IJETST- Vol.||11||Issue||10||Pages 8084-8089||October||ISSN 2348-9480 2024

Open access Journal International Journal of Emerging Trends in Science and Technology

DOI: http://dx.doi.org/10.18535/ijetst/v2024.06

Adaptive Power System Load Frequency Control based on Metaphorless Optimizers

Authors

Dr B. A. Wokoma, Dr. D. E. Ekeriance, Engr. E. O. Olubiyo

Abstract

This research proposes an alternative Load Flow Controller (LFC) to power systems stability studies based on the population-oriented mathematical optimizer called the PI-Rao. This approach is applied to stabilizing frequency deviations in single-area power systems and compared with a basic PI controller. The research employed a dynamic systems model for a singular area system to capture the dynamics of an LFC. The system is composed of two parts: Part 1 is the LFC optimization systems part which makes a global search for the optimal P & I factors based on some prespecified frequency fluctuation. In contrast, Part 2 is the METARPHOLESS-PI part which uses a population-oriented mathematical logic. The presented optimization in (Part 1) follows classical methods inspired by evolutionary approaches to search for the optimal set of fitting parameters. The minimization of area control error (ACE) is considered an objective function involving the minimization of an Integral Time multiplied Absolute Error (ITAE). The results of simulations have shown the superiority of the proposed solution considering the loading changes of 0.02p.u to 0.1p.u and at intervals of 0.02p.u. Thus, the PI-Rao should serve as another potential solution for power systems LFC applications. The current challenges and future research directions for the existing and prospective projects of the power system operators seek microprocessor-based fault analysis solutions.

Keywords: *Frequency deviations, LFC, Power System, Metaphorless, Optimization*

1. Introduction

Utility grid represents a major innovation in the energy industry due to its advantage in presenting useful power to a growing population of teeming consumers. This is made possible by efficient coordination of electrical power systems at the three different levels of generation, transmission and distribution.

The problem with electrical power systems is that they are invariably non-linear in nature leading to a variation in the supply operational state and levels above or below its tolerable reference state. This is largely attributed to reactive and in a great number of cases, active power loading. Thus, due to this effect, there is a simultaneous impact on the performance of generating plant since the speed of the generator machine will enter into a state of power turbulence on entropy such that the regulation is indeed variable leading to power system operating frequency changes (Molina-Garcia *et al.*, 2010).

In a power system, the controllers at generating plant has to be especially designed so as to avert failures due to the violation of tolerance limits of voltages, powers and frequency particularly as it relates to the various power system buses. Indeed, this regulation is deemed necessary so as to ensure that both active and reactive power demands are properly matched. Thus, there is need for adjustments in controller at generator terminals which can be manual or automatic (Bevrani *et al.*, 2004a; Gupta & Singhal, 2010).

In order to enhance the capabilities of modern power control systems, it is necessary to automate the regulation needs or requirements for enhanced frequency control due to small-to-large changes in power system loads or voltage tolerance limits. This is essential due to infeasibility of manually regulating an interconnected power system and to additionally limit the voltage and frequency levels to prescribed limits automatically. This is fundamentally possible by using a controller approach called the Proportionate-Integrate Method (PIM) or simply PI.

The PIM basically uses the negative feedback concepts that seek to minimize an error gain subject to the P & I parameter constants set as the control gain parameters accounting for the current error and a summation of recent errors respectively (Bevrani *et al.*, 2004b). Accordingly, the PIM system initiates a corrective error action in a dynamically industrial process control basing on a measurable process variable and a desired threshold set point. The weighted sum of the P & I actions is typically used to adjust the process via a control element such as the position of a control valve or a power systems supply such as in a heating element.

Due to PIM controller’s fixed gain, frequency oscillations can also appear in the case of power system control or regulation. The implication is that the PIM indicates a poor dynamic performance against system parameters variation including the non-linear conditions such as generation rate constraint. Thus, in recent research studies adaptive solutions have been proposed as in Self-Tuning Fuzzy PI Controller (STFPIC) (Hameed *et al.*, 2010). Furthermore population oriented solutions that are inspired by Artificial Intelligence (AI) and metaphors such as the Particle Swarm Optimization (PSO) have been proposed by several authors for solving dynamically the LFC problem (Arıkuşu *et al.*, 2019).

In this research, a purely mathematical but population-oriented technique is proposed for the solution of the LFA problem.

2. Related Studies

Artificial intelligence (AI) techniques such as fuzzy logic control (FLC) and, artificial neural network (ANN) have been applied for load frequency control to overcome the limitations of the conventional methods (Talaq & Al-Basri, 1999; Aravindan & Sanavullah, 2009); ANN performs better when non-linearity and complexity increase in a system (Prakash & Sinha, 2013). Thus, the choice of artificial intelligence (AI) techniques combining ANN and FLC in a neuro- fuzzy logic controller solution has been shown to obtain satisfactory control performance over conventional PI controllers (Prakash & Sinha, 2013; Syamala & Naidu, 2014). The techniques of ANN and FLC are sometimes referred to as metaphor-based since they employ some sort of symbolic or analogy drawn from natural observation or processes.

However, the challenge of choosing the right metaphor comes with the introduction of a plethora of emergent metaphor-based solutions needed to solve the LFC problem. Indeed, techniques such as the Differential Evolution Algorithm (DEA) controllers (Sahoo *et al.*, 2018), PSO based PI controller (Satheeshkumar & Shivakumar, 2016), and hybridizations involving Particle Swarm Optimization (HCPSO), Real Coded Genetic Algorithm (RCGA) and Artificial Neural Network (ANN) controllers (Shree & Kamaraj, 2016), have equally been proposedand shown to give promising results in recent times.

This research study presents an alternative LFC optimization strategy inspired by purely mathematical methods and providing the advantages of simplicity, speed and compactness.

3. Proposed Design

3.1. Systems Model

The research employed a dynamic systems model for a singular area system to capture the dynamics of an LFC. The system is composed of two parts:

Part 1 is the LFC optimization systems part which makes a global search for the optimal P & I factors based on some prespecified frequency fluctuation and using the Rao optimizer (refer sub-section 3.2 for details). The part 1 is supported and tightly integrated with part 2.

Part 2 is the METARPHOLESS-PI part which uses a population-oriented mathematical logic – the Rao optimizer (refer sub-section 3.2 for details) to fine tune the PI controller in accordance to part 1.

Typically, the two parts are integrated within a power systems model that operates as a standalone unit.

The presented optimization follows from classical methods which are also inspired by evolutionary approaches to search for the optimal set of fitting parameters – in this case, the fuzzy scaling factor (fsf). This optimization has to meet an objective function which serves the additional purpose as being an evaluation or performance metric.

For the purposes of this research, the minimization of area control error (ACE) is considered as an objective function involving the minimization of an Integral Time multiplied Absolute Error (ITAE) as described in the system earlier proposed in (Sahoo *et al.*, 2018; Shabani *et al.*, 2013).

The model objective given by ITAE can be expressed as in equation (1):

$$J = ITAE = \int_{0}^{tsim} \left(|\Delta f| + |\Delta P_{tie}| \right) \cdot t \cdot dt \qquad (1)$$

were,

Δf = system frequency deviation

ΔP_{tie} = incremental change in tie-line power

t_{sim} = simulation time span

The architectural systems view of the Optimal Rao-PI model is as shown in Fig.1 and a representative model implementation is given in Fig.2.

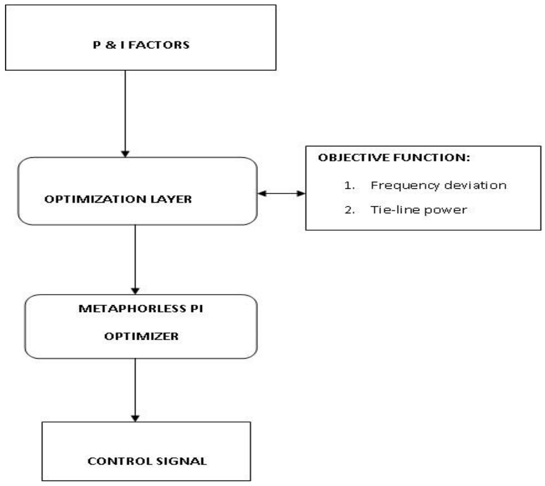

Fig.1 Architectural view of proposed metaphorless Rao-PI power systems model

In Fig. 2 the following parameters were used to build the Simulink model:

ACE: Area Control Error

B1: frequency bias parameter

dPD1: power load demand changes

dPTie: incremental change in tie-line power (p.u.)

dF: system frequency deviation (Hz)

TPS1: power system time constant (secs)

KPS1: power system gain

TD: time delay (sec)

GDB: governor dead band

R1, R2: governor speed regulation parameters (p.u.-Hz) TT1,

TT2: the turbine time constants (secs) TG1, TG2: speed governor time constants (secs)

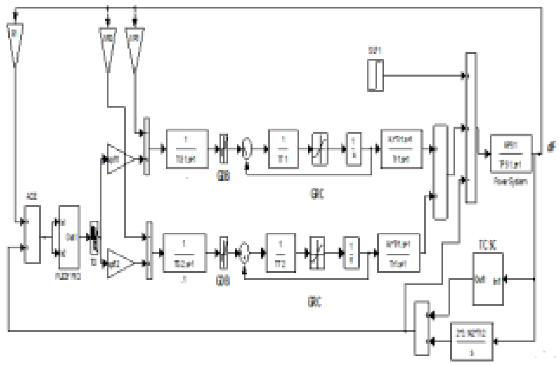

Fig.2 Standalone Power Systems model in SIMULINK (Source: Sahoo *et al.*, 2018)

3.2.Metarpholess Optimizer

The proposed metaphorless optimizer is based on the Rao-type algorithms proposed earlier in Rao, (2020). It exploits a best and worst fitness improvement strategy using population of random numbers and a simple algebraic error computing model to find solutions to optimization problems (Rao, 2020; Jagun *et al.*, 2020).

The algebraic error computing model is derived for various forms of Rao and is describes as in equation (2):

$$X^{new}_{j,k,i} = X^{old}_{j,k,i} + r_{1,j,i}\left(X_{j,best,i} - X_{j,worst,i}\right) \qquad (2)$$

Were,

X_l = the lower bound of X which subsists

X_u = the upper bound of X which subsists

$X^{old}_{j,k,i}$ = the initial or past candidate value of *j-th* variable for *k-th*candidate at *i-th* iteration

$r_{1,j,i}$ = a random perturbation factor of *j-th* variable at *i-th* iteration

$X_{j,best,i}$ = the best (minimum) candidate value of *j-th* variable at *i-th* iteration

$X_{j,worst,i}$ = the worst (maximum) candidate value of *j-th* variable at *i-th* iteration

For the task of minimizing the frequency deviation and with respect to model expression in equation (2), the objective function is stated as equation (3) with the inequality constraint stated in equation (4):

Minimize:

$$f_J = \min(ITAE) = \left| \int_0^{tsim} \left(|\Delta f| + |\Delta P_{tie}|\right)\cdot t \cdot dt \right|_{\min} \qquad (3)$$

s.t. constraints:

$$X_l \leq X \leq X_u \qquad (4)$$

4. Results And Discussions

The isolated power system under study as presented in Fig.2 (Section 3) has parameters taken from the research in (Rao, 2020). The task is to minimize the frequency deviation in Hz following time domain performance results and percent p.u load variations using the proposed Rao-PI control techniques under study. Simulation is done in MATLAB-SIMULINK environment. If the load changes by 0.1 percent for 1 percent change in frequency, then we expect the controller to regulate the system appropriately. The results are reported for both the situation without the Rao optimizer and with it integrated to PI. For the Rao-optimizer, the lower and upper bounds for *X*are set at 0.0 and 1.1p.u respectively.

4.1.Results using PI Without Rao-Optimizer

The error change at the load variation of 0.02p.u showing the PI controller without the Rao optimizer is as shown in Fig.3. The results in Table 1 show the p.u power response of PI controller at 5 different load variations from 0.02p.u to 0.1p.u and at a uniform increment of 0.02p.u.

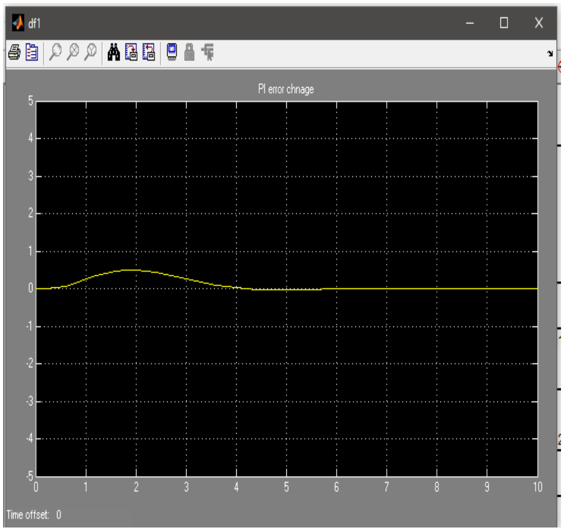

Fig.3 PI frequency error deviation, Δf (Hz), at 0.02p.u load variation

Table 1: Power deviation for different p.u load changes for PI

%Load Change, ΔL (p.u)	Power deviation, *PI* (p.u)
0.02	0.9789
0.04	0.9589
0.06	0.9389
0.08	0.9189
0.10	0.8989

As can be seen in Table 1, there is a graded fall in power as the loading is increased meaning the PI controller will not be able to maintain the power state during excessive power variation.

4.2.Results using PI with Rao-Optimizer

The error change due to the integration of the Rao optimizer leads to major stability in power output delivered to the load. The results of using this optimizer when compared to that of only the PI controller are as shown in Table 2.Also, the result of the frequency error deviation at a load change of 0.02p.u can be clearly seen as in Fig.4.

Table 2. Power deviation for different p.u load changes for PI versus PI-Rao

%Load Change, ΔL (p.u)	Power deviation, *PI* (p.u)	Power deviation, *PI-Rao* (p.u)
0.02	0.9789	0.9613
0.04	0.9589	0.9613
0.06	0.9389	0.9613
0.08	0.9189	0.9613
0.10	0.8989	0.9613

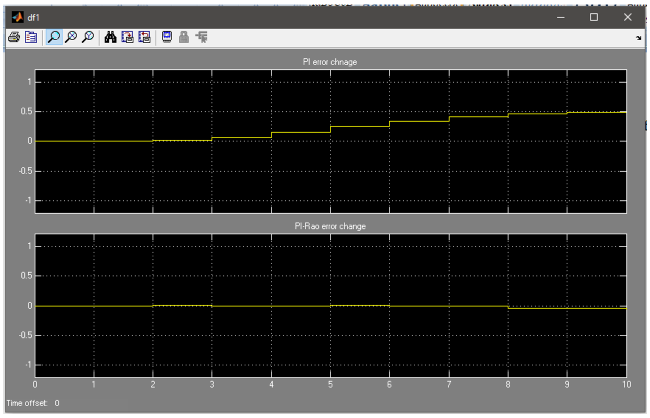

Fig.4 PI vs. PI-Rao frequency error deviation at 0.02p.u load variation

As can be seen in Table 2, the PI-Rao controller is able to keep the power at a stable value of 0.9613p.u for all percent changes in load. Also, as shown in Fig.4, the frequency deviations for the PI controller are much wider from the zero point than that of the PI-Rao controller.Thus it provides a more superior approach to the LFC solution.

5. Conclusions

In this research, a metaphorless based optimizer called the PI-Rao has been applied as an LFC to the minimization of frequency deviation within a given power system. A discovery from the study shows that, the PI-Rao controller is suitable and stable than the PI controllers due to its minimal deviation and considering the increasing load changes up to 0.1p.u.

Possible extension to this work is highly recommended as it is quite useful to model new controllers using adaptive Neuro-Rao-type PI controllers which will be efficient to handle both settling time and deviation in power generating system. It is also necessary to compare the performances at higher loading particularly during cyber attacks to power system.

Acknowledgement

The Sure Pay Foundations Group is acknowledged for programming services.

References

1. Molina-Garcia, A., Bouffard, F., & Kirschen, D. S. (2010). Decentralized demand-side contribution to primary frequency control. *IEEE Transactions on Power Systems*, *26*(1), 411-419.
2. Bevrani, H., Mitani, Y., & Tsuji, K. (2004a). Robust decentralised load-frequency control using an iterative linear matrix inequalities algorithm. *IEE Proceedings-Generation, Transmission and Distribution*, *151*(3), 347-354.
3. Gupta, D. B., & Singhal, E. V. (2010). *Power system operation and control*. S Chand & Company Limited.
4. Bevrani, H., Mitani, Y., & Tsuji, K. (2004b). On robust load-frequency regulation in a restructured power system. *IEEJ Transactions on Power and Energy*, *124*(2), 190-198.
5. Hameed, S., Das, B., & Pant, V. (2010). Reduced rule base self-tuning fuzzy PI controller for TCSC. *International Journal of Electrical Power & Energy Systems*, *32*(9), 1005-1013.
6. Arıkuşu, Y., Bayhan, N., & Tiryaki, H. (2019). Comparison of conventional and

modern controllers for a gas turbine power plant. *Electrica*, *19*(2), 146-157.
7. Talaq, J., & Al-Basri, F. (1999). Adaptive fuzzy gain scheduling for load frequency control. *IEEE Transactions on power systems*, *14*(1), 145-150.
8. Aravindan, P., & Sanavullah, M. Y. (2009). Fuzzy logic based automatic load frequency control of two area power system with GRC. *International Journal of Computational Intelligence Research*,*5*(1), 37-45.
9. Prakash, S., & Sinha, S. K. (2013). Load frequency control of three area interconnected power systems using neuro-fuzzy hybrid intelligent controllers. *Int. J. Sensing, Computing & Control*, *3*, 1-14.
10. Syamala, J., & Naidu, I. E. S. (2014). Load frequency control of multi-area power systems using PI, PID, and fuzzy logic controlling techniques. *International journal of Innovative Research in Science, Engineering and Technology* (IJIRSET), *3*, 1285-1288.
11. Sahoo, D. K., Sahu, R. K., Sekhar, G. C., & Panda, S. (2018). A novel modified differential evolution algorithm optimized fuzzy proportional integral derivative controller for load frequency control with thyristor-controlled series compensator. *Journal of electrical systems and information technology*, *5*(3), 944-963.
12. Satheeshkumar, R., & Shivakumar, R. (2016). Ant lion optimization approach for load frequency control of multi-area interconnected power systems. *Circuits and Systems*, *7*(9), 2357-2383.
13. Shree, S. B., & Kamaraj, N. (2016). Hybrid neuro fuzzy approach for automatic generation control in restructured power system. *International Journal of Electrical Power & Energy Systems*, *74*, 274-285.
14. Shabani, H., Vahidi, B., & Ebrahimpour, M. (2013). A robust PID controller based on imperialist competitive algorithm for load-frequency control of power systems. *ISA Transactions*, *52*(1), 88-95.
15. Rao, R. (2020). Rao algorithms: Three metaphor-less simple algorithms for solving optimization problems. *International Journal of Industrial Engineering Computations*, *11*(1), 107-130.
16. Jagun, Z. O., Okandeji, A. A., Olajide, M. B., Osegi, N. E., & Wokama, B. A. (2020). Adaptive Hybrid PSO-RAO-Type for Predictive Economic Load Dispatch. *Equity Journal of Science and Technology*, *7*(1), 131-131.