Abstract: The Generation expansion planning (GEP) problem is a large scale, mixed integer and the most complicated optimization problem. So we are using Multi-objective differential evolution (MODE) for solving the GEP problem. To calculated for best combinations of conventional sources with and without wind farm, GEP problem is considered for test system of and satisfy the constraints by calculating EENS and LOLP. By computing the optimal point i.e., best compromise solutions using multiple objectives for objective functions like minimization of best investment and best outage costs through Multi-objective differential evolution (MODE) compare them with and without addition of the wind farms and Rank for the best combinations with best investment and outage costs using Multi-criteria decision making method of TOPSIS. 

Keywords: Generation expansion planning (GEP), Multi-objective optimization differential evolution (MODE), Best compromise solution, TOPSIS

Introduction

Renewable energy (Wind, PV, etc.) is critically improving the security of energy supply by drawing upon sustainable natural sources and reducing environmental impacts. The wind power generation is holding the first rank in terms of use and importance. In the last decade, the growth rate of the global installed wind capacity has been about 30% per annum.[1] However, wind resource is intermittent, stochastic and fluctuant, the large-scale integration of wind generation will bring new obstacles to the GENSOCs’ planning. The traditional single-objective approach is no longer suitable for the expansion planning of utilities.[2] So to solve this problem we are using generation expansion planning (GEP) problem[5] which is a large scale, mixed integer and the most complicated optimization problem is finding the most economical generation mix, achieving certain reliability level to meet out the forecast demand which satisfying the constraints.

The criteria are to minimize the total investment cost and outage cost under several operational constraints. GEP describes which generating unit to be constructed or when generating units should come on time over a planning period.

The main purpose of GEP has been to give the sufficient supply of electrical energy at least cost. The fore-most purposes of GEP are to minimize the sum of the investment cost and operating cost of generating units, and to meet the demand and the reliability standards. The optimization techniques are applied to the GEP problem. This GEP problem are largely effective for developing countries, where planning is coordinated by central and state government possessed utilities for capacity addition.

Multi-objective differential evolution (MODE) has been extensively applied in variety of fields. So in this paper based upon the optimization approach to solve the GEP problem. We mostly use Multi-objective differential evolution MODE. A case study on the GEP including large scale wind integration is done. Where the Expected energy not served (EENS) and Loss of load probability (LOLP) for best combinations of conventional and non-conventional plants are calculated.

Multi objective optimization problem as the best solution of each objective along with manageable set of non-dominated solutions are obtained. MODE is applied for obtaining the best investment and outage costs with and without using the wind plant and the results are compared.

GEP Problem Formulation

$$\text{Min } C = \Sigma_{t=1}^{T}[I(U_t) + M(X_t) + O(X_t) - S(X_t)]$$  \hspace{1cm} (1)

Where, $I(U_t)$ is investment cost

$M(X_t)$ is maintenance cost

$O(X_t)$ is outage cost

$C$ is total cost

where,

$$X_t = X_{t-1} + U_t \quad (t=1,2,\ldots,T)$$  \hspace{1cm} (2)

Where, $X_t$ is the cumulative vector

$$I(U_t) = (1 + d)^{-2T} \sum_{i=1}^{N} C_i \times X_{ti}$$  \hspace{1cm} (3)

$$S(U_t) = (1 + d)^{-T} \sum_{i=1}^{N} C_i \times X_{ti} \times U_{ti}$$  \hspace{1cm} (4)

$$M(X_t) = \sum_{i=0}^{T}(1 + d)^{1.5 + t + s} \left( \sum_{j=0}^{N} X_{ij} \times P_C + MC \right)$$  \hspace{1cm} (5)

$$O(X_t) = \text{EENS} \times OC \times \sum_{i=1}^{N} (1 + d)^{1.5 + t + s}$$  \hspace{1cm} (6)

where, EENS is the Expected Energy Not Served

Constraints:

1. upper construction limit, $U_t$ should satisfied

$$0 \leq U_t \leq U_{\text{max},t}$$  \hspace{1cm} (7)

where, $U_{\text{max},t}$ maximum construction bound of the units at stage $t$.

2. Reserve margin,

$$((1 + R_{\text{min}}) \times D_t \leq \Sigma_{i=1}^{N} X_{ti} \leq (1 + R_{\text{max}}) \times D_t)$$  \hspace{1cm} (8)
where, $R_{\text{min}}$ minimum reserve margin; $R_{\text{max}}$ maximum reserve margin; $D_t$ demand at the $t^{\text{th}}$ stage in megawatts (MW); $X_{t}$ cumulative capacity of $t^{\text{th}}$ unit at stage $t$.

3. Reliability criteria,
LOLP$(X_t) \leq \varepsilon$ \hspace{1cm} (9)
where, $\varepsilon$ reliability criterion for permissible LOLP. Lowest reserve margin constraint avoids for a separate demand constraint.

**Wind farms:**

Nowadays wind energy is improved and fastest growing renewable energy technology. Wind farm consist of number of wind turbines in the windy region to grain wind. The total available power of wind farm at each time is equal to the sum of the production of all turbines. The model of wind speed variations should be determined to predict the wind turbine production. The wind generation cost representing the intermittence and fluctuation of wind generation is generally considered as a kind of constraints, such as power flow constraints introduced the wind generation into the objective function. But in this paper wind generation cost is based on the load of probability distribution (LOLP) of wind farm power output. So to solve the GEP problem with and without wind farms, we are applying MODE to GEP.

Reliability indices have also been used in the assessment of different turbine types to be installed in a WF. Since conventional indices such as LOLE, EENS and loss of load frequency (LOLF) resulted in conflicting indices for different WTG types (e.g., LOLE of one type was less than the other while its LOLF was more), two new reliability indices were introduced. Which showed a consistent behavior for WTG types. Reliability based selection of WTG type makes it possible to assess the actual benefit of wind power. Since system reliability is violated mostly in peak load hours, better reliability indices indicate more wind energy during peak hours. It should be noted that more wind power in the peak load hours brings more profit from the WF owner point of view. By injecting more wind energy during high-price hours (i.e., peak hours), not only is the profit of WF owner exploited, but also the security of system improves due to adding wind energy as a negative load to the system. On the other hand, at low-price hours (e.g., the early hours of morning), less energy is brought to the system resulting in preserving load patterns from the viewpoint of system operator. In this way, coincidence of load pattern and wind energy pattern can be assured at the most possible degree. Hence, in case of large WFs, capacity credit of wind power may be taken into account for reliability purposes due to the agreement of load pattern and wind power pattern.

**Mathematical model of wind generators:**

The wind speed is a random variable. A comprehensive review for probability distributions of wind speed can be found. The wind speed distribution is modeled by the Weibull probability distribution function (PDF) as

$$f(v) = \frac{k}{\lambda} \left(\frac{v}{\lambda}\right)^{k-1} \exp\left[-\left(\frac{v}{\lambda}\right)^k\right] \hspace{1cm} (10)$$

From above equation, we assume the WG volatility is subject to a Weibull that is, $f(v)$ is the wind speed random variable. Where $k$ is the shape factor based and $\lambda$ is the scale factor which represents the forecasted WG. Methods of estimating the weibull shape and scale factors using the available wind speed data. Through the wind speed distribution and speed-to power conservation function, the wind power output distribution can be obtained as:

$$P_{\text{wt}} = \begin{cases} \frac{v^k - v^k_{\text{CL}}}{\lambda^k} \left( v_{\text{CL}} \leq v \leq v_{\text{R}} \right) \\ \frac{v^k_{\text{R}} - v^k_{\text{CL}}}{\lambda^k} \left( v_{\text{R}} \leq v \leq v_{\text{CO}} \right) \\ 0 \quad (v < v_{\text{CL}} \text{ and } v > v_{\text{CO}}) \end{cases}$$

Where, $P_{\text{wt}}$ is the total power extracted from wind; $v_{\text{CL}}$ and $v_{\text{CO}}$ is the cut-in and cut-off wind speed of wind turbine; $v_{\text{R}}$ is the wind speed which the mechanical power output will be rate power.

There is a small cost associated with WG operations. The market price of WG is determined based on bilateral contracts or location marginal prices. Upper and lower WG are constrained by the physical characteristics of WG units as well as the optimal operation of power systems.

**Multi-Objective Differential Evolution (MODE)**

There are many problems involve simultaneous optimization of several objective functions. Multi-objective optimization with such conflicting objective functions gives rise to a set of optimal solutions, instead of one optimal solution the reason we are using optimality for many solution is that no one can be considered to be better than other with respect to all objective functions. These optimal solutions are known as paretto optimal solutions.

To overcome the difficulties in traditional optimization techniques new evolutionary population based searching techniques were proposed to solve multi-objective optimization problems (MOP) which is called the Multi objective
Differential Evolution (MODE). The main point of MODE is the a population based searching optimization technique and is specially charters tics by its simplicity, robustness, few control variables and fast convergence.

The proposed MODE technique has been implemented the GEP problem with competing and non-commensurable cost and emission objectives. The results demonstrate the capabilities of the proposed MODE technique to generate a set of well distributed parteo optimal solutions in one single run. [15] The comparison with the different reported techniques demonstrates the superiority of the proposed MODE technique in terms of diversity of parteo solutions.

A multi-objective optimization problem any two solutions \( x_1 \) and \( x_2 \) can have one of two possibilities one dominates the other or non dominates

There are two conditions to satisfied they are :
\[
\forall i \in \{1, 2, \ldots, N_{\text{obj}}\}: f_i(x_1) \leq f_i(x_2) \quad (12)
\]
\[
\exists j \in \{1, 2, \ldots, N_{\text{obj}}\}: f_j(x_1) < f_j(x_2) \quad (13)
\]

The solutions \( x_1 \) does not dominates the solution \( x_2 \). If \( x_1 \) dominates the solution \( x_2 \), \( x_1 \) is called the non dominated solution. The solution that are non dominated within the entire search space are denoted as parteo and constitute the parteo set.

There are few procedure for using the proposed multi-objective differential evolution initialize the control variables and calculate the objectives after that identify the parteo solutions, run fastly with good diversity and convergence and clustered the parteo set. And based on Technique for ordering Preferences by Similarity to Ideal Solutions (TOPSIS) is applied for the non-dominated solutions obtained to determine the Best Compromise Solutions (BCS).

Implementation of MODE

Procedure of MODE:

step 1 : Choose population size \( (N_p) \), crossover probability \( (P_c) \), crossover index \( (N_c) \), mutation parameter \( (F) \), maximum number of iterations and control variable limits.

Step 2 : Generate a random initial population within control variable bounds. Set the iteration count \( g = 0 \).

Step 3 : For each individual in \( N_p \), evaluate the objective function and constraint violations.

Step 4 : Create offspring population \( Q_C \) from \( N_p \) by using mutation strategy and SBX.

a) Perform mutation in the parents to generate mutated parents \( (Q_m) \).

b) Perform recombination using SBX to create \( Q_c \) (of \( N_p \)), for the entire mutated parents \( Q_m \).

Step 5 : Perform non-dominated sorting to combined population \( (N_p Q_c) \), and identify different fronts.

Step 6 : If the size of non-dominated set \( M \) is greater than the population size \( N_p \), then remove the \( (M-N_p) \) individuals from non-dominated set by using DCD based strategy, elsewhere, go to step 4.

Step 7 : If \( g = \) maximum iteration count, then stop the process. Otherwise, increment iteration count \( g=g+1 \) go to step 3.

The Pareto Set:

The parteo set is replacing the dominated solutions for each iteration. During this process, the size of this set may end up with accumulating large number of solutions. The objective space is search to find the nearest solution . Then, the solution that is closer to its next solution then it excluded from the parteo set. This process repeated till the number of parteo solutions. To, solve the diversity of the problem, the size of the parteo set is given a large number during the optimization process. finally, the parteo set is clustered. From the best obtained parteo-front it is usually required to select only solution for the implementation.

TOPSIS Method

The general multi-objective minimization problem, is solved by using this MCDM method TOPSIS – (Technique for Order Preference by Similarity to Ideal Solution). In TOPSIS method
we assume that the ratings of alternatives and weights are represented by numerical data and the problem is solved by a single decision maker. Complexity arises when there are more than one decision makers because the preferred solution must be agreed on by interest groups who usually have different goals. The classical TOPSIS algorithm for a single decision maker and for group decision making is systematically determined. When solutions based on the estimated Pareto-optimal set are found, it is required to choose one of them for implementation. Among many methods, TOPSIS is used extensively in different areas of research. Method is used for the Best compromise solutions (BCS). It is approach to adopt Multi-criteria decision making (MCDM) and BCS for a single decision maker. It is a technique to place the order for similarity the ideal solution.

The ideal solution minimizes the investment cost and maximizes the outage cost during positive cycle and maximizes the investment cost and minimizes the outage cost during negative with the combinations of conventional and non-conventional sources with and without wind farms.

The MCDM problem has n alternatives \( A_1, A_2, \ldots, A_n \) and m decision attribute \( C_1, C_2, \ldots, C_m \) then each alternatives is evaluated with respect to m criteria attribute. The values which are obtained by the alternating with respect to each criteria of decision making denoted by

\[
D = (x_{ij})_{mn} \quad \text{and} \quad D \quad \text{is calculated as}
\]

\[
D = \begin{bmatrix}
  x_{11} & \cdots & x_{1n} \\
  \vdots & \ddots & \vdots \\
  x_{m1} & \cdots & x_{mn}
\end{bmatrix}
\]

then, the normalized decision matrix \( R \) is calculated with \( r_{ij} \) as normalized value,

\[
r_{ij} = \frac{x_{ij}}{\sum_{j=1}^{m}x_{ij}} \quad i=1\ldots m \quad \text{and} \quad j=1,2,\ldots,n
\]

\[
R = \begin{bmatrix}
  r_{11} & \cdots & r_{1n} \\
  \vdots & \ddots & \vdots \\
  r_{m1} & \cdots & r_{mn}
\end{bmatrix}
\]

To determine positive ideal solution and negative ideal solution

\[
A^+ = (V^+_1 \ldots V^+_n) = \left\{ \left( \max_{j=1}^{m} V^+_j \right) \right\}
\]

\[
A^- = (V^-_1 \ldots V^-_n) = \left\{ \left( \min_{j=1}^{m} V^-_j \right) \right\}
\]

calculate the separation measures, n-dimensional Euclidean \( s \) is used. Separation of each alternative from the ideal solution given as

\[
s_j^+ = \sqrt{\sum_{i=1}^{m}(v_{ij} - v^+_i)^2} \quad j=1\ldots n
\]

separation of negative ideal solution,

\[
s_j^- = \sqrt{\sum_{i=1}^{m}(v_{ij} - v^-_i)^2} \quad j=1\ldots n
\]

To calculate the relative closeness to the ideal solution the relative closeness of the alternatives \( A_j \) with respect to \( A^+ \) is defined as,

\[
c_j = \frac{s_j}{s_j^+} \quad j=1,\ldots,n
\]

since, \( s_j^- \geq 0 \) and \( s_j^+ \geq 0 \) then clearly \( c_j \in [0,1] \)

**Best compromise solution:**

Based on differential evolution only we apply the technique to extract the best compromise solution. To Search the solution, to find the \( f_{max} \) and \( f_{min} \) corresponding to each objective function,

\[
u_i = 1 \quad \text{at the limit of} \quad f_i = f_i^{max}
\]
\[ u_i = \frac{f_i^{\text{max}} - f_i^{\text{min}}}{f_i^{\text{max}} - f_i^{\text{min}}} \text{ at the limit of } f_i^{\text{min}} < f_i \leq f_i^{\text{max}} \quad (22) \]

\[ u_i = 0 \text{ at the limit of } f_i = f_i^{\text{max}} \quad (23) \]

Equations satisfied for each objective function of a particular solution and also map the objectives into range 1 to 0. where, M:# of parteo solutions, NO:#of objectives.

Finally, the best compromise solution achieving the maximum member ship function.(uk).

**Simulation Results**

The ideal solution of best combination of generation with the combinations of conventional and non-conventional sources with and without wind farms. Here we are considering generation unit for 6 year and comparing the investment cost and Outage cost.

Table 1
Best Investment costs and Best Outage costs without Wind farm

<table>
<thead>
<tr>
<th>1st Best combination</th>
<th>Min Investment cost</th>
<th>Max Investment cost</th>
<th>Min Outage cost</th>
<th>Max Outage cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Best combination</td>
<td>1.19x10^4</td>
<td>1.22x10^4</td>
<td>1.6x10^4</td>
<td>1.8x10^4</td>
</tr>
<tr>
<td>2nd Best combination</td>
<td>1.19x10^4</td>
<td>1.31x10^4</td>
<td>1.61x10^4</td>
<td>1.81x10^4</td>
</tr>
<tr>
<td>3rd Best combination</td>
<td>1.19x10^4</td>
<td>1.22x10^4</td>
<td>1.6x10^4</td>
<td>1.8x10^4</td>
</tr>
</tbody>
</table>

Table 2
Best Combinations of generating units for 6 years span for Best Investment cost

<table>
<thead>
<tr>
<th>Stage</th>
<th>Oil</th>
<th>LNG</th>
<th>Coal</th>
<th>Nuc (PWR)</th>
<th>Nuc (PWIR)</th>
<th>Capacity Added (MW)</th>
<th>Cumulative Capacity (MW)</th>
<th>EENS</th>
<th>LOLP</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>3060</td>
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</table>

Table 3
Best Combinations of generating units for 6 years span for Best Outage cost

<table>
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<tr>
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Table 4
Best Investment costs and Best Outage costs with Wind farm

<table>
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<tr>
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</tr>
</tbody>
</table>

Table 5
Best Combinations of generating units for 6 years span for Best cost

<table>
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<tr>
<th>Stage</th>
<th>Oil</th>
<th>LNG</th>
<th>Coal</th>
<th>Nuc (PWR)</th>
<th>Nuc (PWIR)</th>
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Table 6
Best Costs with EENS and LOLP Values with and without wind Farm

<table>
<thead>
<tr>
<th>Without wind farm</th>
<th>With wind</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.19x10^4</td>
<td>1.19x10^4</td>
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<tr>
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</tr>
</tbody>
</table>

Table 7
TOPSIS result for GEP without Wind Farm
From fig 1, we can observe that maximum Outage cost and minimum Investment cost.

FIGURE 1: Best compromise solutions without Wind farm

FIGURE 2: Best compromise solutions with Wind farm

CONCLUSION
In this paper, we observe that by applying the Multi-objective Differential evolution technique to the generation expansion planning problem. Also, the program was supported to perform the clustering and extract the best compromise solutions for the objective functions of minimization best investment cost and minimization best outage cost. By applying MODE and TOPSIS method with different best combinations of convention sources with and without addition of wind farms, we compare the results obtained for six-years planning prospects of least cost of generation expansion planning problem.

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