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# Generation Expansion Planning Using Multi-Objective Differential Evolution

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***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 calculate 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.***

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

## 1. 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 GENSCOs' 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 constriants.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

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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.

## 2.GEP Problem Formulation

$Min\ C = \sum_{t=1}^{T}[I(U_t) + M(X_t) + O(X_t) - S(X_t)$ (1)

$s(X_t)$ is salvage new value

I ($U_t$)is investment cost

M($X_t$) is maintenance cost

O ($X_t$) is outage cost

C is total cost

where,

$X_t = X_{t-1} + U_t$ (t=1,2,,…..,T) (2)

Where, $X_t$ is the cumulative vector

$\mathrm{I}(\mathrm{U_t}) = (1+\mathrm{d})^{-2t\sum_{i=1}^{N}\mathrm{CI_i}\times}\mathrm{U_{t,}i}$ (3)

$\mathrm{S}(\mathrm{U_t}) = (1+\mathrm{d})^{-T\sum_{i=1}^{N}\mathrm{CI_i}\times\delta_i} \times \mathrm{U_{ti}}$ (4)

$\mathrm{M}(\mathrm{X_t}) = \sum_{s=0}^{1}(1+\mathrm{d})^{1.5+t+s}(\sum(\mathrm{X_t}\times\mathrm{FC}) + \mathrm{MC})$ (5)

$\mathrm{O}(\mathrm{X_t}) = \mathrm{EENS}\times\mathrm{OC}\times.\sum_{s=0}^{1}(1+\mathrm{d})^{1.5+t+s}$ (6)

where, EENS is the Expected Energy Not Served

### 2.1 Constraints:

1.upper construction limit, $U_t$ should satisfied

$0\leq U_t \leq U_{max}, t$ (7)

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

2.Reserve margin,

$((1+\mathrm{R_{min}})\times\mathrm{D_t} \leq \sum_{i=1}^{N}\mathrm{X_{t,i}} \leq (1+\mathrm{R_{max}})\times\mathrm{D_t}$ (8)

where, $\mathrm{R_{min}}$ minimum reserve margin;

$\mathrm{R_{max}}$ maximum reserve margin;

$D_t$ demand at the $t^{th}$ stage in megawatts(MW);

$\mathrm{X_{t,i}}$ cumulative capacity of $i^{th}$ unit at stage t.

3.Reliability criteria,

$\mathrm{LOLP}(\mathrm{X_t}) \leq \epsilon$ (9)

where, € reliability criterion for permissible LOLP. Lowest reserve margin constraint avoids for a separate demand constraint.

### 2.2 Wind farms:

Now a days 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 loss of load 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

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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

### 2.3 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

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

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:

$$P_{wt} = \begin{cases} P_W^{max} = \dfrac{v^k - v_{CI}^k}{v_R^k - v_{CI}^k} & (v_{CI} \le v \le v_R) \\ P_W^{max} & (v_R \le v \le v_{CO}) \\ 0 & (v < v_{cI}\, and\, v > v_{co}) \end{cases}$$

Where, $P_{Wt}$ is the total power extracted from wind; $v_{cI}\, and v_{co}$ is the cut-in and cutt-off wind speed of wind turbine; $v_R$ 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

### 3.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 Pareto 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 Pareto 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 Pareto 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 :

$\forall i \in \{1,2,\ldots,N_{obj}\}: f_i(x_1) \le f_i(x_2)$ (12)

$\exists j \in \{1,2 \ldots, N_{obj}\}: f_i(x_1) < f_i(x_2)$ (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 Pareto and constitute the Pareto set.

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There are few procedure for using the proposed multi-objective differential evolution initialize the control variables and calculate the objectives after that identify the Pareto solutions, run fastly with good diversity and convergence and clustered the Pareto 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).

### 3.1 Implementation of MODE

**Procedure of MODE:**

Step 1 : Choose population size ($N_p$), crossover probability ($P_c$), crossover index ($N_C$), muta-tion 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.

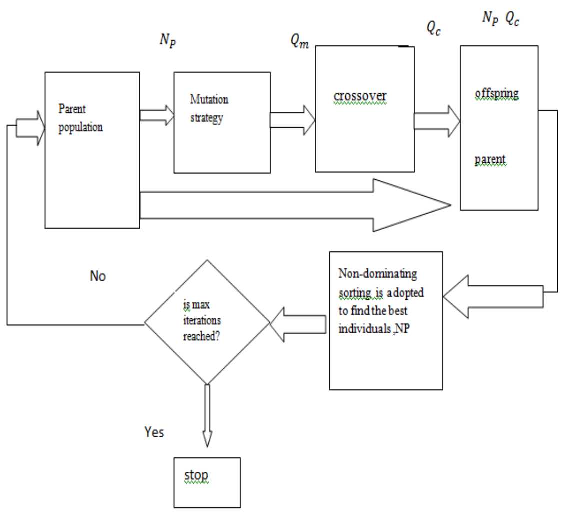


figure 3.1 flow chart for MODE

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

Step 4 : Create offspring population QC 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 $N_p$ size), for the entire mutated parents,$Q_m$.

Step5 : Perform non-dominated sorting to combined population($N_p Q_c$),and identify different fronts.

Step6 : 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.

### 3.2 The Pareto Set:

The Pareto 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 Pareto set. This process repeated till the number of Pareto solutions. To, solve the diversity of the problem, the size of the Pareto set is given a large number during the optimization process. finally, the Pareto set is clustered. From the best obtained Pareto-front it is usually required to select one solution for the implementation

### 3.3 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,

$$u_i = 1 \quad \text{at the limit of } f_i = f_i^{max} \qquad (21)$$

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

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

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).

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## 4.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 results

### Table 4.1

Best Combinations of generating units for 6 years span for Best Investment cost without wind farm

| Stage | Oil | LNG | Coal | Nuc (PWR) | Nuc (PWHR) | Capacity Added (MW) | Cumulative Capacity (MW) | EENS | LOLP |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 1 | 3 | 0 | 0 | 2950 | 8400 | 13.504 | 0.0046 |
| 2 | 3 | 0 | 1 | 0 | 0 | 1100 | 9500 | 18.447 | 0.0054 |
| 3 | 1 | 0 | 0 | 0 | 0 | 200 | 9700 | 20.084 | 0.0068 |
| 1 | 1 | 4 | 2 | 0 | 0 | 3000 | 8450 | 14.640 | 0.0044 |
| 2 | 2 | 2 | 0 | 0 | 0 | 1300 | 9750 | 18.447 | 0.0054 |
| 3 | 1 | 0 | 0 | 0 | 0 | 200 | 9950 | 20.084 | 0.0068 |
| 1 | 1 | 4 | 0 | 1 | 0 | 3000 | 8450 | 19.961 | 0.0057 |
| 2 | 4 | 0 | 1 | 0 | 0 | 1300 | 9750 | 17.082 | 0.0050 |
| 3 | 2 | 0 | 0 | 0 | 0 | 400 | 10150 | 22.092 | 0.0063 |

### Table 4.2

Best Combinations of generating units for 6 years span for Best Outage cost without wind farm

| Stage | Oil | LNG | Coal | Nuc (PWR) | Nuc (PWHR) | Capacity Added (MW) | Cumulative Capacity (MW) | EENS | LOLP |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 0 | 0 | 0 | 3 | 3100 | 8550 | 14.640 | 0.0040 |
| 2 | 5 | 4 | 0 | 0 | 0 | 2800 | 11350 | 11.781 | 0.0038 |
| 3 | 1 | 2 | 0 | 0 | 0 | 1100 | 12450 | 19.961 | 0.0058 |
| 1 | 1 | 2 | 1 | 0 | 2 | 3000 | 8450 | 13.504 | 0.0047 |
| 2 | 3 | 2 | 0 | 0 | 0 | 1500 | 9950 | 17.082 | 0.0050 |
| 3 | 3 | 1 | 0 | 0 | 0 | 1050 | 11000 | 19.961 | 0.0054 |
| 1 | 1 | 4 | 0 | 1 | 0 | 3000 | 8450 | 16.035 | 0.0047 |
| 2 | 0 | 1 | 2 | 0 | 0 | 1450 | 9900 | 10.591 | 0.0027 |
| 3 | 5 | 0 | 0 | 0 | 0 | 1000 | 10900 | 18.190 | 0.0050 |

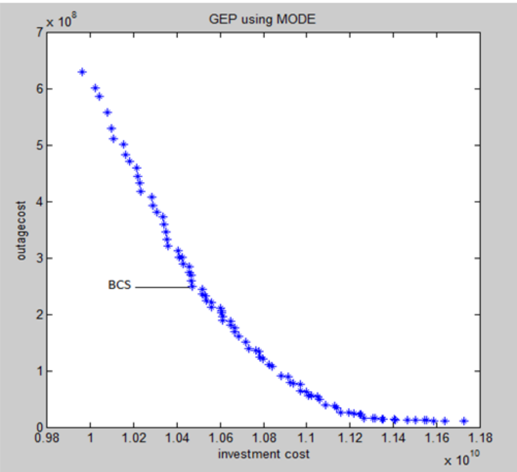


Figure 4.1:Best compromise solutions without wind farm

In table 4.3, we describe the best combinations of Oil, LNG (gas), coal, Nuclear (PWR), Nuclear (PWHR) units for Investment cost with wind farm. The EENS and LOLP are evaluated through MATLAB coding.. Figure 4.1 gives the MODE Convergence characteristics of best Compromise solution without wind farm and we can observe that maximum Outage cost and minimum Investment cost**.**

### Table 4.3

Best Combinations of generating units for 6 years span for Best Investment cost with wind farm

| Stage | Oil | LNG | Coal | Nuc (PWR) | Wind farm | Capacity Added (MW) | Cumulative Capacity (MW) | EENS | LOLP |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 2 | 1 | 2 | 1 | 5400 | 10800 | 26.3 | 0.032 |
| 2 | 1 | 2 | 2 | 0 | 2 | 4100 | 14900 | 12.4 | 0.044 |
| 3 | 1 | 0 | 1 | 0 | 1 | 1700 | 16600 | 20.13 | 0.054 |
| 1 | 1 | 3 | 2 | 1 | 1 | 4600 | 10000 | 13.50 | 0.040 |
| 2 | 5 | 2 | 2 | 1 | 1 | 4900 | 14900 | 12.00 | 0.022 |
| 3 | 1 | 0 | 2 | 1 | 1 | 3200 | 18100 | 25.72 | 0.050 |
| 1 | 5 | 2 | 2 | 1 | 2 | 5900 | 11300 | 20.09 | 0.021 |
| 2 | 1 | 3 | 2 | 0 | 1 | 3500 | 14800 | 22.51 | 0.025 |
| 3 | 1 | 1 | 1 | 0 | 1 | 2150 | 16950 | 11.02 | 0.011 |

In table 4.4, we describe the best combinations of Oil, LNG (gas), coal, Nuclear (PWR), Nuclear (PWHR) units for Outage cost with wind farm. The EENS and LOLP are evaluated through MATLAB coding. Figure 4.2 gives the MODE Convergence characteristics of best Compromise solution wind farm.

### Table 4.4

Best Combinations of generating units for Outage cost with wind farm

| Stage | Oil | LNG | Coal | Nuc (PWR) | Wind farm | Capacity Added (MW) | Cumulative Capacity (MW) | EENS | LOLP |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 2 | 0 | 2 | 1 | 4100 | 9550 | 11.5 | 0.040 |
| 2 | 1 | 1 | 2 | 0 | 2 | 2050 | 11600 | 30.3 | 0.039 |
| 3 | 2 | 1 | 0 | 0 | 1 | 1050 | 12650 | 13.01 | 0.012 |
| 1 | 1 | 2 | 3 | 1 | 1 | 3800 | 9250 | 24.07 | 0.051 |
| 2 | 5 | 1 | 1 | 0 | 1 | 2150 | 11400 | 11.02 | 0.011 |
| 3 | 1 | 0 | 1 | 2 | 1 | 2900 | 14300 | 22.51 | 0.025 |
| 1 | 5 | 1 | 1 | 0 | 2 | 2350 | 7800 | 23.42 | 0.030 |
| 2 | 1 | 2 | 3 | 0 | 1 | 2800 | 10600 | 27.05 | 0.036 |
| 3 | 1 | 1 | 0 | 1 | 1 | 1850 | 12450 | 10.02 | 0.010 |

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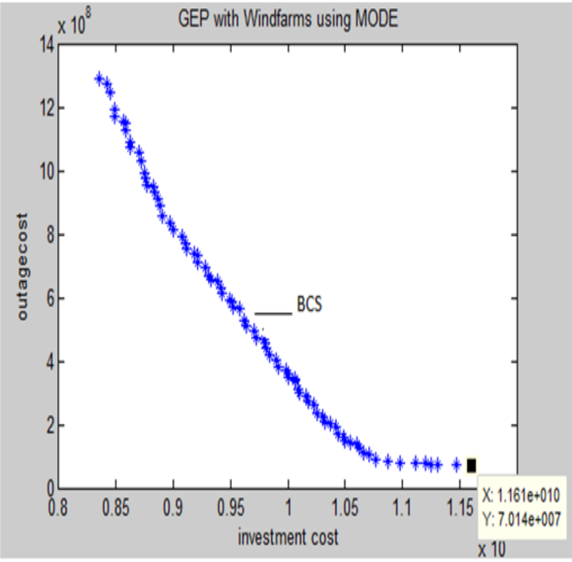


Figure 4.2:Best compromise solutions with Wind farm

## 5. CONCLUSION

In this paper, we observe that applying the Multi-objective Differential evolution technique to the generation expansion planning problem .Also, the program was supported to perform the clustering of objective functions of minimization best investment cost and minimization best outage cost. By applying MODE method with different best combinations of conventional 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. Obtaining the best investment and outage cost of the MODE Results will be continued by applying the TOPSIS Method.

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