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Transmission planning by minimizing curtailment of market transactions

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ABSTRACT

Congestion in the transmission network prevents execution of the desired market transactions. This results in some of the market transactions having to be curtailed, which translates into a loss to customers. This paper suggests that the decision to expand transmission facilities will depend on the loss sustained by the customer due to curtailment of market transactions vs. cost of installing new transmission facilities over a planning period. Thus, in a power system, the sum total cost of investment to expand transmission facilities and cost of cumulative loss due to curtailment of transactions to all the customers is set up as a minimization problem, which results in optimal transmission expansion needed over a planning period. With this consideration, the Benders decomposition technique is used for transmission expansion planning by taking investment cost as the master problem and loss due to curtailment of market transactions as the slave problem. The Southern Brazil power system is used as a test case where this methodology has been employed.

1. Introduction

In the past a single utility owned generation, transmission and distribution of electric power. Thus, traditionally, the objective of the utility's centralized transmission expansion planning was to make decisions on addition of new facilities in an economical way such that the transmission network supported the load requirements of the system. The operating philosophy of the utility would either be to minimize the total system production cost [1] or to minimize the system-wide load curtailment [2–6].

The deregulated electricity market has created a new structure in transmission management and system operation criteria. Accordingly, new transmission planning techniques have evolved to suit the new transmission management and operating criteria. Several transmission expansion schemes have been proposed for deregulated markets. Two transmission management structures exist in the deregulated market, namely: centralized transmission planning, where system planning and operation is done by a single company as in England; or, decentralized transmission planning where competitive transmission services are encouraged as in Australia. Transmission planning under each of these management structures was compared in [7]. Under the centralized transmission planning framework the operating philosophy would be system-wide social welfare maximization problem [7–9]. Under the decentralized transmission planning framework the objective would be to maximize the profits of the network investors [7,10].

Game theory application [11], uncertainty in the availability of data [12], probabilistic criteria and reliability [13], environmental factors [14] and trading of electricity [7–9] are modeled in transmission expansion planning studies. Trading of electricity is usually modeled as generators and customers submitting the bids to the pool market and decisions to expand the transmission system would be based on the market clearing mechanism of the bids. This method needs detailed expected hourly bids from the market participants.

Trading of electricity can be in the medium- to long-term bilateral contracts or in the hourly spot market. The desired set of market transactions are the expected bilateral and spot market transactions of the participants. In this paper, the congestion in the transmission network that prevents the execution of the desired market transactions is taken as the driving signal for expanding the transmission network. Data required for this formulation is relatively easy to obtain. It does not require hourly bid data of generators and customers in the spot market. It only requires generators and customers percentage participation in the bilateral and spot markets.

Several mathematical and heuristic methods such as Linear programming [15], Nonlinear programming [16], Simulated Annealing

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[17], Genetic Algorithm [18], Tabu search [19], Dynamic Programming [20], Branch and Bound [21], Expert Systems [22], Fuzzy Set Theory[23], Benders decomposition [2–10,24] were applied to determine the optimal transmission expansion schedule. In this paper, Benders decomposition is used to solve the proposed transmission expansion planning problem. Investment costs are taken as the master problem and “loss due to curtailment of market transactions” is taken as the operational cost which forms the slave problem. The paper is organized as follows: energy trading model and the mathematical formulation for trading electricity are described in Section 2 and 3. Benders decomposition based transmission expansion planning algorithm is described in Section 4. The proposed framework is applied to the Southern Brazil power system, the test results of which are presented in Section 5, followed by conclusions in Section 6, Appendix and References.

2. Energy trading

An electricity market model consisting of m Gencos and p customers participating in spot, bilateral and reserve markets is considered. For simplicity, a generator bus is modeled as a Genco and a load bus is modeled as a customer. The mathematical formulation for trading electricity in the spot market bilateral contracts and reserve market is presented in this section.

The total power sold by Genco h through the spot market and bilateral contracts is:

$$T_h^{g\max} = T_h^{gs} + \sum_{k=1}^{p} T_{hk}^{b} \tag{1}$$

The total power bought by customer k from the hybrid market is:

$$T_k^{d\max} = T_k^{ds} + \sum_{h=1}^{m} T_{hk}^{b} \tag{2}$$

The total power sold by all the Gencos through the spot market is equal to the power bought by customers through the spot market.

$$\sum_{h=1}^{m} T_h^{gs} = \sum_{k=1}^{p} T_k^{ds} \tag{3}$$

3. Transmission expansion planning formulation

Transmission expansion planning is to determine the need for additional transmission facilities to the existing network to ensure adequate transmission network capacity. Addition of new transmission facilities need huge investments but on the other hand if the investments are reduced there may be congestion in the network, which may result in curtailment of market transactions leading to a loss to the customers. Transmission expansion planning is an optimization problem in which the decisions to expand transmission facilities depend on loss due to transmission network capacity limits and the investment costs of new facilities.

In this paper, the objective of the transmission expansion-planning problem is to minimize the overall cost which consists of the transmission expansion costs and the loss sustained by the customer and the cost of reserve dispatch to determine the optimal transmission expansion needed over a planning period. The investment on transmission facilities are long term costs whereas the loss sustained by customers due to lack of transmission facilities are short term costs. Therefore two different time frames are used during the planning period as in Ref. [9]. Investment costs are modeled in years and the loss due to curtailment of transactions are modeled in hours. The curtailment costs for the bilateral and spot customers in each hour throughout the year are forecasted and these forecasted values are used to estimate the expected loss due to curtailment of transactions. The tradeoff between the investment cost and the expected loss due to curtailment of transactions determines the optimal transmission expansion results. For computational simplification purpose, hourly load throughout the year is simplified by classifying the hourly loads into different load levels and representing as an annual load duration curve. The annual load duration curve is used in this work which represents a simplified but reasonable approximation of the hourly loads in a year.

The problem formulation for minimum cost transmission expansion planning problem is as follows:

$$\begin{aligned}\operatorname{Min} z = & \sum_{t_y\in T}\sum_{x_{l.t_y}} \frac{IC_{l,t_y} x_{l,t_y}}{(1+\tau)^{t_y-t_o}} + \sum_{t_h\in T}\sum_{k=1}^{p}\sum_{h=1}^{m} \frac{\vartheta_{hk}^{b}(t_h) C_{hk}^{b}(t_h)}{(1+\tau)^{t_y-t_o}} \\ & + \sum_{t_y\in T}\sum_{k=1}^{p} \frac{\vartheta_{k}^{ds}(t_h) C_{k}^{ds}(t_h)}{(1+\tau)^{t_y-t_o}} + \sum_{t_y\in T}\sum_{h=1}^{m} \frac{\rho_h^{r}(t_h) R_h(t_h)}{(1+\tau)^{t_y-t_o}}\end{aligned} \tag{4}$$

Subject to the following constraints:

The power balance constraint for each bus

$$T_h^{g}(t_h) + C_h^{gs}(t_h) + \sum_{k=1}^{p} C_{hk}^{b}(t_h) + \sum_{l\in\Omega_h} F_{h,l}(t_h) = \sum_{k=1}^{p} T_{hk}^{b}(t_h) + T_h^{gs}(t_h), \quad h = 1,\ldots,m,\ldots N \tag{5}$$

The spot market constraint

$$\sum_{h=1}^{m} R_h(t_h) = \sum_{h=1}^{m} C_h^{gs}(t_h) - \sum_{k=1}^{p} C_k^{ds}(t_h) \tag{6}$$

The curtailment limits for bilateral transactions

$$0 \le C_{hk}^{b}(t_h) \le T_{hk}^{b}(t_h), \qquad h = 1,\ldots,m, \quad k = 1,\ldots,p \tag{7}$$

The curtailment limits for the Gencos in the spot market

$$0 \le C_h^{gs}(t_h) \le T_h^{gs}(t_h), \quad h = 1,\ldots,m \tag{8}$$

The curtailment limits for the Customers in the spot market

$$0 \le C_k^{ds}(t_h) \le T_k^{ds}(t_h), \quad k = 1,\ldots,p \tag{9}$$

The transaction limits for the Gencos

$$0 \le T_h^{g}(t_h) \le T_h^{g\max}(t_h), \quad h = 1,\ldots,m \tag{10}$$

The limits for reserve

$$0 \le R_h(t_h) \le R_h^{\max}(t_h), \quad h = 1,\ldots,m \tag{11}$$

The transmission limits

$$|F_{x_l}(t_y)| \le F_{x_l}^{\max}(t_y) \tag{12}$$

The limit on the number of transmission line installations

$$x_{l,t_y} \le x_{l,t_y}^{\max} \tag{13}$$

Eq. (5) is based on the transportation model i.e. the active power flows in the transmission system obey Kirchoff's first law: the algebraic sum of power flows arriving or leaving the bus is equal to the net injection (generation minus load) to the bus [2]. Eq. (5) has to be satisfied at all buses. If it is a load bus the spot market transactions of the Gencos should be replaced by the spot market transactions of the customers.