Glowworm Swarm Optimization Technique for Optimal Power Flow

Rahul Dogra\(^1\) and Nikita Gupta\(^2\)

\(^1\)Executive Engineer, Siemens Limited India.
\(^2\)M.Tech Power Systems, Delhi Technological University, Delhi, India.
E-mail: \(^1\)rahul.robbby@gmail.com, \(^2\)guptanikita08@gmail.com

Abstract

This paper presents Glowworm Swarm Optimization (GSO) algorithm to solve the optimal power flow (OPF) problem. The objective is to minimize the fuel cost and keep the power outputs of generators, bus voltages, shunt capacitors/reactors and transformers tap-setting in their secure limits. Glowworm Swarm Optimization algorithm, enables a swarm of agents to split into subgroups, exhibit simultaneous taxis towards each other, and rendezvous at multiple optima (not necessarily equal) of a given multimodal function. In our problem the agents are generation values of the generator. The incorporation of the proposed method using GSO has been examined and tested for standard IEEE 30 bus system in MATLAB and its effectiveness is illustrated.

Keywords: Glowworm Swarm Optimization, optimal power flow, fuel cost.

1. Introduction

The optimal power flow of OPF has had a long history in its development. It was first discussed by Carpentier in 1962 and took a long time to become a successful algorithm that could be applied in everyday use. [1]In an OPF, the values of some or all of the control variables need to be found so as to optimize (minimize or maximize) a predefined objective. Objective function takes various forms such as fuel cost, transmission losses and reactive source allocation. The OPF methods are broadly grouped as Conventional and Intelligent.[2]The conventional methodologies include the well known techniques like Gradient method, Newton method Quadratic Programming method, Linear Programming method and Interior point method. They
have poor convergence, may get stuck at local optimum, they can find only a single optimized solution in a single simulation run and they become too slow if number of variables are large. To overcome the limitations and deficiencies in analytical methods, intelligent methods based on Artificial Intelligence (AI) techniques have been developed in the recent past. Intelligent methodologies include the recently developed and popular methods like Genetic Algorithm, Particle swarm optimization. The main advantages of Intelligent methods are: Possesses learning ability, fast, appropriate for non-linear modeling, etc [3].

In this paper optimal power flow using one of novel nature inspired technique known as Glowworm Swarm Optimization (GSO) is used. GSO is a popular swarm intelligent optimization technique proposed by K.N.Krishnanad and D.Ghose in 2005, which has received some interest recently, and mimics the behavior of glowworms glow to attract companions that can successfully find the global optimum and searching multiple optimum of multimodal function [4]. Now GSO algorithm is widely used in some spheres. Glowworm Swarm Optimization algorithm, enables a swarm of agents to split into subgroups, exhibit simultaneous taxis towards, and rendezvous at multiple optima (not necessarily equal) of a given multimodal function. This was basically inspired from the modified Ant Colony Optimization (ACO) with some significant differences. OPF using GSO helps us to find out the optimal value of generation of generators which will help us to minimize the cost function which is the objective function in our problem, keeping in view the different constraints that come in OPF [5].

2. Optimal Power Flow Problem Formulation

The standard OPF problem can be written in the following form, Minimize $F(x)$ (the objective function) subject to:

$$
\begin{align*}
  h_i(x) &= 0, \quad i = 1, 2, ..., n \text{ (equality constraints)} \\
  g_j(x) &= 0, \quad j = 1, 2, ..., m \text{ (inequality constraints)}
\end{align*}
$$

where $x$ is the vector of the control variables, that is those which can be varied by a control center operator (generated active and reactive powers, generation bus voltage magnitudes, transformers taps etc.) [5],[8]&[11]; the essence of the optimal power flow problem resides in reducing the objective function and simultaneously satisfying the load flow equations (equality constraints) without violating the inequality constraints. The most commonly used objective in the OPF problem formulation is the minimization of the total cost of real power generation. The individual costs of each generating unit are assumed to be function, only, of active power generation and are represented by quadratic curves of second order. The objective function for the entire power system can then be written as the sum of the quadratic cost model at each generator [1][2]&[3] given by eqn(1).

$$
F(x) = \sum_{i=1}^{ng}(ai + biPgi + ciP^2gi)
$$

Where $ng$ is the number of generation including the slack bus. $P_{gi}$ is the generated active power at bus $i$, $ai$, $bi$ and $ci$ are the unit costs curve for $ith$ generator. While minimizing the cost function, it’s necessary to make sure that the generation still
supplies the load demands plus losses in transmission lines. Usually the power flow equations are used as equality constraints, active and reactive power injection at bus \( i \) are defined in the following equation:

\[
P_i(V, \theta) = \sum_{j=1}^{n_{bus}} V_i V_j (g_{ij} \cos \theta_{ij} + b_{ij} \sin \theta_{ij}) \quad i = 2, n_{bus}
\]

\[
Q_i(V, \theta) = \sum_{j=1}^{n_{bus}} V_i V_j (g_{ij} \sin \theta_{ij} + b_{ij} \cos \theta_{ij}) \quad i = n_{pv} + 1, n_{bus}
\]  

(3)

The inequality constraints of the OPF reflect the limits on physical devices in the power system as well as the limits created to ensure system security. The most usual types of inequality constraints are upper bus voltage limits at generations and load buses, lower bus voltage limits at load buses, var. limits at generation buses, maximum active power limits corresponding to lower limits at some generators, maximum line loading limits and limits on tap setting of TCULs and phase shifter. Upper and lower bounds on the active generations at generator buses can be given by eqn (3)

\[
P_{gi} \min \leq P_{gi} \leq P_{gi} \max , \quad i=1, n_{g}.
\]  

(4)

Applications of a conventional optimization technique such as the gradient-based algorithms to a large power distribution system with a very non-linear objective functions and great number of constraints are not good enough to solve this problem.[6] Because it depend on the existence of the first and the second derivatives of the objective function and on the well computing of these derivative in large search space[12].

3. Glowworm Swarm Optimization

In the glowworm swarm optimization algorithm, glowworms are randomly placed in the objective function space, which contain a luminescent quantity called luciferin. The intensity of luciferin is associated with the objective function of glowworm’s location, and a greater luciferin mean better location and objective function value of glowworms[4]. Each glowworm has a local-decision domain that is bound by a radial sensor range. In the local decision domain, each glowworm finds neighbor and is attracted by the brighter glow of other glowworms in the neighborhood set, and the neighbor has the greater luciferin. The glowworm moves toward the brighter glowworm using a probabilistic mechanism. Also, local-decision domain size is variable that is affected by the number of neighbors. When the neighbor has the lower density, the local-decision domain will enlarge in favor of finding more neighbors; when the neighbor density is higher, the local-decision domain will reduce. Finally, the movement of glowworms will lead to majority gathering to multiple optima[5]&[6].

Entire process of GSO algorithm includes four steps: deployment of glowworms phase, luciferin-update phase, movement phase and local-decision domain update phase. Deployment of glowworms phase: in the phase, the purpose is to enable the glowworms to be dispersed in the entire objective space. Each glowworm contains equal quantity of luciferin and sensor range. Luciferin-update phase: during the luciferin update phase, each glowworm changes luciferin value according to the objective function value of their current location. The luciferin update rule is given by eqn(4):
\[ l_i(t + 1) = (1 - \rho)l_i(t) + \gamma f_i(t + 1) \]  

(5)

Where \( \rho \) (0 < \( \rho \) < 1) is the luciferin decay constant, \( l_i(t) \) is the luciferin enhancement constant and \( f_i(t) \) indicates the objective function value at glowworm i’s location at time t. Movement phase: during the movement phase, each glowworm selects a neighbor that has higher luciferin value and moves toward it using a probabilistic mechanism. The probability of glowworms i moving towards a neighbor j is based on the Eq. (2) at iteration t given by eqn(5):

\[ p_j(t) = \frac{(l_j(t)) - (l_i(t))}{\sum_{k \in N_j(t)} (l_k(t)) - (l_i(t))} \]  

(6)

Where \( l_i(t) \) is the luciferin value of glowworm i, \( d(i, j) \) is the Euclidian distance between glowworms i and j. The movement of glowworms i is as follows in eqn(6):

\[ x_i(t + 1) = x_i(t) + s \frac{x_j(t) - x_i(t)}{\| x_j(t) - x_i(t) \|} \]  

(7)

Where s is the step-size. Local-decision domain update phase: when the number of neighbor changes, local-decision domain needs update at each of iteration, local-decision domain update rule can be presented by the following equation (7)

\[ r_i(t + 1) = \min \{ r_s, \max \{ 0, r_i(t) + \beta (n_t - (N_i(t))) \} \} \]  

(8)

Where \( r_i(t + 1) \) is the local-decision domain of glowworm i at the t+1 iteration, \( \beta \) is a constant parameter that affects the rate of change of the neighbor domain, \( n_t \) is threshold that is used to control the number of neighbors [5].

4. GSO Applied to Optimal Power Flow

The GSO-based approach for solving the OPF problem to minimize the cost takes the following steps: First we fix the minimum and maximum value of each generator using the IEEE-30 bus system data that is we fix our workspace. Then we deploy the agents randomly in the workspace (here in our problem the agents are generation values of the generator). Then we give the parameters of GSO in our program for OPF using GSO, which are always fixed for every experiment. Then we formulate the objective function of the six generators (here in our problem formulation the objective function has been taken as cost function). Then we apply the stage of GSO named Luciferin Update phase using its standard formula. This step helps in updating the generation values of the entire individual generator. Then we calculate the probability of movement of agents towards each other. Then accordingly we give the movement step to the agents in the movement phase of OPF using GSO. Then we set the constraints required for the OPF, using the IEEE-30 bus data. Then we give the last phase of our algorithm i.e. the local decision domain range update rule, which helps in effective movement of agents so that they can capture the optimal value effectively. Then we simulate our program in MATLAB and get the final results.
5. Result of OPF Using GSO
The proposed GSO algorithm is tested on standard IEEE 30 bus system. The test system consists of 6 thermal units. The program was written and executed on Intel Core 2 Duo having 2.4 GHZ 3GB RAM. The optimal setting of the GSO control parameters are: $\rho = 0.4, \gamma = 0.6, \beta = 0.08$ and sensor range is 200.

Table 1: Values of parameters achieved using Glowworm optimization technique.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initial Cost of Generation</td>
<td>742.30 $/hr</td>
</tr>
<tr>
<td>Final Cost of Generation</td>
<td>425.90 $/hr</td>
</tr>
<tr>
<td>P1</td>
<td>61.37 MW</td>
</tr>
<tr>
<td>P2</td>
<td>23.23 MW</td>
</tr>
<tr>
<td>P3</td>
<td>33.37 MW</td>
</tr>
<tr>
<td>P4</td>
<td>29.47 MW</td>
</tr>
<tr>
<td>P5</td>
<td>28.68 MW</td>
</tr>
<tr>
<td>P6</td>
<td>15.63 MW</td>
</tr>
<tr>
<td>Time Taken</td>
<td>45.06 seconds</td>
</tr>
</tbody>
</table>

Fig. 1: Fuel cost variation.

6. Conclusion
In this paper for the sake of solving optimal power flow (OPF) problems one of novel nature inspired technique known as Glowworm Swarm Optimization (GSO) has been used for solution of optimal power flow problem of large distribution systems via a simple genetic algorithm. The objective was to minimize the fuel cost and keep the power outputs of generators, bus voltages, shunt capacitors/reactors and transformers tap-setting in their secure limits. GSO has been examined and tested for standard IEEE 30 bus system in MATLAB. We saw that our objective function i.e. cost function was minimized under the constraints and also we got the values of generation of different generator which would give optimum generation under different constraints.
References