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Comparison of Sen Transformer and UPFC for congestion management in hybrid electricity markets

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ABSTRACT

Congestion management (CM) is one of the most important and challenging tasks of the Independent System Operator (ISO) in the deregulated environment. Recently, Sen Transformer (ST) has emerged as an important power flow control device which has the capability of power flow control over a wide range like UPFC. This device with a conventional transformer and tap changers has the capability of bidirectional control of active and reactive power and can play a very important role in future markets for mitigating the congestion problems. In this paper, the capability of ST has been utilized to manage transmission line congestion for hybrid based electricity market model. The main contribution of the paper is: (i) to develop an optimal rescheduling of generators strategy for real time congestion management and impact of ST for congestion management, (ii) the comparison of ST with unified power flow controller (UPFC) for congestion management, (iii) the secure bilateral transactions determination in a hybrid market model and congestion management with both power flow controllers in combined pool and bilateral market model. The optimal location of ST and UPFC has been obtained solving mixed integer non-linear programming model of congestion management. The proposed model has been applied for results on IEEE 24-bus RTS test system.

1. Introduction

With the growing demand of electricity, the transmission network also needs expansion to transfer power. The transmission network with growing concerns of environment, right of way problems, and pressure for effective use of existing facilities in competitive electricity market environment can cause to violate the physical limits of transmission system more frequently to carry more power which leads to the congestion. This congestion in the network may hamper market efficiency, forcing the customers to back down power consumption due to rise in electricity prices and may threaten security of the system making system vulnerable to lower stability margins. Thus, it is the utmost duty of the ISO to mitigate congestion utilizing different techniques may be cost free or cost based [1]. The basic concepts of transmission management and its importance, dispatch model, role of the ISO and its model are presented in [2].

The ISO can utilize corrective measures to manage congestion by utilizing transformer taps, rerouting of lines, and the outage of congested lines. However, the outage of lines can further aggravate the problem of congestion. These solutions may not help the ISO for CM as being not market base solutions which are the need of competitive electricity markets where transparent and fair market solutions provide better market operation. The ISO therefore, utilizes other market based solutions to manage the congestion more effectively. Techniques based on prices, rescheduling of generators, zonal based methods, sensitivity based approaches, financial transmission rights, and FACTS applications to congestion management has been presented in [3–26]. Fang and David [3,4] proposed a transmission dispatch methodology as an extension of spot pricing theory in a pool and bilateral as well as multilateral transaction model. Prioritization of electricity transactions and willingness-to-pay for minimum curtailment strategies has been investigated as a practical alternative to deal with the congestion. Authors in [5] proposed FACTS based curtailment based strategy based on [4] for congestion management. Singh et al. [6] proposed approaches for congestion management based on OPF, which utilizes DC load flow model to minimize the congestion cost for pool model and bilateral model. The nodal pricing theory has been applied in the pool model whereas a method based on congestion cost allocation has been suggested for bilateral model. An optimal power flow based approach using nodal congestion price signals for computing the optimal power output of generators has been proposed in [7].

Authors in [8] proposed combined zonal and Fixed Transmission Right (FTR) scheme for congestion management has been proposed. The combined scheme has been utilized with locational marginal prices (LMPs) to define zonal boundaries appropriately. An OPF approach based on DC load flow as well as AC load flow

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has been formulated to minimize the net cost of re-dispatch to manage interzonal and intrazonal congestion [9]. A novel Lagrangian Relaxation based algorithm for area decomposition OPF, minimizing the congestion cost of re-dispatch in order to deal with the multi-zone congestion management, has been proposed in [10]. Both inter-zonal and intra-zonal congestion management problem has been formulated. Fast LP algorithm to manage congestion by rescheduling generation in Chinese electricity market is presented in [11]. An augmented Lagrangian Relaxation based algorithm has been proposed in [12]. Bompard et al. [13] developed a unified framework for mathematical representation of the market dispatch and re-dispatch problems, which is based on Congestion Management (CM) schemes and the associated pricing mechanisms. A unified framework has been used to develop meaningful matrices to compare the various CM approaches so as to assess their efficiency and effectiveness of the market signals provided to the market participants.

Kumar et al. proposed comprehensive survey of congestion management methods and categorized these methods based on their models for CM [14]. A congestion management approach based on real and reactive power congestion distribution factors based zones and generator's rescheduling was proposed in [15]. Many authors presented FACTS based model for re-dispatching during congestion management [16–22]. However, the congestion management methods have been applied for pool market model. Some of the authors have taken bilateral model into account, however, the ISO must ensure secure bilateral transactions negotiations so that congestion in the network is avoided.

Recently, Sen Transformer has joined the family of power flow controllers where the ST is adequate to provide bidirectional control of both active and reactive power over a wide range like UPFC [23,24]. The traditional technology of transformer and tap changers was utilized for the development of novel device called ST in [23]. The authors studied the operation of the device which has adequate power flow control similar to UPFC. The comparison of ST with UPFC comparing the performance of the devices for active and reactive power flow control [24]. The ST being a cost effective device can provide cost effective solutions to the power flow management in the competitive electricity environment and help the ISO for exploring the better solutions during the peak loads to manage the transmission network congestion. The capability of ST for loadability enhancement and marginal prices variations for both real and reactive power under maximum loadability conditions were presented in [25,26]. Sen Transformer being a power flow control device can also be utilized to provide cost effective solutions for congestion management in deregulated environment.

In the present work, optimal power flow based generation rescheduling approach for congestion management approach has been presented using power flow controllers viz. ST and UPFC. The comparison of results obtained with ST and UPFC has been presented for congestion management. The optimal location of the devices has been obtained using mixed integer non-linear programming based approach. The results have been obtained for a pool + bilateral mix market model where bilateral transactions are ensured optimal by the ISO before dispatching the generators. An optimal power flow problem using mixed integer non-linear programming approach has been solved using DICOPT solver of GAMS with MATLAB interfacing [27,28]. The results have been obtained for IEEE 24 bus Reliability Test System [29].

2. (Pool + bilateral) hybrid market model

The conceptual model of bilateral dispatch is that sellers and buyers enter into transactions where the quantities traded and the trade prices are at the discretion of these parties and not a matter of ISO. These transactions are then brought to the ISO with a request that transmission facilities for the relevant amount of power be provided. If there is no violation of static and dynamic security, the ISO simply dispatches all requested transactions and charges for the service. The bilateral concept can be generalized to the multi-node case where the seller, for example a generation company, may inject power at several nodes and the buyer also draw load at several nodes. The most likely arrangements which will emerge in practical systems in the future is that a pool will exist simultaneously with bilateral and multilateral transactions. All the transactions constituting a group needed to be balanced and secure after dispatching [30]. The significant difference between this model and pool model is that transmission sector is unbundled into a "market" sector and a "security" sector. The ISO is responsible for system operation and guarantees system security and in operational matters and holds a superior position over the power exchanges (PX) and scheduling coordinators (SCs). Market participants may not only bid into the pool but also make bilateral contracts with each other. Therefore, this model provides more flexible options for transmission access. A California model is representative of this category. The Nordic model and the New Zeeland Model also fall into this category with some modifications. Other models such as the New York Power Pool (NYPP) and the Pennsylvania New Jersey Maryland (PJM) model fall somewhere in between these three categories.

A transaction matrix has been taken a collection of transactions between Gencos (G), Discos (D). The transaction matrix can be represented as:

$$[GD] = [DG^T] \tag{1}$$

Each element of GD, namely GD_{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 column j represents the total power consumed at load j.

$$GD \equiv \begin{bmatrix} GD_{1,1} \cdots GD_{1,nd} \\ GD_{2,1} \cdots GD_{2,nd} \\ GD_{ng,1} \cdots GD_{ng,nd} \end{bmatrix} \tag{2}$$

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 as given in (29).

$$\begin{bmatrix} P_d \\ P_g \end{bmatrix} = \begin{bmatrix} GD^T & 0 \\ 0 & GD \end{bmatrix} \begin{bmatrix} u_g \\ u_d \end{bmatrix} \tag{3}$$

Vector u_g and u_d are column vectors of ones with the dimensions of n_g and n_d respectively. There are some intrinsic properties associated with this transaction matrix GD. These are column rule, row rule, range rule, and flow rule. These properties have been explained in [30,31]. Each contract has to range from zero to a maximum allowable value, $GD_{ij}^{\max}$. This maximum value is bounded by the value of corresponding $P_{gi}^{\max}$ or P_{dj} whichever is smaller. The range rule satisfies:

$$0 \leqslant GD_{ij} \leqslant GD_{ij}^{\max} \leqslant \min(P_{gi}^{\max}, P_{dj}) \tag{4}$$

It is also possible for some contracts to be firm so that GD_{ij}^{0} is equal to $GD_{ij}^{\max}$ [30]. According to flow rule the line flows of the network can be expressed as follows:

$$P_{line} = DF_{AC}[P_g - P_d] \tag{5}$$

The matrix DF_{AC} is the distribution factors matrix obtained with AC load flow based approach [31]. If the representations of the P_g and