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Quantum Optimization-Based Load Frequency Control in Interconnected Power Systems

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Abstract: *Load frequency control (LFC) is an important control in interconnected power system to keep the system frequency and scheduled tie-line power exchange near to their needed values when the load demand varies. Nonlinear dynamics and operational constraints make the controller selection and tuning complicated in a two-area system. In this paper, a quantum inspired optimisation technique is applied to tune a fractional order proportional-integral-derivative (FOPID) controller for a nonlinear interconnected two-area thermal power system. The benchmark is taken as the existing adaptive neuro-fuzzy inference system integrated with the Honey Badger Algorithm (ANFIS-HBA). The suggested technique directly tunes five quantities: proportional gain Kp, integral gain Ki, derivative gain Kd, fractional integral order λ, and fractional derivative order μ. It searches using probabilistic state representations, measurement, and quantum-inspired update operations.*

Keywords*: Banking Software Vulnerabilities, OWASP Top 10, National Vulnerability Database (NVD), Cybersecurity Risk Assessment, Vulnerability Analysis*

I. INTRODUCTION

Modern power networks link generation, transmission and the demand of consumers, therefore these components must be kept in balance at all times. A fundamental need for dependable operation is that frequency be maintained close to its nominal value following a change in load or generation. If the generated power does not match the demand, the generator rotor speed will fluctuate and the system frequency will deviate. In an interconnected network, a disturbance in one control area might also affect the surrounding regions as they interchange power through tie-lines. LFC has to eliminate frequency variations while keeping the inter-area power exchange at the scheduled value.

LFC's objective is to return frequency and tie-line power deviations to their reference levels following a disturbance. Area Control Error (ACE) is often taken as the control input as it encompasses frequency error and the corresponding tie-line power error. A good controller should restrict frequency excursions and tie-line swings, settle quickly, prevent big peaks and leave little steady state error. The PI and PID controllers are frequently utilised because of their simple and practical structures. However, its reaction may be influenced by nonlinear system behaviour, unclear parameters, changing operating circumstances and generation restrictions etc. These problems have driven the work on optimization-based and intelligent controllers. Fractional-order control is more flexible because the orders of integration and differentiation do not need to be integers.

The fractional order PID (FOPID) controller is an extension of a regular PID, where the integral and derivative actions are fractional orders . It contains distinct integral and derivative orders and the three standard gains. This leaves five changeable factors which give more flexibility to shape the transient response of a linked system.

$$X = [K_p, K_i, K_d, \lambda, \mu] \quad (1)$$

The FOPID control law is defined by eq. (1).
The additional fractional order variables enable better fine-tuning of the dynamic response of the controlled system. The fractional-order controllers for LFC have been investigated in single-area as well as multi-area systems in the earlier works. The FOPID control is also investigated under nonlinear operational constraints such as governor and generator restrictions

which confirms its importance in the area of interconnected frequency control. Controller tuning is vital because the choice of parameters influences both transient and steady state behaviour. Population based techniques such as genetic algorithms (GA), bacterial foraging optimisation (BFOA), particle swarm optimisation (PSO) and Honey Badger Algorithm (HBA) have been utilised for this purpose. In the benchmark technique presented here, HBA tunes PID gains for the nonlinear two area system.

The data thus obtained are then used for training the ANFIS controllers, with ACE and its derivative being the inputs.
ANFIS-HBA learns a nonlinear mapping between the control inputs and the controller output. In the technique cited, initially a PID controller tuned for HBA is simulated and then ACE, rate of change of ACE and control-output records of PID controller are used for training ANFIS controllers. The stated comparison showed that the ANFIS-HBA had a better transient behaviour than the selected GA-, BFOA-, and HBA-based controllers. The study included multiple generation-rate constraint (GRC) limitations for settling time, peak undershoot, peak overshoot, and ITAE. ANFIS-HBA provides an intelligent nonlinear control approach but it is dependent on the data generated by an optimised PID controller. Then operating condition changes may demand adequate training data or adaption. Conventional PID control also implements integer order integration and differentiation which motivates the research of a controller that can adjust fractional orders directly.

II. LITERATURE SURVEY

Studies on LFC have been carried out on conventional control, intelligent methods and optimisation strategies to improve the dynamic response of interconnected power systems. In 2010, neural predictive control for two area LFC was researched. In 2012, Gravitational Search Algorithm was employed for controller tuning. BFOA based PID control for nonlinear two-area systems was followed in 2013. ANFIS based LFC was published in 2014 . Later works included hybrid BFO-PSO optimisation and ALO-ANFIS for renewable energy systems such as solar and wind sources. The studies of Bees Algorithm and HBA also showed the usage of metaheuristics for LFC. Afterward, optimised ANFIS methods have been used to two area networks.

The proposed design is chosen because a PID controller has three tunable degrees of freedom, while the FOPID has two more tunable parameters, the integral-order and derivative-order variables. These extra variables might be helpful to shape the transient response more accurately under nonlinear situations and generation-rate limits. This five parameter space is searched using a quantum inspired search technique.
Load frequency control modifies active-power production to bring the system frequency back to its scheduled value following load or generation variations. It also regulates tie line power exchange to the scheduled interchange for interconnected locations.

Load frequency control (LFC) is the control of frequency and tie-line power in an interconnected system following a disturbance such that these quantities are kept within operating limits. Controllers do this by tweaking generator output. PID (proportional-integral-derivative) controllers are one of the most used methods.
Thus, LFC equipment is vital for maintaining the frequency stability throughout the whole network. Its main function is to maintain the frequency at nominal value during regular operation and in case of load variations.
The electrical power system is a huge and costly infrastructure, covering over huge geographical areas. It requires significant investment for installation, operation, maintenance and service. It has three primary components : generation, transmission and distribution. The main operating quantities are voltage and frequency and their monitoring is necessary to provide a suitable performance under normal and fault circumstances.

The power system is expected to deliver electrical energy of good quality at the lowest possible generation cost per kWh. The heart of power quality is to keep the voltage and frequency in appropriate values. Voltage can be controlled using automated voltage regulators (AVRs) which control the excitation or field current of an alternator. Other means of controlling voltage include shunt capacitors or inductors, series capacitors, and static VAR devices. Voltage regulation is mainly a local phenomenon. In contrast, frequency regulation is a system wide phenomenon.Frequency can be regulated through the speed-governing system and automatic generation control (AGC). This is achieved by adjusting generator speed, the steam input to the generator, or the position of the steam-control valve.

III.RESULTS

3.1 Load-frequency control using ANFIS-HBA

The benchmark values are taken from the supplied ANFIS-HBA project data. At GRC = ±0.05, ANFIS-HBA has an Area 1 settling time of 1.569 s and a total ITAE of 0.0328. At GRC = ±0.025, its total ITAE is 0.4988 and the Area 1 settling time is 5.670 s. These results indicate that the tighter GRC limit slows the response and increases accumulated error

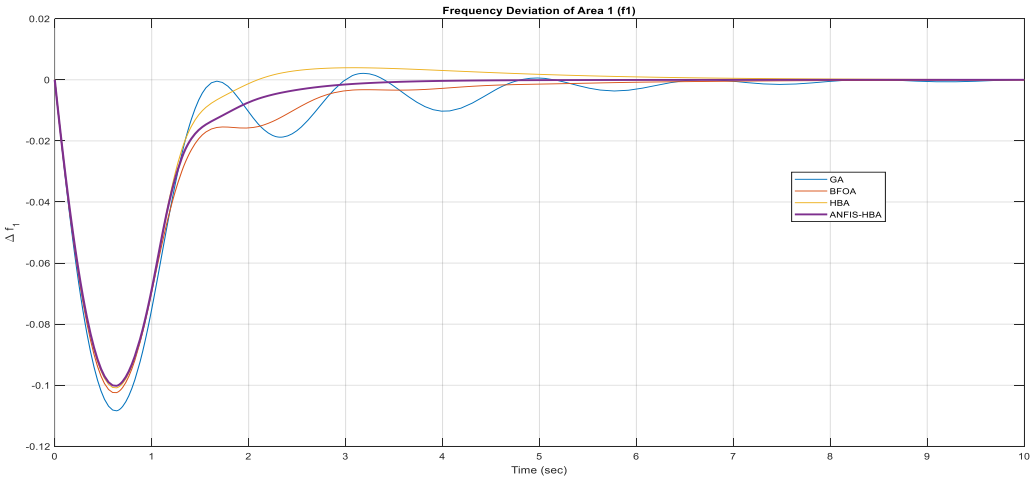


Figure 1.1.1.a Frequency deviation(f1)vs time response for load disturbance of 5% at area-1. (GRC = 0.05)

3.1.1Outputs at 0.05 GRC at 5% load disturbance

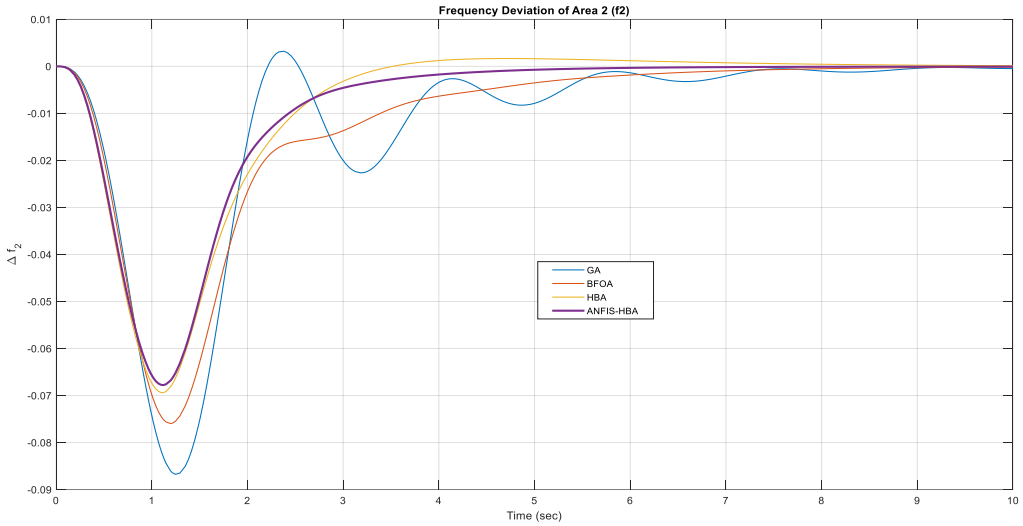


Figure 1.1.1.b Frequency deviation(f2) vs time response for load disturbance of 5% at area-1

3.1.2 Outputs at 0.025 GRC at 5% load disturbance

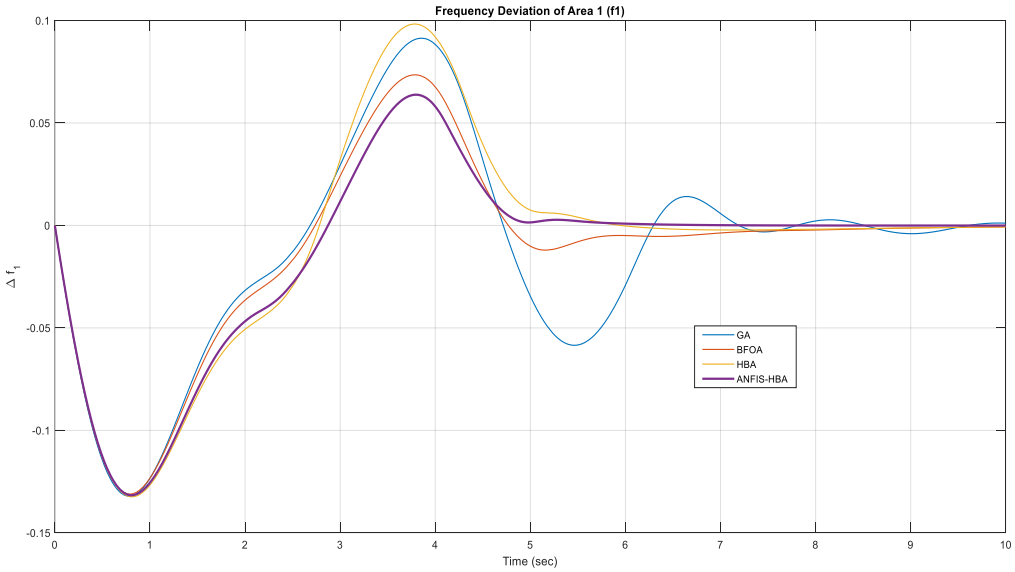


Figure.1.1.2. a Frequency deviation(f1)vs time response for load disturbance of 5% at area-1. (GRC = 0.025)

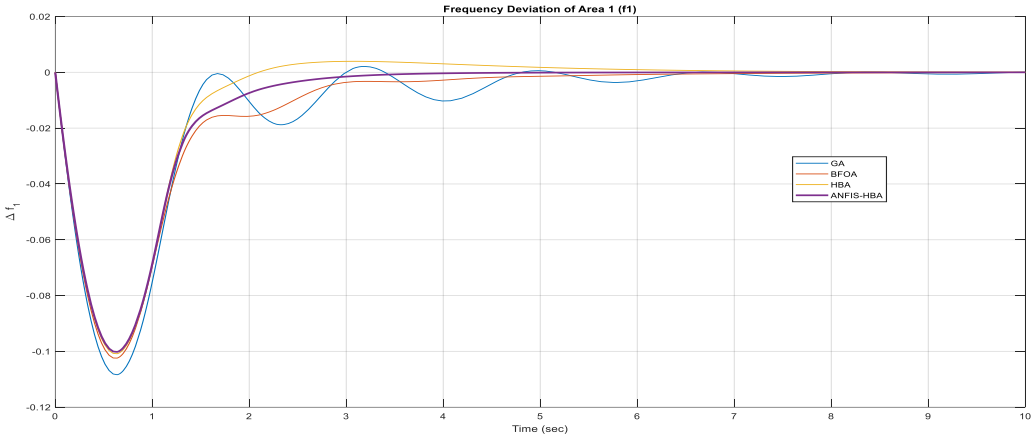


Figure.1.1.2. b Frequency deviation(f2) vs time response for load disturbance of 5% at area-1. (GRC = 0.025)

1.1.2(b). Area 2 frequency deviation over time for a 5% load disturbance in Area 1, with GRC set to 0.025.
This section contains the simulation work and results of FLC of the specified two-area power system as shown in Fig 2.7 & 2.2.2 The simulation work has beenThe simulation study of LFC for the given two-area power system is performed using MATLAB 24b/Simulink. In the selected situations, the performance of the controllers is compared using a Simulink model of the two-area network. Two GRC limitations are considered: α = ±0.05 and α = ±0.025. In each scenario, a 5% load disturbance (ΔPd) is imposed in Area 1 of the TAPS system.

In the first approach, the gains (Kp, Ki, and Kd) of the same PID controllers in both areas are tuned using HBA. The optimised gains of the controllers are presented in Table 1.1 and each gain is searched in the interval from 0 to 1.
Then when HBA computes the PID gains, the obtained HBA-PID data are used to train and build the ANFIS-HBA controller. The controller is again replicated for LFC of TAPS. The time-response study compares the settling time (ST), peak undershoot (PU), peak overshoot (PO) and ITAE of frequency variations in Areas 1 and 2 and tie-line power change. The comparison is as indicated below in "Table. 1.2" Table 1.2 Comparison of different controllers(change)

Fig. 1.1.1.a and Fig. 1.1.1.b shows the frequency deviation vs time curve of Area-1 and Area-2 respectively. Fig. 1.1.1.c shows the Tie line power change vs time curve at =0.05 where the ANFIS-HBA controller compared with other controllers. Similarly, (at = 0.025) 'Fig.1.1.2.a' and 'Fig.1.1.2.b' shows the frequency deviation vs time profile of Area-1 and Area-2 respectively. 'Fig.1.1.2.c' shows the Tie line power change vs time profile for the FLC of TAPS.Figures 1.1.1.a and 1.1.1.b show the frequency deviation vs. time for Areas 1 and 2 at α = 0.05. Figure 1.1.1.c is referred to as the matching tie-line power response. The frequency responses of Area 1 and Area 2 for α = 0.025 are shown in Figs. 1.1.2.a and 1.1.2.b, respectively. The response of the tie-line power is shown in Fig. 1.1.2.c.
As can be seen from the data presented in Table 7.2 and Figures 1.1.1.a-1.1.1.c, ANFIS-HBA converges faster than the other controllers for both areas' frequency deviations and tie-line power change for α=±0.05. Its peak overshoot and peak undershoot are superior or equivalent to HBA, BFOA and GA. The stated ITAE is also the lowest for ANFIS-HBA on the regions evaluated. Therefore, ITAE is an important time-response index to evaluate the total reaction characteristics.
For α = ±0.025, the results reported in Table 7.2 and Figures 1.1.2.a–1.1.2.c show that ANFIS-HBA offers superior performance over the other controllers in terms of settling time, peak undershoot, peak overshoot, and ITAE. The response curves also exhibit less oscillations, which is a good feature for stable operation of power system.

IV. CONCLUSION

In this paper, the load-frequency regulation of a two-area system is considered with ANFIS-HBA as the existing benchmark and a quantum-inspired FOPID controller as the proposed extension. Both approaches are evaluated for the same nonlinear linked thermal plant with 5% load disturbance in Area 1 and two GRC limits.

The results of benchmark test showed the performance improvement of ANFIS-HBA over GA, BFOA and HBA. The suggested FOPID technique has two extra tuning variables, λ and μ, which can provide more freedom in designing the response. The resulting five-dimensional parameter space is searched using a quantum-inspired optimiser based on probabilistic representations and quantum-inspired updating methods.

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