PSO Optimized FLC For The Design Of Load Frequency Control

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Abstract: Load frequency control problem is considered as one of the most important issues in the design and operation of power systems. Due to lack of good efficiency in parameters variation conditions, working conditions of system and non-linear factors, a simple PI controller is not suitable in industrial applications. Instead, fuzzy controllers can be used in order to enhance the performances of the systems. In this paper, the use of the optimized type-1 fuzzy logic controller using Particle Swarm Optimization (PSO) algorithm is proposed to solve the load frequency control problem. To the best of our knowledge, the PSO optimization of fuzzy type-1 controller in order to solve load frequency control problem, has not been investigated so far. The proposed controller has good performance and is capable to solve the load frequency control problem in conditions of wide variations of system parameters and non-linear factors such as generation rate constraint. Simulation results show that the optimized fuzzy controller proposed in this paper exhibits better performance compared to PI controller in damping of system deviations.

Key words: power system, load frequency control, type-1 fuzzy logic controller, PSO algorithm.

I. INTRODUCTION

The main aim of power systems is to provide the required power supply to customers with a given voltage and frequency. Considering the growing energy demand of the customers, the stability and reliability of power systems are important. The load frequency control problem in a power system deals with sudden disturbances that disrupt normal conditions of system operation and occur due to outage and connection of loads on different hours in power system. Any change in active power demand in a point of a power system is reflected throughout the system as a frequency change (Panda, 1998).

The problem of output active power control of a power system in response to power system frequency changes and between regional powers of system lines in a specified range is known as the load frequency control problem. For optimal performance and optimal operation of power systems, the frequency changes must be maintained within certain limits. Many process control systems, such as computers, are sensitive to changes in the frequency of their operation and are impaired. For such systems, their frequency must be regulated and controlled (Chaturvedi et al., 1999; Moon et al., 2002). Therefore, an adequate supplementary controller to regulate and prevent frequency deviations must be used in the main control center.

The purpose of load frequency control problem is to maintain a uniform frequency and to adjust and control converted power between areas of the power system in a planned value. In other words, we can say that the aim of load frequency control problem is keeping the steady-state error of the system to zero. In previous studies on solving the load frequency control problem, various methods have been used. In the proposed methods, the PI controller is most widely used in industry. The PI controller has a fixed gain that is designed in rated operating conditions and its utilization is simple, but frequency oscillations can also appear in this case. This means that the PI controller indicates a poor dynamic performance against of system parameters variation and non-linear conditions such as generation rate constraint (Hameed et al., 2010; Chang & Fu, 1997). Different types of fixed gain controllers are designed in rated operating conditions while they are unable to achieve performance in practice under many changes in the operating conditions of the system.

In order to solve the load frequency control problem and to minimize power system deviations, operating conditions and system parameters variations must be considered; genetic algorithms and other intelligent methods are used to improve the PI controller performance and to optimize controller coefficients. As for the non-linearity of the power system and inability to extract its precise mathematical model, in recent years the use of the fuzzy method in design of controller was proposed (Ying, 2000; Mendel, 2000; Hidalgo et al., 2009; Panda et al., 2009; Ying, 2006). In some studies, fuzzy logic is used to adjust the PI controller parameters.

In this paper, the type-1 fuzzy logic controller optimized using Particle Swarm Optimization (PSO) algorithm is used to damp oscillations of frequency in a single area power system. In designing the proposed controller, the nonlinearity factor of generation rate constraint is considered and the results of the optimized type-1 fuzzy logic controller using PSO algorithm are compared to that of a classical PI controller.
II. THE SINGLE AREA POWER SYSTEM

The load frequency model of the studied single area power system is shown in Fig. 1. In solving the load-frequency control problem of the studied system, the generation rate constraint is considered. The nonlinear turbine model considering the generation rate constraint is shown in Fig. 2.

![Fig. 1: Studied single area power system.](image1)

![Fig. 2: Non-linear turbine model considering the generation rate constraint.](image2)

The studied single area power system parameters are defined with the adding limiter to the turbine that are listed in Table 1. In the studied power system, the area control error (ACE) and its variation (ΔACE) are considered as fuzzy controller inputs.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tg</td>
<td>0.08</td>
</tr>
<tr>
<td>Tt</td>
<td>0.3</td>
</tr>
<tr>
<td>Tp</td>
<td>20</td>
</tr>
<tr>
<td>Kp</td>
<td>120</td>
</tr>
<tr>
<td>R</td>
<td>2.4</td>
</tr>
<tr>
<td>DPL</td>
<td>0.01</td>
</tr>
</tbody>
</table>

III. PI AND TYPE-1 (T1) FUZZY LOGIC CONTROLLERS

The PI controller block-diagram and its parameters are illustrated in Fig. 3. The fuzzy controller uses fuzzy logic rules in control applications. Fuzzy rules have been established based on control laws. Fuzzy logic systems are not designed based on mathematical models. Fuzzy controllers implement the human logic using fuzzy logic based on membership functions, fuzzy rules and membership rules.

![Fig. 3: The Proposed PI controller.](image3)

A fuzzy system is described by a set of IF-THEN rules and uses diverse membership functions. To solve the load-frequency control problem in fuzzy controller, controller inputs, ΔACE, ACE, and its output are considered as the control signal. The fuzzy type-1 controller structure is shown in Fig. 4.
The proposed fuzzy type-1 controller has 4 steps that are presented as follows:

**Step 1:** The first step should be to determine the system dynamic behavior and characteristics. At this stage, the controller input and output variables and their variations range should be determined. In addition, suitable input signals should be determined for load-frequency control problem. Input signals are considered to create the base rules as the IF part and the output signal of the fuzzy controller is considered as the THEN part.

**Step 2:** At this stage, the appropriate fuzzy sets and membership functions are determined. At this stage, the degree of fuzzy membership functions associated with each variable or input, output signals are determined and the process of fuzzification is completed. The membership functions of fuzzy type-1 controller are illustrated in Fig. 5.

![Fig. 5: The membership functions of proposed fuzzy type-1 controller.](image)

**Step 3:** The inference engine is described. In this step, fuzzy rules are formed by the control rules that system performance is based on that rules.

**Step 4:** At this stage, the defuzzification process is performed. Fuzzy rules are combined and the defuzzification process is performed on the output and the output of the fuzzy inference engine becomes crisp.

In this paper, inputs and outputs membership functions are the same and the 5-segments triangular membership functions are used. Since each input has five membership functions, the number of base fuzzy rules is 25 as represented in Table 2.

<table>
<thead>
<tr>
<th>Type</th>
<th>NB</th>
<th>NS</th>
<th>ZZ</th>
<th>PS</th>
<th>PB</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>S</td>
<td>S</td>
<td>M</td>
<td>M</td>
<td>B</td>
</tr>
<tr>
<td>S</td>
<td>S</td>
<td>M</td>
<td>M</td>
<td>B</td>
<td>VB</td>
</tr>
<tr>
<td>ZZ</td>
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<tr>
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<td>VB</td>
<td>VB</td>
<td>VVB</td>
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<tr>
<td>PB</td>
<td>B</td>
<td>VB</td>
<td>VB</td>
<td>VVB</td>
<td>VVB</td>
</tr>
</tbody>
</table>

**IV. OPTIMIZED TYPE-1 FUZZY LOGIC CONTROLLER USING PSO ALGORITHM**

In this paper, to design the self-tuning adaptive and fuzzy load-frequency control system and to achieve a better performance of type-1 fuzzy controller, the PSO algorithm is used to optimize the membership functions parameters with the aim of minimizing system frequency deviations. In the studied system, ACE and ΔACE are considered as the input signals and as for the input signals, the output signals are used to change the set points in the load-frequency control problem.
4.1. PSO Algorithm

In this paper, a PSO algorithm is applied to optimize the membership functions of fuzzy type-1 controller. The optimization problem is defined as follows:

\[
\min f(x)
\]

subject to \( x_i \in X_i, i=1,2,3,... N \) \rightarrow (1)

In (1), \( f(x) \) is the objective function and \( x \) is the collection of the decision variables \( x_i \). The set \( X_i \) is the collection of possible range of variable \( x_i \) and \( N \) is the number of variables. The PSO optimization algorithm (Taher,2008; Kennedy & Eberhart, 1995) is one of the latest and strongest metaheuristic methods of optimization and has been used in solving complex problems up to now.

The PSO algorithm starts to work with a random population (i.e., particles) and then searches the optimal solution (particle) of the problem with each updated generation. Particle \( i \) is defined by its spatial position \( S_i \) and its velocity \( V_i \). At each stage of population movement, each particle is updated by tracking the two best positions.

The first one is the local best position, in terms of competence, which is obtained separately for each particle up to now. This value is \( P_{\text{best}} \). The second one is the global best position, obtained by all the particles among the population, up to now. This value is \( G_{\text{best}} \). After finding the values of the \( P_{\text{best}} \) and \( G_{\text{best}} \), each particle updates its new velocity and position based on the following equations:

\[
V_{i+1}^{k} = W V_{i}^{k} + C_{1} r_{1}(P_{\text{best}} - S_{i}^{k}) + C_{2} r_{2}(G_{\text{best}} - S_{i}^{k}) \rightarrow (2)
\]

\[
S_{i}^{k+1} = S_{i}^{k} + V_{i}^{k+1} \rightarrow (3)
\]

The problem convergence is dependent on the PSO algorithm parameters such as \( W, C_{1}, C_{2}, \) and \( W \) is the updating factor of the particles velocity. \( C_{1} \) and \( C_{2} \) are the acceleration factors, which are the same and are in the range of \([0, 2]\). \( r_{1} \) and \( r_{2} \) are two random variables uniformly distributed in the range of \([0, 1]\). \( W \) is the inertia weight and is constant in the PSO algorithm. In modified PSO, to strengthen the PSO algorithm performance and solve its disadvantages with updating \( W \), for obtaining the best reply in terms of the convergence velocity and accuracy in the optimization problem, the following equation is used:

\[
W^{k} = W_{\text{max}} + \kappa ((W_{\text{min}} - W_{\text{max}}) / \text{iterMax}) \rightarrow (4)
\]

In (4), \( W_{\text{min}} \) and \( W_{\text{max}} \) are the minimum and maximum values of the inertia weight, the iterMax is the maximum number of the algorithm iterations, and \( k \) is the current iteration of the algorithm. The inertia weight is varied by (4) and causes the convergence, which is defined as a variable in the range of \([0.2, 0.9]\). Because of updating the inertia weight with updating the particles velocity, the PSO algorithm has a perfect performance. In solving the optimization problem, the number of algorithm iterations has been reduced and the convergence power has been increased under the conditions of increased community members. Finally, the optimization algorithm is ended by the particles convergence to a certain extent. The optimal parameters of PSO algorithm used in this study are presented in Table 3.

<table>
<thead>
<tr>
<th>Swarm Size</th>
<th>( C_{1} )</th>
<th>( C_{2} )</th>
<th>( W )</th>
<th>iterMax</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>2</td>
<td>2</td>
<td>0.4-0.9</td>
<td>100</td>
</tr>
</tbody>
</table>

4.2. Implementation of the Proposed Method

In the proposed fuzzy type-1 controller for better performance, the processor parts of controller (\( K_{1}, K_{2} \) and \( K_{3} \)) are optimized in a specified range. The fuzzy type-1 controller consists of processor Parts is shown in Fig. 6.
Fig. 6 – The fuzzy type-1 controller with processor parts.

In proposed fuzzy type-1 controller, the parameters $K_1$, $K_2$ and $K_3$ are used to tune the controller for better performance in damping system frequency deviations.

The optimal and accurate performance of the fuzzy controller is determined by the membership functions. That means that if the best membership functions are selected for controller then the best performance of the controller is achieved. Thus, the PSO algorithm is used to determine the parameters of $K_1$, $K_2$ and $K_3$ considering the objective function of optimization problem in Fig. 7.

The objective function is chosen as the Integral of Time multiplied by Squared Error (ITSE) as follow:

$$\int_{t_0}^{t_f} (t \cdot |ACE^2(t)|) dt \rightarrow (5)$$

Fig. 7: Application of PSO algorithm considering objective function for optimization of proposed fuzzy type-1 controller.

V. SIMULATION RESULTS

Using PSO algorithm the optimal parameters of $K_1$, $K_2$ and $K_3$ are determined as Table 4. The curve of PSO algorithm convergence is presented in Fig. 8.

<table>
<thead>
<tr>
<th>Table 4</th>
<th>The Value of Parameters of $K_1$, $K_2$ and $K_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$K_1$</td>
</tr>
<tr>
<td>T1FLC</td>
<td>0.889</td>
</tr>
</tbody>
</table>

Fig. 8: curve of PSO algorithm convergence.

After determination of parameters of $K_1$, $K_2$ and $K_3$, the single area power system is simulated using PI and optimized fuzzy type-1 controllers and the result of simulation is shown in Fig. 9.
Fig. 9: Load frequency control of single area power system using PI and optimized fuzzy

Fig. 9 shows that the frequency deviations of the single area power system are damped by using the proposed optimized fuzzy type-1 controller in less settling time and maximum overshoot versus the PI controller. So the proposed fuzzy controller shows better performance in load frequency control of a single area power system.

VI. CONCLUSIONS

1. In this paper, the optimized type-1 fuzzy logic controller was proposed to solve the load frequency control problem of single area power system.
2. Using PSO algorithm the parameters of the membership function of type 1 fuzzy controller were optimized.
3. Simulation results show that the proposed type-1 fuzzy controller in damping of frequency deviations of power system has a better performance than the PI controller.

REFERENCES
