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# An Analysis of Economic Load Dispatch With Ramp Rate Limit Constraints Using Optimization Techniques

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**Abstract**: The Economic Load Dispatch (ELD) plays an important role in power system operation and control. The losses that occur in power system must be reduced in order to boost its overall performance. This study is to meet the objectives for solving ELD considering ramp rate limit constrain in order to reduce the cost of generating units and obtain an optimal solution at each generating unit. The ramp rate limit will ensure the generating units working at optimum to dispatch enough power in order to fulfil the load demands. This study shows successful implementation of two evolutionary algorithms, namely Particle Swarm Optimization (PSO) and Particle Swarm Optimization with Inertia Weight Factor Approach (PSOIWA). The effectiveness of the proposed method was implemented in case studies for different test system; IEEE-30 Bus System, IEEE-24 Bus System and IEEE-62 Bus System. Both algorithms have been used for each case study. The minimum fuel cost of each algorithm is compared for each case. Therefore, the main objective of this study is to compare the performance of the purposed method, PSO and PSOIWA. The viability of the purposed methods are analysed and compared based on its minimum fuel cost obtain and robustness of the convergence rate.

**Keywords**: **Economic Load Dispatch, PSO, and PSOIWA.**

## 1. Introduction

Economic Load Dispatch (ELD) is one of the fundamental issues in power plant. Generally, economic dispatch is delivering or dispatching of the generation at minimum cost while satisfying the constraints. The purpose of ELD is to minimize the overall cost of generation (Gnanasekaran, 2017). The objective function of problems in the ELD has been approximated as quadratic functions. The modern power generation units are always non-linear and discrete in nature (Hillier & Hillier, 2000). In solving the ELD problems, there is a lot of defects in using the conventional method because of its simple algorithms. Hence, the conventional method is no longer suitable for solving ELD problems.

In order to optimize the algorithm used to solve ELD, few constraints need to be considered such as ramp rate limit, multi-fuel options and others as in previous study (Brar, 2014). These constraints formulate the problem of economic load dispatch (ELD) to find the optimal combination of the output power of all online generating units that minimizes the total cost of fuel, thus meet a constraint on equality and a set of inequality constraints.

The algorithms that are approached in this paper are Particle Swarm Optimization (PSO) and Particle Swarm Optimization with Inertia Weight Approach (PSOIWA). For simplicity of objective function, only ramp rate limit is considered. The losses are also neglected.

## 2. Economic Load Dispatch

A power system in power plant needs to make sure all generator units work at its optimum in order to avoid losses. Less losses also contribute to less variable cost. To fulfill this requirement, an optimization of algorithm takes place (Vita, 2017). For simplicity, the objective function for each generating units in ELD problems has been approximately represented by a quadratic function. Then, the problems solved using mathematical programming algorithm.

The conventional formulation methods have deficiencies due to the simplicity of the models. Example of conventional methods are Netwon method, Lambda iteration and others. The conventional method only can be used to solve Economic Load Dispatch (ELD) if and only if the fuel-cost curves of the units generator are a linear load and incremental in monotonically (Chandrasekar & Ramana, 2011).

Restrictions must be considered in order to minimize the complete cost generation. The optimization needs to take ramp rate limit, prohibited operating zone, valve point effect and multifuel options into consideration to complete the formulation in approached algorithm to solve the Economic Load Dispatch problems.

### 2.1 Optimization Techniques

Optimization is a method of searching the unconventional algorithms which produce the most minimized cost of generation when the generating units performance are at optimum while satisfying all the limits. Optimization will be exploiting the wanted factors and diminish the unwanted ones. If the information or data of generating unit are limited, then the optimization is process cannot be done (Sahoo et al., 2015). Thus, it is important to sufficient information in order to practice the optimization techniques

### 2.2 Particle Swarm Optimization

In the year of 1995, Particle Swarm Optimization (PSO) was introduced by Kennedy and Eberhart (Op et al., 2017). A method of population, based on Evolutionary is inspired by a flock of birds that were searching for food at swarm (Op et al., 2017). PSO is a simple yet powerful optimization technique used to solve Economic Load Dispatch (ELD) problems. The velocity and position are changing and updated in the manner of using guidance from particles' own familiarity and familiarities of its neighbors. Because of the simplicity of PSO algorithm, thus it requires less memory (Valle et al., 2008).

### 2.3 Particle Swarm Optimization with Inertia Weight Approach

After Particle Swarm Optimization (PSO) was discovered in 1995, Shi and Eberhert presented an idea of inertia weight in PSO in 1998 (Sengupta et al., 2019). Before this, the inertia is a constant during early discovery of PSO. Both of them stated that, a large inertia weight can facilitate a global search while a local search is done by small inertia weight.

The balance between exploration and exploitation process is provided by the inertia weight. The contribution rate of the particle previous velocity to the new velocity of particle is determined by inertia weight.

If the inertia is no longer a constant in Particle Swarm Optimization (PSO), the final accuracy and the convergence speed of PSO will be improved. Inertia factors are factors of updating the velocity. It also add up a new coefficient to the position updating equation.

## 2.4 Ramp Rate Limit Constraint

Ramp rate of generator is defined as the capability of a unit of generator in its power response. A precautionary step is required to prevent shortening the equipment's lifespan. It is essential to keep generating units within safe limits. The mechanical constraints such as the ramp rate limit is usually translated into a limit on the rate of increasing or decreasing of the power output. The ramping rate of each generating unit should reach its maximum rate. When generating units at the maximum ramp, the generator is working at an optimum state. Thus, the objective to minimize the total generation cost can be achieved because losses are lesser and power system is fully utilized in generating energy. The unit response in the term of a cooperative power changes in a specified time interval. Ramp rate limit restricted the operating range of on-line units (Pizano-Martínez et al., 2015).

## 3. Objective Function

The function of the objective is to minimize or maximize the problems. Usually in power plant issues, the algorithm is needed to minimize the cost of generation. It is important for generator of power plant to work at its optimum with the most minimized cost used in generating energy. In order to achieve minimization of the generation cost, few constraints is considered. The minimization can take place even after a minor change in the generating unit.

Conventionally in Economic Load Dispatch (ELD) problems, the objective function for generating units has been approached as a quadratic function. Basically these objective functions of modern power generation units are highly nonlinear, and discrete in nature (Ghorbani & Adham, 2015). The quadratic function can be expressed as follow (Pal et al., 2016):

$$\min\ f = \sum_{i=1}^{n} a_i P_i^2 + b_i P_i + c_i \qquad i=1, 2, 3\ldots., n \tag{1}$$

Where;

| | |
|---|---|
| $n$ | = number of generating units |
| $P_i$ | = real power output (MW) |
| $a_i$, $b_i$ & $c_i$ | = cost coefficients |

## 3.1 Particle Swarm Optimization Formulation

Based on PSO concept, mathematical equations for the searching process are (Pal et al., 2016):

a. Velocity updating equation:

$$v_{id}^{(k+1)} = w \times v_{id}^{k} + C_1 \times rand() \times \left(pbest_{id} - x_{id}^{k}\right) + C_2 \times rand() \times \left(gbest_{id} - x_{id}^{k}\right) \tag{2}$$

b. Position updating equation:

$$x_{id}^{(k+1)} = x_{id}^{k} + v_{id}^{(k+1)} \tag{3}$$

c. Inertia weight factor

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} \times iter \tag{4}$$

Where,

$x_{id}^{k}$ $x_{id}^{(k+1)}$ = are the position of $d^{th}$ variable of the $i^{th}$ particle at $k^{th}$ and $(k+1)^{th}$ iteration

$v_{id}^{k}$ $v_{id}^{(k+1)}$ = are the velocity of the $d^{th}$ variable of the $i^{th}$ particle at the $k^{th}$ and the $(k+1)^{th}$ iteration

$C1, C2$ = the cognitive and the social parameters

$rand$ = random numbers uniformly distributed within [0, I]

$pbest_{id}$ = the best position of the $d^{th}$ variable of the $i^{th}$ particle

$gbest_{id}$ = the group best position of the $d^{th}$ variable

$iter_{\max}$ = the maximum number of iteration

$iter$ = the current number of iteration

### 3.2 Particle Swarm Optimization using Inertia Weight Approach Formulation

The inertia weight parameter which provides a balance between global and local explorations (Pal et al., 2016).

$$w^{(k+1)} = w_{\min} - \frac{w_{\max} - w_{\min}}{k_{\max}} \times (k+1) \tag{5}$$

Where;

$w_{\max}$ = the maximum number of iterations: $w_{\max} = 1$, $w_{\min} = 0.4$

$(k+1)$ = the current number of iterations

$k_{\max}$ = maximum number of iteration cycle

Velocity updating equation for Particle Swarm Optimization with Inertia Weight factor Approach (PSOIWA):

$$v_{id}^{(k+1)} = w^{(k+1)} \times v_{id}^{k} + C_1 \times rand() \times \left(pbest_{id} - x_{id}^{k}\right) + C_2 \times rand() \times \left(gbest_{id} - x_{id}^{k}\right) \tag{6}$$

### 3.3 Ramp Rate Limit Formulation

In real on-line generating unit, ramp up and ramp down control the operating range. Ramp rate of generator cannot ramp less than the minimum value or go beyond the maximum range. The optimization techniques strictly need to satisfy these constraints (Dash, 2018).

a. when there is an increment in generating

$$Pi(t) - Pi(t-1) \leq URi \tag{7}$$

b. when there is a decrement in generating

$$Pi(t-1) - Pi(t) \leq DRi \tag{8}$$

Where,

$Pi(t-1)$ & $Pi(t)$ = the previous and current output powers at time period t
$URi$ = ramp-up limits of ith generating unit.
$DRi$ = ramp-down limits of ith generating unit.

## 4. Methodology

The implementation of PSO and PSOIWA methods in ELD problem divided into two general flowcharts which consist of a general flowchart of PSO and flowchart of case studies of IEEE Bus System as shown in **Fig. 1** and **Fig. 2.**

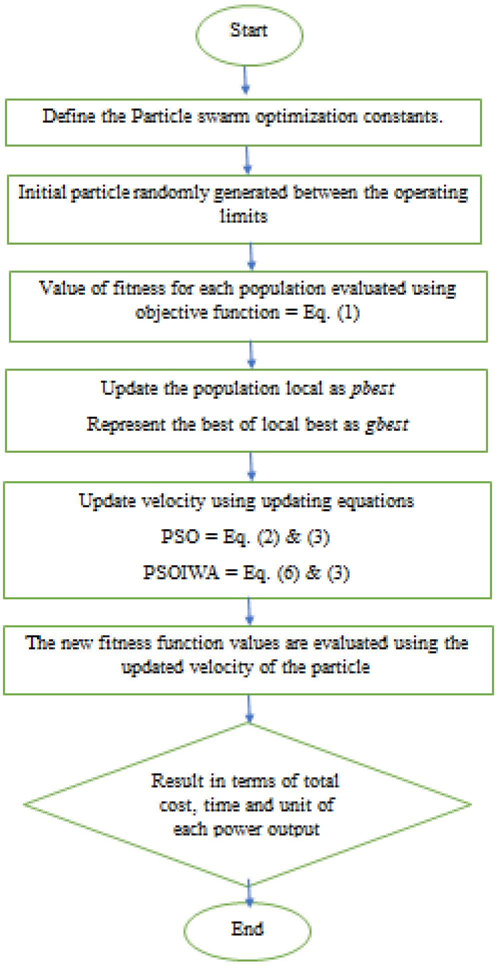


**Fig 1**. General flowchart of Particle Swarm Optimization

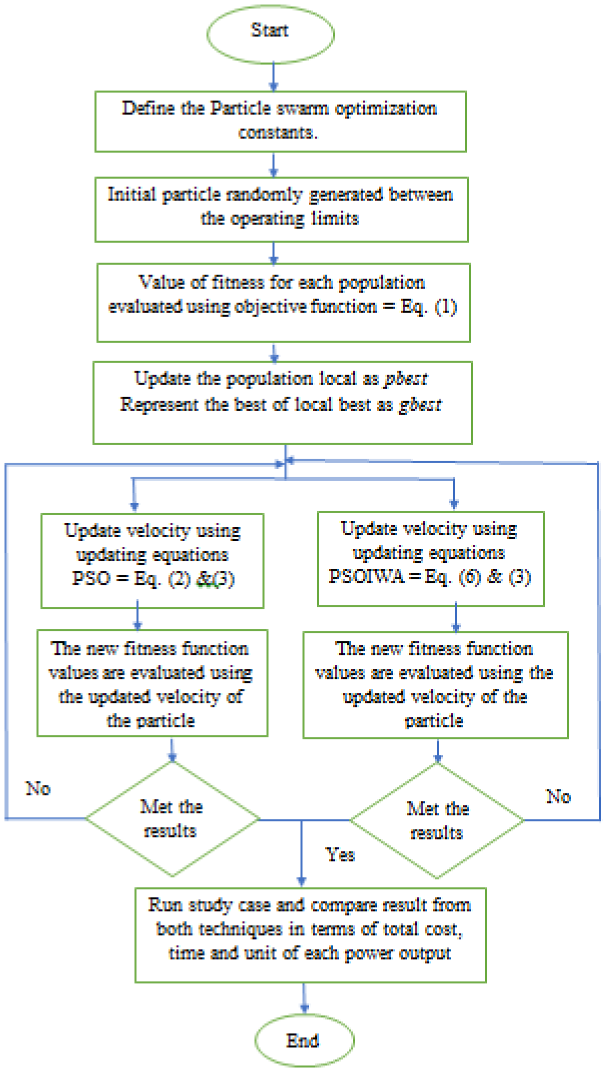


**Fig 2**. Flow chart of IEEE bus system

## 4.1 Case Studies

Case studies then run in simulation of MATLAB and compare results from both techniques in terms of total cost, time and unit of each power output. In simulation, population size is equal to 100, while the maximum iteration is up to 500 (Dasgupta, 2016). The limitation range of maximum and minimum ramp rate constraints is also considered.

### 4.1.1 IEEE-24 Bus System

This IEEE-24 bus system case study consists of ten generator units (González & Miguel, 2016) as in **Fig. 3**. The generating units are in their range of maximum and minimum limits. While, the load demand is $P_D = 2630$ MW.

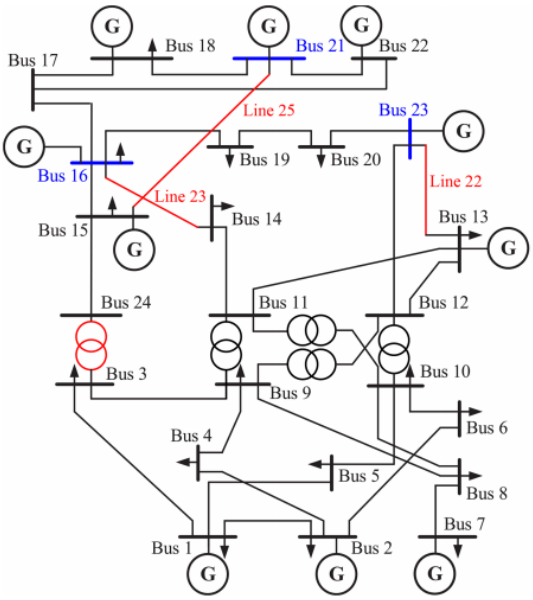


**Fig 3**. IEEE-24 Bus System

### 4.1.2 IEEE- 30 Bus System

The IEEE-30 bus system case study is equipped with six generator units (Alsac & Stott, 1974) as shows in **Fig. 4**. The maximum and minimum range of generating units are stated in the data. The load demand is $P_D$ = 1263 MW**.**

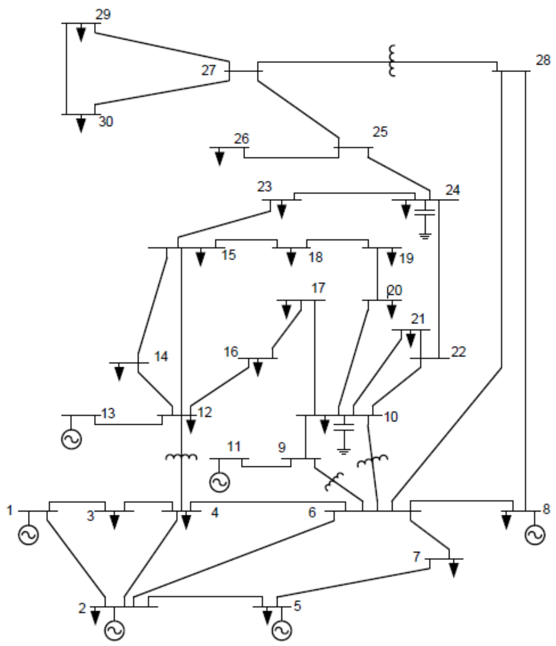


**Fig 4**. IEEE-30 Bus System

### 4.1.3 IEEE- 62 Bus System

The IEEE-62 bus system case study included with 19 generator units (Malival, 2015) as in **Fig. 5**. The generating limits of all generator are within the range of maximum and minimum value. The load demand of the case study is $P_D$= 2930 MW.

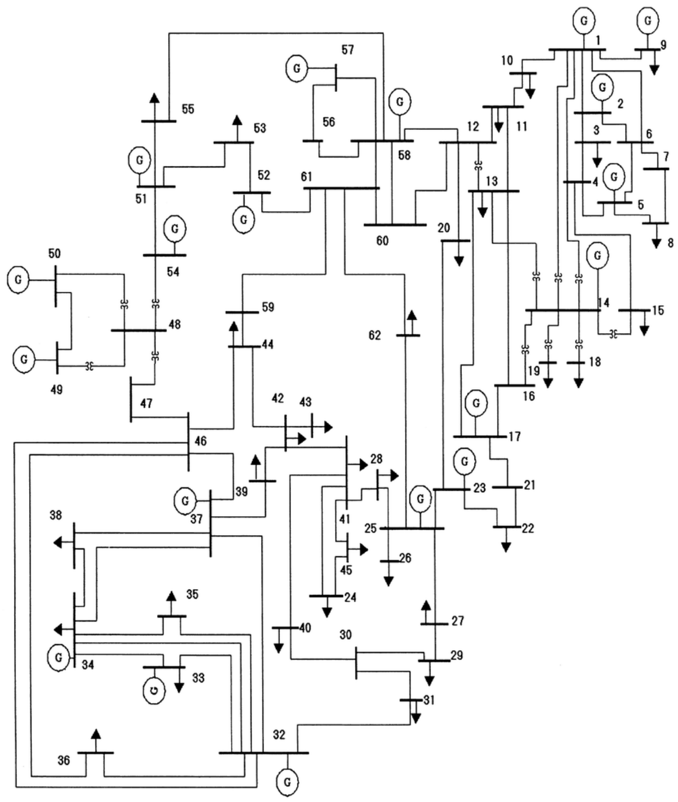

**Fig 5**. IEEE-62 Bus System

## 5. Results and Discussion

The simulations were performed in case studies for different test system; IEEE-30 Bus System, IEEE-24 Bus System and IEEE-62 Bus System with different numbers of generating units, and comparisons are performed between PSO and PSOIWA. The findings affirmed the minimum optimal cost, total power dispatch and time taken in seconds for CPU to run simulation of the coding as well as its robustness and fast convergence of the proposed method over other existing techniques.

### 5.1 Case Studies: IEEE – 30 Bus System, IEEE- 24 Bus System and IEEE- 62 Bus System

According to the findings as per tabulated in **Table 1** for IEEE- 30 Bus System, PSOIWA dispatched more power compared to PSO. PSOIWA produced minimal fuel cost less than PSO as minimum fuel cost produced. Next, the time taken by CPU to process the programming of PSO greater than the time taken by PSOIWA in seconds. The results for other two case studies resume the same finding as shown in **Table 2** and **Table 3**.

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**Table 1.** Optimal power dispatch & optimal ramping rate for IEEE-30 bus system

| Power Dispatch (MW) | PSO | PSOIWA | Optimum Ramping Rate (MW) | PSO | PSOIWA |
|---|---|---|---|---|---|
| $P_1$ | 439.05 | 440.00 | $P_1$ | 117.31 | 118.25 |
| $P_2$ | 169.21 | 170.00 | $P_2$ | 85.89 | 86.68 |
| $P_3$ | 200.00 | 200.00 | $P_3$ | 98.42 | 103.47 |
| $P_4$ | 152.20 | 150.00 | $P_4$ | 84.35 | 82.15 |
| $P_5$ | 187.00 | 190.00 | $P_5$ | 85.88 | 83.09 |
| $P_6$ | 109.28 | 110.00 | $P_6$ | 88.28 | 87.46 |
| Total Power Dispatched (MW) | 1256.74 | 1260.00 | | | |
| Fuel Cost (RM/hour) | 79041.84 | 75771.20 | | | |
| CPU Time (sec) | 271.02 | 199.15 | | | |

**Table 2**. Optimal power dispatch & optimal ramping rate for IEEE-24 bus system

| Power Dispatch (MW) | PSO | PSOIWA | Optimum Ramping Rate (MW) | PSO | PSOIWA |
|---|---|---|---|---|---|
| $P_1$ | 399.06 | 400.00 | $P_1$ | 114.46 | 115.40 |
| $P_2$ | 385.10 | 375.00 | $P_2$ | 118.68 | 112.14 |
| $P_3$ | 105.00 | 105.00 | $P_3$ | 130.00 | 130.00 |
| $P_4$ | 100.00 | 100.00 | $P_4$ | 130.00 | 130.00 |
| $P_5$ | 391.54 | 390.00 | $P_5$ | 119.72 | 118.18 |
| $P_6$ | 398.87 | 400.00 | $P_6$ | 114.90 | 116.03 |
| $P_7$ | 347.53 | 350.00 | $P_7$ | 117.53 | 120.00 |
| $P_8$ | 296.06 | 295.00 | $P_8$ | 98.94 | 97.88 |
| $P_9$ | 102.03 | 105.00 | $P_9$ | 96.89 | 99.75 |
| $P_{10}$ | 109.46 | 110.00 | $P_{10}$ | 95.81 | 96.34 |
| Total Power Dispatch (MW) | 2577.83 | 2630.00 | | | |
| Fuel Cost (RM/hour) | 168072.23 | 162957.34 | | | |
| CPU Time (sec) | 305.89 | 278.17 | | | |

**Table 3.** Optimal power dispatch & optimal ramping rate for IEEE-62 bus system

| Power Dispatch (MW) | PSO | PSOIWA | Optimum Ramping Rate (MW) | PSO | PSOIWA |
|---|---|---|---|---|---|
| $P_1$ | 508.37 | 524.13 | $P_1$ | 126.21 | 141.96 |
| $P_2$ | 509.87 | 524.13 | $P_2$ | 160.77 | 175.03 |
| $P_3$ | 480.57 | 486.99 | $P_3$ | 193.15 | 199.57 |
| $P_4$ | 485.41 | 486.99 | $P_4$ | 8.44 | 10.02 |
| $P_5$ | 486.67 | 486.99 | $P_5$ | 81.36 | 81.68 |
| $P_6$ | 498.98 | 486.99 | $P_6$ | 132.97 | 120.98 |
| $P_7$ | 485.94 | 486.99 | $P_7$ | 88.60 | 120.98 |
| $P_8$ | 494.13 | 486.99 | $P_8$ | 467.28 | 460.14 |
| $P_9$ | 478.15 | 498.54 | $P_9$ | 274.56 | 294.95 |
| $P_{10}$ | 491.33 | 494.33 | $P_{10}$ | 10.46 | 13.46 |
| $P_{11}$ | 497.97 | 494.33 | $P_{11}$ | 82.03 | 78.40 |
| $P_{12}$ | 464.00 | 464.00 | $P_{12}$ | 25.00 | 25.00 |
| $P_{13}$ | 493.35 | 490.00 | $P_{13}$ | 113.61 | 110.26 |
| $P_{14}$ | 315.35 | 310.99 | $P_{14}$ | 44.51 | 40.16 |
| $P_{15}$ | 317.96 | 310.99 | $P_{15}$ | 104.45 | 97.48 |
| $P_{16}$ | 316.31 | 325.00 | $P_{16}$ | 27.69 | 36.38 |
| $P_{17}$ | 309.31 | 297.19 | $P_{17}$ | 38.99 | 26.86 |
| $P_{18}$ | 285.01 | 297.19 | $P_{18}$ | 83.28 | 95.46 |
| $P_{19}$ | 304.49 | 297.19 | $P_{19}$ | 145.54 | 138.24 |
| Total Power Dispatch (MW) | 8223.24 | 8250.00 | | | |
| Fuel Cost (RM/hour) | 605246.31 | 603611.83 | | | |
| CPU Time (sec) | 341.19 | 319. 32 | | | |

Based on convergence characteristic for IEEE- 30 Bus System, PSOIWA produced the least cost fuel compare to PSO. PSO started first iteration at 80094.50 RM/hour at started to converge at iteration 14 with minimum cost fuel 79041.85 RM/hour. While PSOIWA started the first iteration at 79216.66 RM/hour at started to converge at iteration number six with minimum cost fuel 75771.20 RM/hour as shown in **Fig. 6**. PSO started the first iteration at 169286.04RM/hour at started to converge at iteration 14 with minimum cost fuel 168072.23 RM/hour as stated in **Fig. 7**. While the PSOIWA started first iteration at 169292.61 RM/hour at started to converge at iteration number seven with minimum cost fuel 162957.34 RM/hour for IEEE-24 Bus System. Moreover, for IEEE-62 Bus System as shown in **Fig.8**, PSO started first iteration at 610415.49 RM/hour at started to converge at iteration 18 with minimum cost fuel 605246.31 RM/hour. While PSOIWA started first iteration it 618540.43 RM/hour at started to converge at iteration number 17 with minimum cost fuel 603611.84 RM/hour.

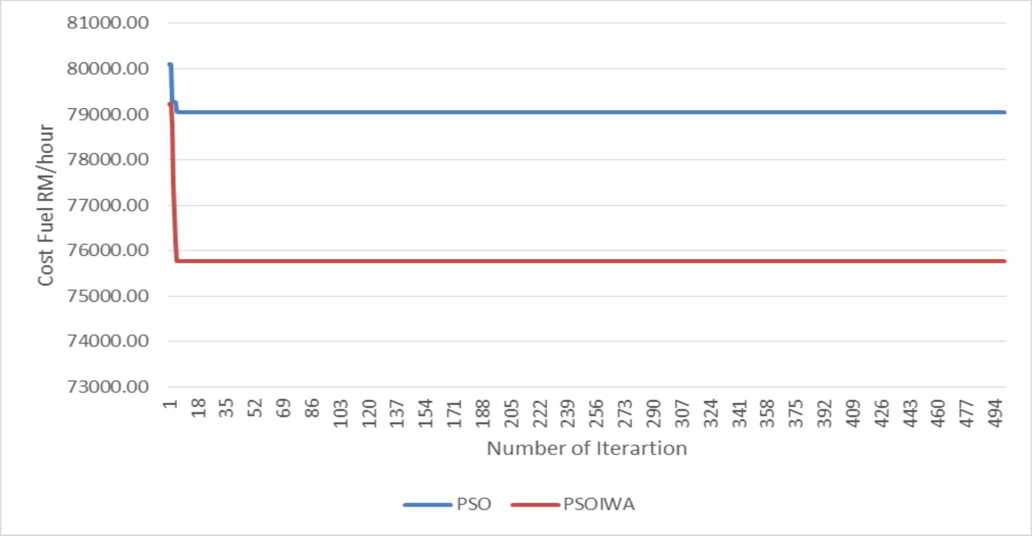


**Fig 6.** Convergence Characteristics for IEEE-30 Bus Bus System

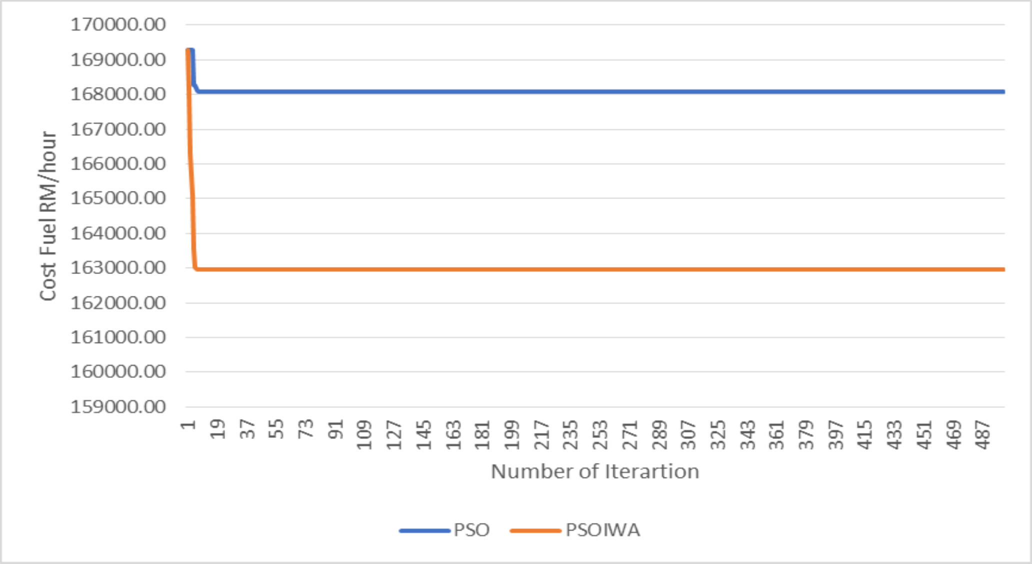


**Fig 7.** Convergence Characteristics for IEEE-24 Bus System

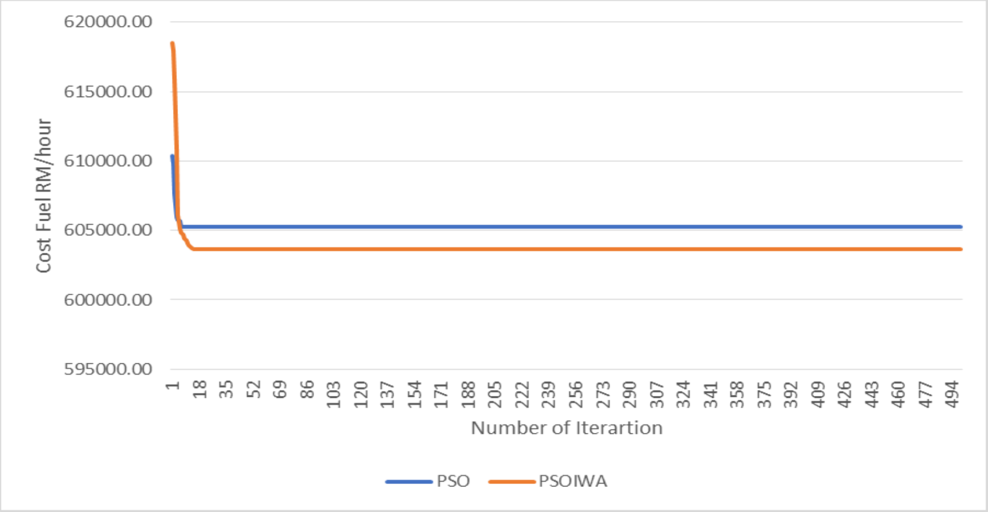


**Fig 8.** Convergence Characteristics for IEEE-62 Bus System

Other than that, PSOIWA method more stable in robustness characteristics compared to PSO as shown in **Fig. 9** for IEEE- 30 Bus System. This also validates for the other two case studies as shown in **Fig. 10** and **Fig. 11**. PSOIWA produces good optimal solutions improving in general the best solutions better than PSO for three case studies.

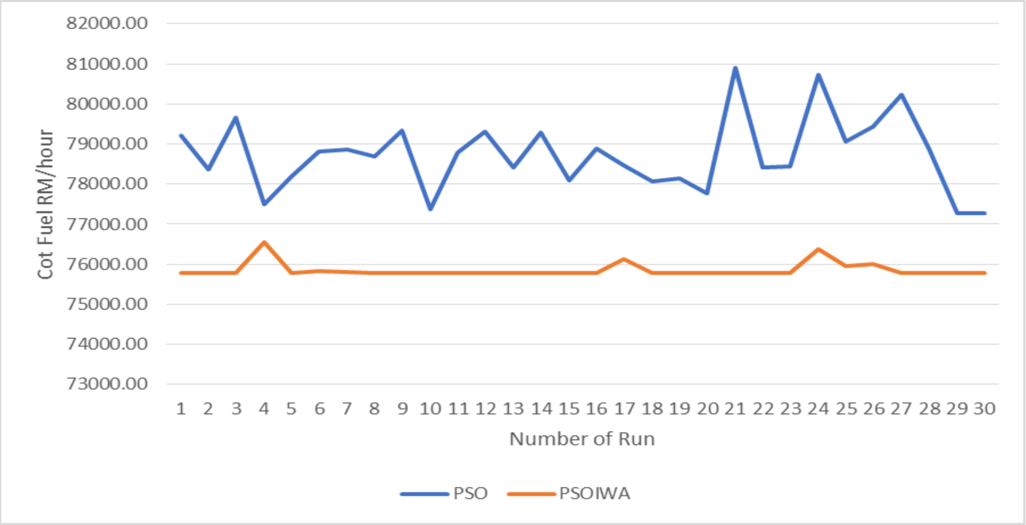


**Fig 9**. Robustness Characteristics for IEEE-30 Bus System

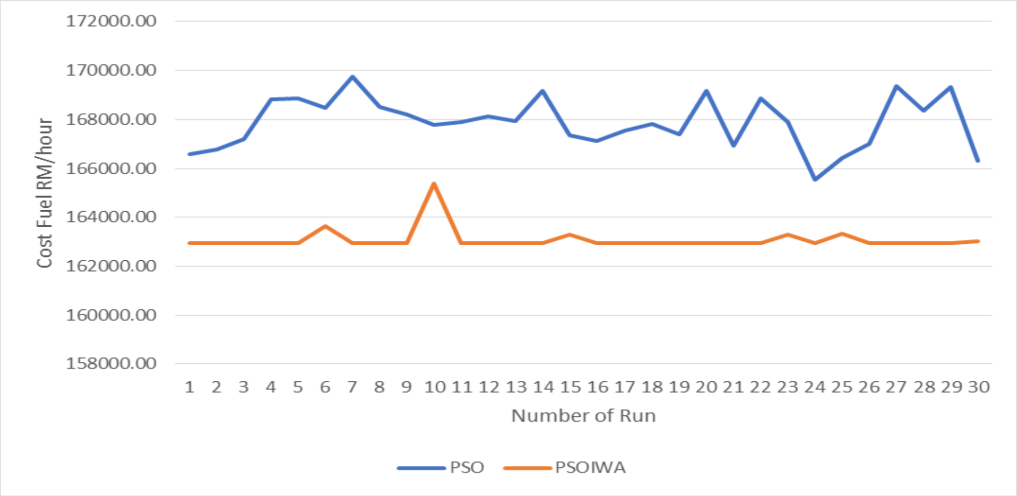


**Fig. 10**. Robustness Characteristics for IEEE-24 Bus System

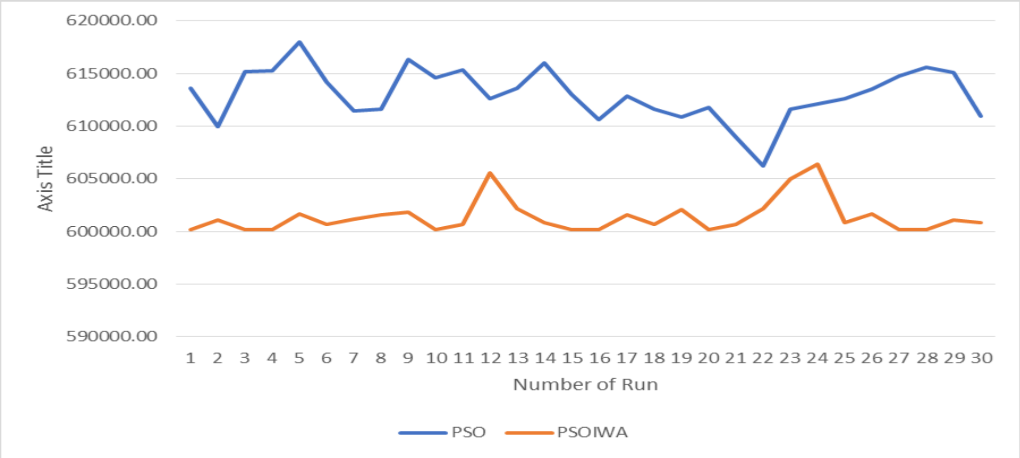


**Fig. 11**. Robustness Characteristics for IEEE-62 Bus System

## 6. Conclusion

The performances of the proposed methods were tested using MATLAB programming on three different case studies for IEEE-24 Bus System, IEEE-30 Bus System and IEEE-62 Bus System. The comparisons were carried out based on the minimum cost fuel achieved, convergence of the optimum cost fuel and robustness characteristics. It was shown that, PSOIWA approach had been demonstrated to have superior features, including high quality solution, stable convergence characteristics and high efficiency at generator system compared to PSO. Moreover, the graph convergence and robustness characteristics of PSOIWA were improved compared to PSO. Thus, the results were improved as the system complexity increases. Therefore, in all electrical power firms, solving the ELD problem is a critical challenge in order to obtain the lowest generating cost that helps to make profit.

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