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MINIMUM COST ESTIMATION OF GENERATION EXPANSION PLANNING INCORPORATING WIND POWER PLANT

J. Booma[1], K. Mahadevan[1] and S. Kannan[2]
[1]Department of Electrical and Electronic Engineering, PSNA College of Engineering and Technology, Dindigul, Tamilnadu, India
[2]Department of Electrical and Electronic Engineering, Ramco Institute of Technology, Rajapalayam, Tamilnadu, India
E-Mail: boomakumar2005@gmail.com

ABSTRACT

The most significant planning bustle in the electric utilities is the Generation Expansion Planning (GEP). This paper aims to incorporate Wind Power Plant (WPP) as one among the candidate option in GEP and analyse the cost incurred to incorporate WPP as one of the candidate. The total cost consists of the Initial cost, Operation and maintenance cost, Outage cost and Salvage cost. Outage Cost is calculated based on Expected Energy Not Served (EENS). In this paper, equivalent energy function method is applied to compute EENS and to compute Loss of Load Probability (LOLP) which is considered as a reliability constraint. Particle Swarm Optimization (PSO) technique has been applied. The results obtained by PSO were compared with Dynamic Programming (DP) method. Addition of WPP to instead of conventional plants is expected to increase the total cost, and it is necessary to study the impact of such increase. The resulting cost and reliability indices variations were also reported.

Keywords: generation expansion planning, wind power plant, expected energy not served, loss of load probability.

INTRODUCTION

In recent years one of the major issues in the world is diminishing availability of fossil fuels and increase in energy demand. In developing countries like India, due to the astronomical increase in power/energy demand, there is a power deficit, which is estimated to be approximately 17% as of February 2015. To meet the ever-increasing energy demand, it is essential to have a number of power generation projects for capacity additions. Generation Expansion planning (GEP) aims to generate sufficient electrical energy in order to meet the increase in demand by incorporating wind power plant (WPP) as one among the candidate plants. To meet the demand growth, it is necessary to find the best expansion alternative for the system [1-2].

The aim of generation planning is to seek the most economical generation expansion scheme achieving a certain reliability level according to the forecast of increase in demand in a certain period of time.

In GEP, the following questions are to be answered [3]:

1) When to invest in new generating units?
2) Where to invest in new generating units?
3) What type of generating units to be installed?
4) What capacity of generating units to be installed?

Proper planning saves project time and ensures that resources are used most economically. For making such planning decisions, analyzing the total cost and reliability of various GEP alternatives are required.

GEP PROBLEM FORMULATION

A. Objective function [4], [5]

The GEP problem is equivalent to finding a set of best decision vectors over a planning horizon that minimizes the investment and operating costs with several constraints. The cost function (objective function) is represented by the following expression:

where,

$$X_t = X_{t-1} + U_t \qquad (t = 1,2,...\mathrm{T}) \tag{1}$$

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

$$\mathrm{S}(\mathrm{U}_t) = (1+d)^{-T'} \sum_{i=1}^{N} \left(CI_i \times \delta_i \times U_{t,i}\right) \tag{3}$$

$$M(X_t) = \sum_{s'=0}^{1} \left((1+d)^{1.5+t'+s'} \left(\sum \left(X_t \times FC\right) + MC \right) \right) \tag{4}$$

$$O(X_t) = OC \times \sum_{s'=0}^{1} \left((1+d)^{1.5+t'+s'} \right) \tag{5}$$

$$t' = 2(t-1) \tag{6}$$

$$T' = 2 \times T - t' \tag{7}$$

and

C = Total cost in dollars
T = Length of the planning horizon
U_t = Vector of introduced units in the stage t (1 stage = 2 years)
X_t = Cumulative capacity vector of existing units in the stage t
$I(U_t)$ = Investment cost of the added unit at t-th stage in dollars
$M(X_t)$ = Operation and maintenance cost of existing and the introduced units in dollars
$O(X_t)$ = Outage cost of the existing and the

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introduced units in dollars

$S(U_t)$ = Salvage value of the added unit at t-th stage in dollars

X_{t-1} = Cumulative capacity vector of existing units in the stage (t–1)

d = Discount rate

N = Total number of different types of units

CI_i = Capital investment cost of i-th unit in dollars

$U_{t,i}$ = i-th element of the introduced unit in stage t

δ_i = Salvage factor of i-th unit used to calculate salvage value

s' = Variable used to indicate that the maintenance cost is calculated at the middle of each year

FC = Fixed cost of the existing as well as added unit in dollars

MC = Maintenance cost of the units in dollars

OC = Outage cost of the units in dollars

EENS = Expected Energy Not Served, MWhrs

B. Constraints

a. Upper construction limit

If U_t be the vector of units to be committed, in the expansion plan at stage t, U_t must satisfy the maximum construction capacity vector of the units to be committed.

$$[0] \le U_t \le U_{\max,t} \tag{8}$$

where,

[0] = vector containing elements of zero value

$U_{\max,t}$ = maximum construction capacity vector of the units at stage t.

b. Reserve margin

The selected units must satisfy the minimum and maximum reserve margin.

$$(1+R_{\min})\times D_t \le \sum_{i=1}^{N} X_{t,i} \le (1+R_{\max})\times D_t \tag{9}$$

where,

$R_{\min}$ = minimum reserve margin, (20%)

$R_{\max}$ = maximum reserve margin, (40%)

D_t = demand at t-th stage in MW

$X_{t,i}$ = cumulative capacity of i-th unit at t-th stage

c. Fuel mix share

The GEP has different types of generating units based on fuel used such as Oil, Liquefied Natural Gas (LNG), Coal, Wind and Nuclear. The selected units along with the existing units of each type must satisfy the fuel mix share.

$$M_{\min}^{j} \le X_{t,j} / \sum_{i=1}^{N} X_{t,i} \le M_{\max}^{j} \qquad j = 1, 2, ..., N \tag{10}$$

where,

$M_{\min}^{j}$ = minimum fuel mix ratio of j-th type

$X_{t,j}$ = cumulative capacity of j-th type at stage t, MW

$M_{\max}^{j}$ = maximum fuel mix ratio of j-th type

j = type of the unit (type of fuel used: Oil, LNG, Coal, Wind and Nuclear)

d. Reliability measure

The selected units along with the existing units must satisfy the reliability criterion, Loss of Load Probability (LOLP).

$$\text{LOLP}(X_t) \le \varepsilon \tag{11}$$

where,

ε = reliability criterion expressed in LOLP.

C. Description of test system

The system consists of existing power systems of 15 nos. and 5 types of candidate options, which are planned for 6 years of time horizon. The planning period is dived to 3 stages (1 stage = 2 years). The cost analysis made with 5 types of candidate plants with 2 cases.

Case I: GEP with Conventional plants

Case II: GEP with WPP by replacing nuclear plant.

Table-1 shows the Peak Demand Forecasted for 6 years [4], [5], [6].

Table-1. Peak demand forecasted.

Stage	Year	Peak demand (MW)
0	2014	5000
1	2016	7000
2	2018	9000
3	2020	10000

D. Assumptions made

i) Reserve Margin's minimum and maximum limits were fixed as 20% and 40%.

ii) Existing system fuel mix share is considered as 0-30%, 0-40%, 20-60%, 30-60% and 30-60% for Oil, LNG, Coal, Nuclear #1 (PWR) and Nuclear #1 (PWHR).

iii) EENS Cost is 0.05 $/ kWh.

iv) Discount rate is 8.5%.

a. Case I- GEP with conventional plants

Oil, LNG C/C, Coal, Nuclear (PWR) and Nuclear (PHWR) are considered as candidate Plants. Table A-I shows the technical and economic data of Candidate Plant for Case I [6].

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b. Case II- GEP with WPP by replacing Nuclear plant

Oil, LNG C/C, Coal, Wind and Nuclear (PHWR) are considered as candidate Plants [6]. Table A-II shows the technical and economic data of Candidate Plant for Case II [6-8]. Table A-III shows the technical and economic data of existing plants [4], [5].

E. Implementation using Dynamic Programming Method

The solution space is modified to find the best solution. The combinations that satisfying the constraints in current stage are combined with next stage combinations and only the cumulative combinations are considered for next stage. Among the number of resultant combinations, there are combinations which provide same cumulative capacity vector and from those combinations, the only combination yielding smaller cost is retained. This reduces the total number of combinations considered further [8], [9], and [10].

F. Implementation using PSO technique

The synchronized movement of flocks of birds without collision was the basic concept of PSO and was observed and studied by Eberhart [9]. The velocity of each agent is modified by adapting the following rule:

$$v_i^{k+1} = wv_i^k + C_1 rand_1 \times (pbest_i - s_i^k) + C_2 rand_2 \times (gbest - s_i^k) \quad (12)$$

The position of each agent is modified by the following rule:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (13)$$

The weighting factor w is modified by

$$w = w_{max} - \frac{w_{max} - w_{min}}{iter_{max}} \times iter \quad (14)$$

PSO is one of the Swarm Intelligence (SI) techniques, which uses the group intelligence behaviour along with individual intelligence to solve the combinatorial optimization problem. Table-2 shows PSO parameters used.

A step-by-step procedure of implementing PSO to the LC-GEP problem is as follows:

Step-1: Initialization of agents and their velocity in the swarms
Step-2: Updating the velocity
Step-3: Updating the position
Step-4: Fitness function evaluation using penalty factor approach (PFA)
Step-5: Termination criteria

Table-2. Parameters of PSO.

Parameters	Size
Population size	20
Max. no. of iteration	200
w_{max}, w_{min}	(0.8, 0.2)
C_1, C_2	2,2
χ	1

RESULTS AND DISCUSSIONS

In Case I, conventional plants only considered for GEP as a candidate options. The results obtained with Conventional plants were listed in Table-3. The number of units selected for every stage, LOLP and total cost were obtained for 6 years' time horizon were also listed in Table-3. Comparison made with the results in literature [5]. The total cost was1.2009*$10^{10}$$ referred and obtained from literature [5]. In order to get this total cost, it should be observed from the past study, the optimal combination of candidate plants at the first stage is four no. of oil plants, one LNG plant, two no. of coal plants and three no of nuclear (PHWR), totally ten no. of conventional plants were required, nuclear (PWR) is not added. The added capacity is 4,350 MW and cumulative capacity is 9,800 MW. The LOLP for first stage is 0.0098 days/year. In second stage, five no. of oil plants, two no. of LNG plants and one coal plant, no nuclear (PWR) and nuclear (PHWR), totally eight no of conventional plants were required. The added capacity becomes 2400 MW and cumulative capacity is 12,200 MW. The LOLP for second stage is 0.0080 days/year. In third stage, one no. of oil plant, two no. of LNG plants, and there is no. need for coal plant, nuclear (PWR) and nuclear (PHWR), totally three no. of conventional plants were required. The added capacity is 1,100 MW and cumulative capacity is 13,300 MW. The LOLP for third stage is 0.0086 days/year.

In Case II along with conventional plants, WPP also incorporated which, is eco-friendly. Table-4 shows the results for 6 years, 3 stages using DP. The total cost is 0.6206*$10^{10}$$. In order get this total cost, it was observed that, the optimal combination of candidate plants at the first stage is five no. of oil plants, three no. of LNG plants, two no. of coal plants, one no. of WPP and one no. of nuclear (PHWR), totally twelve no. of candidate plants were required. The added capacity is 2,900 MW and cumulative capacity is 8,350 MW. The LOLP for first stage is 0.0096 days/year. In second stage, four no. of oil plants, four no. of LNG plants, one coal plant, two no. of WPP and one no. of nuclear (PHWR), totally twelve no. of candidate plants were required. The added capacity becomes 3,250 MW and cumulative capacity is 13,050 MW. The LOLP for second stage is 0.0033 days/year. In third stage, five no. of oil plant, three no. of LNG plants, one coal plant, three no. of WPP and one no. of nuclear

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(PHWR), totally thirteen no. of candidate plants were required. The added capacity is 3,150 MW and cumulative capacity is 15,350 MW. The LOLP for third stage is 0.0054 days/year. From the results it should be noted that in each stage cumulative capacity is excess than the forecasted demand. Therefore some other energy storage system is aimed to make use of generated energy. Hence by considering pollution and degradation to the environmental the addition of WPP is justified as suitable option for candidate plant.

Comparison made for Case-I and Case-II using DP and PSO, total cost were obtained for the optimal combinations of candidate options. Comparative results were listed in Table-6.

CONCLUSIONS

Because of many problems posed towards the environment such as pollution, depletion of ozone layer, emission of CO_2, rising fuel cost and diminishing the availability of fossil fuels leads the attention towards on renewable energy. In this Paper WPP is taken for cost analysis of GEP. While making such a cost effective decision by incorporating WPP, needs to reduce the capacity of WPP than conventional plant. Thus by analyzing both cases with conventional plant and incorporation WPP along with convention plants gives promising cost reduction only by compromising the capacity. Obtained results are validated with DP.

Table-3. Results for 6 years 3 stages using dynamic programming- case I- GEP with conventional plants.

Years	Stage	Selected candidate plants					Added capacity	Cumulative capacity	LOLP (Days / Year)	Total cost $\times 10^{10}$$
		Oil	LNG C/C	Coal (Anthracite)	Nuclear (PWR)	Nuclear (PHWR)				
2016	1	4	1	2	0	3	4350	9800	0.0098	1.2009
2018	2	5	2	1	0	0	2400	12200	0.0080	
2020	3	1	2	0	0	0	1100	13300	0.0086	

Table-4. Results for 6 years 3 stages using dynamic programming-case II – GEP with wind power plants.

Years	Stage	Selected candidate plants					Added capacity	Cumulative capacity	LOLP (Days / Year)	Total cost $\times 10^{10}$$
		Oil	LNG C/C	Coal (Anthracite)	Wind power plant	Nuclear (PHWR)				
2016	1	5	3	2	1	1	2900	8350	0.0096	0.6206
2018	2	4	4	1	2	1	3250	13050	0.0033	
2020	3	5	3	1	3	1	3150	15350	0.0054	

Table-5. Results for 6 years 3 stages using PSO-case II-GEP with wind power plants.

Years	Stage	Selected candidate plants					Added capacity	Cumulative capacity	Total cost $\times 10^{10}$$
		Oil	LNG C/C	Coal (Anthracite)	Wind power plant	Nuclear (PHWR)			
2016	1	0	3	2	3	1	2400	7850	0.6202
2018	2	0	2	1	2	0	850	10650	
2020	3	1	1	0	1	0	500	12700	

Table-6. Comparison of results for 6 years 3 stages using DP & PSO – for case I and case II.

	Years	Stage	Case-I	Case-II
DP	6	3	1.2009×10^{10} $	$0.6206 \times 10^{10}$$
PSO	6	3	$1.2009 \times 10^{10}$$	$0.6202 \times 10^{10}$$

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Appendix Table A-I. Technical and Economic Data of GEP Candidate Plants with Conventional Plant – Case-I [4], [6].

Candidate type	**Maximum construction limit**	**Capacity** (MW)	**FOR** (%)	**Operating cost** ($/ kWh)	**Fixed O&M cost** ($/kW-Month)	**Capital cost** ($/ kW)	**Life time in years**
Oil	5	200	7.0	0.021	2.20	812.5	25
LNG C/C	4	450	10.0	0.035	0.90	500.0	20
Coal (Anthracite)	3	500	9.5	0.014	2.75	1062.5	25
Nuc.(PWR)	3	1,000	9.0	0.004	4.60	1625.0	25
Nuc.(PHWR)	3	700	7.0	0.003	5.50	1750.0	25

Table A-II. Technical and economic data of GEP candidate plants with wind power plant – case II [6].

Candidate type	**Maximum construction limit**	**Capacity** (MW)	**FOR** (%)	**Operating cost** ($/kWh)	**Fixed O&M cost** ($/kW-Month)	**Capital cost** ($/ kW)	**Life time in years**
Oil	5	200	7.0	0.021	2.20	812.5	25
LNG C/C	4	450	10.0	0.035	0.90	500.0	20
Coal (Anthracite)	3	500	9.5	0.014	2.75	1062.5	25
Wind Power Plant	3	250	8.14	0.004	3.00	1000.0	25
Nuc.(PHWR)	3	700	7.0	0.003	5.50	1750.0	25

Table A-III. Technical and economic data of existing plants [4], [6].

Name (fuel type)	**No. of units**	**Unit capacity** (MW)	**F.O.R** (%)	**Operating cost** ($/kWh)	**Fixed O&M cost** ($/kW-Month)
Oil #1 (Heavy oil)	1	200	7.0	0.024	2.25
Oil #2 (Heavy oil)	1	200	6.8	0.027	2.25
Oil #3 (Heavy oil)	1	150	6.0	0.030	2.13
LNG G/T #1 (LNG)	3	50	3.0	0.043	4.52
LNG C/C #1 (LNG)	1	400	10.0	0.038	1.63
LNG C/C #2 (LNG)	1	400	10.0	0.040	1.63
LNG C/C #3 (LNG)	1	450	11.0	0.035	2.00
Coal #1 (Anthracite)	2	250	15.0	0.023	6.65
Coal #2 (Bituminous)	1	500	9.0	0.019	2.81
Coal #3 (Bituminous)	1	500	8.5	0.015	2.81
Nuclear #1 (PWR)	1	1,000	9.0	0.005	4.94
Nuclear #2 (PHWR)	1	1,000	8.8	0.005	4.63

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