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Original article

Dynamic performance enhancement for wind energy conversion system using Moth-Flame Optimization based blade pitch controller

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ABSTRACT

Moth-Flame Optimization (MFO) technique has recently been explored to develop a novel algorithm for distributed optimization and control. In this paper, the MFO-based design of blade pitch controllers (BPCs) is proposed for wind energy conversion system (WECS) to enhance the damping of oscillations in the output power and voltage. The simple Proportional-Integral-Differential (PID) is used to realize the advantage of the proposed hybrid referential integrity MFO technique. The proposed blade pitch controllers are termed as BPC-PID (MFO). Single wind turbine system, equipped with BPC-PID (MFO), is considered to accomplish this study. The suggested WECS model considers small as well as large scale uncertainties. MFO is utilized to search for optimal controller parameters by minimizing a candidate time-domain based objective function. The performance of the proposed controller has been compared to those of the conventional PID controller based on Zeigler Nichols and simplex algorithm and the PID controller optimized by genetic algorithms (GA), to demonstrate the superior efficiency of the MFO-based BPC-PID. Simulation results emphasis on the better performance of the proposed BPC-PID (MFO) compared to conventional and GA-based BPC-PID controllers over a wide range of operating conditions and control system parameters uncertainties.

Introduction

Wind energy source (WES) is one of the most prominent sources of electrical energy in years to come. WES, as a renewable source, has no impacts on the climate issues and greenhouse gases (GHG) emissions. The increasing concerns about environmental problems demand green, renewable, and sustainable ideas. Wind turbines along with solar energy and fuel cells are possible innovative solutions for this dilemma. WES is a non-depleting, site-dependent, non-polluting, and a potential source of the alternative energy option.

Wind energy has already reached a penetration level in many countries, which raises some technical problems concerning grid integration [1–3]. WE has to overcome some technical as well as economic barriers if it should produce a substantial part of electricity [4]. In power systems, the principal objective of the control strategy is providing economical and reliable power as possible while improving the power quality [5,6]. The wind energy conversion system (WECS) is not just be used for generating electricity from the wind, but also about using this energy efficiently. Wind turbine (WT) is often equipped with a blade pitch control (BPC) for high-quality power generation from wind source and decreasing mechanical fatigue. To improve the dynamic performance of the WECS, a BPC system is used. WECSs typically use BPCs to fulfill two primary functions are assigned to the BPC, which are; (i) it monitors, adjusts, and controls the speed of the turbine rotor to maintain the turbine's energy production at its rated value, and (ii) it turns the blade out of the wind in cases of high wind speeds or emergency command to avoid any damages on the WT and ensure safe operation.

Over the past five decades, several approaches have been presented for BPC system modeling. Modeling of the appropriate BPC system is the prerequisite of WECS for maintaining the power extracted from WT at its rated value and enhancing aerodynamic performance [7,8]. The complete dynamical model of WECS is very complicated because it is an under-actuated, highly coupled and nonlinear system [9]. Such dynamical system is usually decomposed into a generator system and wind turbine system during controller design phase [10]. In [11], the BPC had been developed based on a simplified blade pitch model which is derived out by neglecting blade torsional dynamics. In this case, the simplified blade pitch model has a relatively significant difference in the actual design. A new simplified blade pitch model was firstly

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Nomenclature

R_{tl}	transmission line resistance (p.u. ohm)
X_{tl}	transmission line reactance (p.u. ohm)
N_r	turbine speed (r.p.m)
r_b	blade radius (m)
V_W	wind speed (m/s)
PP	no. of poles
h	inertia constant
ζ	damping coefficient
R_a	generator armature resistance (p.u. ohm)
X_d	D-axis reactance (p.u. ohm)
X_q	Q-axis reactance (p.u. ohm)
$V\infty$	infinite bus voltage (p.u. V)
P	active power (p.u. MW)
K_{th}	torque factor
$X_{d'}$	transient d-axis reactance (p.u. ohm)
$X_{d''}$	sub-transient d-axis reactance (p.u. ohm)
$X_{q''}$	sub-transient q-axis reactance (p.u. ohm)
$\tau_{do'}$	D-axis transient field time constant (s)
$\tau_{do''}$	Q-axis sub-transient field time constant (s)
$\tau_{qo''}$	Q-axis sub-transient field time constant (s)
ω_o	base angular speed of the generator (rad/s)
ω_n	nominal angular speed of the generator (rad/s)
τ_p	wind turbine filter time constant (s)
τ_e	exciter time constant (s)
K_e	exciter gain
N	gear ratio
Q	reactive power (p.u. MVAR)

presented in [10] by taking the pitch servo motor, actuator, and blade torsional dynamics into consideration. The proposed model is more reasonable. The proposed BPC model is constructed and built using Matlab Simulink as demonstrated in Fig. 1.

The preliminary results on control designs of BPC were firstly presented in [7,8]. The challenge of BPC, to achieve good performance, is the complex nonlinear mathematical equations in large-scale systems.

A robust dynamic output feedback designs of BPC have been addressed in [12,13]. However, such robust-based design does not account for system nonlinearities and results in a controller with the same plant order, which in turn makes the design very complex especially for large WECSs. Various conventional control strategies are being used for BPCs. Methodologies for a conventional design of sliding mode and proportional–integral (PI) controllers are limited by slow, lack of efficiency and poor handling of system nonlinearities [11]. Artificial Intelligence (AI) techniques like fuzzy logic control (FLC), artificial neural networks (ANNs), genetic algorithms (GAs), particle swarm optimization (PSO), ant colony optimization (ACO) and artificial bee colony (ABC) have been applied for BPC to overcome the limitations of conventional methods [14–18]. Among various types of BPCs, proportional–integral–derivative (PID) controllers have commonly used thanks to its structural simplicity and its better dynamic response. On the contrary, the performance of PID controllers is degraded significantly when the controller parameters change.

Genetic algorithms (GAs) have been extensively considered for the design of BPC. The parameters of optimal BPC-based PID controller have been optimized via GAs for WECS [18]. The application of PSO for optimizing an integral controller and a PI controller is reported in [19]. The authors of [19] tuned the PI controllers via PSO using a new cost function. The design of a fuzzy logic controller based BPCs is presented in [20]. In [18], a robust PID design based on the grey wolf algorithm (GWA) has been considered for BPC application. Ant bee colony optimization algorithm (ABCOA) has been suggested by Salah et al. for optimizing PID-based BPCs for WECS [18].

The classical BPC-PID commonly used in practice is a dynamic output feedback, a lead type, with a single stage and uses the electrical power deviation ΔP_e as a feedback signal [19]. Conventional fixed-parameter BPC may fail to maintain system stability over a wide range of operating conditions or at least leads to performance degradation. Traditional fixed-parameter BPC is not enough anymore, but it has to work reliably in any environment because of the dramatically continuous variation in climate conditions. Moreover, BPC has to effectively cope with mechanical and electrical systems uncertainties imposed by the continuous change in operating points. The control of such systems which have the characteristics of time-varying, structured and unstructured uncertainty, and neglected dynamics, has been an exciting challenge to the researchers.

Over the last few decades, the interest in defining resilient and non-fragile stability limits for PID controllers gains has progressed significantly. Progressive interest in resiliency and non-fragility results from its fast response and stability against nonlinearities, constraints and parameters uncertainties [21]. These powerful features of resilient and non-fragile stability limits will enhance the performance of proposed BPC-PID. The author of [21], presented some primary results on resilient and non-fragile PID controller applications in BPC. In [19], Mohamed et al. introduced the PID-based BPC of wind energy power plant where the controller parameters limits were determined arbitrarily. However, the design did not account for the system nonlinearities that was only considered while modeling simulation. Remarkably, such design may lead to a degraded system performance once the real application of that controller.

Recently, the novel metaheuristic optimization techniques have been used for adjusting the PID controller parameters. They are featured by their significant capability for dealing with continuous nonlinear optimization problems, shorter calculation and simulation time besides their better convergence characteristics compared to other stochastic techniques [22–30]. Thus, the most recent metaheuristic optimization techniques are used for designing the BPC-PID controller

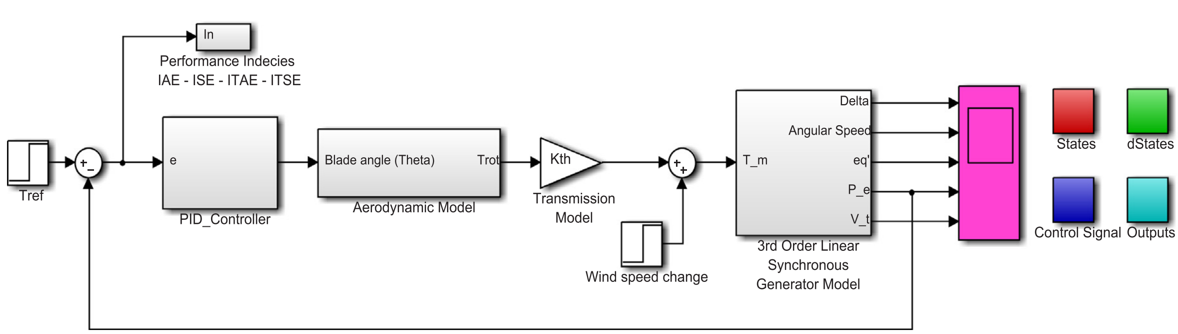

Fig. 1. Wind energy conversion system Simulink Model.