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Reactive and Active Power Output Optimization in a Wind Farm Using the Particle Swarm Optimization Technique

Nazha Cherkaoui, Abdelaziz Belfqih, Faissal El Mariami, Omar Sabri, Jamal Boukherouaa, Mohamed Nouh Dazahra, Meriem Majdoub

Laboratory of Electric Systems and Energy, ENSEM, Casablanca, Morocco

***Abstract*—*In the recent years, the contribution of the wind power to energy supply has increased considerably; hence, the wind farms have to be able to participate to the grid power stability. In this paper, an optimization algorithm allows obtaining the reactive and active power dispatch in a wind power plant is presented. The aim of the proposed algorithm is to minimize the power losses and the difference between the reactive power obtained and required by the transmission system operator at the point of common coupling. The simulation results show the validity and the performance of the proposed algorithm.*

Keywords*—*wind farms; grid stability; optimization algorithm; the reactive and active power dispatch; transmission system operator; point of common coupling.

I. INTRODUCTION

In the last years, the integration of wind energy into power grids has grown significantly. In order to ensure the power quality of the grid, transmission system operators (TSO) in different countries require from wind farms (WFs) to be able to contribute to ancillary services, especially in reactive power control.

Many works have been done in order to get an optimal reactive power dispatch using several methods such as particle swarm optimization (PSO) technique. In [1] a PSO technique for a reactive power wind farm function is presented. This technique allows obtaining the reactive power reference for each wind turbine with the aim to optimize the reactive power dispatch at a wind farm and minimize its power losses.

This paper is organized as follows: First, the doubly fed induction generator (DFIG) is presented. Second, the reactive power limitations of a wind turbine are determined using the method proposed in [2]. Then, a multi objective function that allows getting under several constraints both the reactive and active power set point for each wind turbine (WT) is presented. Finally, simulation results are reported.

II. DOUBLY FED INDUCTION GENERATOR (DFIG)

The doubly fed induction generator is coupled to the grid with the stator windings, while the rotor windings are connected to the grid via a back-to-back converter [3], as shown in figure 1. The DFIG exchanges the power with the grid through the stator windings as well as the rotor windings. The main part of the power passes from the generator through the stator into the grid, whereas only a fraction of the power is passed from the rotor windings through the power converter [2].

The DFIG technology is the most widely used generator in the wind farms for several reasons. First, it has the ability to control electrical torque (hence active power) and reactive power exchange with the grid. Besides, the DFIG is the cheapest solution to realize variable speed operation because the converters are sized only for 20%-35% of the stator power (not total turbine power) depending on the slip (or operating speed) range and reactive power requirements [4].

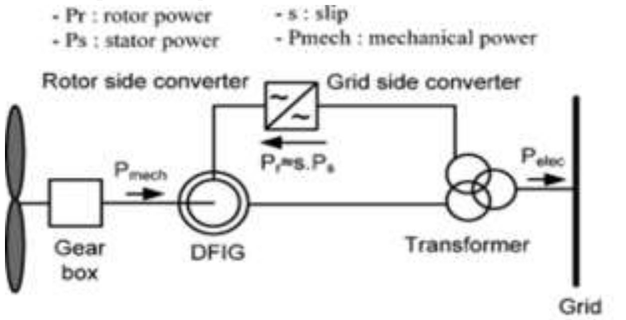

Fig. 1: The basic layout of a DFIG wind turbine [5]

III. DFIG CAPABILITY LIMITS CURVE

We use the method proposed in [2] in order to get the reactive power capability of a 2MW DFIG based wind turbine. In this method, we consider that the reactive power capability is limited by three parameters: stator current (Is), rotor current (Ir), and rotor voltage (Vr). In order to obtain the PQ diagram, the stator voltage is considered to be equal to 1 p.u, and the steady state T-

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equivalent circuit, as shown in figure 2, is used to derive the complex powers from the stator and the rotor windings.

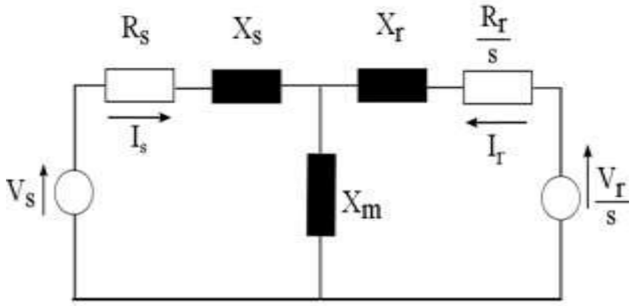

Fig. 2: Steady state T-equivalent circuit for the DFIG [2]

The reactive power capability of a DFIG is obtained by the most restrictive of the three limitations. Figure 3 shows the PQ curve of 2MW DFIG based wind turbine using the parameters illustrated in table I.

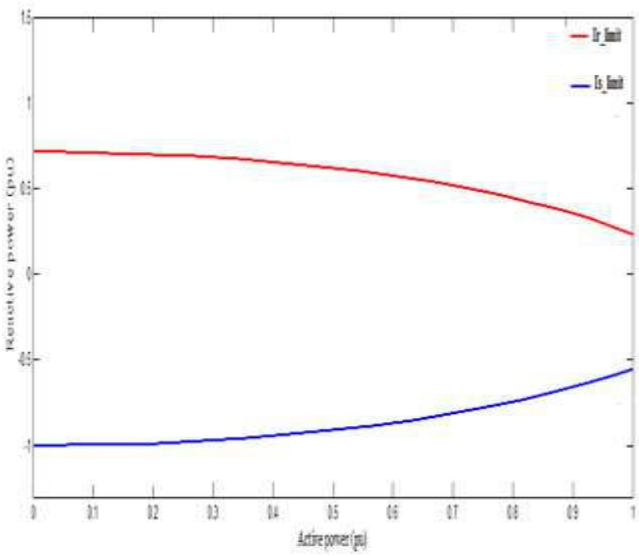

Fig. 3: Results reactive power capability used in this paper

Table I: REpower MM82 parameters [6]

Machine parameter	**Value**
Nominal active power	2MW
Nominal stator voltage	690 V
Stator resistance	0.00206 Ω
Stator inductance	0.032 Ω
Rotor resistance	0.0028 Ω
Rotor inductance	0.021 Ω
Magnetizing resistance	36.4 Ω
Magnetizing inductance	0.83 Ω
Turn ratio	2.43
slip	-0.2

IV. PARTICLE SWARM OPTIMIZATION METHOD

Particle swarm optimization is a heuristic global optimization method put forward originally by Doctor Kennedy and E berhart in 1995(Kennedy J,Eberhart R,1995;EberhartR,Kennedy J,1995). It is developed from swarm intelligence and is based on the research of bird and fish flock movement behavior [7].

The particle swarm model consists of a group of particles that are randomly initialized in the d-dimensional search space. During an iterative process, particles explore this space effectively by exchanging information to find the optimal solution. Each i-th particle is described by its position xi, velocity vi, and best position pbesti. Moreover, the particles have access to the best global position gbest that has been found by any particle in the swarm [8].

Then, each particle updates its coordinates based on its own best search experience pbesti and gbest according to the following velocity and position update equations: [9]

$$v_i^{k+1} = w\, v_i^k + c1\, r1\left(pbest_i^k - x_i^k\right) + c2\, r2\left(gbest^k - x_i^k\right) \quad (1)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (2)$$

Where:

w: Inertia weight

c1, c2: Acceleration coefficients

r1,r2: Two separately generated uniformly distributed random numbers in the range [0,1] added in the model to introduce stochastic nature.

The inertia weighting factor for the velocity of particle is defined by the inertial weight approach

$$w^k = w_{max} - \frac{w_{max} - w_{min}}{k_{max}} \times k \quad (3)$$

Where:

$k_{max}$is the maximum number of iterations, and k is the current number of iterations.

w_{max}andw_{min} are the upper and lower limits of the inertia weighting factor, respectively.

V. PROBLEM FORMULATION

We propose to use a multiobjective optimization function to calculate the reactive and active power set point for each wind turbine within the wind power plant. The multiobjective function is expressed as follows:

$$\min F(X) = \left|Q_{pcc}^{set} - Q_{pcc}\right| + \lambda P_{loss} \quad (4)$$

Where:

- X=(Q1,Q2,Q3,Q4,Q5,P1,P2,P3,P4,P5)

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Pi is the WT active power generation.
Qi is the WT reactive power consumption/generation.

- Q_{pcc}^{set} is the reactive power required at the PCC by the TSO
- Q_{pcc} is the reactive power generated by the wind farm at the PCC ,and it is obtained as follows:

$$Q_{pcc} = \sum Q_{g_i} - Q_{Losses} \qquad (5)$$

Where Q_{g_i} is the generated or absorbed reactive power of each iDFIG, and Q_{Losses} is the reactive power losses within the wind power plant.

- P_{loss} is the real power losses within the wind power plant.
- λ is the weight coefficient.

The minimization of the multiobjective function is subject to the following constraints:

1). The node power equation

$$P_i = U_i \sum_{j=1}^{Nb} U_j \left(G_{ij} \cos\theta_{ij} + B_{ij} \sin\theta_{ij} \right) \qquad (6)$$

$$Q_i = U_i \sum_{j=1}^{Nb} U_j \left(G_{ij} \sin\theta_{ij} - B_{ij} \cos\theta_{ij} \right) \qquad (7)$$

Where:

U_i and U_j are the voltage amplitude of nodes i and j respectively;

$\theta_{ij} = \theta_i - \theta_j$ is voltage phase angle difference of node i and j;

G_{ij} and B_{ij} are mutual conductance and susceptance of admittance matrix respectively;

P_i and Q_i are injected active and reactive power of node i.

2). DFIG reactive capability limits

$$Q_i^{min} \le Q_i \le Q_i^{max} \qquad (8)$$

3). DFIG active power limits

$$P_i^{min} \le P_i \le P_i^{max} \qquad (9)$$

The PSO algorithm is initialized with the population of individuals being randomly placed between the space of possible values [Q_{WT}^{min},Q_{WT}^{max}] and [P_{WT}^{min},P_{WT}^{max}], and it looks for the optimal solution by updating individual generations. The velocity and the position of each particle are updating, at each iteration, according to its previous best position (Pbest) and the best of the group gbest, as illustrated in figure 4.

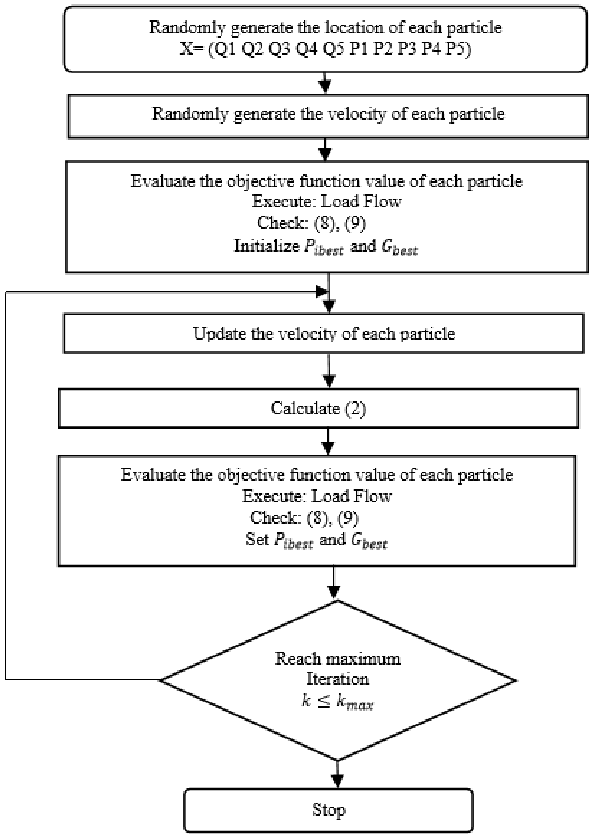

Fig.4: Flow chart of the proposed PSO algorithm

VI. SIMULATION RESULTS

An example system is used as shown in figure5 in order to verify the validity and performance of the proposed optimization algorithm. The wind farm consists of five 2 MW wind turbines, and it is connected to a 20 kV distribution system which exports power to 63 kV grid through a 10 km 20 kV feeder.

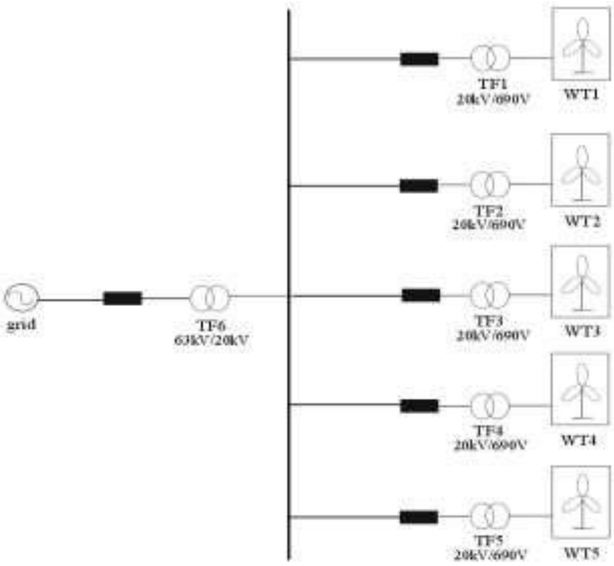

Fig. 5: An example system for simulation

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Three different cases to do the reactive power dispatch are tested and compared. The WTs within the wind power plant are operating at full active power in both case 1 and 2;also, the reactive power Q_{pcc}^{set} required at the PCC by the TSO is equal to 0,7 Mvar in the all cases.

- Case1: the reactive powerQ_{pcc}^{set} required at the PCC is proportionally distributed between the WTs within the wind power plant.
- Case2: The reactive power reference for each WT is obtained using the PSO optimization technique proposed in [1], where the OF is to minimize both the deviation between the reactive power Q_{pcc}^{set} required atthe PCC and the reactive power generated by the WF and the losses along the branches of the WF, as shown in equation (4). In this case X= (Q1, Q2, Q3, Q4, Q5).

  Three values of the weight coefficient λ are tested:

  λ = 0 ;λ = 0,5 ; λ = 0,9
- Case3: the reactive and active power set point for each wind turbine within the wind power plant are obtained using the objective function as shown in equation (4). In this case X=(Q1,Q2,Q3,Q4,Q5,P1,P2,P3,P4,P5).

  The same values of λused in the case 2 are tasted in this case.

The results of the reactive and active power dispatching in the three cases are presented in table II:

Table II: Simulation results

	Case1	Case2			Case3		
		λ=0	λ=0,5	λ=0,9	λ=0	λ=0,5	λ=0,9
Q1	0,14	0,46	0,46	0,46	0,13	0,38	0,17
Q2	0,14	0,46	0,46	0,46	-0,01	0,04	0,33
Q3	0,14	0,46	0,46	0,46	0,29	0,07	0,21
Q4	0,14	0,46	0,46	0,46	0,20	0,28	0,23
Q5	0,14	0,46	0,46	0,46	0,28	0,12	-0,04
P1	2,00	2,00	2,00	2,00	1,00	1,00	1,00
P2	2,00	2,00	2,00	2,00	1,00	1,00	1,00
P3	2,00	2,00	2,00	2,00	1,00	1,00	1,00
P4	2,00	2,00	2,00	2,00	1,00	1,00	1,00
P5	2,00	2,00	2,00	2,00	1,00	1,00	1,00
Objective function	-	0,0182	0,0982	0,1623	0,0044	0,0098	0,0177
$\lvert Q_{pcc}^{set} - Q_{pcc}\rvert$	1,59	0,0182	0,0182	0,0182	0,0044	3,41e-7	3,12e-7
Line losses (MW)	0,161	0,1601	0,1601	0,1601	0,0196	0,0196	0,0196

The case 1 has the most important value of line losses, but it decreases significantly in the case 3 which represents a reduction of 87,83% in comparison with the case 1.

We obtain the important value of the error in reactive power at the PCC in the case 1. This error decreases in the case 2 which represents a reduction of 98,85% in comparison with the case 1. However, the error is almost equal to 0 in the case 3 for all the values of λ.

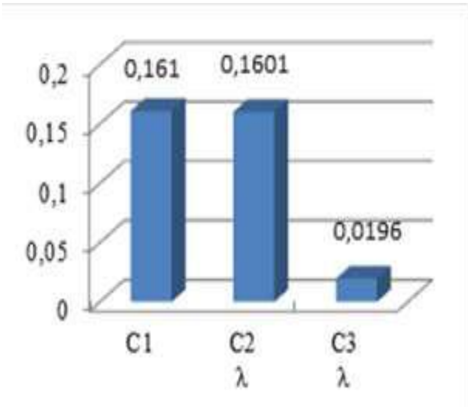

Fig. 6: Power losses in the WF in each case for λ=0

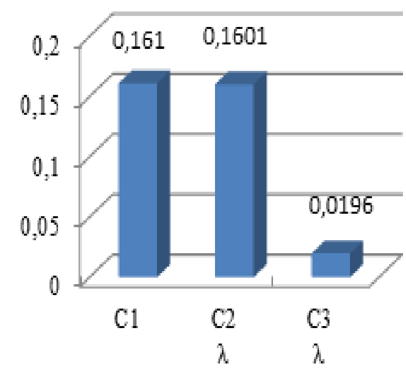

Fig. 7: Power losses in the WF in each case for λ=0,5

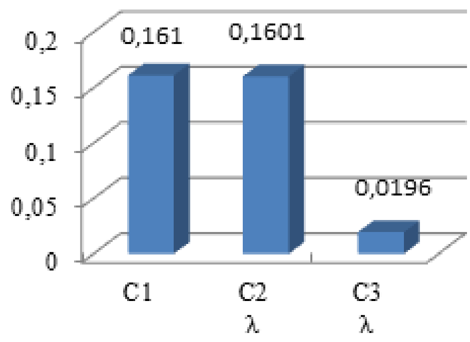

Fig. 8: Power losses in the WF in each case for λ=0,9

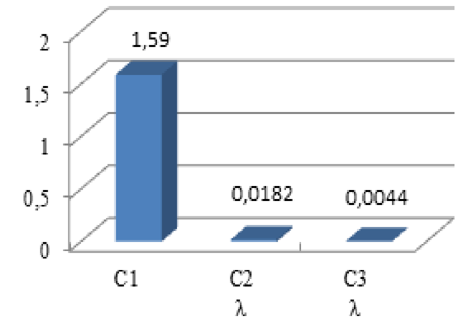

Fig. 9: Error in reactive power at the PCC in each case for λ=0

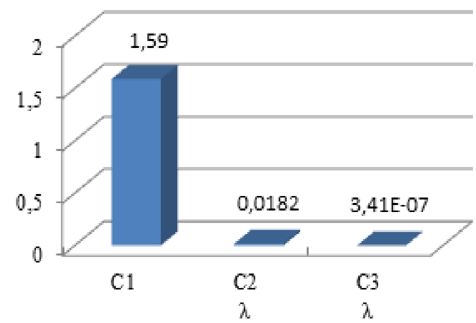

Fig. 10: Error in reactive power at the PCC in each case for λ=0,5

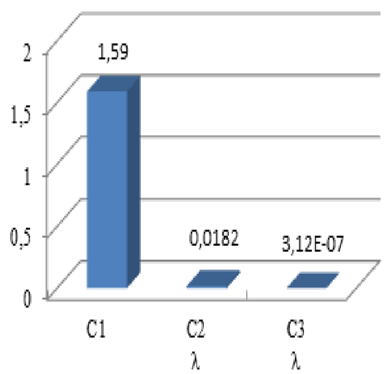

Fig. 11: Error in reactive power at the PCC in each case for λ=0,9

Comparing the results of the three cases, we can conclude that the case 3 is the most advantageous because it allows reducing significantly the line losses in the WF, and obtaining an accurate value of the reactive power generated at the PCC that corresponds to Q_{PCC}^{set}required by the TSO, in comparison with all the other cases.

VII. CONCLUSION

In this work, we present an optimization algorithm of reactive and active power dispatch in a wind farm. The proposed algorithm allows minimizing both the power losses in the WF and the deviation between the reactive power reference $Q_{pcc}^{set}$and the reactive power generated by the wind power plantat the point of common couplingQ_{pcc}. By analyzing the obtained results, we can conclude that the proposed method is the most suitable to use in order to get an accurate value of the reactive power at the point of common coupling and minimize the power losses in the wind farm.

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