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HAL Id: hal-02472629

https://hal.science/hal-02472629

Submitted on 22 Oct 2021

Available online at www.sciencedirect.com

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Energy

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Special Issue on Emerging and Renewable Energy: Generation and Automation

Dynamic Behavior Analysis for Optimally Tuned On-Grid DFIG Systems

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Abstract

Metaheuristic Optimization Techniques (MOTs) such as the Artificial Bee Colony (ABC) algorithms and Grey Wolf Optimizer (GWO) can be conveniently used for reaching the Maximum Power Point Tracking (MPPT) of Wind Energy Conversion System (WECS). This paper presents an enhanced control strategy for both Rotor Side Converter (RSC) and Grid Side Converter (GSC) of the Doubly Fed Induction Generator (DFIG)-based WECS using the ABC and the GWO algorithms to ensure the MPPT for the WECS. The control strategy for the RSC and GSC are verified via 9 MW DFIG Wind Turbine (WT) using MATLAB[TM]/ Simulink. The dynamic performance improvement of the DFIG depends on the appropriate choice of the optimal PI controllers' gains. The numerical simulation results show the superiority of the proposed GWO-PI and the ABC-PI optimal controllers over the traditional PI regulators towards enhancing the DFIG system dynamic performance.

Keywords: Keywords: Doubly-fed induction generator; Metaheuristic Optimization Techniques; Wind Energy Conversion System

1. Introduction

Nowadays, Wind Energy (WE) is very popular due to the whole power that able to produce efficiently. The WE is a pollution-free resource which contributes in reducing undesirable emissions of fossil fuel power plant operation. The WE have attracted large attention for generating the maximum available power from the wind [1].

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Wind Turbines (WTs) are designed to operate at its maximum energy conversion output. The concerns about the environmental pollution have led to more extensive researches in different Renewable Energy (RE) forms. Among the different RE sources, WE have proven to be one of the most economical energy source with significant power production [1]. With the increase of the WT penetration, the wind farms directly affect the power system stability. With the development of the WT techniques, different types of WT have been used. Based on the application, the WTs can be either constant or variable speed generators.

The majority of wind farms use a variable speed wind turbine generator equipped with Doubly-Fed Induction Generators (DFIG). The WT-DFIGs have some advantages regarding the variable speed operation, comparatively high efficiency, active and reactive power capabilities and flexible control [2]. The DFIGs have been widely used for large-scale wind generation systems. Their control and operation have been a subject of intense research during the last few years [2-4]. The conventional DFIG control structures consist of the decoupled PI rotor current controllers with stator flux orientation and machine parameter-dependent compensating terms. Due to their simple structure and often robust appearance, the conventional PI controllers are the most common controllers used for achieving desirable dynamic performance decoupled control solution of the active and reactive power for the DFIG. However, the success of the PI controller and consequently the performance of the DFIG depend on the appropriate choice of the controllers gains. The tuning of the PI parameters using the traditional trial and error method to optimize the performance is time consuming and almost cumbersome especially for nonlinear systems [5]. Therefore, the use of the recent intelligent optimization algorithms such as Mine Blast Algorithm (MBA), Whale Optimization Algorithm (WOA), Moth Swarm Algorithm (MSA), Cuckoo Search (CS) [6], Particle Swarm Optimization (PSO), Genetic Algorithms (GAs), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC) and the Grey Wolf Optimizer (GWO) has been successfully used in various applications [6-7]. Different performance indices such as the Integration of the Absolute Error (IAE), Integration of the Square Error (ISE), Integration of the Time Weighted Square Error (ITWSE), and Integration of the Time Weighted Absolute Error (ITWAE) have been considered to satisfy the required criteria in active and reactive output power of the DFIG. In this study, the ITWSE is used as the performance index [8].

In this paper, the ABC and the GWO approaches have been used for optimizing the PI controller parameters for both Rotor Side Converter (RSC) and Grid side Converter (GSC) of DFIG based WT to validate power tracking performance and thus confirming the effectiveness of this proposed control strategy. The detailed model for the representation of DFIG based wind farm in power system dynamics simulations is presented. The numerical simulations are performed using MATLAB™/ Simulink software. The Maximum Power Point Tracking (MPPT) of Wind Energy Conversion System (WECS) can be conveniently performed via the proposed approaches ABC-PI and GWO-PI. The improved accuracy of the Metaheuristic Optimization Techniques (MOTs) over the conventional PI controllers is tested. The GWO and the ABC dynamic behaviors are compared to determine which algorithm provides the enhanced performance.

Recently developed optimization techniques known such as the ABC, PSO, GA and GWO have been applied to solve the optimization problem. The efficiency of the GWO and ABC algorithms developed in this paper are evaluated by solving the optimization problem. The numerical simulation results demonstrate that GWO and ABC are very competitive compared to the state-of-the-art optimization methods. Ramadan et al. (2017) have applied the ABC algorithm and MBA for scheduling the optimal gains of the robust non-liner Sliding Mode Control (SMC) for the Voltage Source Converters High-Voltage Direct Current (VSC-HVDC) systems. Both optimal SMC-based techniques have been compared in terms of the behavioural analysis and robustness [9]. Sharma et al. (2016) have developed the GWO for optimal sizing of battery energy storage device to minimize operation cost of micro-grid. The proposed algorithm has been tested on a typical micro-grid. The numerical simulation results establish that the GWO outperforms several existing optimization techniques such as GA and PSO [10]. Soued et al. (2017) have employed the advanced MOTs for enhancing the dynamic behavior of the wind power plant. The GA, ABC algorithm and the GWO technique are used for the optimal tuning of the Blade Pitch Control (BPC) system parameters [11]. Tan et al. (2016) have presented a case study for multi variable and multimodal design optimization of DFIG based on surrogate-model optimization algorithm. The PSO algorithm has been applied on the DFIG system to obtain higher efficiency of DFIG and to achieve the machine design optimization [12]. Zhang et al. (2017) have proposed a chaotic GWO to select the optimal control parameters of the hybrid power system, a micro-grid mainly including a pumped storage unit and a wind power plant to enhance control performances under the complicated operating conditions [13]. Ramadan (2017) has used advanced meta-heuristic optimization techniques such as the CS, GWO and ABC to find the optimal gain of the conventional PI controller) and the Fractional Order (FOPI) controller in the PV-grid connected systems. [14].

Furthermore, different recent research have been realized on the control development for the WT based DFIG to enhance dynamic performance of WECS.

Moreover, Zhang et al. (2018) have proposed an automatic power control strategy for wind farm to minimize the imbalance between the wind farm active output and its reference value, which is considered the dispatching of safe operation of grid and the number of start/stop of wind turbines. The proposed method effectiveness has been verified with simulation example analysis [15]. Aissaoui et al. (2013) have proposed a control strategy based on FLC to extract the maximal wind power [16]. In [16], the overall model of WECS based on the induction generator (IG) has been developed. Wang et al. (2017) have applied the distributed control strategy for cooperative optimization active power output. In [17], the simple type division algorithm has been proposed to solve offshore wind farm dispatch problem. Chang et al. (2019) have presented a comparative evaluation of the conventional SMC, integral SMC and Integral Terminal Attractor (ITA) controlled PWM inverters. The ITA has provided better performance for practical applications compared to other sliding modes. In [18], the Experimental results have shown that the ITA can be regarded as a viable controller for the PWM in wind power, photovoltaic and fuel cell inverters.

Based on the literature review, rare researches has discussed the optimal control strategy for both the RSC and GSC of the DFIG based on the WECS. The technical research gap was applied the new MOTs to enhance control strategy for both the RSC and GSC by scheduling the optimal control gains. Therefore, the idea behind this research is to employ the ABC and GWO algorithms to optimally select the gains of the PI controller that will minimize the steady-state error of the system dynamic behaviour.

The rest of the paper is organized as follows: In Section 2, the DFIG modeling and control is exhibited. Then the MOTs approaches are presented in Section 3. The simulation results and the discussion are outlined in Section 4. Finally, the paper conclusions and perspectives are summarized in Section 5.

Nomenclature

ABC	Artificial Bee Colony	PWM	Pulse Width Modulation
D, Q	Direct, Quadrature axes	P_s, Q_s	Stator active, reactive powers
I_{dqr}, V_{dqr}	Rotor Current, Voltage in d-q references	R_{sr}	Stator and Rotor resistance (Ω)
I_{dqs}, V_{dqs}	Stator current, voltage in d-q references	RES	Renewable Energy Source
RES	Renewable Energy Source	VFC	Variable Frequency Converter
GWO	Grey Wolf Optimize	WT	Wind Turbines
GSC	Grid-Side Converter	WECS	Wind Energy Conversion System
M	Mutual inductance (H)		

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2. DFIG Modeling and Control

The general electrical state model of the induction generator equations are explained in [19, 20]. The DFIG-WT control system should be designed in order to regulate the rotor speed of the DFIG for maximum wind power capture, to maintain the DFIG stator output voltage frequency constant and to control the DFIG reactive power. Different research have been undergone to decouple the active and reactive powers control [19]. The most efficient schemes for decoupled control of active and reactive powers are the vector control. Various types of controllers are used like the simple conventional PI controller, fuzzy logic controller, and the SMC in the vector control scheme for the control of active and reactive power [20]. The PI controller is the most primitive and highly used controller in electrical power and industrial applications due to its simplicity. As the stator winding of DFIG is the infinite grid connected, the magnitude and frequency of stator voltage can be approximately considered constant. Therefore, the DFIG usually adopts stator flux linkage-oriented control strategy.

2.1. Rotor Side Converter Control.

The vector control is applied to the RSC to control the stator active power and terminal voltage. The d axis loop is used for controlling the stator terminal voltage control whereas the q axis is for active power control. The stator flux-oriented vector control is employed to the RSC. The overall vector control scheme of the DFIG-RSC is shown in Fig. 1 (a) [4-5, 19]. The control of DFIG stator active power P_s and voltage V_s is achieved by controlling the rotor current I_{rabc} in the stator flux-oriented reference frame, where the rotor current I_{rabc} is transferred to I_{dr} and I_{qr}.

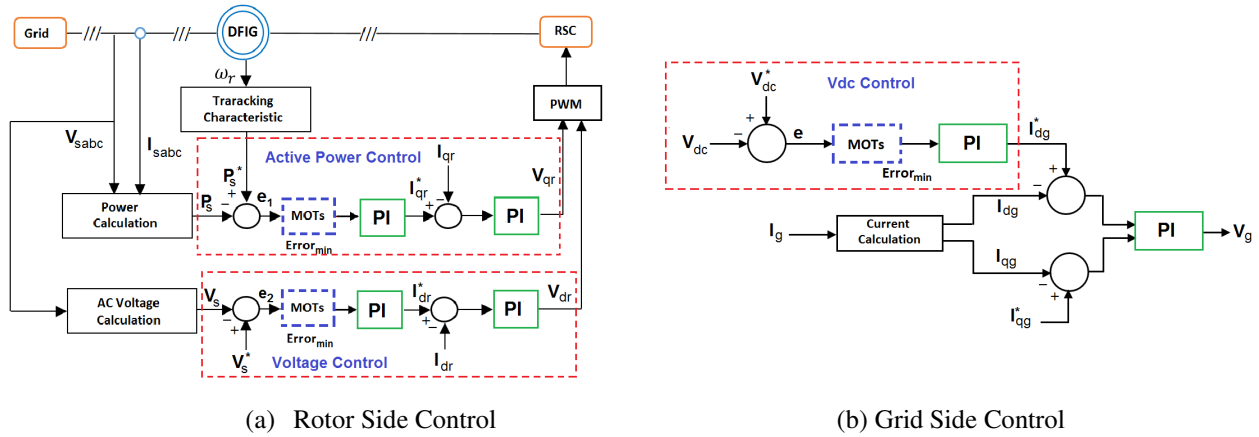(a) Rotor Side Control   (b) Grid Side Control

Fig. 1: DFIG Control.

The reference signals (I_{dr}^* and I_{qr}^*) for the outer control loops are generated by controlling the stator reactive and active powers respectively. Then, the error signal is generated by deducting the current signals (I_{dr} and I_{qr}) from the corresponding reference signals (I_{dr}^* and I_{qr}^*) respectively. The generated error signals are used for producing two voltage signals (V_{dr} and V_{qr}) using two PI controllers. Finally, voltage signals (V_{dr} and V_{qr}) are then connected to the PWM to create the signal for the IGBT gate control [19-21].

2.1. Grid Side Converter Control.

The GSC is directly connected to the grid at the stator and used for the voltage regulation of the DC bus capacitor. The GSC is connected to the grid through RL filter and the DC-link. The role of this converter is to maintain the DC-link voltage as a constant value [19, 20]. For GSC controller, the voltage signal V_{dc} is compared to its reference signal V_{dc}^* as shown in Fig. 1 (b). The error signal from inputs to the proportional-integral (PI) controller which generates the reference current I_{dg}^*. The current regulator controls the magnitude and phase of the voltage generated by GSC (V_g) from the I_{dg}^* reference produced by the DC voltage regulator and specified I_{qg}^* reference.

3. The MOT Approaches

The MOTs are becoming more popular for solving engineering application problems. Nature-inspired MOTs solve optimization problems by mimicking biological or physical phenomena. The MOTs classified into three main categories: evolution- based, physics-based, and swarm-based methods [22]. Evolution-Algorithms are inspired by the laws of natural evolution. The most popular evolution-inspired technique is GA that simulates the Darwinian evolution. Other popular algorithms are Evolution Strategy (ES), Probability-Based Incremental Learning (PBIL), Genetic Programming (GP), and Biogeography-Based Optimizer (BBO). Physics-based Algorithms are imitated the physical rules in the universe. The most popular algorithms are Simulated Annealing (SA). The third group is the swarm-based Algorithms that mimic the social behavior of groups of animals. The most popular algorithm is PSO other swarm-based techniques are ABC and GWO. Moreover, swarm-based algorithms have some advantages over

evolution-based algorithms. For example, swarm-based algorithms preserve search space information over subsequent iterations while evolution-based algorithms discard any information as soon as a new population is formed [23, 24].

In this paper, the authors focus on the GWO and ABC hybridized with the conventional PI controller to form a novel optimal PI controller appropriate for reaching the best dynamic performance. The GWO and the ABC optimal controller dynamic behavior are compared to determine which algorithm provides enhanced performance.

4. Simulation Results

For enhancing dynamic behaviour of the DFIG grid connected system the proposed control strategies GWO and ABC have been applied. Both GWO-PI and ABC-PI controllers' simulation analysis are compared to the conventional PI controller once. For the same operation condition, GWO and ABC algorithms are used for attaining the optimal controller gains for the RSC and GSC. The objective of the control is to enhance the dynamic behavior of WT -DFIG. The proposed method provides easily tracks the reference signal of the active power of a dynamic system.

In this study, the PI controllers are considered for the control loops of the RSC and GSC. Upon tuning these controllers via MOT, the RSC and GSC performance are improved to achieve the optimal output power. In order to validate the proposed controller effectiveness, two Cases are studied.

Case 1: Applying GWO-PI and ABC-PI for RSC only using the objective function F_1 that related to the RSC.

Case 2: Applying GWO-PI and ABC-PI for both RSC and GSC using objective function F_2.

The objective function for RSC and GSC can be designed as Eq. (1, 2):

$$F_1 = \int_0^\infty [w_1\, (t(\varepsilon_V)^2) + w_2(t(\varepsilon_{Ps})^2) + w_3(t(\varepsilon_{Ir})^2] \tag{1}$$

The objective function for both RSC and GSC can be designed as:

$$F_2 = \int_0^\infty [w_1\, (t(\varepsilon_V)^2) + w_2(t(\varepsilon_{Ps})^2) + w_3(t(\varepsilon_{Ir})^2 \; + \; w_4(t(\varepsilon_{Ig})^2) \; + w_5(t(\varepsilon_{Vdc})^2)] \tag{2}$$

where, the ε_{Ps}, ε_V and ε_{Ir} are the RSC active power, voltage and current regulation error respectively. The ε_{Ig} refers to the grid current regulation and ε_{Vdc} voltage DC regulation. The coefficients ($w_1, w_2, w_3,\ w_4$ and w_5) are the positive weighting factors, which are selected according to GWO and ABC optimization technique.
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The simulation is carried out using the Matlab^{TM} /Simulink software. The controller parameters of the system can be divided in this study to, six PI gains for RSC controller namely, $[(K_p\_V_{reg}, K_i\_V_{reg})]$, $[(K_p\_P_{reg}, K_i\_P_{reg})]$ and $[(K_p\_I_{reg}, K_i\_I_{reg})]$ that deal with the controller gains of the voltage regulator, power regulator and rotor currents regulator respectively. For GSC controller four PI gains namely $[(K_p\_Vdc_{reg}, K_i\_Vdc_{reg})]$, $[(K_p\_Ig_{reg}, K_i\_Ig_{reg})]$ that express the controller gains for both Cases are presented in Table 1 and Table 2 respectively.

A comparative study is presented to verify the effectiveness of the proposed MOTs over conventional PI controller considering Case1 and Case 2. This comparative analysis is based on the time response specifications such as maximum overshoot, settling time and rise time. From the results in Table 1 and 2 the ABC-PI has better dynamic performance than GWO-PI and conventional PI controllers. Explicitly, for Case 1 different settling time of (19.45s, 19.40s, and 19.30s), percentage overshoots are (7.04%, 5.06% and 0.20%) and rise time of (19.21s, 19.17s and 9.33s) in case of (conventional PI, GWO-PI and ABC-PI) respectively.

Similarly, for Case 2 the system dynamic response is significantly improved in case of using the ABC-PI, where the settling time of (19.45s, 19.44s and 19.40s),), percentage overshoots are (7.04%, 5.16% and 2.61%) and rise time of (19.21s, 9.33s, 9.30s) in case of (conventional PI, GWO-PI and ABC-PI) respectively. Therefore, ABC-PI still has the most desired dynamic trajectories than GWO-PI optimization technique and conventional PI controller.

Table1: The PI controller gains for Case 1

Controller	Voltage Regulator	Current Regulator	Power Regulator	Overshoot (%)	Setting time (s)	Rise time (s)
PI				7.04	19.45	19.21
KP	1.25	0.3	1			
KI	300	8	100			
GWO-PI				5.06	19.40	19.17
KP	0.76	0.51	1.47			
KI	156.5	9.80	138.1			
ABC-PI				0.20	19.30	9.33
KP	1.31	0.49	8.42			
KI	294.2	14.58	196.9			

Table 2: The PI controller gains for Case 2

Controller	Voltage Regulator	Current Regulator	Power Regulator	DC Voltage Regulator	Grid Current Regulator	Overshoot (%)	Setting time (s)	Rise time (s)
PI						7.04	19.45	19.21
KP	1.25	0.3	1	0.002	1			
KI	300	8	100	0.05	100			
GWO-PI						5.16	19.44	9.33
KP	0.59	0.48	6.85	0.172	0.26			
KI	286.2	14.33	226.4	0.171	47.88			
ABC-PI						2.61	19.40	9.30
KP	0.65	0.33	0.940	0.006	1.40			
KI	154.8	7.02	19.93	0.79	69.27			

To illustrate how the agents' movement will be, the traces of search agents of GWO and ABC applied in the active power, voltage and current regulator respectively during the numerical simulations for both RSC and GSC are shown in Fig. 2 (a, b, c). Obviously, the area of more number of agents (high density of agents) is predominantly the zone where the optimal gains of the PI controllers will be found.
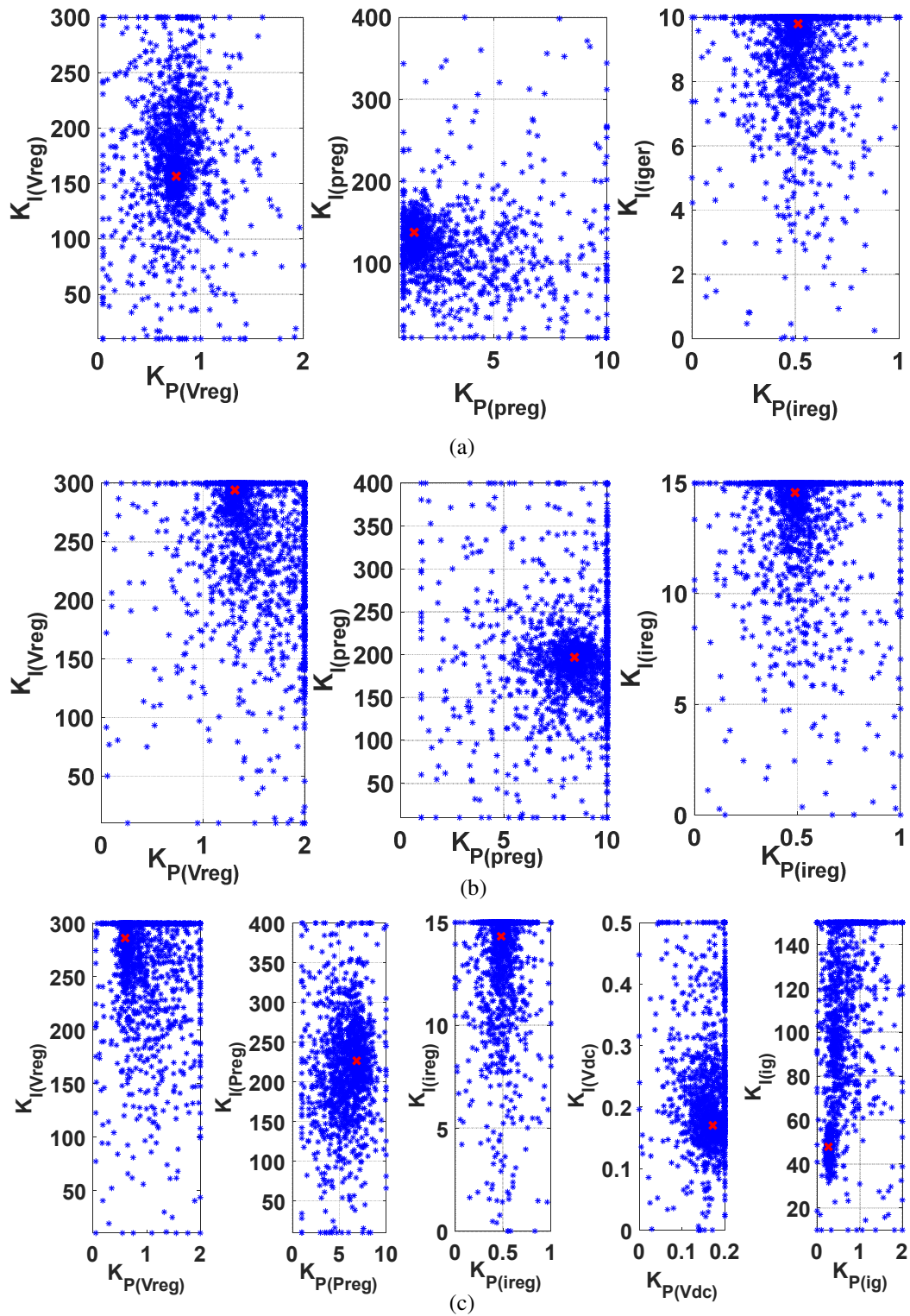
Fig. 2. Trace of search agents for 30 agents in 50 iterations, (a) Trace of search agents using GWO Case 1, (b) Trace of search agents using ABC Case 1, (c) Trace of search agents using GWO Case 2.

Fig. 3 (a, b) shows the dynamic behavior of the current components direct and quadrature($d-q$) considering Case1 and Case2 for GWO-PI and ABC-PI. The rotor current (I_{qr}, I_{dr}) damping and the grid current time responses (I_{qg}, I_{dg}) with GWO and ABC tuned PI controller is decreased as compared to the conventional PI controller or the over-current in the rotor circuit is reduced while using conveniently the MOT-PI.
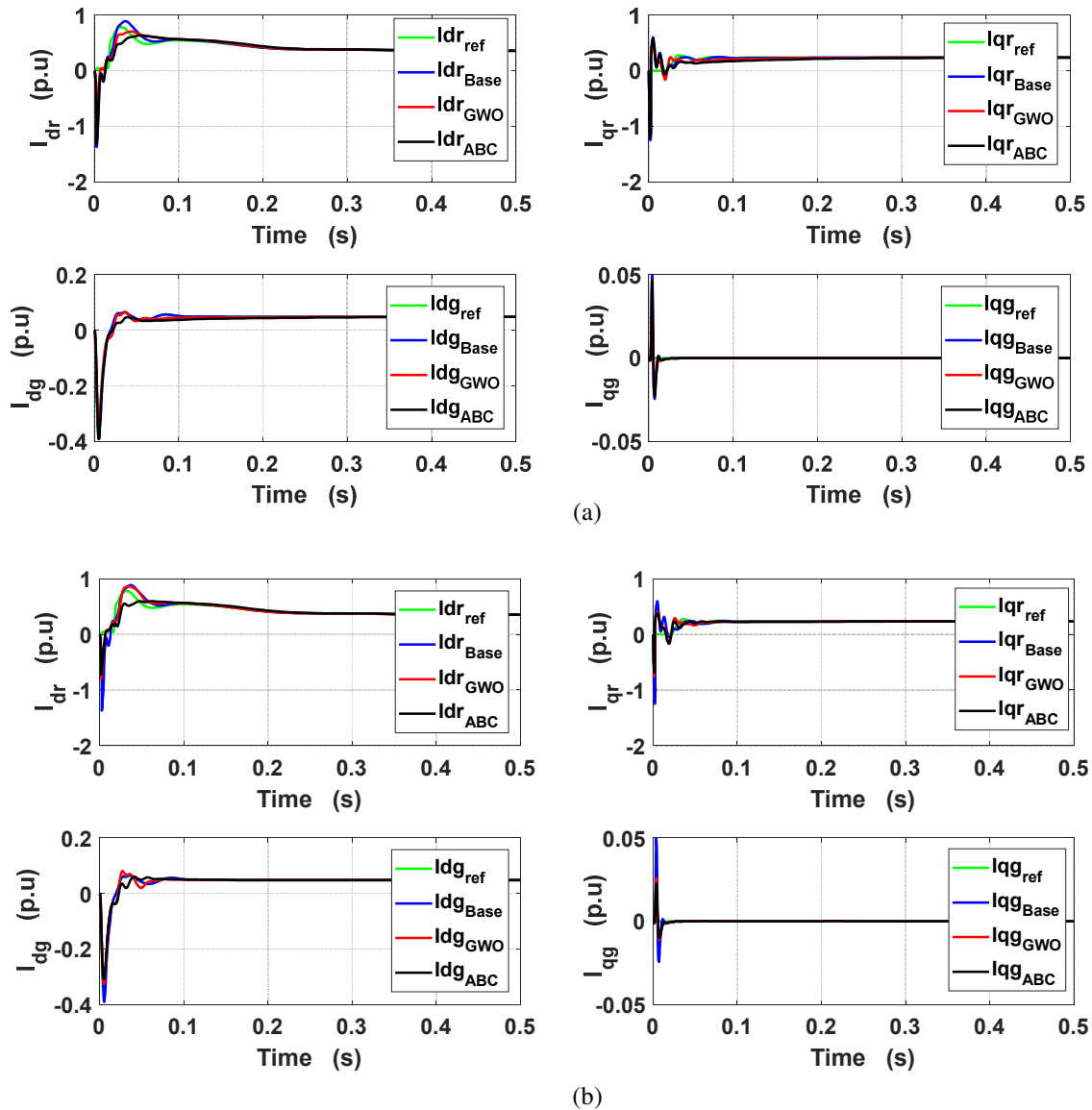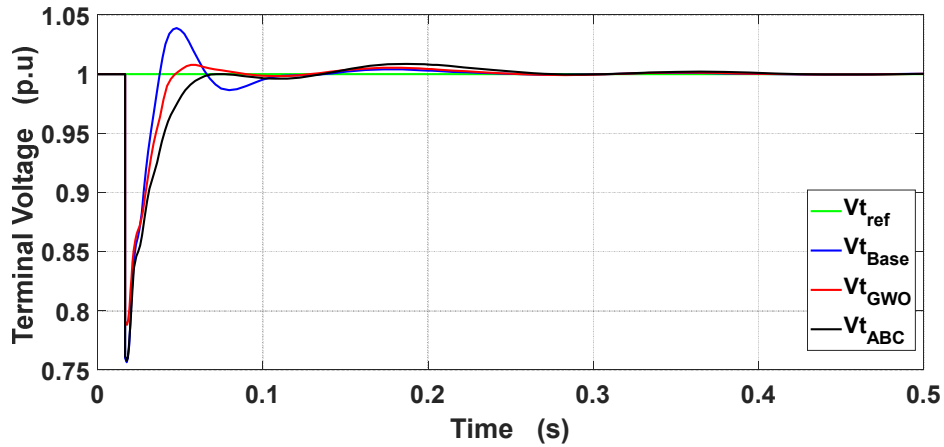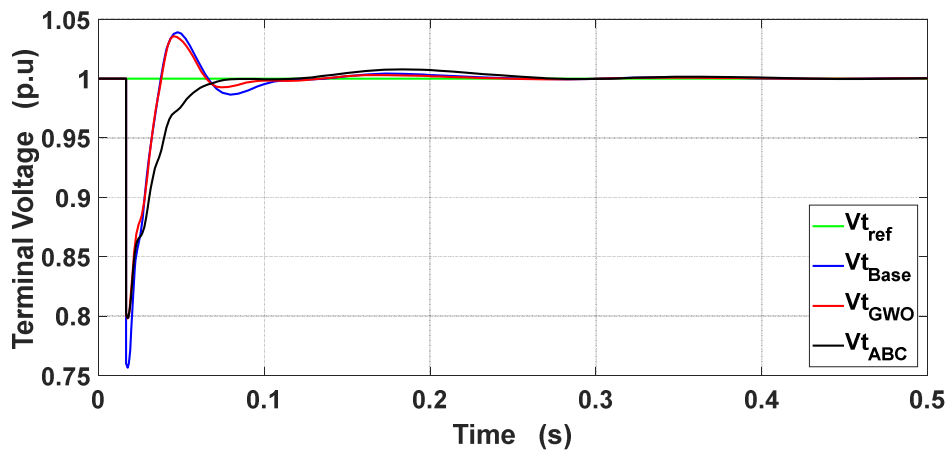

(a)

(b)

Fig. 3. Dynamic behavior of the $d-q$ current components, (a) Applying GWO-PI and ABC-PI for RSC, (b) Applying GWO-PI and ABC-PI for both RSC and GSC.

The GWO-PI and ABC-PI have better dynamic performance than the conventional PI regarding the settling time, overshoot and steady state error, for (GWO, ABC) respectively. The terminal voltage dynamic behavior for MOTs considering two cases are shown in Fig. 4 (a, b). The oscillations of the transient response of the system when using the GWO-PI and ABC-PI are significantly enhanced compared to conventional PI.

(a)

(b)

Fig. 4. Dynamic performance of the DFIG terminal voltage, (a) Applying GWO-PI and ABC-PI for RSC, (b) Applying GWO-PI and ABC-PI for both RSC and GSC.

The use of optimization techniques is still a research challenge in different renewable energy applications [25-27].

5. Conclusion and Perspectives

The control for both RSC and GSC are achieved through direct and quadrature axes currents. The originality of this paper is to present an optimal PI controllers design for the DFIG. The GWO and ABC techniques are presented in order to ensure MPPT. The proposed GWO-PI and ABC-PI have been provided more efficient in seeking for the global optimum PI parameters with respect to the desired performance indices compared to the conventional PI controller. Therefore, the MOTs offer a significant optimization tool for tuning PI controller when compared to the conventional PI controller. The MOTs controller numerical results are compared to that obtained by the conventional PI controller to explain the merits of each one. Both GWO and ABC are successfully used for optimizing the control parameters of the RSC and GSC to ensure a MPPT of the DFIG based WECS under variable speed conditions. The simulation results show that the GWO-PI and ABC-PI provide enhanced dynamic performance.

For the control, strategy for both RSC and GSC of the DFIG-based WECS will be enhanced using: Adaptive AI-based MOTs and the comparison with other novel MOTs such as Whale Optimization Algorithm (WOA).

References

[1] Kumar D, Chatterjee K. "A Review of Conventional and Advanced MPPT Algorithms for Wind Energy Systems", *Renewable and Sustainable Energy Reviews* (55) (2016): 957-970.

[2] A Tabanjat, M Becherif, M Emziane, D Hissel, HS Ramadan, B Mahmah; ''Fuzzy logic-based water heating control methodology for the efficiency enhancement of hybrid pv–pem electrolyser systems'' *International Journal of Hydrogen Energy* 40 (5), (205) 2149-2161.

[3] Özsoy EE, Golubovic E, Sabanovic A, Bogosyan S, Gökaşan M. ''Modeling and control of a doubly fed induction generator with a disturbance observer: a stator voltage-oriented approach'' *Turkish Journal of Electrical Engineering & Computer Sciences* (24) (3) (2016):961-72.

[4] A Allag, MY Hammoudi, SM Mimoune, MY Ayad, M Becherif, A Miraoui, ''Tracking control via adaptive backstepping approach for a three phase PWM AC-DC converter Industrial Electronics''. *IEEE International Symposium*, ISIE (2007).

[5] Carneiro TC, Melo SP, Carvalho PC, Braga AP. "Particle Swarm Optimization method for estimation of Weibull parameters: A case study for the Brazilian northeast region". *Renewable energy* (86) (2016): 751-9.

[6] Ramadan HS. "Optimal Fractional Order PI Control Applicability for Enhanced Dynamic Behavior of On-Grid Solar PV Systems," *International Journal of Hydrogen Energy* (42) (7) (2017): 4017-31.

[7] Gao R, Gao Z. "Pitch Control for Wind Turbine Systems using Optimization, Estimation and Compensation", *Renewable Energy* (91) (2016): 501-15.

[8] Osman AS, El-Wakeel AS. "Optimal Tuning of PI Controllers for Doubly-Fed Induction Generator-Based Wind Energy Conversion System using Grey Wolf Optimizer", *Int. Journal of Engineering Research and Applications* (5) (11) (2015): 81-87.

[9] Ramadan HS, Fathy A, Becherif M. ''Optimal gain scheduling of VSC-HVDC system sliding mode control via artificial bee colony and mine blast algorithms''. *IET Generation, Transmission & Distribution.* (12) (3) (2017):661-9.

[10] Sharma S, Bhattacharjee S, Bhattacharya A."Grey Wolf Optimization for Optimal Sizing of Battery Energy Storage Device to Minimize Operation Cost of Microgrid." *IET, Generation, Transmission & Distribution* (10) (3) (2016): 625-37.

[11] Soued S, Ebrahim MA, Ramadan HS, Becherif M. Optimal blade pitch control for enhancing the dynamic performance of wind power plants via metaheuristic optimizers'' *IET Electric Power Applications* (11)(8) (2017):1432-40.

[12] Tan Z, Baker NJ, Cao W. "Novel Optimization Algorithm of Electrical Machines", *8th IET, International Conference on Power Electronics, Machines and Drives, PEMD, Glasgow*, UK, (2016): 6.

[13] Zhang Y, Zhou J, Zheng Y, Xu Y. Control optimization for pumped storage unit in micro-grid with wind power penetration using improved grey wolf optimizer. *IET Generation, Transmission & Distribution* (11) (13) (2017):3246-56.

[14] Ramadan, H. S. "Optimal fractional order PI control applicability for enhanced dynamic behavior of on-grid solar PV systems." *International Journal of Hydrogen Energy (*42) (7) (2017): 4017-4031.

[15] J. Zhang, J. Chen J, X. Kong, Song W, Zhang Z, Wang Z, Kong D. ''Research on Active Power Automatic Control Strategy of Wind Farm Energy Station Access System'' *Energy Procedia* (152) (2018):1033-8.

[16] Aissaoui AG, Tahour A, Abid M, Essounbouli N, Nollet F. ''Power control of wind turbine based on fuzzy controllers''. *Energy Procedia.* (42) (2013):163-72.

[17] Wang L, Wen J, Cai M, Zhang Y. Distributed optimization control schemes applied on offshore wind farm active power regulation. *Energy Procedia* (105) (2017):1192-8.

[18] E. C. Chang, Y. C. Liu, C. H. Chang, ''Experimental performance comparison of various sliding modes controlled PWM inverters'' *Energy Procedia,* (156), (2019):110-114.

[19] Becherif M, Bensadeq A, Mendes E, Henni A, Lefley P, Ayad MY. From Dynamic Modeling to Experimentation of Induction Motor Powered by Doubly Fed Induction Generator by Passivity-Based Control. *In Electric Machines and Drives* (2011). In Tech.

[20] A Saadi, M Becherif, D Hissel, HS Ramadan, Dynamic modeling and experimental analysis of PEMFCs: A comparative study International Journal of Hydrogen Energy, (2017), 42 (2), 1544-1557.

[21] O Kraa, H Ghodbane, R Saadi, MY Ayad, M Becherif, A Aboubou, M Bahri, Energy management of fuel cell/supercapacitor hybrid source based on linear and sliding mode control*, Energy Procedia*, (2015), 74, 1258-1264.

[22] Mirjalili S, Mirjalili SM, Lewis A. "Grey Wolf Optimizer", *Advances in Engineering Software*, (69) (2014): 46-61.

[23] Sebaa H, Guerriche KR, Bouktir T. "Optimal Sizing and Placement of Renewable Energy Source in Large Scale Power System using ABC", *In Renewable and Sustainable Energy Conference (IRSEC), IEEE International (2014): 294-299.*

[24] L. Mogaka, D. K. Murage M. J. Saulo. "Power Optimization and Prioritization in an Island Supplied by a Rotating Machine Based Distributed Generator using Artificial Bee Colony Algorithm", *International Journal of Energy and Power Engineering* (5) (1), (2016): 15-21.

[25] Ramadan HS, Bendary AF, Nagy S. "Particle Swarm Optimization for Capacitor Allocation Problem in Distribution System with Wind Turbine Generators", *Journal of Electrical Power and Energy Systems*, (84) (2017):143-52.

[26] Ahmed M, Ebrahim MA, Ramadan HS, Becherif M. ''Optimal genetic-sliding mode control of VSC-HVDC transmission systems''. *Energy Procedia*. (1) (74) (2015):1048-60.

[27] J. G. Jamnani, Maulikkumar Pandya ''Coordination of SVC and TCSC for Management of Power Flow by Particle Swarm Optimization'' *Energy Procedia*, (156): (2019), 321-326.