70	75	7
4	120	128	6
5	120	121	0.8
6	90	92	2
7	90	90	0
8	80	79	1
9	140	144	2
10	140	131	6
Average error in %			3.38

The comparison of the SVM and RPF methods is shown in Table 2 to compare their performance in terms of time. The SVM model has a significantly inferior processing time model compared to the RPF method. Another unique feature is that it can estimate the ATC values for multiple operating conditions simultaneously. Table 6 and 7 show the percentage errors generated by the model in this manner.

The SVM model's accuracy is not significantly affected when the ATC is simultaneously estimated for several operating conditions. The time required to estimate the ATC for five different conditions is shown in Table 8 and table 9. The difference between the two models is that the RPF model estimates at a sequential pace, while the SVM model does so simultaneously [7].

Table 7: Comparison of computation time (in seconds) for IEEE 24 bus system

Test Case	Computation Time in Seconds	
	RPF	SVM
1	0.904	0.0042
2	0.736	0.0044

Table 8: ATC obtained of three transactions case

Transaction	ATC using RPF (MW)	ATC using SVM (MW)	Error %
1	70	67	4
2	130	124	5
3	70	71	1

Table 9- ATC obtained of five transactions case

Transaction	ATC using RPF (MW)	ATC using SVM (MW)	Error %
1	70	72	3
2	100	95	5
3	90	97	7
4	90	86	4
5	70	70	0

Table 10- Comparison of computation time for five operating conditions

Test Case	Computation Time in Seconds	
	RPF	SVM
1	4.72	0.0058
2	3.91	0.0051

3.5- Result 5 (artificial intelligence techniques (ACLF, BPA, RBF & ANFIS) compare with AC Flow methods)

The 24-bus reliability test solution has been equipped with three different intelligence techniques to perform real-time ATC calculations. These include the Back Propagation algorithm, the Neural Network, and a Fuzzy Inference.

An open-access information system known as Anfis hosts the ATC for both the buyer and seller. The ISO also keeps track of the ATC. The three different methods are compared with the standard full AC load flow method for determining the ATC values for different situations and line outage scenarios.

Different techniques are used to generate the ATC figures for the test cases of the base case and the line outage. They are included in Table 10 and 11, respectively. Out of the 60 test patterns, 30 correspond to normal operational conditions, while the remaining 30 are related to line outages [9].

Table 11: ATC Between Bus 23 To Bus 16 For Various Load Variation Test Cases Under Normal Operating Condition (PU)

Test Patterns	ACLF ATC	BPA ATC	RBF ATC	ANFIS ATC
1	13.00001	13.053	13.506985	12.97
2	9	8.9914	9.518487	8.97
3	10.3	10.281	11.043727	10.309
4	8.3	8..2917	8.965892	8.3094
5	12.00001	12.039	12.720891	11.975
6	7.99999	8.0358	8.613604	7.9748
7	9.6	9.6559	10.296741	9.6234
8	7.6	7.6841	8.222308	7.6237

9	10.90001	10.809	11.352566	10.913
10	8.9	8.8253	9.379425	8.9124
11	11.30001	11.415	11.786911	11.315
12	7.3	7.3441	7.835326	7.3142
13	8.7	8.7402	9.192936	8.6707
14	2.7	2.6969	2.946276	2.6687
15	8.3	8.3976	8.770634	8.3445
16	6.3	6.3528	6.688462	6.3451
17	7.99999	7.9974	8.302246	7.9698
18	4	4.0289	4.134586	3.9714
19	7.2	7.1004	7.273947	7.2113
20	3.2	3.2284	3.222071	3.2188
21	7.6	7.495	7.373643	7.5562
22	1.6	1.73	1.535939	1.5938
23	5.2	5.2348	5.062666	5.2498
24	3.2	3.1999	3.068753	3.2468
25	6.5	6.5503	6.115197	6.6203
26	4.5	4.4658	4.138824	4.6191
27	3.8	3.4563	3.128177	3.4477
28	1.8	1.4665	1.144288	1.5144
29	4.6	5.1265	4.550518	4.8551
30	2.6	2.9055	2.621739	2.8556

Table 12: ATC Between Bus 23 To Bus 16 For Various Load Variation Test Cases Under Single Line Outage (PU)

Test Patterns	ACLF ATC	BPA ATC	RBF ATC	ANFIS ATC
31	12.80001	12.964	14.77582	12.801
32	9.5	9.952	11.346738	9.5025
33	9.9	10.141	10.166296	9.9001
34	8.6	8.9781	8.73677	8.6016
35	7	7.1053	6.681277	7
36	5.1	4.9325	3.966622	5.0999
37	6.5	6.4989	4.601788	6.4999
38	5.2	5.3608	3.105386	5.2077
39	1.9	1.9331	0.414151	1.9096

40	6.6	6.614	3.990614	6.5997
41	11.50001	11.34	11.803089	11.501
42	7.7	7.8051	8.00868	7.7019
43	8.8	8.81	8.951054	8.8002
44	7.6	7.444	7.837973	7.6012
45	5.4	5.3226	5.604135	5.4016
46	4	4.0617	4.146664	4.002
47	5.7	5.594	5.592674	5.6999
48	4.5	4.3272	4.477858	4.5004
49	2.3	2.2584	2.302838	2.3005
50	2.9	2.8876	2.897452	2.8998
51	11.80001	11.694	11.165541	11.768
52	6.8	6.5329	6.266925	6.7367
53	8.4	8.4842	8.085509	8.4004
54	6.4	6.3507	6.172842	6.4003
55	5	4.8195	4.810942	5.0366
56	2.3	2.3278	2.116342	2.3004
57	3.6	3.5195	3.495235	3.5999
58	1.2	1.2906	1.269242	1.2505
59	3.5	3.5012	3.433395	3.5455
60	2.2	2.162	2.135205	2.1744

4. DISCUSSION

A detailed discussion about the different techniques is provided in sections 3.1 to 3.5 following an extensive review of the data. According to Section 3.1, the researchers used the power world simulator and the NRLF method to compare the results of the evaluation. The DCPTDF is a basic technique that only provides an approximate value of ATC. The NRLF method is not ideal for deregulated markets as it is time-consuming and doesn't work well. The results of the ACPTDF method are closely related to those of the former.

In the six-bus system, the researchers were able to demonstrate that the proposed method was able to improve the ATC values by 25.85% compared to the DCPTDF. But, when compared to the ACPTDF, the researchers only managed to improve its value by 9.34%. The findings of the evaluation indicate that the proposed method is more reliable and produces consistent results than the conventional methods.

The values of ATC in a 30-bus system using the MEEPSO technique were 34.8% higher than those of the ACPTDF. On the other hand, the DCPTDF exhibited a 33.06% increase. 3.3 clearly states that a precise assessment of the ATC is required in order to increase the transmission capability of the network. It is also feasible to perform delicate line sorting. The SENSATC program and approach can be utilized to accomplish this. The use of the proposed method in the planning phase and in real-time control over the transmission network are some of the advantages that it provides. It can be utilized to determine the necessary increase in the transmission capacity during network congestion.

Section 3.4 states that the SVM model's accuracy can be improved by simultaneously calculating the ATC for different operating conditions. The study also noted that the suggested method can provide an approximate value of ATC for various operating conditions without compromising its accuracy. The RPF model takes longer to calculate the ATC than the SVM model. The results of the evaluation revealed that the SVM model is capable of accurately estimating the average transaction cost.

The researchers utilized various AI techniques such as the Back-Propagation Algorithm, the Neural Networks, and the Adaptive Fuzzy Neuro Inference System to calculate the ATC in real time. They were able to get an absolute error of 0.5265 for the base case and 0.352 for the line outage.

The researchers found that the RPF model exhibited the highest absolute error when it comes to calculating the ATC in two different scenarios: the base case and the line outage. The ANFIS model had the lowest absolute error when it comes to calculating the ATC in the base case.

The ANFIS model exhibited minimal errors in its base case and line outage scenarios, which made it an ideal choice for real-time applications of ATC computation.

5. CONCLUSION

According to the literature review, the quick and precise calculation of ATC is essential in order to increase the system's capacity during congestion. This issue can be triggered by the increasing load flow over the lines or by the minimum ATC. Different methods such as the PTDF, RPF, and linear approximation have been analysed. In order to maintain system security and reduce congestion, fast prediction of the ATC is necessary in real-time power system operations. This paper presents an overview of the various AI techniques that are used in this field. The researchers concluded that the SVM model is more efficient when it comes to calculating the ATC than other techniques. In real-time applications, the ANFIS method can be utilized since it has minimal errors when it comes to performing ATC computations.

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