

The Impact of System Cascading Collapse and Transmission Line Outages to the Transfer Capability Assessment

N. A. Salim, M. M. Othman, I. Musirin, M. S. Serwan

Abstract—Uncertainty of system operating conditions is one of the causative reasons which may render to the instability of a transmission system. For that reason, accurate assessment of transmission reliability margin (TRM) is essential to ensure effective power transfer between areas during the occurrence of system uncertainties. The power transfer is also called as the available transfer capability (ATC) which is the information required by the utilities and marketers to instigate selling and buying the electric energy. This paper proposes a computationally effective approach to estimate TRM and ATC by considering the uncertainties of system cascading collapse and transmission line outages. In accordance to the results that have been obtained, the proposed method is essential for the transmission providers which could help the power marketers and planning sectors in the operation and reserving transmission services based on the ATC calculated.

Keywords—Available transfer capability, System cascading collapse, Transmission line outages, Transmission reliability margin.

I. INTRODUCTION

IN many countries around the world, electric power systems are operating in a deregulated environment where the generation, transmission and distribution systems owned by different companies will enhance intense competition in the electricity market among them in order to provide more reliable, cost effective and efficient electricity to the consumers. In order to ensure a secure operation of deregulated power system with persuasive activities in electricity market, the Independent System Operator (ISO) is responsible in congestion management for the attainment of system security and the Available Transfer Capability (ATC) determination to ensure effectiveness in the electricity market [1]. ATC is defined as the amount of power transfer above the base case flows that remains in the system for further use without exposing the system to any type of risk [2]. The value of ATC should be obtained corresponds to a precise and realistic

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information about the capability of the interconnected system to reliably transfer the power between two areas. The ATC is determined by taking into account the accurate amount of transmission reliability margin (TRM) in which this is to ensure effective power transfer between areas can be attained during the presence of system uncertainties. The uncertainty of system cascading collapse is one of the reasons that could lead to the calamitous collapse of a power system.

In order to consider the uncertainties of power system operating conditions in the computation of ATC, various approaches have been proposed to assess the ATC. However, at present, not much work has been done in the assessment of TRM. Chun-Lien et al. [3] proposes a two-point estimate method in order to assess the power transfer capability uncertainty. This method uses a numerical method to calculate the moments of transfer capability where it is then used to obtain the probability distribution fitting. Zhang et al. [4] applies the Monte-Carlo simulations in quantifying TRM by applying a formula which quantifies TRM based on transfer capability sensitivities and probabilistic characterization of various uncertainties. Zaini et al. [5] uses the bootstrap technique in order to determine TRM by taking into consideration the uncertainties of transmission line outages and system parameters. The similar technique used can be found in [6].

Based on the literature study that has been performed, it is important to evaluate the ATC and TRM by taking into consideration the uncertainty of system cascading collapse, which is identified as one of the reasons that could lead to the calamitous collapse of a power system. For that reason, this paper proposes a computational effective method of TRM and ATC determination. The analysis is performed in order to study the impact of uncertainty of system cascading collapse and transmission line outages to the power transfer. The IEEE RTS-96 is used as a case study in order to validate the effectiveness of the proposed technique considered in the assessment of TRM and ATC. The assessment of TRM and ATC needs to be performed consistently in the power system planning and operation so that the power system could be prevented from any type of catastrophic events.

II. FRAMEWORK OF ATC CALCULATION

This section will discuss on the method used to estimate TRM and ATC taking into consideration uncertainty associated with system cascading collapse and transmission line outages. The first subsection explains in detail on the

TRM calculation pertaining the uncertainty of system cascading collapse. Then, the steps taken to calculate TRM by taking into account the uncertainty of transmission line outages is explain in the following section. Finally, the value of ATC taking into account the uncertainty of system cascading collapse and transmission line outages is described in the last subsection.

A. TRM Determination Considering System Cascading Collapse

Due to severe impact of system cascading collapse to the operation of power system, it is crucially important for a power system operator and planning to determine the uncertainty related to system cascading collapse. Therefore, the uncertainty of system cascading collapse ought to be included in the evaluation of TRM for effective selling and buying of electricity based on the information of ATC. This section will explain on the procedure of TRM determination by taking into account the uncertainty of system cascading collapse. The proposed methodology is described comprehensively in the following procedure [7].

- i. Increase the system loading level, l by 10% while maintaining a constant power factor at all buses.
- ii. Determine the average probability of system cascading collapse, P_i^{cc} for initial tripping event of all transmission lines. The detail procedure to determine P_i^{cc} has been explained in [7].
- iii. Calculate the risk of a system cascading collapse, R_l^{cc} , at loading level l by applying (1).

$$R_l^{cc} = \frac{l}{I} \sum_{i=1}^I P_i^{cc} \quad (1)$$

where,

I = set of transmission lines whose tripping event shall trigger to a system cascading collapse.

- iv. Reiterate steps i-iii in order to obtain the risk of system cascading collapse, R_l^{cc} for the subsequent increment of system loading level, l . This process is reiterated until the system loading level reaches to a specified value from its base case value. For the IEEE RTS-96 analytical hypothesis has proven that the risk of a system cascading collapse, R_l^{cc} commence to increase exponentially from 130% up to 220% of the base case value [8].
- v. Record the risk of system cascading collapse for different level of system loading condition.
- vi. Calculate a sample of ATCs determined based on various system loading levels, ATC_l , by using (2).

$$ATC_l = R_l^{cc} \times ATC_0 \quad (2)$$

where,

ATC_0 = base case value of ATC at a given case of power transfer.

- vii. Arrange the ATC_l in ascending order. Hence, calculate TRM_{col} by taking into consideration the uncertainty of system cascading collapse using (3).

$$TRM_{col} = D\sigma ATC_l \quad (3)$$

where,

D = a constant that can increase the value of TRM_{col}

B. Determination of TRM Considering the Uncertainty of Transmission Line Outages Using Non-Parametric Bootstrap Technique

This part presents a brief explanation on the non-parametric bootstrap technique that used to determine the TRM considering the uncertainty of transmission line outages. In brief, TRM_{out} is determined based on the standard deviation of ATC. Whereby, the ATC is calculated for every non-parametric bootstrap sample of transmission line outages. The detail procedures on the non-parametric bootstrap technique that is used to determine TRM_{out} has been explained in detail in [5]. TRM_{out} is obtained based on the standard deviation of ATCs (σATC) selected at a certain percentage of normal probability density, %PDF and it is given by (4).

$$TRM_{out} = D\sigma ATC \quad (4)$$

TRM_{out} is increased by the constant D as it is set to a higher percentage of normal probability density, %PDF. Equation (5) is used to determine the value of D which refers to the %PDF.

$$\%PDF = \frac{1}{\sigma\sqrt{2\pi}} \int_{\mu-D\sigma}^{\mu+(D\sigma)} e^{\frac{-(t-\mu)^2}{2\sigma^2}} dt \times 100\% \quad (5)$$

III. DETERMINATION OF ATC

Generally, the process in resolving the ATC involves the description of a base case, determination of system reaction and searching for the highest power transfer. The determination of ATC of a transmission system is performed by applying repetitive AC power flow solution under a particular set of operating conditions. The procedure in determining the ATC by recursive AC power flow solution is illustrated in the following procedures [5].

- i. Perform a base case AC power flow solution.
- ii. Identify the areas of power transfer. The area-to-area transfer is the participation of the entire generators in the specific selling and all loads in the particular buying area.
- iii. Increase the power injected and extraction at both sides of the selected areas equally until whichever one of the MVA power flows or the voltage magnitude has reached is limit.
- iv. Compute the value of ATC which is the maximum power transfer at the limiting case, minus the base case power flow and minus TRM.

IV. RESULTS AND DISCUSSION

The performance of the proposed technique of TRM and ATC determinations are investigated pertaining to the impact of uncertainty of system cascading collapse and transmission line outages. The IEEE RTS-96 [9] is used as a test system for the TRM and ATC analyses. The total load for this test system is 2850 MW and the total generation capacity is 3405 MW for each area. The results obtained in this analysis will discuss on the TRM and ATC for the transfer case from area 3 to area 2. This section provides the discussion on TRM and ATC results by taking into consideration the uncertainty associated with system cascading collapse and transmission line outages. The algorithm to compute TRM incorporating the impact of system cascading collapse and transmission line outages has been explained in the previous section. As mentioned in the previous section, the risk of a system cascading collapse has to be determined in the first place. The procedure and results of risk of system cascading collapse for IEEE RTS-96 can be obtained in [8]. Subsequently, the risk is then incorporated in (2), (3) in order to calculate the TRM and ATC.

Fig. 1 is depicting the sequential variations of ATC at 0% and 95% of bootstrap confidence intervals on 1st March 2002. As an example, $ATC_{n,b=0\%}^g$ of 1044.46 MW is obtained at 20:00 hour, is chosen to incorporate the uncertainty of system cascading collapse resulting to TRM_{col} of 48.89 MW. Therefore, at 20:00 hour, $ATC_{n,b=95\%}^g$ of 995.57 MW is obtained by subtracting TRM_{col} of 48.89 MW with $ATC_{n,b=0\%}^g$ of 1044.46 MW. This indicates that the maximum allowable amount of power that can be transferred from area 3 to area 2 at 20:00 hour, 1st March 2002 due to large uncertainty of system cascading collapse occurred at 95% of confidence interval is 995.57 MW.

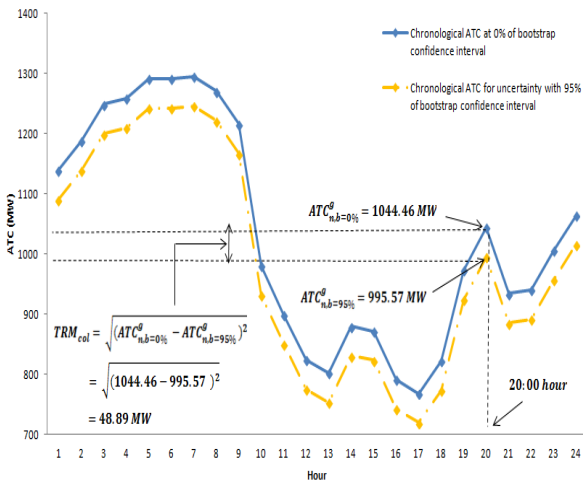


Fig. 1 ATC and TRM variations considering uncertainty of system cascading collapse on 1st March 2002

Fig. 2 represents the results of $ATC_{n,b=95\%}^g$ produced by considering TRM pertaining the uncertainty of transmission line outages, TRM_{out} which is obtained in 1st March 2002. Fig. 2 exemplify that the ATC is reduced by $TRM_{out} = 16.42$ MW from $ATC_{n,b=0\%}^g = 1044.46$ MW to $ATC_{n,b=95\%}^g = 1028.04$ MW at 20:00 hour in 1st March 2002. Therefore, $ATC_{n,b=95\%}^g = 1028.04$ MW is the maximum allowable quantity of power that can be transferred even though a large uncertainty of system cascading collapse occurred at 95% of confidence interval on 1st March 2002.

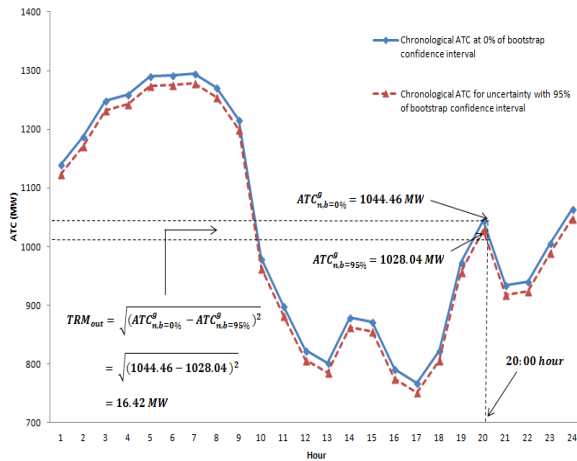


Fig. 2 ATC and TRM variations considering uncertainty of transmission line outages on 1st March 2002

TABLE shows the results of TRM_{col} and TRM_{out} taking into consideration the uncertainties of system cascading collapse and transmission line outage based on the transfer of power for different areas of IEEE RTS-96. It can be seen that the TRM_{col} produced larger amount of TRM for all area of power transfer as compared to the TRM_{out} . This entails that it is important to consider the uncertainty of system cascading collapse as it brings to a significant effect that yield to a large amount of TRM.

TABLE I
RESULTS OF TRM_{col} AND TRM_{out} FOR DIFFERENT TRANSFER CASES OF IEEE RTS-96

Area of Power Transfer	TRM_{col} (MW)	TRM_{out} (MW)
1 to 2	67.98	15.89
2 to 1	27.88	10.58
1 to 3	57.85	16.03
3 to 1	38.09	15.25
2 to 3	62.71	12.29
3 to 2	48.89	16.42

V. CONCLUSION

In an electric power deregulation industry, the need for efficient and secure electricity is important in order to supply electricity to the whole nation. The importance of TRM is to make sure a safe and secure operation of the interconnected system due to the impact of enormous uncertainty of the system operating condition. The escalating amount of system cascading collapse happened recently has discovered that there is an imperative need for innovative techniques to determine the amount of power transfer taking into consideration uncertainty of system cascading collapse required by the system planning and operation. This paper presented a framework for TRM and ATC determinations by considering the uncertainty of system cascading collapse and transmission line outages. The effectiveness of the developed framework was demonstrated by applying it to the IEEE RTS-96. The results indicate that it is important to consider the uncertainty of system cascading collapse in the determination of TRM and ATC as it could give significant impact of the transfer capability assessment.

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REFERENCES

- [1] S. A. Busan, "Dynamic Available Transfer Capability Calculation Considering Generation Rescheduling," Master of Science, Electrical Engineering, Universiti Teknologi MARA, 2012.
- [2] I. Dobson, S. Greene, R. Rajaraman, C. L. DeMarco, F. L. Alvarado, and R. Zimmerman, "Electric Power Transfer Capability: Concepts, Applications, Sensitivity, Uncertainty " Power Systems Engineering Research Center 2001.
- [3] S. Chun-Lien and L. Chan-Nan, "Two-point estimate method for quantifying transfer capability uncertainty," IEEE Transactions on Power Systems, vol. 20, pp. 573-579, 2005.
- [4] J. Zhang, I. Dobson, and F. L. Alvarado, "Quantifying Transmission Reliability Margin," International Journal of Electrical Power & Energy Systems, vol. 28, pp. 697-702, 2004.
- [5] R. H. Zaini, M. M. Othman, I. Musirin, A. Mohamed, and A. Hussain, "Determination of transmission reliability margin considering uncertainties of system operating condition and transmission line outage," European Transaction on Electrical Power, vol. 21, pp. 380-397, 2011.
- [6] M. M. Othman, A. Mohamed, and A. Hussain, "Determination of Transmission Reliability Margin Using Parametric Bootstrap Technique," IEEE Transactions on Power Systems, vol. 23, pp. 1689-1700, 2008.
- [7] N. A. Salim, M. M. Othman, M. S. Serwan, M. Fotuhi-Firuzabad, A. Safdarian, and I. Musirin, "Determination of available transfer capability with implication of cascading collapse uncertainty," IET Generation, Transmission & Distribution, pp. 1-12, 2013.
- [8] N. A. Salim, M. M. Othman, I. Musirin, and M. S. Serwan, "Critical System Cascading Collapse Assessment for Determining the Sensitive Transmission Lines and Severity of Total Loading Conditions," Mathematical Problems in Engineering, vol. 2013, p. 10, 2013.

- [9] C. Grigg, P. Wong, P. Albrecht, R. Allan, M. Bhavaraju, R. Billinton, Q. Chen, C. Fong, S. Haddad, S. Kuruganty, W. Li, R. Mukerji, D. Patton, N. Rau, D. Reppen, A. Schneider, M. Shahidehpour, and C. Singh, "The IEEE Reliability Test System-1996. A report prepared by the Reliability Test System Task Force of the Application of Probability Methods Subcommittee," IEEE Transactions on Power Systems, vol. 14, pp. 1010-1020, 1999.



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