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Optimal controllers designs for automatic reactive power control in an isolated wind-diesel hybrid power system

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ABSTRACT

The paper presents the bacterial foraging optimization algorithm (BFOA) and particle swarm optimization (PSO) algorithm based robust controllers for voltage deviations due to the variation of reactive power in an isolated wind-diesel hybrid power system. The isolated wind-diesel system consists of wind energy conversion system (WECS) utilizing a permanent magnet induction generator (PMIG). Further, a synchronous generator (SG) is used with the diesel engine set for power generation. The mismatch between generated and consumed reactive power in the system causes voltage fluctuations, which will occur at generator terminals. These oscillations further causes reduction in the stability and quality of the power supply. The static synchronous compensator (STATCOM) and an automatic voltage regulator (AVR) are used to suppress voltage fluctuations in an isolated wind-diesel hybrid power system. The STATCOM is used as a reactive power compensator and the AVR is used to keep the terminal voltage constant for the synchronous generator. Both STATCOM and AVR are having proportional and integral (PI) controllers with single input. In modeling for the system, a normalized co-prime factorization is applied to show the possible unstructured uncertainties in the power system such as variation of system parameters and generating and loading conditions. The performance and robust stability conditions of the control system are formulated as the optimization problem, which is based on the Hα loop shaping. BFOA and PSO algorithms are implemented to solve this optimization problem and to achieve PI control parameters of STATCOM and AVR simultaneously. In order to show the efficiency of the proposed controllers, the performance of the proposed controllers is compared with the performance of the conventional controller and genetic algorithm (GA) based PI controllers for the same wind-diesel system. The dynamic responses of the system for four different small-disturbance case studies has been carried out in MATLAB environment.

Introduction

An interconnected power systems supplies power to consumers. Optimum utilization of this available power is a topic of concern today. Due to constraints on arranging additional transmission lines, rapid growth in load and environmental reasons, the gap between demand and supply is increasing. The renewable energy sources along with the alternative energy sources have been introduced extensively in power systems to reduce this increasing gap between demand and supply. Diesel generators are the main source of providing power in the remote areas. These renewable energy sources in parallel with diesel generator units have benefited the areas, where grid supply is not available [1–5]. These systems are termed as isolated hybrid power systems. This paper investigates performances of the proposed controllers in an isolated wind-diesel hybrid power (IWDHP) system.

In an isolated wind-diesel hybrid power system, the diesel engine set along with a SG act as an isolated grid. The wind energy conversion system (WECS) with an induction generator (IG) are in parallel to fulfill the load demand of the isolated area [3–5]. An IG is more advantageous compare to a SG. This is because IG has less unit cost, ruggedness, no brushes requirement (in squirrel cage structure), no need of a separate DC source for excitation, less maintenance, self-protection against severe overloads, short circuits, etc. [4]. However, in an IG for excitation, a magnetizing current from the source is needed, which causes a reduction in its performance in terms of voltage regulation [4].

The utilization of a PMIG can improve the power factor, voltage regulation and efficiency [6–8]. The need of machine reactive power gets significantly reduced as the required magnetizing

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Nomenclature

$H_p(s)$	Loop shaped plant function
$W_o(s)$	the post compensated output weighting function
$W_i(s)$	pre compensated input weighting function
$H(s)$	plant transfer function
$K_p(s)$	loop shaped controller function
$W_o^{-1}(s)$	the inverse of the post compensated output weighting function matrix
$K(s)$	the plant controller transfer function
$W_i^{-1}(s)$	the inverse of the pre compensated input weighting function
$S_{p_y}(s)$	the output sensitivity function
$I = I_p$	identity matrix or unit matrix
$\varepsilon_{\max} = \frac{1}{\gamma_{\min}}$	the maximum stability margin
$\gamma_{\min}$	inverse of $\varepsilon_{\max}$
ρ	the spectral radius
K_{p1} and K_{i1}	proportional and integral controller parameters of the STATCOM
K_{p2}, K_{i2}	proportional and integral controller parameters of the AVR
$\Delta_{\overline{M}}, \Delta_{\overline{N}}$	plant uncertainties on the left factorization decomposition for the coprime factors
M^{-1}, N	matrix from the decomposition of the plant with left factorization coprime factor theory.
RH_∞	the set real coefficients for stable, rational, proper transfer h-infinity matrices
$(A\ B)$	1 by 2 matrix
$\Delta V_{ref}, \Delta V$	small changes in reference voltage, voltages of the terminal voltage, respectively
$\Delta V_a, \Delta V_f$	small changes in amplifier output voltage and exciter feedback voltage respectively
$\Delta E_q, \Delta E'_q$	small changes in internal armature emf under steady state and transient condition respectively
ΔE_{fd}	small changes in the voltages of the exciter,
$\Delta\alpha'_{STATCOM}$	incremental change in the output of the transport lag of the STATCOM
$\Delta\alpha_{STATCOM}$	incremental change in the phase angle of STATCOM
S_f	saturation function
K_E, K_A	exciter and Voltage regulator gains
K_f, K_v	stabilizer and inverse of the load voltage characteristics gains
T_A, T_E, T_f	voltage regulator, stability and exciter time constant respectively
T_d, T_α	average dead time of zero crossings in a 3 phase system and firing delay time of the STATCOM
$K_1, K_2, K_3, K_4, K_5, K_6, K_7, K_8, K_9$	gain constants

current reduces due to permanent-magnets. The direct driven PMIG can be used without a gearbox and hence reduces its maintenance issues [7]. In addition to these advantages, the PMIG can operate at high efficiency over a wide range of slip even if the voltage of the power grids is unbalanced [8].

Because of the mismatch between generated and consumed reactive power, voltage fluctuations will occur at generator terminals in the isolated wind diesel system. This causes a reduction in the stability and quality of the power supply. In an isolated system, the load and the PMIG both requires reactive power. Under varying condition, the mismatch between generated and consumed reactive power may cause surplus of reactive power that may result high voltage spikes in the system. This may damage the connected equipment on the network [3].

To eliminate the mismatch between generation and consumption of reactive power, a variable source of reactive power like static VAR compensator (SVC), STATCOM is required [3,4]. The STATCOM is more advantageous than SVC. It employs a voltage source converter (VSC) that internally generates inductive/capacitive reactive power as needed [9–12]. A relatively small sized of STATCOM is required when PMIG is used with WECS in as compared to IG to supply variable reactive power in isolated wind-diesel system [3].

In [13], a fixed-structure robust H_∞ loop shaping controller to coordinate design of SVC and AVR for robust stabilization of voltage fluctuations in an isolated wind-diesel hybrid power system has been presented. To consider the robust stability, system uncertainties were modeled by normalized co-prime factor [13]. For achieving the optimal parameters of PI controllers, the performance and robust stability conditions in the H_∞ loop shaping technique were formulated as an objective function. The genetic algorithm (GA) has been applied to solve this optimization problem [13].

GA is a population based search algorithm which works with a population of strings which represent different solutions. GA has implicit parallelism that enhances its search capability and the optima can be located swiftly when applied to complex optimization problems, but it suffers with some identified deficiencies [14–17]. This degradation in efficiency is apparent in applications with highly epistatic objective functions [14]. The premature convergence of GA degrades its performance which reduces its search capability [14].

BFOA is proposed as a solution for the above-mentioned problems and drawbacks [18,19]. As BFOA has unique dispersal and elimination techniques. It finds favorable regions when the population involved is small. These unique features of the algorithms overcome the premature convergence problem and also enhance the search capability. Hence, BFOA is a more suitable optimization tool for power system controllers.

PSO algorithm is a stochastic based optimization technique [20,21] which is inspired by the flocking behavior of birds and the schooling behavior of fish. In PSO, the objective function is evaluated for the number of particles placed at locations within the search space of the function. The particle velocity at any point gives an update of particle location. One major advantage of particle swarm system is that it has memory.

The paper presents BFOA and PSO algorithms to solve an optimization problem and to achieve PI controller parameters of STATCOM and AVR simultaneously. Based on the Hα loop shaping, the performance and robust stability conditions of the control system are formulated as the optimization problem. With minimizing the time domain objective function of the voltage deviations, stability performance of the system is improved.

Simulation results assure the effectiveness of the proposed controller in providing good damping characteristic for the system voltage oscillations for four different small-disturbance case-studies. The considered four different small-disturbance case-studies are as follows: