Applied Energy 88 (2011) 4678–4686

Contents lists available at ScienceDirect

Applied Energy

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

Reactive power dispatch in wind farms using particle swarm optimization technique and feasible solutions search

Marcela Martinez-Rojas [a,*], Andreas Sumper [a,b,c], Oriol Gomis-Bellmunt [a,b,c], Antoni Sudrià-Andreu [a,b,c]

[a] Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC), Departament d'Enginyeria Elèctrica, Universitat Politècnica de Catalunya, EU d'Enginyeria Tècnica Industrial de Barcelona, C. Comte d'Urgell, 187, Pl. 2, 08036 Barcelona, Spain

[b] Centre d'Innovació Tecnològica en Convertidors Estàtics i Accionaments (CITCEA-UPC), Departament d'Enginyeria Elèctrica, Universitat Politècnica de Catalunya, ETS d'Enginyeria Industrial de Barcelona, Av. Diagonal, 647, Pl. 2, 08028 Barcelona, Spain

[c] IREC, Catalonia Institute for Energy Research, C. Josep Pla, 2, edifici B2, Planta Baixa, 08019 Barcelona, Spain

ARTICLE INFO

Article history:
Received 20 October 2010
Received in revised form 2 June 2011
Accepted 4 June 2011
Available online 1 July 2011

Keywords:
Wind farm
Reactive power compensation
Particle swarm optimization

ABSTRACT

In this paper, an optimization method for the reactive power dispatch in wind farms (WF) is presented. Particle swarm optimization (PSO), combined with a feasible solution search (FSSPSO) is applied in order to optimize the reactive power dispatch, taking into consideration the reactive power requirement at point of common coupling (PCC), while active power losses are minimized in a WF. The reactive power requirement at PCC is included as a restriction problem and is dealt with feasible solution search. Finally an individual set point, particular for each wind turbine (WT), is found. The algorithm is tested in a WF with 12 WTs, taking into consideration different control options and different active power output levels.

1. Introduction

Nowadays, the amount of wind power has reached important penetration rates in power systems. Due to this growth, power systems have greater control requirements, meaning that wind farms (WF) have to meet such control needs, mainly voltage or reactive power control [1,2] and frequency control [3–5]. Recent technology development has made it possible for WF to participate in power system control and support tasks, similar to conventional power plants [6,7].

Therefore, Transmission System Operators (TSO) in different countries have been working to integrate control requirements for WFs into their grid codes [8–10]. The necessity of control capabilities at WF level is an important and determinant characteristic. Active and reactive power controls have to be carried out by the WF with the aim of fulfilling the principal TSO voltage and frequency control requirements. In most grid codes, a voltage level in PCC is required and it is defined through a power factor requirement [11]. In the Irish case, for the automatic voltage regulation, the WF should be capable of receiving a voltage regulation set point at PCC and should act to regulate it, adjusting the reactive power output [12].

Currently, the most common technology used is the doubly fed induction generator (DFIG), which is able to provide reactive power support. A large variety of control strategies can be used in the operation of DFIG [13]. Nevertheless, an internal WF optimization procedure to manage the wind turbines' (WTs) reactive power support is needed, taking into account WT and WF characteristics [14].

The need to optimize generation has been studied for different purposes and by using several methods [15,16]. In Refs. [17,18] optimization is used in network capacity analysis. An specifically reactive power control problems have been handled with optimization techniques. A method of finding the optimal reactive power distribution in a power system is presented in Ref. [19]. The method considers transformer taps, generator voltages and switchable VAR sources. The application showed be an useful tool to assist the system operator to take control decisions to improve the voltage profiles and minimize the system losses. The problem of locating and sizing capacitors for reactive power compensation in electric radial distribution networks was proposed as a multi-objective programming problem presented in Ref. [20]. In Ref. [21] fuzzy adaptive PSO (FAPSO) has been used to solve an optimization problem and determine the reactive power distribution between different available equipments. An optimization algorithm based on a Chaotic Improved Honey Bee Mating Optimization (CIHBMO) applied in the daily volt/var control in distribution networks is proposed and tested in Ref. [22].

Since the end of the twentieth century, new optimization techniques have been studied, using the analogy of animal swarm behavior. In Ref. [23], an ant colony optimization was developed. Eberhart and Kennedy developed a particle swarm optimization (PSO), based on the swarm behavior of birds or fish [24]. Recently, this new technique has been used in power system controls [25];

* Corresponding author. Tel.: +34 934137432; fax: +34 934017433.
E-mail address: marcela.martinez@citcea.upc.edu (M. Martinez-Rojas).

0306-2619/$ - see front matter
doi:10.1016/j.apenergy.2011.06.010

in the OPF problem [26]; to solve economic dispatch [27]; and for reactive power and voltage control [28,29]. PSO allows handle with mixed-integer nonlinear optimization problem (MINLP) easily, is easy to apply to various problems compared with conventional methods and is able to handle continuous state variables [28].

There is an increasing interest to apply optimization techniques in distributed generation [30,31]. In Ref. [32], an optimization algorithm used for wind power generation is presented, using a primal–dual predictor corrector interior point method, applied to find the operating points of a single WTs in a WF.

In this paper, a modified PSO method for the dispatch of WTs in a WF has been proposed. The problem of reactive power dispatch between the single WTs of a WF is formulated as an optimization problem, subject to specific restrictions. Active power losses are minimized as an objective function, and the reactive power requirement is treated as a restriction. Then, the necessary reactive power support for the voltage control is guaranteed while the losses are kept at a low value. The proposed method is tested on a sample WF grid. The contribution of this work is the proposal of the feasible solution search (FSS) applied to PSO techniques in order to satisfy the restrictions of reactive power and voltage levels given.

This paper is set out as follows: Section 2 explains the reactive power capacity of a WF; in Section 3, the basic PSO methods are introduced; in Section 4, the problem formulation and the proposed algorithm are presented. The tested WF description and simulation results are presented in Section 5.

2. Reactive power capacity and control options in wind farms

The requirement for the participation of WFs in grid control tasks has boosted the incorporation of power electronics and the development of new wind turbine generation concepts, resulting in variable speed wind turbines [33]. Amongst them, the most common wind generation technology used today is the DFIG. The DFIG is a wound rotor induction generator, in which the stator is directly connected to the grid and the rotor is connected to the grid by means of a back-to-back power converter [34], responsible for the control of the generator torque, allowing a voltage control capability [35].

In this paper, the DFIG technology is considered. The capability of reactive power injection into the grid mostly depends on the control strategy used, the converter size and the active power production. Normally, a P-Q characteristic curve can be drawn. The P-Q characteristic of the WTs used in this paper is shown in Fig. 1. Namely, it represents the commercial wind generator Gamesa WT G80-2.0 MW [36]; the principal characteristics are shown in Table 1. The WT G80 works with power factor 0.96 inductive and 0.98 capacitive; therefore, the reactive power capacity is limited, depending on the active power generation. In a DFIG based WF, the reactive power capacity is defined by the WT's characteristic and the effects of cable and lines. Therefore, the WF P-Q characteristic is similar to that of the WTs, but shifted to the capacitive side, as can be seen in Fig. 2. The grey dashed line represents the P-Q characteristic of WF for the power factor equal to the unity. Then, for a power generation lower than 10 MW, the cable effect is higher than the transformer effect, whereas the transformer effect is predominant for high output power from WF. Therefore, new generation and consumption WF zones are defined, since there is a range in which the WF changes the reactive power requirements. If the WF receives a capacitive reactive power set point in the low active power generation range, the WTs set point will change to be inductive.

Voltage control could be carried out through transformer taps and reactive power injection, as it is shown in Table 2. The WTs equipped with the DFIG technology inject reactive power into the grid [32]. The transformer taps provide a variable turns ratio.

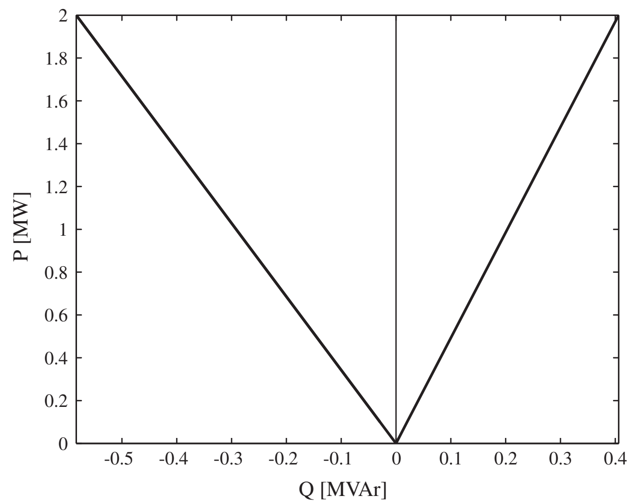

Fig. 1. P vs. Q characteristic of a single WT belonging to G80-2.0 MW.

Table 1
Characteristics Gamesa G80-2.0 MW.

Parameter	Value
Diameter	80 m
Rotational speed	1690 rpm
Type	DFIG
P_N	2.0 MW
Voltage	0.69 kV
Power factor	0.98 CAP – 0.96 IND

Moving the tap up or down, the effective number of turns of the transformer winding is changed, this is called a load tap changer (LTC). Typically, a transformer has a discrete number of tap setting positions to be adjusted. The reactive power injection could be carried out by capacitor banks [37], synchronous condensers [38], or parallel FACTS like Static Var Compensators (SVC) or Static Compensators (STATCOM) [39,40]. The reactive power output of SVC, STATCOM and synchronous condensers can be continually adjusted, while the capacitor banks have discrete steps that are usually connected through switches.

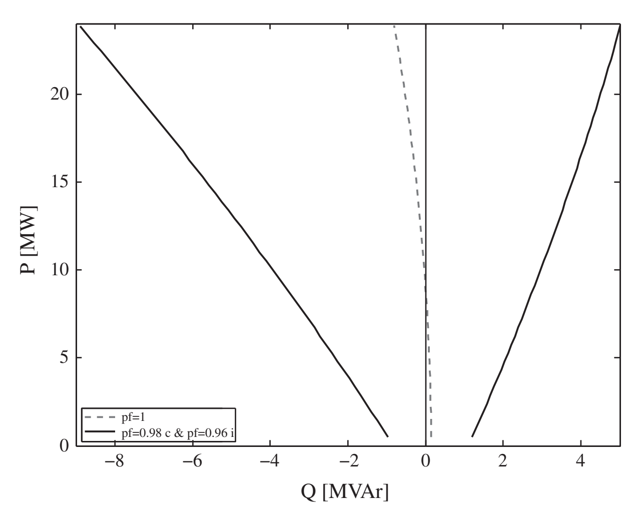

Fig. 2. P vs. Q characteristic of the tested WF consisting of twelve G80-2.0 MW WTs, without considering compensation equipment.