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Speed control of induction motor supplied by wind turbine via Imperialist Competitive Algorithm

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A R T I C L E I N F O

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A B S T R A C T

This paper proposes the speed control of IM (Induction Motor) fed by wind turbine using ICA (Imperialist Competitive Algorithm). The wind turbine plays as a prime mover to a connected DC (Direct Current) generator. PWM (Pulse Width Modulation) is used to get three phase AC (Alternating Current) voltage from the output of DC generator. The proposed design problem of speed controller is established as an optimization problem. ICA is adopted to search for optimal controller parameters by minimizing the time domain objective function. The behavior of the proposed ICA has been estimated with the behavior of the conventional ZN (Ziegler–Nichols) and GA (Genetic Algorithm) in order to prove the superiority of the proposed ICA in tuning PI (Proportional plus Integral) controller. Also, the behavior of the proposed controller has been tested over a wide range of operating conditions. Simulation results confirm on the better behavior of the optimized PI controller based on ICA compared with other algorithms.

1. Introduction

IM (Induction Motor) is the object of several works because of its robustness, low cost, reliability and efficiency. However, its control presents difficulties because of its high non-linearity [1,2]. Many intelligent approaches are used to speed control of IM such as ANN (Artificial Neural Network) [3,4]. The ANN approach has its own advantages and disadvantages. The performance of the system is improved by ANN based controller, but the main problem of this controller is the long training time, the selecting number of layers and the number of neurons in each layer. Another artificial intelligence approach likes FLC (Fuzzy Logic Control) is introduced in Refs. [5–7], but it requires finer tuning.

Global optimization techniques have caught the attention in the field of controller parameter optimization [8]. GA (Genetic Algorithm) is illustrated in Refs. [9–13] for speed control of IM despite this optimization technique requires a very long run time that may be several minutes or even several hours depending on the size of the system under study. SA (Simulated Annealing) is introduced in Ref. [14] for optimal tuning of speed controllers but this technique might fail by getting trapped in one of the local optimal. ABC (Artificial Bee Colony) is presented in Refs. [15,16] for speed control of AC (Alternating Current) and DC (Direct Current) drives but it is slow to converge and the processes of the exploration and exploitation contradict with each other, so the two abilities should be well balanced for achieving good optimization performance. ACO (Ant Colony Optimization) algorithm is introduced in Ref. [17] to control the speed of switched reluctance motor but its theoretical analysis is difficult and probability distribution changes by iteration. Speed control of DC series motor supplied by photovoltaic system via firefly algorithm is given in Ref. [18]. Swarming strategies in fish schooling are used in the PSO (Particle Swarm Optimization) and presented in Ref. [19] for speed control of IM and DC permanent magnet motor [20–26]. However, PSO suffers from the partial optimism, which causes the less exact at the regulation of its speed and the direction [27,28]. Also, the algorithm pains from slow convergence in refined search stage, weak local search ability and algorithm may lead to possible entrapment in local minimum solutions. A relatively newer evolutionary computation algorithm, called BF (Bacteria Foraging) scheme has been presented by Ref. [28] and further established recently by Refs. [29–33]. The BF algorithm depends on random search directions which may lead to delay in reaching the global solution. In order to solve these drawbacks, this paper introduces a new evolutionary algorithm known as ICA (Imperialist Competitive Algorithm) to design a

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Nomenclature

R_s, L_{ls}	stator resistance and leakage inductance
R'_r, L'_{lr}	rotor resistance and leakage inductance
L_m	magnetizing inductance
L_S, L'_r	total stator and rotor inductances
V_{qs}, i_{qs}	q axis stator voltage and current
V'_{qr}, I'_{qr}	q axis rotor voltage and current
V_{ds}, i_{ds}	d axis stator voltage and current
V'_{dr}, I'_{dr}	d axis rotor voltage and current
$\varphi_{qs}, \varphi_{ds}$	stator q and d axis fluxes
$\varphi'_{qr}, \varphi'_{dr}$	rotor q and d axis fluxes
ω_m	angular velocity of the rotor
θ_m	rotor angular position
P	number of pole pairs
ω_r	electrical angular velocity (ω_m P)
θ_r	electrical rotor angular position (θ_m P)
T_e	electromagnetic torque
T_L	shaft mechanical torque
J_c	combined rotor and load inertia coefficient
B	combined rotor and load viscous friction coefficient
R	the wind turbine rotor radius
V_ω	the wind speed
ω_t	the mechanical angular rotor speed of the wind turbine
β	the blade pitch angle
λ	the tip speed ratio
P_t	wind power (hp)
ρ	air density (kg/m^3)
V	wind speed (m/s)
R_A	the area of turbine blades (m^2)
C_P	wind power coefficient
i_a, V_a	the armature generator current and terminal voltage
i_f, V_f	the field generator current and voltage
R_a, L_a	the armature resistance and inductance
R_f, L_f	the field resistance and inductance
R_L, L_L	the load resistance and inductance
R_t	$R_a + R_L$
L_t	$L_a + L_L$
M_{af}	the mutual inductance between stator and rotor
$w_{reference}$	the reference speed
w_{actual}	the actual speed
e	error
J	objective function
K_P, K_i	the gains of PI controller
K_P^{min}, K_P^{max}	the lower and the upper limit of Proportional gain
K_i^{min}, K_i^{max}	the lower and the upper limit of Integral gain

List of abbreviations

IM	Induction Motor
DC	Direct Current
AC	Alternating Current
FLC	Fuzzy Logic Controller
ANN	Artificial Neural Network
SA	Simulated Annealing
GA	Genetic Algorithm
ABC	Artificial Bee Colony
ACO	Ant Colony Algorithm
PSO	Particle Swarm Optimization
BF	Bacteria Foraging
ICA	Imperialist Competitive Algorithm
ZN	Ziegler–Nichols
PWM	Pulse Width Modulation
PI	Proportional plus Integral
IAE	The Integral of Absolute value of the Error
ITAE	The Integral of the Time multiplied Absolute value of the Error
ISE	The Integral of Square Error
ITSE	The Integral of Time multiply Square Error

robust speed controller for IM. ICA is recently addressed that is inspired by the imperialistic competitive [34]. ICA has shown good performance in solving optimization problems in different areas such as linear IM design [35], reconfiguration problem of distribution systems [36], optimal sitting and sizing problem of distributed generation [37,38], economic power dispatch [39] and emission dispatch [40,41]. It is a meta-heuristic optimization method that is based on modeling of the attempts of countries to command other courtiers [37]. Also, it is suggested here to design speed control of IM.

This paper proposes the ICA for optimal designing of PI (Proportional plus Integral) controller for speed control of IM supplied by wind turbine, which has a simple structure and robust performance in a wide range of operating conditions. The design problem of the proposed controller is formulated as an optimization problem and ICA is employed to search for optimal controller parameters. By minimizing the time domain objective function, in which the deviations in error between the reference and actual speed is involved; speed control of IM is improved. Simulations results validate the effectiveness of the proposed controller in providing good speed control over a wide range of load torque and speed turbine. Also, these results assure the superiority of the proposed ICA method in tuning controller compared with GA and conventional method.

2. System under study

The system under study consists of wind turbine that plays as a prime mover to a connected DC generator. The DC output voltage is converted to three phase voltage through a PWM (Pulse Width Modulation). The three phase output voltage of PWM is supplied to the three phase IM. The proposed controller based on ICA is used to control the speed of IM. The schematic block diagram is shown in Fig. 1.

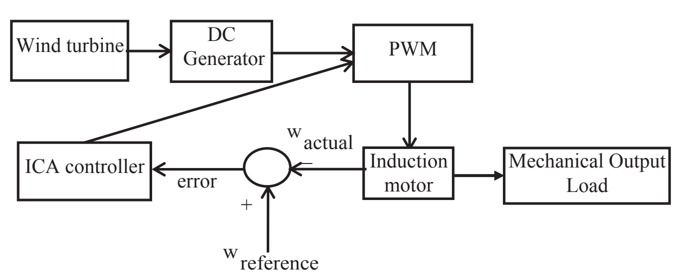

Fig. 1. The schematic block diagram of system under study.