

These curves indicate the capability of the HGA-PSO in reducing the settling time and damping power system oscillations in large interconnected power system. Furthermore, the mean settling time of these variations reducing effectively. From where, hybrid GA-PSO based PID controller greatly enhances the system stability and improves the characteristics of frequency power supply. Critical analysis of the system responses clearly reveals that dynamic performance of the system is significantly attained with proposed approach. From the results shown in Table 5, it can be concluded that, the proposed control strategy provides a robust and stable control satisfactorily and the optimum values of controller parameters obtained with the proposed hybrid GA-PSO are the best.

From the simulation results, we can conclude that the LFC scheme based on the proposed HGA-PSO approach suppresses the fluctuations of the system successfully. It is clear from the results, the proposed algorithm yields the best performances compared to all types of control strategy.

5. Conclusion

In this paper, the optimal load frequency control (LFC) of interconnected power systems is investigated. The impact of LFC control method on the fluctuations caused by step load disturbance is examined; also the effect of LFC controller is analyzed. The Proportional-Integral-Derivative (PID) controller parameters of the investigated LFC model are optimized by different techniques. An application of new approach based on hybrid Genetic Algorithm and Particle Swarm Optimization (HGA-PSO) to solve LFC problem is developed. The proposed hybrid GA-PSO algorithm is first applied to the two-area interconnected power system and then extended to the large three-area 9-unit interconnected power system model. The main objective is to combine the advantages of GA and PSO to create a strong robust algorithm with more excellent performance to solve frequency regulation problem. The interconnected test systems have been simulated for various step load disturbances. To achieve the best performances different objective functions were tested, which are: ISE, IAE, ITAE, ITSE, or their combination. The results of the proposed hybrid GA-PSO algorithm are compared with other classical and intelligent methods such as: Ziegler-Nichols, GA, BFOA, PSO, ABC and hybrid BF-PSO. The simulation results show the high performance of hybrid GA-PSO algorithm which minimizes the frequency fluctuations for the system more than the other methods. The obtained results are very promising and the robustness of the proposed approach is confirmed.

List of Symbols

Δf_i : Frequency Deviation.
 ΔP_{tie} : Tie-lien Power Flow Deviation.
 β_i : Frequency Bias.
 C_1 : PSO Cognitive Coefficient.
 C_2 : PSO Social Coefficient.
 D_i : Load-Damping.
 g_{best} : Global Best Position.
 K_{ps} : Power System Gain Constant.
 P_{best} : best position for the i^{th} Agent.
 R_i : Governor Speed Regulation Parameter.
 T_H : Governor Time Constant.
 T_{ij} : Tie-line Rigidity Factor.
 T_{PS} : Area Aggregate Inertia.
 t_{sim} : Simulation Time.
 T_T : Turbine Time Constant.
 U_i : Control Signal.
 V : PSO Velocity Vector.
 X : PSO Position Vector.
 α_{12} : Constant.

ΔP_T : Turbine Power.
 ΔP_V : Valve Position Variation.

Abbreviations

AGC: Automatic Generation Control.
ACE: Area Control Error.
ABC: Artificial Bee Colony.
BFO: Bacterial Foraging Optimization.
DEA: Differential Evolution Algorithm.
EDC: Economic Dispatching Control.
GA: Genetic Algorithm.
GenCos: Generation Companies.
GSA: Gravitational Search Algorithm.
HBF-PSO: Hybrid Bacterial Foraging and Particle Swarm Optimization.
HGA-PSO: Hybrid Genetic Algorithm and Particle Swarm Optimization.
HPSO-PS: Hybrid Particle Swarm Optimization and Pattern Search.
LFC: Load Frequency Control.
NSGA: Non-dominated Sorting Genetic Algorithm.
PSO: Particle Swarm Optimization.

Appendix

A.1 Data of a typical two-area power system:

$P_R = 2000$ MW (rating), $P_L = 1000$ MW (nominal load-ing); $f = 60$ Hz, $B_1, B_2 = 0.045$ pu MW/Hz;
 $R_1 = R_2 = 2.4$ Hz/pu; $T_{H1} = T_{H2} = 0.03$ s; $T_{T1} = T_{T2} = 0.3$ s; nominal power system parameters: $K_{PS1} =$
 $K_{PS2} = 120$ Hz/pu MW; $T_{PS1} = T_{PS2} = 20$ s; $T_{I2} = 0.545$ pu; $a_{I2} = -1$.

A.2 Data of a typical three-area power system:

All data of the three-area 9-unit test system are available in [9].

A.3 Proposed hybrid GA-PSO parameters:

- *GA parameters:*
Population size = 30; Maximum number of generation = 100; Crossover probability = 1;
Mutation probability = 0.1.
- *PSO parameters:*
Population size = 30; Maximum iteration = 100; Correction factor = 0.4; Inertia = 0.2.

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Nour EL Yakine KOUBA was born in Algiers, Algeria, in 1990. He received the Master and PhD degrees in Electrical Engineering from Faculty of Electrical Engineering & Computing; University of Sciences & Technology Houari Boumediene of Algiers in 2012 and 2017, respectively. Currently, he is a teacher and researcher of electrical power engineering at the electrical engineering department, USTHB. He is a member of the Association of Science and Electrical Technologies (ASTE) since 2014, PES, PELS, IAS and IEEE Member since 2017. His interests include Power System Stability and Control, Automatic Generation Control (AGC), FACTS devices, PID Controller, Optimization Techniques, Storage system and Renewable Energy.



Mohamed Menaâ was born in Algiers, Algeria, on December 14, 1971. He received the Ing and M.S. Degrees in electrical engineering from Houari Boumediene University of Sciences and Technology “USTHB”, and he received the PhD degree from Algiers Polytechnic School, Algiers, Algeria in 2007. Currently, he is an Associate Professor of electrical power engineering at the electrical engineering department, USTHB. His research interests include Modeling and control of electric systems, Identification and sensorless control, Renewable energy, Spiral vector theory.



Mourad Hasni received the Engineer, Master and Doctorate degrees in Electrical Engineering in 1991, 1996 and 2007 respectively from National Polytechnic School of Algiers. Currently M. HASNI is professor in Electrical Engineering Department at Houari Boumediene University of sciences and technology (USTHB, Algiers, Algeria). His research interests are in modeling, parameter estimation, fault detection of electrical machines and Power Systems.



Mohamed Boudour received the B.Sc, M.Sc and PhD in Electrical Engineering from the Polytechnic School of Algiers in 1991, 1994 and 2004, respectively. Since January 1994, he has been with the University of Sciences and Technology Houari Boumediene of Algiers (USTHB) as a teacher and researcher. He was awarded as a Fulbright fellowship in the University of Washington, Seattle (USA) from 2005-2006. He is a member of the executive committee of ARELEC (Algerian CIGRE) and IEEE Senior Member since 2007. His main interests are Power Systems Stability and Control using intelligent programming, integration of renewable energy sources in smart grids. He is currently the Director of Electrical and Industrial System Laboratory.