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Optimal Utilization of Renewable Energy Sources for Congestion Management

J. Jeslin Drusila Nesamalar*. P. Venkatesh**
S. Charles Raja***

** Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, Tamilnadu-625015, India (e-mail: jeslindrusila@gmail.com)*
*** Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, Tamilnadu-625015, India (e-mail: pveee@tce.edu)*
**** Department of Electrical and Electronics Engineering, Thiagarajar College of Engineering, Madurai, Tamilnadu-625015, India (e-mail: charlesrajas@tce.edu)*

Abstract: This article analyse the optimal utilization of Renewable Energy Sources (RES) to manage congestion under power system restructured environment. The proposed congestion management problem is formulated to minimize the rescheduling cost of renewable and conventional generators to alleviate congestion subject to operational, line overloading, seasonal and time constraints. The rescheduling has been done by generator selection based on the proposed Apparent power Congestion Index. Particle swarm optimization with time varying acceleration coefficient minimizes the deviation of rescheduled generator power output from scheduled values. The seasonal and time constraints considered in this paper, is the pioneering work in congestion management involving RES. The validation of the proposed method has been studied on IEEE 30-bus system and the obtained results certify the advantages of RES.

Keywords: Apparent power Congestion Index, Congestion Management, Generator rescheduling, Particle Swarm Optimization, Seasonal and time constraints.

1. INTRODUCTION

With the fruitful results obtained after deregulating aviation, communication and postal systems, it has been expected in the area of power system. With rising population and demand, electric utilities have been forced to increase their generation. The existing transmission lines are limited by thermal limit, voltage limit and stability limit and when the limit is reached, the line is said to be congested (Christie et al. (2000)). But, due to the lack of transmission line expansion, unscheduled transaction or contingency cause congestion on the existing transmission lines. Independent System Operator (ISO) need to relieve congestion depending on the willingness of generator rescheduling for every hour on day-ahead basis.

Many literatures have explored ideas towards congestion management schemes. Based on benders decomposition technique, Xiao et al. (2009) analyzed congestion management by considering hybrid market. Hazra and Sinha (2007) proposed a multi-objective problem for alleviation of overload and minimization of operational cost which are optimized to provide pareto-optimal solutions. Optimal rescheduling of generators based on Particle Swarm Optimization has been discussed by Dutta and Singh (2008) by taking line flow in MW instead of MVA. Venkaiah and Vinod Kumar (2011) present fuzzy adaptive bacterial foraging based congestion management by rescheduling the active power of generators.

Electricity generation based on fossil fuel is accounted for considerable release of carbon dioxide and other greenhouse gases. Alternatively, technologies deriving energy from nature which are continually replenished on a human timescale are viewed as environmental friendly and clean energy for unlimited period of time. As the renewable generation portfolio is considerably increasing in the restructured power sector, opportunities can be given for RES in congestion management. Based on the statistics of potential of renewable energy and geological profile, renewable energy sources for peak load demand management in India has been suggested by Dudhani et al. (2006). Babu and Ashok (2009) analyzed the optimal utilization of renewable energy-based IPPs for industrial load management.

The congestion effect on inclusion of wind power in Norway where hydropower is already surplus is evaluated by Førsund et al. (2008). A generalized model of congestion management for deregulated system has been discussed by Sood and Singh (2010) by considering RES as firm transaction. By compensating renewable or by giving incentives among power adjustment offers, the actions for increasing the revenue of renewable producers during congestion is discussed by Vergnol et al (2000). Considering combined operation of hydro and thermal generator companies, the cost of re-dispatching both generators has been formulated by Singh et al. (2011).

But none of the model has taken care about the intermittent nature, seasonal and time variations of renewable generation in congestion management of deregulated power sector. This topic deserves more attention as higher penetration of renewable generation is foreseeable in power system. In this study, solar, wind, biomass, small-hydro and cogeneration

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renewable sources have been considered. The season and time constraints have a significant role when determining congestion cost when selecting RES for congestion. If this is not considered, then it may lead to immature decision by ISO in the short run which will eventually lead to rejection of RES for congestion in the long run.

In this work, static compensation equipments are employed to meet the reactive power support while rescheduling reactive power of wind and solar plant. For rest of RES, reactive power rescheduling is done by generator voltage variation.

The power generation from RES is subjected to seasonal variations as well as diurnal/hourly changes. For example, solar energy has a seasonal variation with the peak in summer and diurnal basis variation from dawn to dusk peaking during mid-day (Moreno et al. (2013)). Wind energy is higher at day than at night and higher during warm season than during cool season. Biomass availability is large indicating that global biomass primary energy potential could satisfy seasonal energy demands in a sustainable manner and is independent of time variations.

Seasonal variations determine the water level in the river. But as water is being stored in dams, small-hydro plant is subjected to minimum fluctuation for seasonal variations and is independent of diurnal changes. Cogeneration plant employing bagasse or other raw material have a season period of 150-200 days and is independent of time variations (Karagali et al. (2013)).

The main objective of this paper is to minimize rescheduling cost of renewable and conventional generators subject to operational, line overloading, seasonal and time constraints on day-ahead and hourly basis market. Apparent power congestion index has been used to select the real and reactive power generators participating and Particle Swarm Optimization with Time Varying Acceleration Coefficient (PSO_TVAC) is used for solving combined conventional-renewable generation based congestion management problem on IEEE 30-bus system.

2. PROBLEM FORMULATION

The real and reactive power flow equation in a transmission line connected between bus 'i' and bus 'j' can be written as,

$$P_{ij} = -V_i^2 G_{ij} + V_i V_j G_{ij}\cos(\theta_i - \theta_j) + V_i V_j B_{ij}\sin(\theta_i - \theta_j) \quad (1)$$

$$Q_{ij} = -V_i^2 B_{ij} - V_i^2 B_i - V_i V_j G_{ij}\sin(\theta_i - \theta_j) + V_i V_j B_{ij}\cos(\theta_i - \theta_j) \quad (2)$$

From these basic equations, apparent power can be derived as,

$$\left|S_{ij}\right| = (V_i^4(G_{ij}^2 + B_{ij}^2) + V_i^4 V_j^2 (G_{ij}^2 + B_{ij}^2) - 2V_i^3 V_j \cos(\theta_i - \theta_j)(G_{ij}^2 + B_{ij}^2) + 2V_i^4 B_{ij} B_i + 2V_i^3 V_j B_i (G_{ij}\sin(\theta_i - \theta_j) - B_{ij}\cos(\theta_i - \theta_j)) + V_i^4 B_i^2)^{1/2} \quad (3)$$

2.1 Apparent power Congestion Indices (SCIs):

An efficient way of determining the most sensitive generators to the congested line is by defining sensitivity factor and by calculating the participating generators. In power system terminology, apparent power is denoted by 'S'. Thus, the proposed index has been coined as SCI. SCI_P of a line 'k' for a generator 'g' can be calculated from the change in apparent power flow ΔS_k in the transmission line 'k' with respect to the real power ΔP_g injection by a generator bus 'g' and is written as,

$$SCI\_P_{k,g} = \frac{\Delta S_k}{\Delta P_g} \quad (4)$$

Similarly, SCI_Q can be calculated from the change in apparent power flow ΔS_k with respect to the reactive power ΔQ_g injection by a generator bus 'g' and is written as,

$$SCI\_Q_{k,g} = \frac{\Delta S_k}{\Delta Q_g} \quad (5)$$

The total change in apparent power flow incorporating SCIs can be written as

$$\Delta S_k = \left(SCI\_P_{k,g} \times \Delta P_g\right) + \left(SCI\_Q_{k,g} \times \Delta Q_g\right) \quad (6)$$

Using Taylor series approximation and neglecting P-V coupling and Q-θ coupling, (4) and (5) can be written as

$$SCI\_P_{k,g} = \frac{\partial S_k}{\partial \theta_i}.\frac{\partial \theta_i}{\partial P_g} + \frac{\partial S_k}{\partial \theta_j}.\frac{\partial \theta_j}{\partial P_g} \quad (7)$$

$$SCI\_Q_{k,g} = \frac{\partial S_k}{\partial \left|V_i\right|}.\frac{\partial \left|V_i\right|}{\partial Q_g} + \frac{\partial S_k}{\partial \left|V_j\right|}.\frac{\partial \left|V_j\right|}{\partial Q_g} \quad (8)$$

Differentiating (3) with respect to phasor angle and voltage,

$$\frac{\partial S_{ij}}{\partial \theta i} = \left(U_{ij}\right)^{\frac{-1}{2}} \times \begin{bmatrix} 2V_i^3 V_j \sin(\theta_i - \theta_j)\left(G_{ij}^2 + B_{ij}^2\right) \\ + V_i^3 V_j B_i \left(G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\right) \end{bmatrix} \quad (9)$$

$$\frac{\partial S_{ij}}{\partial \theta_j} = \left(U_{ij}\right)^{\frac{-1}{2}} \times \begin{bmatrix} -2V_i^3 V_j \sin(\theta_i - \theta_j)\left(G_{ij}^2 + B_{ij}^2\right) \\ -V_i^3 V_j B_i \left(G_{ij}\cos(\theta_i - \theta_j) + B_{ij}\sin(\theta_i - \theta_j)\right) \end{bmatrix} \quad (10)$$

$$\frac{\partial S_{ij}}{\partial \left|V_i\right|} = \left(U_{ij}\right)^{\frac{-1}{2}} \times \begin{bmatrix} 2V_i^3\left(G_{ij}^2 + B_{ij}^2\right) + V_i V_j^2 \left(G_{ij}^2 + B_{ij}^2\right) - 3V_i^2 V_j \cos(\theta_i - \theta_j)\left(G_{ij}^2 + B_{ij}^2\right) \\ +4V_i^3 B_i B_{ij} + 3V_i^2 V_j B_i G_{ij}\sin(\theta_i - \theta_j) - 3V_i^2 V_j B_i B_{ij}\cos(\theta_i - \theta_j) + 2V_i^3 B_i^2 \end{bmatrix} \quad (11)$$

$$\frac{\partial S_{ij}}{\partial \left|V_j\right|} = \left(U_{ij}\right)^{\frac{-1}{2}} \times \begin{bmatrix} V_i^2 V_j \left(G_{ij}^2 + B_{ij}^2\right) - V_i^3 \cos(\theta_i - \theta_i)\left[G_{ij}^2 + B_{ij}^2\right] \\ +V_i^3 B_i \left(G_{ij}\sin(\theta_i - \theta_j) - B_{ij}\cos(\theta_i - \theta_j)\right) \end{bmatrix} \quad (12)$$

Where $U_{ij} = \left|S_{ij}\right|^2$ (13)

$\frac{\partial \theta_i}{\partial P_g}$, $\frac{\partial \theta_j}{\partial P_g}$, $\frac{\partial \left|V_i\right|}{\partial Q_g}$, $\frac{\partial \left|V_j\right|}{\partial Q_g}$ are obtained from the Jacobian matrix and (7) and (8) can be calculated.

2.2. Congestion Management Problem Formulation:

ISO select generators by using the proposed SCI methodology with the objective of minimizing congestion cost. Day-ahead schedule will be checked for congestion and if congestion occurs, generator rescheduling will be done to satisfy the objective function and constraints for the congested hour. Once rescheduling notice has been sent to renewable and conventional generators, the day-ahead schedule will be dispatched as modified. Suppose, while executing the hour-ahead schedule, contingency occurs leading in congestion, ISO need to do congestion management again for the particular hour.