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# Congestion management solution under secure bilateral transactions in hybrid electricity market for hydro-thermal combination

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ABSTRACT

The deregulation of power system has created an environment of competitiveness among different market players and the transmission lines are forced to operate near to their thermal or stability limits. It is a challenge with System Operators (SO) to ensure a secure and reliable transmission of power under these conditions. This paper proposes a rescheduling based congestion management strategy in hybrid (pool + bilateral) electricity market structure for a combination of hydro and thermal units. The proposed congestion management problem has been formulated as mixed integer nonlinear programming (MINLP) problem with an objective to minimize the congestion management cost by suitably rescheduling the hydro and thermal units based on their up and down generation cost bids. The hydro units having lowest operational cost and fast startup time have been used to alleviate the congestion by considering non-concave piecewise linear performance curves for them. The secure bilateral transactions have been ensured while rescheduling of the generators for alleviating the congestion. The performance of the proposed model has been demonstrated by solving the congestion management problem on modified IEEE-24 bus system.



## Introduction

With advancement in technological research, the installed capacity of Renewable Energy Sources (RESs) is increasing continuously in the generation to meet the growing energy demand. The rise in generation sources combined with increasing demand put additional burden on our existing transmission infrastructure. The transmission lines capability to transmit the electric power is limited by many factors such as voltage limit, MVA limit, and stability limits. The power system is said to be congested when any of these parameters reach to its limit. Further, the deregulation of electricity sector has created a competitive environment among all the market players and increase in number of market players has added complexity in the operation of the power system [1]. In present competitive environment, the transmission lines are made to operate nearer to their thermal or other stability limits. Sometimes, the congested lines may prevent the market players to have bilateral contracts leading to increase in the price of the electricity. Thus, independent system operators (ISO) have a major challenge to coordinate among the various market players and manage a secure and reliable flow of power on the highly burdened existing transmission infrastructure [2].

Reactive power support, rescheduling of generation, demand re-adjustment etc. are few approaches which have been applied to manage the congestion problem. A comprehensive literature survey has been presented on conventional congestion management techniques in [3]. The congestion management approaches ensure that the transfer limits on any transmission line are not violated while keeping the costs of adjustments to minimum possible. The comparison of five congestion management schemes applied to different electricity markets have been presented in [4].

There are two broad approaches by which the congestion is managed; one is technical and the other is financial. The rescheduling based congestion management falls under the category of financial approach and the methods such as the applications of flexible alternating current transmission systems (FACTS) devices to provide the reactive power support is a technical approach. The rescheduling based congestion management approach has been applied by various authors for different market set ups considering one or the other issues in competitive electricity market [5–8]. A congestion management method based on real and reactive power congestion distribution factor-based zones and generator's rescheduling has been proposed in [9]. Kumar et al. proposed distribution factor-based generators' rescheduling for zonal

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**List of Symbols**

*Sets*

| | |
|---|---|
| $G$ | set of thermal generators |
| $H$ | Set of hydro generators |
| $N$ | Set of buses |
| $L$ | Set of blocks of non-concave linear characteristics curves of hydro units |

*Parameters*

| | |
|---|---|
| $P_{gi}^{\min} P_{hi}^{\min}$ | minimum generation from thermal and hydro units in MW |
| $P_{gi}^{\max} P_{hi}^{\max}$ | maximum generation from thermal and hydro units in MW |
| $Q_{gi}^{\min} Q_{hi}^{\min}$ | minimum reactive power generation from thermal and hydro units in MVAR |
| $Q_{gi}^{\max} Q_{hi}^{\max}$ | maximum reactive power generation from thermal and hydro units in MVAR |
| $V_i^{\min} V_i^{\max}$ | Min and Max values of the voltages at bus $i$ in per unit |
| $\delta_i^{\min} \delta_i^{\max}$ | Min and Max values of the angles at bus $i$ in radians |
| $GD_{ij}^{\min} GD_{ij}^{\max}$ | min and max transactions entry |
| $P_{di}$ | load demand at bus $i$ in MW |
| $P_{db}$ | bilateral load demand in MW |
| $Q_{di}$ | reactive power demand at bus $i$ MVAR |
| $C_{gi}^{up} C_{hi}^{up}$ | up cost bid by thermal and hydro units in $/MW h |
| $C_{gi}^{down} C_{hi}^{down}$ | down cost bid by thermal and hydro units in $/MW h |
| $P_i^0 P_{hi}^0$ | scheduled power for thermal and hydro units in MW |
| $\phi_{hi}^{\min} \phi_{hi}^{\max}$ | min and max discharge of hydro units in $m^3/s$ |
| $r_{hi}^l$ | slope of the piecewise-linear unit performance curve of hydro generator at $i$ th bus in block $l$ MW/$m^3$/s |
| $q_{hi}^{\max,l}$ | maximum water discharge of hydro unit at $i$ th bus in block $l$ $m^3/s$ |
| $M$ | 0.0036 (Conversion factor to convert $m^3/s$ to H $m^3/h$) |
| $W_{hi}$ | max water contents allocated to hydro generating unit $i$ |
| $S_{ij}^{\max}$ | maximum power flow limit in MVA |
| $\Delta P_{gi}^{up,ramp}$ | thermal unit up ramp rate limit in MW |
| $\Delta P_{gi}^{down,ramp}$ | thermal unit down ramp rate limit in MW |
| $\Delta P_{hi}^{up,ramp}$ | hydro unit up ramp rate limit in MW |
| $\Delta P_{hi}^{down,ramp}$ | hydro unit down ramp rate limit in MW |

*Variables*

| | |
|---|---|
| $P_{gni}$ | rescheduled power generation of the thermal generating units $i$ in MW |
| $P_{ghi}$ | rescheduled power generation of the hydro generating units $i$ in MW |
| $P_{gi}$ | power generation of the thermal generating units $i$ in MW |
| $P_{hi}$ | power generation of the hydro generating units $i$ in MW |
| $P_{gp}$ | pool power generated by thermal generating units in MW |
| $P_{gb}$ | bilateral power generated by thermal generating units in MW |
| $Q_{gi}$ | reactive power generation of the thermal generating units $i$ in MVAR |
| $Q_{hi}$ | reactive power generation of the hydro generating units $i$ in MVAR |
| $V_i$ | voltage at bus $i$ in per unit on 100 kV base |
| $\delta_i$ | angle at bus $i$ |
| $u_{hi} v_{hi}^l$ | binary variables showing status of hydro units |
| $u_b$ $v_h$ | binary variable for ensuring generation change either up or down at any bus |
| $q_{hi}^l$ | water discharge of hydro unit at $i$ th bus in block $l$ $m^3/s$ |
| $\Delta P_{gi}^{up}$ | increment of generation by thermal unit $i$ in MW |
| $\Delta P_{gi}^{down}$ | decrement of generation by thermal unit $i$ in MW |
| $\Delta P_{hi}^{up}$ | increment of generation by hydro unit $i$ in MW |
| $\Delta P_{hi}^{down}$ | decrement of generation by hydro unit $i$ in MW |
| $\emptyset_{hi}$ | water discharge of hydro unit $i$ in $m^3/s$ |

congestion management [10]. The FACTS controllers' application in the transmission line controls the power flow and helps in congestion management. A congestion management method based on locating series FACTS devices in deregulated electricity market to minimize the congestion cost have been presented in [11]. Many authors have applied heuristics techniques like particle swarm optimization (PSO), genetic algorithm (GA) and techniques like Bender's Decomposition to minimize the cost of congestion during congestion management [7,12–14].

The congestion management techniques have been applied to various electricity market structures. The common market structure prior to deregulation, which has been studied is the pool market structure. But post de-regulation, the hybrid (pool + bilateral) market model has become the most favored market structure [15,16]. Kumar et al. have solved congestion management problem in pool and bilateral market structures considering demand response based congestion management, using generic load models and FACTS devices ensuring loadability limit [17–20]. The detailed modeling how different market players deal in open access bilateral market model has been presented in [21]. There are few case studies which have been applied to alleviate congestion problem in bilateral market, but most of them have ignored the secure bilateral transactions during the congestion management studies. The combination of pool and bilateral model is the most preferred model of future electricity market and the congestion management can be extended to ensure the secure transactions in a hybrid electricity market.

The RESs due to their unpredictable nature are not preferred for managing the congestion. They supply power either through firm transactions or through power pool. Among the cleaner and cheaper sources of energy, hydro is the second largest energy resource available in India. The hydro units have fast turn on characteristics and negligible operational cost, which make them suitable to meet the peak and emergency demand [22]. Hydro units have been used along with thermal units to manage the congestion in a pool market structure. The duration considered for the congestion management is generally low (1 h) and the characteristics (variations in reservoir level, head etc.) of the hydro units can be used to increase and decrease the generation to manage the congestion in such short duration [23]. The hydro generation entity can also carry out self scheduling of generated energy in day-ahead market to maximize their profit. The Market Clearing Price (MCP) is decided by scheduling the thermal units only and the hydro units are generally considered to be the price takers which helps in maximizing their revenue by bidding power at a price close to but lesser than system marginal price [24,25]. However, hydro units due to their better performance characteristics can be used to bid in the electricity market along with thermal units to alleviate the congestion. The hydro units have been used in combination with wind units to bid in the markets as hydro can support the