



## ORIGINAL RESEARCH ARTICLE

## A REVIEW OF PROBABILISTIC APPROACHES FOR AVAILABLE TRANSFER CAPABILITY CALCULATION

O. O. Mohammed<sup>1,2\*</sup>, M. W. Mustafa<sup>1</sup>, A. O. Otuoze<sup>2</sup>, S. Salisu<sup>3</sup>, A. Y. Abdulrahman<sup>2</sup>,  
N. T. Surajudeen-Bakinde<sup>2</sup>

<sup>1</sup>School of Electrical Engineering, Universiti Teknologi Malaysia, Johor, Johor Bahru

<sup>2</sup>Department of Electrical and Electronics Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria

<sup>3</sup>Department of Electrical Engineering, Ahmadu Bello University, Zaria, Nigeria

\*Corresponding Author: [mohammed.oo@unilorin.edu.ng](mailto:mohammed.oo@unilorin.edu.ng), [reacholaabdul@gmail.com](mailto:reacholaabdul@gmail.com)

---

**ARTICLE INFORMATION**

Submitted 12 January, 2019

Revised 15 February, 2018

Accepted 1 March, 2018

---

**Keywords:**

available transfer capability  
probabilistic load flow Monte  
Carlo simulation  
artificial intelligence

**ABSTRACT**

Several deterministic approaches have been proposed in literature for available transfer capability (ATC) computation. However, the gradual shift in power generation sources from fossil fuels to renewable energy sources has a remarkable influence on the ATC evaluation. The deterministic approaches do not incorporate the uncertainties of the renewable energy sources efficiently, therefore, various probabilistic techniques have been proposed in literature. This article presents a review of the various probabilistic methods for ATC computation. It provides the background, techniques and the features of ATC. Several contributions made by researchers, using probabilistic techniques for ATC computation, have been highlighted in this paper. This review has shown that there is a need for improvement in the existing approaches in order to evaluate ATC accurately. The improvement includes the development of a robust technique incorporating the system uncertainties and the uncertainties due to the renewable energy system as well as complete system dynamics in ATC computation. In addition, evaluation of ATC incorporating the transfer capability margins (TRM and CBM) is necessary to avoid over-/under-estimation of ATC value. This review will serve as a guide for the entrants in this research area

---

© 2019 Faculty of Engineering, University of Maiduguri, Nigeria. All rights reserved.

---

**1.0 Introduction**

The economic and effective system operations associated with power system restructuring have instigated electric power utilities globally to follow progressive transformation from vertical power system structure to a more efficient framework known as deregulated systems. The monopoly structure has given rise to ineffective economic turnout, technical degradation and administrative mismanagement in the sector resulting in customers' dissatisfaction. However, experiences have shown that an effective reformation scheme for the electricity sector is necessary for efficiency enhancement which will attract economic, sustainable, and reliable power supply (Jamasb *et al.*, 2014, Sureban and Ankaliki, 2017). Therefore, the majority of the utilities are going through restructuring to control the ineffectiveness of the non-competitive market (Kröger, 2008). This transformation has given rise to competition at the different level of utilities thereby regulating the existing monopolistic structure and encouraging non-

governmental participation in power system investment and control with guaranteed access to open access transmission network (Christie *et al.*, 2000). The operations of various utilities are included in the generation and distribution, and the decision about generation schedules and load dispatch is based on their contract agreement (Lai, 2001). Therefore, the power flow (PF) schemes in the deregulated environment are presumably different from the previous existing monopoly structure (Lai, 2001). All stakeholders try to take advantage of cheaper derivation and broader profit differences; this consequently leads to transmission network congestion. The transmission congestion leads to the violation of voltage limits, voltage stability, and thermal limits, thereby threatening the system security. Although the economic ways of transmission expansion have not been simulated (Rodrigues and Da Silva, 2007), this is due to the antecedence constraints and economic challenges faced by the power sector in achieving the expansion. These constraints have forced transmission providers to operate the system network close to their limits. Consequently, economic capacity indices have been employed to provide a quantitative measure for power transfer reliability assessment, among these indices is available transfer capability (ATC). Therefore, independent system operators (ISO) are required to regularly update their ATC on Open Access Same-Time Information System (OASIS), established by United State Federal Energy Regulatory Commission (FERC), for efficient system operation. Hence, any scheduled power transfer either firm or non-firm transfer has to be within the ATC of the interconnected systems.

Accurate evaluation of ATC is very important to know the economic and technical feasibility of the available transmission system capability for security monitoring and efficient market operations. Future upgrading of the transmission network can be predicted using system ATC values (Othman *et al.*, 2009). The computation of ATC should incorporate the following system limits; voltage limit, thermal limit, voltage stability limit, real and reactive power generation limit, and system uncertainties (Rep, 1996), to avoid inaccuracies in ATC evaluation. Overestimation of ATC has remarkable adverse effects on the system security (Kundur *et al.*, 2004) and underestimation of ATC value results in ineffective utilization of the power system resources. For example, the major blackout in the North-eastern United States and Ontario in August 2003 was a result of an overestimation of ATC (Jacobs). Therefore, the results of ATC inaccuracies can cause huge loss to the utilities. The information about the size of ATC is vital to system utility and the planner as it depicts the general performance of the power system regarding efficiency and economic activities (Sauer, 1997).

Essentially, ATC is an index for measuring the transfer capability remaining in the physical transmission network over and above already committed uses, for future commercial activity (Rep, 1996). The value of ATC is obtained by considering various parameters associated with transfer capabilities such as total transfer capability (TTC), transmission reliability margin (TRM), and capacity benefit margin (CBM). TTC is the summation of the transfer capability margins (TRM and CBM), ATC and the existing transmission commitments. TRM is the network margin reserved for system uncertainties. CBM is the network margin reserved for the utilities to have access to external generation in case of emergency supply shortage (Rep, 1996, Dobson *et al.*, 2001). The graphical representation of these terms is as shown in figure 1, the purple, blue and green dotted lines represent the TTC at different system limits as shown in the figure. The power transfer capability simulation is based on the equality and inequality constraints of load flow equations and the system limits (thermal, voltage and stability), respectively. TTC is obtained as the result of the simulation and it varies with the system limits. After then, ATC value is obtained

by deducting other parameters (TRM, Existing transmission commitments and CBM) from the TTC obtained from the simulation. The ATC can increase/decrease depending on the system operating conditions and the system limits. The purple line is the most restricted TTC value as shown in figure (Min TTC) and hence, taken as the systems' TTC (Rep, 1996, Khairuddin and Alhammi, 2014, Shin *et al.*, 2007, Mohammed *et al.*, 2019b).

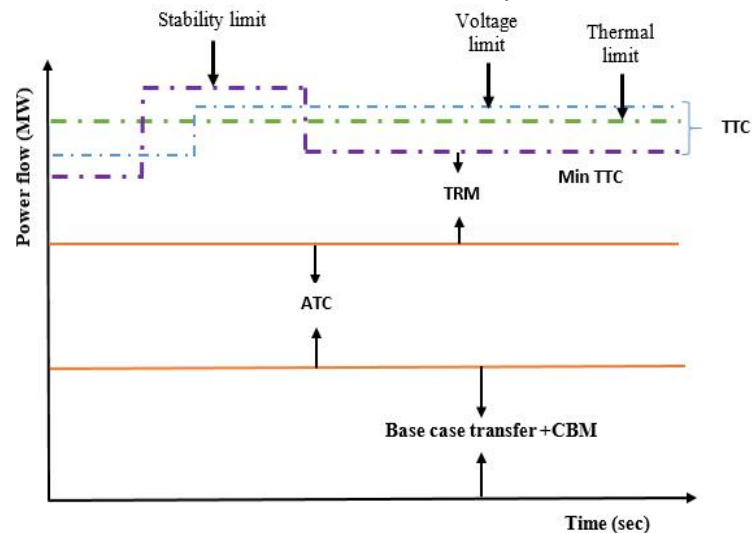


Figure 1: ATC limitations and related parameters.

Mathematically, ATC can be expressed as (Rep, 1996):

$$ATC = TTC - TRM - ETC(\text{including CBM})$$

¥\* MERGEFORMAT (1)

The quest for energy sustainability around the world has instigated a large integration of renewable energy sources in the modern power system network (Mohammed *et al.*, 2019a). However, renewable energy sources are stochastic in nature, thereby, the evaluation of the network capacity can only be assessed probabilistically. Despite the enormous deterministic approaches for ATC computation, only a few probabilistic techniques exist. The objective of this paper is to present a review of the probabilistic ATC determination methods. The probabilistic techniques include; numerical methods (e.g., Monte Carlo Simulation (MCS)), Analytical based techniques (e.g., using convolution technique with PDF of the system states) and approximate techniques (e.g., point estimation method) (Chen *et al.*, 2008). The various existing techniques are reviewed and the merits and demerits of each of the approaches are highlighted.

### Probabilistic approaches for ATC computation

The deregulation in the electric power structure has started since 1996, and till present, many approaches have been suggested in the literature for accurate determination of ATC. The calculation of ATC is generally based on computer simulations, by simulating the interconnected transmission network operation for a postulated set of operating conditions. Deterministic approaches are employed on a daily basis for the analysis and assessment of system planning and operation. It performs the steady-state simulation of power systems, i.e., specific values of the system generations and demands of a particular network configuration is used to compute PF and the system states (Chen *et al.*, 2008). However, the system uncertainties cannot be efficiently conveyed in the deterministic approaches. Figure 2 summarizes the various probabilistic methods employed in literature to determine ATC.

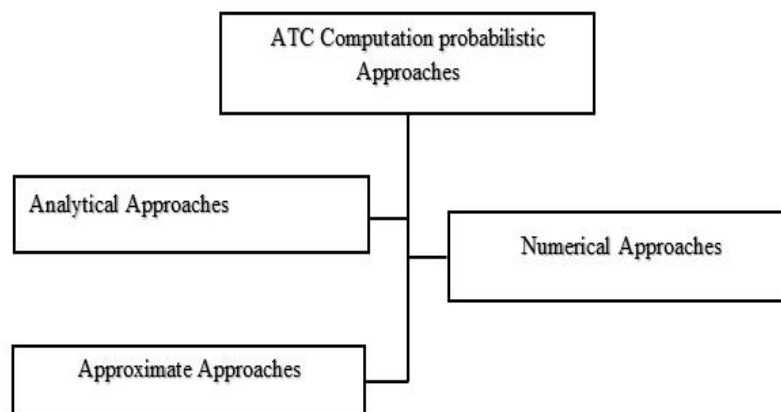


Figure 2: Probabilistic Approaches for ATC computation

The continuous increase in the percentage of renewable energy integration has created a great concern on the reliability of generation systems due to the stochastic nature of the power output from renewables especially the wind and solar energies. This has increased the uncertainties associated with power system operations (Sharifzadeh *et al.*, 2017). Moreover, uncertainties in system loads due to costumers' consumption patterns and weather variability, the outage of generators, and the change of network configurations also contribute to system uncertainties (Chen *et al.*, 2008). The traditional deterministic techniques determine the steady-state simulation of power systems, which indicate the snapshot of particular operating conditions of the network (Shin *et al.*, 2007). Evidently, it is impractical to implement ideal load flow computations for every feasible and likely combination of generating unit outages and bus loads because of the eventuality of the extensive computational problem (Shin *et al.*, 2007, Shin *et al.*, 2003). To solve this limitation of the deterministic methods, probabilistic load flow techniques were proposed (Rodrigues and Da Silva, 2007, Shin *et al.*, 2007, Morales and Perez-Ruiz, 2007, Zhang and Lee, 2004, Usaola, 2009, Borkowska, 1974). Probabilistic load flow is a principal tool used to provide essential information on power system planning, operation, and control (Prusty and Jena, 2016). It aimed at assessing node voltages, and network flow in responses to the system parameters' uncertainties (Aien *et al.*, 2014). The uncertainty analysis of power system performance is crucial, and generally, the uncertainties in any engineering system study can be solved probabilistically (Aien *et al.*, 2016). Probabilistic methods are not only accurate but also give more information such as the expected value and variance of ATC. They can be broadly categorized into three methods (Chen *et al.*, 2008, Gupta, 2016, Le *et al.*, 2017): numerical-based probabilistic techniques (e.g. MCS), Analytical-based probabilistic techniques (e.g. using convolution technique with probability density function (PDF) of the system states) and approximate techniques (e.g. point estimation method). Various artificial intelligence methods have been employed in literature for ATC computation (Jain *et al.*, 2011, Luo *et al.*, 2000, Jain *et al.*, 2007, Yi and Yang, 2005, Pandey *et al.*, 2010) and remarkable progresses have been achieved due to the robustness, fastness, and the capability to solve complex nonlinear problems which are not feasible to be solved analytically (Mohammed *et al.*, 2019b).

### Numerical based approach

Monte Carlo Simulation (MCS) method is usually adopted for the numerical based probabilistic method (Chen *et al.*, 2008). Random number generation and random sampling are the two significant features of MSC. Generally, the probabilistic technique using MCS computes PF by using deterministic load flow for a large number of times with different combinations of nodal

power value at the inputs. It uses repeated distributions of nodal powers, network flows and losses (Hojabri *et al.*, 2010). The load flow computation is performed based on the samples of uncertain factors for many times and the statistical analysis is used to find the probability distribution of the reliability indices and the specified system states (Li and Zhang, 2009). Therefore, the general non-linear load flow equations can be used for probabilistic analysis (Chen *et al.*, 2008).

Several probabilistic methods based on MCS have been employed in the literature for ATC evaluation (Sekita *et al.*, 2008, Da Silva *et al.*, 2004, Rodrigues and Da Silva, 2007, Gupta and Kumar, 2016b, Gupta and Kumar, 2016a, Shin *et al.*, 2007). Assessment of ATC, TTC and power system reliability margins (TRM and CBM) based on MCS considering system uncertainties was proposed in (Sekita *et al.*, 2008). The total benefit of the ATC and CBM are compared based on the period of utilization. It was affirmed that the overall benefit strongly depends on the period of usage. However, in a deregulated environment the system security and the economic benefit are of paramount importance. ATC serves as an economic index to measure the viability of the economic activity and should have a more significant benefit than the CBM whose value is a fixed amount and may not be utilized if there is no any loss of generation in the specified area. Moreover, in this work LOLE is evaluated based on the largest demand in the areas, this may lead to underutilization of transmission equipment during the off-peak period because the space that could be used for ATC has been reserved for CBM. An algorithm based on non-sequential MCS (Da Silva *et al.*, 2004) to select system state and linear programming with DC PF model was employed to analyse and optimize each selected state. The probability density of the ATC incorporating uncertainties from the unavailability of the system equipment was determined. The objective was to evaluate PDF associated with maximum power transfer from one area to another and to locate the best point in the system where additional generation and loads can be considered without jeopardising the existing system security and transactions. The chronological variation in ATC due to uncertainties associated with hourly load fluctuations and equipment unavailability was assessed for a weekly study period (Rodrigues and Da Silva, 2007) using the MCS method with sequential simulation. Linear DC OPF was used to evaluate the ATC of each generated state. The results show that time-dependent uncertainties have a remarkable influence on the ATC.

A probabilistic assessment of ATC incorporating wind power resources was used (Gupta and Kumar, 2016a, Gupta and Kumar, 2016b) while MCS and Latin hypercube sampling were used to deal with the stochastic nature of the system load demand and wind resources (Gupta and Kumar, 2016a). The problem was formulated as an OPF subject to the constraints of PF equations, voltage limits, line flow, generator active and reactive power limits. Three different scenarios were assessed, in the first case, probabilistic nature of load was not considered, the second case incorporates the probabilistic nature of load using MCS and third case using LHS in place of MCS. The results indicate that the ATC increases with wind power injection. Incorporating the probabilistic nature of load reduces the values of ATC using MCS, using LHS further reduced the ATC values and gave better ATC results due to an efficient approximation of normally distributed load compared with MCS. In (Shin *et al.*, 2007), TTC was determined using the CPF approach, TRM and CBM are evaluated by probabilistic load flow (PLF) and MCS respectively. The PLF method converts the load flow problem from deterministic to the stochastic formulation using the Gram-Charlier series. The results from the stochastic approach define the range of PF analysis output quantities, i.e. bus voltage, real and reactive power, and line flows along with the

related probabilities. Evaluation of ATC using a cubic-spline interpolation technique is proposed in (Othman *et al.*, 2005, Busan *et al.*, 2010). In this technique, the curves of voltage magnitude and PF variations are traced, and the ATC was determined at the point where the PF or the voltage limits intersect the curves. Contingency ranking and selection techniques are employed to select the critical lines that can influence the ATC assessment. Four incremental steps of power transfer were used, which was assumed to be sufficient to produce an accurate fitting of the curve, to avoid substantial computation time. Sensitivity method was used to predict the maximum power transfer for the step four. The technique is faster than the repeated AC PF method. However, this technique will result in a substantial computation for large-scale power systems.

The results obtained from other probabilistic methods using simplified load flow equations are usually compared with MCS results as a reference to check the accuracy of those methods. This is due to the ability of the MCS to use exact non-linear load flow equations (Chen *et al.*, 2008). However, considerable computation time is required as a result of a large number of load flow equations to be computed and also the number of system states to be sampled increases with the system size. Different variance reduction methods (Jirutitijaroen and Singh, 2008) have been employed to reduce the time of computation (Li and Zhang, 2009). Nevertheless, the enormous time of computations is still required to get accurate results, especially in bulk power systems.

### **Analytical approach**

Convolution methods are the analytical methods commonly employed in the past to find the probability distributions of the desired variables (Borkowska, 1974, Allan *et al.*, 1974, Allan and Al-Shakarchi, 1977). The PDFs of the stochastic variables of the system states and line flows are determined using the convolution approach. However, the efficiency of the computation is very low; hence improvements have been made by using fast Fourier transforms (Allan and Da Silva, 1981, Allan *et al.*, 1981b) which leads to the development of numerical characteristics based methods such as moments and cumulants methods. The assumptions of these methods are: linearization of the non-linear load flow equations, the input power variables at different buses are independent or linearly correlated, load and generation follow a normal distribution and discrete distribution respectively, and network configurations and parameters are constant (Chen *et al.*, 2008, Li and Zhang, 2009). The details on the convolution methods for mixed continuous and discrete variables can be found in (Allan *et al.*, 1976, Allan *et al.*, 1981b, Allan *et al.*, 1981a).

Various analytical approaches have been employed in ATC determination. An OPF based ATC model is formulated and extended blind number algorithm incorporating the various types of uncertainties was applied (Gao *et al.*, 2009) for the evaluation of the ATC. The objective functions are to maximize the total active power of the source area and the total loads of the sink area as well as maximizing the active PF of the interconnecting lines. The algorithm was able to evaluate the approximate values of the interarea ATC incorporating the uncertainties in the system load demand. However, the algorithm is impractical for large power systems, as it is computationally expensive. A probabilistic PF incorporating a correlated wind power model to evaluate the impact of high wind penetration in ATC calculation was proposed in (Fang *et al.*, 2014). The proposed model compensates the imbalance caused by the wind variation using a set of conventional generators instead of using only slack bus through specific sharing factors. ATC computation was converted to a linear programming problem via DC OPF and sensitivity analysis approach. A stochastic algebraic methods (SAM) is proposed in (Stahlhut and Heydt, 2007) to evaluate ATC, the uncertainties due to bus loading and transmission element status are

incorporated as well as voltage and thermal limits. The approach adopted in calculating the ATC is based on the concept of linear system behaviour, stationarity of statistics and uncorrelated bus load statistics. Three different cases were considered and analysed. The first case used MCS incorporating the uncertainty due to bus loading; the second case employed SAM with the same uncertainty while the third case includes both the bus loading and lines outages uncertainties using SAM. The first case and the second case were compared, and the results show a similarity of 1% in mean and 12% in standard deviation. The algorithm is faster in comparison with MCS, the computation time for the MCS is 24 hours while the algorithm took 1 minute.

Analytical methods are computationally effective compared to numerical methods. However, the drawbacks of this method are the complicated mathematical computations involved and the degradation in the accuracy of the results due to linearization and assumptions. The assumptions are valid for a specific range of system operating conditions, as the network configuration changes, the results deviate from actual values.

### **Approximate approach**

Accuracy and computational speed can be achieved by using approximate methods. First-order second-moment method (Madrigal *et al.*, 1998) and the point estimate method (Su, 2005) are commonly employed in approximate methods. Point estimate method is a combination of both analytical and numerical methods. It also makes use of numerical characteristics of input variables, similar to analytical methods. However, different techniques are employed to find the numerical features of the outputs without linearizing the load flow equations (Li and Zhang, 2009). The detailed formulation and procedure for analytical and approximate methods can be found in (Li and Zhang, 2009).

A mathematical model of ATC for HVDC-AC hybrid system was formulated (Wei *et al.*, 2013), and the sequential solution method was employed to solve the AC-DC PF. Golden section is used to accelerate the PF convergence. Several statistical indices were applied to evaluate the ATC due to the uncertainties of the system. The hybrid algorithm of Monte Carlo and bootstrap was used to solve the statistical indices. A stochastic parallel algorithm was proposed (Stahlhut *et al.*, 2005) to evaluate ATC. Different statistical indices are applied to calculate ATC, and they are calculated based on MCS and OPF. The OPF is used for PF solution. The results show that the proposed technique is faster, more effective and practical than conventional MCS.

### **Summary of the probabilistic approaches**

Table 1 summarizes the efficacy of some of the important probabilistic approaches based on the system constraints and the uncertainties considered (Hojabri *et al.*, 2010). Due to the limitation of the methodology employed in these approaches, the incorporation of all the constraints is not feasible. Using Table 1 to evaluate the performance of these approaches, it is evident that MCS is better than other methods because it incorporates more constraints and uncertainties than other techniques. In spite of the accuracy of these techniques, which is very crucial in the deregulated environment, they are rarely used for online applications because of the enormous computational time required especially for large power systems, and they are less accurate for relatively small power systems. Therefore, probabilistic methods cannot completely replace the deterministic techniques in ATC assessment due to some factors such as complex computations, substantial computation time which make probabilistic techniques unattractive in real-time applications. However, artificial intelligence can be modified to accommodate all the constraints and uncertainties in the face of large ATC data (Mohammed *et al.*, 2019b).

**Table 1:** System uncertainties and limitations considered in some of the essential probabilistic approaches.

Uncertainties and constraints	Stochastic programming	MCS	Cubic spline	Artificial intelligence
V limit	✓	✓	✓	✓
Thermal limit	✓	✓	✓	✓
P <sub>g</sub> limit	✗	✓	✗	✓
Q <sub>g</sub> limit	✗	✓	✗	✓
P <sub>L</sub> limit	✗	✓	✗	✓
Voltage stability limit	✓	✗	✗	✗
Load variations	✓	✓	✗	✗
System components outages	✓	✓	✓	✓

### Comparison of the methods

The comparison of the existing probabilistic approaches in terms of their advantages and disadvantages are highlighted in Table 2. The accurate estimation of ATC depends on the incorporation of the entire system dynamics, system's parameter limits (voltage, thermal and stability) and system uncertainties in the approach employed which will eventually result in a considerable time of computation. However, fastness and simplicity rely on the use of linearized and simplified techniques.

**Table 2:** Comparison of different methods with advantages and disadvantages.

Methods	Advantages	Disadvantages
Numerical method	It incorporates system uncertainties, and accurate ATC result can be obtained.	Remarkable computation time is required due to the enormous number of load flow equations to be calculated.
Analytical method	It considers most system uncertainties, and it is computationally efficient compared with the numerical method.	Due to linearization and some assumptions in the mathematical formulation of the equations employed, the accuracy of the results is degraded.
Approximate method	Accurate ATC results can be obtained without linearization of the load flow equations and the computational time is faster than the numerical method.	They are seldom used for online application due to remarkable computation time required.
Artificial intelligent method	Fast and accurate	To accurately evaluate ATC, enormous ATC data is required as input to these techniques, and this may eventually require remarkable computational resources.



## Conclusion

The review of the existing probabilistic approaches for ATC determination has been presented in this paper. The three probabilistic techniques which include; numerical, analytical and approximate methods have been reviewed, evaluated and compared. Each of the methods has its distinguishing attributes which have been highlighted in this paper. The merits and demerits of each approach have been emphasized. It is evident from the existing literature that much work has not been done on ATC using probabilistic methods relative to deterministic approaches and most of the probabilistic methods do not incorporate the required system uncertainties and limits such as load uncertainties and state transition of system equipment (generator outages, tie-line outages, and transformer faults). Of all the papers reviewed, only three papers (Gupta and Kumar, 2016b, Gupta and Kumar, 2016a, Fang *et al.*, 2014) incorporate wind energy resources in ATC evaluation. Therefore, more efforts are required in the consideration of renewable energy sources in the ATC computation due to the global shifting from conventional sources of generating systems to renewable energies. Hence, it can be concluded that a robust technique incorporating all system constraints, system uncertainties, and remarkable renewable energy sources in an online ATC evaluation is essential for accurate assessment of ATC in modern power systems.

## References

- Aien, M., Hajebrahimi, A. and Fotuhi-Firuzabad, M. 2016. A comprehensive review on uncertainty modeling techniques in power system studies. *Renewable and Sustainable Energy Reviews*, 57, 1077-1089.
- Aien, M., Rashidinejad, M. and Fotuhi-Firuzabad, M. 2014. On possibilistic and probabilistic uncertainty assessment of power flow problem: A review and a new approach. *Renewable and Sustainable Energy Reviews*, 37, 883-895.
- Allan, R. And Al-Shakarchi, M. 1977. Probabilistic techniques in ac load-flow analysis. Proceedings of the Institution of Electrical Engineers, 1977. IET, 154-160.
- Allan, R., Borkowska, B. and Grigg, C. Probabilistic analysis of power flows. Proceedings of the Institution of Electrical Engineers, 1974. IET, 1551-1556.
- Allan, R. and Da Silva, AL. 1981. Probabilistic load flow using multilinearizations. IEE Proceedings C (Generation, Transmission and Distribution), 1981. IET, 280-287.
- Allan, R., Da Silva, AL., Abu-Nasser, A. and Burchett, R. 1981a. Discrete convolution in power system reliability. *IEEE Transactions on Reliability*, 30, 452-456.
- Allan, R., Da Silva, AL. and Burchett, R. 1981b. Evaluation methods and accuracy in probabilistic load flow solutions. *IEEE Transactions on Power Apparatus and Systems*, 2539-2546.
- Allan, R., Grigg, C. and Al-Shakarchi, M. 1976. Numerical techniques in probabilistic load flow problems. *International Journal for Numerical Methods in Engineering*, 10, 853-860.
- Borkowska, B. 1974. Probabilistic load flow. *IEEE Transactions on Power Apparatus and Systems*, 752-759.
- Busan, S., Othman, M. and Musirin, I. 2010. Transfer capability computation considering steady-state and transient stability constraints. Power Engineering and Optimization Conference (PEOCO), 2010 4th International, 2010. IEEE, 331-336.

- Chen, P., Chen, Z. and Bak-Jensen, B. 2008. Probabilistic load flow: A review. Electric Utility Deregulation and Restructuring and Power Technologies, 2008. DRPT 2008. Third International Conference on, 2008. IEEE, 1586-1591.
- Christie, RD., Wollenberg, BF. And Wangensteen, I. 2000. Transmission management in the deregulated environment. *Proceedings of the IEEE*, 88, 170-195.
- Da Silva, Al., Costa, J., Manso, L. and Anders, G. 2004. Evaluation of transfer capabilities of transmission systems in competitive environments. *International journal of electrical power and energy systems*, 26, 257-263.
- Dobson, I., Greene, S., Rajaraman, R., Demarco, CL., Alvarado, FL., Glavic, M., Zhang, J. and Zimmerman, R. 2001. Electric power transfer capability: concepts, applications, sensitivity and uncertainty. Power Systems Engineering Research Centre, Cornell University New York, NY, USA.
- Fang, X., Li, F. and Gao, N. 2014. Probabilistic available transfer capability evaluation for power systems including high penetration of wind power. Probabilistic Methods Applied to Power Systems (PMAPS), 2014 International Conference on, 2014. IEEE, 1-6.
- Gao, C., Pan, H., Wan, Q. and Lai, LL. 2009. Available transfer capability evaluation based on extended blind number. Systems, Man and Cybernetics, 2009. SMC 2009. IEEE International Conference on, 2009. IEEE, 4189-4194.
- Gupta, A. and Kumar, A. 2016. ATC calculation including wind: A probabilistic study and a comparison of MCS and LHS. Power Systems (ICPS), 2016 IEEE 6th International Conference on, 2016a. IEEE, 1-6.
- Gupta, A. and Kumar, A. 2016. Optimal power flow based ATC calculation incorporating probabilistic nature of wind. Electrical, Electronics and Computer Science (SCECS), 2016 IEEE Students' Conference on, 2016b. IEEE, 1-6.
- Gupta, N. 2016. A review on the inclusion of wind generation in power system studies. *Renewable and Sustainable Energy Reviews*, 59, 530-543.
- Hojabri, M., Hizam, H., Mariun, N. and Abdullah, SM. 2010. Comparative Analysis of ATC Probabilistic Methods. *Journal of American Science*, 6.
- Jacobs, M. 2003. The Largest Power Outages in History—and What They Tell Us About the 2003 Northeast Blackout. Union of Concerned Scientists: <http://blog.ucsusa.org/mike-jacobs/2003-northeast-blackout-and-13-of-the-largest-power-outages-in-history-199> adresinden alınmıştır.
- Jain, T., Singh, S. and Srivastava, SA. 2007. neural network based method for fast ATC estimation in electricity markets. Power Engineering Society General Meeting, 2007. IEEE, 2007. IEEE, 1-8.
- Jain, T., Singh, SN. and Srivastava, SC. 2011. Fast static available transfer capability determination using radial basis function neural network. *Applied Soft Computing*, 11, 2756-2764.
- Jamasb, T., Nepal, R., Timilsina, G. and Toman, M. 2014. Energy Sector Reform, Economic Efficiency and Poverty Reduction. University of Queensland, School of Economics.
- Jirutitijaroen, P. and Singh, C. 2008. Comparison of simulation methods for power system reliability indexes and their distributions. *IEEE Transactions on Power Systems*, 23, 486-493.
- Khairuddin, A. and Alhammi, A. 2014. Review of Available Transfer Capability Determination with Grid Connected Hybrid Wind System using Probabilistic Collocation Method.
- Kröger, W. 2008. Critical infrastructures at risk: A need for a new conceptual approach and extended analytical tools. *Reliability Engineering and System Safety*, 93, 1781-1787.

Kundur, P., Paserba, J., Ajarapu, V., Andersson, G., Bose, A., Canizares, C., Hatziargyriou, N., Hill, D., Stankovic, A. and Taylor, C. 2004. Definition and classification of power system stability. *IEEE transactions on Power Systems*, 19, 1387-1401.

LAI, LL. 2001. *Power system restructuring and deregulation: trading, performance and information technology*, John Wiley and Sons.

Le, DD., Nguyen, NTA., Van Duong, N. and Berizzi, A. 2017. Advanced probabilistic power flow methodology for power systems with renewable resources. *Turkish Journal of Electrical Engineering and Computer Sciences*, 25, 1154-1162.

Li, G. and Zhang, XP. 2009. Comparison between two probabilistic load flow methods for reliability assessment. Power and Energy Society General Meeting, 2009. PES'09. IEEE, 2009. IEEE, 1-7.

Luo, X., Patton, A. and Singh, C. 2000. Real power transfer capability calculations using multi-layer feed-forward neural networks. *IEEE Transactions on Power Systems*, 15, 903-908.

Madrigal, M., Ponnambalam, K. and Quintana, V. 1998. Probabilistic optimal power flow. Electrical and Computer Engineering, 1998. IEEE Canadian Conference on, 1998. IEEE, 385-388.

Mohammed, OO., Otuoze, A., Salisu, S., Ibrahim, O. and Rufa'I, N. 2019a. VIRTUAL SYNCHRONOUS GENERATOR: AN OVERVIEW. *Nigerian Journal of Technology (NIJOTECH)*, 38, 153-164.

Mohammed, OO., Mustafa, MW., Mohammed, DSS. and Otuoze, AO. 2019b. Available transfer capability calculation methods: A comprehensive review. *International Transactions on Electrical Energy Systems*, e2846.

Morales, JM. and Perez-Ruiz, J. 2007. Point estimate schemes to solve the probabilistic power flow. *IEEE Transactions on Power Systems*, 22, 1594-1601.

Othman, M., Mohamed, A. and Hussain, A. 2005. Fast evaluation of available transfer capability using cubic-spline interpolation technique. *Electric Power systems research*, 73, 335-342.

Othman, M., Rahman, KA., Musirin, I., Mohamed, A. and Hussain, A. 2009. The application of Box-Jenkins models in short term load forecasting. *International Journal of Power, Energy and Artificial Intelligence*, 2, 104-110.

Pandey, SN., Pandey, NK., Tapaswi, S. and Srivastava, L. 2010. Neural network-based approach for ATC estimation using distributed computing. *IEEE Transactions on power systems*, 25, 1291-1300.

Prusty, BR. and Jena, D. 2016. A critical review on probabilistic load flow studies in uncertainty constrained power systems with photovoltaic generation and a new approach. *Renewable and Sustainable Energy Reviews*.

Rep, N. 1996. Available transfer capability Definitions and determinations. *North American Electric Reliability Council (NERC)*.

Rodrigues, AB. and Da Silva, MG. 2007. Probabilistic assessment of available transfer capability based on Monte Carlo method with sequential simulation. *IEEE Transactions on Power Systems*, 22, 484-492.

Sauer, PW. 1997. Technical challenges of computing available transfer capability (ATC) in electric power systems. System Sciences, 1997, Proceedings of the Thirtieth Hawaii International Conference on, 1997. IEEE, 589-593.

Sekita, K., Yokoyama, A., Verma, S. and Nakachi, Y. 2008. Probabilistic evaluation method of available transfer capability considering reliability margins in transmission network. Power System Technology and IEEE Power India Conference, 2008. POWERCON 2008. Joint International Conference on, 2008. IEEE, 1-6.

Sharifzadeh, M., Lubiano-Walochik, H. and Shah, N. 2017. Integrated renewable electricity generation considering uncertainties: The UK roadmap to 50% power generation from wind and solar energies. *Renewable and Sustainable Energy Reviews*, 72, 385-398.

Shin, DJ., Kim, JO., Kim, KH. and Singh, C. 2007. Probabilistic approach to available transfer capability calculation. *Electric power systems research*, 77, 813-820.

Shin, DJ., Lee, HS. and Kim, JO. 2003. Quantification Method of TRM (Transmission Reliability Margin) Using Probabilistic Load Flow. *IFAC Proceedings Volumes*, 36, 679-684.

Stahlhut, J., Heydt, G. and Sheblé, GA. 2005. stochastic evaluation of available transfer capability. Power Engineering Society General Meeting, 2005. IEEE, 2005. IEEE, 3055-3061.

Stahlhut, JW. and Heydt, GT. 2007. Stochastic-algebraic calculation of available transfer capability. *IEEE Transactions on Power Systems*, 22, 616-623.

Su, CL. 2005. Probabilistic load-flow computation using point estimate method. *IEEE Transactions on Power Systems*, 20, 1843-1851.

Sureban, MS. and Ankaliki, SG. 2017. Computation of Available Transfer Capability in Electrical Transmission System-A Review. *i-Manager's Journal on Power Systems Engineering*, 5, 35.

Usaola, J. 2009. Probabilistic load flow with wind production uncertainty using cumulants and Cornish-Fisher expansion. *International Journal of Electrical Power and Energy Systems*, 31, 474-481.

Wei, J., Li, G. and Zhou, M. 2013. Monte Carlo simulation and bootstrap method based assessment of available transfer capability in AC-DC hybrid systems. *International Journal of Electrical Power and Energy Systems*, 53, 231-236.

Yi, H. Y. and Yang, HC. 2005. Multi-layer feedforward neural network-based atc estimator. Power Tech, 2005 IEEE Russia, 2005. IEEE, 1-7.

Zhang, P. and Lee, ST. 2004. Probabilistic load flow computation using the method of combined cumulants and Gram-Charlier expansion. *IEEE transactions on power systems*, 19, 676-682.