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A probabilistic modeling based approach for Total Transfer Capability enhancement using FACTS devices

M.A. Khaburi [a], M.R. Haghifam [b,*]

[a] Science and Research Branch, Islamic Azad University, Tehran, Iran
[b] Department of Electrical Engineering, Tarbiat Modares University, P.O. Box 14115-111, Tehran, Iran

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ABSTRACT

Available Transfer Capability (ATC) is a key concept in the restructuring of power systems. ATC is used by system operators to determine the ability of transmission system to transfer power and by system planners to indicate a system's strength. ATC calculation involves determination of Total Transfer Capability (TTC) and two margins, Transmission Reliability Margin (TRM) and Capacity Benefit Margin (CBM). In fact, if the values of TRM and CBM are assumed to be constant, ATC is directly expressed by TTC. Therefore, improvement of TTC is an important topic in the current deregulation environments. Due to the uncertainty of power system behavior, the events such as transmission line outage can cause the transfer capability to decrease. Accordingly, transmission capability analysis needs a statistical forecast for an expected range of transfer capability. Thus, it is necessary to study TTC problem from a probabilistic point of view and consider the probabilistic feature of the power systems and the related contingencies.

1. Introduction

Due to large investment in power systems along with environmental problems, determination and enhancement of Available Transfer Capability (ATC) are attractive topics in both regulated and deregulated power markets. The situation becomes more complex due to willingness to buy power from the cheapest sellers causing some transmission corridors operate near to their limits or getting overloaded. From this viewpoint and also in order to avoid overloading, calculation of ATC has to be performed.

According to NERC report [1], "Available Transfer Capability Definitions and Determination", ATC is mathematically defined as the Total Transfer Capability (TTC) less the Transmission Reliability Margin (TRM), less the sum of the Existing Transmission Commitments (ETC) and the Capacity Benefit Margin (CBM).

Some techniques and methodologies have been proposed to compute these components before calculating ATC. In fact, if the CBM, TRM, and ETC values are assumed to be constant, then ATC is directly expressed by TTC. Thus, TTC is usually addressed as the basis for ATC determination [2].

First, in this paper, we introduce TTC calculation methods. Second, the general procedure to calculate TTC using Repeated Power Flow (RPF) method is presented. Then, the probabilistic analysis of TTC and the effect of series Flexible AC Transmission System (FACTS) devices on TTC via probabilistic models will be implemented in IEEE Reliability Test System (RTS).

2. ATC fundamentals

ATC is determined as a function of increase in power transfer between different systems through interfaces, and ATC determination involves several parameters such as TTC, CBM and TRM [1,3]. It can be expressed as:

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

$$TTC = \mathrm{Min}\,\{\mathrm{Thermal}, \mathrm{Voltage}, \mathrm{Stability\ Limits}\} \tag{2}$$

Total Transfer Capability (TTC) may be limited by the physical and electrical characteristics of a system including thermal, voltage, and stability limits.

Transmission Reliability Margin (TRM) accounts for the inherent uncertainty in system conditions, its associated effects on ATC calculations and the need for operation flexibility to ensure reliable system operation as system conditions change.

Preservation of CBM for a load serving entities (LSE) allows the entity to reduce its installed generating capacity below what may otherwise have been necessary without interconnections to meet its generation reliability requirements.

ETC is the Existing Transmission Commitment. Among these parameters, TRM and CBM are the factors that account for the uncertainties and reliability in the power system [4].

* Corresponding author. Tel.: +98 21 82884347; fax: +98 21 88006544.
E-mail addresses: m.khaburi@gmail.com (M.A. Khaburi), haghifam@modares.ac.ir (M.R. Haghifam).

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3. TTC calculation methods

Although various mathematical methods and algorithms have been developed to compute TTC, the currently used methods can be divided into three types as follows:

I. *Security Constrained Optimal Power Flow (SCOPF) method:* This method can be implemented by many optimization approaches such as interior point approach, neural network approach [5] and two-level optimization approach [6].
II. *Continuation Power Flow (CPF) method:* The implementation of this mathematically complicated method involves predictor, parameterization, corrector and step-size control steps [7,8].
III. *Repeated Power Flow (RPF) method:* This method repeatedly solves power flow equations at a succession of points along the specified load generation increment.

In this paper, RPF method was used to evaluate TTC in IEEE Reliability Test System [8,9]. Then, it was generalized to include FACTS devices to enhance TTC.

The proposed procedure for TTC evaluation under operating conditions is shown in Fig. 1. First, in this procedure the power factor for bus i is calculated to obtain a constant power factor. Then, for the real power of load bus i, normal distribution function having two percent variance is determined. For example, if real power is P, mean value and variance are P and $0.02 \times P$, respectively.

Then, the Monte Carlo simulation is used to select a random load level for bus i. Also power factor and load level values are used to calculate the reactive power for bus i.

Finally, RPF method is performed to calculate TTC and probabilistic distribution of TTC for the system at this load level.

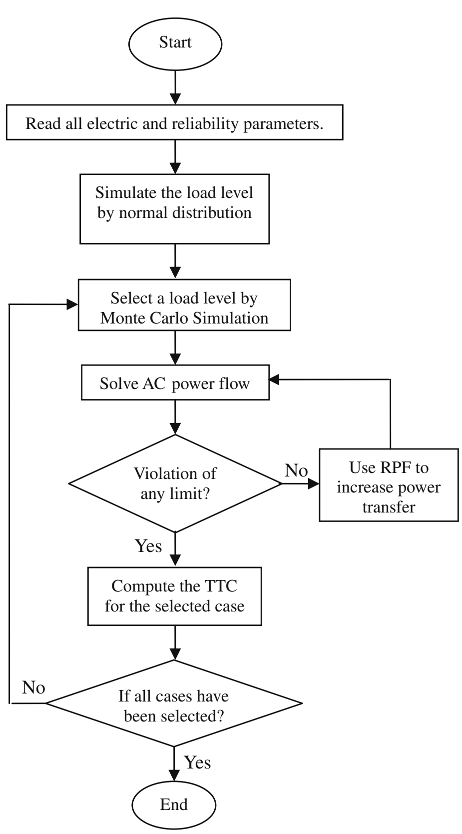

Fig. 1. Procedure of TTC evaluation.

4. RPF Algorithm

Repeated Power Flow (RPF) method enable to increase the transfer of power by increasing the complex load with uniform power factor at every load bus in the load area (sink) and increasing the injected real power at generator buses in the generation area (source) in incremental steps until exceeding of the limits.

The mathematical formulation of TTC using RPF can be expressed as follows:

Maximize λ

Subject to:

$$\begin{cases} P_{Gi} - P_{Di} - \sum_{j=1}^{n} |U_i| \cdot |Uj| (G_{ij} \cos\delta_{ij} + B_{ij} \sin\delta_{ij}) = 0 \\ Q_{Gi} - Q_{Di} - \sum_{j=1}^{n} |U_i| \cdot |Uj| (G_{ij} \sin\delta_{ij} - B_{ij} \cos\delta_{ij}) = 0 \end{cases} \tag{3}$$

$$|Ui|_{\min} \le |Ui| \le |Ui|_{\max} \tag{4}$$

$$S_{ij} \le S_{ij\ \max} \tag{5}$$

where λ is scalar parameter representing the increase in the area's load or generation, $\lambda = 0$ corresponds to no transfer (base case) and $\lambda = \lambda_{\max}$ corresponds to the maximum transfer; $|U_i|$, $|U_j|$ are voltage magnitudes at bus i and j; G_{ij}, B_{ij} are real and imaginary parts of the ijth element of bus admittance matrix; δ_{ij} is voltage angle difference between bus i and bus j and S_{ij} is apparent power flow in line ij.

In the power flow equations (3), P_{Gi} (generator real output in generation area), P_{Di} (real load in load area) and Q_{Di} (reactive load in load area) are calculated as:

$$\begin{aligned} P_{Gi} &= P^{o}_{Gi} \cdot (1 + \lambda \cdot k_{Gi}) \\ P_{Di} &= P^{o}_{Di} \cdot (1 + \lambda \cdot k_{Di}) \\ Q_{Di} &= Q^{o}_{Di} \cdot (1 + \lambda \cdot k_{Di}) \end{aligned} \tag{6}$$

where P^{o}_{Gi} is original real power generation at bus i in the generation area; P^{o}_{Di}, Q^{o}_{Di} are original real and reactive load demands at bus i in the load area and k_{Gi}, k_{Di} are constants used to specify the change rate in the generation and load as λ varies.

Eqs. (4) and (5) indicate the voltage limit of the buses and the thermal limit of transmission lines, respectively.

TTC level in each case (normal or contingency) is calculated as follows:

$$\mathrm{TTC} = \sum_{i \in Sink\ Area} P_{Di}(\lambda_{\max}) - \sum_{i \in Sink\ Area} P^{o}_{Di} \tag{7}$$

where $\sum_{i \in SinkArea} P_{Di}(\lambda_{\max})$ is sum of the load at the sink area when $\lambda = \lambda_{\max}$ and $\sum_{i \in SinkArea} P^{o}_{Di}$ is sum of the load at the sink area when $\lambda = 0$.

5. FACTS devices

FACTS devices have the ability to modify power flow pattern. More importantly, they can change their parameters smoothly and rapidly, allowing a more desirable control on power flow [12]. Therefore, FACTS devices are good candidates for transfer capability improvement of transmission systems. In addition, there are fewer restrictions on the installation of FACTS devices than on the construction of new transmission lines or power plants. Thus, we propose the use of these devices as the tools for the enhancement of transfer capability. There are three important operational parameters that FACTS devices can control, i.e., impedance, voltage and phase angle.

Among the FACTS devices, Thyristor Controlled Series Capacitor (TCSC) is the most efficient and economical one to increase TTC. This paper will investigate the effects of TCSC which can control transmission lines impedance.