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Wind Farm Management using Artificial Intelligent Techniques

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ABSTRACT

This paper presents a comparative study between the genetic algorithm and particle swarm optimization methods to determine the optimal proportional–integral (PI) controller parameters for wind farm supervision algorithm. The main objective of this study is to obtain a rapid and stable system by tuning of the PI controller, thereby providing an excellent monitor for our wind farm by sending separate set points to all wind generators. A supervisory system controls the active and reactive power of the entire wind farm by sending out set points to all wind turbines. A machine control system ensures that the set points at the wind turbine level are reached. The entire control is added to the normal operating power reference of the wind farm established by a supervisory control. Finally the performance of the proposed algorithm is verified through MATLAB/Simulink simulation results by considering a wind farm of three doubly-fed induction generators.

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1. INTRODUCTION

The home of the environment, the strategy of which is environmental protection, has spared no effort since it opened its doors for the protection formal nuisances. Recently, this greenhouse handled an important topic related to renewable energy and environmental protection. In the third millennium, the importance of renewable energy is of continuing concern to researchers and environmentalists worldwide. Experts have reported that many climate change nuisances, such as floods, cyclones, greenhouse gas emissions, accelerated soil erosion, and losses in genetic diversity, have appeared innumerous countries. Experts have also explained that all these nuisances pose an unprecedented ecological threat on a global scale. Thus, the question that currently arises is how to address this situation and how to control energy. The only solution that could save the Earth is orienting toward renewable energy from the sun, the wind, and tides [1].

The major difficulty associated with decentralized energy sources (e.g., wind farm and solar plant) is that these sources do not participate in the general services system (i.e., voltage adjustment, frequency, possibility to operate on islanding). This case is particularly true with renewable energy sources, the production of which is unpredictable and considerably fluctuating. The integration of decentralized production units in a network poses several problems, including random and unpredictable producible (e.g., wind power, solar), lack of frequency–power and voltage adjustments, and sensitivity to voltage dips. The failure to participate in services system brings this type of energy source to behave similarly to passive generators of electricity. Penetration of distributed generation must be limited (20% or 30% of the power consumed after a few feedbacks) to ensure network stability in acceptable conditions; thus, power supervision of these farms is necessary [1].

Current research in the field of wind farms is oriented toward the development of supervision algorithms to distribute the total power reference between wind generators. In this context, several algorithms have been proposed. Proportional distribution algorithm [2], [3], was developed to distribute power references in a proportional manner. From a safety concern, this algorithm ensures that each wind generator constantly functions far from its limits, as defined by the (P, Q) diagram [2]. The algorithms based on optimized objective function [4-6] permits an optimal distribution of the active and reactive power references on the wind generators. It needs optimization methods, such as genetic algorithm (GA) [7], neurons networks [8], particles swarm optimization (PSO) [5], and methods that combine the latter with fuzzy logic[09], [4]. The last supervision algorithms are based on proportional–integral (PI) regulators. This class of algorithms regulates the problem of supervision by using a simple PI regulator [10], [11], [29].

The current research work presents a comparative study of the GA and PSO methods to determine the optimal PI controller parameters for the wind farm supervision algorithm, and compared with the non-optimized PI controller, in which the parameters are adjusted manually.

2. POWER SYSTEM CONFIGURATION

The system studied in this study as presented in the following diagram mainly compound from different electric Elements, the wind farm connect through a transformer (20KV / 690V) to the electrical network, additional different variable loads also connect to the network but with another transformer. we have focused more on central supervision unit that can control the wind farm in active and reactive power (PWE, QWF) following the network system operator TSO required plan.

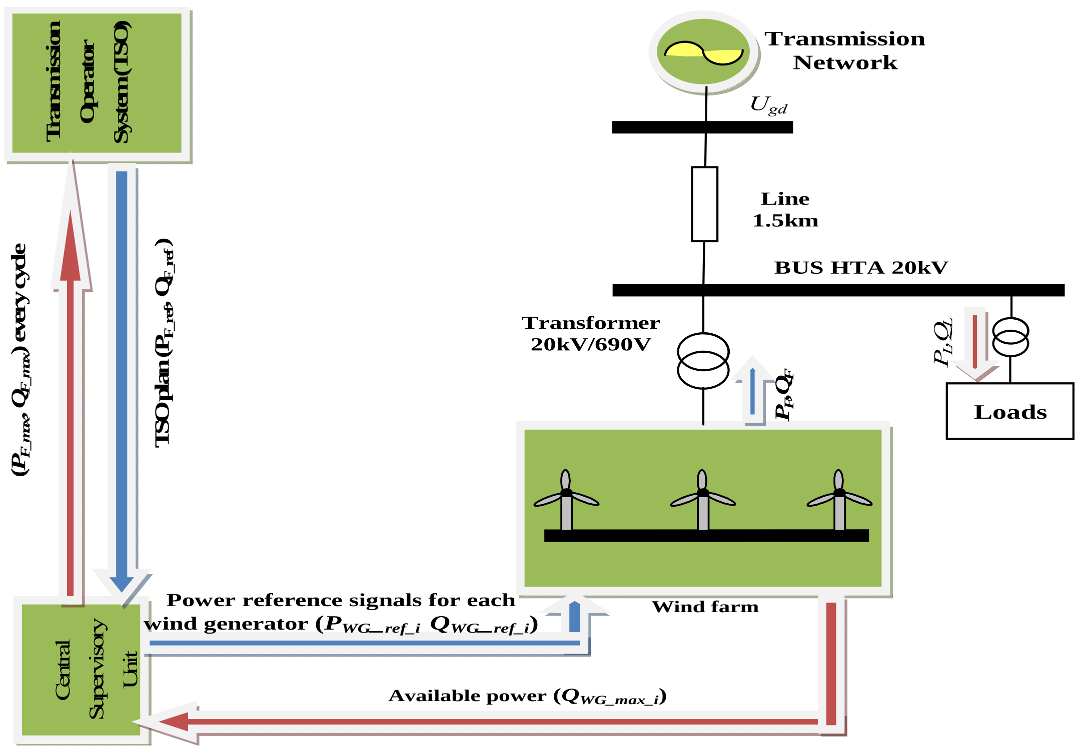


Figure 1. Power System Configuration [1]

The main components of wind generators used in this wind farm are turbine, gearbox, doubly-fed induction generator (DFIG) when its stator is directly connected to the grid and to two inverters one side DFIG rotor (RSC) permits to control active and reactive powers of DFIG, the other one side grid (GSC) allows to manage transient balanced power and current to grid, as shown in Figure 2 [1], [13].

a. Turbine Model : The amount of aerodynamic power P_{aer} captured from wind turbine Figure 2(a) can be expressed by the following Equation [3]:

$$P_{aer} = C_p P_v = C_p(\lambda, \beta) \frac{\rho S V^3}{2} \quad (1)$$

where:

P_{aer} is the obtained wind power(w), ρ is the air density(kg/m^3), V is the wind speed(m/s), S is the swept area of the turbine, and C_p is the Power coefficient.

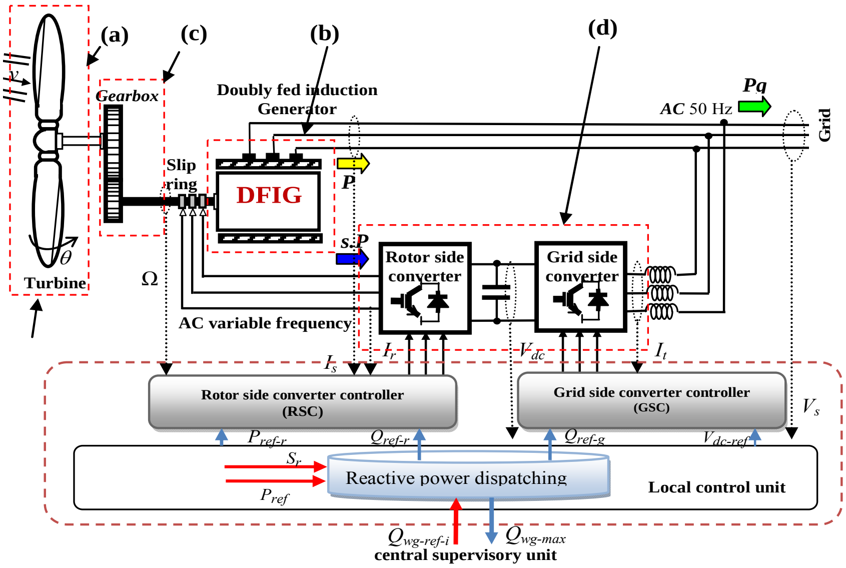


Figure 2. DFIG based Wind Energy Conversion System

with

λ : speed ratio defined as follow:

$$\lambda = \frac{\Omega_t R}{V_{wind}} \quad (2)$$

where :

Ω_t : is turbine speed, V_{wind} is the wind speed, and β : is blade pitch angle;

The aerodynamic torque is given by :

$$C_{aer} = \frac{P_{aer}}{\Omega_{turbine}} = C_p * \frac{\rho S V^3}{2} * \frac{1}{\Omega_{turbine}} \quad (3)$$

b. Gearbox model

As shown in Figure 2(c), the Gearbox torque can be presented by following Equation:

$$C_g = \frac{C_{aer}}{G}$$

C_g : gearbox torque ;

C_{aer} : aerodynamic torque ; and
G : Gearbox multiplying factor for speed, we have:

$$\Omega_{turbine} = \frac{\Omega_{mec}}{G}$$

where:
Ω_{mec} is the mechanical speed

c. General DFIG Model
As shown in Figure 2(b), the DFIG is modeled in d, q Park model, the stator and rotor voltages can be written as:

$$\begin{cases} V_{ds} = R_s I_{ds} + \frac{d}{dt}\psi_{ds} - \omega_s \psi_{qs} \\ V_{qs} = R_s I_{qs} + \frac{d}{dt}\psi_{qs} + \omega_s \psi_{ds} \\ V_{dr} = R_r I_{dr} + \frac{d}{dt}\psi_{dr} - (\omega_s - \omega)\psi_{qr} \\ V_{qr} = R_r I_{qr} + \frac{d}{dt}\psi_{dr} + (\omega_s - \omega)\psi_{dr} \end{cases} \quad (4)$$

The stator and rotor flux are given as follows:

$$\begin{cases} \psi_{ds} = L_s I_{ds} + M_{sr} I_{dr} \\ \psi_{qs} = L_s I_{qs} + M_{sr} I_{qr} \\ \psi_{dr} = L_r I_{dr} + M_{sr} I_{ds} \\ \psi_{qr} = L_r I_{qr} + M_{sr} I_{qs} \end{cases} \quad (5)$$

where:
R_s, R_r L_s and L_r are the resistances and inductances, respectively, of the stator and rotor windings, and M_{sr} is the mutual inductance .

$V_{ds}, V_{dr}, V_{qs}, V_{qr}, I_{ds}, I_{dr}, I_{qs}, I_{qr}, \psi_{ds}, \psi_{dr}, \psi_{qs}$ and ψ_{qr} are the d and q components of the stator and rotor voltages , respectively, currents and flux where as ω is the rotor speed in electrical degree .
The active and reactive powers at the stator side and rotor side of DFIG are defined as:

$$\begin{cases} P_s = V_{ds} I_{ds} + V_{qs} I_{qs} \\ Q_s = V_{qs} I_{ds} - V_{ds} I_{qs} \end{cases} \quad (6)$$

$$\begin{cases} P_r = V_{dr} I_{dr} + V_{qr} I_{qr} \\ Q_r = V_{qr} I_{dr} - V_{dr} I_{qr} \end{cases} \quad (7)$$

The electromagnetic torque is expressed as:

$$C_{em} = P \frac{M}{L_s} \psi_{ds} I_{qr} \quad (8)$$

Where P is the number of pole pairs.

d. Converters Model

For the DFIG model presented in the Park model, we follow a continuous equivalent model of converters in the Park reference [1], [29] to simplify the analysis of the complete power generation system. The currents and voltages of RSC and GSC shown in Figure 2(d) are defined by the following Equations:

$$\begin{bmatrix} V_{rmd} \\ V_{rmq} \end{bmatrix} = \frac{U}{2} \begin{bmatrix} V_{rd-reg} \\ V_{rq-reg} \end{bmatrix} \quad (9)$$

$$I_{m-mac} = \tfrac{1}{2} \begin{bmatrix} V_{rd-reg} & V_{rq-reg} \end{bmatrix} \begin{bmatrix} i_{rd} \\ i_{rq} \end{bmatrix} \quad (10)$$

where:

V_{rmd} , V_{rmq} i_{rd} , i_{rq} : express voltages and currents in Park model; and

V_{rd-reg}, V_{rq-reg}: Express adjusted voltages in Park model.

3. PI Algorithm for Wind Farm Supervision

The main objective of the PI regulator-based algorithm is to satisfy the system operator reference operating set-point (Q_{WF-ref} , P_{WF-ref}). These values are compared with the active and reactive powers at the point of common coupling (PCC)[17], and the difference in power is determined, which is distributed in an identical manner($P_{WG-ref-i}$, $Q_{WG-ref-i}$) between the wind generators of the wind farm. The following Figure 3 presents the principle of this algorithm.

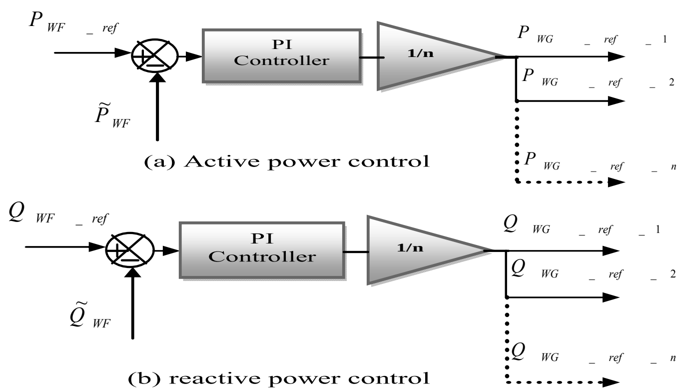


Figure. 3. PI controller for wind farm supervision

where:

$\tilde{P}_{WF}$: active power generated by wind farm

$\tilde{Q}_{WF}$: reactive power generated or absorbed by

A general block diagram for a PI control system is shown in Figure 4. The control signal U(t) is generated from the error, E(t), as in (11):

$$U(t) = K_p [E(t) + \frac{1}{T_i} \int_0^T E(t) dt] \quad (11)$$

The transfer function of the PI controller is defined by $G_c(s)$ as follows:

$$G_c(s) = K_p + \frac{K_i}{s} \quad (12)$$

where K_p is the proportional gain and K_i is the integral gain.

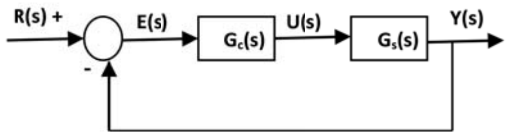


Figure 4. Block diagram of PI control system.

For the optimum performance of the control system, the PI controller gains, K_p and K_i , are optimally tuned by minimizing a performance index; Thereafter, this is selected to satisfy several control specifications, such as [22]:

$$f(t) = \int_0^\infty (W_1|e(t)| + W_2|e_y(t)|)dt \quad if \quad e_y(t)\langle 0 \quad (13a)$$

$$\int_0^\infty (W_1|e(t)|)dt \quad otherwise \quad (13b)$$

where (13b) is the weighted integral of absolute error (IAE) value, and the weighted absolute term in $e_y(t)$ in (13a) is added to weighted IAE in order to avoid overshoot.

4. Performance of PSO and GA for PI Controller Optimization

The PSO and GA methods are employed because of their effectiveness in solving optimization problems. A brief review of these algorithms is presented in the following section.

4.1. PSO Algorithm

The particle swarm optimization (PSO Particle Swarm Optimization) is an evolution algorithm which uses a population of candidate solutions to develop an optimal solution for such problem. This algorithm was proposed by Eberhart and Russel James Kennedy [14]. It builds on the social behavior of animals living in swarm, such as schools of fish and flock of birds. Indeed, one can observe in these animals relatively complex motion dynamics, more details about PSO algorithm was described in [15], [16].

The use of this method in tuning PI regulator appear in some applications among them, an optimal tuning PI regulator using PSO has been applied by Chien-Hung et al. [17] to perform the static synchronous compensator (STATCOM).Experiment results under different loading conditions were used to proof the effectiveness of the proposed control approach. In another study Hongqing et al. [18], an improved particle swarm optimization is proposed for optimal Proportional–Integral–Derivative [PID] for monitoring water turbine governor system. Authors in this work introduced the nominal average position of swarm beside the individual best position and the global best position in IPSO. S. Bouallegue et al. [19] used PSO in order to optimize a new PID-type fuzzy logic controller [FLC]tuning strategy , and for checking their results,they have investigated the case of an electrical DC drive benchmark. M. Muhammad and T. Ali [20] studied the optimization problem of dual axis solar tracker system with DC motor drive, and to tackle optimization approach they have used PSO algorithm compared to firefly algorithm (FFA) and Cuckoo Search Algorithm (CSA).H. Bevrani et al[21] presented a combination of the fuzzy logic and the particle swarm optimization (PSO) techniques for optimal tuning of PI-regulator-based frequency controllers in the AC micro grid system. The performance of proposed intelligent control is compared with the pure fuzzy PI and Ziegler-

Nichols PI control design methods. M. sayed et al [22] in order to control the boiler-turbine unit, authors have taken a hybrid jump PSO algorithm for tuning gains of PI regulator, based on observing the local and global best particles which are not improved in a predefined number of iterations and moving these particles to a new best position.

4.2. Genetic Algorithms (GA)

Genetic algorithms theory (GAs Genetic Algorithms) was originally developed by John Holland in 1960-1970 period and has been fully elaborated in his book "Adaptation in Natural and Artificial Systems such as inheritance, mutation, selection and crossover "published in 1975 [19]. Its main objective wasn't the development of an optimization algorithm, but rather the modeling process of adaptation, and shows how this process could be useful within a computing system. A number of researches have used application of GA for adapting PI controller such as:

T.jimene et al [23] in order to manage networks parameters in passive optimal networks have used PID controller automatic tuning process with GA; obtained results show that the control strategy reduces tuning time up to 64% compared to traditional methods as Ziegler Nichols (ZN) . h .M.hasanien and S.M Moyen [2] treated the problem of using power conversion system unit in renewable energy ,energy storage system, variable speed drives area, they introduced a cascaded control scheme based on four proportional integral [PI] tuned by [GA], and compared with Taguchi approach under the grid fault condition. A.harrag et al [3] used PID controller based on genetic algorithm to adjust a new modified Perturbation and Observation (P&O) maximum power point tracking algorithm with adaptive duty cycle. K. M. Elbzyomy et al. [4] optimized PID controller parameters attached to electro-hydraulic servo actuator system (EHSAS) using GA in order to control the angular position of the rotary actuator which control the movable surface of space vehicles. F.daneshfor and H. Bevrani [5] propsed the tuning of PI regulator parameters using GA approach to handle the load-frequency control(LFC) issue, which is the major subject in a power system.

5. RESULTS AND DISCUSSION

The wind farm model with three wind generators situated in different wind profiles (system data are reproduced in the Appendix) is used to observe the behavior of this control algorithm using the Matlab/Simulink tools. The block diagram of the control system with a PSO–PI and GA–PI controllers for power distribution is shown in Figure 5.

To converge toward the optimal solution, the PSO, and GA algorithms must be guided by the cost function. Hence, it should be properly defined before the PSO algorithm is executed. In the present study, the used cost function (F) is defined by the following Equation [28]:

$$F = \sum_{i=1}^{N} |e_1(i)| + |e_2(i)| \tag{14}$$

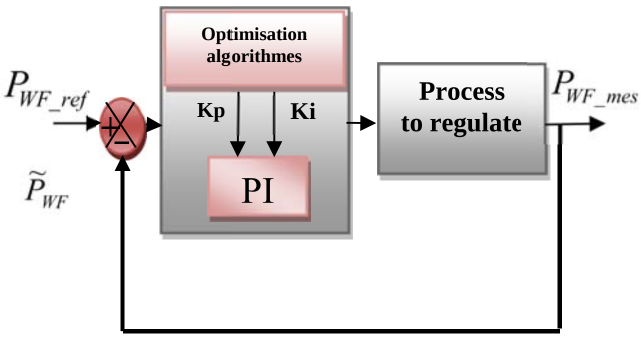


Figure 5. Block diagram of Tuning PI parameters with PSO and GA algorithms for wind farm supervision.

When $e_1(i)$ is the trajectory error of i^{th} sample for active power $(P_{WF\text{-}ref} - \tilde{P}_{WF})$ and $e_2(i)$ is the trajectory error of i^{th} sample for reactive power $(Q_{WF\text{-}ref} - \tilde{Q}_{WF})$. The region of the parameters to be optimized is set as follows:

$0<k_p,\ k_i<10$

For the PSO algorithm, the population size is set to 20 particles. The parameters c_1, c_2 and W are set to 2.05, 2.05 and 0.7298, respectively. The maximum number of iteration n is set to 20 iterations.

For the GA algorithm parameters are selected as below:

a. Selection: normalized geometric selection
b. Crossover: arithmetic crossover
c. Mutation: uniform method
d. Population number: 20
e. Generation (iteration) number: 20
f. The same search interval and objective function as PSO algorithm.

First, the PI controller gains are adjusted manually. Thereafter, we perform an optimization process using the PSO and GA methods. Figure 6 shows the cost function evolution during the optimization process using PSO and GA. After 20 iterations, the PSO and GA converge to the optimal parameters.

Tables 1 and 2 show that all of these parameters obtained from both algorithms are different from one another for the active and reactive power controllers. The simulation results of the controlled system with the optimized PI are shown in Figures 7(a, b).The optimized PI controller by the PSO and GA methods are also compared with the non-optimized PI for the active and reactive powers.

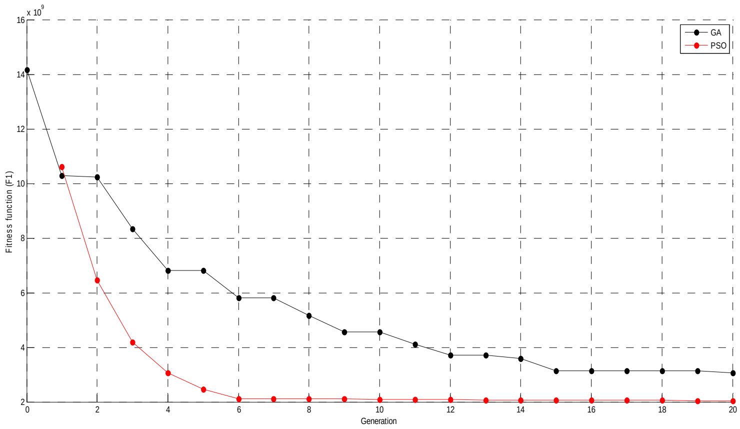


Figure 6. Evolution of the cost function (*CF*)

Table 1. Parameters PI controller obtained by different methods for active power

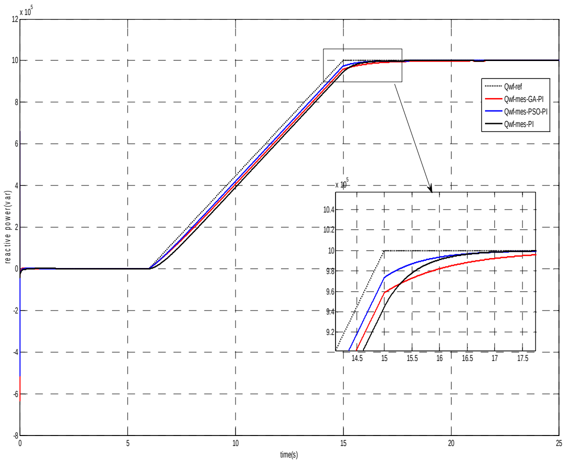
Parameters \ Method	Traditional method	GA	PSO
K_p	0.1	1.812	0.5098
K_i	2	6.649	10

Table 2. Parameters PI controller obtained by different methods for reactive power

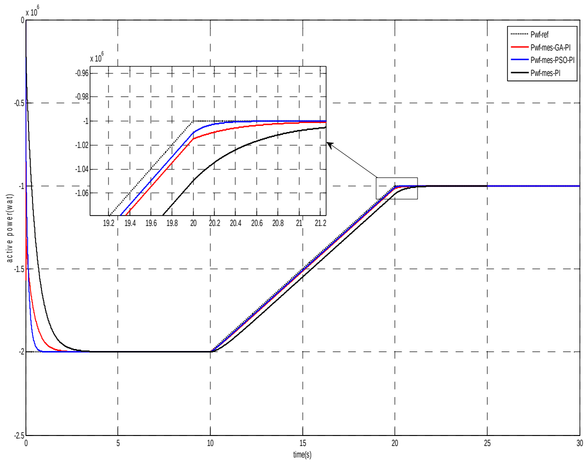
parameters \ method	Traditional method	GA	PSO
K_p	0.1	2.181	1.9648
K_i	2	2.674	4.1773

Figures 7(a, b) show that the optimized PI controller using the PSO method has better performance, such as rapid response and trajectory tracking task, compared with the GA method and the non-optimized PI.

Figures 8 and 9 shows the entire wind farm with the active and reactive powers and distribution order powers for each wind generators using the PSO–PI controller algorithm.

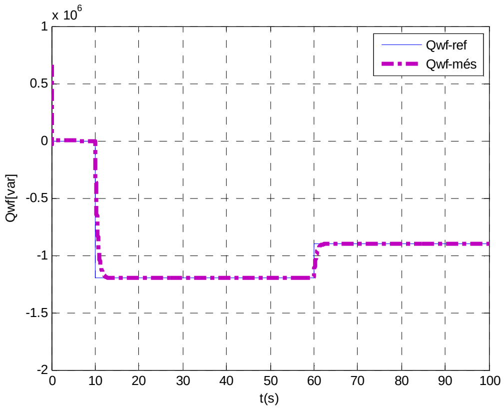


(a) Active Power

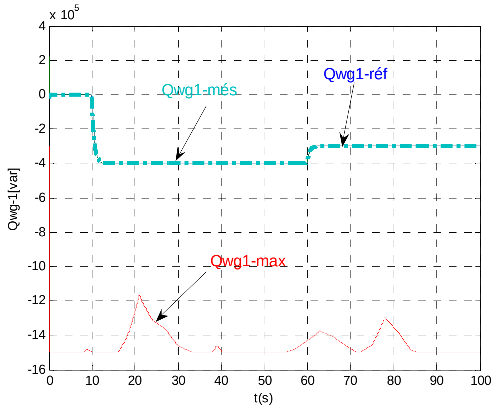


(b) Rective Power

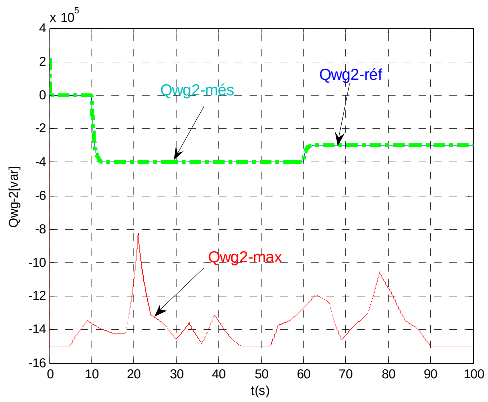
Figure 7. Comparison results obtained by PI optimized by PSO, GA. And non-optimized PI



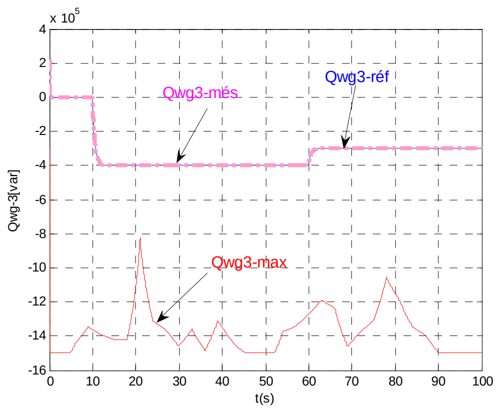
(a) Reactive Power produced by the wind farm



(b) Reactive Power produced by the first wind generator

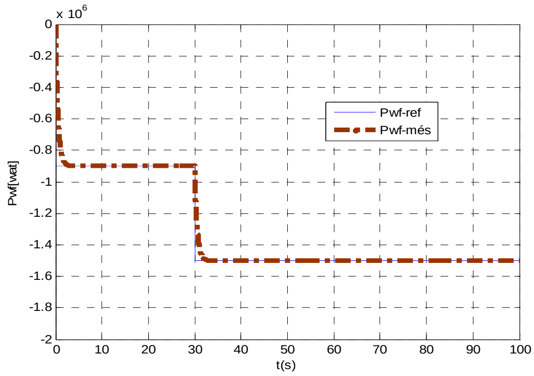


(c) Reactive power produced by the second wind generator

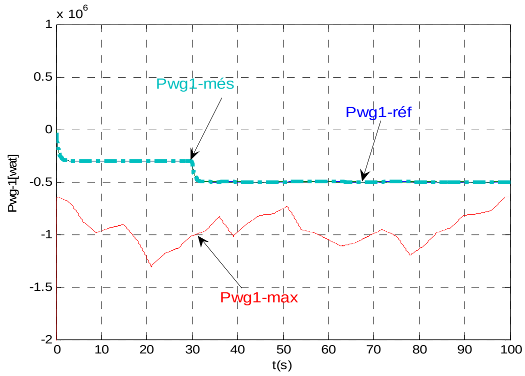


(d) Reactive power produced by the third wind generator

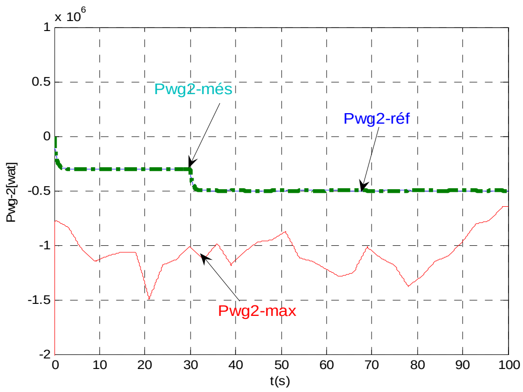
Figure 8. Simulation Results the centralized supervision of the reactive power [PSO-PI]



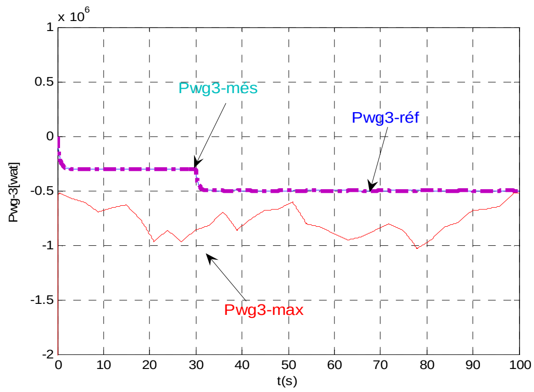
(a) Active Power produced by the wind farm



(b) Active power produced by the first wind generator



(c) Active power produced by the second wind generator



(d) Active power produced by the third wind generator

Figure.9.Simulation Results the centralized supervision of the active power [PSO-PI]

6. CONCLUSION

In this study, different approaches for wind farm supervision were presented. We focused our study on one of them which is based on proportional integral [PI] algorithm. In order to obtain the controller parameters, the comparative study have been taken between PSO and GA methods. To verify the effectiveness of the proposed methods, a model of the wind farm compound with three wind generators was simulated using Matlab/Simulink. The simulation results show that the optimized PI controller tuned by the PSO method exhibits better performance than the one tuned by the GA method and the non-optimized PI.

APPENDIX

Plant Parameters
1.5 MW Wind Turbine Parameters:
Rotor diameter: 35.25 m . blades Number: 3
Inertia: 1000 kg/m2
Air density ρ =1.22 kg/m3
1.5 MW DFIG Parameters :

R_s =0.012 Ω , R_r =0.021 Ω

L_s =2.037.10e -4 H: L_r =1.75.10e -4H

M_{sr} =0.035 H: L_s =0.035+2.037.10e-4 H

L_r =0.035+1.75.10 e-4 H

Friction coefficient of DFIG: f=0.0024 N.m.s/rd
Capacitors for DC Link:
C1=C2=4400 μf
Grid Parameters:
Phase voltage (rms): 690 V Frequency: 50

REFERENCES

[1] B. Benlahbib *et al.,* "Aerodynamic Power Forecasting in Order to Enhance Wind Farm Supervision Adrar Station in South Algeria"*, Journal of Electrical Engineering* vol.15, no.4, 2015.
[2] A. Tapia, et al., "Reactive Power Control of a Wind Farms for Voltage Control Applications", *Renewable Energy*, vol. 29, no.3, pp.377-392, 2004.
[3] A. D. C, "Centralised Power Control of Wind Farm with Doubly Fed Induction Generators", *Renewable and Sustainable Energy*, vol. 31, no. 07, pp. 935–951, 2006.
[4] C. Dai, et al., "Seeker Optimization Algorithm for Optimal Reactive Power Dispatch", *IEEE Transactions on Power Systems,* vol. 24, no.3, pp.1218-1231, 2009.
[5] Y. Li, et al., "Dynamic Optimal Reactive Power Dispatch based on Parallel Particle Swarm Optimization Algorithm", *Computers and Mathematics with Applications*, vol. 57, no.11, pp.1835-1842, 2009.
[6] J. Zhao, et al., "Reactive Power Control of Wind Farm made up with Doubly Fed Induction Generators in Distribution System", *Electric Power Systems Research*, vol. 80, no.6, pp.698-706, 2010.
[7] S. Liu , et al, "A Two-Stage Robust Reactive Power Optimization Considering Uncertain Wind Power Integration in Active Distribution Networks", *IEEE Transactions on Sustainable Energy*, Vol.7 , no.1, pp.301 – 311,2016.
[8] L. Krichen, et al, "ANN for Multi-Objective Optimal Reactive Compensation of a Power System with Wind Generators", *Electric Power Systems Research*, vol.78, no. 9, pp.1511–1519, 2008.
[9] W. Zhang et Y. Liu, "Multi-Objective Reactive Power and Voltage Control based on Fuzzy Optimization Strategy and Fuzzy Adaptive Particle Swarm", *Electrical Power and Energy System*, Elsevier, vol.30, no.9, pp.525-532, 2008.
[10] W. Dwiono, "Fuzzy PI Controllers Performance on Boost Converter," *Int. J. Electr. Comput. Eng.*, vol. 3, no. 2, pp. 215–220, 2013.
[11] Y. P. O. Latha, et al., "Control Strategy for Three Phase Shunt Active Power Filter with Minimum Current Measurements," *Int. J. Electr. Comput. Eng.*, vol. 1, no. 1, pp. 31–42, 2011.
[12] F. Bouchafaa et al., "Control the Flywheel Storage System by Fuzzy Logic Associated with the Wind Generator", *International Journal of Renewable Energy Research*, vol. 2, no. 4, 2012.
[13] F.Bouchafaa et al., "Control the Flywheel Storage System by Fuzzy Logic Associated with the Wind Generator", *International Journal of Renewable Energy Research*, vol. 2, no. 4, 2012.
[14] B. Vasumathi and S. Moorthi, "Implementation of hybrid ANNPSO algorithm on FPGA for harmonic estimation," *Eng. Appl. Artif. Intell.*, vol. 25, no.3, pp. 476–483, 2012.
[15] B. Vasumathi and S. Moorthi, "Implementation of hybrid ANNPSO algorithm on FPGA for harmonic estimation," *Eng. Appl. Artif. Intell.*, vol. 25, no.3, pp. 476–483, 2012.
[16] N. Bouarroudj, et al., "A Hybrid Fuzzy Fractional Order PID Sliding-Mode Controller design using PSO algorithm for interconnected Nonlinear Systems", *CEAI*, vol. 17, no. 1, pp. 41-51, 2015.
[17] C.Hung Liu and Yuan-Yih Hsu, "Design of a Self-Tuning PI Controller for a STATCOM Using Particle Swarm Optimization," *IEEE Trans. Ind. Electron.*, vol. 57, no. 2, pp. 702–715, Feb. 2010.
[18] H. Fang, L. Chen, Z. Shen, "Application of an Improved PSO Algorithm to Optimal Tuning of PID Gains for Water Turbine Governor," *Energy Convers. Manag.*, vol. 52, no. 4, pp. 1763–1770, 2011.
[19] S. Bouallègue, et al "PID-Type Fuzzy Logic Controller Tuning based on Particle Swarm Optimization," *Eng. Appl. Artif. Intell.*, vol. 25, no. 3, pp. 484–493, 2012.
[20] M. M. Sabir, T. Ali, "Optimal PID Controller Design Through Swarm Intelligence Algorithms for Sun Tracking System," *Appl. Math. Comput.*, vol. 274, pp. 690–699, 2016.
[21] H. Bevrani, et al., "Intelligent Frequency Control in an AC Microgrid: Online PSO-Based Fuzzy Tuning Approach," *IEEE Trans. Smart Grid*, vol. 3, no. 4, pp. 1935–1944, Dec. 2012.
[22] M. Sayed, et al., "Gain tuning PI controllers for boiler turbine unit using a new hybrid jump PSO," *J. Electr. Syst. Inf. Technol.*, vol. 2, no. 1, pp. 99–110, 2015.
[23] T. Jimnez, et al., "An Auto-Tuning PID Control System based on Genetic Algorithms to Provide Delay Guarantees in Passive Optical Networks," *Expert Syst. Appl.*, vol. 42, no. 23, pp. 9211–9220, 2015.
[24] H. M. Hasanien, S. M. Muyeen, "A Taguchi Approach for Optimum Design of Oroportional-Integral Controllers in Cascaded Control Scheme," *IEEE Trans. Power Syst.*, vol. 28, no. 2, pp. 1636–1644, 2013.
[25] H. M. Hasanien and S. M. Muyeen, "A Taguchi approach for optimum design of proportional-integral controllers in cascaded control scheme," IEEE Trans. Power Syst., vol. 28, no. 2, pp. 1636–1644, 2013.
[26] K. M. Elbayomy, et al., "PID Controller Optimization by GA and its Performances on the Electro-Hydraulic Servo Control System," *Chinese J. Aeronaut.*, vol. 21, no. 4, pp. 378–384, 2008.
[27] F. Daneshfar, H. Bevrani, "Load–Frequency Control: A GA-based Multi-Agent Reinforcement Learning," *IET Gener. Transm. Distrib.*, vol. 4, no. 1, p. 13, Feb. 2010.
[28] Y.Su Kim, et al., "Tuning of the PI Controller Parameters of a PMSG Wind Turbine to Improve Control Performance under Various Wind", *Journal of Energies*, vol. 8, pp.1406-1425, 2015.

[29] B. Benlahbib, et al., *"Fractional Order PI Controller for wind farm supervision",* in 2014 IEEE International Conference on Industrial Engineering and Engineering Management, pp. 1234–1238, 2014.

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