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Security constrained generation scheduling for grids incorporating wind, photovoltaic and thermal power

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ABSTRACT

In this paper, security constrained generation scheduling (SCGS) problem for a grid incorporating thermal, wind and photovoltaic (PV) units is formulated. The formulation takes into account the stochastic nature of both wind and PV power output and imbalance charges due to mismatch between the actual and scheduled wind and PV power outputs. A hybrid technique in which the basic elements are a genetic algorithm (GA) with artificial neural network (ANN) and a priority list (PL) is used to minimize the total operating costs while satisfying all operational constraints considering both conventional and renewable energy generators. Numerical results are reported and discussed based on the simulation performed on the IEEE 24-bus reliability test system. The results demonstrate the efficiency of the proposed approach to reduce the total production cost for real time operation. Moreover, the results verified that the proposed approach can be applied to different problem dimensions and can score more favorably compared with analytical techniques.

1. Introduction

In the regulated power industry, generation scheduling (GS) refers to minimizing the cost of operating generation resources to satisfy the load demand. In the restructured power-system arena, GS is further developed and extended to resolve new problems posed by the unbundling of generation and transmission facilities. For instance, generating companies (GENCOs) use price-based generation scheduling (PBGS) for maximizing their bidding strategy in power markets. In this case, individual GENCOs' objective is to optimize the scheduling of generation resources for maximizing the GENCO's profit rather than satisfying the load demand. In several electricity markets, the independent system operator (ISO) plans the day-ahead schedule using security-constrained generation scheduling (SCGS). Besides the prevailing constraints (such as load balance, system spinning reserve, ramp rate limits, and minimum up and down time limits) considered by traditional generation scheduling algorithm, SCGS incorporates the ac network flow constraints in the generation scheduling formulation for minimizing the network violation and maintaining the transmission security in power systems [1]. A growing interest in renewable energy resources has been observed for several years, due to their pollution free, availability in all over the world, and continuity. Among the renewable energy resources, the energy through the PV effect can be considered as one of the most essential and prerequisite sustainable resource because of the ubiquity, abundance and sustainability of solar radiant energy [2]. Due to the increasing demand of PV power generation in the general amount of power generation within the network grid and with the development of inverter's technology, it is expected that the size of PV system grows in relation to utility system capacity. However, in some cases, it cannot provide a continuous source of energy due to the low availability during the no-sun period and the winter. On the other hand, wind power generation (WPG) has taken great penetration in the power systems due to its environmentally friendly and cost-predictable nature. Unlike the conventional thermal units, wind and PV power generators have intermittent nature which results in a new challenge to the economical operation problems. The primary problem associated with the incorporation of wind and PV powers into the SCGS model is the fact that the future wind speed and solar irradiance, which are the power sources for the wind and PV energy conversion systems, is an unknown at any given time. Several investigations have looked at the prediction of wind speed and solar irradiance for use in determining the available wind and PV powers [3,4]. Because the focus of this paper is on the SCGS problem and not on wind and PV power forecasting, theories to develop the wind speed and solar irradiance profiles will not be used, but a known probability distribution function (PDF) for the wind speed

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and solar irradiance will be assumed, and then, transformed to the corresponding wind and PV power distributions for use in the SCGS model.

Security constrained generation scheduling (SCGS) is a high-dimensional, non convex, mixed-integer programming problem, and extremely difficult to obtain the exact optimal solution [5]. Great effort has been made in studying the SCGS problem over the past decades. A stochastic model for the long term solution of security-constrained unit commitment is presented in [6] to model the stochastic behavior of input uncertainties based on the probability density function and scenario generation. In [7] the effects of capacity limit of lines connecting wind electric generators (WEGs) on the optimal unit commitment schedule are studied. Stochastic characteristic of the WEGs is used to compute expected energy not served, a measure which quantifies the amount of output that may not become online from WEGs at any given hour. In [8], A methodology to estimate the maximum firm wind energy that can be integrated to a given power transmission network is outlined. A model is developed to include the wind energy conversion system in the economic dispatch (ED) problem. The stochastic wind speed characterization based on the Weibull probability density function is applied to characterize the wind power uncertainty. The uncertainty of electrical energy cost coefficients and load demand are considered in the expected objective functions of ED [9,10].

In this paper, a two-stage adaptive robust optimization model for the SCGS problem, where the first-stage unit commitment decision and the second-stage ED decision, are proposed. An adaptive hybrid technique comprising of the artificial neural network (ANN) with genetic algorithm (GA) and a priority list (PL), ANN/GA/PL, proposed in [11] is developed for this purpose and tested on the IEEE 24-bus reliability test system after incorporating wind and PV power plants. To facilitate comparing the results of the effect of the integration of wind and PV power plants on the SCGS problem and in order to test the feasibility of the hybrid technique consisting of ANN/GA/PL, the same SCGS problem formulation as in [11] is followed. Consequently, the critical constraints such as network constraints, ramp rate constraints and transmission security constraints, deterministic reserve are incorporated into the proposed model. However, the primary characteristic that differentiates wind and PV powered from conventional generators in the SCGS problem is the stochastic nature of wind speed and solar irradiance. After developing SCGS model that incorporates thermal, wind and PV power sources is developed, it is still necessary to characterize the stochastic nature of the wind speed and solar irradiance in order to analyze the problem with numerical results.

2. Wind energy stochastic model

The wind speed distribution for selected sites as well as the power output characteristic of the chosen wind turbine is the factors that have to be considered to determine the WPG output. Since the wind speed 'v' is a random variable, a long-term meteorological data is desirable to describe wind energy potential of the sites. In order to account the variability of wind speed, it is assumed that the wind speed profile at a given location most closely follows a Weibull distribution over time with a scale parameter 'c' and a shape parameter k [12]. The probability density function (pdf), $f_v(v)$, for a Weibull distribution is given in [8] as:

$$f_v(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{(k-1)} e^{-(v/c)^k} \tag{1}$$

where v, c and k are wind speed random variable, scale factor, and shape factor, respectively. There are several methods used to calculate the Weibull factors [13,14]. In this paper, the factors k and c are calculated approximately using the mean wind speed v_m and the standard deviation σ as follows:

$$k = \left(\frac{\sigma}{v_m}\right)^{-1.086} \tag{2}$$

$$c = \frac{v_m}{\Gamma(1+1/k)} \tag{3}$$

The output power of a wind turbine is dependent on the wind speed at the site as well as the parameters of the power performance curve. Therefore, once the Weibull pdf is generated for a specific time segment, the output power during the different states is calculated for this segment using the following equation

$$w = \begin{cases} 0 & 0 \le v \le v_i \\ w_r * \dfrac{(v-v_i)}{(v_r-v_i)} & v_i \le v \le v_r \\ w_r & v_r \le v \le v_o \\ 0 & v_o \le v \end{cases} \tag{4}$$

The probability density function, $f_w(w)$, for the power output of the wind turbine can be obtained using Eqs. (1) and (4) by the application of the transformation theorem [8]

$$f_w(w) = \begin{cases} \left(\dfrac{klv_i}{c}\right)\left(\dfrac{(1+\rho l)v_i}{c}\right)^{k-1} \exp\left(\left(\dfrac{(1+\rho l)v_i}{c}\right)^k\right) & \text{for } 0 < w \le w_r \\ 1-\exp\left[-\left(\dfrac{v_i}{c}\right)^k\right]+\exp\left[-\left(\dfrac{v_o}{c}\right)^k\right] & w = 0 \\ \exp\left[-\left(\dfrac{v_r}{c}\right)^k\right]-\exp\left[-\left(\dfrac{v_o}{c}\right)^k\right] & w = w_r \end{cases} \tag{5}$$

where $\rho = \frac{w}{w_r}$ and $l = \frac{v_r - v_i}{v_i}$, v_r is rated wind speed, w_r is rated wind power, v_i is cut in speed and v_o is cut out speed.

3. PV stochastic model

The amount of solar radiation that reaches the ground, besides the daily and yearly apparent motion of the sun depends on the geographical location (latitude and altitude) and on the climatic conditions (e.g., cloud cover). To account for the difference between the values of solar radiation measured outside the atmosphere and on earthly surface an hourly clearness index, k_t, has been defined as the ratio of the irradiance on a horizontal plane, I_t [kW/m^2], to the extraterrestrial total solar irradiance I_o [kW/m^2] [15,16], i.e.

$$k_t = \frac{I_t}{I_0} \tag{6}$$

In this work, the clearness index pdf [16] shown in (7), is utilized to model the hourly solar irradiance.

$$f_{kt}(k_t) = c'(1 - k_t/k_{t\,\max})\exp(\lambda k_t) \tag{7}$$

where c' and λ are functions of the maximum value of clearness index, $k_{t\max}$, and the mean value of clearness index, k_{tm}, as follows [17]:

$$c' = \frac{\lambda^2 k_{t\,\max}}{(exp(\lambda k_{t\,\max})) - 1\lambda k_{t\,\max}} \tag{8}$$

$$\lambda = \frac{2\gamma - 17.519\exp(-1.3118\gamma) - 1062\exp(-5.0426\gamma)}{k_{t\,\max}} \tag{9}$$

$$\gamma = \frac{k_{t\,\max}}{k_{t\,\max} - k_{tm}} \tag{10}$$

Therefore, once λ is determined from (9) for a specific value of $k_{t\max}$, the corresponding value of 'c' can be determined from (8).