An Application of Multi-Verse Optimizer for Optimal Reactive Power Dispatch Problems

Mohd Herwan Sulaiman 
Fakulti Kejuruteraan Elektrik & Elektronik 
Universiti Malaysia Pahang 
26600 Pekan, Pahang 
mherwan@ieee.org

Zuriani Mustaffa 
Fakulti Kejuruteraan Sistem Komputer & Kejuruteraan Perisian 
Universiti Malaysia Pahang 
26300 Gambang, Pahang 
zuriani@ump.edu.my

Mohd Rusllim Mohamed 
Fakulti Kejuruteraan Elektrik & Elektronik 
Universiti Malaysia Pahang 
26600 Pekan, Pahang 
rusllim@ump.edu.my

Omar Aliman 
Fakulti Kejuruteraan Elektrik & Elektronik 
Universiti Malaysia Pahang 
26600 Pekan, Pahang 
omaraliman@ieee.org

Abstract — This paper proposes a new algorithm namely Multi-Verse Optimizer (MVO) in solving the Optimal Reactive Power Dispatch (ORPD) problem. It is inspired from the three main concepts in cosmology viz. white hole, black hole and wormhole. These concepts are developed mathematically to perform exploration, exploitation and local search respectively. This algorithm is applied to obtain the best combination of control variables such as generator voltages, tap changing transformer’s ratios, reactive compensation devices as well as real power generation. In this paper, to show the effectiveness of MVO into ORPD problem, IEEE-30 bus system with 25 control variables is utilized and compared with recent algorithms available in literature. The result of this study shows that MVO is able to achieve less power loss than those determined by other techniques.

Keywords - loss minimization; multi-verse optimizer; nature inspired algorithms; optimal reactive power dispatch

I. INTRODUCTION

Optimal reactive power dispatch (ORPD) is one of the nonlinear and non-convex problems in power system planning and operation. Control variables or parameters for ORPD normally have close relationship with reactive power flow such as voltage magnitudes of generator buses, transformer tap ratios and reactive compensation elements [1]. In literature, there are several objective functions that have been addressed and assessed to achieve the successful of ORPD such as loss, voltage deviation and voltage stability index minimizations [2]. Nevertheless, for this paper, only loss minimization is used for objective function to overcome the ORPD problem. In order to achieve this objective, the stated control variables need to be controlled and set accordingly.

It is a nonlinear problems and difficult task since all the controlled variables need to be set simultaneously to achieve the minimum loss. That is why there are massive researches have been done to overcome this problem such as by using classical techniques including Newton techniques [3], sequential quadratic programming [4] and non-linear solver with penalty based [5].

Recently, many nature inspired algorithms have been proposed to solve ORPD such as grey wolf optimizer (GWO) [6], artificial bee colony (ABC) [1], harmony search algorithm (HSA) [2], particle swarm optimization (PSO) [7], honey bee mating optimization (HBMO) [8], gravitational search algorithm (GSA) [9] and many more to come.

This paper proposes the recent algorithm based on the universe cosmology concepts to solve ORPD problem. This algorithm has been proposed by [10]. The organization of this paper is as follows: Section 2 presents the ORPD formulation while brief description of MVO is discussed in Section 3. It is followed by the implementation of MVO into solving ORPD problem in Section 4. Section 5 presents the results and discussion and finally the conclusion is stated in Section 6.

II. OPTIMAL REACTIVE POWER DISPATCH

ORPD problem is one of the most complex problems in power engineering system which can be described as the minimization of function \( f(x, u) \) subject to the following expressions:

\[
\begin{align*}
    g(x, u) &= 0 \\
    h(x, u) &\leq 0
\end{align*}
\]  

(1)

where \( g(x,u) \) and \( h(x,u) \) are the equality and inequality constraints respectively, \( x \) is the dependent variables and \( u \) is the control variables. In this paper, the objective function of \( f(x, u) \) is to minimize the transmission loss system.
The equality constraint equation is the power balanced of load flows which are expressed as follow [2]:

\[
P_{G_i} - P_{D_i} = V_i \sum_{j} V_j (G_{ij} \cos \theta_{ij} + B_{ij} \sin \theta_{ij})
\]

\[
Q_{G_i} - Q_{D_i} = V_i \sum_{j} V_j (G_{ij} \cos \theta_{ij} - B_{ij} \sin \theta_{ij})
\]

(2)

The inequality constraints are represented in terms of operating constraints such as generators’ constraints (upper and lower bound), transformer tap setting as well as reactive elements’ upper and lower limits, expressed as follow [6]:

\[
P_{G_i}^{\min} \leq P_{G_i} \leq P_{G_i}^{\max} \quad i = 1, ..., N_G
\]

(3)

\[
V_{G_i}^{\min} \leq V_{G_i} \leq V_{G_i}^{\max} \quad i = 1, ..., N_G
\]

(4)

\[
T_{i}^{\min} \leq T_{i} \leq T_{i}^{\max} \quad i = 1, ..., N_T
\]

(5)

\[
Q_{C_i}^{\min} \leq Q_{C_i} \leq Q_{C_i}^{\max} \quad i = 1, ..., N_C
\]

(6)

where \(N_G\), \(N_T\) and \(N_C\) are number of generators, number of transformers and number of shunt compensators respectively. It is worth to highlight that in this paper that the MATPOWER software package [11] is utilized to obtain total transmission loss by running the load flow program in order to obtain the precise result.

III. MULTI-VERSE OPTIMIZER

MVO algorithm is inspired by the concept of multi-verse theory which consists of three verses: white holes, black holes and wormholes. In this algorithm, a population based is divided the search process into two phases: exploration and exploitation. White hole and black hole concepts are used as exploration and wormhole is treated as exploitation in this algorithm.

There are rules have been applied in MVO to the universe [10]:

a) The higher inflation rate, the higher probability of having white hole.

b) The higher inflation rate, the lower probability of having black holes.

c) Universes with higher inflation rate tend to send objects through white holes.

d) Universes with lower inflation rate tend to receive more objects through black holes.

e) The objects in all universes may face random movement towards the best universe via wormholes regardless of the inflation rate.

The conceptual of this algorithm is depicted in Fig 1.

The development of MVO initially can be described as the following expression:

\[
U = \begin{bmatrix}
x_1^1 & x_1^2 & \cdots & x_1^d \\
\vdots & \vdots & \ddots & \vdots \\
x_n^1 & x_n^2 & \cdots & x_n^d
\end{bmatrix}
\]

(7)

where \(U\) is a set of solution, \(d\) is the number of variables (dimension) and \(n\) is the number of universes (candidate of solution) which can be described as follows:

\[
x_i^j = \begin{cases} 
x_j^i & r_1 < NI(U_i) \\
x_j^i & r_1 \geq NI(U_i)
\end{cases}
\]

(8)

where \(x_i^j\) is the \(j\)th parameter of \(i\)th universe, \(U_i\) shows the \(i\)th universe, \(NI(U_i)\) is normalized inflation rate of the \(i\)th universe, \(r_1\) is a random number between 0 and 1, and \(x_i^j\) is the \(j\)th parameter of \(k\)th universe selected by a roulette wheel selection mechanism.

The universes keep exchanging objects without perturbation. To maintain the diversity of universes and to exploit the searching process in MVO, each universe is treated to have wormholes to transport its objects through space randomly. In order to provide local changes for each universe and have high probability of improving the inflation rate using wormholes, that particular wormhole tunnels are always established between a universe and the best universe formed so far, which can be described as follows:

\[
x_i^j = \begin{cases} 
X_j + TDR \times (ub_j - lb_j) & r_3 < 0.5 \\
X_j - TDR \times (ub_j - lb_j) & r_3 \geq 0.5
\end{cases}
\]

(9)

where \(X_i^j\) is the \(j\)th parameter of best universe formed so far, \(TDR\) (travelling distance rate) and \(WEP\) (wormhole existence probability) are coefficients, \(lb_j\) and \(ub_j\) are the lower bound and upper bound of \(j\)th variable respectively, \(x_i^j\) is the \(j\)th parameter of \(i\)th universe and \(r_2, r_3\) are random numbers.
between 0 and 1. WEP and TDR are treated as adaptive formula as follow:

\[
WEP = \min + l \times \left( \frac{\max - \min}{L} \right) \quad (10)
\]

\[
TDR = 1 - \frac{l^{1/p}}{L^{1/p}} \quad (11)
\]

where \(\min\) is the minimum (for this paper is set to 0.2), \(\max\) is the maximum (for this paper is set to 1), \(l\) is the current iteration, \(L\) is the maximum iterations and \(p\) is the exploitation accuracy over the iterations (for this paper is set to 6). The higher \(p\), the sooner and more accurate exploitation/local search [10].

It is worth to highlight that the MVO algorithm depends on number of iterations, number if universes, roulette wheel mechanism and universe sorting mechanism. Quicksort algorithm is used to sort universe at each iteration and roulette wheel selection is run for every variable in every universe over iterations. Details description of MVO can be obtained in [10].

IV. MVO FOR ORPD PROBLEM

The application of MVO in solving the ORPD is to find the optimal combination of control variables in order to achieve loss minimization by fulfilling all the constraints mentioned in section 2. Initially, the number of universe or search agents and maximum iteration are set. The universes (candidate for solution) is constructed in matrix form as depicted in eqn. (7) where the row represents the number of universes and the column represents the number of control variables to be optimized.

To obtain the objective function, each universe is mapped into the load flow data and then the load flow program using MATPOWER software package is executed to find the total transmission loss. Once the loss has obtained for respected universe (after updating the variables using eqns. (8-9)), the matrix is sorted where the best solution so far is located at the top while the worst result is located at the bottom of the population matrix. The updated position process is done by using roulette wheel selection. If the updated variables are out of bound from the constraints, they are pegged at the minimum or maximum boundaries so that the result obtained is correct. The implementation of MVO in solving ORPD is depicted in Fig. 2.

V. RESULTS AND DISCUSSION

In order to show the veracity and effectiveness of MVO in solving ORPD problems, the IEEE-30 bus system is utilized as the test system in this paper. The simulation was implemented in MATLAB.
total loss if MVO is compared with the ABC and MVO is slightly better compared to GWO. This table also shows that all control variables for all algorithms converged within their respective limits.

### Table I. Results for Optimized Control Variables for IEEE 30-Bus System

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower</td>
<td>Upper</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$P_1$</td>
<td>0.5</td>
<td>2</td>
<td>0.5462</td>
<td>0.516117</td>
</tr>
<tr>
<td>$P_2$</td>
<td>0.2</td>
<td>0.8</td>
<td>0.7863</td>
<td>0.79793</td>
</tr>
<tr>
<td>$P_3$</td>
<td>0.15</td>
<td>0.5</td>
<td>0.4903</td>
<td>0.5</td>
</tr>
<tr>
<td>$P_4$</td>
<td>0.1</td>
<td>0.35</td>
<td>0.3477</td>
<td>0.34933</td>
</tr>
<tr>
<td>$P_{11}$</td>
<td>0.1</td>
<td>0.3</td>
<td>0.2999</td>
<td>0.3</td>
</tr>
<tr>
<td>$P_{12}$</td>
<td>0.12</td>
<td>0.4</td>
<td>0.3945</td>
<td>0.4</td>
</tr>
<tr>
<td>$V_i$</td>
<td>1</td>
<td>1.1</td>
<td>1.0927</td>
<td>1.1</td>
</tr>
<tr>
<td>$V_j$</td>
<td>1</td>
<td>1.1</td>
<td>1.088</td>
<td>1.0981</td>
</tr>
<tr>
<td>$V_k$</td>
<td>1</td>
<td>1.1</td>
<td>1.0695</td>
<td>1.0766</td>
</tr>
<tr>
<td>$V_m$</td>
<td>1</td>
<td>1.1</td>
<td>1.0722</td>
<td>1.087</td>
</tr>
<tr>
<td>$V_{11}$</td>
<td>1</td>
<td>1.1</td>
<td>1.086</td>
<td>1.097</td>
</tr>
<tr>
<td>$V_{12}$</td>
<td>1</td>
<td>1.1</td>
<td>1.0926</td>
<td>1.1</td>
</tr>
<tr>
<td>$T_i$</td>
<td>0.9</td>
<td>1.1</td>
<td>0.9983</td>
<td>0.9912</td>
</tr>
<tr>
<td>$T_j$</td>
<td>0.9</td>
<td>1.1</td>
<td>0.9994</td>
<td>1.0402</td>
</tr>
<tr>
<td>$T_k$</td>
<td>0.9</td>
<td>1.1</td>
<td>0.9984</td>
<td>1.0332</td>
</tr>
<tr>
<td>$T_m$</td>
<td>0.9</td>
<td>1.1</td>
<td>1.0034</td>
<td>0.99125</td>
</tr>
<tr>
<td>QC$_{10}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0155</td>
<td>0.043587</td>
</tr>
<tr>
<td>QC$_{12}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0394</td>
<td>0.010303</td>
</tr>
<tr>
<td>QC$_{15}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0347</td>
<td>0.026824</td>
</tr>
<tr>
<td>QC$_{17}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0331</td>
<td>0.05</td>
</tr>
<tr>
<td>QC$_{20}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0332</td>
<td>0.00058404</td>
</tr>
<tr>
<td>QC$_{23}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0395</td>
<td>0.030001</td>
</tr>
<tr>
<td>QC$_{25}$</td>
<td>0</td>
<td>0.05</td>
<td>0.013</td>
<td>0.00056929</td>
</tr>
<tr>
<td>QC$_{32}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0371</td>
<td>0.045864</td>
</tr>
<tr>
<td>QC$_{30}$</td>
<td>0</td>
<td>0.05</td>
<td>0.0399</td>
<td>0.00438272</td>
</tr>
<tr>
<td>Total Loss (MW)</td>
<td></td>
<td>3.041</td>
<td>2.9377</td>
<td>2.9311</td>
</tr>
</tbody>
</table>

### VI. Conclusion

This paper has proposed a recent nature inspired computing algorithm, Multi-Verse Optimizer algorithm in solving ORPD problem. The effectiveness of MVO was demonstrated using IEEE 30-bus system. Simulation results showed that MVO is better compared to other selected algorithms in terms of finding the minimum power loss. The implementation of MVO into other objective functions such as voltage deviation as well as including the practical constraints related to generating units will be proposed in the near future.
Figure 5. Performance of various numbers of universe of MVO.

ACKNOWLEDGMENT

This research study is supported by Universiti Malaysia Pahang under UMP Research Grant #150362.

REFERENCES


