Comparison of Artificial Intelligence Methods for Load Frequency Control Problem

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Abstract: The Load Frequency Control (LFC) problem has been one of the major subjects in electric power system design/operation and is becoming much more significant today in accordance with increasing size, changing structure and complexity in interconnected power systems. Practice LFC systems use simple proportional-integral (PI) or integral (I) controllers. But the PI control parameters are usually tuned based on the classical or trial-and-error approaches and they are incapable to obtain good dynamic performance under various load conditions. For this problem, in this paper the artificial intelligence methods such as Genetic Algorithms (GA) and Fuzzy logic are proposed to tune the controllers for LFC problem in power system. A two-area power system example is considered as case study to illustrate the proposed methods. To show effectiveness of proposed methods and also comparing the performance of GA and Fuzzy controllers, several time domain simulations for various load changes scenarios are presented. Simulation results emphasis on the better performance of Fuzzy controllers than GA controllers in LFC problem.

Key words: Power System Load Frequency Control, Multi-Area Power System, Genetic Algorithms, Fuzzy Logic

INTRODUCTION

For large scale power systems with interconnected areas, Load Frequency Control (LFC) is important to keep the system frequency and inter-area tie power as near to the scheduled values as possible. The input mechanical power to the generators is used to control the frequency of output electrical power and to maintain the power exchange between the areas as scheduled.

A well designed and operated power system must cope with changes in the load and with system disturbances, and it should provide acceptable high level of power quality while maintaining both voltage and frequency within tolerable limits.

Many control strategies for Load Frequency Control in power systems have been proposed by researchers over the past years. For example see (Daneshfar and Bevrani, 2010; Lim, et al., 1996; Wang, et al., 1998; Stankovic, et al., 1998; Taher and Hematti, 2008; Yamashita and Miagi, 1991; Xiaofeng and Tomovic, 2004; Talaq and Al-basri, 1999; Doolia and Bhatti, 2006; Grigor’ev, 2005; Gvozdev and Samkharadze, 2005; Moon, et al., 2001; Taher, et al., 2008; Rerkpreedapong, et al., 2003; Liu, et al., 2003). This extensive research is due to fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits. Robust adaptive control schemes have been developed in (Lim, 1996; Wang, 1998; Stankovic, 1998) to deal with changes in system parametric under LFC strategies. A different algorithm has been presented in (Yamashita, 1991) to improve the performance of multi-area power systems. Viewing a multi-area power system under LFC as a decentralized control design for a multi-input multi-output system, it has been shown in (Yamashita, 1991) that a group of local controllers with tuning parameters can guarantee the overall system stability and performance. The result reported in (Lim, 1996; Wang, 1998; Stankovic, 1998; Yamashita, et al., 1991) demonstrates clearly the importance of robustness and stability issue in LFC design. In addition, several issues have been addressed in (Xiaofeng and Tomovic, 2004; Talaq and Al-basri, 1999; Doolia and T.S. Bhatti, 2006; Grigor’ev, 2005) which include recent technology utilized by vertically integrated utilities, augmentation of filtered area control error with LFC schemes and hybrid LFC that encompasses an independent system operator and bilateral LFC. The applications of artificial neural network, Genetic Algorithms and optimal control to LFC
have been reported in (Taher, et al, 2008; Rerkpreedapong, et al, 2003; Liu, et al, 2003).

The objective of this paper is to investigate and comparison the ability of artificial intelligence methods such as Genetic Algorithms (GA) and Fuzzy logic for Load Frequency Control and inter-area tie power control problems. The GA and Fuzzy logic based controllers are considered to LFC control problem. In GA case a PI type controller is considered and an optimal control scheme based Genetic Algorithms (GA) method is used to tune the parameters of this PI type controller. In Fuzzy logic case, a nonlinear PI-type Fuzzy logic controller is considered to LFC problem.

The proposed controllers are simulated for a two area power system. To show effectiveness of proposed methods and also comparing the performance of these two methods, several changes in demand of first area, demand of second area and demand of two areas simultaneously are applied. Simulation results show that the both proposed methods are suitable for LFC problem but Fuzzy controllers have better performance than GA based controllers.

2. Plant Model:

A two-area power system, shown in Fig. 1 is considered as a test system. The state-space model of system is as (1) (Wood and Wollenberg, 2003).

\[
\begin{cases}
\dot{x} = Ax + Bu \\
y = Cx
\end{cases}
\]

(1)

The parameters in (1) are as follow:

\[
u = [\Delta P_{G1}, \Delta P_{G2}, U_1, U_2]\]

\[
y = [y_1, y_2] = [\Delta \omega_1, \Delta \omega_2, \Delta P_{tie}]\]

\[
x = [\Delta T_{G1}, \Delta P_{T1}, \Delta \omega_1, \Delta P_{tie}, \Delta T_{G2}, \Delta P_{T2}, \Delta \omega_2]\]

\[
A = \begin{bmatrix}
-\frac{1}{T_{G1}} & 0 & -1 & 0 & 0 & 0 & 0 & 0 \\
0 & -\frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & -\frac{1}{M_1} & -\frac{1}{M_1} & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & -\frac{1}{T_{T2}} & 0 & -\frac{1}{R_1 T_{T2}} & 0 & 0 \\
0 & 0 & 0 & 0 & -\frac{1}{T_{T2}} & 0 & -\frac{1}{R_1 T_{T2}} & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{M_2} \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & -\frac{1}{M_2}
\end{bmatrix}
\]

\[
B = \begin{bmatrix}
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix}
\]
Fig. 1: Block Diagram of Two-area Power System with Controllers

The parameters of model are defined as follows:
A: Deviation from nominal value
M = 2H: Constant of inertia
D: Damping constant
R: Gain of speed droop feedback loop
Tt: Turbine Time constant
TG: Governor Time constant
G1: First area controller
G2: Second area controller
\( \omega \): System frequency
B = (1/R) + D: Frequency bias factor

The typical values of system parameters for nominal operating condition are as follows:

<table>
<thead>
<tr>
<th>First area parameters</th>
<th>Tt1 = 0.03</th>
<th>TG1 = 0.08</th>
<th>M1 = 0.1667</th>
<th>R1 = 2.4</th>
</tr>
</thead>
<tbody>
<tr>
<td>D1 = 0.0083</td>
<td>B1 = 0.401</td>
<td>T1 = 0.425</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Second area parameters</th>
<th>Tt2 = 0.025</th>
<th>TG2 = 0.091</th>
<th>M2 = 0.1552</th>
<th>R2 = 2.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>D2 = 0.009</td>
<td>B2 = 0.300</td>
<td>T2 = 0.425</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The objective is to design the controllers G1 and G2 for Load Frequency Control (LFC). As mentioned in the introduction, many methods have been applied to design these controllers so far. In this paper, artificial intelligence methods like Genetic Algorithms and Fuzzy logic are applied to design the foregoing controllers. The goals are to study the ability of these methods in Load Frequency Control (LFC) problem and also comparing the performance of these methods. In the next sections, the process of controllers design is developed.

3. Fuzzy Logic Based LFC Control:

The proposed Fuzzy LFC control block diagram for the first area is given in Fig. 2 and LFC control block for the second area is considered like it for the first area. In fact, this controller is a nonlinear PI-type Fuzzy logic controller with two inputs and one output. In this paper, the speed deviations DW1 and its rate are modulated in order to inputs of the controller for the first area and DW2 and its rate are modulated in order to inputs of the controller for the second area. The structure of Fuzzy controller is shown in Fig. 2. Where, the inputs are the frequency deviation of first area (X1) and its rate (X2) which are filtered by washout blocks to eliminate the DC components. The output (u) is sent to the main controller. Fuzzy controller accepts these inputs and it has to convert them into fuzzified inputs before the rules can be evaluated and fired. To accomplish this, one of the most important and critical blocks in the whole Fuzzy controllers should be built and it is the knowledge base. It consists of two more blocks namely the data base and the rule base (Rajasekaran and Vijayalakshmi, 2007).
3.1. Data Base:

Data base consists of the membership function for input variables \((X_1)\) and \((X_2)\) described by the following linguistic variables:

For input 1 \((X_1)\):
- Positive (P)
- Negative (N)

For input 2 \((X_2)\):
- Negative (N)
- Near Zero (NZ)
- Positive (P)

For output:
- Positive (P)
- Positive Small (PS)
- Near Zero (NZ)
- Negative Small (NS)
- Negative (N)

The "Gaussian membership functions" are used as membership functions for the input variables and "Triangular membership functions" for output variable (Rajasekaran and Vijayalakshmi, 2007). The Figs. 3-5 illustrate these in detail, indicating the range of all the variables.

3.2. Rule Base:

The other half of the knowledge base is the rule base, which consists of all the rules formulated by the experts. It also consists of weights which indicate the relative importance of the rules among themselves and indicates the influence of a particular rule over the net fuzzified output. The Fuzzy rules used in this scheme are as mentioned in the Table I. The next section specifies the method adopted by the inference engine, especially the way it uses the knowledge base consisting of the described data base and rules base (Rajasekaran and Vijayalakshmi, 2007). Plotting inputs versus output is shown in Fig. 6. This plot is based rule base.
**Fig. 4:** Membership function of input 2 (X2)

**Fig. 5:** Membership function of output

**Table 1:** Fuzzy rules

<table>
<thead>
<tr>
<th>Rule</th>
<th>If</th>
<th>(X2) is</th>
<th>then (y) is</th>
<th>[1]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rule 1</td>
<td>(X2)</td>
<td>NZ</td>
<td>NZ</td>
<td></td>
</tr>
<tr>
<td>Rule 2</td>
<td>(X2)</td>
<td>P</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Rule 3</td>
<td>(X2)</td>
<td>N</td>
<td>N</td>
<td></td>
</tr>
<tr>
<td>Rule 4</td>
<td>(X2)</td>
<td>NZ</td>
<td>P</td>
<td></td>
</tr>
<tr>
<td>Rule 5</td>
<td>(X2)</td>
<td>NZ</td>
<td>N</td>
<td></td>
</tr>
</tbody>
</table>

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3.3. Fuzzy Inference Engine:

Though have been mentioned many methodologies in evaluating the various expressions like Fuzzy union (OR operation), Fuzzy intersection (AND operation) and etc, with varying degree of complexity, here in Fuzzy scheme the most widely used methods are used for evaluating such expressions. The function used for evaluating OR is “MAX”, which is nothing but the maximum of the two operands i.e.

\[ \text{MAX}(X_1, X_2) = X_1 \text{ if } X_1 > X_2 = X_2 \text{ if } X_1 < X_2 \]

Similarly the AND is evaluated using “MIN” function which is defined as the minimum of the two operands i.e.

\[ \text{MIN}(X_1, X_2) = X_1 \text{ if } X_1 < X_2 = X_2 \text{ if } X_1 > X_2 \]

Another important point to note here is that in the present research paper, equal importance to all the rules in the rules base have been assigned and all the weights are equal and this is indicated in Table I in the bracket against each rule.

3.4. Defuzzification Method:

The Defuzzification method followed in this study is the “Center of Area Method” or “Gravity method” (Rajasekaran and Vijayalakshmi, 2007). It should be note that, the process of controller design for first area and second area is same and the mentioned approach is applied to design controllers of the both area (G₁ and G₂).

4. Genetic Algorithms:

Genetic Algorithms (GA) are global search techniques, based on the operations observed in natural selection and genetics (Randy and Sue, 2004). They operate on a population of current approximations- the individuals- initially drawn at random, from which improvement is sought. Individuals are encoded as strings (chromosomes) constructed over some particular alphabet, e.g., the binary alphabet \{0, 1\}, so that chromosomes values are uniquely mapped onto the decision variable domain. Once the decision variable domain representation of the current population is calculated, individual performance is assumed according to the objective function which characterizes the problem to be solved. It is also possible to use the variable parameters directly to represent the chromosomes in the GA solution. At the reproduction stage, a fitness value is derived from the raw individual performance measure given by the objective function, and used to bias the selection process. Highly fit individuals will have increasing opportunities to pass on genetically important material to successive generations. In this way, the Genetic Algorithms search from many points in the search space at once and yet continually narrow the focus of the search to the areas of the observed best performance.
The selected individuals are then modified through the application of genetic operators. In order to obtain the next generation Genetic operators manipulate the characters (genes) that constitute the chromosomes directly, following the assumption that certain genes code, on average, for fitter individuals than other genes. Genetic operators can be divided into three main categories (Randy and Sue, 2004): Reproduction, crossover and mutation.

Reproduction: selects the fittest individuals in the current population to be used in generating the next population.

Cross-over: Causes pairs, or larger groups of individuals to exchange genetic information with one another

Mutation: causes individual genetic representations to be changed according to some probabilistic rule.

Genetic Algorithms are more likely to converge to global optimal than conventional optimization Techniques, since they search from a population of points, and are based on probabilistic transition rules. Conventional optimization techniques are ordinarily based on deterministic hill-climbing methods, which, by definition, will only find local optima. Genetic Algorithms can also tolerate discontinuities and noisy function evaluations.

4.1. Genetic Algorithms Based LFC Control:

In this paper PI type controller optimized by Genetic Algorithms is designed for LFC and tie-power control. The goals are to control frequency and inter area tie-power with a suitable performance. The structure of system with PI type controller is show in Fig. 7.

The area control error (ACE) for the $i^{th}$ area is defined as follow:

$$\Delta CE_i = \Delta P_{tiei} + \Delta \omega_i$$

With PI controller, the conventional Automatic Generation Controller (AGC) has a control strategy as (2).

$$\Delta PC_i = K_{pi} (\Delta P_{tiei} + \Delta \omega_i) + K_{ii} \int (\Delta P_{tiei} + \Delta \omega_i) \quad i = 1,2$$

Where $K_{pi}$ is the gain of the proportional controller and $K_{ii}$ is the gain of integral controller for the $i^{th}$ area.

In this study, the optimum values of the parameters $K_p$ and $K_i$ for PI controllers, which minimize an array of different performance indices, are accurately computed using a Genetic Algorithms. In a typical run of the GA, an initial population is randomly generated. This initial population is referred to as the 0th generation. Each individual in the initial population has an associated performance index value. Using the performance index information, the GA then produces a new population. The application of a Genetic Algorithms involves repetitively performing two steps:

1. The calculation of the performance index for each of the individuals in the current population, to do this the system must be simulated to obtain the value of the performance index. The Genetic Algorithms then produces the next generation of individuals using the reproduction crossover and mutation operators.

2. These two steps are repeated from generation to generation until the population has converged to some minimum value of the performance index producing near optimal parameters set.

In this study the performance index is considered as (3).

$$P_I = \int_0^t |\Delta \omega_1| dt + \int_0^t |\Delta \omega_2| dt + \int_0^t |\Delta P_{tie12}| dt$$

In fact this performance index is total area under the curves (output responses) and it is a suitable benchmark to compare cases with each other. The parameter "t" in performance index is the simulation time. It is clear to understand that the controller with lower performance index is better than the other controllers or on the other words the controller with lower performance index has better performance than the other controllers. To compute the optimum parameter values, a unit step load change is assumed in area 1 and the performance index is minimized using a Genetic Algorithms. In the next section, the optimum values of the Parameters $K_p$ and $K_i$ for PI controllers, resulting from minimizing the performance index are presented.

4.2. Controllers Design Using ga:

To calculate the performance index, a digital simulation of the system was performed over a solution time period of 100 seconds, for each of the individuals of the current population. The values of the performance index thus obtained were fed to the Genetic Algorithms in order to produce the next generation of individuals. The procedure was repeated until the population had been converged to some minimum value of the performance index producing near optimal parameters set. The Genetic Algorithms used here utilizes direct manipulation of the parameters. The following Genetic Algorithms parameters are used here:
In this part of the study, a conventional AGC, which is proportional-integral, is considered. The optimum value of the parameters \( K_p \) and \( K_i \) for performance index are obtained using Genetic Algorithms and summarized in the table II.

In next part, Fuzzy logic controllers and GA based controllers are compared to show effectiveness of these methods for Load Frequency Control problem.

<table>
<thead>
<tr>
<th>Table. II: Optimum values of KP and KI for PI controllers</th>
</tr>
</thead>
<tbody>
<tr>
<td>First area controller (G₁)</td>
</tr>
<tr>
<td>Second area controller (G₂)</td>
</tr>
</tbody>
</table>

5. Results and Discussions:

The designed Fuzzy and GA controllers are applied to the system and their responses are compared with each other. Two cases are considered as follow:

Case 1: Step increase in demand of first area (\( \Delta P_{d1} \))

Case 2: Step increase in demand of first area and second area simultaneously.

5.1. Step Increase in Demand of First Area:

As first test case, a step increase in demand of first area (\( P_{d1} \)) is applied. The frequency deviation of first area (\( \omega_1 \)), the frequency deviation of second area (\( \omega_2 \)) and inter area tie-power (\( P_{tie} \)) are shown in Figs. 8-10. It is clearly seen that the both applied control strategies are successful in control power system and damping oscillations. The frequency deviations and inter area tie-power quickly driven back to zero and system oscillations damping is acceptable. But from comparison view, Fuzzy controllers have better performance in frequency control than GA controllers. Also responses without any controller can not driven back to zero and have a steady state error.

5.2. Step Increase in Demand of First Area and Second Area Simultaneously:

In this case, a 0.5 step increase in demand of first area (\( P_{d1} \)) and a step increases in demand of second area (\( P_{d2} \)) are simultaneously applied. The system responses are shown in Figs. 11-13. This case can be considered as a heavy load change because of simultaneously change in demand of two areas. For this case the responses clearly emphasis on the suitable performance of proposed methods for LFC. With Fuzzy and GA controllers, the frequency and inter area tie-power deviations quickly driven back to zero and also system oscillations damping is in the range of acceptable. But the Fuzzy controllers have a significant better performance than optimized GA controllers.
5.3. Comparison Using Performance Index:

For more comparison purposes, the performance index which presented in (3) is a suitable benchmark to compare the proposed methods with each other.

The performance index has been calculated following step change at several inputs. The results are shown at Table III. The results show that Fuzzy method has lower performance index than GA method and in turn Fuzzy controllers have a better performance than GA controllers.

<table>
<thead>
<tr>
<th></th>
<th>Performance index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuzzy controllers</td>
<td>GA controllers</td>
</tr>
<tr>
<td>Step increase in demand of first area</td>
<td>0.8284</td>
</tr>
<tr>
<td>Step increase in demand of second area</td>
<td>0.8713</td>
</tr>
<tr>
<td>Step increase in demand of two areas simultaneously</td>
<td>1.0251</td>
</tr>
</tbody>
</table>
6. Conclusions:

In this paper Genetic Algorithms and Fuzzy logic have been successfully applied to design controllers for conventional Automatic Generation Systems Control. A two-area power system was assumed to demonstrate the methods. Design strategies include enough flexibility to set the desired level of stability and performance, and considering the practical constraint by introducing appropriate uncertainties. The proposed methods were applied to a two area power system. Simulation results demonstrated that the proposed methods capable to guarantee the robust stability and robust performance under a various load conditions. From comparison views, Fuzzy method has a significant better preference than GA method and it is because of the non-linear structure of Fuzzy method in controller design. These results and the suitability of Fuzzy logic to nonlinear problems, open the door to study the effect of non linear constraints on the AGC parameters.


