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Optimal generation share based dynamic available transfer capability improvement in deregulated electricity market

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This paper presents a bi-level programming approach for determining optimal generation share to maximize the available transfer capability (ATC) considering Hopf bifurcation limit in the bilateral/multilateral transaction. In the deregulated electricity market of open transmission access, all the market participants try to utilize the transmission system fully; hence it is important to improve the oscillatory stability based ATC for allowing more electricity contracts in future without any transmission limit violation . In the multi-nodal case of bilateral electricity market and multilateral electricity market, ATC significantly varies dependent on the points of electric power injection in the transmission system. This paper suggests the method for establishing bilateral/multilateral contract based on the optimal generation sharing of injection power to maximize the ATC. Real coded genetic algorithm (RGA) is used as an optimization tool to solve the proposed approach. The proposed method is tested in WSCC 3 machine 9-bus system and New England 10 machine 39-bus system.

1. Introduction

In recent years, the incorporation of many new feasible electricity trade models increases the number of participants thereby creates the market more competitive. Bilateral/multilateral contractual trade model is one among the feasible electricity trade models. In the bilateral/multilateral electricity trade, the establishment of contract between seller and buyer is the direct negotiation of these parties not the matter of system operator. The established contract can be committed only when sufficient available transfer capability is available for that interface.

Available transfer capability is a measure of the transfer capability remaining in the physical transmission network for the further commercial activity over and above already committed uses [1]. System operator is responsible for the determination of ATC before any bilateral/multilateral contract is committed. ATC may be broadly classified as static ATC and dynamic ATC [2]. Determination of ATC considering static limits such as line thermal limit, bus voltage limits and steady state stability limits constraints is termed as static ATC. Static ATC can be calculated in various methods such that continuation power flow routine based on Newton power flow algorithm [3,4], an optimization based method using DC load flow [5], and linear sensitivity factor methods [6]. Comparison of UPFC and SEN Transformer for ATC enhancement has been proposed using an optimal power flow with intact and contingency cases in Ref. [7]. Generally, in the open access electricity market with continuously varying generation schedules and loads, the system is subjected to small disturbances and large disturbances. Therefore, the dynamics of the system, as a whole has to be studied and analyzed for stability. ATC calculated with the dynamic stability limits along with static constraints is referred as dynamic ATC. Ref. [8], proposed an iterative algorithm for determining dynamic ATC. The algorithm is based on the Gauss–Newton solution of a non-linear least square problem. A static optimization based approach is considered to assess ATC. The approach is prone to integrate both static and dynamic security constraints in Ref. [9]. Ref. [10] developed an interior point non-linear programming methodology for evaluating dynamic ATC with transient stability constraints. Ref. [11], presents a model to describe dynamic constraints ATC, using equilibrium equations as steady state constraints and dot product as stability criterion. Ref. [12], proposed a fast and accurate dynamic method considering transient stability analysis and voltage stability analysis for computing ATC using potential energy boundary surface (PEBS) and point of maximum potential (POMP). A hybrid energy function method has been proposed in Ref. [13] to enhance the dynamic ATC through optimal placement of FACTS controllers. Ref. [14] evaluated ATC with long term dynamic voltage stability constraints based on quasi steady state (QSS) approximations. An optimization formulation for dynamic ATC assessment, with an objective to minimize the real part of the critical eigenvalue subjected to the Hopf bifurcation and power balance constraints in Ref. [15]. Ref. [16] developed a novel

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optimization formulation by utilizing bifurcation approach for dynamic ATC assessment, with an objective of maximizing the scalar loading parameter.

The literature survey from [17] reveals that the convergence of the traditional optimization methods depends upon the nature of the objective function. To overcome this difficulty, many heuristic search algorithms have been proposed by many researchers. Ref. [18], proposed the application of floating point based genetic algorithm for static ATC assessment. Real coded genetic algorithm associated with analytical hierarchy process (AHP) and fuzzy sets are implemented as a hybrid heuristic technique to determine optimal location of TCSC in [19] for static ATC enhancement. RGA and hybrid mutation particle swarm optimization (HMPSO) are used as an optimization tool to determine optimal location of FACTS devices such as SVC and TCSC and their capability in static ATC enhancement has been discussed in Refs. [20,21] respectively.

In the bilateral/multilateral electricity trade, desire amount of power is wheeled between seller and buyer this reduces the ATC of the transmission system thereby reduces other participants transmission utilization. Hence it is necessary to maintain the ATC in larger amount. This paper suggests the method for establishing the bilateral/multilateral contract to maximize the available transfer capability and also the desire amount of power is wheeled between seller and buyer without violating the transmission system security. The proposed idea is based on the significant ATC variation corresponding to the point of injection and the amount of power injection at the different points in the bilateral/multilateral contract. In this work, ATC is maximized by optimally sharing the generation share and the ATC for each combination of generation share is calculated by finding optimum loading factor related to the occurrence of Hopf bifurcation. This problem has been formulated as bi-level programming problem (BLPP) [22]. A BLPP is balanced by an outer and an inner optimization problem. The proposed bi-level programming model positions the optimum generation share based maximum ATC as outer optimization problem and determination of optimum loading factor for different combination of generator bus share at the minimum real part of the eigenvalue corresponding to the occurrence of Hopf bifurcation as inner optimization problem are illustrated in Fig. 1.

Refs. [23,24] used a BLPP approach to determine maximum total transfer capabilities in the transmission interfaces and to determine the optimal contract price of dispatchable distributed generation (DG) units in distribution systems respectively. Ref. [25], proposed a specialized GA which is based on non-linear BLPP framework to determine the location and contract price of dispatchable distributed generation (DG) units in distribution systems.

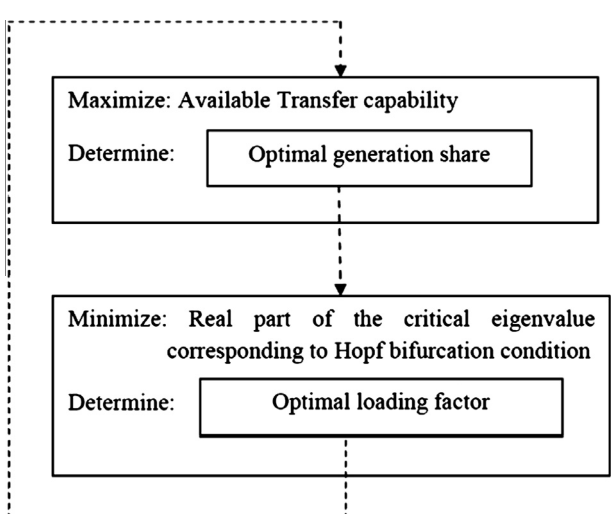

Fig. 1. Structure of proposed bi-level programming problem.

Real coded genetic algorithm is used for solving the proposed bi-level optimization problem. The proposed method has been applied for various bilateral/multilateral transactions on Western System Coordinating Council (WSCC) 3 Machine 9-bus system and New England 10 Machine 39-bus system.

2. Problem description

2.1. Available transfer capability

NERC defines the available transfer capability (ATC) in [1]. Mathematically ATC can be defined total transfer capability (TTC) less the transmission reliability margin (TRM), less the sum of the existing transmission commitment (ETC) and the capacity benefit margin (CBM). Thus, ATC can be formulated as:

$$\mathrm{ATC} = \mathrm{TTC} - \mathrm{TRM} - (\mathrm{CBM} + \mathrm{ETC}) \tag{1}$$

2.2. Multi-nodal/multilateral contracts in bilateral electricity trades

In the deregulated electricity environment, suppliers and buyers are allowed to trade directly in bilateral transactions. In a practical system, not all the suppliers have bilateral contracts with buyers and vice versa. A bilateral transaction between a supplier and buyer involves in injection of power at one location and the same amount of power is extracted at the same time at another location of the transmission network without violating the transmission constraints.

The bilateral concept can be generalized to the multi-nodal case where a seller, for example a generation, may inject power at several nodes and the buyer also draw load at several nodes. Similar to the multi-nodal bilateral contract, a multilateral contract is also the generalization of bilateral concept but it differs from this multi-nodal case in that it envisages the activity of power broker. The concept of power broker is that of a firm which enters into purchase and sales agreements with several buyers and sellers, a group. In this case, power balance constraints are that the broker's aggregate purchases from all generators at any time equal aggregate sales to all the broker's buyers. That is all the transactions constituting a group need to be balanced.

Mathematically, multi-nodal/multilateral transaction k is the total sum of power injected in different buses m is equal to the total sum of load power taken out at various buses

$$\sum_m P_{Gm}^k - \sum_n P_{Dn}^k = 0, \quad k = 1, 2, \ldots t_k \tag{2}$$

where P_{Gm} is the power injections into the seller bus-m, P_{Dm} the power taken out at the buyer bus-n, t_k is the total number of the multi-nodal/multilateral contracts.

2.3. Oscillatory stability and eigenvalue

Oscillatory stability is defined as the ability of a power system to maintain a steady state operating point when the power system is subjected to small disturbance. This disturbance result from system changes such as variations in load or generation. Oscillatory stability of such systems can be evaluated by eigenvalue analysis of the system dynamic equation around the operating point. The system equations both dynamic and algebraic are linearized around the operating point for this purpose [28].