Performance Enhancement of Hydraulic Turbine Regulating System (HTRS) Using Multi Objective Ant Colony Optimization

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Abstract- In this paper a design method for performance enhancement of Hydraulic Turbine Regulating System(HTRS) proposed. A multi-objective Ant Colony Optimization algorithm is implemented to the PID controller of Hydraulic Turbine Regulating System (HTRS). Multi-objective controller design method is differ from single-objective optimization and it has more than one objective functions. In this paper ISE and ITSE are chosen as two objective functions. Objective is to achieve shortest rise time and minimum overshoot simultaneously.

Index Terms- HTRS, PID controller, Ant Colony Optimization, multi-objective function, speed regulation.

I. INTRODUCTION

Hydro power is an important and cost effective renewable energy source. It plays a significant role in today’s electricity generation, contributing to more than 16% of electricity generation worldwide and about 85% of global renewable electricity. Its benefits are very relevant in this environment condition. Primarily it is clean renewable electricity and secondly it is also enable to greater contribution of other renewables on the grid. Always the generation process is not smooth. Different disturbances are emerging and it drops the stable operation of the system that is the process is not a linear one. Hence there is a need for a regulatory system, it is called Hydraulic Turbine Regulatory System (HTRS). HTRS includes a governor, a controller, a turbine and a generator. Conventionally the controller used in the HTRS is a PID because of its structural simplicity and reliability.

II. REVIEW OF LITERATURE

Zhihuan Chen[1] focused on the design of the FOPID controller using chaotic non-dominated sorting genetic algorithm II (NSGAII) for hydraulic turbine regulating system (HTRS). The parameters chosen of the FOPID controller is formulated as a multi-objective optimization problem, in which the objective functions are composed by the integral of the squared error (ISE) and integral of the time multiplied squared error (ITSE). The chaotic NSGAII algorithm, which is an incorporation of chaotic behaviors into NSGAII, is used as the optimizerto search true Pareto-front of the FOPID controller and designers can implement each of them based on objective functions priority. The designed chaotic NSGAII based FOPID controller procedure is applied to a HTRS system. A comparison study between the optimum integer order PID controller and optimum fractional order PID controller is presented in this paper. The simulation and some experimental results validate the superiority of the fractional order controllers over the integer controllers Fang H.et.al.[2] used an intelligent meta-heuristic optimization methods for the controller design in the hydropower system. It recently received a lot of attentions from the contemporary researchers.

Coello CA.C.et.al [3] did an evolutionary multi-objective optimization algorithm, namely adaptive grid particle swarm optimization (AGPSO), issued for generating a solutions set for designing the PID controller in the HTR system. Naik KA.et.al. [4] observed a remarkable improvement in stability of this system with the IMC tuning method while compared with the traditional singular frequency based method and Ziegler-Nichols closed loop optimization. Pangao Kou [5] presented a new approach of Bacterial Foraging Optimization Algorithm (BFOA) is introduced in this study. To improve the precision of the identification process, a modified objective function is proposed based on the measurement of gate opening, mechanical torque and generator speed from a simulated model. The improved objective function (IOF) and the conventional objective function (COF) are used in the identification and two sets of parameters are derived and compared. The results show that BFOA is effective in identification of hydraulic turbine governor system and parameters derived from the modified objective function have a higher accuracy.

Kanasottu AN [6] introduced a remarkable improvement in stability of this system has been observed with the IMC tuning method while compared with the traditional singular frequency based method and Ziegler-Nichols closed loop optimization. Jagatheesan Kaliannan.et.al. [7] describe the application of an Artificial Intelligence (AI) optimization technique to design Proportional-Integral-Derivative (PID) controller for Load Frequency Control (LFC) of single area re-heate thermal power system.

Rajeev Kumar [8] studied different PID tuning formulas for a third order process. They are based on the knowledge of the ultimate gain, ultimate period and minimization of integral squared error (ISE) and integral absolute error (IAE). The performance of various tuning methods has been compared by applying a step input to the given process. Simulation results show that tuning a PID controller with Ziegler-Nichols (ZN) tuning method results in less rise time (tr), peak time (tp), and integral squared error (ISE). The Relay Auto tuning method...
is applicable when less ISE is required while Modulus Optimum (MO) tuning method is applicable when less settling time (t_s) and less overshoot is required and Computational Optimization (CO) method is helpful when the desired closed loop specifications are decided by the designer. The robustness factors gain margin (GM), phase margin (PM), gain crossover frequency, phase crossover frequency and stability are considered.

Chuanwen Jiang et al. [9] proposes an improved evolutionary programming (EP) method with deterministic mutation factor for on line PID parameters optimization of hydro turbogoverning systems. The mutation factors are usually generated with Gaussian or Cauchy random series in conventional evolutionary algorithms. The mutation factors are usually generated with Gaussian or Cauchy random series in conventional evolutionary programming algorithms. EnsiEnim et al. [10] treat a tuning of PID controllers using multi-objective ant colony optimization. The design objective was to apply the ant colony algorithm in the aim of tuning the optimum solution of the PID controllers (K_p, K_i, and K_d) by minimizing themulti-objective function. The potential of using multi-objective ant algorithms is to identify the Pareto optimal solution.

III. MODEL OF THE HYDRAULIC TURBINE REGULATING SYSTEM

Usually a hydro power plant consists of a reservoir, penstock, wicket-gate, water turbine with generator sets attached and the draft tube. Water from the reservoir flows through the penstock and then is regulated by means of guide wicket gates, which are always moved by hydraulic servo mechanism controlled by turbine speed controller. The controller acts when there is a mismatch between the torque developed by turbine and the electrical demand on the synchronous generator. HTRS is focused on the frequency control among the given speed reference r, controller output u, servomechanism device output y, water turbine mechanical torque output m_t, and flow rate q, conduit output h, and generator speed output x. In this section, a kind of non-linear models of HTRS has been studied and models of other components are added respectively. Read already published work in the same field.

3.1 Model of turbine governor

PID is the widely used controller for speed governing of HTRS. The transfer function of the PID controller is

\[ GPID(s) = K_p + \frac{K_i}{s} + K_d s \]  \hspace{1cm} (3.1)

K_p = Proportional gain, K_i = Integral gain, K_d = Derivative gain

3.2 Model of servomechanism

The servomechanism plays the role of actuator of water turbine. It is made up by the major servomotor and auxiliary servomotor, thus the model can be conducted as a first ordersystem.

\[ G_c(s) = \frac{1}{T_y(s)+1} \]  \hspace{1cm} (3.2)

Where, Ty is major servo time constant

3.3 Model of water turbine and penstock system

In HTRS, it usually considered water turbine and the penstock system as a whole. As flow rate is nonlinear to pressure, it is difficult to describe movement laws of fluid in the penstock. However, neglecting plant parameter changes and water column elasticity effect in the penstock, the transfer function of inelastic water hammer could be expressed as

\[ Gh(s) = \frac{h(s)}{q(s)} = T_w s \]  \hspace{1cm} (3.3)

Where, h(s) and q(s) are the Laplace transform of effective water head h and flow rate q. T_w is known as water response time constant.

The dynamic characters of turbine and penstock system can be expressed as

\[ G_t(s) = e^{-\frac{1-\text{em}T_w}{1 + \text{e}q h T_w s}} \]  \hspace{1cm} (3.4)

3.4 Model of generator system

Model of the synchronous generator used in this section is a simplified first order transfer function

\[ G_g(s) = \frac{1}{T_{as} + \text{en}} \]  \hspace{1cm} (3.5)

Where, Ta is the inertia time constant of generator, en is the adjustment coefficient of generator.

IV. MULTI-OBJECTIVE ANT COLONY OPTIMIZATION ALGORITHM ON HTRS

The ACO was first proposed by Marco Doriga, Vittorio a nezza and Alberto Colorni in 1995. The main duties to be done in an ACO algorithm are the solution construction, the management of pheromone trails, and the local search. In addition to that there is a need to initialize the data structure and parameters. The blind ant deposit a chemical substance called pheromone on their path for mutual communication. While each ant starts initially at random positions and each of them moves in search of food source, the one that finds food source first returns the nest first and that makes the shortest distance and more number of travels between the food and the nest. Thus the pheromone content becomes stronger and rest of them uses this path. ACO has been tested over various of problems such as traveling salesman problem, generation scheduling etc. ACO based real time optimization has started.

4.1 Application of Ant Colony Optimization for HTRS

The development of Ant Colony Optimization based algorithm can be described as follows. The various steps involved are

4.1.1 Data Initialization

In this step, (1) the instance has to be read, (2) the distance matrix has to be computed, (3) the pheromone matrix has to be initialized, (4) the ants have to be initialized, (5) the algorithm’s parameters must be initialized, (6) some variables that

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keep track of statistical informations such as the used CPU time, number of iterations, or the best solutions found so far, have to be initialized. A data initialization procedure is like as follows:

a) Initialize Data
b) Read instance
c) Compute Choice information
d) Initialize Ants
e) Initialize Parameters
f) Initialize Statistics
g) End-procedure

4.1.2 Solution Construction

The optimization is managed by the procedure Construct Solutions. It includes these phases; the ant's memory must be emptied. And deploying ants initially: In this task ants are randomly deployed in a feasible solution space with respect to the constraint. Here, the position of an ant represents one complete solution set of the problem. In this problem there are three parameters to be optimized, viz Kp, Ki, Kd. So the location of an ant is the point in the three dimensional space having axes Kp, Ki, Kd.

Each ant constructs a solution set at these procedure ants apply a Decision rule to find out the probability of next node from current node. At first the current node of each ant is determined. The probabilistic choice of next node is calculated by equation

\[ P_{ij}^A(t) = \frac{[\tau_{ij}]^\alpha[\eta_{ij}]^\beta}{\sum_{ij} [\tau_{ij}]^\alpha[\eta_{ij}]^\beta} \] (4.1)

ACO uses a pheromone matrix \( \tau = \tau_q \) for the construction of good solutions.

4.1.3 Local Search

Once the solutions are constructed, they may be updated by a local search procedure. Since the details of the local search are not important for understanding how ACO algorithms can be coded efficiently.

4.1.4 Pheromone Update

One of the critical steps in an iteration is the pheromone update. It includes two pheromone update procedures: Pheromone evaporation and pheromone deposit. The pheromone evaporation decreases the value of pheromone on the path of the ants by constant factor \( \rho \). The pheromone deposit adds the pheromone strength to the path of the ants. The pheromone content in the \( j \) position is given by the equation

\[ \tau_{ij}(t) = \rho \tau_{ij}(t-1) + \sum_{A=1}^{NA} (\Delta \tau_{ij}^A)(t) \] (4.2)

Where NA: number of ants, and \( \rho \) : the evaporation rate 0 < \( \rho \) < 1.

4.1.5 Termination Condition

The program stops if at least one termination condition applies. Usual termination conditions are: \( e(1) \) The algorithm has found a solution within a predetermined distance from a lower bound on the optimal solution quality. (2) A maximum number of tour constructions or a maximum number of algorithm iteration has been reached. (3) A maximum CPU time has been spent. (4) The algorithm shows stagnation behavior.

The flow chart for ACO algorithm is presented in Figure 4.1

4.1.6 Multi-Objective Function

The regulators used in HTRS are usually a PID controller. So the system performance strictly depends on the PID gain values. It is desirable to reduce rise time and decrease damped oscillations simultaneously. Thus, objective functions to be selected will carry the responsibility. Objective functions respected to the rise time and damped oscillations are considered for the optimization of PID controller. They are: Integral of squared error (ISE) and Integral of time multiplied squared error (ITSE).

\[ \text{ISE} = \int e^2(t) dt \] (5.1)

\[ \text{ITSE} = \int te^2(t) dt \] (5.2)

\( e(t) \) is the error signal and \( t \) is the time.

Objective function ISE tries to ensure shortest rise time and the second objective function ITSE tries to eliminate damped oscillations. Both objective functions must be minimized for effective operation of control loop. Lower value of ISE makes the system faster and minimizing ITSE ensures to eliminate oscillations.

VI. RESULTS AND DISCUSSION

The performance of the system with proposed ACO based HTRS has been examined through dynamic analysis for various system loading conditions such as no load and on load. The steps mentioned in the above chapter are used for HTRS design.
Dedicated program is developed in MATLAB for the implementation of the ACO algorithm. The system parameters taken are listed in table 6.2. The parameters used in the implementation of ACO are listed in table 6.1. Parameter variations of ACO based system under no load and on load are shown in figure 6.1 and Figure 6.2 respectively.

### Table 6.1 ACO data

<table>
<thead>
<tr>
<th>Running Condition</th>
<th>No load</th>
<th>On load</th>
</tr>
</thead>
<tbody>
<tr>
<td>ey</td>
<td>0.9080</td>
<td>1.40</td>
</tr>
<tr>
<td>eqy</td>
<td>0.7887</td>
<td>1.23</td>
</tr>
<tr>
<td>eh</td>
<td>1.4191</td>
<td>0.35</td>
</tr>
<tr>
<td>eqh</td>
<td>0.4571</td>
<td>0.15</td>
</tr>
<tr>
<td>en</td>
<td>0.45</td>
<td>0.45</td>
</tr>
<tr>
<td>Ta</td>
<td>12</td>
<td>5.72</td>
</tr>
<tr>
<td>Tw</td>
<td>0.83</td>
<td>0.83</td>
</tr>
</tbody>
</table>

### Table 6.2 System parameters

<table>
<thead>
<tr>
<th>Ant population</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of iterations</td>
<td>100</td>
</tr>
<tr>
<td>Evaporation constant</td>
<td>0.7</td>
</tr>
<tr>
<td>No. of nodes</td>
<td>10000</td>
</tr>
</tbody>
</table>

Figure 6.1 Parameter variation under no load condition

Figure 6.2 Parameter variation under on load condition
The step responses of the ACO based HTRS under no load condition and on load conditions are shown in Figure 6.3, Figure 6.4 respectively. The time domain specification of ACO based HTRS under no load and on load conditions are compared. Figure 6.5 shows the comparison.

Figure 6.3 No load step response of ACO based HTRS

Figure 6.4 No load step response of ACO based HTRS

Figure 6.5 Comparison of time domain specifications of ACO based HTRS under no load and on load conditions

VII. CONCLUSION

Ant Colony Optimization has been successfully employed in recent times for the optimal identification of system parameters. In this work multi-objective Ant Colony Optimization algorithm is proposed for the performance enhancement of Hydraulic Turbine Regulating System. The robustness and convergence characteristics of proposed algorithm based on the foraging behavior of ants are analyzed and presented. It is observed that all ants distributed in bounded solution space coherently converge to the global optima with lesser number of iterations as natural ants do while foraging. ACO ensures the better performance of the system with shortest Rise time and minimum Overshoot.

REFERENCES


[9] Chuanwen Jiang,Yuchao Ma,"PID controller parameter optimization of hydro-turbine governing system using deterministic chaotic mutation evolutionary programming".


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