ALO Optimized multistage PDF plus (1+PI) controller for AGC of multi-area multi source non-linear power system

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Abstract
The research paper proposes a novel derivative filter based multistage controller and is well known as proportional derivative filter with unit gain complimented PI controller (PDF plus (1+PI) controller) to establish Automatic Generation Control (AGC) in an inter connected complex non-linear thermal and wind generating station based three area power network. Different non-linearity constraints like GDB and GRC are included to make non-linearity to the proposed network. In this proposed work to develop most accurate and close optimum of controller gain values; the proposed controller gain parameters are tunes by nature oriented optimization technique called Ant Lion Optimization (ALO) algorithm. While optimizing different gain parameters to develop least value oriented settling time and over shoot Integral of Time Multiplied Absolute Error (ITAE) has been used as fitness function for this analysis. To depict superior nature of our proposed controller a comparative analysis has been done among few other implemented controllers like conventional I, PI and PID controllers. Again a comparative observation is developed among different techniques like MFO, PSO and GA to impose Excellency of our proposed MFO algorithm. Finally the supremacy of ALO optimized proposed multistage controller is verified through random based step load pattern and are examined through different dynamic responses.

Keywords: Automatic generation control (AGC), Ant Lion Optimization (ALO), Integral of Time Multiplied Absolute Error (ITAE), Generation Rate Constraint (GRC), GDB (Governor Dead Band)

I. INTRODUCTION
Generated powers from different generating stations are inter linked through different tie lines and delivered to different level of consumers through transmission and distribution lines. The generation amount should always satisfy the net consumer demand and total line loss in order to provide reliable operation of the system. The control mechanism which maintains both active power generation and system frequency in response to total load demand of different consumer is known as automatic generation control (AGC) or automatic load frequency control (ALFC)[1-2]. AGC of multi area non-linear system is very important and also gives challenges to the power engineers. In this research article a complex wind thermal based three area model is considered for AGC analysis. In the research scenario of power system to develop AGC in three area system different secondary controllers [3] have been utilized for control mechanism purposes. Different advanced controllers like classical controllers PI, PID [4,5,6,7], Sliding mode controller(SMC)[8] and fuzzy logic controller[9,10] have been applied to reduce different error signals of the network for creating AGC in power network. In this research article a novel derivative filter based multistage unit gain oriented PDF plus (1+PI) controller is proposed for AGC analysis. In optimized research scenario to tune the gains of different implanted secondary controllers advanced optimization techniques like DE [11], CSA [12], TLBO 13[], Bat algorithm [14], Flower Pollination Algorithm[15], GA [16], hybrid PSO [17], have been utilized to tune the different controller gain values. Th main frame work of this proposed research work is as follows

a) A novel advanced derivative filter oriented unit gain added PI controller is proposed for controlling different error signals of three area network model for AGC analysis.

b) The above proposed controller gain variables are tuned by implementing nature oriented population based Ant Lion Optimization (ALO) technique.

SYSTEM INVESTIGATED
The considered network model for AGC analysis in this research article is a wind thermal based three area complex electrical networks. In this huge network each area consists of single thermal and renewable energy based wind power conversion system. Each area is assigned with a power rating of 2000MW where from total capacity thermal system is responsible for 80% and renewable energy based wind energy based power generation system participates for rest 20% for power generation. The system is considered as non-linearity in nature by introducing GDB, GRC and Boiler dynamics in the network model shown in fig1(a, b).In the proposed model GRC of thermal unit is ±3% per min is considered. The values of GDB are 0.05% is considered for thermal unit. In the present study back lash non-linearity is consider as GDB which produce oscillation for the natural period of 2
second. In this paper for stabilization proposed derivative filter based multistage controller and for comparison additional controllers like I, PI controller and PID controllers are taken individually. For analysis and supremacy variety of responses are developed in consideration with a step type load(SLP of 2%) at area one only. The model developed for this analysis is designed in simulation based MATLAB environment and simulated through linked optimization programming written in editorial window with .m file. The detailed model along with proposed controller is depicted in fig.1(a). The aim of this research is to maintain both system frequency and inter line power flow by implementing suitable intelligent techniques. In this three area inter connected power system the governor, reheat type turbine of thermal station and power system are expressed by their single time constant transfer function. Also individual blocks of wind power generation are expressed by their transfer function. According to this the transfer functions are expressed through different equations. Here equation (1) depicts the power balance equation of AGC. According to this

$$\Delta P_e(s) = \Delta P_{ref}(s) - \frac{\Delta f(s)}{R} \tag{1}$$

Equation (2) depicts Hydraulic actuator (Governor) Transfer function.

$$G_h(s) = \frac{\Delta P_e(s)}{\Delta P_f(s)} = \frac{1}{1 + T_H s} \tag{2}$$

Equation (3) depicts Turbine dynamics Transfer function. That is

$$G_r(s) = \frac{\Delta P_f(s)}{\Delta P_r(s)} = \frac{1}{1 + T_f s} \frac{1}{1 + s T_r K_r} \tag{3}$$

The dynamic nature based power system has been energised through generating system is expressed by equation (4)

$$G_p(s) = \frac{K}{1 + s T_p} \tag{4}$$

Here,

- $\Delta P_g$ = Regulated governor output power
- $\Delta P_{ref}$ = Regulated governor reference power
- $\Delta f$ = Variation in frequency

$$R = \frac{\Delta f}{\Delta P_g}, D = \frac{d \Delta P_g}{df}, T_p = \left( \frac{2H}{FD} \right)$$

H= Constant for inertia, T = Tie-line power coefficient.

The above Transfer function equations are for Thermal power station. Like this the wind generating station is modelled by its Transfer function equations.

The first stage Transfer function equation of wind generating station is described in equation (5)

$$G_1(s) = \frac{1}{T_{D1} s + 1} \tag{5}$$

Like this the second stage transfer function equation of wind generating station is described in equation (6)

$$G_2(s) = \frac{K_D (1 + s T_{D2})}{1 + s} \tag{6}$$

Like this the Third stage transfer function equation of wind generating station is described in equation (7)

$$G_3(s) = \frac{K}{1 + s} \tag{7}$$

Finally, $\Delta f(s) = G_p(s) (\Delta P_e(s) - \Delta P_{ref}(s) - \Delta P_{ne})$.

Tie-line power between ar1 and ar2 for this proposed model is depicted inequation (8)

$$\Delta P_{tie}(s) = \frac{2 \pi T}{s} (\Delta f(s) - \Delta f_2(s)) \tag{8}$$
1. Pdf Plus (1+Pi) Multistage Controller

The most favored controller in the area of engineering research is PID controller which is expressed through transfer function and
is

\[ T_{f_{PID}} = K_p + \frac{K_i}{s} + K_ds \]  

(9)

In complex and time variant non-linear network the conventional PID controller is unable to give superior performance due to some limitations. Though integral gain helps to reduce the steady state error of the response but presence of integral gain makes slower to the system and also reduce stability of the system in system transient conditions. So while designing controller proper selection of gain parameter with adequate tuned value is so important. So to give better output responses the parameter should be activated at proper time duration. It is required to inactive in integral gain of the controller during transient period to develop the dynamic response. To achieve such performance a derivative filter based unit gain oriented PDF plus (1+PI) controller is proposed in this article. In this controller the first stage includes a filter oriented PD controller and second stage includes unit gain based PI controller which is depicted in fig.2

![Fig2. Multistage PDF plus (1+PI) controller](image)

**II. Fitness function**

The purpose of the Fitness function is to find the best parameters of controller which minimizes the frequency deviation.

Optimization of controller gain parameter is associated with their corresponding fitness functions. The proposed fitness function helps to develop most superior responses in terms of their settling time and overshoot. From literature survey it has been studied that variety of fitness functions like ITAE (Integral of Time Multiplied Absolute Error), IAE (Integral of Absolute Error) and ISE (Integral of Squared Error) have been proposed in optimization scenario. This article has implemented ITAE as fitness function and is expressed through equation (10)

\[ J = \sum_{t=0}^{t_{sim}} [(\Delta f_1)+ (\Delta f_2)+ (\Delta f_3)+ (\Delta P_{tie})] dt \]  

(10)

Where

- \( \Delta f_1 \) = frequency deviation in area1
- \( \Delta f_2 \) = frequency deviation in area2
- \( \Delta f_3 \) = frequency deviation in area3
- \( \Delta P_{tie} \) = Incremental change in tie line power
- \( t_{sim} \) = time range of simulation.

**III. Ant Lion Optimizer (ALO)**

ALO is a population based nature oriented optimization technique whose technique of operational principle is specially depends on the hunting action of ant lions in natural environment. On their life period ant lions specially go through two different stages. The preliminary stage is larva phase and the second or terminated stage is adult phase. In the nature the larva phase is associated with the hunting behavior of ant lion and the followed adult phase is largely responsible for reproduction of ant lion. In the living style of ant lion to catch ants designed and smoothed cone shape holes are dug by the ant lions on the muddy earth surface. The holes are designed in such a way that once the ant felt down in the hole it will be easily caught by the lion at bottom of the hole. The principal operation of ALO technique is followed by five different steps. These steps are ants random movement, Hole structure, Trapping action of ants, catching to ants and Re build up of holes.

**Stage-I Ant’s random movement**

Ants always move randomly on their way to search different foods until to get suitable food. The random movement helps them to find food easily. The below equation depicts the random walking nature of ant.

\[ X(k) = [0, csum(2r(k) - 1), csum(2r(k_2) - 1), ... csum(2r(k_n) - 1)] \]

Here \( k \) = size of step, \( n \) = maximum number if ants, \( csum = \) cumulative sum.

Different matrices are used to hold the corresponding fitness value and positions. For this analysis matrix \( Pt \) and matrix \( Qr \) are notated to store their positions and fitness values respectively.

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Step- 2 Hole Construction
Initially a fittest ant lion is selected with the use of roulette wheel mechanism. The construction of hole is done in such a way that once the ant comes near the hole it slips down towards its bottom immediately. The sliding behaviour of the ant is expressed through different equations i.e.

\[ C^k = \frac{C_k}{I}, \quad I = 10^w \frac{i}{s}, \quad d^k = \frac{d_k}{I} \]

Here \( k \) = current iteration, \( s \) = maximum iteration of process.

\[
W = \begin{cases} 
2, & \text{if } t > 0.15 \\
3, & \text{if } t > 0.55 \\
4, & \text{if } t > 0.755 \\
5, & \text{if } t > 0.95 \\
6, & \text{if } t > 0.955
\end{cases}
\]

Step-3 Ant’s trapping behaviour
Whenever the ants are felt down in the cone shaped holes these are trapped by the Lions. The trapping behaviour is expressed through different equations.

\[
C^k_m = \text{Ant} - \text{lion}^k_n + C^k \\
da^k_m = \text{Ant} - \text{lion}^k_n + d^k
\]

Step-4 & 5 Catching and Re-build up holes
Whenever the ant comes down to the bottom of the hole it is easily caught by the lion. For next operation and for new hunting process the ant updates its position along with re-building the new holes. The entire process is developed through mathematical equations

\[
\text{Ant} \_\text{Lion}^k = \text{Ant}^k_m \text{if } \text{(Ant}^k_m \geq f(\text{Ant} \_\text{Lion}^k))
\]
IV. Result & Analysis

Frequency variation of area-1, area-2 & area-3 along with tie-line power variation ($\Delta P_{13}$) are plotted with different intelligence technique and with different controllers which shows the superiority of ALO based Multistage PDF plus (1+PI) controller.

Fig.4 Frequency deviation of (a) area-1 and (b) area-3 with different controllers having 2% step load perturbation in area-1.

Fig.5 Deviation of tie-line power between area-1 and area-3 with different controllers having 2% SLP at ar-1.
Fig. 6 (a) Frequency deviation of (a) area-1 with different algorithms having 2% step load perturbation in area-1.

Fig. 6 (b) Convergence curve

Fig. 7 (a) Random load pattern
Fig. 7 (b) Deviation of frequency in area 3 due to RLP at area 1 only

Table 1: Settling Time, Peak Overshoot and Peak Undershoot of $\Delta P_{12}$ with different controllers and different Algorithms

<table>
<thead>
<tr>
<th>Controller</th>
<th>Algorithm</th>
<th>PI</th>
<th>PID</th>
<th>Multistage 1+PI</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>GA</td>
<td></td>
<td>15.0202</td>
<td>14.8802</td>
<td>13.2628</td>
<td>Settling Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.00058</td>
<td>0.00054</td>
<td>0.00048</td>
<td>Peak Overshoot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.0058</td>
<td>-0.00568</td>
<td>-0.00462</td>
<td>Peak Undershoot</td>
</tr>
<tr>
<td>PSO</td>
<td></td>
<td>14.2122</td>
<td>13.8288</td>
<td>12.6208</td>
<td>Settling Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.00030</td>
<td>0.00028</td>
<td>0.00021</td>
<td>Peak Overshoot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.0034</td>
<td>-0.0027</td>
<td>-0.0028</td>
<td>Peak Undershoot</td>
</tr>
<tr>
<td>ALO</td>
<td></td>
<td>13.9872</td>
<td>11.0256</td>
<td>10.8600</td>
<td>Settling Time</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.00020</td>
<td>0.00018</td>
<td>0.0001</td>
<td>Peak Overshoot</td>
</tr>
<tr>
<td></td>
<td></td>
<td>-0.0032</td>
<td>-0.0026</td>
<td>-0.0011</td>
<td>Peak Undershoot</td>
</tr>
</tbody>
</table>

Table 2: Optimized values of different controller parameters with MFO Technique

<table>
<thead>
<tr>
<th>Controller</th>
<th>Multistage PID Controller</th>
<th>PID Controller</th>
<th>PI Controller</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parameters</td>
<td>$K_P$ $K_{PP}$ $K_I$ $K_D$</td>
<td>$N$ $K_P$ $K_I$ $K_D$</td>
<td>$K_P$ $K_I$</td>
</tr>
<tr>
<td>AREA1</td>
<td>-1.9986 1.9767 0.3992 -1.9971</td>
<td>76.6982 -1.6156 -1.9215 -1.9013</td>
<td>0.3034 -1.1639</td>
</tr>
<tr>
<td>AREA2</td>
<td>-0.2353 1.8408 0.1285 -1.9964</td>
<td>15.7962 -0.5681 -0.0327 -0.4573</td>
<td>-0.4668 -0.0350</td>
</tr>
<tr>
<td>AREA3</td>
<td>-1.9962 -0.7845 1.5415 -0.2862</td>
<td>87.9471 -0.6504 1.8382 -0.4641</td>
<td>0.4819 -1.6653</td>
</tr>
<tr>
<td>ITAE value</td>
<td>$4.168 \times 10^{-2}$</td>
<td>$8.697 \times 10^{-2}$</td>
<td>$131.54 \times 10^{-2}$</td>
</tr>
</tbody>
</table>
Table 3: Performance analysis of different optimization techniques with different signals and fitness function

<table>
<thead>
<tr>
<th>Technique/Performance</th>
<th>Multistage (1+PI) (ALO)</th>
<th>PID (ALO)</th>
<th>PI (ALO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΔF1</td>
<td>8.4523</td>
<td>0.4500</td>
<td>-1.9200</td>
</tr>
<tr>
<td>ΔF2</td>
<td>12.1634</td>
<td>0.3264</td>
<td>-0.6256</td>
</tr>
<tr>
<td>ΔF3</td>
<td>11.6218</td>
<td>0.3824</td>
<td>-0.8256</td>
</tr>
<tr>
<td>ΔP13</td>
<td>8.3244</td>
<td>0.8654</td>
<td>-6.6232</td>
</tr>
<tr>
<td>ΔP23</td>
<td>9.0876</td>
<td>0.9292</td>
<td>-7.1004</td>
</tr>
<tr>
<td>ITAE value</td>
<td>41.68 x 10^{-2}</td>
<td>42.80 x 10^{-2}</td>
<td>102.74 x 10^{-2}</td>
</tr>
</tbody>
</table>

V. Conclusion

In this proposed work AGC is developed in complex non-linearity based wind thermal oriented three area inter connected power network with introducing GDB and GRC non-linearity constraints. The analysis is done through matlab software and implementing different controllers like multistage PDF plus (1+PI) controller, PID controller, PI controller and I controller. It is observed from different figures and tables that Multistage PDF plus (1+PI) controller shows better performance in terms of settling time, over shoot and under shoot. Also it is not necessary to update the controller gains again while changing the different system parameters which reflect robust nature of the multistage controller. Besides this a Random Load Pattern (RLP) and a Noise load pattern is implemented in areal only for analysis of different system responses. Controller gains are simultaneously optimized with different meta-heuristic optimization techniques like ALO, PSO and GA and finally it observed that ALO depicts superior performance.

APPENDIX

Nomenclature & Values of the parameters

\[ a_{23} = -1, \Delta P_{32} = a_{23} \Delta P_{23} \]

Boiler Dynamics data

\[ K_1 = 0.85; K_2 = 0.095; K_3 = 0.92; K_{IB} = 0.03; \]
\[ T_{IB} = 26 \text{ Sec}; T_{RB} = 69; C_B = 200; T_B = 0; T_F = 10; \]

\[ \Delta P_D = \text{Variation in disturbance} = 0.01 \text{ P.u} \]
\[ a_{12} = \text{constant of value -1}, \Delta P_{21} = a_{12} \Delta P_{12} \]
\[ a_{13} = -1, \Delta P_{31} = a_{13} \Delta P_{13} \]

\[ \Delta \]

\[ \Delta \]

\[ \Delta \]

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\[ \Delta \]

\[ \Delta \]
Reference


