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Linear programming based determination of optimal bilateral real power contracts in open access

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ABSTRACT

Under a deregulated environment, electricity consumers and suppliers generally establish various bilateral power transactions/contracts. The transmission company normally honors and executes these bilateral contracts within the limits permitted by the system design and operating conditions. This article describes determination of optimal bilateral contracts by using line flow factors (LFFs). An innovative approach for obtaining the set of line flow factors is presented. The line flow factors are evaluated from existing load flow information. A generalized linear programming formulation is proposed to determine the optimal bilateral real power contracts under a deregulated environment subjected to the steady-state security constraints (e.g. generation and line flow limits). It is demonstrated that the proposed methodology would be an effective tool to study the intricate relationships between the bilateral contracts and system security. Examples are presented to illustrate the use of this formulation to minimize the cost of any bilateral contract to comply with the security requirements. The results obtained show great prospects for practical application of the proposed algorithm for optimal bilateral contracts on a real-time basis.

1. Introduction

The open access transmission regime is spearheading the rapid disintegration of the well-entrenched vertically integrated structure of the electric power industry. The entry of a large number of new players and the unbundling of electricity services has pushed the industry toward the widespread use of transactions to meet customer demands [1,2]. The driving forces of deregulation are aiming to establish a more competitive market in order to achieve lower rates for the consumers and higher efficiency for the suppliers. Power suppliers, both the conventional utilities as well as the Independent Power Producers (IPP), are actively competing with one another for acquiring customers. The consumers can therefore establish various service contracts with any supplier in order to obtain the lowest rate and most desirable service [3,4].

In a deregulated electricity market, the task of the independent system operator (ISO) is to ensure that contracted power transactions are carried out reliably. However, due to the large number of transactions that take place simultaneously, transmission networks may easily get congested. A number of methods, both technical and economical, dealing with congestion management in deregulated electricity markets, have been proposed in the literature. The technical methods are generally based on optimal generation re-dispatch with security and transmission constraints, operation of transformer taps, outage of congested lines, load curtailment, and operation of Flexible AC Transmission System (FACTS) devices.

Three different methods of operation of transmission system in deregulated power systems are discussed in [5]. The first is based on optimal power flow (OPF), as implemented in the UK, parts of USA, Australia, and New Zealand. The second method is the point-of-connection tariff and price area congestion model as used in Sweden and Norway, respectively. Finally, a transaction-based model as used in the USA is discussed. Each method succeeds in maintaining power system security, but differs in its impact on the economics of the energy market. In [6], a minimum-distance generation re-dispatch is proposed, which disregarded the economic value of the transaction adjustment. In [7], price (marginal cost) signal is used for the generators to manage congestion and the solution under rational behavior assumption is found to be identical to an OPF solution. A similar approach is suggested for the pool model [8], where the cost of congestion is bundled within the marginal cost at each bus. A bilateral model is also investigated, and a congestion cost minimization approach is proposed [9–11]. A new unified method which allocates transmission losses either to buses in a pool market or to individual transactions in a bilateral contract market is presented in [12]. In [13] an optimal

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List of symbols

P_{gi}	supplier at bus i
P_{dj}	customer at bus j
P_{dj}^{gi}	power contract between customer at bus j and supplier at bus i
P_{l-k}	actual power flow in line $l-k$ due to all customers and suppliers
P_{l-k}^{gi}	power flows in line $l-k$ due to supplier at bus i
P_{l-k}^{ij}	power flow in line $l-k$ with supplier at bus i and customer at bus j
L_{l-k}^{ij}	line flow factor of a line $l-k$ when the supplier and customer are at buses i and j, respectively.

power flow formulation in which the generation is dispatched in order to compensate for losses allocated to different transactions is presented. In [14] a new approach to the transmission loss allocation problem in a deregulated system is presented. This approach belongs to the set of incremental methods. It treats all the constraints of the network, i.e. control, state and functional constraints. In [15] a new approach for transmission pricing is presented. The contribution of a contract on power flow of a transmission line is used as extent-of-use criterion for transmission pricing.

2. Power markets

2.1. Pool market

In the pool market model, there are two main entities participating in the market, i.e. customer and supplier. The pool operator considers electricity transaction bids and offers from these two entities and dispatches them in an economical manner depending on the price and MW biddings. In general, the customers and suppliers do not directly interact with each other, but only indirectly through the pool operator. After all bids and offers have been received, an optimization tool will be used to solve the problem, which includes loss allocation, congestion management, and other ancillary services. Here, the pool operator, also known as independent system operator, is responsible for both market settlement including scheduling and dispatch and the transmission system management including transmission pricing, and security aspects.

2.2. Bilateral market

Bilateral market has two main market participants, i.e. customers and suppliers who make the contracts. It is these participants, and not the system operator, who decides the electricity prices and transacted MW. Once the transactions are settled, the ISO needs to be informed about the trade since ISO is responsible for ensuring that the transactions do not endanger system security.

The models used in Nordic Pool and California are examples of this model. The energy auction and future markets are conducted by an independent entity called Power Exchange (PX) and the system is operated by another independent body called independent system operator (ISO), who assures equal opportunities to all sellers and buyers through open access to grid. The buyers and sellers have an option of entering into bilateral transactions or they can be participants in the energy auction conducted by the PX. The auction conducted by PX is a double-sided auction as sellers as well as buyers place the bids. The sellers and buyers are allowed to place a portfolio bid, i.e. a combined bid for many generators.

Modeling of bilateral transactions is usually through the use of bilateral transaction matrices (BTM), denoting the linkages between various parties involved. The construction of BTM requires adhering to certain rules, such as the column rule and row rule, which ensures that the BTM elements satisfy the basic constraints of demand supply balance. Assuming that a buyer and seller can be located at the same bus, one can formulate the following relations for a BTM.

Consider a system of n-buses, bilateral transactions can take place between any generator and any load, located at any bus. It may also take place between a generator and a load located at the same bus. The BTM, denoted by T, can then be defined as follows:

$$T = \begin{bmatrix} T_{1,1} & T_{1,2} & \cdots & T_{1,n} \\ T_{2,1} & T_{2,2} & \cdots & T_{2,n} \\ \cdots & \cdots & \cdots & \cdots \\ T_{n,1} & T_{n,2} & \cdots & T_{n,n} \end{bmatrix} \tag{1}$$

In (1), the elements $T_{i,j}$ over a row define the bilateral contract of a generator i with all possible loads j. Thus the first row of T ($T_{1,j}$) defines the bilateral contracts a generator at bus 1 may enter into with loads at buses j. Similarly, the column elements define the bilateral contract a load j may enter into with all possible generators i. Thus, the first column of T ($T_{1,i}$) defines the bilateral contracts a load at bus 1 enters into with other generators at bus i. Accordingly, the matrix T should satisfy the following conditions for the bilateral transactions to be feasible.

$$\sum_i T_{i,j} = PD_j$$
$$P_i^{\min} \leqslant \sum_j T_{i,j} = P_i^{sch} \leqslant P_i^{\max} \tag{2}$$

In (2), PD is the demand at bus j, whereas P_i^{sch} is the generation scheduled by a generator located at a bus i to meet its bilateral transaction commitments. This is submitted to the ISO in advance. Understandably, the generation scheduled should be within the upper and lower bounds of generation from the unit, $P^{\max}$ and $P^{\min}$, respectively.

The following assumptions are made:

- Multiple candidate power suppliers are being included in the generation set.
- Multiple candidate power customers are being included in the load set.
- The reactive power of load is compensated locally, and only real power transaction is supplied by the transaction.
- The transmission system has enough transmission capability to carry this amount of MW transaction sent from a supplier to a customer. This alternatively implies that the transaction amount is decided after taking into account the results of the Available Transfer Capability (ATC) analysis.
- The proposed method evaluates the optimal bilateral transactions by considering all the transactions at a time.
- It is assumed that the market model considered is the bilateral market model used in Nordic Pool and California, limiting the analysis for evaluation of optimal bilateral transactions with constraints on active power generations and line flow limits.
- The Californian and Norwegian markets were initially based on the cost minimization and favored profit maximization in the