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Application of DE for Least Cost GEP with Solar Power Plant

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Abstract:
Generation Expansion Planning (GEP) is a significant decision making problem in electricity power sector. It is the one of the important problem as both the supply side and demand side for energy have sequential and spatial variations. The development of infrastructure is an essential aspect to sustain the economic growth. The energy sector is one of the most important infrastructure elements for any economy. The achievement of energy security requires modification of our energy resources and the sources of their supply as well as measures for saving of energy in India, so far we were dependent on conventional resources of energy like thermal, hydro and nuclear. The benefits of solar energy penetration are drawing the attention of power system planners to incorporate solar energy in the power system. In this study, the influence of the addition of solar power plants is examined for 14-year planning horizon/limit using Differential Evolution Algorithm (DEA). The model formulated in this study integrates all critical elements of the system.

Keywords: *DEA, Emission, GEP, Solar Power Plants and Reliability Indices.*

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I. INTRODUCTION

The Generation expansion planning (GEP) defines the what types of power plant, when it is commissioned and which location the new power generation units/ expand the existing unit to be added/upgraded over the planning horizons under various constraints to satisfy the electricity demand [1, 2]. While solar power plant can generate electric power without CO2 emissions, the restricted availability to store the electricity and availability of control for solar energy system are playing important role at all levels of electrical power system [3].

Optimal GEP is usually concentrated on reducing the total investment cost while filling operational constraints. In the traditional GEP to represent realistic physical systems, the mathematical methodologies are used [4]. Since 1950's, many mathematical methodologies such as Dynamic Programming [5], Dynamic Programming with tunnel constrained [6], Branch and Bound method [7], Benders-Decomposition [8] have been used. Some of the other methods used in GEP problem are discussed in [9].

Genetic Algorithm (GA) and its variants are used to solve the GEP [10-12]. Hybrid approaches such as GA with Immune algorithm [4] and Dynamic Programming [13] are also used. Different Meta-heuristic techniques have been applied to solve GEP problem and the available results are compared with Dynamic Programming in [14]. The authors have concluded that Differential Evolution (DE) [15] performs better than other Meta-heuristic techniques. DE has been widely applied in a various engineering application problems including GEP [16].

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II. GEP PROBLEM FORMULATION

The GEP problem resembles to find the set of optimal decision variables over a planning period which reduces the total asset cost and functioning costs under certain constraints. The predicted maximum electricity demand at each stage is shown in the Table A1. The technical and economic data of candidate plants, solar power plants and existing plants are referred in [11]. The Performance of the proposed systems are evaluated by two reliability indices like Loss of Load Probability (LOLP) and Expected Energy Not Served (EENS). The assumptions considered in this study are referred from [14] and the problem formulation and its constraints are referred from [15].

III. RESULTS AND DISCUSSIONS

In this section, three cases based on the availability of solar power plants in the system are analyzed for including emission cost. In case I, GEP study is carried out without consideration of solar plant i.e. considering only conventional plants. In case II (a) and in case II (b) consider as existing solar plants and also include the candidate solar plants with 10-20% penetration levels. In case III (a) and in case III (b) the solar plant is considered as 6th expansion candidate plants in addition to five conventional plants with same penetration level as in case II.

3.1 Case I – Without solar power plant (Without emission cost)

In this case, solar plants are not considered as an expansion candidate and only conventional plants are considered as candidate plants. The 14 years planning horizons results obtained without consider the solar power plant are given in Table 2. It shows that the number of units selected for each stage, cumulative capacity, LOLP, EENS, maintenance cost, outage cost and the overall cost of the GEP problem. Comparison made with the result of a past study [14].

The total cost was 2.1811□ 1010$ and there are ten number of oil plants, five number of LNG plants, eleven number of coal plants, two number of nuclear (PWR) and three numbre of nuclear (PHWR) plants are selected. The values of LOLP and EENS at the end of 14 years planning horizon are computed as 0.0098 days/year and 3.8012□ 104 MWh respectively.

3.2 Case II (a) (consider as Existing solar plant and Candidate Solar plant)

In this case consider as Oil plant in addition to sixth expansion type of Existing solar plant and Candidate Solar plant. The obtained results are given in Table 3. The total cost is 2.2930□ 1010$ and the number of plants selected are such as ten number of oil plants, four number of LNG plants, seven number of coal plants, two number of nuclear (PWR) plants, six number of nuclear (PHWR) plants and seven number of solar plants. The values of LOLP and EENS at the end of the planning horizon are computed as 0.0070 days/year and 2.7292□ 104 MWh respectively.

3.3 Case II (b) (consider as Existing solar plant and Candidate Solar plant)

In this case consider as Oil plant in addition to sixth expansion type of Existing solar plant and Candidate Solar plant. The penetration of solar is fixed as 10-20%. The obtained results are given in Table 4. The total cost is 2.4390□ 1010$ and the plant considered are seventeen number of oil plants, one number of LNG plants, seven number of coal plants, two number of nuclear (PWR) plants, five number of nuclear (PHWR) plants and ten number of solar plants are selected. The values of LOLP and EENS at the end of 14 years planning horizon are computed as 0.0142 days/year and 5.7595□ 104 MWh respectively.

3.4 Case III (a) (With separate addition of 5-10% of solar power plant).

In this case, solar plant is considered as sixth expansion candidate. The obtained results using DE algorithm are given in Table 5. The total cost is 2.6087□ 1010$ and the plant selected are such as six number of oil plants, five number of LNG plants, five number of coal plants, five number of nuclear (PWR) plants, three number of nuclear (PHWR) plants and two number of solar plants. The values of

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LOLP and EENS at the end of the planning horizon are computed as 0.0091 days/year and 3.8952□104 MWh respectively.

3.5 Case III (b) (With separate addition of 10-20% of solar power plant)

In this case, solar plant is considered as sixth expansion candidates. The penetration of solar is fixed as 10-20%. The obtained results are given in Table 6. The total cost is 2.9874□1010$ and the selected plants are fifteen number of oil plants, six number of LNG plants, five number of coal plants, three number of nuclear (PWR) plants, four number of nuclear (PHWR) plants and three number of solar plants are selected. The values of LOLP and EENS at the end of 14 years planning horizon are computed as 0.0056 days/year and 2.1771□104 MWh respectively.

Comparison of LOLP, EENS and Overall cost are shown in Table 7. For 14 years planning horizon for case I (without solar plant) the LOLP is 0.0098 days/year, EENS is 3.8012□104 MWh and the overall cost is 2.1811□1010$. If the solar plant considers as Oil plant in addition to sixth expansion type of existing solar plant and also includes the candidate solar plant (Case II) overall cost, LOLP, EENS increases with increase in solar penetration. If the solar plant is added as 6th type of plant (Case III) overall cost, LOLP, EENS increases with increase in solar penetration.

IV. CONCLUSIONS

The study carried in this work demonstrates the influence of penetration of solar power plants into the system as resource diversity. When renewable energy sources like solar plants are introduced as a resource substitute, there will be an increase in the installed capacity required; it will be compensated from the benefits of the reduced emission costs. In this research the application of DE algorithm applied to solve the GEP problem with different penetration level of solar power plants for the 14-year planning horizons. It has been observed that, the solar energy penetration level increases, the reliability of the power system is decreased with increased overall cost. For without considering the emission, the overall cost increases by a minimum of 5.13% and 36.9% and with considering the emission the overall cost increases by a minimum of 6.76% and 35.4% for 14 years planning horizon. An India having abundant solar energy resources should give importance to solar energy for expansion of electrical energy system. So it is important to harness the untapped solar energy potential in cost effective manner to satisfy the electric power requirements. In future, the dispatch characteristic of solar energy needs to be integrated in the GEP studies in order to have accurate results.

TABLE 1
RESULTS FOR 14-YEARS PLANNING HORIZON
(CASE I WITHOUT SOLAR PLANT)
WITHOUT EMISSION COST

Stage (t)	Selected candidate plants					Capacity added (MW)	Cumulative Capacity (MW)	LOLP (Days/Year)	EENS $\times10^4$ (MWh)	Cost ($)		
	Oil	LNG C/C	Coal (Bitum)	Nuc (PWR)	Nuc (PHWR)					Maintenance$\times10^9$	Outage$\times10^6$	Overall$\times10^{10}$
1	4	1	2	0	3	4350	9800	0.0093	2.7373	1.8797	2.3271	
2	0	0	3	1	0	2500	12300	0.0090	2.9861	1.9518	2.1565	2.1811
3	1	0	2	0	0	1200	13500	0.0082	2.8410	1.8596	1.7428	
4	0	0	3	1	0	2500	16000	0.0074	2.7629	1.8391	1.4397	

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5	3	1	0	0	0	1050	17050	0.0088	3.2631	1.7577	1.4444
6	1	1	1	0	0	1150	18200	0.0087	3.3643	1.6462	1.2650
7	1	2	0	0	0	1100	19300	0.0098	3.8012	1.5705	1.2141

Stage (t)	Selected candidate plants						Capacity added (MW)	Cumulative Capacity (MW)	LOLP (Days/Year)	EENS × 104 (MWh)	Cost ($)		
	Oil	LNG C/C	Coal (Bitum)	Nuc (PWR)	Nuc (PHWR)	Solar					Maintenance × 109	Outage× 106	Overall× 1010
1	5	0	3	1	0	2	3900	9950	0.0408	14.190	1.9976	1.2064	
2	2	0	0	0	3	1	2700	12650	0.0238	8.5977	1.9706	6.2090	
3	0	1	0	0	1	1	1350	14000	0.0222	8.1720	1.8524	5.0132	
4	5	0	1	0	1	3	2800	16800	0.0185	7.0287	1.8948	3.6627	2.439
5	1	0	2	0	0	1	1400	18200	0.0155	5.9555	1.7494	2.6362	
6	3	0	1	0	0	1	1300	19500	0.0150	5.7631	1.6239	1.4857	
7	1	0	0	1	0	1	1400	20900	0.0142	5.7595	1.4444	3.5568	

TABLE 2
RESULTS FOR 14-YEARS PLANNING HORIZON (CASE II-A WITH 5-10% SOLAR PLANT)
(EXISTING SOLAR PLANT AND CANDIDATE SOLAR PLANT)
(OIL PLANT IN ADDITION 6TH TYPE OF SOLAR PLANT)

Stage (t)	Selected candidate plants						Capacity added (MW)	Cumulative Capacity (MW)	LOLP (Days/Year)	EENS × 10^4 (MWh)	Cost ($)		
	Oil	LNG C/C	Coal (Bitum)	Nuc (PWR)	Nuc (PHWR)	Solar					Maintenance × 10^9	Outage × 10^6	Overall× 10^{10}
1	1	2	2	0	3	0	4200	10250	0.0105	3.1970	1.8926	2.7179	
2	5	1	2	0	1	2	3550	13800	0.0012	0.3374	2.0112	0.2437	
3	0	0	0	0	0	0	0	13800	0.0163	5.5890	2.0270	3.4286	
4	1	0	1	2	0	0	2700	16500	0.0110	4.2044	1.8925	2.1909	2.2930
5	2	0	1	0	0	2	1300	17800	0.0142	5.5852	1.7695	2.4723	
6	1	1	1	0	1	0	1850	19650	0.0039	1.4483	1.5841	0.5445	
7	0	0	0	0	1	3	1300	20950	0.0070	2.7292	1.4298	0.8717	

TABLE 3
RESULTS FOR 14-YEARS PLANNING HORIZON (CASE II-B WITH 10-20% SOLAR PLANT)
(EXISTING SOLAR PLANT AND CANDIDATE SOLAR PLANT)
(OIL PLANT IN ADDITION 6TH TYPE OF SOLAR PLANT)

TABLE 4
RESULTS FOR 14-YEARS PLANNING HORIZON (CASE III-A WITH 5-10% SOLAR PLANT)
(EXISTING NO SOLAR PLANT AND CANDIDATE SOLAR PLANT)
(OIL PLANT IN ADDITION 6TH TYPE OF SOLAR PLANT)

Stage (t)	Selected candidate plants						Capacity added	Cumulative Capacity	LOLP (Days/Year)	EENS × 104	Cost ($)		
	Oil	LNG	Coal	Nuc	Nuc	Solar					Maintenance	Outage×	Overall×

		C/C	(Bitum)	(PWR)	(PHWR)		(MW)	(MW)		(MWh)	× 109	106	1010
1	3	0	2	3	0	1	5600	11050	0.0099	3.5942	1.7363	3.0557	
2	0	1	2	1	1	0	3150	14200	0.0025	0.8938	1.7853	0.6455	
3	0	0	1	0	0	0	500	14700	0.0092	3.2714	1.7350	2.1909	
4	0	2	0	1	1	0	2600	17300	0.0066	2.6412	1.7448	1.3763	2.6087
5	2	2	0	0	0	0	2300	19600	0.0007	0.2805	1.6337	0.1241	
6	0	0	0	0	0	0	0	19600	0.0067	2.7402	1.5717	1.0304	
7	1	0	0	0	1	1	1900	21500	0.0091	3.8952	1.4374	1.2441	

TABLE 5
RESULTS FOR 14-YEARS PLANNING HORIZON (CASE III-B WITH 10-20% SOLAR PLANT)
(EXISTING NO SOLAR PLANT AND CANDIDATE SOLAR PLANT)
(OIL PLANT IN ADDITION 6TH TYPE OF SOLAR PLANT)

	Selected candidate plants										Cost ($)		
Stage (t)	Oil	LNG C/C	Coal (Bitum)	Nuc (PWR)	Nuc (PHWR)	Solar	Capacity added	Cumulative Capacity (MW)	LOLP (Days /Year)	EENS × 104 (MWh)	Maintenance × 109	Outage× 106	Overall× 1010
1	4	1	3	1	1	2	6450	11900	0.0081	2.4461	1.9617	2.0949	
2	5	0	2	1	1	0	3700	15600	0.0004	0.1291	1.9711	0.9325	
3	0	0	0	0	0	0	0	15600	0.0062	2.0851	1.9178	1.2791	
4	3	2	0	1	0	0	2500	18100	0.0051	1.8363	1.9807	0.9569	2.9874
5	1	0	0	0	1	0	900	19000	0.0080	3.0666	1.8092	1.3574	
6	2	3	0	0	0	1	2750	21750	0.0024	0.8465	1.7415	0.3183	
7	0	0	0	0	1	0	700	22450	0.0056	2.1771	1.5835	0.6953	

TABLE 6
COMPARISON OF LOLP, EENS AND OVERALL COST AT END OF THE PLANNING YEAR HORIZON

Case	LOLP(days/year)	EENS×104 (MWh)	Overall Cost (×1010 $)	Capacity added
Case I [Without Solar Plant] (Without Emission)	0.0098	3.8012	2.1811	19300
Case II (a) [5-10% solar plant] Oil plant in addition 6th type of solar plant Existing Solar plant and Candidate Solar plant	0.0070	2.7292	2.2930	20950
Case II (b) [10-20% solar plant] Oil plant in addition 6th type of solar plant Existing Solar plant and Candidate Solar plant	0.0142	5.7595	2.4390	20900
Case III (a) [5-10% solar plant] Oil plant in addition 6th type of solar plant Existing no Solar plant and Candidate Solar plant	0.0091	3.8952	2.6087	21500
Case III (b) [10-20% solar plant] Oil plant in addition 6th type of solar plant Existing no Solar plant and Candidate Solar plant	0.0056	2.1771	2.9874	22450

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TABLE 7
FORECASTED PEAK DEMAND [11]

Stage (Year)	0	1	2	3	4	5	6	7
Peak (MW)	5000	7000	9000	10000	12000	13000	14000	15000

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