Implementation of Multistage Invasive Weed Optimization (IWO) Technique for Solving Optimal Power Flow Problem

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Abstract **- This paper presents an implementation Invasive Weed Optimization (IWO) algorithm technique to solve the optimal power flow problems. This technique used the concept of the invasive habits of growth or weeds in nature, which is a population-based intelligence algorithm. The main goal of this paper is to minimize the total power losses and the total generation cost while satisfying the power flow equations. The overall operating cost is composed by the generation cost, transmission cost, and the consumer benefit. IWO has been implemented on the standard IEEE 26-bus system.**

Keywords – Invasive Weed Optimization (IWO), Optimal Power Flow (OPF)

1 INTRODUCTION

1 (a) Optimal Power Flow

Optimal Power Flow is an important tool for power system operators both in planning and operating stages. The main purpose of an OPF program is to determine the settings of control variable for economic and secure operation of a power system. Amongst a number of different operational objectives is to minimize the fuel cost subject network and generator operation constraint [1].

However, optimal power flow problem is one of the main problems in operation of power system which included MVAR dispatch or Optimal Reactive Power Dispatch and MW dispatch problem [2]. This problem has been frequently solved by many optimization methods such as Newton based nonlinear programming (NLP) method [3], Linear programming (LP) method [4], reduced gradient method [5], interior point (IP) methods, successive linear programming (SLP) method [6] and sequential quadratic programming (SQP) method [7]. Among the many variants of IP methods, primal-dual logarithmic barrier IP method and its predictor-corrector variant have become efficient OPF solution algorithms due to their best theoretical complexity properties and computational efficiency [8].

1(a)(1) The formulation of OPF

This study has proposed the minimization of the total power loss and total generation cost as objective function. The variables of this study are;

1. The active power output of generator, Pg
2. The reactive power output of generator , Qg
3. The injected reactive power, Qi
4. The transformer tap changer, Tx

These the formulations of the OPF;

$$\text{minimize} \begin{cases} \text{Tloss} = \sum_{i=0}^{n}(Pgi^2) & (1) \\ \text{Tcost}= \sum_{i=0}^{n}(Xi + YiPgi + ZiPgi^2) & (2) \end{cases}$$

Where;

1. Pg = The generated active power
2. X, Y and Z is cost coefficient of generation
3. i = the number of data bus
4. n = the number of the last data bus that have been use.

The voltage limitation;

$$Vi\ min \leq Vi \leq Vi\ max, \qquad i = 1, 2, \ldots\ldots, n \tag{3}$$

The generator constraint;

$$\text{Pg}i\ min \leq \text{Pg}i \leq \text{Pg}i\ max, \qquad i = 1, 2, \ldots\ldots, n \tag{4}$$

$$\text{Qg}i\ min \leq \text{Qg}i \leq \text{Qg}i\ max, \qquad i = 1, 2, \ldots\ldots, n \tag{5}$$

The injected reactive power constraint;

$$\text{Qi}i\ min \leq \text{Qi}i \leq \text{Qi}i\ max, \qquad i = 1, 2, \ldots\ldots, n \tag{6}$$

The transformer tap changer constraint;

$$\text{Tx}i\ min \leq \text{Tx}i \leq \text{Tx}i\ max, \qquad i = 1, 2, \ldots\ldots, n \tag{7}$$

To continue the search for the effective method to optimize the optimal power flow, one new algorithm has been implemented. This algorithm is known as Invasive Weed Optimization.

1 (b) Invasive Weed Optimization

IWO algorithm originally can only optimize problems in which the elements of the solution are continuous real numbers, while it can't be applied to discrete problems directly. This algorithm is imitating the behaviour of weeds.

Weeds are plant whose vigorous, invasive habits of growth pose serious threat desirable, cultivated plants making them a treat for agriculture. Weeds have shown to be very robust and adaptive to change in environment. As a form of evolutionary algorithm, it is tried to mimic robustness, adaptation and randomness of colonizing weeds. The algorithm is simple but has proven effective in converging to optimum solution using only basic properties, such as seeding, growth and competition, in weed colony [9].

2. METHODOLOGY

The flow charts in Figure 1 and Figure 2 representing the overall Single stage and Multistage IWO algorithm process. These processes include initialization, reproduction, spatial dispersal and competitive exclusion.

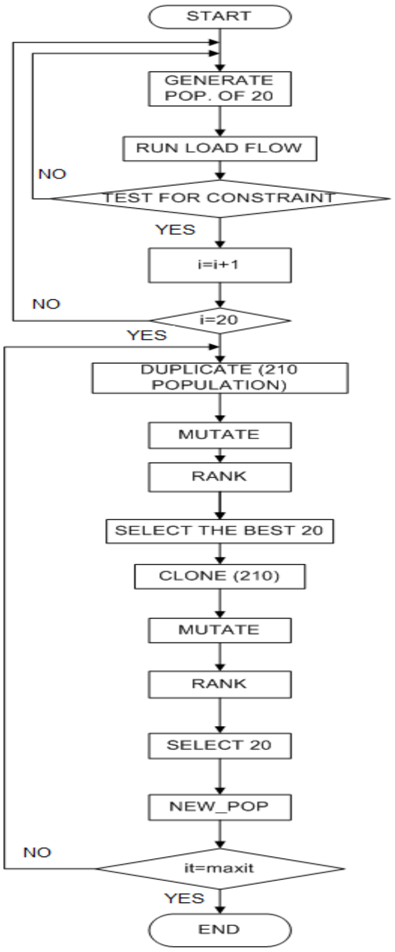


Figure 1: The overall flowcharts of IWO

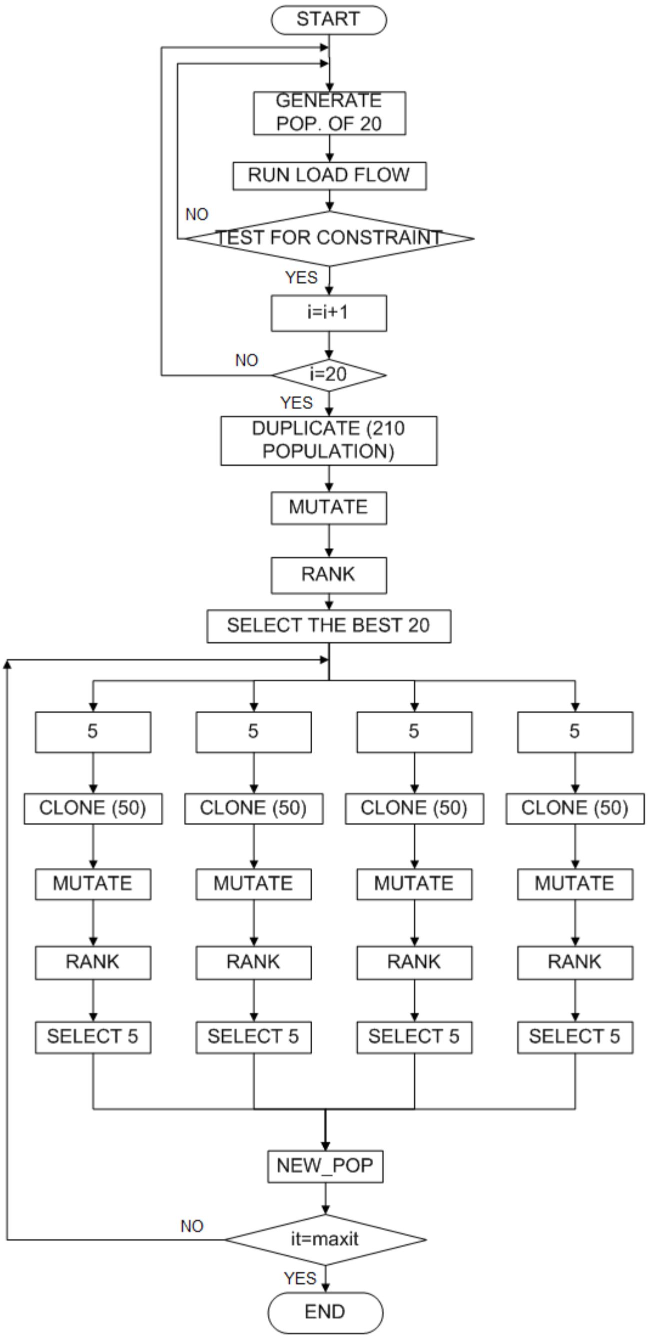


Figure 2: The overall flowcharts of multistage IWO

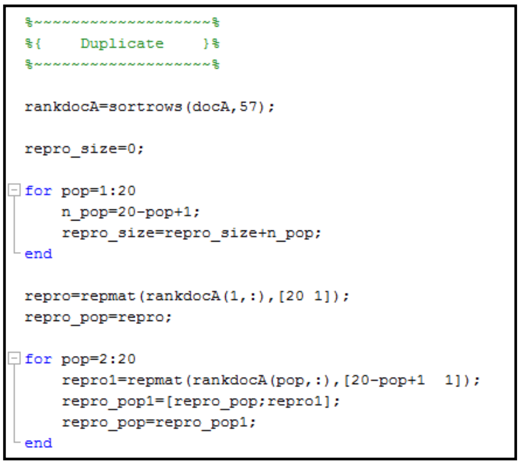
2 (a) Initializing a Population

The first process is to generate initial population which randomly in search space. In this case, 20 populations have been formed by generating a set off random variables which is generated real and reactive power (Pg and Qg), injected reactive power (Qin), and transformer tap changer (Tx). These variables are to determine the objective function of the experiment.

2 (b) Reproduction

Reproduction process also known as clone process. This process is to raising the population by clone itself. Cloning is a process in which the control variables copied according to their objective function and then to multiply the control variables by some factor.

In this problem, 20 clone populations have been used. The population will duplicate 20 times with deduct by 1 at every time of duplication. After that, the size is computed. As a result, 210 numbers cloned since the population size of parents is 20. Figure 3 shows the duplication command in this process.



```
%~~~~~~~~~~~~~~~~~~~%
%{    Duplicate    }%
%~~~~~~~~~~~~~~~~~~~%

rankdocA=sortrows(docA,57);

repro_size=0;

for pop=1:20
    n_pop=20-pop+1;
    repro_size=repro_size+n_pop;
end

repro=repmat(rankdocA(1,:),[20 1]);
repro_pop=repro;

for pop=2:20
    repro1=repmat(rankdocA(pop,:),[20-pop+1  1]);
    repro_pop1=[repro_pop;repro1];
    repro_pop=repro_pop1;
end
```

Figure 3: Duplication Command

2 (c) Spatial Dispersal

The producing of offspring is by performing the random number in spatial dispersal process. An offspring in the population is determined by:

$$\eta'_i(j) = \eta_i(j) \exp(\tau' N(0,1) + \tau Nj(0,1)) \qquad (8)$$

$$Q'_i(j) = Q_i(j) + \eta'_i(j) Nj(0,1) \qquad (9)$$

Where;

$$\tau = [\,(2(n)^{½})^{½}\,]^{-1}$$
$$\tau' = (2(n)^{½})^{-1}$$

$N(0,1)$ is a normally distributed random number with mean is 0

$Nj(0,1)$ is indicate the random number will be new for each value of j.

η'_i is spatial dispersal strategic parameter.

Q'_i is the spatial dispersal variable

2 (c)(1) Single stage IWO

There are 26 variables that will undergo spatial dispersal. Only the constraint with minimum voltage between 0.9p.u. and 1.05p.u. were selected and proceed to next process. For IWO algorithm, it will mutate the numbers are produce offspring which is 210 new numbers are produced.

2 (c)(2) Multistage IWO

After selecting the best 20 in the reproduction process, this population will divide into 4 stages which are 5 populations each. Then, the clone process will raising the population by copied the control variables by some factor accordingly to their objective function exactly same as the reproduction process. But this time, 5 selected clone populations have been used with the factor equal to 10. 50 numbers of population sizes are cloned.

2 (d) Competitive Exclusion

2 (d)(1) Single stage IWO

In selection, the offspring produced by mutation process will be sort and rank. The best 20 values are chosen from the top 20 of it. The objective function in this project are to minimize the total cost, Tcost and total loss, Tloss which derived as fitness will selected in the end of the process.

2 (d)(2) Multistage IWO

After the spatial dispersal process complete, the number of population will produce the offspring through a mutation process. Then, the production will be sort and rank. The top 5 of the population will be selected and combined with each stage. These combinations produce the best 20 populations.

3 RESULT AND DISCUSSION

IWO and multistage IWO have been developed in this study and tested on IEEE 26-bus test system. The objectives are to minimize total cost of generation and total power loss in the system.

The best solution for this problem meets at 100 iterations in simulating for a few times with different initial seed numbers. Tables below show the best result for each objective function.

The results were to the initial value for both objective function as a comparison to test either this solution is successful and failures meets.

Initial Tloss = 15.677 MW
Initial Tcost = 16763.37 $/h

3(a) Total loss (Tloss) as an objective function

Table 1: The best result by using single stage IWO technique from three simulations

Vmin	Vmax	Tloss (MW)	Tcost ($/h)	completion(s)
0.966125311	1.045	11.85153644	15517.79022	6992.9916
0.964261984	1.05	11.83790143	15440.40296	6487.528623
0.967482565	1.045	11.86491767	15492.5453	3799.508621

Table 1 shows the best result by using single stage IWO technique that apply total loss as an objective function. The minimum value of Tloss is 11.83790143 MW within 3799.508621 second completion time after 3 times test running.

Table 2: The best result by using multistage IWO technique from three simulations

Vmin	Vmax	Tloss (MW)	Tcost ($/h)	completion(s)
0.960484626	1.05	12.1248146	15441.89841	4322.929331
0.962162896	1.045	11.98750513	15442.21445	4553.869897
0.966125311	1.045	11.85153644	15517.79022	3624.82182

Table 2 shows the results obtained using IWO technique with total loss as the objective function. The best result that minimizes Tloss after the third test running is 11.85153944 MW.

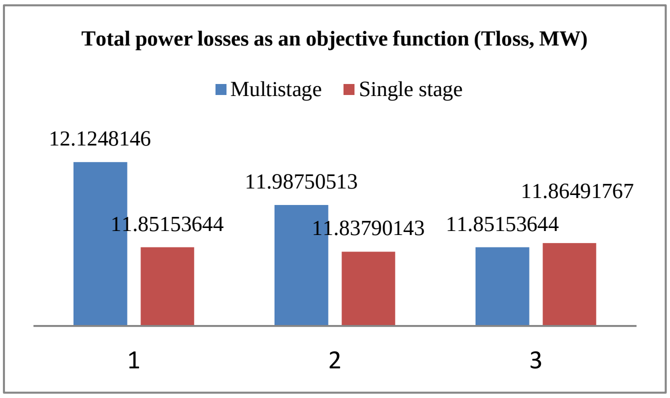


Figure 4: The graph of Tloss while using Tloss as an objective function

Figures 4 shows the best minimum total losses meet when implemented multistage IWO with setting that the total losses as the objective function.

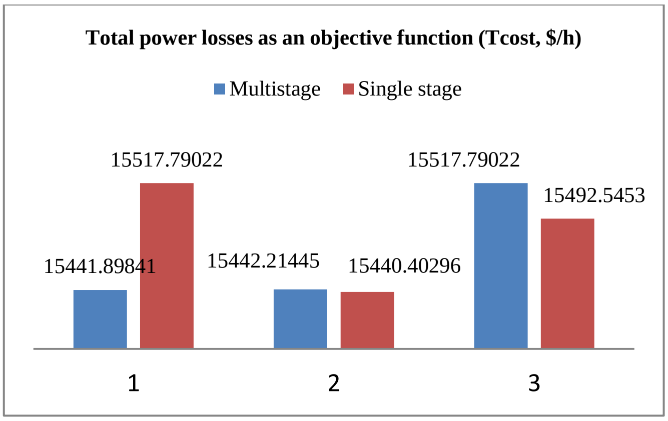


Figure 5: The graph of Tcost while using Tloss as an objective function

From the Figure 5 above, it was found that the best minimum total generation cost in the power system with total losses as the objective function are when applying single stage IWO technique.

3(b) Total cost (Tcost) as an objective function

Table 3: The best result by using single stage IWO technique from three simulations

Vmin	Vmax	Tloss (MW)	Tcost ($/h)	completion(s)
0.959852806	1.05	12.60965974	13827.84355	6217.606432
0.959852806	1.05	12.60965974	13827.84355	6322.707007
0.959852806	1.05	12.60965974	13827.84355	6225.369424

Table 3 shows the best result by using multistage IWO technique that applies total cost as an objective function. The minimum value of Tcost is 13827.84355 $/h after 3 times test running. The results have achieved the minimum optimization because each three times of simulation is same but different in completion time.

Table 4: The best result by using multistage IWO technique from three simulations

Vmin	Vmax	Tloss (MW)	Tcost ($/h)	completion(s)
0.962746409	1.045	12.23362621	15446.69286	5334.189951
0.956418569	1.05	12.32073738	15444.64703	3883.226141
0.962398533	1.05	12.00340429	15439.93929	3404.217289

Table 4 shows the results obtained using multistage IWO technique with total cost as the objective function. The best result that minimizes Tcost after the third test running is 15439.93929 $/h.

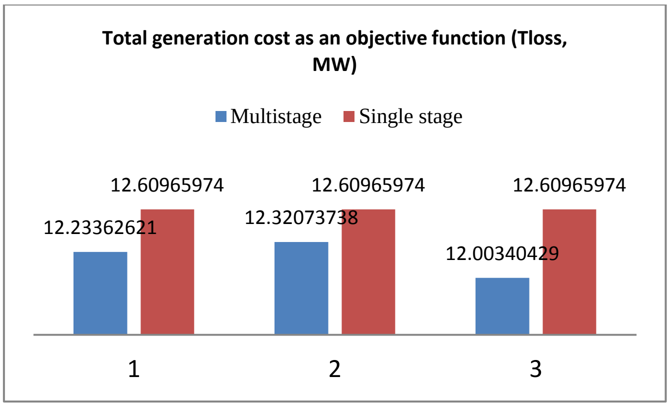


Figure 6: The graph of Tloss while using Tcost as an objective function

Figure 6 shows the results of the total generation cost as an objective function. From the graph found that single stage IWO give the minimum result for total losses compared to multistage IWO technique.

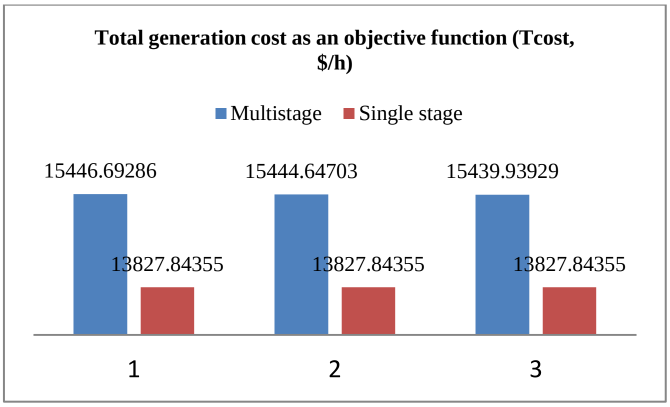


Figure 7: The graph of Tcost while using Tcost as an objective function

Figure 7 present the minimum total cost while using total generation cost as the objective function. The minimum total generation cost is when implemented the multistage IWO technique.

3(c) Comparitive study with Economic Dispatch by Hadi Saadat

Table 5: the comparison of Tcost and Tloss of Linear Programming and Proposed technique

	Linear programming (LP)	**Proposed technique(PT)**	**LP – PT**
Tloss (MW)	12.733	12.609	0.1235
Tcost ($/h)	15677.72	13827.84	1849.88

$\text{Saving}_{\text{cost}}$ = 1849.88 x (24hrs x [365days/year]) (9)

= **16,204,948.80 $/year**

$\text{Saving}_{\text{loss}}$;

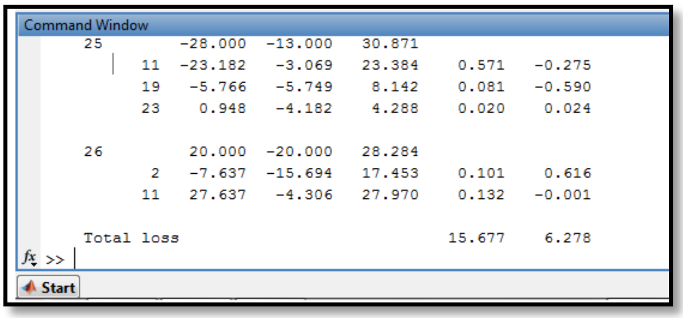
0.1235M x (1000k/1M) = 123.5 kW (10)

123.5 k x 9.88 ¢/kwh = 1220.18 ¢/h (11)

1220.18 ¢/h ÷ 100 = 12.2018 $/h (12)

12.2018 $/h x (24 x 365) h/yr = **106,887.77 $/year** (13)

3(d) Cost saving from loss minimization



```
Command Window
     25          -28.000   -13.000    30.871
          |  11  -23.182    -3.069    23.384     0.571    -0.275
             19   -5.766    -5.749     8.142     0.081    -0.590
             23    0.948    -4.182     4.288     0.020     0.024

     26           20.000   -20.000    28.284
              2   -7.637   -15.694    17.453     0.101     0.616
             11   27.637    -4.306    27.970     0.132    -0.001

     Total loss                                 15.677     6.278
fx >> |
```

Figure 7: Total losses

Tloss reduction $= \text{Tloss}_{\text{original}} - \text{Tloss}_{\text{proposed technique}}$ (14)
= 15.677M – 12.609M
= 3.068MW

3.068M x (1000k/1M) = 3068kW (15)
3068k x 9.88 ¢/kwh = 30311.84 ¢/h (16)
30311.84 ¢/h ÷ 100 = 303.1184 $/h (17)
303.1184 h x (24 x 365) h/yr = **2,655,317.18 $/year** (18)

i. Note : 9.88 ¢/kwh as an average retail price of electricity in 2010.
ii. Reference : US Energy Information Administration

3(e) Cost saving from cost minimization

Pg1 = 719.677
Pg2 = 79
Pg3 = 20
Pg4 = 100
Pg5 = 300
Pg26 = 60

$C1=240+7.0Pg(1)+0.0070(Pg(1))^2 = 8903.28$ (19)
$C2=200+10.0Pg2+0.0095(Pg2)^2 = 1049.29$ (20)
$C3=220+8.5Pg3+0.0090(Pg3)^2 = 393.8$ (21)
$C4=200+11.0Pg4+0.0090(Pg4)^2 = 1390$ (22)
$C5=220+10.5Pg5+0.0080(Pg5)^2 = 4090$ (23)

$$C26=190+12.0Pg26+0.0075(Pg26)^2 = 937 \quad (24)$$

$$Tcost_{original} = C1+C2+C3+C4+C5+C26 = 16763.37 \text{ \$/h} \quad (25)$$

$$Tcost\ reduction = Tcost_{original} - Tcost_{proposed\ technique} = 16763.37 - 13827.84 = 2935.53 \text{ \$/h} \quad (26)$$

$$Saving = 2935.53 \times (24hrs \times [365days/year]) = \mathbf{25{,}715{,}242.80\ \$/year} \quad (27)$$

4 CONCLUSION

The Multistage Invasive Weed Optimization was implemented for solving the Optimal Power Flow problem in this study. There were two objective functions that have been tested. Firstly is to minimize total power losses and secondly is to minimize total generation cost in power system.

When the first objective function is implemented, it shows the multistage of IWO have a better total cost (Tcost) minimizing compared to single stage IWO technique. The completion time in this stage also reduce.

By implemented the second objective function, the result are more consistent while reducing of Tcost with acceptable Tloss from the base case for both single stage and multistage IWO.

The proposed gives better result than linear programming (LP) optimization method by Hadi Saadat in ‘Power System Analysis’, page 300-309. The total saving by implementation the proposed is 16,204,948.80 $/year by minimizing the cost and, 106,887.77 $/year by minimizing the losses in the system.

At the end of this study found that the total power losses and the total generation cost in the system have been minimized.

5 FUTURE DEVELOPMENT

For future development, the multistage IWO algorithm can be suggested to implemented resolve other multi-objective function to achieve any power system network requirement such as improving power factor to be enhance the production of power system. Further, modification should be include to get the better result and reduce the completion time of the simulation by using different technique in cloning and mutating.

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