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Congestion management with generic load model in hybrid electricity markets with FACTS devices

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ABSTRACT

The load variations during the entire day specially during the peak hours have substantial impact on the loading pattern of the transmission system. The voltage profile become poor during such situation of peak loading of the network and can lead to congestion during such events. This paper attempts congestion management considering the impact of constant impedance, current, and power (ZIP) load model along with the load variation pattern in a day-a-head hybrid electricity market. The main contribution of the proposed work is: (i) Optimal rescheduling based congestion management for a hybrid market model with three bid offer from generators, (ii) study of the impact of ZIP load model and load variations on rescheduling and congestion cost, (iii) impact of third generation FACTS devices on congestion management, (iv) comparison of results obtained for hybrid market model without and with ZIP load model. The generators offer three block bid structure to the ISO in a day-a-head market for congestion management. The base case economic load dispatch has been obtained for generators and is taken as base case generation output data during the congestion management to obtain new generation schedule. The three block bid structure submitted to the ISO has been modeled as a linear bid curve which is a function of increment/decrement (inc./dec.) of generation within the upper and lower bounds offered for congestion management. The results have been obtained for IEEE 24 bus test systems.

1. Introduction

Fair and open access of transmission system is one of the key requirements for competitive electricity markets existence. The congestion that may occur in transmission system due to violations of physical limits is undesirable as it can distort market behavior due to change in the prices and increased risk of market manipulations and may compromise security of the system [1]. The North American Electric Reliability Council (NERC) Interchange Distribution Calculator (IDC) which consists of a set of applications, hardware, communication infrastructure, and procedures is designed to manage transmission congestion and mitigate transmission system security limit violations in the North American Eastern Interconnection [2]. The implementation of the Transmission Loading Relief (TLR) procedure to manage the flow in a particular interfaces/flowgates on a NERC Reliability Coordinators request, the IDC calculates the adjustments to interchange transactions. A framework for transmission dispatch and congestion management with key responsibilities of the ISO and its models was proposed in [3].

Congestion management as one of the key elements of transmission system dispatch may be relieved in many cases by cost-free means such as network reconfiguration and enhancement of transmission system capability to alleviate congestion using network expansion planning [4,5]. The other methods like operation of transformer taps, voltage regulators, and operation of flexible alternating current transmission systems (FACTS) devices can be utilized by the transmission system operators to alleviate overloads by means of switching operations that may avoid costly generation or load curtailments. In extreme cases of system operation, it may not be possible to relieve congestion by cost-free means, and the system operator can adopt some non-cost-free control methods, such as re-dispatch of generation, curtailment of loads and other market based financial instruments for relieving transmission congestion [6–15]. Since there is a wide range of events which can lead to transmission system congestion, a key function in system operation is to manage and respond to operating conditions in which system voltages and or power flow limits are violated adopting different congestion management based approaches [6].

The congestion management (CM) is one of the important tasks of the ISO and includes both congestion relief actions and the ISO can utilize market based approaches for alleviating congestion. The market-based methods using locational marginal prices

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Nomenclature

k index for an hr
t index for bid block of generator bid function
$t_{\max}$ maximum no of bid blocks for each generator and is taken as three
$a(i,k)$, $b(i,k)$, $c(i,k)$ cost coefficients of generator-i at hr k
$a_p(i,k)$, $b_p(i,k)$, $c_p(i,k)$ coefficients for real ZIP load at each load bus and hr k
$a_q(i,k)$, $b_q(i,k)$, $c_q(i,k)$ coefficients for reactive ZIP load at each load bus and hr k
$P_g(i,t,k)$ base case real power generation at each bus-i for bid block t and hr k
$Q_g(i,t,k)$ base case reactive power generation at each bus-i for bid block t and hr k
$P_d(i,k)$ base case power demand at each bus-i for hr k
$P_{gn}(i,t,k)$, $Q_{gn}(i,t,k)$ new power generation schedule after congestion management for bid block t and hr k considering ZIP load model
$\Delta P_g^{up}(i,t,k)$ active power increment for generator at bus-i for each bid block and k hrs
$\Delta P_g^{down}(i,t,k)$ active power decrement for generator bus-i for each bid block t and hrs k
$\Delta \mathbf{P}^{\mathbf{up}}_{\mathbf{gmin}}, \Delta \mathbf{P}^{\mathbf{up}}_{\mathbf{gmax}}$ vector of upper and lower limit for up generation
$\Delta \mathbf{P}^{down}_{\mathbf{gmin}}, \Delta \mathbf{P}^{down\mathbf{p}}_{\mathbf{gmax}}$ vector of upper and lower limit for down generation
CC, $CC(k)$ total congestion cost and congestion cost for hr k
$\Delta C(P_g^{up}(i,t,k))$ price offered by generator for up generation at bus-i for congestion management for each bid block t and hr k
$\Delta C(P_g^{down}(i,t,k))$ price offered by generator for up generation at bus-i for congestion management for each bid block-t and hr k
GD_{ij}^{secure} secure bilateral transaction matrix
$GD_{ij,,\max}^{secure}$ upper limit for secure bilateral transaction
G_{ij}, B_{ij} real and imaginary part of Y_{bus}
G_{sh}, B_{sh} shunt conductance and succeptance of STATCOM
$P_{exchange}$ real power exchange via DC link
P_i^C, Q_i^C real and reactive power injection at a bus with STATCOM
P_{ij}^C, Q_{ij}^C real and reactive power injection with SSSC and UPFC
$\boldsymbol{P_g^b}, \boldsymbol{P_g^p}$ vector of bilateral and pool generation
$\mathbf{P_d^b}, \boldsymbol{P_d^p}$ vector of bilateral and pool demand
$P(i,k)$ real power injection at bus-i based on the demand variation for hr k
$Q(i,k)$ reactive power injection at bus-i based on the demand variation for hr k
$P_g^{\max}(i), P_g^{\min}(i), Q_g^{\max}(i), Q_g^{\min}(i)$ upper and lower limits for real and reactive power generation for base case
$P_{gn}^{\max}(i), P_{gn}^{\min}(i), Q_{gn}^{\max}(i), Q_{gn}^{\min}(i)$ upper and lower limits for real and reactive power generation during congestion management
$k_{1n}(i,t,k)$ and $k_{2n}(i,t,k)$ price coefficients of linear bid curve (\$/MW h) offered by the generator to increase and decrease its power schedule for congestion management
$R_g^{up}(i,t,k)$ and $R_g^{down}(i,t,k)$ price offered in (\$/h) as constant part of linear bid curve by the generator to increase and decrease its power schedule for congestion management
$(P_{ij}^{t,k}), (Q_{ij}^{t,k})$ real and reactive power flow calculated for each block t and hours k
$V_{sh,STATCOM}$ and $\delta_{sh,STATCOM}$ shunt voltage and angle for STATCOM
$V_{se,SSSC}$ and $\delta_{se,SSSC}$ series injected voltage and angle for SSSC
$V_{sh,UPFC}$, $\delta_{sh,UPFC}$ shunt voltage and angle, Series injected voltage and angle as control parameters for UPFC
$V_{se,UPFC}, \delta_{se,UPFC} V_{(i,k)}^0, V_{(i,,k)}$ voltage at any bus-i for base case and during congestion management at hr k
$V_i^{\max}, V_i^{\min}$ upper and lower limit for voltage
$V_{(i,k)}^{\max}x, V_{(i,k)}^{\min}$ upper and lower limit for voltage at bus-i at hr k

(LMPs) and other economic signals [7–11] have been proposed to manage and relieve transmission congestion. The essence of these methods is to modify the injection and withdrawal patterns of power flows so that the transmission network can accommodate them without violating the constraints. The market based approaches can be categorized based on LMPs, price area zones, financial transmission rights, and curtailment of preferred schedules of generation and loads. A congestion management system based on LMPs with two new approaches for locational power market screening was presented in [9]. Authors presented a novel control scheme for obtaining optimal power balancing and congestion management in electrical power systems using nodal prices developing an explicit controller that guarantees economically optimal steady-state operation while respecting all line flow constraints in steady-state [11]. Financial transmission rights as a market solution that can hedge congestion charges when utilized with LMPs thereby defining zonal boundaries to manage congestion and efficient use of transmission system [12–14].

Re-dispatching based schemes, curtailment of preferred schedules along with re-dispatch, security constrained OPF, zonal based approach with sensitivity factors, and impact of FACTS to manage transmission congestion minimizing the congestion cost is presented by many authors [15–32]. Fang and David [15,16] proposed a transmission dispatch methodology as an extension of spot pricing theory in a pool and bilateral as well as multilateral transactions 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 [17] proposed FACTS based curtailment strategy based on [15] for congestion management. The phase-shifters and tap transformers play vital preventive and corrective roles in congestion management. These control devices can help the ISO to mitigate congestion without re-dispatching generation away from preferred schedules. A procedure for minimizing the number of adjustments of preferred schedules to alleviate congestion and apply control schemes to minimize interactions between zones taking contingency-constrained limits into consideration was presented in [18]. A method for the decentralized solution of the congestion management problem in large interconnected power systems is presented [19]. A transmission congestion management procedure has been formulated using a combination of load curtailment and generation re-dispatch based on the set of indices to measure the effectiveness of the extent of load curtailment and economic impact [20]. The multi-area congestion management is achieved through cross-border coordinated re-dispatch by regional transmission system operators. A method of congestion management with generation rescheduling and load shedding based on the sensitivities of the overloaded lines to bus injections and the costs of generation and load shedding considered for ranking the generation and load buses has been presented in [21]. Two approaches for a unified management of congestions due to voltage instability and thermal overload in a deregulated environment simultaneously handling of operating and security constraints with respect to several contingencies is proposed with an objective of