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Research paper

Loss Minimization in Optimal Reactive Power Planning (ORPP) Based on Whale Optimization Algorithm

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Abstract

The key of RPP is the optimal allocation of reactive power considering location and size. This paper presents the loss minimization in optimal reactive power planning (ORPP) based on Whale Optimization Algorithm (WOA). The objective is to minimize transmission loss by considering several load conditions at bus 3, bus 15 and bus 21. Reactive Power Scheduling (RPS) and Transformer Tap Changer Setting (TTCS) were set as the control variables. Validation was conducted on the IEEE 30 Bus RTS. Results from the study indicate that the proposed WOA can minimize transmission loss better than Evolutionary Programming (EP).

Keywords: *Loss Minimization; Optimal Transformer Tap Changer Setting; Reactive Power Planning; Whale Optimization Algorithm*

1. Introduction

Nowadays, optimization has become one of the concerns in all aspects [1]. Recent optimization able to solve lots of complex mathematical formula including solving power system problem. The optimal value able to save annual cost besides making the system becomes more stable and sustainable.

Reactive Power Planning (RPP) indicates an optimal size of reactive power source allocation [2]. Conventionally, the allocation of new VAR sources was estimating or assumed due to a complex formulation and solution algorithm. As a large-scale non-linear programming problem [3], the optimal reactive power in power system is a part of general problem in power system control. That is the reason for RPP were defined as most challenging problems in power system [4]. There are several conditions need to be considered include assuming the system is balance. Besides that, it can assume that the size of the VAR source treated as a continuous variable by the same time in fact it is discrete. This problem had significant influence on secure and economic operation of power system [5].

In order to sustain the desired levels of voltage profile and reactive power flow, the operators may employ a number of control tools such switching power generator, VAR sources and transformer tap changing [6]. The real power transmission losses, reactive power losses, cost of investment can minimize by adjusting those control tools. In order to perform ORPP, two techniques that are Reactive Power Scheduling (RPS) and Transformer Tap Changer Setting (TTCS), were considered. Through RPS, the actual reactive power needed was able to regulate for minimizing transmission loss. Meanwhile, in TTCS, it will alter transmission line properties affecting I^2R loss [7].

Due to the swelling of the reactive power loading, the transmission loss also increases. At the same time, it will make the system operate in dangerous situation and collapse. Based on the [8], the analysis of RPP is one of the most complex problems in power systems, as it requires achieving an objective function. Through findings, a meta-heuristic optimization algorithm capable to solve Reactive Power Planning (RPP) in power system. The literature shows that there is a numerous type of optimization either conventional or not, able to solve the RPP problems such as Linear Programming (LP), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and also Different Search Algorithm (DSA). Reference [9] describe on optimal reactive power planning using improved differential evolution (IDE). It compares the findings with Evolutionary Programming (EP). Besides that, reference [10][11][12][13] describe on another method for solving RPP includes Particle Swarm Optimization (PSO), risk analysis, and modified Genetic Algorithm.

In this paper, a new method for determining loss minimization was proposed. This paper presents the loss minimization in optimal reactive power planning (ORPP) based on Whale optimization algorithm (WOA). A comparative study was conducted with respect to Evolutionary Programming (EP), performed on the IEEE 30 Bus RTS.

2. Whale Optimization Algorithm (WOA)

2.1. Brief Review of Whale Optimization Algorithm

Whale Optimization Algorithm (WOA) is one of the newest nature-inspired optimization technique. This algorithm was introduced by Syedali Mirjalili in 2015. WOA simulates the behavior of the humpback whale that has many fascinating points, especially in their social behaviors [14]. The most special about humpback

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whale is their hunting method called bubble-net feeding method. The movement of the humpback whale is illustrated in Figure 1.

The hunting begins emitting high pitch calls that cause the fish flee to the surface. Then, the whale starts to release bubbles in a circle or 9-spiral shape around the prey. The bubbles act as an obstacle for trapping fish. Then, the whale leader emits a sound that queues all whales to ascend with open mouth.

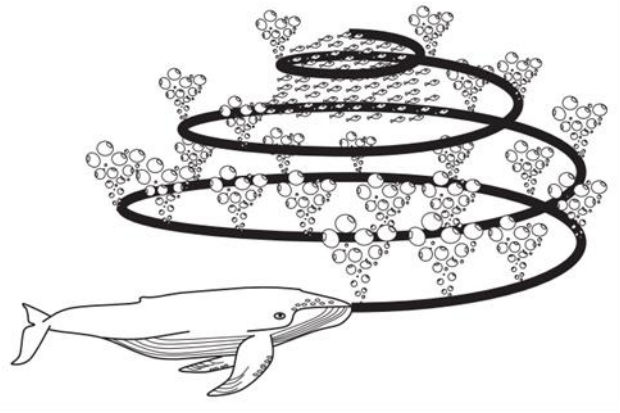


Fig. 1: Bubble-net feeding method of humpback whale

Every method had its own objective and mathematical formula in order to meet the goal setting. For the ORPP, the objective is to minimize the active power loss in the transmission network in the power system.

2.2. Mathematical Model of Optimization

Through this part, mathematical model will perform the optimization in order to achieve objective function. The model was divided into several parts which are:

2.2.1. Shrinking Encircling Mechanism

On the behaviour of the whale itself, the hunting mechanism is by encircling their prey. For the study, the optimal value targeted as prey.

$$\vec{D} = \left| \vec{C}.\vec{X}^{*}(t) - \vec{X}(t) \right| \quad (1)$$

$$\vec{X}(t+1) = \vec{X}^{*}(t) - \vec{A}.\vec{D} \quad (2)$$

In the equation above, t represents the current iteration. Meanwhile, A and C are coefficient vector and X^* indicate the best position so far. Noted that X^* need to be updated for each iteration if there has better solution. For that, A and C can be calculated as follows:

$$\vec{A} = 2\vec{a}.\vec{r} - \vec{a} \quad (3)$$

$$\vec{C} = 2.\vec{r} \quad (4)$$

Where $\vec{a}$ linearly decreased from 2 to 0 in both exploration and exploitation phases and $\vec{r}$ is a random number between [0,1].

2.2.2. Spiral Updating Position

In this section, the spiral will update the position of the whale nearly to the prey. The design of mathematical spiral is given by:

$$\vec{D}' = \left| \vec{X}^{*}(t) - \vec{X}(t) \right| \quad (5)$$

$$\vec{X}(t+1) = \vec{D}'.e^{bl}.(\cos 2\pi l) + \vec{X}^{*}(t) \quad (6)$$

As mentioned in the above equation (5) and (6), b is a constant that defines the spiral movement of the whale. For l, it is a random number in the range -1 to 1. By the movement of the whale itself, there is 50% probability for encircling way. It will be either shrinking encircling or spiral path during achieving the optimization. Equations (7a) and (7b) show the mathematical model of those probabilities and p indicate the probability of the encircling way:

$$\vec{X}(t+1) = \vec{X}^{*}(t) - \vec{A}.\vec{D} \quad \text{if } p < 0.5 \quad (7a)$$

$$\vec{X}(t+1) = \vec{D}'.e^{bl}.(\cos 2\pi l) + \vec{X}^{*}(t) \quad \text{if } p > 0.5 \quad (7b)$$

In order to perform a comprehensive exploration, the position of the whale is updated randomly instead depends on the best whale so far. These approaches are employed if the value of vector A is greater than 1 and X_{rand} choose randomly from whales in the iteration looping. The mathematical equations are given by:

$$\vec{D}' = \left| \vec{C}.\vec{X}_{rand}(t) - \vec{X}(t) \right| \quad (8)$$

$$\vec{X}(t+1) = \vec{X}_{rand}(t) - \vec{A}.\vec{D} \quad (9)$$

2.3. Computational Procedure of the WOA

The procedure of WOA illustrated in the following pseudo code: -

start
Initialize the whale population X_i (i = 1, 2, … n)
X^* is the best whale agent
for t = 1 : maximum_iteration
  for each whale agent
    Update a, A, C, l and p
    if $p < 0.5$
      if $|A| < 1$
        Update position of the current whale agent by (7a).
      else if $|A| \geq 1$
        Select a random whale agent (X_{rand}).
        Update position of the current whale agent by (9).
      end if
    else if $p \geq 0.5$
      Update the position of the current whale agent by (7b)
    end if
  end for
  Check if any search agent goes beyond the search space and amend it.
  Fitness calculation for each whale agent.
  Update X^* if there is a better solution.
  $t = t + 1$
end for
return X^*

3. WOA for Reactive Power Planning

WOA is used for solving Reactive Power Planning (RPP), which aims to find optimal values of control variables in order to minimize transmission loss. Through this study, separate engines of WOA implement the RPS and OTTCS. All of the details are explained in the subsequent sections. The step considered in optimizing the function correlated to RPP is enumerated in Figure 2.

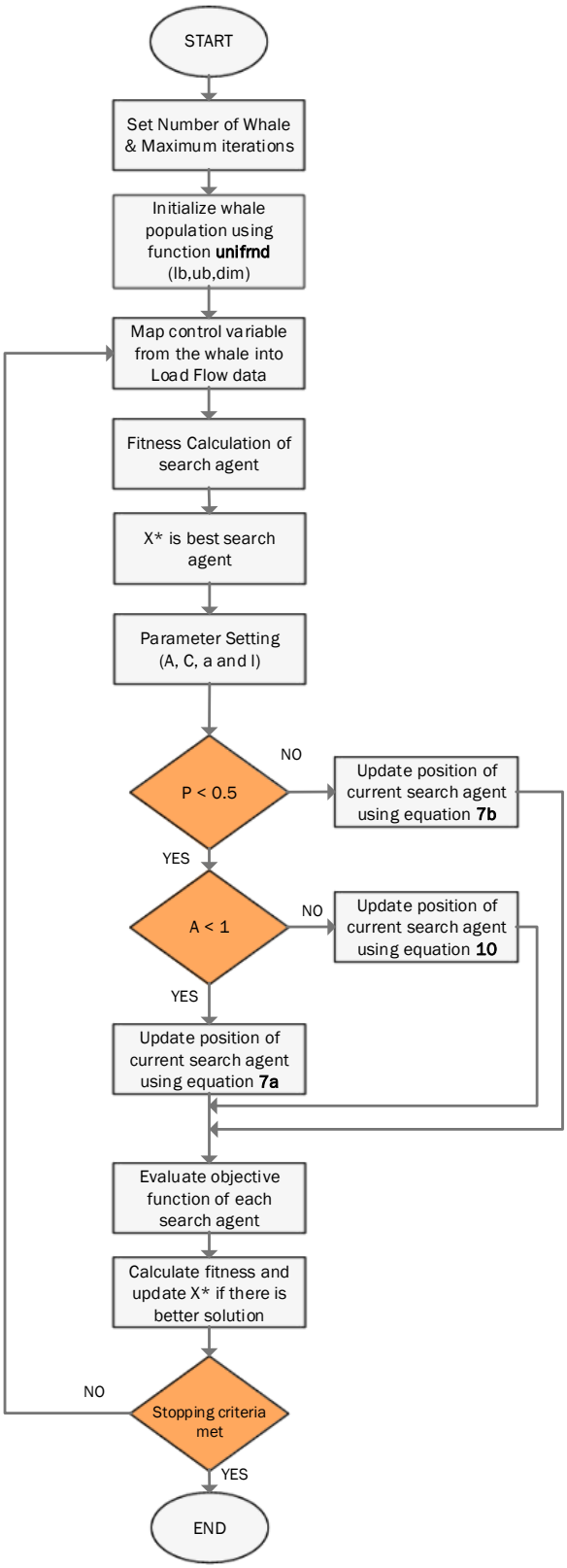


Fig. 2: Flowchart for WOA implementation

3.1. Reactive Power Scheduling (Rps)

For the first part, RPS was implemented in the IEEE 30 Bus system. This is one of the methods on improving total loss in the system. The injected reactive power for the generator buses were set as control variables. Through the technique, WOA able to obtain optimal value of reactive power to be injected. For IEEE 30 Bus system, there are five generator buses exclude slack bus. In this study, generator bus 2 picked as controlled variable. The variable will assign to the load bus (Q_d) as injected reactive loaded (load negatively). This value is the actual value to be injected at generator bus. The bus code of the generator was changed to load bus code. Then the real power loading sign also changed to negative. The following procedures were applied in WOA for RPS optimization:

i. Set the number of whales, *N=20* and maximum iteration up to 200 iterations.
ii. The lower boundary and upper boundary were sets based on the range of the Q_{g2}.
iii. Initialize whale positions, *x*.
iv. Map the control variable from whale initialization into IEEE 30-bus RTS load flow data.
v. Calculate the fitness by running load flow program to evaluate total loss.
vi. Define *X** as the current best search agent so far, with the corresponding minimum transmission loss.
vii. Set the parameters *A*, *C*, *a* and *l*. The setting leads to movement of the whale.
viii. Generate random number of *p*. Updating position the whale leader with equation (7b).
ix. Update the position of the whale. If *A≥1*, the generated random is chosen as the *A* value. If *A<1*, the position is chosen as the best solution. The position update is implemented by equation (7a) or equation (10).
x. Re-evaluate the fitness using the best solution so far.
xi. Update *X** if there is a better solution.
xii. Meet the stopping criteria? If no, go to step iv.
xiii. Stop.

3.2. Transformer Tap Changer Setting (TTCS)

In order to improve the total loss of the test system, TTCS was controlled. TTCS value was taken as the control variable, so that the total loss of the system improved. For this study purpose, only one transformer was taken as a control variable. Once the TTCS has been optimized, the total loss improved. The following procedures were applied in WOA for TTCS optimization:

i. Set the number of whales, *N=20* and maximum iteration up to 200 iterations.
ii. The lower boundary and upper boundary were set based on the range of the *Tap1*.
iii. Initialize whale positions, *x*.
iv. Map the control variable from whale initialization into IEEE 30-bus RTS load flow data.
v. Calculate the fitness by running a load flow program to evaluate total loss.
vi. Define *X** as current best search agent so far with the corresponding minimum transmission loss.
vii. Set the parameters *A*, *C*, *a* and *l*. The setting leads to movement of the whale.
viii. Generate random number of p. Update the position of the whale leader using equation (7b).
ix. Update the position of the whale. If *A≥1*, the generated random is chosen as the *A* value. If *A<1*, the position is chosen as the best solution. The position update is implemented by equation (7a) or equation (10).
x. Re-evaluate the fitness using the best solution so far.
xi. Update *X** if there is a better solution.
xii. Meet the stopping criteria? If no, go to step iv.
xiii. Stop.

4. Result and Discussion

The results in this paper were divided into two subsections that are Reactive Power Scheduling (RPS) and Optimal Transformer Tap Changer (OTTCS).

Table 1 tabulates the initial losses for all cases. By considering loading conditions, the value of losses will be different for each case.

Table 1: Pre-optimization loss

Load Condition (MVAr)	Initial Losses – Qd3 (MW)	Initial Losses – Qd15 (MW)	Initial Losses – Qd21 (MW)
0	17.5883	17.5759	17.5265
50	18.5291	19.6869	18.8888
100	20.7552	26.4969	24.2923
150	24.5519	45.5096	39.5330

4.1. Loss Minimization Using RPS

The optimization is performed for RPS with several load variations. The results are tabulated in Table 2. The total loss reduction was recorded as the load condition increased. It can be observed that, the total loss has been improved in all cases during the RPS performed on generator bus 2.

Table 2: Result of reactive power scheduling (RPS)

Reactive Power Scheduling (RPS) At Bus 2				
Case 1: Loading Condition at Load Bus 3				
	EP		WOA	
	Qg2	Loss (MW)	*Qg2*	Loss (MW)
100	76.6831	20.4411	58.8519	20.4098
150	105.94	23.9116	105.4624	23.9088
Case 2: Loading Condition at Load Bus 15				
100	76.6831	26.1494	59.8775	26.1014
150	152.4396	43.9002	141.9437	43.8093
Case 3: Loading Condition at Load Bus 21				
100	76.6831	23.9613	85.0304	23.8066
150	117.7953	37.6796	120.6705	37.6552

In case 1 that using WOA, when Qd3 was reactively loaded with 150 Mvar, the losses were minimized from 24.5519 MW to 23.9088 MW. Meanwhile using EP, the total loss can only be improved from 24.5516 MW to 23.9116 MW. From Figure 3, it clearly indicates that Whale Optimization Algorithm (WOA) can minimize total loss better than Evolutionary Programming (EP). As the load variation at load bus 3 is increased, the total loss can be improved.

4.2. Loss Minimization Using TTCS

Table 3 indicates the recorded results for loss minimization using Transformer Tap Changer Setting (TTCS).

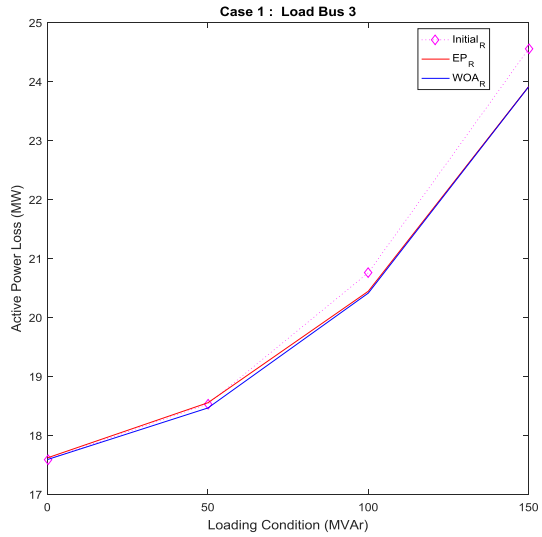


Fig. 3: RPP with loading condition on load bus 3

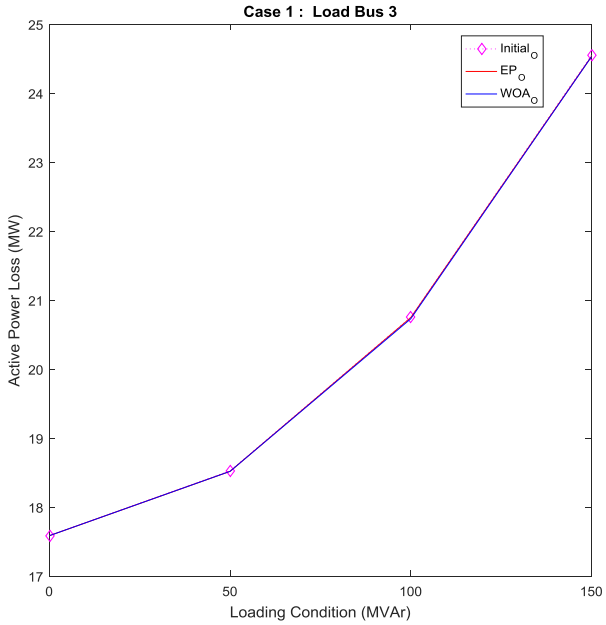


Fig. 4: OTTCS with loading condition on bus 3

From the table, the total loss for all cases were improved as the load increase. By using WOA, the total loss is reduced from 24.5519 MW to 24.5296 MW when Qd3 = 150 MVAr. Using EP, the total loss only reduces to 24.5331 MW. Through TTCS, the loss minimization compared with EP as shown in Figure 4. The loss reduction only slightly different between WOA and EP.

4.3. Comparative Studies

The results of the optimization process implemented using WOA are then compared with EP with load condition at bus 3, Qd3 = 150 MVAr. From the Table 4, it is clearly shown that by using RPS technique, the loss reduced from 24.5519 MW to 23.9088 MW while Evolutionary Programming (EP) technique can only reduce the total loss to 24.9116 MW. It indicates that the WOA can minimize the total loss better than the EP. The results for comparative studies are presented in Fig. 5.

Table 3: Result of transformer tap changer setting

Transformer Tap Changer Setting (TTCS) at line 6-9				
Case 1: Loading Condition at Load Bus 3				
Load Condition (MVAr)	EP		WOA	
	Q_{g2}	Loss (MW)	Q_{g2}	Loss (MW)
100	0.9835	20.7489	0.9723	20.7318
150	0.9656	24.5331	0.9672	24.5296
Case 2: Loading Condition at Load Bus 15				
100	1.0662	26.317	1.0545	26.3017
150	0.9015	45.259	0.9	45.2499
Case 3: Loading Condition at Load Bus 21				
100	0.9015	23.6764	0.9	23.6692
150	0.9015	37.418	0.9	37.3777

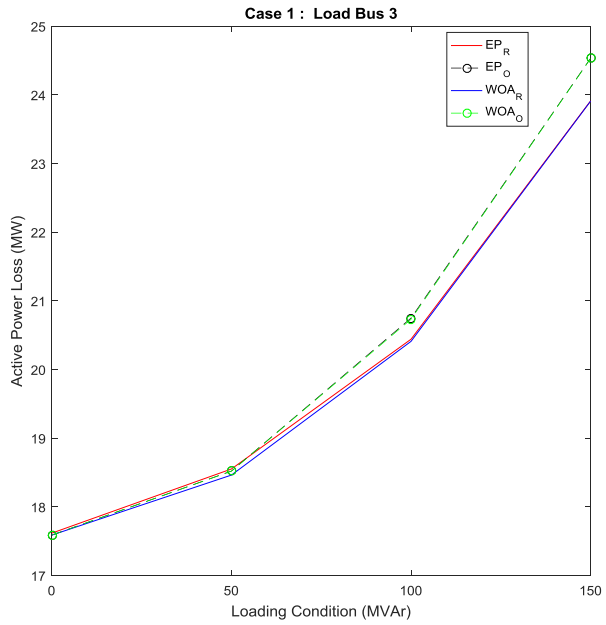


Fig. 5: Combination RPP with OTTCS

Table 4: Result of comparative study

	Initial loss (MW)	Loss after optimization (MW)	
		EP	WOA
RPS	24.5519	23.9116	23.9088
OTTCS		24.5331	24.5296

5. Conclusion

This paper has presented Whale Optimization Algorithm (WOA) for loss minimization in Optimal Reactive Power Planning (ORPP). This includes the reactive power support and transformer tap changer setting optimization. The study revealed that with the optimal size of reactive power sources, the total loss has been reduced. Through the optimization of OTTCS as the second scheme, total transmission loss can also be minimized. Comparative studies between RPS and OTTCS exhibited that implementation of RPS is a better choice. Comparative studies with respect to EP revealed that WOA outperformed EP, making it a good choice for solving other future problems in power system planning. It is also feasible for implementation in larger scale systems with appropriate modification.

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