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New secure bilateral transaction determination and study of pattern under contingencies and UPFC in competitive hybrid electricity markets

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ABSTRACT

In the competitive electricity environment, the flexibility of power transactions is expected to drastically increase among the trading partners and can compromise the system security and reliability. These transactions are to be evaluated ahead of their scheduling in a day-ahead and hour-ahead market to avoid congestion and ensure their feasibility with respect to the system operating conditions. The security of the transactions has become essential in the new environment for better planning and management of competitive electricity markets. This paper proposes a new method of secure bilateral transaction determination using AC distribution factors based on the full Jacobian sensitivity and considering the impact of slack bus for pool and bilateral coordinated markets. The secure bilateral transactions have also been determined considering critical line outage contingencies cases. The bilateral transaction matrix pattern has also been determined in the presence of unified power flow controller (UPFC). The optimal location of UPFC has been determined using mixed integer non-linear programming approach. The proposed technique has been applied on IEEE 24-bus reliability test system (RTS).

1. Introduction

Electric supply industries throughout the world are transforming their vertical integrated electrical utilities (VIU) into open access competitive environment with an objective to achieve lower rates of electrical energy and higher operational efficiency. Traditional power companies are therefore gradually shifting into independent business entities by unbundling and privatization of their generation, transmission and distribution functions [1,2]. Several open access transmission models for the implementation and management of competition adopted in many electricity markets are: (i) Poolco model where one single entity Pool Company purchases power from competitive generators in open market and sells it at single price to the retail loads, (ii) Wholesale Competition where retail loads can purchase power from one or more trading entities who are in competition with each other and who purchase power from competing generators, (iii) Retail Competition is the most general competition model where both Pool and direct transactions between retail loads and generators are allowed [2]. Thus, in this open access environment, the consumers can therefore establish various service contracts with any supplier in order to obtain the lowest rates and efficient service.

A transaction is a bilateral exchange of power between generators and customers acting as seller and buyer buses and can be firm and non-firm. These bilateral transactions can affect the loading of transmission facilities and that may require system operator (SO) to reschedule the system generating units in order to accommodate them. A bilateral transaction is deemed to be feasible if it can be accommodated without any violation of system operating constraints such as transmission interface limits, equipments ratings, and system economic dispatch etc. A bilateral transaction is deemed to be infeasible if it violates any of system operating constraints. Infeasible bilateral transactions cannot be allowed as it may cause congestion, can threaten system security, reliability and alter economic dispatch schedule. Thus, it has become important to determine the secure bilateral transactions in an open access environment before these can be negotiated between buying and selling entities [2].

Reference [3] described a method for evaluating potential non-firm contracts, where the potential contracts were assessed individually to determine their feasibility with respect to system operating constraints and operating costs. The method however, did not discuss the feasibility of simultaneous transmission contracts. A method for evaluating the impact of non-firm transactions on reliability and operating cost of power systems, however, it cannot handle the case with large number of bilateral transactions [4]. A method based on available transfer capability (ATC) concept for assessing the feasibility of simultaneous transactions has been described in [5]. A mathematical framework for the analysis and

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management of power transactions under open access subject to system security has been presented in [6].

Cheng et al. proposed determination of bilateral contract model through transaction matrix defined in [6] using DC load flow based approach addressing various operational and planning problems [7]. Same authors proposed probabilistic approach to analyze multiple random simultaneous transactions on the basis of system security utilizing Monte Carlo simulations [8]. However, the methodology proposed in [7,8] was based on DC distribution factors and DC load flow approach and was applied for pure bilateral market model. This paper presented transaction assessment method for allocating transmission services to individual transactions using a simple AC power flow based procedure [9]. An optimization procedure that assures the transmission security with minimum corrections in contractual transactions was proposed in [10]. Transaction analysis using game theory was proposed in [11]. Li and Liu proposed stability analysis of the strategic transaction in a deregulated environment [12]. This paper proposed a methodology based on the concept of feasible and secure transactions, which, estimates the adequacy of a deregulated network and from this adequacy, the remedial measures required to improve this adequacy such as FACTS controllers were examined in [13]. A secure bilateral transaction matrix for hybrid electricity markets based on DC load flow approach was proposed in [14]. The paper proposed secure bilateral transaction matrix based on AC load flow approach [15]. However, the results obtained may be more optimistic as the method utilizes DC distribution factors for the determination of secure bilateral transactions which are constant based on network parameter and do not reflect the impact of change in operating conditions of a system.

A modeling of power exchanges in the form of multilateral trades along with some possible curtailments schemes were proposed with a focus on equity and incontestability of the curtailment rule for security control of transmission system [16] A new concept of an optimal rescheduling of transactions between different entities in a multilateral environment considering benefits of both buyers and sellers has been proposed in [17]. A framework for modeling and evaluation of interruptible power supply contracts to assure appropriate level of reliability was proposed in [18]. Wu proposed novel algorithm for contingency constrained available transfer capability (ATC) computation and suggested trading strategy for independent power producers and trading transactions in deregulated environment based on ATC computation [19].

The secure bilateral transaction matrix determined for bilateral model [7] and for hybrid model [14] are based on DC distribution factors and may not give accurate signal for the security of transmission system as DC load flow equations are based on assumptions. It is observed from the literature review that there is need to address the impact of line outage contingencies on the bilateral transactions so that the SO can negotiate the bilateral transactions within the posted ATC for the secure operation of an electricity market.

In this paper, a new secure bilateral transaction matrix has been determined using a non-linear programming approach based on AC load flow equations for a hybrid market model. AC distribution factors (ACDF) have been determined to obtain secure bilateral transaction matrix. ACDF reflect change in operating conditions in a system and are accurate compared to DC distribution factors. The distribution factors have been determined from the full Jacobian sensitivity matrix considering coupling between P–V and Q–δ equations. The impact of slack bus on the distribution factors have also been considered to determine new ACDFs. The application of FACTS controllers to a deregulated network is an effective way to improve the transmission system adequacy relieving congestion, improving ATC and adequate bilateral transactions negotiations. A study on the pattern of bilateral transactions matrix has been carried out in the presence of UPFC. The impact of critical line outage contingencies needs to be addressed on the pattern of bilateral transactions so that the SO can reserve the transactions without violating the operating limits of the network under contingencies also. The pattern of the transaction matrix specifies the variations of an amount of the transactions between the generators and the loads acting as seller and buyer buses. The pattern of secure transactions matrix has also been obtained under single and two line outage cases without and with the presence of UPFC. The generation pattern has also been obtained to determine the generators share for pool and bilateral transactions without and with line outage contingencies and UPFC. The mixed integer non-linear programming (MINLP) approach using GAMS 21.3 CPLEX solver [20] has been utilized for optimal placement of UPFC. The proposed approach has been tested for IEEE 24-bus system reliability test system (RTS) [21].

2. A lossless bilateral contract model: transaction matrix, T

The bilateral contract model used in this paper is basically a subset of the full transaction matrix proposed in [6]. In its general form, the transaction matrix T as shown in Eq. (1) is a collection of all possible transactions between Generation (G), Demand (D), and any other trading Entities (E) such as the marketers and the brokers.

$$T = \begin{bmatrix} GG & GD & GE \\ DG & DD & DE \\ EG & ED & EE \end{bmatrix} \tag{1}$$

In this present paper, it is assumed that there are no activities incurred by the Trading Entities (E). All transactions are therefore restricted to the suppliers (G) and the consumer (D). This assumption is made only to help understand the new concept and it can be expanded in any further study. It is also noted that the diagonal block matrices (GG and DD) are zero because it is assumed that there are no contracts made between two suppliers or two consumers. Neglecting transmission losses, the transaction matrix can be simplified as:

$$T \equiv [GD] = [DG^T] \tag{2}$$

Each element of T, namely t_{ij}, represents a bilateral contract between a supplier (P_{gi}) of row i with a consumer (P_{dj}) of column j. Furthermore, the sum of row i represents the total power produced by generator i and the sum of the column j represents the total power consumed at load j.

$$T \equiv \begin{bmatrix} t_{1,1} & \cdots & t_{1,nd} \\ t_{2,1} & \cdots & t_{2,nd} \\ t_{ng,1} & \cdots & t_{ng,nd} \end{bmatrix} \tag{3}$$

where n_g = number of generators, and n_d = number of loads.

In general, the conventional load flow variables, generation (P_g) and load (P_d) vectors, are now expanded into two dimensional transaction matrix T as given in Eq. (4).

$$\begin{bmatrix} P_d \\ P_g \end{bmatrix} = \begin{bmatrix} T^T & 0 \\ 0 & T \end{bmatrix} \begin{bmatrix} u_g \\ u_d \end{bmatrix} \tag{4}$$

Vector u_g and u_d are column vectors of ones with the dimensions of n_g and n_d respectively.

3. Some intrinsic properties of the bilateral transaction matrix

There are some intrinsic properties associated with this transaction matrix T [8]: