A ROUGH SET -PSO FOR LARGE SCALE ECONOMIC LOAD DISPATCH WITH WIND PARK


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Resumen: Este trabajo presenta un eficiente algoritmo de teoría de conjunto áspero híbrido-PSO (RPSO) para resolver problemas de carga económica a gran escala (ELD) en redes eléctricas con turbinas eólicas. Para realizar el despacho de carga económica, se considera aquí el efecto de carga de la válvula, la demanda de carga del sistema, las pérdidas de potencia, los límites de velocidad de rampa y las zonas de operación prohibidas. Las simulaciones se realizaron en cuatro sistemas de potencia diferentes con 3, 6, 15 y 40 unidades generadoras y los resultados se comparan con dos formas de sistemas de potencia, un sistema de energía es con el generador de energía eólica y otro sistema de energía sin generador de energía eólica. Los resultados de este estudio revelan que el enfoque propuesto es capaz de encontrar soluciones apreciables de despacho de carga económica que los de algoritmos anteriores.

Palabras clave: Teoría de conjuntos aproximados, Optimización de enjambres de partículas, Envío de carga económica, Generador de energía eólica, Efecto de carga de puntos de válvula

Abstract: This paper presents an efficient a hybrid rough set theory-PSO (RPSO) algorithm for solving large-scale economic load dispatch (ELD) problems in power networks with wind turbine. To realize the economic load dispatch, the valve-point loading effect, system load demand, power losses, ramp rate limits and prohibited operation zones are considered here. Simulations were performed on four different power systems with 3, 6, 15 and 40 generating units and the results are compared with two forms of power systems, one power system is with wind power generator and other power system is without wind power generator. The results of this study reveal that the proposed approach is able to find appreciable economic load dispatch solutions than those of previous algorithms.

Keywords: Rough Set Theory, Particle Swarm Optimization, Economic Load Dispatch, Wind Power Generator, Valve Point Loading Effect

1. INTRODUCTION

Wind energy has become an increasing source of electrical energy generation in recent years. For this reason, it is important to study the possible impact a wind power generation on the power network where it is connected. Therefore, economic load dispatch (ELD) with wind power generation is one of the important optimization problems in operation of modern power system. For this reason, that is used to determine the optimal combination of electrical power outputs of all generating units to minimize the total fuel cost while satisfying various constraints over the entire dispatch periods.

Over the last few years, various solutions have applied to solve ELD problems by different classic programming methods and optimization techniques in the literatures. Such classical optimization methods (Wood et al., 1984) are highly sensitive to starting points and often converge to local optimum or diverge altogether. Lately, heuristic search techniques such as bacterial foraging algorithm (Farhat and Hawary, 2010), Genetic algorithm (LI et al., 2009), Wait-and-See approach (Liu, 2010), evolutionary algorithm (Liao, 2011), Artificial Bee Colony (Davoud et al., 2015), Gravitational search algorithm (Mondal et al., 2013), Here-and-Now approach (Nishant and Souvik, 2015) and hybrid rough set theory-PSO technique (Safari, and Sheibai, 2015) are being used to find global or near global optimal solution.

The PSO method is still one of the best methods, because the rest of the intelligent methods have a long time running problem, the main advantages of PSO are its simple concept, computational efficiency and easy implementation. The PSO has been effectively applied to ELD problems. However, the PSO method exist some defects such as premature convergence. Therefore, many variations have been proposed for the classical PSO by various researchers.

In our study, we compare the two form of electrical network performance of the RPSO algorithm. This paper is organized as follows: Section 2 presents the formulation of ELD problems. Section 3 presents the formulation of ELD problems with wind power penetration. Section 4 then review of the PSO and RPSO algorithm. Detailed process of using the RPSO method to solve the ELD problems is presented in Section 5. Section 6 shows four application cases using the proposed method to solve the ELD problems and the results have been compared to form of network.

2. ECONOMIC LOAD DISPATCH FORMULATION

The ELD problem is minimizing the fuel cost of generation units so as to accomplish optimal generation dispatch among operating units and in return satisfying the system load demand and losses, generator operation constraints.

2.1. Objective function

The cost function of ELD corresponding to the total generation cost is approximated by a quadratic function of the power output from the generating units. It can be mathematically described as follows [2]:

$$F_T = \sum_{i=1}^{N_g} F_i(P_i) = \sum_{i=1}^{N_g} (a_i P_i^2 + b_i P_i + c_i)$$

Because the fuel cost is the main factor determining in the economic operation, the fuel input-output curves is important. In this curve, the slope of the curve at any point is efficiency of generative unit fuel at that point. Power cost function is not always a convex and due to the effects of some steam valves and it has a non-convex shape and form of this cost function equation, is considered to be in two sentences. The input-output characteristic curve of large steam turbine generators is not always convex and smooth. This type of generation units have some supply steam valves, upon increase production request the valves open one by one and respectively for increasing output power. When the unit load’s increase, the input (fuel) to the unit increases, and between points in each of the two valves open, the incremental heat rate increases, however, when valve is first opened, due to a rapid losses the throttling, the incremental heat rate to be large and suddenly rise, which will rise to discontinuities in the incremental heat rate characteristic. The valve point loading effects introduce ripples in the heat rate curves and make the cost function discontinuous, non-convex and multiple minimum (Su et al., 2009). One of the ways to model the valve effect is adding a second sentence to the sine function for the generator cost function. These features are non-convex and could not easily used in optimization methods that need convex characteristics.

$$C = \sum_{i=1}^{N_g} F_i(P_i) = \sum_{i=1}^{N_g} (a_i P_i^2 + b_i P_i + c_i) + \sum_{i=1}^{N_g} \sin\left(\alpha_i \left( P_{in} - P_i \right) \right)$$

2.2. Equality and Inequality constraints

Power balance
Fundamental constraint on the operation of this system is known as the power balance constraint, so that the total power output \( \sum_{i=1}^{N_g} P_i \) must be equal to the total load \( P_0 \) and total loss of system \( (P_L) \). Namely:

\[
P_L = P_D = \sum_{i=1}^{N_g} P_i \tag{3}
\]

System losses equation is a function of the B coefficients and sum of the generators generation. The most famous system losses equation is the formula known as Kron (4). It is noticeable that using any other losses function (E.g. Jorge equation \( P_L = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i \times B_{ij} \times P_j \) and …) for ELD will produce the same results and only will change cost (Chaturvedi et al, 2009). The B coefficient matrices are achieved by using a series of conversions on the total impedance matrices related to transmission network.

\[
P_L = B_{ii} + \sum_{i=1}^{N_g} B_{ij} \times P_j + \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} P_i \times B_{ij} \times P_j \tag{4}
\]

**Generator ramp rate limits**

Often, it is supposed that the output of the generating units, soft and instantly adjust to changing times and changes consumable load. But in reality, when the consumable load changes, the unit output cannot change, and interval operation of production units within the production is into ramp rate limitation. District operation of all production units being produced by the limit, i.e. up rate limit \( UR_i \), within the previous down rate limit \( DR_i \) and \( P_i^0 \) are finite. When the ramp rate limitation of generator is proposed, namely the operation of the ith unit has been changed as follows:

\[
\text{Max}(P_i^{\text{min}}, P_i^0 - DR_i) \leq P_i \leq \text{Min}(P_i^{\text{max}}, P_i^0 + UR_i)
\]

\[
\tag{5}
\]

**2.3. Prohibited operating zone**

Generators are practically discontinuous cost curve, as all units operating range (between maximum production and minimum production) for the work is not always possible. In other words, generating units due to some faults on the shaft bearing or mechanical vibrations or other accessories such as pumps, compressors or boilers, etc., are prohibited operating zone (Manjaree, 2009). The prohibited operating zone, loading within a unit is divided into several maximum and minimum generating ranges. Due to the following number sub zone convex regions, the total cost curve of the piece-the piece. Best economy is achieved when the operating units don’t be in these prohibited zones. A production unit with a prohibited operating zone, input-output characteristic curve is discontinuous. The forbidden operating zone can be exploited for ELD issues to be formulated this way (Safari and Shayegehi, 2011):

\[
P_{il} \in \begin{cases} P_{il}^{\text{min}} \leq P_i \leq P_{il}^{\text{max}} \left. \right| \begin{array}{l} P_{il}^{\text{min}} \leq P_i \leq P_{il}^{\text{max}} \\ P_{il}^{\text{min}} \leq P_i \leq P_{il}^{\text{max}} \end{array} \right. \end{cases}
\]

\[
\tag{6}
\]

**3. WIND POWER GENERATION**

Equation (3) is modified so that the power generated by wind source \( P_w \) is deducted from the total power demand.

\[
P_L + P_D = \sum_{i=1}^{N_g} P_i + P_w \tag{7}
\]

The wind power \( P_w \) in equation (7) is limited by the availability amount from the wind park \( P_{aw} \).

\[
P_L + P_D - \sum_{i=1}^{N_g} P_i \leq P_{avw} \tag{8}
\]

**4. REVIEW OF PSO THEORY**

In the PSO (Kennedy and Eberhart, 1995), the particles are in the search space, and change the location of particles in the search space is influenced by experience and knowledge and their neighbors. Therefore, positions of other particle mass effects on how to find a particle. Modeling social behavior is a result of a search process, the particles towards the areas they desire. The PSO is based on the principal that each moment of each particle its location in the search space according to the best place so far it has been and there is the best place in itself whole neighborhood, will set up. This optimizer can be used to solve many of the several problems as genetic algorithm, artificial bee colony, and does not suffer from some of previous algorithms difficulties. Therefore, it has been found to be robust in solving problem featuring non-linear, non-continuous and high dimensionality. For this purpose, the PSO approach is a high potential in providing an optimal response at the appropriate time to address the ELD problems. The PSO algorithm consists of, at each step, changing the velocity of each particle toward its pbest and gbest according to Eq (9).

\[
V_{id}^{(t+1)} = C \left( \omega V_{id}^{(t)} + C_1 \cdot r_1 \left( P_{id}^{(t)} - x_{id}^{(t)} \right) + C_2 \cdot r_2 \left( g_{id}^{(t)} - x_{id}^{(t)} \right) \right)
\]

\[
\tag{9}
\]
Here, \( C \) is a constant factor, \( C_1 \) and \( C_2 \) are acceleration coefficients for cognition sentence and social sentence, respectively. They are random numbers between 0 and 4, that in this paper \( C_1 = C_2 = 2 \). The \( r_1 \) and \( r_2 \) are random numbers between 0 and 1 whereas \( w \) is inertia weight and for each iteration calculated using the following equations:

\[
w = (w_{\text{max}} - w_{\text{min}}) \times \left( \frac{\text{iter}_{\text{max}} - \text{iter}}{\text{iter}_{\text{max}}} \right) + w_{\text{min}} \tag{10}\]

Here \( \text{iter} \) is number of iteration and the \( \text{iter}_{\text{max}} \) is maximum number of iteration and \( w_{\text{min}} = 0.4, w_{\text{max}} = 0.9 \). The \( C \) is a constant factor from the following relationship is obtained [15].

\[
C = \frac{2}{\sqrt{1 + \phi^2} - \phi} \tag{11}\]

Where, \( \phi \) is a random number between in the [4.1,4.2], as is observed with increasing \( \phi \), the factor \( C \) decreases and convergence becomes slower because population diversity reduced (Safari, 2011). The position of the \( i \)th particle is then updated according to:

\[
x_{\text{id}}^{(i+1)} = x_{\text{id}}^{(i)} + V_{\text{id}}^{(i+1)} \tag{12}\]

Where, \( V_i \) velocity vector between the intervals \([V_{\text{min}}, V_{\text{max}}]\) are considered. The \( V_{\text{max}} \) most commonly 10% - 20% of the value is \( X_{\text{max}} \), or otherwise convergence is achieved immediately or is exit from the search space. The biggest problem with standard PSO, is that sometimes causes premature convergence, so try to optimize our algorithms.

5. REVIEW OF PSO AND ROUGH SET THEORY

Rough set theory in 1982 by Pawlak (Pawlak, 1982) was proposed. But in recent years to speed up population-based optimization problems using this theory are realized. The RS extension of classical set theories is based on the logic of three values. This is a new mathematical method for analyzing the data table is working, intelligent data analysis and data mining, loss or reduction of surplus properties and by the most important features is used. The RS philosophy on the assumption that the any object of the world can be as the data (information) considered. The RS theory is a powerful tool for reasoning in that case is unclear and unreliable methods to eliminate and reduce information or irrelevant knowledge database provides surplus to requirements. Objects described by the same data, the information about them are indistinguishable from the point. In this methodology, the basic on RS theory of mathematics is being indistinguishable relationship obtained, namely rough set theory based on the concept of class or category (Andries and Brecht, 2007).

Let \( x \) be an attribute in the description of an object and \( \underline{x}, \overline{x} \) represent lower and upper bounds of \( x \) such that \( \underline{x} \leq x \leq \overline{x} \). The lower and upper bounds are endpoint of rough pattern. A rough pattern value of each variable features, including lower and upper bounds can by Equation (13) is shown.

Can seeing a rough model with drawing in Fig. 1.

\[ x \rightarrow \rightarrow \rightarrow R \]

**Figure 1. A rough value**

Rough model is a subset of closed, compact and bounded of the real numbers set \((x \in R)\). The middle point (mid), radios (rad) and length of x rough value to be formulated this way (Lingras et al, 1999) and (Alatas, 2008):

\[
\text{mid} (x) = \frac{(\overline{x} + x)}{2} \tag{14}\]

\[
\text{rad} (x) = \frac{(\overline{x} - x)}{2} \tag{15}\]

\[
\text{width} (x) = (\overline{x} - x) = 2 \times \text{rad} (x) \tag{16}\]

The rough values can representation with middle point and radios instead end points as following:

\[
x = (\text{mid}(x) - \text{rad}(x), \text{mid}(x) + \text{rad}(x)) \tag{17}\]

The rough values are useful for indicate to intervals or set of values for an attribute, where only lower and upper bounds are considered relevant in a computation. The rough values may be is vague for most areas of calculation mathematics. For example, if the calculations are performed by rough values, it is possible to evaluate a function over an entire interval rather than a single value. In other words, if we evaluate a function \( f(x) \) over some interval of \( x \) (for example \([x \in (\overline{x}, \underline{x})]\)), we know what the possibly overestimated bounds of the function are within that interval (Alatas, 2008). Rough values of the application, most real bounds or overestimate offer that is not a critical value of the function (Alatas, 2008). So, to find the robust root and
the global minimum, maximum and other optimization problems are also very beneficial. In fact, a conventional pattern can be easily represented as a rough pattern to apply to replace the two lower and upper bounds, to be of equal value. Some of the operating on the rough value can be implanted as follows (Alatas, 2008):

\[
x + y = (x, \bar{x}) + (y, \bar{y}) = (x + y, \bar{x} + \bar{y})
\]

(18)

\[
x - y = (x, \bar{x}) + (y, \bar{y}) = (x - y, \bar{x} - y)
\]

(19)

\[
x \times y = \left(\min\{xy, \bar{x}\bar{y}\}, \max\{xy, \bar{x}\bar{y}\}\right)
\]

(20)

\[
1 \div x = \left(1, \frac{1}{\bar{x}}\right) \quad 0 \notin (x, \bar{x})
\]

(21)

\[\begin{align*}
x & = (x, \bar{x}) = (x, \bar{y})
\end{align*}\]

0 \notin (x, \bar{x})

\[
\begin{align*}
\frac{x}{y} & = \left(\frac{1}{y}, \frac{1}{\bar{y}}\right)
\end{align*}\]

(22)

\[
c \times x = c \times (x, \bar{x}) = (c \times x, \bar{c} \times \bar{x})
\]

if \(c \geq 0\)

\[
c \times x = c \times (x, \bar{x}) = \begin{cases} (c \times x, \bar{c} \times \bar{x}) & \text{if } c < 0 \\ (c \times x, \bar{c} \times \bar{x}) & \text{if } c \geq 0 \end{cases}
\]

(23)

The algebraic properties of addition and multiplication operations on values in the Table 1 are described.

\[\text{Table 1. Algebraic properties}\]

<table>
<thead>
<tr>
<th>Algebraic properties</th>
<th>Description</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Commutativity</td>
<td>(x + y = y + x) (x, y = y, x)</td>
<td>No condition</td>
</tr>
<tr>
<td>Associativity</td>
<td>((x + y) + z = x + (y + z)) ((x, y), z = x, (y, z))</td>
<td>No condition</td>
</tr>
<tr>
<td>Neutral element</td>
<td>(0 + x = x) (1 \times x = x)</td>
<td>No condition</td>
</tr>
<tr>
<td>Distributivity</td>
<td>(x, (y + z) = x, y + x, z) If (x = \bar{x}) (x, (y + z) = x, y + x, z) If (y \geq 0 and z \geq 0) (non-negative terms) (x, (y + z) = x, y + x, z) If (y \leq 0 and z \leq 0) (non-positive terms)</td>
<td></td>
</tr>
</tbody>
</table>

Rough particle \(x\) is a string of \(x_i\) rough parameters. Namely:

\[x = (x_i \mid 1 \leq i \leq n)\]

(24)

Rough parameter \(x_i\) is a pair of conventional parameters, the one used for lower bound and the lower parameter is

\[x_i = (x_i, \bar{x}_i)\]

(25)

Figure 2. shows an example of rough particles

Figure 2. The values of each rough parameter, a range that varies. The use of this range indicates that the data represents a rough particle is not accurate. Hence, a data measure called precision (Alatas, 2008), which may be used when evaluating fitness levels. The conventional parameters and particles used at PSO, is a special case of their rough equivalents. This content showed in Fig. 3.
In the boundary constant problems, that’s very important to assured that decision variable values established inside the allowed range, after update the position and velocity equations. This technique can be to make prevalent for RPSO with this constraint that, lower bounds smaller than upper bounds. The particles which are being produced and modify along the evaluation process represent rules. Each of parts involved decision variables that indicate items and intervals. A positional encoding, used where the $i^{th}$ decision variable is encode. Each decision variable consists of the three parts. The first part ($AC_i$) of decision variable indicate antecedent or consequent of the rule and it can be between $[0 , 1)$ and second indicate lower bound ($LB_i$) and third part indicate upper bound part ($UB_i$). If $AC_i$ is between $[0 , 0.33)$, this item is antecedent of the rules and if the $AC_i$ is between $[0.33 , 0.66)$, this item is consequent of the rules and if $AC_i$ is between $[0.66 , 1]$, this item is involved of the rules (Andries, 2007). The structure of a particle is shown in Figure 4.

<table>
<thead>
<tr>
<th>Variable1</th>
<th>Variable2</th>
<th>…</th>
<th>Variablem</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>L</td>
<td>A</td>
<td>U</td>
</tr>
<tr>
<td>B</td>
<td>U</td>
<td>C</td>
<td>LB</td>
</tr>
<tr>
<td>1</td>
<td>B1</td>
<td>B2</td>
<td>m</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>m</td>
</tr>
</tbody>
</table>

**Fig. 4.** Particle representation

### 6. IMPLEMENTATION OF RPSO

Considering the constraints and inequality constraints are very difficult to solve these equations, that exclusively we can solve it with the constraints expressed as a function of output units (Safari and Shayeghi, 2011). To reduce the random motion of particles and the possible diversion that is sometimes causing premature convergence, RPSO method is useful because the data that the deviations are randomly removed and not allowed to enter in the search process shows. The process of the RPSO algorithm for solving ELD problems can be summarized as follows:

Step 1: generate initial population randomly;
Step 2: convert the data table to the decision table;
Step 3: calculate the significant of each attribute and assigned to any given feature;
Step 4: calculate fitness of particles;
When optimization algorithm are applied for constrained ELD problems, it is common to handle constraints using concepts of penalty factors. The popular penalty function method employs functions to reduce the merit of the particle in relation to the magnitude of the constraints violation. The penalty factors are carefully chosen to distinguish between feasible and infeasible solution space. The evaluation function is defined as follows:

$$C = \sum_{i=1}^{N_b} F_i(P_i) + \alpha \left[ \sum_{i=1}^{N_b} P_i - P_{\text{LB}} - P_{\text{UB}} \right] + \beta \left[ \sum_{i=1}^{n} P(\text{violation})_i \right]$$

(26)

Where $\alpha$ is the penalty parameter for not satisfying load demand and $\beta$ is the penalty for unit loading falling white in a prohibited operating zone.

Step 5: Check the stop criterion, the criterion was satisfactorily completed the go to seven step, otherwise, go to the six step;
Step 6: update the particle velocity and position according to equation (9) and (12) and back to the step 4;
Step 7: Finish the RPSO algorithm solving.

### 7. CASE STUDY

#### 7.1. Problem characteristics and setup for all the referred algorithm

To validate the performance of the proposed RPSO efficiently, four standard problems have been taken from the literature of multi-minima ELD for thorough analysis. In each case study, 50 independent runs were made for each of the optimization methods. In implementation of proposed algorithm, some RPSO parameters should be predefined. The parameters of RPSO are selected as following: $C_1 = C_2 = 2$, $w_{\text{max}} = 0.9$ and $w_{\text{max}} = 0.4$. We consider the number of iterations to end criteria, and the number of iterations to solve ELD problems for 3, 6 and 15 units is 200 and 300 generations for 40 units. The initial population was selected 500 and the generator cost range between minimum and maximum and the average generator cost is achieved in 50 iterations and All computation is performed with MATLAB 7.11 and 32-bit microcomputer with Intel Core 2 Duo P8700@2.53GHz CPU and 4 GB RAMs. In order to clarify this issue, we compared the RPSO with two previous methods.

#### 7.2. Description of the case studies

Case I: The first small case contains three thermal units whose characteristics are given in (Krishna and
The load demand of the system is \( P_D = 850 \text{MW} \). The power network losses are obtained by B matrix loss formula. The characteristics of the three thermal units are shown in (Krishna and Manjaree, 2009). The best solutions using the proposed RPSO are shown in Table 2 that satisfies the generator constraints to prove its effectiveness. It can be seen from Table 2 that the RPSO provided better results compared with two networks.

### Table 2. Result obtained by different networks for case I

<table>
<thead>
<tr>
<th>Solution Technique</th>
<th>Best Value</th>
<th>Mean Value</th>
<th>Worst Value</th>
<th>CPU Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation with wind power</td>
<td>8084.417575578924</td>
<td>8143.680287668247</td>
<td>8332.409553355403</td>
<td>0.009160</td>
</tr>
<tr>
<td>Generation without wind power</td>
<td>8811.334799128394</td>
<td>8875.874819912472</td>
<td>9081.562447086305</td>
<td>0.007116</td>
</tr>
</tbody>
</table>

Case II: The second small case is contains six thermal generating limits, 26 buses and 46 transmission lines. The consumable demand is \( P_D = 1263 \text{MW} \). The characteristics of the six thermal units are given in (Gaing, 2006). The network losses are calculated by B-matrix loss formula. The characteristics of the six thermal units are in (Gaing, 2006). Table 3 presents the best cost achieved by the ABC algorithms for the six unit system. It can be seen from Table 3 that the RPSO perform for network with wind power generator better than the ABC perform for network without wind power generator.

### Table 3. Result obtained by different networks for case II

<table>
<thead>
<tr>
<th>Solution Technique</th>
<th>Best Value</th>
<th>Mean Value</th>
<th>Worst Value</th>
<th>CPU Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation with wind power</td>
<td>14196.186306973889</td>
<td>14200.007127760241</td>
<td>14204.178736766855</td>
<td>0.034726</td>
</tr>
<tr>
<td>Generation without wind power</td>
<td>15446.366939085898</td>
<td>15450.532718439719</td>
<td>15455.034816447425</td>
<td>0.032851</td>
</tr>
</tbody>
</table>

Case III: The system contains fifteen thermal units whose characteristics are given in (Gaing, 2006). The consumable demand of the system is \( P_D = 1630 \text{MW} \). Table 4 shows the optimal solutions with execution time determined by RPSO for the fifteen units. It can be seen from Table 4 that the RPSO algorithm at network with wind power is significantly better than the other electric network.

### Table 4. Result obtained by different networks for case III

<table>
<thead>
<tr>
<th>Solution Technique</th>
<th>Best Value</th>
<th>Mean Value</th>
<th>Worst Value</th>
<th>CPU Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation with wind power</td>
<td>30351.045517247061</td>
<td>30480.028193721138</td>
<td>30924.507982962825</td>
<td>0.071264</td>
</tr>
<tr>
<td>Generation without wind power</td>
<td>33014.707108951914</td>
<td>33178.910324637111</td>
<td>33691.82537080587</td>
<td>0.079831</td>
</tr>
</tbody>
</table>

Case IV: The system contains forty thermal units whose characteristics are given in (Wang, 2007). The load demand of the system is \( P_D = 10500 \text{MW} \). The network losses are zero. Through the evolutionary process of the proposed method, it best solutions are shown in Table 5. All of the constraints mentioned before are all satisfied.

### Table 5. Result obtained by different networks for case IV

<table>
<thead>
<tr>
<th>Solution Technique</th>
<th>Best Value</th>
<th>Mean Value</th>
<th>Worst Value</th>
<th>CPU Time (Sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation with wind power</td>
<td>120910.644002240170</td>
<td>122500.775511097717</td>
<td>128521.368101464288</td>
<td>0.210102</td>
</tr>
<tr>
<td>Generation without wind power</td>
<td>131432.470878428985</td>
<td>133161.122285756560</td>
<td>139661.096615394598</td>
<td>0.209725</td>
</tr>
</tbody>
</table>

8. CONCLUSION

In this work, to enrich the searching behavior uses a rough set theory hybrid with PSO algorithm. The integration of wind power into generation and its impact on the ELD are explored. The application feasibility of RPSO for solving economic load dispatch with smooth and non-smooth cost function by taking into account of various systems constraints have been investigated and
analyzed successfully. Furthermore, problem formulation incorporated wind energy to demonstrate and assess the economic benefits of integration wind power plant into power networks. The numerical results obtained for four cases clearly demonstrated that proposed algorithm which is capable of achieving global solutions is simple, computationally efficient and has stable dynamic convergence characteristics.

9. APPRECIATION

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REFERENCES


