Optimization by Genetic Algorithm of a Wind Energy System applied to a Dual-feed Generator

Mourad Guediri
Laboratory of Electrical Engineering and Industrial Electronics L2EI, University of Jijel, Jijel, Algeria
mourad.guediri@univ-jijel.dz (corresponding author)

Nabil Ikhlef
Laboratory of Electrical Engineering and Industrial Electronics L2EI, University of Jijel, Jijel, Algeria
ikhlefnabil@yahoo.fr

Bouchekhou Hocine
Laboratory of Electrical Engineering and Industrial Electronics L2EI, University of Jijel, Jijel, Algeria
bouchekhou_hocine@yahoo.fr

Abdelhafid Guediri
Faculty of Technology, VTRS Laboratory, University of El Oued, El Oued, Algeria
abdelhafid-guediri@univ-eloued.dz

Abdelkarim Guediri
Faculty of Technology, VTRS Laboratory, University of El Oued, El Oued, Algeria
guediri-abdelkrim@univ-eloued.dz

Received: 13 June 2024 | Revised: 12 July 2024 | Accepted: 16 July 2024

 DOI: https://doi.org/10.48084/etasr.8122

ABSTRACT

In an attempt to improve wind energy production using a Doubly Fed Induction Generator (DFIG), this paper presents a model for power maximization through controlling the turbine speed by utilizing a Maximum Peak Power Tracking (MPPT) controller, and through also controlling the stator active and reactive power for DFIG. In the context of increasing the search for new electric energy production sources, including renewable energies, Proportional Integral (PI) contributed to the modeling of the control and improvement of the wind energy conversion system, with the aim of exploiting wind energy to produce clean energy without pollution. To enhance the benefits of classic PI regulators, and so obtain efficient performance, the study seeks to determine the parameters of PI regulators. PI is used for wind turbines without including classical analytical methods for final calculation. Thus, optimization algorithms, namely Genetic Algorithms (GA) or Particle Swarm Optimization (PSO), which seek to minimize the error in a controlled system between the input signal and the output signal, were developed in this study. The basis of this approach is the management of both reactive and active power. In order to increase performance and efficiency, the new approach incorporates GA ideas into the control technology used in the wind turbine. The simulation results derived after this incorporation provide wind turbine systems that are more stable and efficient producing significantly better results than traditional PI regulators. Then, a simulation program, which includes the artificial intelligence controls and GA, is created in Matlab.

Keywords-Doubly Fed Induction Generator (DFIG); Maximum Peak Power Tracking (MPPT); Proportional Integral (PI) ; maximizaton of wind power production; Hybrid Genetic Algorithm (HGA)

I. INTRODUCTION

The most promising and rapidly expanding renewable energy source is wind power. One of the primary reasons governments worldwide are taking action to reduce pollution emissions is the worsening of air quality. Environmentally friendly energies, such as wind energy, have helped in adapting to the new regulations of the governments, with many wind energy plants being established globally, as this type of energy is both inexpensive and capable of large-scale production [1].

Stochastic approaches deploy methods that involve stochastic exploration of potential solutions despite their effectiveness [2]. One notable member of this diverse family of stochastic optimization algorithms is GA, inspired by principles of evolution and natural selection. GA excel in solving a variety of problems by employing probabilistic searches grounded in genetic dynamics and natural selection. Essentially, a GA maintains a population of diverse solutions and evolves them towards the optimal one [3].

To find the best solution in a complex environment is very hard. To achieve a balance between two objectives, robust exploration of the proper solution and of superior alternatives, is crucial. According to scientific research, a GA handles this condition optimally [4]. The theoretical structure of GA is presented in this article. Then their application to fine-tune the parameters of the two controllers recently used to adjust the speed of the DFIG will be examined. GA is a significant technique for identifying the optimal from a set of possible solutions. The principle of Darwinian selection, which is utilized in GA, suggests that genetic variations carrying valuable features are passed down through successive generations, thereby reinforcing these features [5]. The main idea is to generate the best possible progeny and to progressively improve the best quality seeds [6]. There is a class of numerical optimization techniques known as pattern search—also referred to as direct search, derivative-free search, or black-box search— which does not require gradients. Therefore, it can be applied to functions that are non-continuous or non-differentiable. One such pattern search method is 'convergence,' which is based on the positive basis theory with the purpose of locating the solution with the lowest error value [7].

A recent approach involves the application of artificial intelligence in GA, particularly Hybrid Genetic Algorithms (HGA), to solve optimization problems [8]. The objective of this work is to evaluate the relevance of the HGA employment to the optimization of active power.

II. MAXIMIZING POWER WITH CONTROLLING SPEED

The control model is based on the idea that at a steady state the wind speed varies slightly and is obtained through [9]:

$$C_{aer} = C_p \cdot \frac{1}{2} \cdot \rho \cdot S \cdot \frac{1}{\Omega_{turbine\_estimated}} \cdot v_{estimated}^3 \qquad (1)$$

where:

$$v_{estimated} = \frac{\Omega_{turbine\_estimated} \cdot R}{\lambda} \qquad (2)$$

The reference torque C_{em_ref} is directly proportional to the square of the generator speed Ω_{mec} when adding (1) and (2) and setting the speed ratio to $\lambda_{Cp\ max}$, which corresponds to the highest power factor $C_{p\ max}$ [10]:

$$C_{em\_ref} = \frac{\rho \pi R^5}{2G^3} \frac{C_p}{\lambda^3_{C_{p\max}}} \Omega^2_{mec} \qquad (3)$$

$$C_p(\lambda, \beta) = 0.73\left(\frac{151}{\lambda_i} - 0.58\beta - 0.002\beta^{2.14} - 13.2\right)e^{\frac{-18.4}{\lambda_i}} \qquad (4)$$

$$C_t = \frac{P_{aero}}{\Omega_t} = \frac{1}{2\lambda} \cdot \rho \cdot \pi \cdot R_t^3 \cdot V_v^2 \cdot C_p(\lambda, \beta) \qquad (5)$$

$$\Omega_{t\_ref} = \frac{\lambda_{opt} \cdot V_v}{R_t} \qquad (6)$$

The model and flowchart for maximizing the power extracted with speed control are illustrated in Figure 1. Figures 2 and 3 show the power coefficient and speed, respectively.

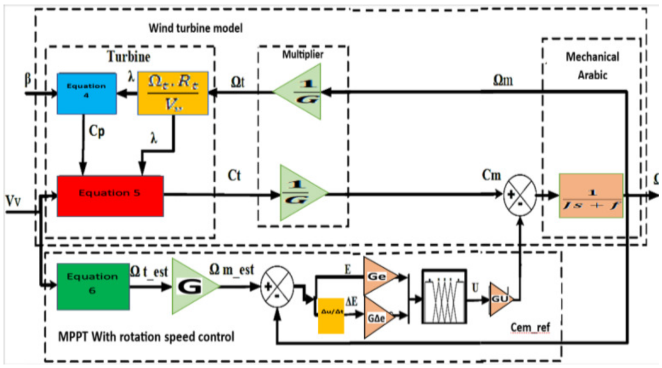

Fig. 1. Maximization of power extracted with speed control.

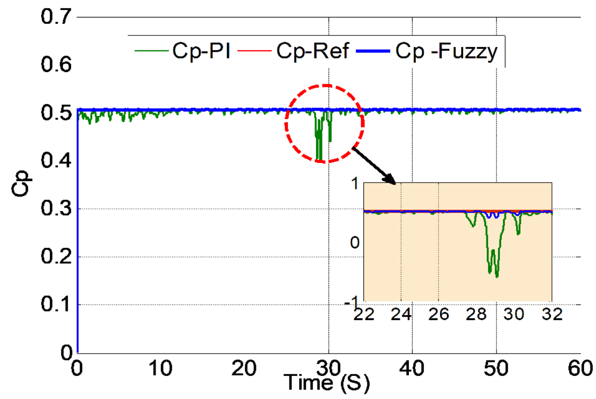

Fig. 2. Power coefficient $C_p(\lambda, \beta)$ based on PI and fuzzy regulators.

III. SYSTEM DESCRIPTION

In this type of function, the stator is connected to the network, and a converter supplies the rotor, as evidenced in Figure 4. This solution makes it possible to provide a fixed voltage and frequency even with fluctuating speed [11]. In this case, the majority of the power is distributed to the grid by the stator and less than 32% of the total power is passed through the transducer by the rotor. This allows using smaller converters, and is thus less costly [12].

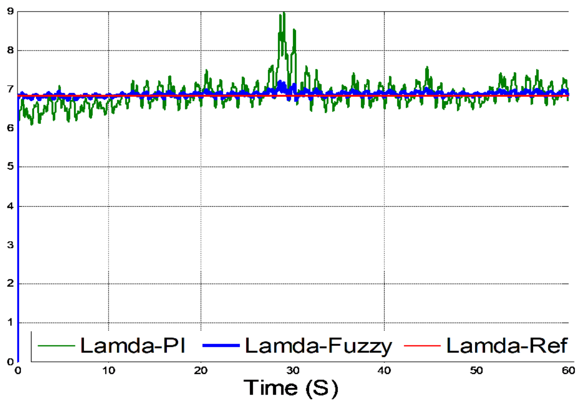

Fig. 3. Speed λ based on PI and fuzzy regulators.

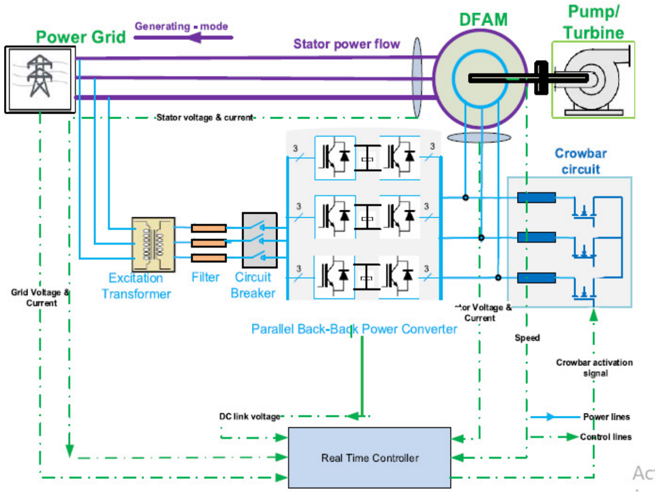

Fig. 4. DFIG system generator powered by one adapter.

The following equations are used to display the active and reactive power [13]:

$$\begin{cases} P_s = -V_s \dfrac{M}{L_s} \cdot I_{rq} \\ Q_s = \dfrac{V_s \cdot \varphi_s}{L_s} - \dfrac{V_s \cdot M}{L_s} \cdot I_{rd} \\ P_r = g \cdot V_s \dfrac{M}{L_s} \cdot I_{rq} \\ Q_r = g \cdot V_s \dfrac{M}{L_s} \cdot I_{rd} \end{cases} \quad (7)$$

The objective is to control the DFIG in a grid connected using a rotor-side converter. The focus is on achieving constant power control. Initially, a stator flux orientation control strategy will be implemented for the DFIG, with torque tracking control [10]. The reference electromagnetic torque is set negative to enable generator operation mode, thus determining the reference flux based on this torque reference. Subsequently, artificial intelligence techniques will be applied [14].

IV. ARITHMETIC CROSSOVER

This technique was developed using the "MICHALEWICZ" function in Matlab. For this form of crossover, random points were selected. Applying the process to the parent_1 and parent_2, the two children, child_1 and child _2 (offsprings), were generated, who include the genes E_1 and E_2 [15]:

$$\begin{cases} E_1 = aC_1 + (1-a)C_2 \\ E_2 = (1-a)C_1 + aC_2 \end{cases} \quad (8)$$

When an arithmetic crossover is uniform, the value is a user-selected constant; however, if the value is randomly generated within the interval [-0.5, 1.5], then a non-uniform arithmetic crossover occurs [16]. An example of this kind of crossover application is depicted in Figure 5. According to this, the two new genes E_1^3, E_2^3 were born [14]:

$$\begin{cases} E_1^3 = aC_1^3 + (1-a)C_2^3 \\ E_2^3 = (1-a)C_1^3 + aC_2^3 \end{cases} \quad (9)$$

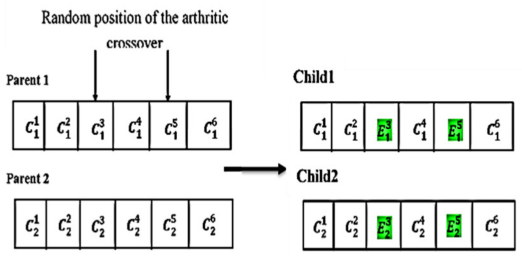

Fig. 5. The arithmetic crossover.

V. UNIFORM MUTATION

This operation replaces the value of the chosen gene with a uniform random value selected of a user-specified interval for that gene. For each mutated gene, the τ values were extracted. For a positive change, the first value can be +1, and for a negative change, -1 [14]. The randomly generated number within the interval [0, 1] constitutes the second value, which determines the magnitude of the shift. In these circumstances, one of the following two relationships is used to calculate which gene C'_i will replace the mutant gene C_i:

$$\begin{cases} C'_i = C_i + (C_{\max} - C_i)\left[1 - r^{\left(1-\frac{G_F}{G_T}\right)^5}\right] & \text{if } \tau = +1 \\ C'_i = C_i - (C_i - C_{\min})\left[1 - r^{\left(1-\frac{G_F}{G_T}\right)^5}\right] & \text{if } \tau = -1 \end{cases} \quad (10)$$

where C_{min} and C_{max}, respectively imply the bottom and upper bounds of the parameter price. Also when $GF \le GT$ is true, indicates that the mutation cancels out.

VI. OPTIMIZATION PROCEDURE FOR THE TWO REGULATORS

The optimization technique is a hybrid algorithm that operates within the regulator's parameters, combining a local search strategy, gradient or simplex, with a genetic set of rules [8]. The method's diagram is portrayed in Figure 6.

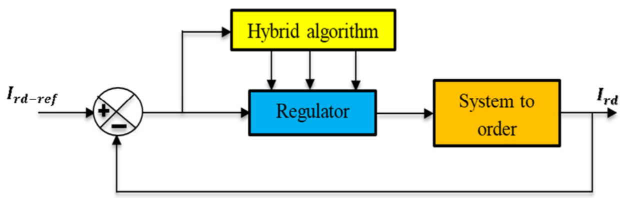

Fig. 6. Optimization principle.

The stages for optimizing the regulator parameters are [17]:

- Initialization: Start by randomly generating an initial set of parameter configurations.
- Evaluation: Assess the performance of each parameter configuration based on predefined criteria.
- Genetic Operators: Use selection, crossover, and mutation to create new parameter configurations (offspring) from the current population.
- Offspring Evaluation: Evaluate the performance of the newly generated offspring.
- Iteration: Repeat the genetic operator and evaluation process for a specified number of iterations or until a termination condition is met.
- Selection: Identify the offspring with the best performance.
- Local Search: Apply a local search method, such as gradient descent or simplex method, to further optimize the best performing offspring.

VII. OPTIMIZING THE CLASSIC PI REGULATOR

The regulator optimization utilizes an HGA with simplex rules, created through the Matlab's "Gatool" method. The algorithm parameters used are specified as [18]:

- Offspring size T=20.
- Selection method: roulette wheel selection.
- Multiple crossovers with a probability $pc = 0.8$.
- Uniform mutation probability $pm = 0.01$.
- Number of offspring $N = 49$.
- Hybridization technique: simplex method.

VIII. RESULTS AND DISCUSSION

According to the simulation results obtained, it is possible to see an improvement in the overall dynamic performance by optimizing classical PI gains using the GA combined with the simplex method. Based on the simulation results, the GA that manipulates the wind power machine mainly rely on DFIG to supply electricity to the grid, as shown in Figure 7, a significant improvement was observed at the dynamic level compared to the PI regulators.

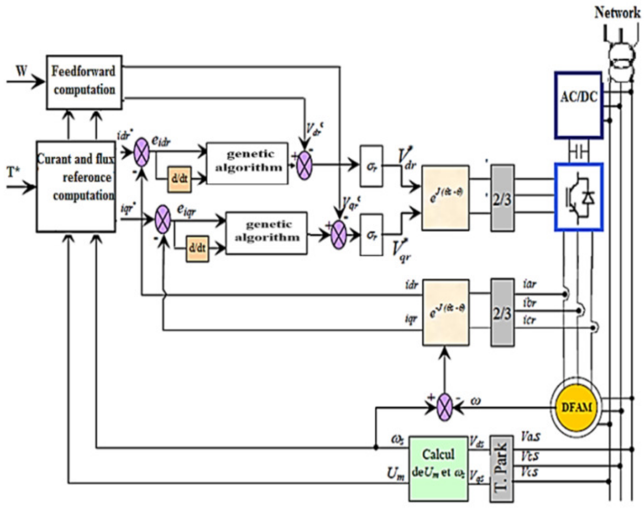

Fig. 7. DFIG with GA optimization.

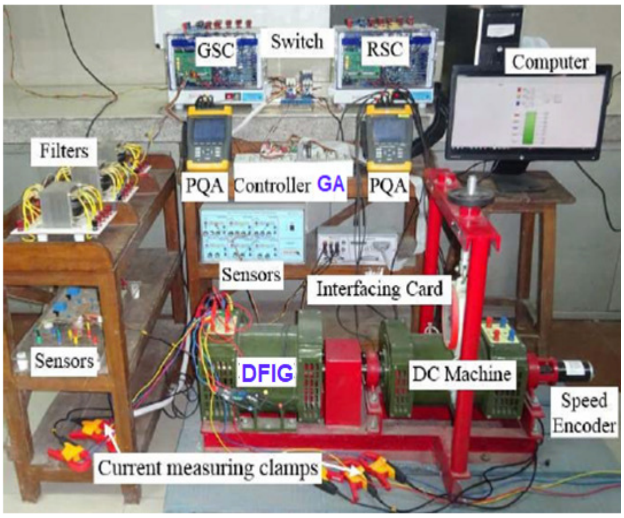

Fig. 8. Experimental system setup.

Figure 8 represents an experimental setup of a comprehensive system designed to test and optimize control strategies for a Dual Induction Generator (DFIG) used in wind power generation applications. This system consists of several main components: a direct current motor that simulates wind speed, which is mechanically connected to the DFIG, as well as a two-way power converter that connects the DFIG windings to the electrical grid. The system uses GA to adjust variables such as rolling resistance and specific turbulence.

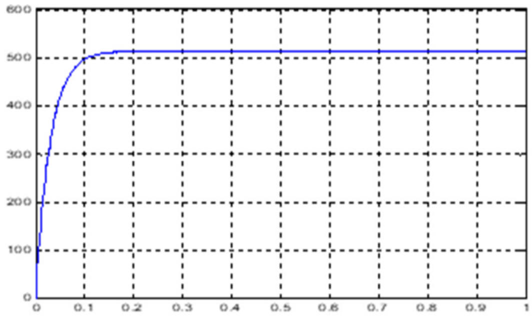

Fig. 9. DC bus voltage (V).

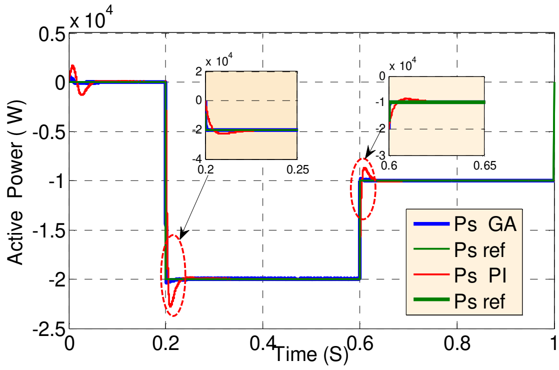

Fig. 10. Active power (W).

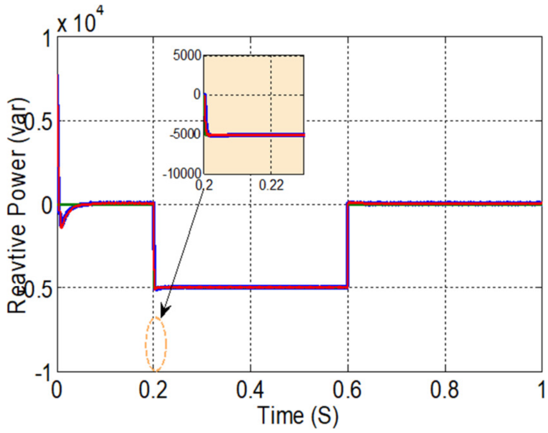

Fig. 11. Reactive power (VAR).

This system setup aims to validate theoretical models and enhance them through practical experimentation. Its primary goal is to improve the efficiency, stability, and reliability of DFIG operation, specifically in regulating the delivery of active and reactive power to the grid. By utilizing GA for control optimization, the system seeks to achieve optimal performance under varying wind conditions, contributing to advancements in renewable energy technologies.

The above shows the superiority of the GA regulator used in comparison to the PI regulator. Figures 9-15 show that GA regulator gave amazing outcomes extremely near the reference values in contrast to the PI regulator although the accuracy is not on par with that of a PI controller.

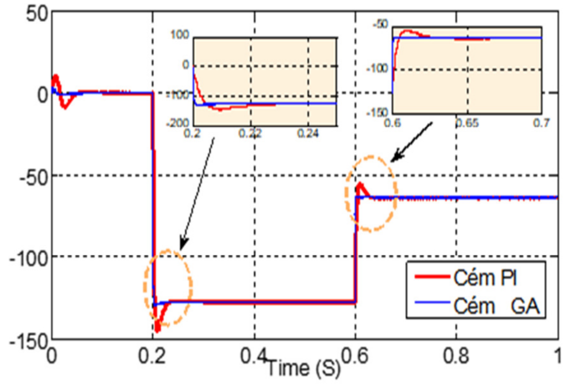

Fig. 12. Electromagnetic torque.

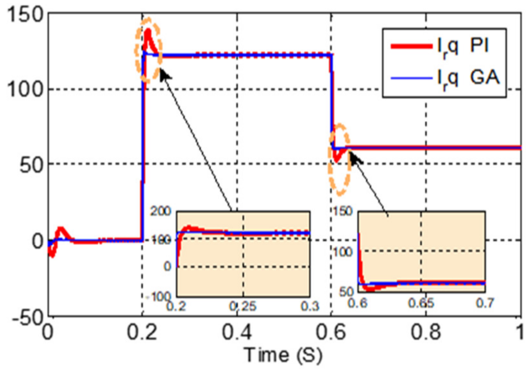

Fig. 13. Direct currents rotorique.

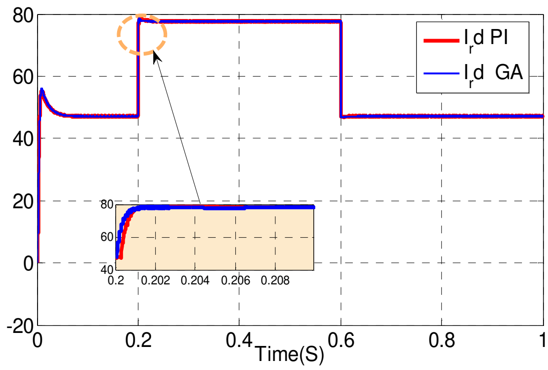

Fig. 14. Rotor quadrature.

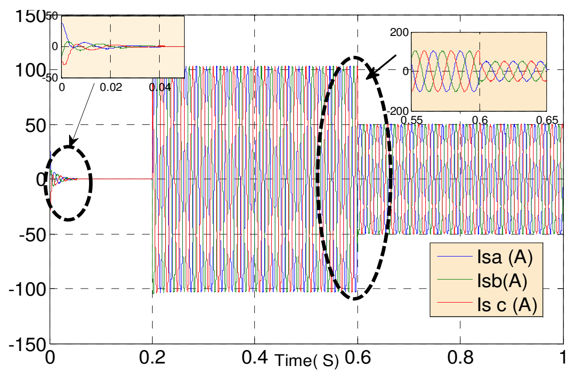

Fig. 15. Three-phase stator.

The main disadvantage of GA regulators lies in the fact that they do not guarantee the stability of the system. Furthermore, the calculation depends only on the two values: the error and the error variation.

IX. DISCUSSION AND COMPARISON WITH OTHER WORKS

In the pursuit of greater precision and improved error outcomes compared to previous studies, the number of iterations was intentionally increased. This adjustment was made after observing that fewer iterations produced less precise results. Figure 16 showcases the improvement of the objective function applied to these results.

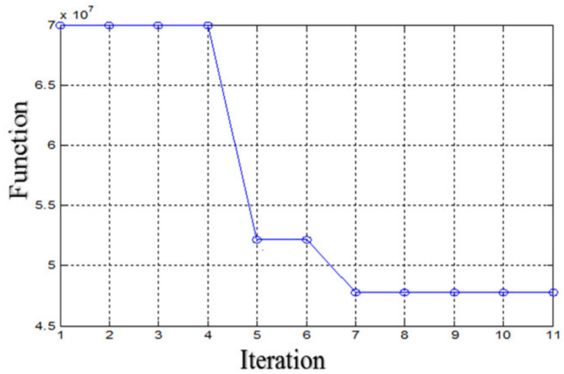

Fig. 16. Optimization of the objective function.

X. RESULT SIMULATION PROGRAM IN MATLAB

```
KP_p=kp_pmin+(kp_pmax-
kp_pmin)*kp_pde/Gmax;
KP_i=kp_imin+(kp_imax-
kp_imin)*kp_ide/Gmax;
KI_p=ki_pmin+(ki_pmax-
ki_pmin)*ki_pde/Gmax;
KI_i=ki_imin+(ki_imax-
ki_imin)*ki_ide/Gmax;
%%%%%%%%%%%%%%%%%%%%%%%
SELECTION AND CROSSOVER
%%%%%%%%%%%%%%%%%%%%%%%
[fun,index]= fate (fan);
for i1=1:NC/2
paron(i1,:)=POP(index(i1),:);
end
Lu=randsrc(1,1,[1:NB-1]);
child (1:NC/4,:)=[paron(1:NC/4,1:Lu)
paron(NC/4+1:NC/2,Lu+1:NB)];
child
(NC/4+1:NC/2,:)=[paron(NC/4+1:NC/2,1:Lu)
paron(1:NC/4,Lu+1:NB)];
POP=[paron ; child];
%%%%%%%%%%%%%%%%%%%%%%%%
MUTATION
%%%%%%%%%%%%%%%%%%%%%%%
Mu=rand(NC,NB);
for i=1:NC
for j=1:NB
if Mu(i,j)<=pm
if POP(i,j)==1
POP(i,j)=0;
else
POP(i,j)=1;
end
end
end
end
i9=i9+1;
fanf(i9)=Val;
end
figure
stud (funf,'-o')
title(' Function optimization objective ')
xlabel ('Itération')
ylabel('Function')
grid
```

XI. CONCLUSION

In this article, active and reactive control power using a Genetic Algorithm (GA) for a Doubly Fed Induction Generator (DFIG) network is presented. The effectiveness of the GA was tested under various operating conditions, demonstrating improvements across several key aspects measured by multiple metrics. Dynamics and response to changes in rolling resistance and torque disturbances are enhanced, response times are reduced, and precision and speed are improved, while system stability is also maintained and fine errors are minimized. Compared to previous research, this study stands out for its overall improvement in control performance deploying GA.

APPENDIX

PARAMETERS OF THE 1.5 MW DFIG

Symbol	Parameters	Value
P_n	Rated Power	1.5 MW
V_s	Stator Voltage	300 V
F_s	Stator Frequency	50 Hz
R_s	Stator Resistance	0.012 Ω
L_s	Stator Leackage Inductance	0.0205 H
R_r	Rotor Resistance	0.021 Ω
L_r	Rotor Leackage Inductance	0.0204 H
M	Mutual Inductance	0.0169 H
P	Pairs of poles number	2
J	Rotor inertia	1000 Kg.m2

PARAMETERS OF THE TURBINE

Symbol	Parameters	Value
R	Blade radius	35.25 m
N	Number of blades	3
G	Gearbox ratio	90
J	Moment of inertia	1000 $Kg.m^2$
f_V	Viscous friction coefficient	0.0024 $N.m.s^{-1}$
V	Nominal wind speed	16 m/s
V_d	Cut-in wind speed	4 m/s
V_m	Cut-out wind speed	25 m/s

REFERENCES

[1] L. Pan, Z. Zhu, Y. Xiong, and J. Shao, "Integral Sliding Mode Control for Maximum Power Point Tracking in DFIG Based Floating Offshore Wind Turbine and Power to Gas," *Processes*, vol. 9, no. 6, Jun. 2021, Art. no. 1016, https://doi.org/10.3390/pr9061016.

[2] Y. Dbaghi, S. Farhat, M. Mediouni, H. Essakhi, and A. Elmoudden, "Indirect power control of DFIG based on wind turbine operating in MPPT using backstepping approach," *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 11, no. 3, pp. 1951–1961, Jun. 2021, https://doi.org/10.11591/ijece.v11i3.pp1951-1961.

[3] U. Yilmaz, A. Kircay, and S. Borekci, "PV system fuzzy logic MPPT method and PI control as a charge controller," *Renewable and Sustainable Energy Reviews*, vol. 81, pp. 994–1001, Jan. 2018, https://doi.org/10.1016/j.rser.2017.08.048.

[4] S. S. G, A. E. X. S, and R. VR, "Fatigue load mitigation in wind turbine using a novel anticipatory predictive control strategy," *Proceedings of the Institution of Mechanical Engineers, Part I: Journal of Systems and Control Engineering*, vol. 234, no. 1, pp. 60–80, Jan. 2020, https://doi.org/10.1177/0959651819850388.

[5] M. Benmeziane, S. Zebirate, A. Chaker, and Z. Boudjema, "Fuzzy sliding mode control of doubly-fed induction generator driven by wind turbine," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 3, pp. 1592–1602, Sep. 2019, https://doi.org/10.11591/ijpeds.v10.i3.pp1592-1602.

[6] H. A. Aroussi, E. Ziani, M. Bouderbala, and B. Bossoufi, "Improvement of direct torque control applied to doubly fed induction motor under variable speed," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, pp. 97–106, Mar. 2020, https://doi.org/10.11591/ijpeds.v11.i1.pp97-106.

[7] T. Mebkhouta, A. Golea, R. Boumaraf, T. M. Benchouia, and D. Karboua, "A High Robust Optimal Nonlinear Control with MPPT Speed for Wind Energy Conversion System (WECS) Based on Doubly Fed Induction Generator (DFIG)," *Periodica Polytechnica Electrical Engineering and Computer Science*, vol. 68, no. 1, pp. 1–11, 2024, https://doi.org/10.3311/PPee.22595.

[8] A. J. P. Delima, A. M. Sison, and R. P. Medina, "A modified genetic algorithm with a new crossover mating scheme," *Indonesian Journal of Electrical Engineering and Informatics (IJEEI)*, vol. 7, no. 2, pp. 165–181, May 2019, https://doi.org/10.52549/ijeei.v7i2.1047.

[9] A. K. Guediri and D. Ben Attous, "Modeling and fuzzy control of a wind energy system based on double-fed asynchronous machine for supply of power to the electrical network," *International Journal of System Assurance Engineering and Management*, vol. 8, no. 1, pp. 353–360, Jan. 2017, https://doi.org/10.1007/s13198-015-0367-1.

[10] J. O. Spiegel and J. D. Durrant, "AutoGrow4: an open-source genetic algorithm for de novo drug design and lead optimization," *Journal of Cheminformatics*, vol. 12, no. 1, Apr. 2020, Art. no. 25, https://doi.org/10.1186/s13321-020-00429-4.

[11] A. Guediri and S. Touil, "Optimization Using a Genetic Algorithm Based on DFIG Power Supply for the Electrical Grid," *International Journal of Engineering*, vol. 35, no. 1, pp. 121–129, Jan. 2022, https://doi.org/10.5829/ije.2022.35.01A.11.

[12] S. Kharoubi and L. E. Menzhi, "Wind turbine doubly-fed induction generator defects diagnosis using rotor currents lissajous curves," *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 4, pp. 2083–2090, Dec. 2020, https://doi.org/10.11591/ijpeds.v11.i4.pp2083-2090.

[13] A. Tan, Z. Tang, X. Sun, J. Zhong, H. Liao, and H. Fang, "Genetic Algorithm-Based Analysis of the Effects of an Additional Damping Controller for a Doubly Fed Induction Generator," *Journal of Electrical Engineering & Technology*, vol. 15, no. 4, pp. 1585–1593, Jul. 2020, https://doi.org/10.1007/s42835-020-00440-7.

[14] A. Radaideh, M. Bodoor, and A. Al-Quraan, "Active and Reactive Power Control for Wind Turbines Based DFIG Using LQR Controller with Optimal Gain-Scheduling," *Journal of Electrical and Computer Engineering*, vol. 2021, no. 1, 2021, Art. no. 1218236, https://doi.org/10.1155/2021/1218236.

[15] Z. Zeghdi, L. Barazane, Y. Bekakra, and A. Larabi, "Improved Backstepping Control of a DFIG based Wind Energy Conversion System using Ant Lion Optimizer Algorithm," *Periodica Polytechnica Electrical Engineering and Computer Science*, vol. 66, no. 1, pp. 43–59, Jan. 2022, https://doi.org/10.3311/PPee.18716.

[16] B. Kelkoul and A. Boumediene, "Stability analysis and study between classical sliding mode control (SMC) and super twisting algorithm (STA) for doubly fed induction generator (DFIG) under wind turbine," *Energy*, vol. 214, Jan. 2021, Art. no. 118871, https://doi.org/10.1016/j.energy.2020.118871.

[17] M. Parvane, E. Rahimi, and F. Jafarinejad, "Optimization of Quantum Cellular Automata Circuits by Genetic Algorithm," *International Journal of Engineering*, vol. 33, no. 2, pp. 229–236, Feb. 2020, https://doi.org/10.5829/ije.2020.33.02b.07.

[18] A. Guediri, M. Hettiri, and A. Guediri, "Modeling of a Wind Power System Using the Genetic Algorithm Based on a Doubly Fed Induction Generator for the Supply of Power to the Electrical Grid," *Processes*, vol. 11, no. 3, Mar. 2023, Art. no. 952, https://doi.org/10.3390/pr11030952.