Optimal Active and Reactive Power Dispatch Problem Solution using Grey-Wolf Optimizer Algorithm

Siddharth A. Parmar
Department of Electrical Engineering
L.E. College, Morbi (Gujarat) India
saparmar92@gmail.com

R. H. Bhesdadiya
Department of Electrical Engineering
L.E. College, Morbi (Gujarat) India
rhblec@gmail.com

Motilal Bhye
Department of Electrical Engineering
L.E. College, Morbi (Gujarat) India
mtbhoye@gmail.com

Indrajit N. Trivedi
Department of Electrical Engineering
GEC, Gandhinagar (Gujarat) India
forumtrivedi11@gmail.com

Pradeep Jangir
Department of Electrical Engineering
L.E. College, Morbi (Gujarat) India
pkjmtech@gmail.com

Arvind Kumar
Department of Electrical Engineering
S.S. College, Bhavnagar (Gujarat) India
akbharia8@gmail.com

Abstract—In this work, the most common problem of the modern power system named optimal power flow (OPF) is optimized using the novel meta-heuristic optimisation algorithm Grey Wolf Optimizer (GWO). GWO is inspired by natural hunting process of grey wolves. GWO has a fast convergence rate due to use of roulette wheel selection method. In order to resolve the optimal power flow problem, standard IEEE-30 bus system is used. GWO is implemented for the solution of proposed problem. The problems considered in the OPF problem are Active Power Loss Minimization and Reactive Power Loss Minimization. The results obtained by GWO is compared with other technique such as Particle Swarm Optimization (PSO). Results shows that GWO gives better optimisation values as compared PSO that confirms the effectiveness of the suggested algorithm.

Keywords- Optimal power flow, Reactive Power Loss, Power system Optimisation, Grey Wolf Optimizer.

I. INTRODUCTION

At the present time, The Optimal Power Flow (OPF) is very significant problem and most focused objective for power system scheduling as well as operation [1]. The OPF is the elementary tool which permits the utilities to identify the economic operational and much secure states in the system [2]. The OPF is one of the utmost operating desires of the electrical power network. The prior aim of the OPF is to evaluate optimum operational state of an electric network by minimizing a specific objective function within the limits of the operational constraints like equality constraints and inequality constraints [3]. Hence the Optimal power flow problem can be defined as a highly non-linear and non-convex multimodal optimisation problem [4]. From the past few years too many optimisation techniques were used to solve the Optimal Power Flow (OPF) problem [5]. Some traditional methods are used to solve the proposed problem have been suffered from some limitations like converging at local optima, not suitable for binary or integer problems and also have the assumptions like the convexity, differentiability, and continuity [6]. Hence these techniques are not suitable for the actual OPF situation [7]. All these limitations are overcome by meta-heuristic optimisation methods like BHBO, TLBO, LCA, etc.

In the present work, a newly introduced meta-heuristic optimisation approach named Grey Wolf Optimizer (GWO) is used to solve the problem of Optimal Power Flow. The GWO technique is a biological and sociological inspired algorithm. This technique is based on natural hunting process of grey wolves. [8]. The capabilities of GWO are finding the global solution, fast convergence rate due to use of roulette wheel selection, can evaluate continuous and discrete optimisation problems. In the present work, the GWO is implemented for standard IEEE-30 bus [10] test system to solve the OPF problem. There are two objective cases considered in this paper that has to be optimize using Grey Wolf Optimizer (GWO) technique are Active Power Loss Minimization and Reactive Power Loss Minimization [11]. The result shows the optimal adjustments of control variables in accordance with their limits. The results obtained using GWO technique has been compared with Particle Swarm Optimisation (PSO) technique. The results show that GWO gives better optimisation values as compared to different method which proves the strength of the suggested method.
II. OPTIMAL POWER FLOW PROBLEM FORMULATION

As specified before, OPF is a common power flow problem that provides the optimal values of control variables by minimizing a predefined objective function with respect to the operating bounds of the system. The OPF can be mathematically calculated as [3]:

\[
\text{Minimize} \{ f(a,b) \} \quad (1)
\]

Subject to \( s(a,b) = 0 \) \quad (2)

And \( h(a,b) \leq 0 \) \quad (3)

Where, \( b \) = vector of control variables, \( a \) = vector of state variables, \( f(a,b) \) = objective function, \( s(a,b) \) = set of equality constraints, \( h(a,b) \) = set of inequality constraints.

A. Variables

1. Control variables

These are the variables that may be adjusted to fulfill the power flow equations. The control variables can be represented as [3]:

\[
b^T = [P_{G1} \ldots P_{G_{NGen}} \ldots V_{G1} \ldots V_{G_{NGen}} \ldots Q_{G1} \ldots Q_{C_{NCom}} \ldots T_1 \ldots T_{NTr}] \quad (4)
\]

Where: \( P_G \) = real power output at the generator buses not including the slack bus. \( V_G \) = Voltage magnitude at generator buses. \( Q_C \) = Shunt VAR compensation. \( T \) = tap settings of the transformer. \( NGen, NTr, NCom \) = no. of generator units, the no. of transformers and the no. of shunt reactive power compensators, respectively.

2. State variables

The variables that need to characterize the operating state of the network. The set of state variables can be represented as [3]:

\[
a^T = [P_G, V_h, V_{NLB} \ldots Q_{G1} \ldots Q_{G_{NGen}}, S_{i1} \ldots S_{i_{Nline}}] \quad (5)
\]

Where: \( P_G \) = the real power generation at reference bus. \( V_L \) = the voltage at load buses. \( Q_G \) = the output of reactive power of all generators. \( S_i \) = the line flows. \( NLB \), \( Nline \) = no. of PQ buses, and the no. of lines, respectively.

B. Constraints

Power system constraints may be categorized into equality constraints and inequality constraints.

1. Equality constraints

The equality constraints reveal the physical behavior of the system. These constraints are [3]:

1.1 Real power constraints

\[
P_{Gj} - P_{Di} - V_{ji}^{NB} \sum_{j=1}^{NB} V_j G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij}) = 0 \quad (6)
\]

1.2 Reactive power constraints

\[
Q_{Gj} - Q_{Di} - V_{ji}^{NB} \sum_{j=1}^{NB} V_j G_{ij} \cos(\delta_{ij}) + B_{ij} \sin(\delta_{ij}) = 0 \quad (7)
\]

Where, \( \delta_{ij} = \delta_i - \delta_j \)

Where, \( NB \) = No. of buses, \( P_G \) = the output of active power, \( Q_G \) = the output of reactive power, \( P_D \) = real power load demand, \( Q_D \) = reactive power load demand, \( G_{ij} \) and \( B_{ij} \) = elements of the admittance matrix \( Y_{ij} = (G_{ij} + jB_{ij}) \) showing the conductance and susceptance among bus i and bus j, respectively.

2. Inequality constraints

The inequality constraints show the bounds on electrical devices existing in the power system plus the bounds formed to ensure system safety [3].

2.1 Generator constraints

For every generator together with the reference bus:

- Voltage, real and reactive outputs should be constrained by the minimum and maximum bounds as follows:

\[
V_{G1}^{lower} \leq V_{G1} \leq V_{G1}^{upper}, i = 1, \ldots, NGen \quad (8)
\]

\[
P_{G1}^{lower} \leq P_{G1} \leq P_{G1}^{upper}, i = 1, \ldots, NGen \quad (9)
\]

\[
Q_{G1}^{lower} \leq Q_{G1} \leq Q_{G1}^{upper}, i = 1, \ldots, NGen \quad (10)
\]

2.2 Transformer constraints

Transformer tap positions should be constrained inside their stated minimum and maximum bounds as follows:

\[
T_{G1}^{lower} \leq T_{G1} \leq T_{G1}^{upper}, i = 1, \ldots, NTr \quad (11)
\]

2.3 Shunt VAR compensator constraints

Shunt reactive compensators need to be constrained by their minimum and maximum bounds as follows:

\[
Q_{C1}^{lower} \leq Q_{C1} \leq Q_{C1}^{upper}, i = 1, \ldots, NGen \quad (12)
\]

2.4 Security constraints

These comprise the bounds of a voltage at PQ buses and line flows. Each load bus Voltage should not violate from its minimum and maximum operational bounds. Line loading over each line should not exceed to its maximum bounds. These limitations can be expressed as:

\[
V_{L1}^{lower} \leq V_{L1} \leq V_{L1}^{upper}, i = 1, \ldots, NLB \quad (13)
\]

\[
S_{i1} \leq S_{i1}^{upper}, i = 1, \ldots, Nline \quad (14)
\]

The inequality constraints comprise load bus voltage, the output of real power at reference bus, the output of reactive power and line flow may be encompassed as quadratic penalty functions.

Penalty function can be formulated as:

\[
J_{avg} = J + \tilde{c}_P \sum_{i=1}^{NTr} (P_{Di}^{lim} - P_{Di})^2 + \tilde{c}_Q \sum_{i=1}^{NGen} (Q_{Di}^{lim} - Q_{Di})^2 + \tilde{c}_V \sum_{i=1}^{NLB} (V_{Li}^{lim} - V_{Li})^2 + \tilde{c}_S \sum_{i=1}^{Nline} (S_{i1}^{lim} - S_{i1})^2 \quad (15)
\]

Where, \( \tilde{c}_P, \tilde{c}_Q, \tilde{c}_V, \tilde{c}_S \) = penalty factors

\( U_{lim} \) = Boundary value of the state variable U.

If U is greater than the maximum bound, \( U_{lim} \) takes the value of that one, if U is lesser than the minimum bound \( U_{lim} \) takes the value of that bound so:

\[
U_{lim} = \begin{cases} 
U_{upper} & \text{if } U > U_{upper} \\
U_{lower} & \text{if } U < U_{lower}
\end{cases}
\]

(16)
III. GREY WOLF OPTIMIZER

Grey wolf optimizer (GWO) based on natural hunting process of grey wolves [8]. Hunting process and dominance of wolves in troops shown top to bottom in fig. 1.

Figure 1. Wolves in a troop (top (highest dominant) to bottom (lowest dominant)).

- When $|\alpha|\geq 1$ diverge away from the prey.
- When $|\alpha|\leq 1$ suitable position ready to attack on the prey for target archive.

During the hunting, the grey wolves encircle prey. The mathematical model of the encircling behavior is presented in the following equation [8]:

$$\begin{align*}
\vec{D}_\alpha &= |\vec{C}_3 \times \vec{X}_\beta - \vec{X}| \\
\vec{X}_1 &= \vec{X}_\alpha - \vec{A}_1 \times (\vec{D}_\alpha) \\
\vec{X}_2 &= \vec{X}_\beta - \vec{A}_2 \times (\vec{D}_\beta) \\
\vec{X}_3 &= \vec{X}_\gamma - \vec{A}_3 \times (\vec{D}_\gamma) \\
\vec{X}(t+1) &= \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3}
\end{align*}$$

During the hunting, the grey wolves encircle prey. The mathematical model of the encircling behavior is presented in the following equation [8]:

$$\begin{align*}
\vec{D}_\alpha &= |\vec{C}_3 \times \vec{X}_\beta - \vec{X}| \\
\vec{X}_1 &= \vec{X}_\alpha - \vec{A}_1 \times (\vec{D}_\alpha) \\
\vec{X}_2 &= \vec{X}_\beta - \vec{A}_2 \times (\vec{D}_\beta) \\
\vec{X}_3 &= \vec{X}_\gamma - \vec{A}_3 \times (\vec{D}_\gamma) \\
\vec{X}(t+1) &= \frac{\vec{X}_1 + \vec{X}_2 + \vec{X}_3}{3}
\end{align*}$$

IV. APPLICATION AND RESULTS

The GWO technique is implemented to resolve the OPF problem for standard IEEE 30-bus test system and for a number of cases with various objective functions. The software program is inscribed in MATLAB 2013a and applied on a 2.60 GHz i5 PC with 4 GB RAM. In the present work the GWO population size or no. of search agents are selected to be 40.

IEEE 30-bus test system

With the purpose of elucidating the effectiveness of the suggested GWO technique, it is examined for the standard IEEE 30-bus test system. The IEEE 30-bus test system selected in this work has comprises [9], [10]: 6 generating units at buses 1,2,5,8,11 and 13, four transformers with off-nominal tap ratio at lines 6-9, 6-10, 4-12, and 28-27, nine shunt reactive compensators at buses 10,12,15,17,20,21,23,24 and 29.

In addition, the line data, bus data, generator data and the upper and lower bounds for the control variables are specified in [4], [11].

A. Case 1: Minimization of Active Power Losses

In the case 1 the Optimal Power Flow objective is to reduce the active power transmission losses, which can be represented by power balance equation as follows [5]:

$$J = \sum_{i=1}^{N_{Gen}} P_i = \sum_{i=1}^{N_{Gen}} P_{gi} - \sum_{i=1}^{N_{Gen}} P_{bi}$$

Figure 2. Minimization of Active Power Losses with Different Algorithms.
Fig. 2 shows the tendency for reducing the total real power losses objective function using the different techniques. The active power losses obtained with different techniques are shown in Table I which made sense that the results obtained by GWO give better values than the PSO and BHBO optimization methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Ploss (MW)</th>
<th>Method description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWO</td>
<td>2.958</td>
<td>Grey Wolf Optimizer</td>
</tr>
<tr>
<td>PSO</td>
<td>3.026</td>
<td>Particle Swarm Optimization</td>
</tr>
<tr>
<td>BHBO</td>
<td>3.503</td>
<td>Black Hole Based Optimization (5)</td>
</tr>
</tbody>
</table>

**TABLE I. OPTIMAL VALUE OF ACTIVE POWER LOSSES FOR DIFFERENT METHODS**

The accessibility of reactive power is the main point for static system voltage stability margin to support the transmission of active power from a source to sinks [5]. Thus, the minimization of VAR losses are given by the following expression:

\[ J = \sum_{i=1}^{N_{gen}} Q_i = \sum_{i=1}^{N_{gen}} Q_{g_i} - \sum_{i=1}^{N_{gen}} Q_{d_i} \]  

(29)

**B. Case 2: Minimization of Reactive Power Losses**

The statistical values of reactive power losses obtained with different methods are shown in Table II which displays that the results obtained by GWO are better than the PSO and BHBO optimization methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Qloss (MVAR)</th>
<th>Method description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWO</td>
<td>-24.630</td>
<td>Grey Wolf Optimizer</td>
</tr>
<tr>
<td>PSO</td>
<td>-23.407</td>
<td>Particle Swarm Optimization</td>
</tr>
<tr>
<td>BHBO</td>
<td>-20.152</td>
<td>Black Hole Based Optimization (5)</td>
</tr>
</tbody>
</table>

**TABLE II. OPTIMAL VALUE OF REACTIVE POWER LOSSES FOR DIFFERENT METHODS**

It is notable that the reactive power losses are not essentially positive. The variation of reactive power losses with different methods shown in Fig. 3. It demonstrates that the suggested method has good convergence characteristics.

**ACKNOWLEDGMENT**

Authors acknowledge financial support extended by World Bank and Government of Gujarat through TEQIP-II project. The authors would also like to thanks professor seyedali mirjalili for his valuable comments. GWO source code available at http://www.alimirjalili.com/GWO.html.

**REFERENCES**