Electrical Power and Energy Systems 54 (2014) 306–314

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Optimal power flow solution of wind integrated power system using modified bacteria foraging algorithm

Ambarish Panda, M. Tripathy *

Department of Electrical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha, India

ARTICLE INFO

Article history:
Received 19 February 2013
Received in revised form 27 June 2013
Accepted 13 July 2013

Keywords:
Optimal power flow
Wind energy conversion system
Bacteria foraging algorithm
Doubly fed induction generator

ABSTRACT

Owing to the intermittent nature of wind flow, optimal power flow in a power system with considerable wind energy penetration is a challenging issue. In this paper an OPF solution is proposed for IEEE 30 bus power system modified by replacing three conventional generators with equivalent wind energy conversion systems (WECS).The uncertain nature of wind power has the risk of over or under estimating the capacity of available wind power. This uncertainty has been suitably modeled and included in the OPF framework. Moreover, to justify the limitation of reactive power generation capability of doubly fed induction generator based WECS during under estimation, additional cost component corresponding to external reactive power (Q) generating sources has been added in the objective function. The scheduling problem of WECS integrated power system is solved by formulating it as an optimization problem. Genetic algorithm and a modified bacteria foraging algorithm are employed separately to determine the optimal schedule. The optimal solution obtained with a modified version of BFA has been found to give better results compared to GA. The results depict the impact of wind and thermal scheduling on total system cost and reiterate the need of additional support of reactive power resources to maintain stable voltage profiles of the wind–thermal system.

1. Introduction

The global electrical energy consumption is rising there by increasing the demand of power generation. In this scenario, the use of renewable energy resources like wind power has become necessary. Conventionally, the scheduling of generators is carried out based on economic criteria. Besides economic criteria, decision regarding the scheduling of generators in an OPF framework [1] plays a vital role. Due to the variable nature of wind, it cannot be assured that the scheduled power from WECS will match with the power available from wind energy. Therefore, in wind integrated systems, the nature of wind makes the above problem to be different in its modeling. In order to manage the uncertainty of wind power in the scheduling problem, additional cost components need to be added. Additional penalty and reserve costs have been considered to account for under and over estimation of available wind power [2]. Authors in [3] have discussed the impact of stochastic nature of wind on overall system operational cost. The process to develop wind farm model and its integration to conventional power system has been discussed in [4]. In [5], various cost components of wind integrated power system is presented. Additionally, authors in [6,7] have sought to forecast wind speed and power using fuzzy logic and neural network respectively. In [8], Cailliau et al. have presented methodology to operate the system in a secured manner in the presence of increased stochastic wind power generation. Similarly, the authors in [9–11] have demonstrated that apart from modeling the uncertainties of wind, when various operational constraints of the conventional system are required to be included in an OPF formulation, physical limitations of WECS cannot be ignored. In another work [13], research has shown that during under estimation, the reactive power (Q) capability of doubly fed induction generator (DFIG) may limit the system's ability to maintain nominal grid bus voltage. To address the security concerns in the system, the authors in [13] have formulated a security constrained economic dispatch in DFIG based WECS where reactive power capability of DFIG [14] has been analyzed. Authors in [15–17] have tried to incorporate some dynamic issues related to grid synchronization of DFIG in variable speed wind generation system .In addition to the aspects discussed in [12,13], this proposed work has attempted to include an additional cost component related to the cost involved in reactive power violation in the system. The above mentioned extra cost is meant for the reactive power requirement (Q_c) from other local Q-generating sources at WECS buses so that the Q-generating capacity of wind farms are not violated during under estimation of wind power, and it may be possible to operate the system in a voltage secure manner. In this

* Corresponding author. Tel.: +91 9861041031.
E-mail addresses: ambarish101@gmail.com (A. Panda), manish_tripathy@yahoo.co.in (M. Tripathy).

0142-0615/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.ijepes.2013.07.018

regards, the total cost in OPF formulation is obtained by adding the total conventional generation cost, cost of constraint violation and additional cost Q_c. Evolutionary techniques i.e. genetic algorithm (GA) and a modified bacteria foraging algorithm (BFA) are applied to optimize the objective functions. The optimized generating schedules are tested for their ability to operate the system securely, when the system is subjected to numbers $(N-1)$ contingencies in the form of line outages. Simulations are carried out in MATLAB/SIMULINK environment.

The paper is organized in the following manner. The main problem is formulated in Section 2. Section 3 discusses about the capability of reactive power in DFIG integrated WECS. Section 4 presents a brief overview of optimization techniques applied in this work. In Section 5, procedural details of simulations and results are presented. In the same section few pertinent observations are made regarding the results obtained which has led to conclusions in Section 6.

2. Problem formulation

2.1. Problem

For satisfactory operation of wind integrated power system, wind power fluctuation must be balanced by other types of generation. The nature of uncertainty of wind emphasizes, that the system should incorporate additional cost due to power imbalance. Moreover, as discussed earlier the limited capacity of reactive power of DFIG warrants additional reactive power support at the WECS buses. As these additional costs may prove to be uneconomical, therefore their inclusion in the cost function would be more realistic. Considering this aspect, two types of objective functions are formulated as presented in (1) and (2) respectively. An additional cost Q_c which corresponds to the cost of additional reactive power resources is added in F_2 unlike in F_1. The problem is formulated as below

Minimize

$$F_1 = \sum_{t}^{N_g} C_t(P_{gt}) + \sum_{r}^{N_w}[C_{wr}(P_{wr}) + C_{p,wr}(P_{wr,av} - P_{wr}) + C_{r,wr}(P_{wr} - P_{wr,av})] + Pf_1 + Pf_2 \tag{1}$$

Minimize

$$F_2 = \sum_{t}^{N_g} C_t(P_{gt}) + \sum_{r}^{N_w}[C_{wr}(P_{wr}) + C_{P,wr}(P_{wr,av} - P_{wr}) + C_{R,wr}(P_{wr} - P_{wr,av})] + Pf_1 + Pf_2 + Q_c \tag{2}$$

Subject to constraints:

$$\sum_{t}^{N_g} P_{gt} + \sum_{r}^{N_w} P_{wr} = P_{loss} + P_{load} \tag{3}$$

$$\sum_{t}^{N_g} Q_{gt} + \sum_{r}^{N_w} Q_{wr} = Q_{loss} + Q_{load} \tag{4}$$

$$P_{gt}^{min} \leqslant P_{gt} \leqslant P_{gt}^{max} \tag{5}$$

$$Q_{gt}^{min} \leqslant Q_{gt} \leqslant Q_{gt}^{max} \tag{6}$$

$$V_t^{min} \leqslant V_t \leqslant V_t^{max} \tag{7}$$

$$P_{wr} \leqslant P_{wr}^{max} \tag{8}$$

$$Q_{wr}^{min} \leqslant Q_{wr} \leqslant Q_{wr}^{max} \tag{9}$$

In the function F_1 defined above notations t and g denote the conventional (thermal) units and r and w denote the renewable (wind) units. The first and second terms in (1) denote the cost of thermal power generation and the cost of power purchase from wind power producer as defined in (10) and (11) respectively. Similarly, the third and fourth terms in (1) are the additional costs of under and over estimated wind power components to account for the wind power intermittency [5]. Pf_1 and Pf_2 are suitable penalty functions to consider the effect of additional cost required to operate the system within the physical constraints. Details of the above terms are presented in the following sub-sections.

2.2. Evaluation of cost of thermal generating units

Widely acclaimed quadratic cost function for thermal generators are adopted which is explained by (10) as follows

$$C_t(P_{gt}) = a_t P_{gt}^2 + b_t P_{gt} + c_t \tag{10}$$

Where a_t, b_t, c_t are the cost coefficients of tth thermal unit and P_{gt} is the power output of tth generator. These are specified in Table 1.

2.3. Evaluation of direct cost

The cost of purchase of wind power from wind power producer is termed as the *direct cost* and is expressed in (11) as the follows

$$C_{wr}(P_{wr}) = d_r P_{wr} \tag{11}$$

where d_r is the direct cost coefficient of the rth wind generator and P_{wr} is the scheduled power output of rth wind unit.

2.4. Evaluation of cost corresponding to surplus wind power

When the scheduled power is found to be less than the capacity of actual wind power available, the scenario is known as *under estimation*. During underestimation, there will be a surplus amount of available wind power. From the system operation point of view, the ISO should maximize the utilization of available wind power. It can be done by reducing the power output of conventional generators by fast re-dispatch and automatic generation control. In the case when it is not feasible then ISO has to pay an equivalent cost to the wind power producer (WPP) for not utilizing all available wind resources. The above cost is termed as *penalty cost*, which can be represented as follows

$$C_{p,wr}(P_{wr,av} - P_{wr}) = K_{Pr}(P_{wav} - P_{wr}) = K_{pr}\int_{P_{wr}}^{P_{ro}} (w - P_{wr}) f_w(w)dw \tag{12}$$

K_{Pr} is the penalty cost coefficient for the rth wind generator and $f_w(w)$ WECS wind power probability density function (PDF) [18]. In order to model and characterize the wind speed suitably and to convert it into wind power, Weibull distribution function [18,19] has been used in this work. P_{wr}, P_{ro}, P_{wav} are respectively the scheduled, rated power and available wind power from rth wind powered generator.

2.5. Evaluation of cost corresponding to deficit wind power

There may be situations when the actual available wind power could fall behind the scheduled value. The scenario is referred as *over estimation*. During this situation, in order to meet the load demand and to compensate the differential amount, some reserve units' need to be committed by the ISO. The cost of committing the reserve generating units to meet the wind power shortage is called the *reserve cost*. The cost as a function of power can be represented as follows