Adaptive Particle Swarm Optimization based Optimized PID Controller for Load Frequency Control

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ABSTRACT
Frequency deviation is one of major technical issue of a interconnected power system. In this paper an optimized Proportional-Integral-Derivative (PID) controller is proposed for controlling the frequency deviation. To optimize the gain values of controller, the Adaptive Particle Swarm Optimization (APSO) algorithm is utilized. Tuning of controllers is done in order to get the gain values or controller parameters such that the desired frequency and power interchange with interconnected systems. Controllers must possess the property of being sensitive against deviations in frequency. Tuning of proposed controller based on APSO algorithm is justified by making a comparison with PSO optimized PID and Conventional Ziegler–Nichols tuned PID controller.

Keywords— Load Frequency Control, PID Controller, Particle swarm optimization, Particle swarm optimization, Ziegler–Nichols method.

I. INTRODUCTION

Electricity is a commodity for power system. A power plant needs to keep an eye on the load conditions and serve consumers entire day. Uniform power generation throughout a day is not relevant. So depending on load power generation varies. The objective of control strategy is to generate and supply power in an interconnected system while maintaining the frequency and voltage within the limits. The frequency is mainly affected due to change in load, while reactive power depends on changes in voltage and is less sensitive to frequency.

To keep the frequency deviation zero a controller is utilized which controls the turbines used for tuning the generators and also the steady state error of system frequency is reduced. There are several types of control strategy like classical control, optimal control, variable structure control; artificial intelligence techniques based control strategies etc. From past so many decades classical control technique e.g. PI, PID control being utilized by power engineers due to its simplicity and robustness. But these classical controllers condemned by fixed optimum operating point. Proper tuned PID controller can overcome by this drawback. Bio-inspired algorithm can be utilized for this purpose. There are different bio-inspired algorithms for tuning of controller parameters for load frequency control of an interconnected power system like genetic algorithm, ant colony optimization, particle swarm optimization, etc. But most of these algorithms are difficult to implement because of their complexity. From past two decades PSO become popular due to its simple structure and easy implementation. It is also having ability to complex problems.

Here APSO based PID controller proposed for Load frequency control in which PID controller parameters are optimized using APSO and results also compared w.r.t. PSO based optimized PID controller and classical technique Ziegler–Nichols tuned PID controller. Comparison is done by selecting two performance indices, first one is peak undershoot and other one is settling time.

II. LOAD FREQUENCY CONTROL

A power system is a highly non-linear and complex system with different dynamic responses and characteristics. Several interconnected generating units supply a variety of loads across the huge geographical area through tie-lines. So, it is highly desirable to improve the performance of power system during normal and abnormal operations. But it is not that much easy task, due to constantly changing load, frequency as well as voltage instability and so many environmental disturbances. In real power systems, frequency instability may lead to systems fail. The frequency is closely related to the real power balance whereas voltage is related to reactive power. The real power and frequency control is referred as LFC [1].

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LFC is very important in power systems to supply reliable electric power at consumer end. However, on the consumers’ side, loads fluctuate randomly. Change in load demand leads to adjustment of generation so that there is power imbalance. To bring the power system in balance condition power generation need to control in same manner. So, this control is very important to nullify the unbalancing effects due to load fluctuation[2].

If there are changes in load then this will affect both frequency as well as bus voltages. LFC adjusts the power flow between different areas while keeping the frequency constant. LFC is actually a loop that regulates output in the range of megawatts and frequency of the generator [3]. LFC basically consists of two control loops; these are primary loop and secondary loop.

III. APSO OPTIMIZED PID CONTROLLER FOR LFC

Controller is a device, which monitor the variable and process them to alter the operating conditions. The fundamental of control loop can be simplified as in Fig. 2.

![Fig. 1 LFC for two area interconnected power system](image1)

![Fig. 2 Controller in closed loop with plant](image2)

A. PID Controller

There are different types of controllers based on their structure but from last few decades most popular controller utilized in power system applications is PID controller. The transfer function of the PID controller is given by,

$$U(s) = K_p \left(1 + \frac{1}{\tau_i s} + \tau_d s\right)$$  \hspace{1cm} (1)

Where, \(\tau_i\): Derivative time

\(\tau_d\): Integral time

PID controller combines the effect of proportional, derivative and integral components. Suitable value of proportional, integral and derivative gains give desired performances e.g. elimination of steady state error, fast
response, and low undershoot, less peak overshoot. PID controllers widely accepted for different industrial processes due to its simplicity and robustness.

### B. Ziegler–Nichols tuning Method for PID controller

The gains of PID controller can be tuned by classical ZN method, this is one of popular tuning method for PID controllers. The ZN method is a heuristic approach to tune PID controller and preferable for very complex system.

ZN method is based on selection of proper value of proportional gain at which sustained oscillation occurs, by which ultimate gain $K_u$ and oscillation period $T_u$ are obtained [4]. From ultimate gain and oscillation period the gains value of PID controller can be calculated, as per given below in Table I.

<table>
<thead>
<tr>
<th>Controller Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K_p$</td>
<td>$0.6K_u$</td>
</tr>
<tr>
<td>$K_i$</td>
<td>$1.2K_u/T_u$</td>
</tr>
<tr>
<td>$K_d$</td>
<td>$3K_uT_u/40$</td>
</tr>
</tbody>
</table>

### C. Objective Function

The objective function is the medium for finding optimum values of parameters by using optimization. Objective function based on error which is a function of error known as integral of the square of the error (ISE). ISE has the benefits of fast response [5]. ISE penalize large error over small errors. The objective function is,

$$ J = \int_0^\infty |e|^2 \, dt $$

(2)

Here for present system, the objective function is modified in such a way,

$$ J = \int_0^T |\Delta f_1|^2 + a|\Delta f_2|^2 + b|\Delta P_{tie}|^2 \, dt $$

(3)

Where $a$ and $b$ are weighting factors and $T$ is simulation time.

### IV. ADAPTIVE PARTICLE SWARM OPTIMIZATION

PSO is a stochastic population based optimization method based on swarm intelligence. It is originated by idea of the bird and fish flock movement behavior. PSO algorithm is first introduced by Kennedy and Eberhart in 1995 [6]. This algorithm is broadly used for so many applications because of its easy to implement.

Basic idea of PSO is while the birds in search of food from one place to another, there will always a bird that is moving close to food very well or having information of good food. Then birds will eventually flock to the place where food can be found, their movement is inspired by their best known position as well as flock best known position. As far as PSO algorithm is concerned, each bird position is compared to the best known position of swarm as well as their best known position, and the birds’ next move from one place to another root for development of the solution, good position is equal to most optimist solution.

$$ v_i^m(\text{iter} + 1) = w \cdot v_i^m(\text{iter}) + c_1 \cdot R_1(0,1) \cdot (p_{\text{best}}^m(\text{iter}) - x_i^m(\text{iter})) + c_2 \cdot R_2(0,1) \cdot (g_{\text{best}}^m(\text{iter}) - x_i^m(\text{iter})) $$

(4)

$$ x_i^m(\text{iter} + 1) = x_i^m(\text{iter}) + v_i^m(\text{iter} + 1) $$

(5)

Where, $\text{iter}$ Iteration number

$i$ Particle index

$m$ Dimension

$v_i^m$ Velocity of $i^{th}$ particle in $m^{th}$ dimension

$x_i^m$ $i^{th}$ Particle position in $m^{th}$ dimension

$g_{\text{best}}^m$ Swarm global best position in $m^{th}$ dimension

$p_{\text{best}}^m$ Particle best position of $i^{th}$ particle in $m^{th}$ dimension

$w$ Momentum

$c_1, c_2$ Acceleration constants

$R_1, R_2$ Random numbers with uniform distribution [0, 1]

After initial development of PSO by Kennedy and Eberhart up to now several variants of PSO algorithm have been proposed by researchers. Introduction of an inertia weight parameter in the velocity update equation of the initial PSO resulting in eq. (30), this PSO model which is now accepted as the global best PSO algorithm. Various inertia weighting strategies have been proposed by researchers. Initial inertia weighting strategies contains inertia weight either a constant value or randomly determined. Another type of inertia weighting strategies in which inertia weight is defined as a function of time or iteration number. But these strategies do not monitor the situation of the particles in the search space or lack of adaptiveness. So, later on another class of the inertia weight strategies introduced in which a feedback parameter to monitor the state of the algorithm and adjust the value of the inertia weight.

In proposed APSO approach, the inertia value has become adaptive based on the feedback. So, the velocity of particle can be fast or slow and particles position can approach the global optimum. This current approach is proposed in reference [7]. In this approach the inertia will be updated based on success hit to find new better position. Here, a flag is
introduced that will be updated when in each iteration on every particle new position is found better than its previous best known position. On each successful hit this flag will be incremented by one. And at end on iteration the flag will be averaged by number of particle in swarm and further inertia is updated based on eq. (8), as shown below:

\[
sc = \begin{cases} 
sc + 1; & \text{new position } > \text{pbest} \\
\text{No change}; & \text{otherwise} 
\end{cases}
\]  
\[sc_{avg} = \frac{sc}{\text{no of particles}} \]  
\[w = (w_{max} - w_{min}) \times sc_{avg} + w_{min} \]  

D. Pseudo Code for APSO

Setting lower and higher limits of position;  
Setting lower and higher limits of velocity;  
Setting size of swarm;  
Setting maximum numbers of steps;  
Setting problem dimensions;  
Setting acceleration constants;  
Setting initial value Inertia;  
Setting lower and higher values of Inertia;  
Initialize Population;  
while iter < max_iteration do  
\(sc = 0;\)
  for each particle do  
    Update the velocity using eq. (1);  
    Update position using eq. (2);  
    Evaluate the fitness of particle;  
    if \(f(x_i) < f(p_{best})\) then  
      \(p_{best} = x_i;\)
      \(sc = sc + 1;\)
    end if  
    if \(g_{best} < f(g_{best})\) then  
      \(g_{best} = g_{best};\)
    end if  
  end for  
  avg_sc = sc/size of swarm;  
  Inertia = (Inertia_{max} - Inertia_{min}) * avg_sc + Inertia_{min};  
  iter = iter + 1;  
end while

V. SIMULATION RESULTS

A. Tuning of PID controller

In this paper, tuning or optimization of PID controller is done through three method, these are Z-N method, PSO optimization and APSO optimization respectively. After 20 runs the best values of found by PSO and APSO optimization for PID tuning and these fitness values at every iteration is shown in Fig. 3. PID controller gains for different tuning or optimization algorithm have been shown in Table II.

![Fig. 3 Comparison of Fitness vs Iteration for PSO and APSO](image)

<table>
<thead>
<tr>
<th>PID controller gains for different controllers</th>
<th>PID controller for area-1</th>
<th>PID controller for area-2</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Z-N tuned PID</strong></td>
<td>1.0286</td>
<td>1.2939</td>
</tr>
<tr>
<td><strong>PSO optimized PID</strong></td>
<td>1.22</td>
<td>1.94</td>
</tr>
<tr>
<td><strong>APSO optimized PID</strong></td>
<td>1.54</td>
<td>1.94</td>
</tr>
</tbody>
</table>

E. System response at step load

At initial stage the system at balance condition, after sudden step load system will be unbalanced. In consequence the frequency at both areas will change and tie-line power will change. For this present system, the loads applied in both areas are 0.01p.u. and 0.02p.u. respectively. These changes from nominal values are shown in Fig. 4, 5. and 6. for deviation in frequency of area-1, area-2 and deviation in tie-line power error respectively.

![Fig. 4 Change in frequency of area-1 for different controller that ZN tuned PID controller, PSO optimized PID controller and APSO optimized PID controller](image)

![Fig. 5 Change in frequency of area-2 for different controller that ZN tuned PID controller, PSO optimized PID controller and APSO optimized PID controller](image)

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Fig. 6 Change in tie-line power connecting between area-1 and area-2 error for different controller that ZN tuned PID controller, PSO optimized PID controller and APSO optimized PID controller

**TABLE III  COMPARISON OF PEAK UNDERSHOOT FOR DIFFERENT CONTROLLERS**

<table>
<thead>
<tr>
<th>Controller</th>
<th>Z-N PID</th>
<th>PSO PID</th>
<th>APSO PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Af1</td>
<td>0.029245</td>
<td>0.025628</td>
<td>0.024614</td>
</tr>
<tr>
<td>Af2</td>
<td>0.020745</td>
<td>0.016807</td>
<td>0.016659</td>
</tr>
<tr>
<td>Apfc12</td>
<td>0.002839</td>
<td>0.002452</td>
<td>0.002160</td>
</tr>
</tbody>
</table>

Result in above figures shows that performance of three different controllers for LFC. In comparison, it is found that PSO optimized controller gives better results than Z-N tuned PID controller. In another comparison APSO PID controller performance shows much better results than PSO optimized PID controller. But these results for proper comparison need to quantify, for that two performance indices i.e. peak undershoot and settling time obtained from results as shown in Table III and IV.

**TABLE IV  COMPARISON OF SETTLING TIME FOR DIFFERENT CONTROLLERS**

<table>
<thead>
<tr>
<th>Controller</th>
<th>Z-N PID</th>
<th>PSO PID</th>
<th>APSO PID</th>
</tr>
</thead>
<tbody>
<tr>
<td>Af1</td>
<td>4.606644</td>
<td>3.952912</td>
<td>3.019415</td>
</tr>
<tr>
<td>Af2</td>
<td>5.187201</td>
<td>4.314669</td>
<td>3.577454</td>
</tr>
<tr>
<td>Apfc12</td>
<td>3.335983</td>
<td>2.017887</td>
<td>1.918869</td>
</tr>
</tbody>
</table>

VI. CONCLUSIONS

Maintaining the balance between the power generation and demand is most prime requirement of power system. It is challenging task to design a superior controller for minimize the frequency deviation. PID controller is suitable for this purpose, but hard to find gain values for optimum performance. In this paper, APSO is used to tune parameters of PID controllers. An interconnected two-area power system is taken into consideration for application of this proposed controller. The ISE is used for objective function. Different graphs of frequency as well as tie-line power error deviation were obtained by applying different step load demand of both areas. This graphs shows superiority of proposed control strategy over other method taken for consideration. Further results are quantified by means of two performance indices, these are peak undershoot and settling time and this comparison of performance indices shows supremacy of proposed optimization method for PID controller for LFC of two-area interconnected power system.

REFERENCES


