Improving Load Frequency Control in Power Systems with ABC-Based PI Controller Optimization

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ABSTRACT
Control of frequency and generation is one of the major problems in the operation of interconnected power networks. The large deviations of network frequency beyond the +10% limit may result in asynchronism and even unit fall-outs from the network. This second level of Automatic Generation Control, also known as supplementary control, is necessary to hold the interconnection of the network stable while taking all these variations of frequency into account. This paper proposes a methodology using the Artificial Bee Colony algorithm to optimize the PI parameters for better frequency regulation. In this paper, it has been shown from computer simulations that the proposed technique optimizes the PI parameters and reduces frequency oscillations.

Keywords: *Load frequency control, Artificial Bee Colony, generation control.*

I. INTRODUCTION

Issues of overall stability in large-scale multi-area power systems have frequency stability as one of their important concerns. Stability of the system is held by active power balance along with frequency, since frequency is directly linked to active power balance. Any imbalance in generation or demand of power results in deviations of frequency, leading to oscillations that may further lead to severe instability if not controlled properly. In this regard, LFC systems are indispensable to properly regulate the power generation and active power interchange over tie lines in interconnected grids. The researchers have proposed a three-level AGC scheme very important in the mutual relationship between active power and frequency for multi-area power systems. In such systems, each area must govern its generation control in order to maintain the scheduled power interchange and guarantee the frequency stability across the network. The LFC typically has two main control loops: primary and secondary control. The primary control is responsible for balancing active power and is provided by the turbine-governor system. However, it must be considered that the frequency is not possible to be maintained exactly in its scheduled one, for instance, 50 Hz and, in a lot of cases, there exists a steady-state frequency error [1]-[3]. Therefore, a secondary control level will be needed, especially in a bigger and more complexly interconnected system, to accomplish frequency restoration in all parts of the system. The secondary, or supplementary, level acts on the active power interchange at the tie lines between neighbouring areas by centrally augmented and local load control centres. The reason large power plants play an important role in the frequency control is that they have a high strategic importance altogether with a high capacity, e.g. the Atatürk Power Plant in Turkey [4]-[7].

The last level of control is economic dispatch, which enables lowering the cost of generating power of each unit, simultaneously avoiding losing the system's stability. LFC system has been recently enhanced with many advanced controllers. Neural networks applied to nonlinear control in the area of power systems or layered neural networks applied to the control of steam turbines are good examples of such application. A few other neural net controllers have proved their results on the fuzzy logic-based adaptive optimal load frequency control. Such advanced systems accumulate the pattern recognition with parallel-distributed computational architectures for excellent results. Apart from neural net approaches, controllers using the optimizing PI and PID parameters have been developed, where the techniques used include fuzzy-based gain scaling and dynamic wavelet neural networks -. This study based on application of genetic algorithms for PI parameter optimization and using developed PI controller in two-area power system. The proposed controller is developed to effectively damp frequency oscillations and restore system frequency. Hence, it has huge potential to improve power system stability considerably in the case of interconnected networks [17]-[19]. The objective is the improvement of load frequency control performance in power systems through the proper tuning of PI controller parameters. It shall build on some very recent developments in controller designs, such as those by Yavuz Güler and Ibrahim Kaya [20] and P. Gopi et al. [21], which unmask the potential of ABC for system stability and response by efficiently finding the gains of control parameters.

II. LOAD FREQUENCY CONTROL IN TWO AREA NETWORKS

II.1. Major Principals of LFC

For the modern power system with several interconnected areas, the scheduling of the active power generation in the areas is very critical to maintaining the scheduled energy interchange [1]. The stability and efficiency of the power system lie in the correct dispatch of power so that the energy schedule between areas is met. Computer-aided controllers have become instrumental in managing such complex systems with the view of implementing precise control and optimization. Figure 1: Schematic diagram of a two-interconnected-areas power system. Figure 2: System with primary and secondary control loops interconnected through a tie line. The above setting requires the setting to have an effective frequency control by balancing the power flows across the tie line and damping oscillations that might be caused by power-balance fluctuation. The primary control loop responds to immediate frequency deviations; the secondary control loop provides further regulation to ensure stability and smooth operation. A linearized model of the system, shown in Figure 3, can analyze and optimize the aforementioned control strategies. This simplification of the complex dynamics of the power system allows for detailed simulation to make an estimate of control performance and improve it. The linearized model has the advantage of being very useful while studying primary-secondary control loop interactions for ensuring efficient power and frequency management over the interconnected areas. The approach described herein would thus help in stable and efficient operation, mitigating immediate and long-term challenges in control for improved overall stability and performance of the system.

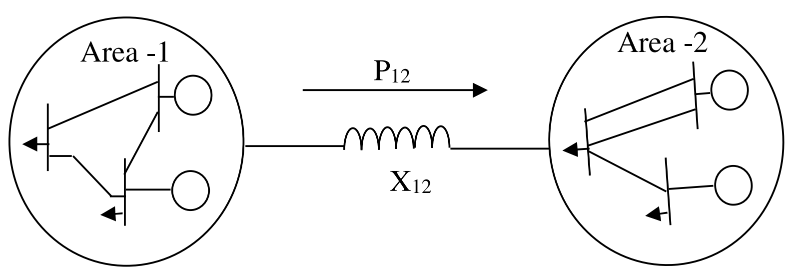

Fig.1 Interconnection between two areas

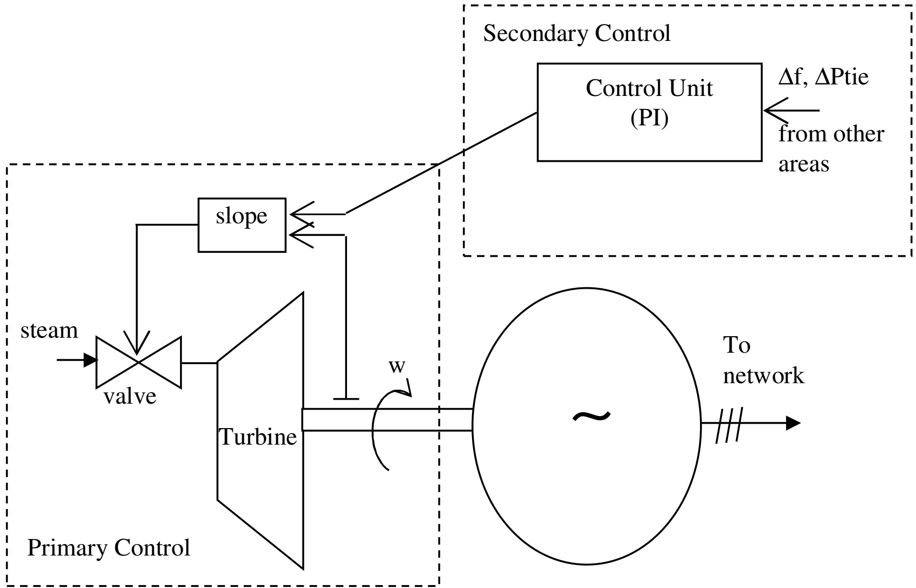

Fig.2 Principal Scheme for Primary and Secondary Control Levels

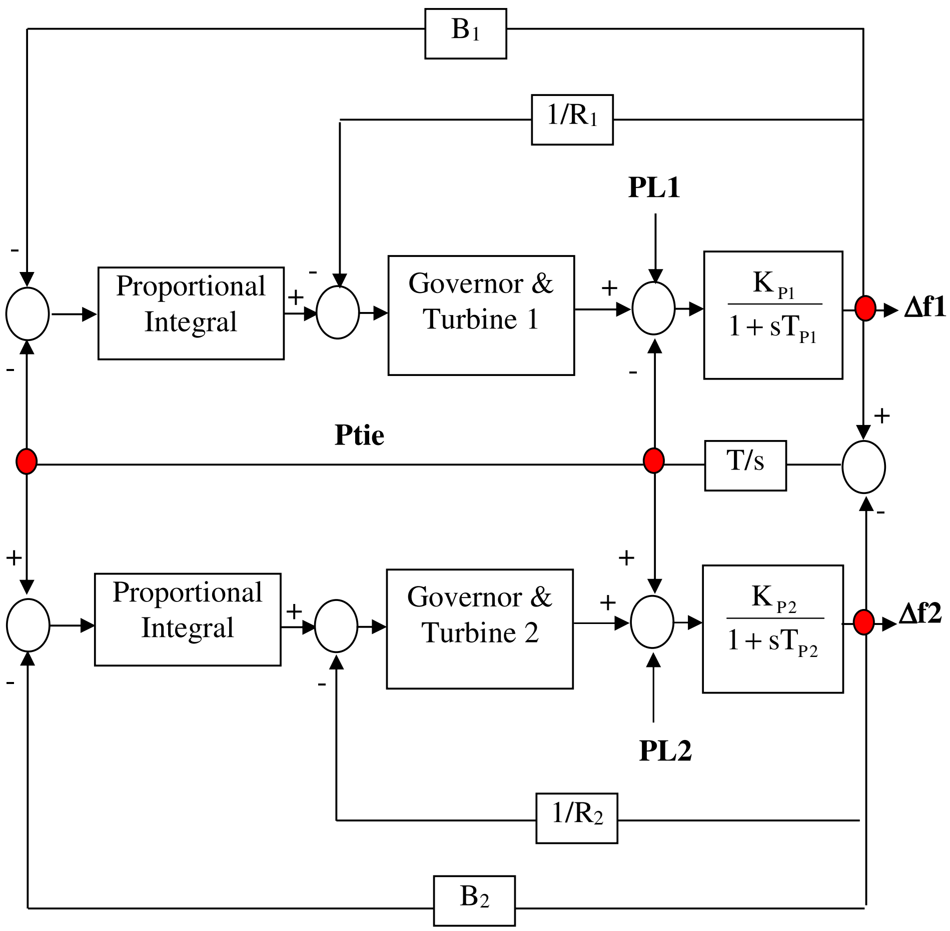

Fig.3. Linearized Block Diagram of Two Area Power Systems

II.2. Tie Line Power Interchange and Linearized Model

Consider the two-area interconnected power system shown in Fig. 1. This two-area power system interlinks the two power areas through a transmission line called the tie line, through which required power is transferred from one area to the other. A very critical parameter in determining the impedance and, therefore, the power flow between the two areas of this system is the reactance of the tie line, represented by X_{12} Figure 4 shows the equivalent circuit diagram of the system, considering a simplified model that does not take into account the dynamic oscillations between the machines in both areas. With the exception of dynamic effects from these, the diagram gives the steady-state view of electrical characteristics in the system. This will be useful in simplifying it for the basic interactions and power flow through the tie line; it excludes added complexity of machine dynamics, in some cases rather difficult to model and analyze. The equivalent circuit representation helps in analyzing how power is transferred between the two areas and changes in system parameters with regard to the overall performance. This serves to understand system stability, different strategies of controls, and, in general, how different operating conditions influence power flow and frequency regulation. Even though this model neglects dynamic oscillations, it still provides a basic understanding of how the system behaves and is fundamental for the design and assessment of control mechanisms for ensuring stability and performance within the interlinked power areas.

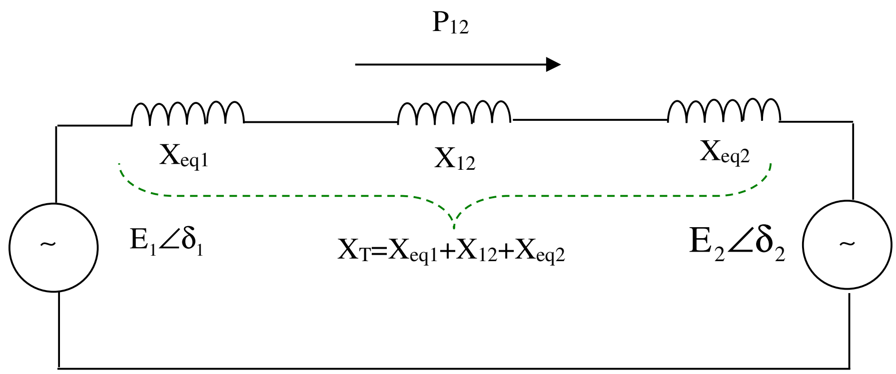

Figure 4 Simplified Equivalent Diagram of Two Area Power System

Power flow from area 1 to area 2 throughout tie line is calculated by following equation.

$$P_{12} = \frac{E_1.E_2}{X_T}.\mathrm{Sin}(\delta_1 - \delta_2) \quad (1)$$

After linearization, power change in tie line is found by Eq.2.

$$\Delta P_{12} = T = \frac{E_1.E_2}{X_T}.\mathrm{Cos}(\delta_{10} - \delta_{20}).(\Delta\delta_1 - \Delta\delta_2) \quad (2)$$

Above power flow deviation depends on frequency (Δf) and rotor angle deviation ($\Delta\delta$) can be calculated by Eq.3 and 4 in time domain and –s domain.

$$\Delta P_{12} = 2\pi T\left[\int \Delta f_1.dt - \int \Delta f_2.dt\right] \quad (3)$$

$$\Delta P_{12}(s) = \frac{2\pi T}{s}\left[\Delta f_1(s) - \Delta f_2(s)\right] \quad (4)$$

Mathematical representation of two area power systems given in Figure 3 is modeled by Eq.5 in this paper.

$$\dot{X} = A.X + BU \tag{5}$$

State variables are chosen as following form.

$$X = [\Delta f_1 \quad \Delta P_{M1} \quad \Delta X_{T1} \quad \Delta X_{G1} \quad \Delta X_{I1} \quad \Delta f_2 \quad \Delta P_{M2} \quad \Delta X_{T2} \quad \Delta X_{G2} \quad \Delta X_{I2} \quad \Delta Ptie]^T \tag{6}$$

III. Tunıng of PI parameters by usıng Artificial Bee Colony

The process of tuning the parameters of the Proportional-Integral controller is of essence in load frequency control for power systems. In that respect, the Artificial Bee Colony optimization algorithm offers a very strong technique with very forefront advantages over traditional methods. ABC is a heuristic, swarm-based, optimization algorithm inspired by the foraging behavior of honeybees that efficiently explores the parameter space seeking the optimum or near optimum solution parameters for PI controllers. PI controllers are very vital in keeping the stability and performance of the system within par by regulating frequency deviations and power imbalances. The gains, Kp and Ki, should be finely tuned so that errors are minimal and operation remains stable. Traditional heuristic methods of manual tuning and trial-and-error usually can't guarantee optimum performance. On the other hand, the ABC algorithm systematically searches for the best values of parameters, hence significantly improving the efficiency and accuracy of the tuning process. The ABC algorithm goes through three phases: employed bee phase, onlooker bee phase, and scout bee phase. In the phase of an employed bee, potential solutions are explored and evaluated. Onlooker bees will make evaluations of the fitness of the best solutions for further exploitation of the areas, and scout bees discover new search areas in order to prevent this stagnation. This type of mechanism helps balance exploration and exploitation, whereby the ABC algorithm can effectively optimize the parameters of PI. In this regard, efficiency of ABC has been proved through several studies. For example, Malik and Hope [2] proved that the use of genetic algorithms in controller optimization can be very effective, which turned way for the use of ABC later on. Kim [3] emphasized the need of accurate PI tuning for load frequency control. The more recent research in this area can be found in Singh and Samantaray [11] and Das and Roy [13]. These papers have proved that ABC can further improve the control performance of a power system by the optimization of PI parameters, thus improving the stability and response. the Artificial Bee Colony algorithm offers an efficient and effective approach for tuning PI controller parameters, enhancing system stability and performance through its sophisticated optimization capabilities.

III.1 Fitness Evaluation and Parent Selection in ABC Algorithm:

Artificial Bee Colony algorithms are used to minimize error criteria of PI (Proportional-Integral) in each iteration. The integral square error (ISE) is used to define the PI controller's error criteria. This criterion is formulated in Eq. (6). At first, Physical system is represented as a set of differential equations. This equations is used to evaluate the system responses. The responses are calculated by using ISE equation.

$$ISE = \int_{o}^{T} [r(t) - y(t)]^2 .dt \tag{6}$$

Where r(t) is the reference input and y(t) is the measured value. In each iteration, the fitness values of each member are evaluated by the results of Eq. (6). These fitness values are used to select best parents from population.

IV. Sımualtıon Results

In simulations, the impact of a 10% increase in active power generation in Area-1 on the frequency deviations was studied. The results, as illustrated in the following figures, demonstrate a comparison between the proposed secondary controller and a traditional integral controller. It can be seen from Figures 5 and 6 that there is a significant enhancement in frequency stability with the secondary controller in comparison to the integral controller. In particular, from both plots it can be clearly stated that the secondary controller efficiently damps the frequency oscillations in both areas; this can be clearly observed in the smoothness of the frequency response curves. This performance improvement in stability is important for interconnected power systems. The results clearly indicate that the change improved the frequency stability because the secondary controller was able to balance the power flow through the tie line connecting the two areas. Figure 7 presents an increase in power flow across the tie line, which helps in the process of better power balance between the two areas. This adjustment balances out all the disturbances caused by the change in power generation and helps maintain more stable frequency control. First, the frequency response has a peak that cannot be completely damped due to intrinsic time delay in the governor control. The secondary controller then cuts down the peak and reduces the oscillations much more efficiently than the integral controller. It is one of the known disadvantages of governor control, that is, intrinsic time delay, which is improved by the additional corrective action of the secondary controller. It can thus be concluded that the secondary controller performance, under improved power flow management and more effective frequency regulation, is much better compared to integral controllers. Indeed, this provides more effective damping of frequency oscillations and better stability of the interconnected power system.

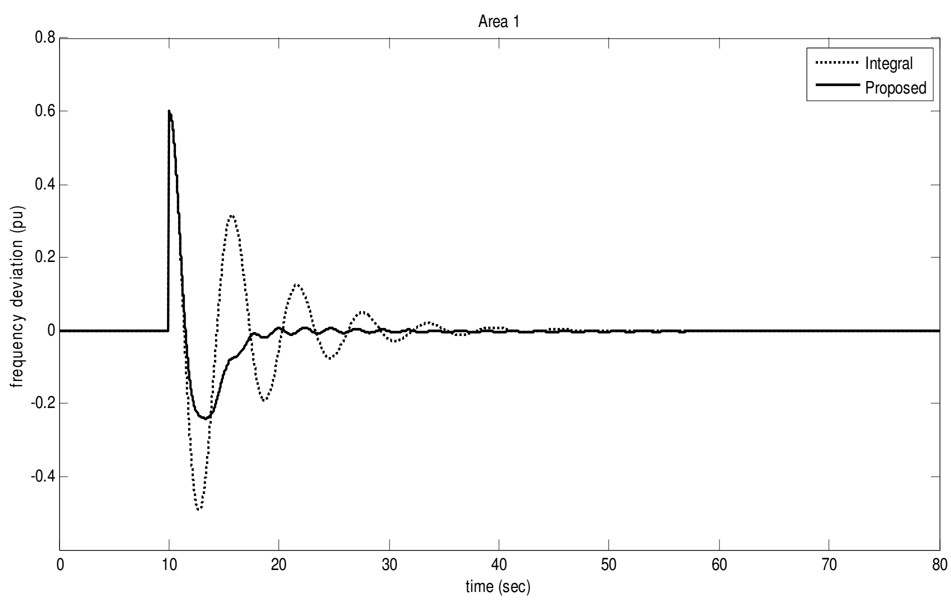

Figure 5 Frequency deviation in Area-1 (10% decrease in power demand)

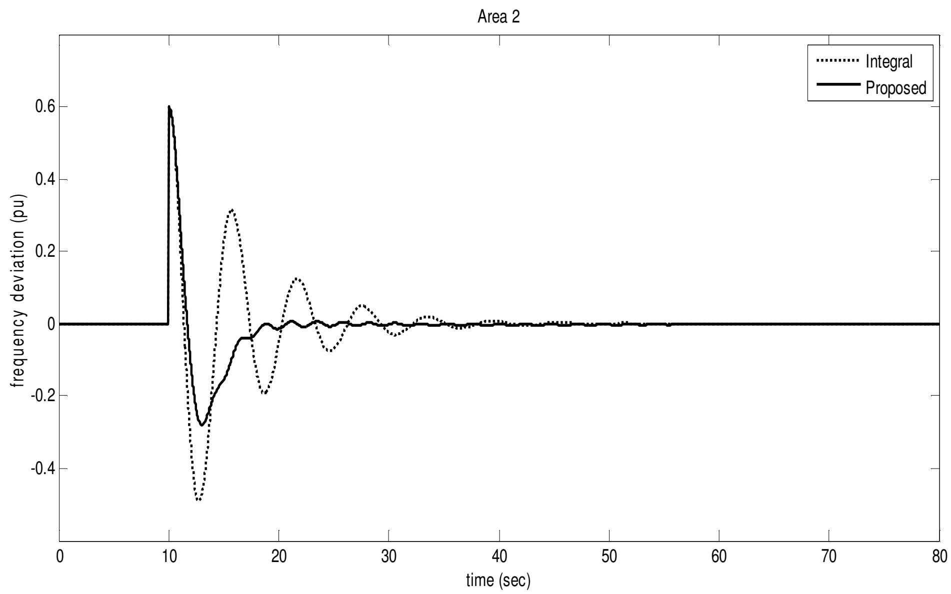

Figure 6 Frequency deviation in Area-2 (10% decrease in power demand)

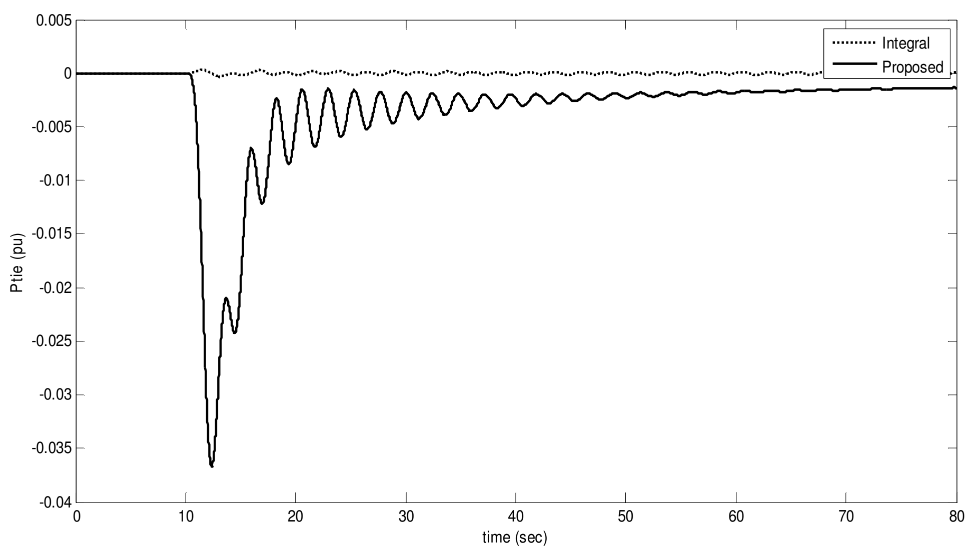

Figure 7 Tie lie power deviation between areas (10% decrease in power demand)

IV. CONCLUSION

In this work, a PI controller with parameters optimised using the Artificial Bee Colony (ABC) method is described. The ABC algorithm, inspired on honeybee foraging behaviour, provides a reliable approach for optimising controller settings, which is critical for system stability and performance. Load frequency control (LFC) in linked power networks is crucial owing to frequency sensitivity and its influence on system functioning. Accurate regulation of frequency and active power balance is critical for maintaining network interconnections and guaranteeing steady operation on national and continental grids. Given the operational obstacles, particularly the necessity for quick decision-making and minimum delays, sophisticated optimisation approaches are essential. The ABC algorithm suggested in this paper is a versatile and efficient method for adjusting PI controller settings. Its ability to comprehensively investigate the parameter space while optimising controller performance makes it an invaluable tool for LFC applications. Power utilities may increase control and stability by using ABC, allowing them to more effectively manage the complex needs of contemporary interconnected power networks. To summarise, the ABC algorithm improves the performance of the PI controller by providing a realistic strategy for regulating load frequency regulation and contributing to the stable functioning of linked power networks.

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