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Rescheduling of real power for congestion management with integration of pumped storage hydro unit using firefly algorithm

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ABSTRACT

Post-deregulation era of power system operation produces more pressure on Independent System Operator (ISO) to ensure congestion free transmission network without destroying system security. In order to relieve transmission congestion, ISO initiates correct methods by maintaining system reliability and security. This paper considers a novel efficient technique for congestion management like generator real power rescheduling by integrating a pumped storage hydro unit (PSHU) in the system. This paper presents an optimization model for congestion management by incorporating the calculation of two factors like generator sensitivity factor (GSF) and bus sensitivity factor (BSF). Optimal location of PSHU is identified using the value of BSF's and the numbers of participated generators for congestion management by rescheduling their outputs are determined using the value of GSF's. The impact of PSHU has been investigated to manage transmission congestion which further reduces the congestion cost and improves security of the system. The proposed method for congestion management considering PSHU is tested on modified IEEE-39 bus New England test system and the validity is obtained by considering the same problem without the presence of PSHU. The result of proposed work with proper utilization of PSHU illustrates the impact of PSHU towards the congestion management and also exploration of firefly algorithm for minimizing the transmission congestion cost.

Introduction

It is necessary to maintain the power system security margin within a reliable limit for continuous power supply to the consumers without affecting the system. As thermal limits of transmission lines are fixed, generators have to be rescheduled to minimize the line congestion [1]. It is very difficult to alleviate congestion in electricity market due to the random variation of power transaction. Several methods have been applied in deregulated market to minimize the congestion. In [2], authors have discussed about the utilization of Sen Transformer for congestion management in hybrid electricity market which is a single core, three phase transformer with a Y-connected primary winding and nine secondary windings and it provides function of both voltage and impedance regulation for independent control of bidirectional active and reactive power flows in a transmission system.

In [3–5], authors have discussed about the usefulness of Flexible AC Transmission System (FACTS) devices that are used to enhance the existing transmission networks by increasing power transfer capacity. The series FACTS devices can be used to relieve congestion management by improving voltage and transient stability. In [6], transient stability criterion has been introduced for congestion management which results in better transient stability margin. The new generation and load shedding schedule for these buses are then computed based on a simple method considering cost and sensitivity to line currents. Rescheduling of real power generation based on relative electrical distance (RED) concept has been introduced in [7]. Effectiveness of market flow strategy in congestion management have been reported in the literature [8–10]. A clusters-based congestion method, which identifies the group of users according to their impact on transmission constraints of interest, has been proposed in [11]. Real and reactive power rescheduling using a zonal congestion management approach has been discussed in [12,13].

In [14,15] authors have mentioned that wind and hydro power generation plays an important role in deregulated electricity market. Three bidding strategies are used to formulate the day-ahead bidding model. Wind energy sources have become one of the fastest

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Nomenclature

C_g^t	cost of the active power rescheduling corresponding to the incremental/detrimental price bids submitted by generator at each interval
ΔP_g^t	active power adjustment of the generator at each interval
P_g^{min}	minimum real power generation limit for each generators
P_g^{max}	maximum real power generation limit for each generators
ΔP_g^{min}	minimum change in active power generation limit
ΔP_g^{max}	maximum change in active power generation limit
$F_k{}^0$	power flow in the transmission line k
F_k^{max}	MVA flow limit of kth transmission line connected between bus-i and bus-j
E^t	hourly energy storage level in the reservoir
$E^{Initial}$	initial energy levels of the reservoir
E^{Final}	final energy levels of the reservoir
V_i, δ_i	voltage magnitude and angle at bus-i
Y_{ij}, θ_{ij}	magnitude and angle of ijth element of Y_{Bus} matrix
ΔP_{ij}	change in real power flow of line k
η_P	efficiencies associated with pumping operations
η_H	efficiencies associated with generation operations
P_H^t	hourly active power produced of the pumped storage unit
P_P^t	hourly active power consumed of the pumped storage unit
P_P^{min}	minimum active power consumed limit
P_P^{max}	maximum active power consumed limit
P_H^{min}	minimum active power generation limit
P_H^{max}	maximum active power generation limit
E^L	lower limit of the reservoir
E^U	upper limit of the reservoir
t	index of hour or interval
n	number of buses
s	slack bus in the system
β	variation of attractiveness

growing renewable energy sources and can be alternate of other non renewable sources in the world. But generation of wind power depends on the factors like environmental conditions; wind speed, etc., therefore the level of wind power generation is unpredictable. So it is important to study the possible impact of wind power in power system network. In [16,17], authors have considered the presence of wind energy in the system for congestion management.

PSHU is considered as the most suitable storage technology for achieving high wind penetration levels in medium or large autonomous power systems. Therefore, generation of wind power can manage positive and negative energy imbalances over the entire scheduling time i.e., it has the capability to meet the real power demand by wind generation power. The pumped-storage plants provide the flexibility for the wind farm producer and to reduce the penalties for energy deviations over the entire scheduling time [18].

Firefly algorithm has been successfully implemented to solve different power system problems [19–21]. Economic dispatch problem has been solved using firefly algorithm and its solution gives superior result then other optimization algorithm [20]. In [21], firefly algorithm has been used in frequency control in combined cycle gas turbine power plant for optimization of controller gains. Result reported using FA algorithm in [21] gives better performance as compared to other algorithm.

In this paper, incorporation of PSHU is introduced for congestion management problem. The operation of PSHU depends on the active power demand and availability of the reservoir energy. So, to maintain the system security and voltage profile, PSHU is operated as a load and as a generator as per requirement. The objective of the paper is to minimize congestion cost as well as voltage profile of the system. In this paper, location for PSHU has been chosen based on bus sensitivity factor (BSF). Incorporation of PSHU is the most sensitive bus not only reduces system violation, it also reduces system active power loss and improves minimum voltage profile. Then generator sensitivity factor (GSF) is calculated to select the participated generators for rescheduling and results are compared with result reported in [1]. Incorporation of PSHU drastically reduces congestion cost during generating mode of operation as compared to the pumping mode of operation.

Problem formulation

In the proposed method, it is expected that the pumped storage hydro unit will recover the variation of load demand to maintain secure load profile of the system. If there is a surplus of power, it is necessary to store that power by pumping water to the upper reservoir. On the other hand, when there is a deficit of power, the PSHU uses the water stored in the upper reservoir and operated as generator, to supply the required power to maintain the load profile at reliable margin. In each hour of the scheduling time, the total system load must be maintained by conventional generator and pumped storage hydro unit. If any congestion occurs in the scheduled time due to line outage, then some conventional generator has been rescheduled to overcome this congestion. The following mathematical expressions are used for the operation of system [1].

Congestion cost is obtained by:

$$Minimize \sum_{g=1}^{N_g} C_g^t(\Delta P_g^t)\Delta P_g^t \tag{1}$$

The objective function in Eq. (1) is formulated as minimize the congestion cost at every instant of 24 h scheduling period.

Subject to:

GSF constraint:

$$\sum_{g=1}^{N_g}((GSF_g^t)\Delta P_g^t) + F_k^0 \leqslant F_k^{\max} \quad k = 1,2,\ldots\ldots..n_1, \quad \forall t = T \tag{2}$$

Pump storage constraint [18]:

$$E^t = E^{Initial} \quad t = 0, \quad E^t = E^{Final} \quad t = 24 \tag{3}$$

$$E^{t+1} = E^t + t\left(\eta_P P_p^t - \frac{P_H^t}{\eta_H}\right) \quad \forall t = T \tag{4}$$

$$P_P^{\min} \leqslant P_P^t \leqslant P_P^{\max} \quad \forall t = T \tag{5}$$

$$P_H^{\min} \leqslant P_H^t \leqslant P_H^{\max} \quad \forall t = T \tag{6}$$

$$E^L \leqslant E^t \leqslant E^U \quad \forall t = T \tag{7}$$

Ramp limit:

$$\begin{gathered} P_g^t - P_g^{\min} = \Delta P_g^{\min} \leqslant \Delta P_g^t \leqslant \Delta P_g^{\max} = P_g^{\max} - P_g^t \\ g = 1,2,\ldots\ldots N_g, \quad \forall t = T \end{gathered} \tag{8}$$

Power limit of generator: