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Study on Fuzzy Logic-Based Controllers with Simplified Rules to Load-Frequency Control of Electric Power Grid Interconnections

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Abstract:*As an essential part of automatic generation control, load-frequency control (LFC) strategy in a large-scale electric power grid aims to maintain network frequency at a nominal value (50Hz or 60Hz) against load changes. It is a fact that the whole power network in a nation consists of many sub-power plants which are connected via transmission lines or tie-lines, making control schemes to stabilize the network more challenging. One of the most crucial control schemes in such a power interconnection is the LFC, which is built up to bring the network back to the stability after time-by-time continuous and random load variations. It is clear applying conventional LFC regulators e.g., PID (proportional – integral – derivative) with poor control performances may not meet increasingly demanding criteria. Intelligent counterparts using modern fuzzy logic techniques should be a great alternative solution to them. This study concentrates on proposing and comparing the conventional LFC regulator and a typical fuzzy logic counterpart with a newly simplified fuzzy rule set determined by a proper optimization mechanism. A typical three-area electric power interconnection model with random load change is also designed to demonstrate an effective applicability of the intelligent fuzzy logic controllers.*

Keywords:*LFC, Fuzzy logic controller, Rule base, Power grid interconnections, Network frequency fluctuation.*

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I. INTRODUCTION

Electric power grids in a country are considered to be large-scale systems due to their complicated characteristics. An undeniable fact is that each power system typically consists of many substations defined as control-areas. These areas are connected through tie-lines which are alternative names of transmission lines. Besides, loads are continuously changeable because they depend upon person-by-person, home-by-home, factory-by-factory and so on. This unwanted feature affects a balance between power demand and consumption, resulting the network frequency deviation from a nominal value (50Hz or 60Hz). Such a phenomenon also creates a negative effect on the tie-line power exchange to be varied from scheduled values. Therefore, this phenomenon needs to be minimized by applying an efficient control solution. Such a proper control is defined as load-frequency control (LFC), which is considered to be a major part of automatic generation control [1-15].

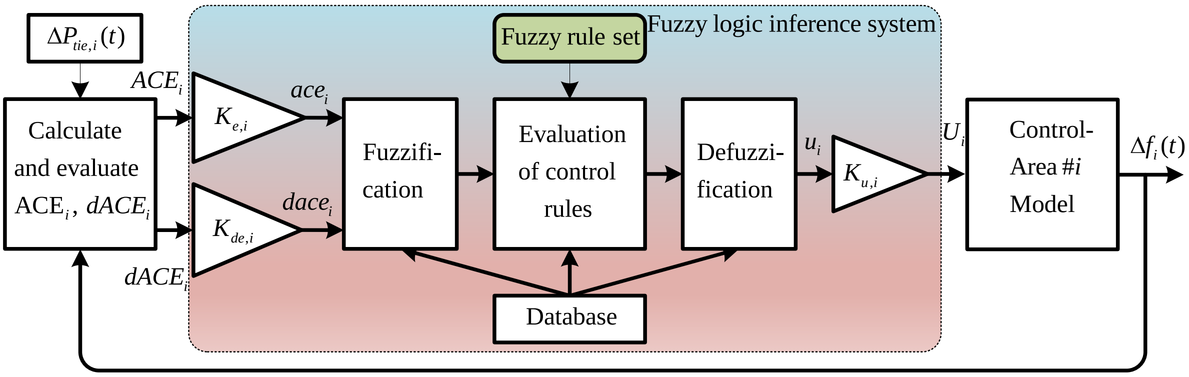
It was obvious that a huge number of LFC strategies has been proposed in both theoretical and practical contexts. Not only traditional regulators i.e. Integral (I), Proportional – Integral – Derivative (PID) but also advanced counterparts such as fuzzy logic and artificial neural network controllers have been used for this control problem. Control results with acceptable quality criteria have been confirmed [16-25].

This paper continues studying one of the most popular types of intelligent controllers, namely fuzzy logic one, in dealing with the LFC issue. The major contribution of the paper istofocus on designing a feasible set of fuzzy logic rules by using genetic algorithm optimization method in order to speed up executing process, thereafter reducing time delay of the controller. This makes a lot of meaningful sense in a super large-scale system like a real power system that consists of thousands of different controllers [26-35].

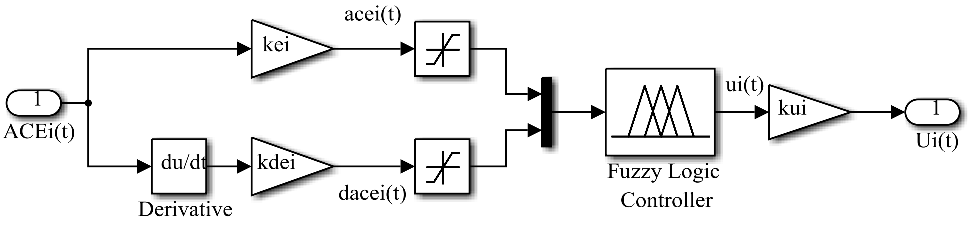
The rest of this study includes three sections. Section II presents the structure of a typical fuzzy logic – based LFC controller with a minimizing rule base. Section III shows simulation results regarding a three – control – area interconnected power grid model taken into consideration. Section IV provides several conclusions and future works inspired from this study.

II. FUZZY LOGIC - BASED CONTROLLERS FOR LOAD-FREQUENCY CONTROL

It is well known fuzzy logic technology – based controllers have been considered to be a perfect replacement for the conventional regulators such as I, PI and PID. This statement has also been clarified by a lot of studies and production reality. For the load-frequency control issue, a typical fuzzy logic model is chosen to be embedded in each control – area as depicted in Figure 1(a). As shown, each fuzzy logic model includes two inputs, namely ***ace$_i$*** (area control error) and ***dace$_i$*** (derivative of area control error). An output, i.e. control signal ***u$_i$***, is transmitted to the control plant to execute control activity. Through several crucial steps, fuzzification, execution of fuzzy logic rule inference and defuzzification, the controller is completely able to fulfill control problems. In this perspective, load-frequency controller can bring an electric power grid back to the stability as well as ensure its economical achievement. Figure 1(b) illustrates a model of the fuzzy logic controller which has been built in MATLAB platform. Such a fuzzy logic inference will be used in this study to solve the LFC problem.



a) The proposed fuzzy logic architecture



b) A MATLAB/Simulink model of the proposed fuzzy logic model

Figure 1:Typical fuzzy logic – based control scheme for the load-frequency control problem

To perform the fuzzy logic – based controller as mention above, the fuzzy rules depending upon experts must be specially taken into consideration. Theoretically, if these rules are proposed in a proper manner, the control performances are able to be perfectly obtained. In contrast, if they are too complicated or highly sketchy, the control system cannot be performed in an enough efficient desired way. Furthermore, the executed time for this control system may not be ensured, strongly affecting the control quality. In this paper, an only 9-rule base is proposed to implement the fuzzy logic inference. Remember that, to obtain this fuzzy logic rule set, a strong optimization method needs to be used. In our work, we used GA (genetic algorithm) mechanism to determine these fuzzy logic rules. Two typical rules obtained are as follows:

*If **ace$_i$** reduces too big quantity and **dace$_i$** increases excessively big then the control **u** must accelerate large enough.*

*If **ace$_i$** and **dace$_i$** donot change then the output **u** should not vary.*

Following these fuzzy rules, the control criteria can be obtained as good as desired. The next section will present a typical example of a three-area interconnection for power networks applying the proposed fuzzy logic controller.

III. SIMULATION RESULTS AND DISCUSSIONS

Now let us consider a typical case study of three-area interconnections for power systems as plotted in Figure 2. A set of parameters used for simulation objective was presented in the Appendix of the paper. Together with the fuzzy logic technique-based controller presented in the previous section, we also investigatethe conventional PID regulators which are added for the necessary comparison. The operation principle of these traditional regulators for one control-area of the large-scale power systemis presented below:

$$\begin{aligned} u_i(t) &= K_{P,i} ACE_i(t) + K_{I,i} \int_0^t ACE_i(\tau)d\tau + K_{D,i} \frac{d}{dt} ACE_i(t) \\ &= K_{P,i} \left(ACE_i(t) + \frac{1}{T_{Ii}} \int_0^t ACE_i(\tau)d\tau + T_{D,i} \frac{d}{dt} ACE_i(t) \right) \end{aligned} \quad (1)$$

$$U_i(s) = K_{P,i} \left(1 + \frac{1}{sT_{I,i}} + sT_{D,i} \right) ACE_i(s) \quad (2)$$

The simulation condition represented by load variations is depicted in Figure 3. Here, load changes are assumed to be occurred at different instants.

After simulation process in MATLAB/Simulink environment, the results are plotted in Figure 4 and Figure 5. It is obvious from these Figures, the network frequency when applying the PID regulators may not damped to oscillate in an acceptable tolerance. It means that they cannot be forced into zero after permissible time and/or the network frequency fluctuations are unstable. In contrast, the fuzzy logic – based load-frequency controllers, as illustrated in Figure 5, obtain much better control performances. The system frequency values are forced to zeros after short times from load deviation occurrences. In this scenario, the system can completely be maintained at stability state. This result leads to the feasible applicability of the fuzzy logic – based controller proposed in the present study.

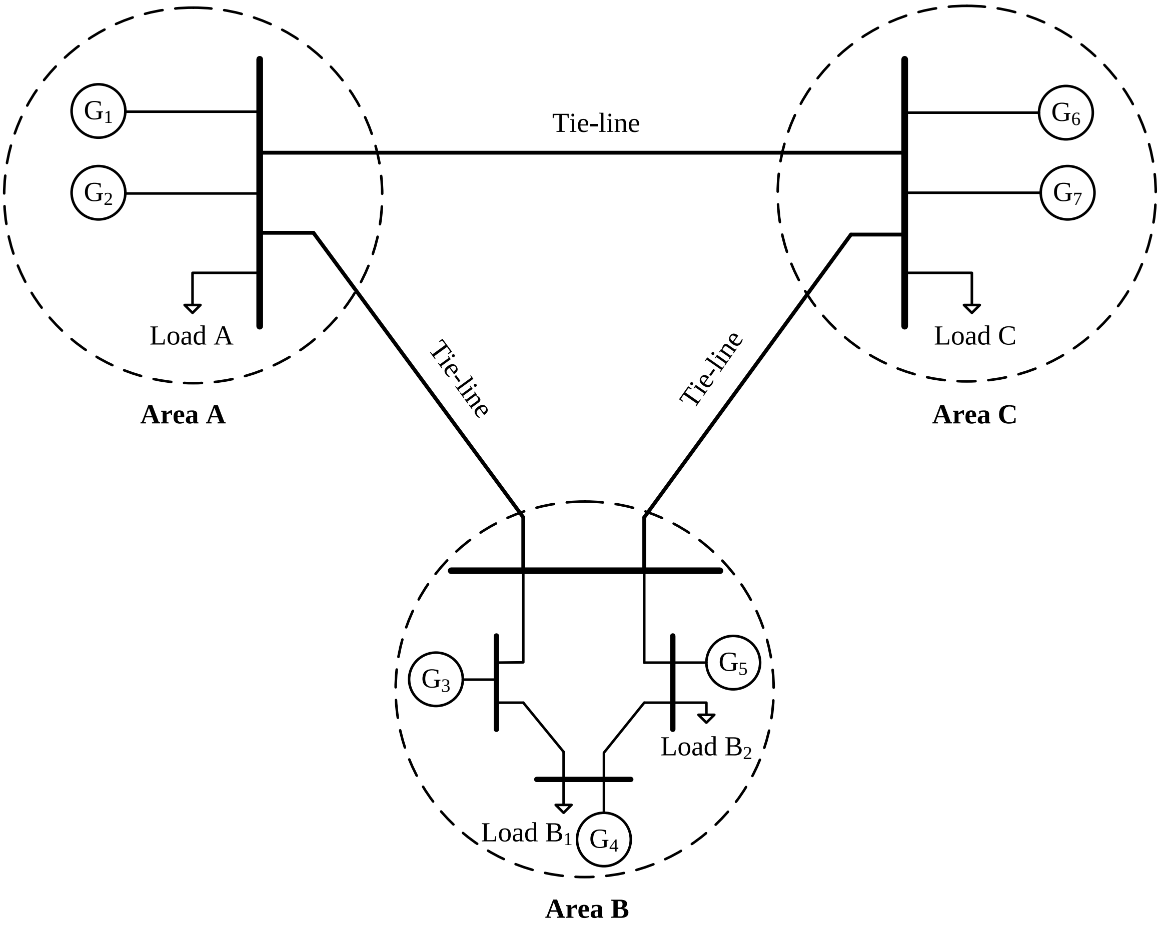


Figure 2: A model of three-area interconnected electric power grid under study

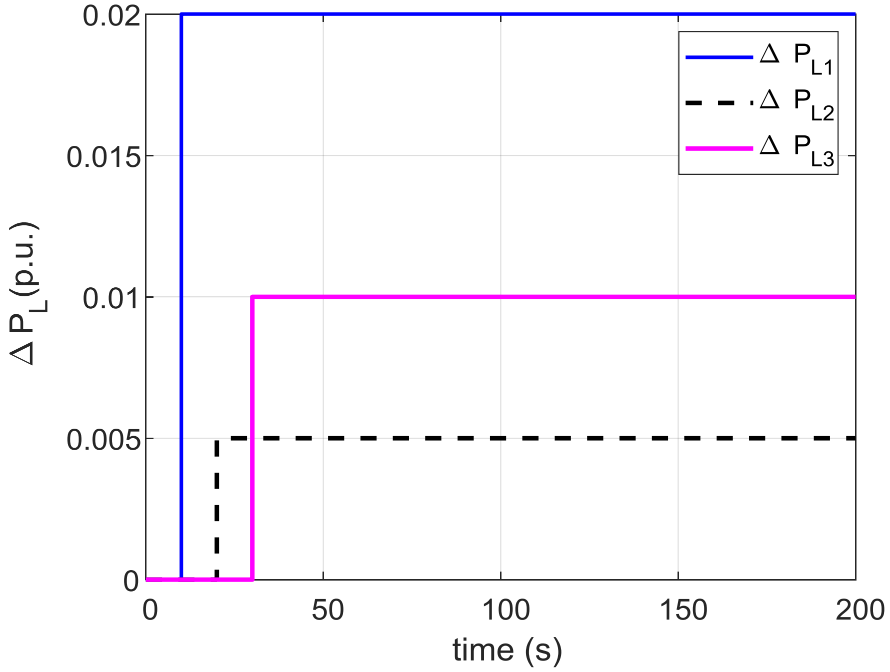


Figure 3: Load changes embedded in the three-area power system model

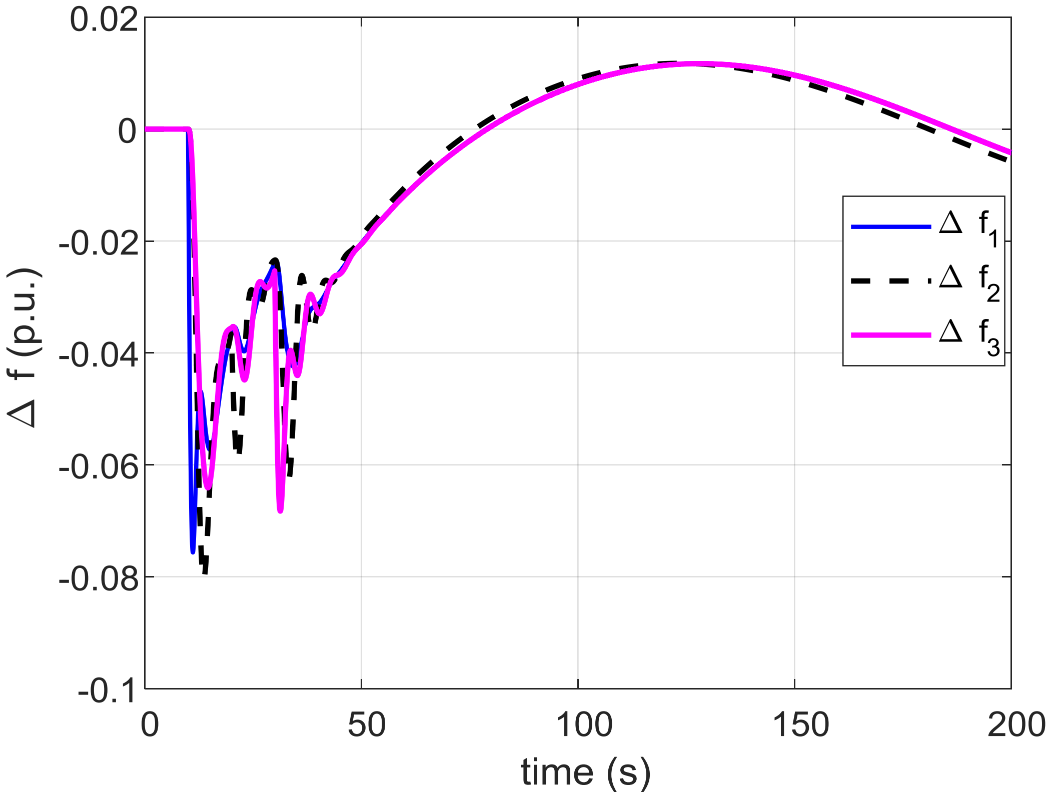


Figure 4: Simulation results for the PID regulators

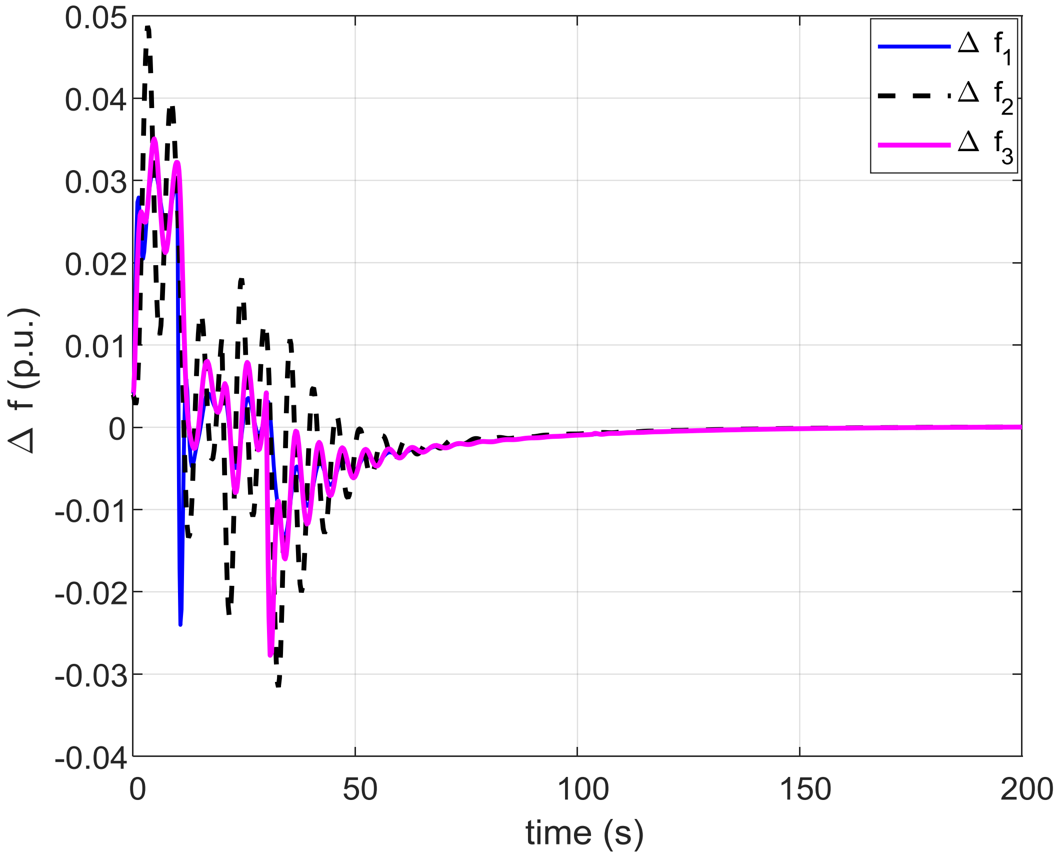


Figure 5: Simulation results for the proposed fuzzy logic controllers

IV. CONCLUSIONAND FUTURE WORKS

This paper has proposed a fuzzy logic technique – based load-frequency controller which is able to obtain good control performances. Such a fuzzy logic regulator uses a simplified rule base to work in the inference process. The GA algorithm has been integrated to determine this fuzzy logic rule set. The executed time has been significantly reduced, demonstrating the promising feasibility of the control solution proposed in this study.

Further works inspired from this study are to continue applying the proposed method to other power systems. Additionally, artificial neural network-based architectures need to be taken into study in order to compare withintelligent controllers; thereby the most effective one can be further deduced.

Conflict of interest

There is no conflict to disclose.

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APPENDIX

Simulation parameters of the three-control-area power system model under this study.

$T_{G,1} = 0.08$, $T_{G,2} = 0.12$, $T_{G,3} = 0.1$

$T_{Tnr,1} = 0.3$, $T_{Tnr,2} = 0.3$, $T_{Tnr,3} = 0.35$

$K_{P,1} = 120$, $K_{P,2} = 100$, $K_{P,3} = 98$

$T_{P,1} = 18$, $T_{P,2} = 20$, $T_{P,3} = 25$; $T_{ij} = 0.071$, $R_1 = 2.5$, $R_2 = 2.4$, $R_3 = 2.3$

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