Economic Dispatch and Losses Minimization using Multi-Verse Optimizer on 150 kV Mahakam Transmission System

Yun Tonce Kusuma Priyanto
Electrical Engineering Department
Kalimantan Institute of Technology
Balikpapan, Indonesia

Muhammad Robith
Electrical Engineering Department
Kalimantan Institute of Technology
Balikpapan, Indonesia

***Abstract*-On this paper, Multi-Verse Optimizer (MVO) is proposed to solve multiobjective optimal power flow. This algorithm inspired from interaction of universes using black holes, white holes, and wormholes. This algorithm is used to solve multiobjective optimal power flow on 150 kV Mahakam transmission system on East Kalimantan. As comparison, PSO and FA would be used to solve the same problem. As seen on discussion section, each algorithm provide really competitive result at economic dispatch, losses minimization, and both. On the first case, MVO successfully solve the problem with most plausible result, reaching 442552.19 point. MVO also succeed solve the latter case and overcome another algorithms with 4.42 MW. On last case, MVO still solve the problem with the best result with 279499.774 point. From this results, MVO can be used to solve multiobjective optimal power flow.**

Keywords-Economic Dispatch, Losses Minimization; Multiobjective Optimization; Optimal Power Flow; Multi Verse Algorithm; Power Generation, Capacitors

I. INTRODUCTION

Population growth and technological advances are some causes that increases demand of electrical energy [13]. This demand increases faster than number of electrical energy resource discovered. To solve this problem, electrical energy must be managed optimally. Optimality of this management can be seen on many factors, two of them are their cost and power losses that happens on system. This problem categorized as Optimal Power Flow (OPF), where the aiming for the best combination of some variables like generated power and Static VAR Compensators (SVC). OPF problems are really flexible and complex problems [1]. This means that OPF problems may have many objectives to deal with, and these objectives may conflict each other. Until now, there are some methods proposed to solve this problem, from classical differentiation-based methods like Newton-Raphson method [2,3,4,6,8] to metaheuristic methods like Particle Swarm Optimization (PSO) [5,7]. However, first mentioned methods sometimes trapped on local optima. On the other hand, metaheuristic methods successfully overcome this problem. On this paper, new algorithm is proposed to OPF problems, called Multi-Verse Optimizer (MVO) [14,15]. This algorithm inspired from universes' interaction mechanism. This algorithm will be tested on 150 kV Mahakam transmission system on East Kalimantan, and will be compared with two well-known algorithms, PSO and Firefly Algorithm (FA) [9-12].

II. MULTIOBJECTIVE OPTIMAL POWER FLOW FORMULATION

Generally, every optimization problem can be represented using this following model:

$$\begin{aligned} &\text{minimize/maximize } f(x) \\ &\text{subject to } g(x) = 0 \\ &\qquad\qquad b(x) \le 0 \end{aligned} \tag{1}$$

On (1), f(x) is the objective function, where x is a vector containing all variables that can be controlled. g(x) and b(x) are constraints in equality or inequality forms, respectively. On this paper, cost and losses function are used as objective function. Objective function and constraints used here will explained on next section [8].

A. *Power Losses Function*

Power losses represented on this equation:

$$P_{loss} = \sum_{k=1}^{N_l} g_k \left[(t_k V_i)^2 + V_j^2 - 2 t_k V_i V_j \cos(\theta_i - \theta_j) \right] \tag{2}$$

On (2), V_i and V_j are voltage magnitude on bus i and bus j respectively; N_l is total branches; g_k is conductance of branch k; t_k is transformer tap ratio installed on branch k; θ_i and θ_j are voltage angle on bus i and bus j respectively.

B. *Cost Function*

Operational cost of a thermal generators modeled as a cost function based on real power generated by that generator. Mathematical model used is quadratic function as below:

$$F_e(P_g) = \sum_{i=1}^{N_g} \alpha_i + \beta_i + \gamma_i P_{gi}^2 \tag{3}$$

On (3), *α, β,* and *γ* are cost characteristic coefficients. P_{gi} is real power supplied by generator i and N_g is total generators.

C. *Real and Reactive Power Balance*

On power flow, (4) and (5) must hold, where P and Q are real and reactive power respectively. Gi, load, and losses indexes are tags to mark any variables above to generator i, load, and losses respectively.

$$\sum_{i=1}^{M} P_{Gi} = P_{load} + P_{losses} \quad (4)$$

$$\sum_{i=1}^{M} Q_{Gi} = Q_{load} + Q_{losses} \quad (5)$$

D. Constraints

These following inequalities are constraints used in this paper:

$$\mathrm{P}_{\mathrm{Gi}}^{\mathrm{min}} \le P_{Gi} \le P_{Gi}^{\max} \quad (6)$$

$$\mathrm{Q}_{\mathrm{Gi}}^{\mathrm{min}} \le Q_{Gi} \le Q_{Gi}^{\max} \quad (7)$$

$$\mathrm{Q}_{\mathrm{shunt\,i}}^{\mathrm{min}} \le \mathrm{Q}_{\mathrm{shunt\,i}} \le \mathrm{Q}_{\mathrm{shunt\,i}}^{\mathrm{max}} \quad (8)$$

$$\mathrm{t}_{\mathrm{i}}^{\mathrm{min}} \le t_i \le t_i^{\max} \quad (9)$$

On (6) to (9), P_{gi} is real power supplied by generator i, Q_{gi} is real power supplied by generator i, $Q_{shunt\text{-}i}$ is capacity of capacitor banks installed on bus i, and t_i is transformer tap ratio installed on branch i. min and max indexes are tags to mark any variables above to maximum and minimum values respectively. Inequality (6) represent real power constraint; inequality (7) represent reactive power constraint; inequality (8) represent capacity constraint on installed capacitor; and inequality (9) is transformer tap ratio constraint.

III. METHODOLOGY

A. Weighted Sum Method

Optimal solutions of multiobjective function are solutions from some objective functions simultaneously. To simplified those functions, weighted sum method is proposed. This methods combine all objective functions into a single objective function. For multiobjective optimal power flow in this paper, this method formulated as follow:

$$\mathrm{F} = \alpha\, \mathrm{w}_1 \mathrm{f}_1 + \beta\, \mathrm{w}_2 \mathrm{f}_2 \quad (10)$$

$$\alpha = \frac{\mathrm{f}_{\mathrm{ref\ max}}}{\sum_{\mathrm{k=1}}^{\mathrm{Nl}} P_{\mathrm{Losses\ Max}}} \quad (11)$$

$$\beta = \frac{\mathrm{f}_{\mathrm{ref\ max}}}{\sum_{\mathrm{i=1}}^{\mathrm{Ng}} \alpha_{\mathrm{i}} + \beta_{\mathrm{i}} + \gamma_{\mathrm{i}} \mathrm{P}_{\mathrm{gi}}^{2}} \quad (12)$$

$$w_1 + w_2 = 1 \quad (13)$$

On (10), $f_1(x)$ and $f_2(x)$ will be subtituted with (2) and (3). α and β are *penalty factor*. w_1 and w_2 are *weighting factors*, where $|w| \le 1$ and satisfy (13) [10].

B. Multi-Verse Optimizer

Multi-Verse Optimizer (MVO) founded by Seyedali Mirjalili on 2015 [14]. MVO is a new algorithm that inspired by interaction between universes with a mechanism known as black holes, white holes, and wormholes. There are some theories that explain universe's origin, one of them is Multi-Verse Theory. This theory states that there are other universes outside the universe that mankind live, where each universes interact each other. When interaction occurs, they interact using some mechanism known as black holes and white holes. These holes connect two different universes where an object enters black hole and come out through white hole. In addition to these holes, there are wormholes that connects two point on the same universe. MVO is created using these interaction described above. To convert this to a mathematical model, we apply these approachs:

- A galaxy is assumed as a combination of some objects (or variables) to be optimized. This algorithm search for a galaxy with the best objective value through some mechanisms.
- Probability of black holes or white holes existence on a galaxy determined from it's objective value. White holes probability is higher whenever it's objective value is far from optimum, and vice versa.
- Every objects has chances to moving randomly in the same galaxy.

Flowchart of this algorithm for multiobjective power flow is given in fig. 1. First operation executed is black and white holes mechanism. First, each galaxy are sorted based on their objective values, then normalized them. For each variable, we assign a variable form a galaxy randomly (not nessecary different). Randomly selected galaxy are chosen by roulette wheel method. This method chosen for provide variables from the best galaxy to others. This mechanism works like GA's crossover, but GA exchange their gen with others. Pseudocode of this mechanism is given at fig. 2.

Second operation executed is wormholes mechanism. On this mechanism, each variable may move randomly. There are two parameters used for this mechanism, Wormhole Existence Probability (WEP) and Travelling Distance Rate (TDR). WEP determine each variable move or not, and TDR determine how far they move. This movement following one of these equations:

$$x_{i,j} = X_{i,j} + \mathrm{TDR} \times \left(r3 \times \left(ub_j - lb_j\right) + lb_j\right) \quad (14)$$

$$x_{i,j} = X_{i,j} - \mathrm{TDR} \times \left(r3 \times \left(ub_j - lb_j\right) + lb_j\right) \quad (15)$$

Where $X_{i,j}$ is the best variable reached so far, ub and lb are upper and lower bound of that variable respectively. Constant value may be assigned for WEP and TDR, but these values may be vary following these equation:

$$\mathrm{WEP} = \min + l \times \frac{\max - \min}{L} \quad (16)$$

$$\mathrm{TDR} = 1 - \left(\frac{l}{L}\right)^{1/p} \quad (17)$$

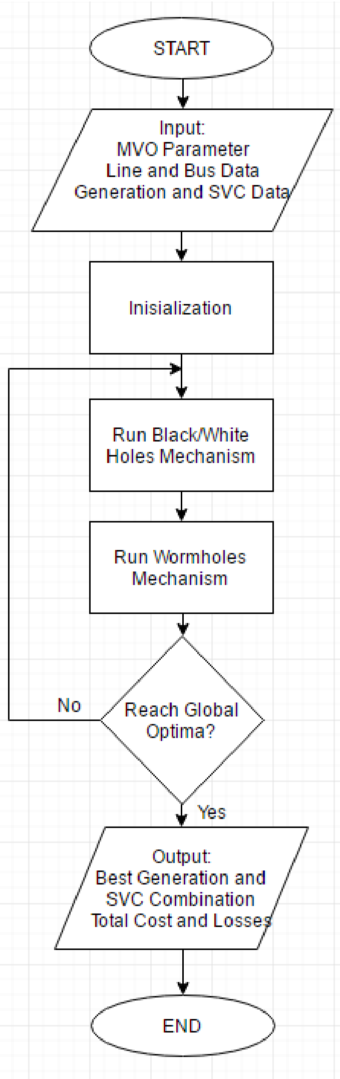

Fig. 1. Multi-verse optimizer flowchart for this paper

```
SG = sorted_galaxy
NF = normalized_fitness
for each galaxy indexed by i
    black_hole_index = i
    for each variable indexed by j
        r1 = random(0,1)
        if r1 < $NF(x_i)$
            white_hole_index = roulette_wheel(NF)
            G(i,j) = SG(white_hole_index,j)
        end if
    end for
end for
```

Fig. 2. Black and white hole mechanism

On (16) and (17), min and max are manimum and maximum values assigned for WEP. On this paper min = 0.2 and max = 1 are assigned. *p* describe algorithm's exploitation ability, where 6 is assigned on this paper. *l* and *L* are on-going and maximum iteration respectively. Pseudocode of this mechanism given on fig. 3.

IV. SIMULATION AND DISCUSSION

Input data, test cases, and algorithms used as comparison algorithm will be summarized before simulations started. Transmission system that would be used on this paper is 150 kV Mahakam transmission system on East Kalimantan. Single line diagram of this system given in fig.3. There are three test cases to be examined. They are economic dispatch, losses minimization, and both. Algorithms used as comparison algorithm on this paper are PSO and Firefly Algorithm (FA). On this paper, each algorithm using 20 search agents that searching for best combination for 10000 iterations, performed 10 times on 64-bit Intel Core i7-6700 computer with 16 GB RAM. Parameters used by all algorithms and cost characteristic functions of all generators shown in tables below.

```
apply (16) and (17)
for each galaxy indexed by i
    for each variable indexed by j
        r2 = random(0,1)
        if r2 < WEP
            r3 = random(0,1)
            r4 = random(0,1)
            if r4 < 0.5
                apply (14)
            else apply (15)
            end
        end if
    end for
end for
```

Fig. 3. Wormhole mechanism

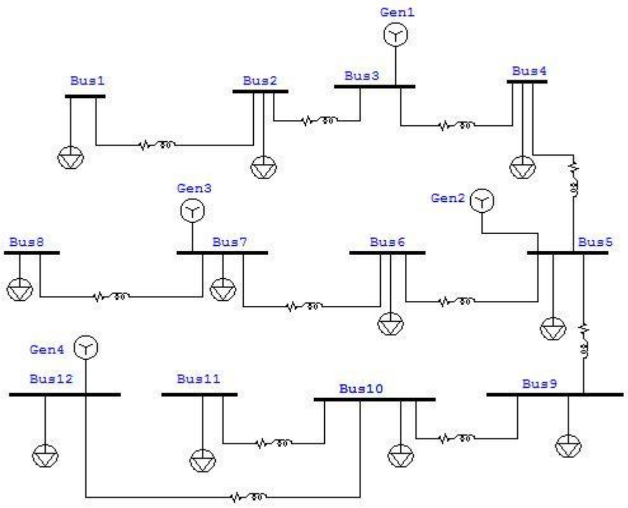

Fig. 4. 150 kV Mahakam transmission system single line diagram

TABLE 1. GENERATORS' COST CHARACTERISTIC FUNCTION

Generator	Cost characteristic function	Minimum Power	Maximum Power
Generator 1	$C_1 = -16{,}873\ P_1^2 + 2288{,}5P_1 – 1524{,}5$	41	100
Generator 2	$C_2 = 1658{,}7P_2$	20	80
Generator 3	$C_3 = 2213{,}2P_3$	11	190
Generator 4	$C_4 = 2628{,}8P_4$	1.74	50

TABLE 2. LOAD DATA FOR EACH BUS

Bus Number	Bus Code	Real Power Load (MW)	Reactive Power Load (MW)
1	0	56.164	18.396
2	0	60.925	19.374
3	2	0	0
4	0	49.622	11.519
5	2	23.264	4.385
6	0	77.442	32.866
7	1	57.116	8.033
8	0	18.747	4.790
9	0	18.331	6.368
10	0	11.179	2.785
11	0	23.439	9.759
12	2	15.452	4.541

TABLE 3. LINE IMPEDANCE DATA FOR EACH BUS

Bus Number		Resistance (p.u.)	Impedance (p.u.)	Supceptance (p.u.)
From	*To*			
1	2	0.058135	0.167716	0.002392
2	3	0.016497	0.048836	0.000825
3	4	0.016497	0.048836	0.000825
4	5	0.185652	0.549582	0.009285
5	6	0.020436	0.060498	0.001022
5	9	0.032907	0.094933	0.001354
6	7	0.038903	0.115164	0.001946
7	8	0.056216	0.162178	0.002313
9	10	0.017728	0.052480	0.000887
10	11	0.110800	0.328000	0.005541
10	12	0.221600	0.656000	0.011083

TABLE 4. MVO PARAMETERS

Parameter	Value
min	0.2
max	1
p	6

TABLE 5. PSO PARAMETERS

Parameter	Value
w	0.9
c1	0.1
c2	0.1

TABLE 6. FA PARAMETERS

Parameter	Value
beta	1
gamma	0.5

A. Test Case 1: Economic Dispatch

On the first case, each algorithms perform economic dispatch on 150 kV Mahakam transmission system. Table 5 and 6 shows simulation result of this case. From table 9, MVO and PSO provide adjacent power generation, while FA provide a little different result power generation 3 and 4. However, even each algorithms provide variative capacitor result, these algorithms provides competitive fitness values. MVO successfully overcome other algorithms, as seen on table 6. To obtain each algorithms' characteristic, fig. 5 provide the best fitness value reached each iterations from any randomly selected data, where MVO represented on blue curve, PSO on red curve, and FA on yellow curve. It can be seen that MVO actually can overcome all other algorithms near 1000th iterations and converge even at the start at process.

TABLE 5. OBTAINED VARIABLES FROM EACH ALGORITHM FROM TEST CASE 1

Variable	MVO	PSO	FA
Generation Power 1 (MW)	99.999	99.973	99.977
Generation Power 2 (MW)	79.910	78.672	79.428
Generation Power 3 (MW)	110.92	112.570	101.19
Generation Power 4 (MW)	2.2490	1.996	11.847
SVC 1 (MVAR)	28.302	19.858	38.092
SVC 2 (MVAR)	18.310	48.716	35.159
SVC 3 (MVAR)	19.266	10.283	27.068
SVC 4 (MVAR)	39.385	21.040	42.041
SVC 5 (MVAR)	27.372	27.964	20.575

TABLE 6. TEST CASE 1 SIMULATION RESULT

Method used	Best Fitness
MVO	442552.19
PSO	443506,526
FA	445471.413

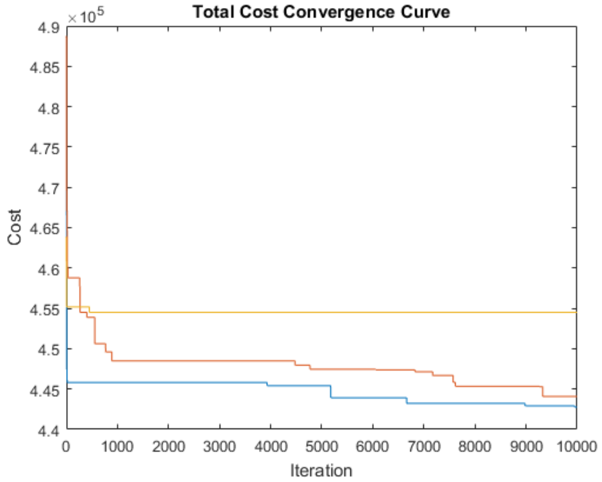

Fig. 5. Total cost convergence curve

B. Test Case 2: Losses Minimization

On the second case, each algorithms perform losses minimization on 150 kV Mahakam transmission system. Table 7 and 8 shows simulation result of this case. From these tables, each algorithm give adjacent result on all generation power, but slightly different SVC results. However, each algortihm provides really competitive fitness value. MVO successfully overcome other algorithms, as seen on table 8. To obtain each algorithms' characteristic, fig. 6 provide the best fitness value reached each iterations from any randomly selected data, where MVO represented on blue curve, PSO on red curve, and FA on yellow curve. It can be seen that MVO sometimes get another best fitness value, different than other algorithms that can converge at the start of iteration.

TABLE 7. OBTAINED VARIABLES FROM EACH ALGORITHM FROM TEST CASE 2

Variable	MVO	PSO	FA
Generation Power 1 (MW)	99,999	99,828	99,883
Generation Power 2 (MW)	79,985	79,565	79,260
Generation Power 3 (MW)	93,196	89,957	91,512
Generation Power 4 (MW)	18,839	22,809	21,457
SVC 1 (MVAR)	24,090	27,151	29,034
SVC 2 (MVAR)	23,013	32,392	20,631
SVC 3 (MVAR)	10,209	22,313	13,298
SVC 4 (MVAR)	35,921	48,418	49,444
SVC 5 (MVAR)	24,295	13,703	47,066

TABLE 8: TEST CASE 1 SIMULATION RESULT

Method used	Best Fitness
MVO	4.42
PSO	4.513
FA	4.56

C. Test Case 3: Economic Dispatch and Losses Minimization

As the last test case, all algorithms would be used to solve multiobjective optimal power flow on same transmission system, where both Economic Dispatch and Losses Minimization melted into a single objective function by weight sum method. Table 9 and 10 shows simulation result of this case. From table 9, one can see that these results has almost the same characteristic with results on test case 1. MVO gives the minimum fitness value than others, as seen on table 10. To obtain each algorithms' characteristic, fig. 7 provide the best fitness value reached each iterations from any randomly selected data, where MVO represented on blue curve, PSO on red curve, and FA on yellow curve. It can be seen that result of this case is almost the same with previous case.

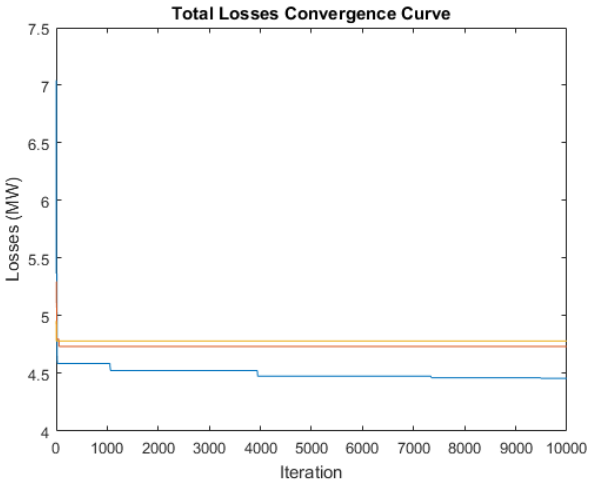

Fig. 6. Total losses convergence curve

TABLE 9: OBTAINED VARIABLES FROM EACH ALGORITHM FROM TEST CASE 3

Variable	MVO	PSO	FA
Generation Power 1 (MW)	100	99,846	99.978
Generation Power 2 (MW)	80	79,319	79.622
Generation Power 3 (MW)	95.689	96,224	94.283
Generation Power 4 (MW)	22.335	16,683	18.225
SVC 1 (MVAR)	2.869	23,956	22.203
SVC 2 (MVAR)	32.728	21,581	40.113
SVC 3 (MVAR)	8.948	4,767	29.834
SVC 4 (MVAR)	38.725	23,425	45.350
SVC 5 (MVAR)	31.029	12,323	26.731

TABLE 10: TEST CASE 3 SIMULATION RESULT

Method used	Best Fitness	Total Cost	Power Losses (MW)
MVO	279499.774	448513.690	4.470
PSO	280474.940	447149.492	4.472
FA	280982.273	447265.95	4.507

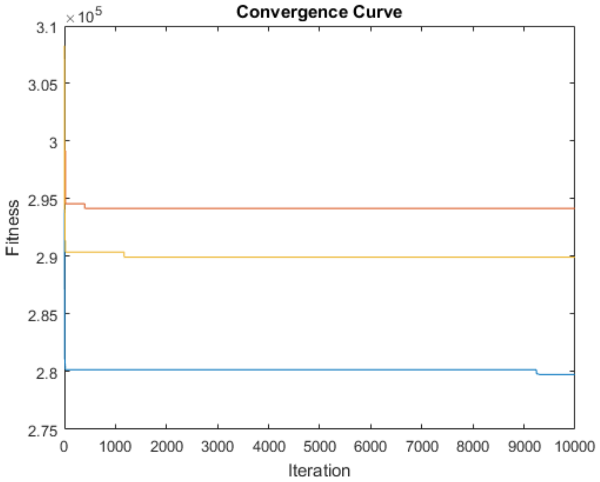

Fig. 6. Test case 3 convergence curve

V. CONCLUSION

On this paper, a new algorithm is proposed to solve multiobjective optimal power flow. This algorithm called Multi-Verse Optimizer (MVO). This algorithm inspired from interaction of universes using black holes, white holes, and wormholes. This algorithm is used to solve multiobjective optimal power flow on 150 kV Mahakam transmission system. As comparison, PSO and FA would be used to solve the same problem. As seen on discussion section, each algorithm provide really competitive result at economic dispatch, losses minimization, and both. Each algorithms provide almost the same result on generation power on each generator, but really different SVC values, that proves non-linearity of each cases. MVO successfully overcome other algorithms on each cases. This makes MVO as a option to solve any multiobjective optimal power flow.

REFERENCES

1. Dommel, H.W., Tinney, W.F. (1968). *Optimal power flow solution*, IEEE Transactions on Power Apparatus and Systems, PAS-87(10), 1866-1876.
2. Sun, D.I., Ashley, B., Brewer, B., Hughes, A., Tinney, W.F. (1984). *Optimal power flow by Newton approach*. IEEE Transactions on Power Apparatus and Systems, PAS-103(10), 2864-2880.
3. Santos A, da costa GR. (1995). *Optimal power flow by Newton's method applied to an augmented langrangian function*. IEE Proc Gener Transm Distrib, 33-36
4. Wood, A.J., Wollenberg, B.F. (1996). *Power generation operation and control*, NJ: John Wiley & Sons Ltd.
5. Abido, M.A (2002), *Optimal power flow using particle swarm optimization*, International Journal of Electrical Power and Energy System, 24(7), 563-571.
6. Saadat, H. (2004). *Power system analysis (2nd edition)*, NY: McGraw-Hill
7. Roy. R., Ghoshal, S.P. (2008). *A novel crazy swarm optimized economic load dispatch for various types of cost function*, Electrical Power and Energy Systems 30(4), 242-253.
8. Zhu, J. (2009). *Optimization of power system*, NJ: John Wiley & Sons
9. Yang, X.S. (2009). *Firefly algorithms for multimodal optimization*, in: *Stocasthic Algorithms: Foundations and Applications*, 5792, 169-178
10. Yang, X.S. (2010). *Engineering optimization: An introduction with metaheuristic applications*, NJ: John Wiley & Sons
11. Yang, X.S. (2010). *Firefly algorithm, L'evy flights and global optimization*, in: *Research and development in intellegent systems*, 209-218
12. Yang, X.S. (2010). *Firefly algorithm, stochastic test function, and design optimization*, Int. J. Bio-Inspired Computation, 2(2), 78-84
13. Priyanto, Y.T.K., Hendarwin, L. (2015). *Multi objective optimal power flow to minimize losses and carbon emission using wolf algorithm*, International Seminar on Intelligent Technology and Its Applications.

14. Mirjalili, S., Mirjalili S.M., Hatamlou, A. (2015). *Multi-Verse Optimizer: a nature-inspired algorithm for global optimization*. Neural Comput. & Applic. http://dx.doi.org/ 10.1007/s00521-015-1870-7
15. Jangir, P., Parmar, S.A., Trivedi, I.N., Bhesdadiya, R.H. (2016). *A novel hybrid Particle Swarm Optimizer with multi verse optimizer for global numerical optimization and Optimal Reactive Power Dispatch problem*. Eng. Sci. Tech., Int. J. http://dx.doi.org/10.1016/j.jestch.2016.10.007