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A Goal Programming Approach to Large Scale Thermal Power Generation Units

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Abstract

In this paper we employ a Goal Programming technique to determine the maximization of thermal power generation level with some selecting restrictions imposed on its units. The contribution margin is being affected by the method of running of the units at part loads. This method gives the non-availability of the time for preventive maintenance, increased the maintenance cost. Similarly the higher oil consumption also increases the acid corrosion to boilers.

Keywords: Power Generation, Goal Programming.

INTRODUCTION

Preventive maintenance of thermal generating units is a classical problem of resource scheduling in power systems. This is large scale non linear stochastic optimization problem with constraints [3, 8]. Firstly, the number of independent variables in a mathematical model is determined by the number of units and by the number of time stages. The non linearity is an inherent feature of power systems, manifested in the relationship between fuel consumption and generated power, limited energy units or the fact that many variables are integer. Finally, the stochastic nature of Maintenance Scheduling (MS) problem derives from load, thermal units forced outages and natural hydro inflows.

There exist several goals when solving planning and scheduling problems and in most cases, they are antagonistic. However the conventional approach in existing power systems optimization algorithms is such that the most important criterion is formulated as the optimization objective, while other criteria are defined as constraints of introduced into the objective function in the form of penalties. Such single-objective methods do not completely meet the requirements of utility planners, whose most important task is the determination of the best compromise solution of the objectives considered. The use of goal programming techniques is therefore a logical step in overcoming the lacks of single-objective models.

The maintenance scheduling model proposed is a medium term production cost model formulated as a large scale mixed integer optimization problem subject to operation and maintenance constraints. The optimization is performed in two stages including two different criteria minimum total variable operation costs and minimum differences between the reserve margins of consecutive periods.

The binary nature of the MS problem makes a very reasonable method for integer optimization. For example the branch and bound approach can be applied in solving integer and mixed integer problems, as well as non linear integer problems. According to **Kraji B and Petrovic R [8]**, it guarantees to find the feasible solution and the optimal solution with respect to the chosen optimality criterion. Also this method is computationally acceptable even for problems with a large number of variables and constraints. But in MS a compromise between those requirements must be achieved, adequate reliability with minimal fuel costs, maximum efficiency in using available resources or minimal difference between period reserve margins. These requirements are of conflicting nature, it is obvious that the Ms Problem is essentially of a multi objective type. This was recognized by **Mukerji et al. [9],** discussing the solutions obtained by optimization of two alternative objective criteria: costs or reliability. In this paper we develop a Goal Programming model to determine the maximization of thermal power generation level with some selective restrictions imposed on units.

DATA OF THE PROBLEM

This study was carried out on Raichur Thermal Power Station, Karnataka, India. Kanataka Power Corporation Ltd is a premier power generating company in Karnataka, Generating 75% of power needs of Karnataka state. Kanataka Power Corporation Ltd was established in 1970 for implementing design, construction and operation of power projects in Karnataka is the pioneer in the field of hydel power generation way back in 1898. In this field, Karnataka has seen several land marks. The year 1902 will be remembered in the history of India, as it saw the completion of the first and largest hydro power station in Asia at Shivasamudram, on the banks of river Cauvery. When the Bangalore city lighting scheme was completed on 3rd August 1905 saw Karnataka as the first to embark on alternate current.

Two stalwarts whose vision and genius took Karnataka state to the very fore fornt of Hydeal power generation are Sir. M.Vishwesvaraya and Sir Mirza Ismail. Whose vision continue to fire the enthusiasm of every succeeding generation and inspire its policy makers in power generation and distribution. The Karnataka State has the further distinction of being the first state in the Country to conceive and set up a professionally managed Corporation called KPCL. The Karnataka State was the first to have the longest transmission line in the world in1902 from Shivasamudram to KGF covering a distance of 147 Kms.

Blessed with many rivers, Karnataka state has wisely harnessed the latent power of water for the twin purposes of irrigation and hydro electric power generation.The rivers in Karnataka state fall in to two distinct categories called west and east flowing rivers.The west flowing rivers originate at high altitudes in the mighty western ghats are short in length and flow through hilly terrain. This makes them ideally suited for power generation. Some of the west flowing rivers are Mahadayi, Kalinadi, Gangavalli, Bedthi, Aghanashini, Sharavathi, Varahi, Nethravathi and Barapole. Tapping the power potential of the east flowing rivers is largely confined to the foot of the irrigation dams and at the canal head works.

The KPCL is a trend setter in power generation with a track record of commissioning 31 dams and 17 power houses of varying sizes 0.35MW to 1260MW .The Kanataka Power Corporation Ltd has to its credit several engineering marvels like the Kalinadi Hydel project, which includes Supa dam, Tattihalli dam, Bommanahalli dam, and Nagjhari power house.

Kanataka Power Corporation Ltd is now having an installed capacity of 3868MW and is in the process of adding another 1400MW in the next 2 to 3 years. The Kanataka Power Corporation Ltd in its 31 years of existence has acquired rich and varied experience in the fields of investigation , planning, design, execution and effective operation, maintenance of large scale power projects.Also under takes hydro electric power projects installation on turn key basis.

To avoid heavy dependance on hydel projects, which depended on purely on monsoon. The Kanataka Power Corporation Ltd under took RTPS in 1980, which is now a big station with installed capacity of 1260MW. The unit-5 was commissioned in just 28 months mainly due to effective and modern project management techniques against minimum period of 36 months. The Kanataka Transimission Power Corporation Ltd (KTPCL) previously called as Karnataka Electricity Board, purchases power generated by Kanataka Power Corporation Ltd. The KTPCL is vested mainly with the function of transimission and distribution to the consumers. The Kanataka Power Corporation Ltd is fully geared to meet the challenges and energy demands of India’s fastest growing state in all fields. The Kanataka Power Corporation Ltd seeks to be a world class organisation emphasising efficiency, cost effectiveness and harmony with the environment in the field of power generation.

RAICHUR THERMAL POWER STATION

Location

Raichur Thermal power Station is located on the right bank of river Krishna, about 18 kms from Raichur in Karnataka state, At persent, It is the only thermal power station. The foundation stone for Raichur Thermal power Station complex was laid on by Sri(Late) N.Sanjiva Reddy, Former president of our country and opened on 29.03.1985. The place where the power station and the town ship for the employees is located is named as "Shaktinagar". The shaktinagar is situated at an altitude of 350 mtrs above mean sea level and is easily approachable by both rail and roads. Raichur to Hyderabad state high way road runs adjacent to the power station. This power station is situated at a distance of 185 kms from Hyderabad and 515 kms from Bangalore. The nearest railway station is Raichur which is situated on the broad gauge line between Guntakal and Wadi stations of south central railway. Raichur station is at a distance of 121 kms from Guntakal junction and 108 kms from Wadi junction. Raichur is well connected directly by rail to major cities in India.

Capacity

The infrastructure at RTPS is built for seven units and it has grown up in stages as detailed below. The total capacity will be 6x210MW now and 1470MW after completion of seventh unit.

I stage: Unit-1 commissioned on 29-03-1985
Unit-2 commissioned on 02-03-1986

II stage: Unit-3 commissioned on 30-03-1991
Unit-4 commissioned on 29-09-1994

III stage: Unit-5 commissioned on 31-01-1999
Unit-6 commissioned on 22-07-1999

IV stage:Unit-7 commissioned in 2003

Inputs

The principle inputs required for the thermal power generation are water, coal, spares for plant equipments, trained man power. The water is drawn from Krishna river at intake point and is suitabelly treated both physically and chemically. The water requirement for RTPS complex is around. The Karnataka state has got plenty of gold mines, iron ore mines and other mineral mines, But coal mines are not available. The

RTPS is importing coal from other states and occassionally from foreign countries. The RTPS was originally linked to M/s.Singareni Colliers Company Ltd(SCCL) for coal supply and later from M/s.Wester Coal Fields. After globalisation, The coal is drawn from different coal mines like SCCL, WCL,MCL(Talcher) ets on economic point of view. The hurdles faced by the all thermal power stations are in procurement of good quality of coal and movement of coal in time by railway's. The coal mines bellampally, mandamari, manchirial, ramagundam, yellandu, mangaru of SCCL are at a distance of 532 kms from RTPS and pandharapavani, new sasti, chanrapur, ballarsha, ghugus, new majri of WCFL are at a distance of 700 kms from RTPS complex. The longest coal mine is talcher of M/s.Mahanadi Coal Mines Ltd is at a distance of 1575 kms from RTPS. The railway freight charges per MT basis from the above said mines is Rs.500/-, 700/- and 1100/- respectively. Where as the rate at which coal is procured at coal mines is approximately Rs,1000/- per MT. The major portion in procurement of coal is spent on the tranportation. Even then, The per unit cost of energy produced and sold is very less compared to M/s. Dhabol Power Corporation and other private generating companies. The cost can be further reduced if pitted station. I.e coal mines are adjacent to the power station.

Maintenance Norms and Forced Outages Planned Maintenance Norms

1. **200 MW Units**

(a) i. Minor maintenance : 15 days shut down every 6 months

ii. Boiler overhaul : 45 days shut down in 2 years

iii. Capital overhaul : 75 days shut down once in 3 years

(b).

Units :	I	II	III	IV	V	Total
Shut down (days):	15+45	15+15	15+75	15+15	15+45	270

Average maintenance per day = 54 days

(c) For a particular year:

i. Two units shall have two minor maintenance

ii. Two units shall have boiler maintenance and overhaul maintenance

iii. One unit shall have capital overhaul and a minor maintenance

2. 500 MW Units

(a) i. Minor maintenance : 20 days shut down every 6 months

ii. Boiler overhaul : 50 days shut down in 2 years

iii. Capital overhaul : 90 days shut down once in 3 years

(b) Years	:	I	II	III	IV	V	Total
Shut down (days)	:	20+20	20+50	20+20	20+20	20+90	260

Average maintenance per day = 52 days

(c) For a particular year:

i. One unit shall have two minor maintenance

ii. Other units shall have boiler overhaul maintenance and one minor maintenance

3. Forced Outages

(a) 200 MW Units (Outages hours):

Particulars	2003-04	2004-05	Average
Unit 1	80	112	96
Unit 2	133	351	242
Unit 3	130	453	291.5
Unit 4	177	58	117.5
Unit 5	931	435	683
Total	1451	1309	1380

Average forced outage taken: 380 days for 200 MW

(b) 500 MW Units (Outages hours):

Particulars	2003-04	2004-05	Average
Unit 5	924	1016	970
Unit 6	635	453	544
Total	1559	1469	1514

Availability of Units

(a) 200 MW Units:

Unit Number	Planned Shut down (hours)	Average Forced Outage (hours)	Total Max. Outage (hours)	Operating Available (hours)
Unit 1	650	100	750	8010
Unit 2	870	240	1110	7650
Unit 3	990	290	1280	7480
Unit 4	670	120	890	7870
Unit 5	1250	680	1930	6830
Total	4430	1380	5960	37840

(b) 500 MW Units:

Unit Number	Planned Shut down (hours)	Average Forced Outage (hours)	Total Max. Outage (hours)	Operating Available (hours)
Unit 5	1040	970	2010	6750
Unit 6	2950	540	3490	5270
Total	3990	1510	5500	12020

Partial Loading Data

1. Partial Loading due to Grid Restrictions

(a) Grid Restrictions imposed by Southern Region for Raichur Thermal Power Station

Period	Load Restriction (MW)
6 Hours to 12 Hours	1200 MW
12 Hours to 6 Hours	1400 MW

(b) Average Auxiliary Consumption

Year:	2003-04	2004-05	2005-06	Average
200 MW	8.54	8.13	8.72	8.46
500 MW	6.10	6.25	5.25	5.87

Weighted Auxiliary Consumption = [(8.46 x 1000) + (5.87 x 1000)] / 2 = 7.17

(c) Load Restriction at Station including Auxiliary Power Consumption

Period	Load Restriction (MW)
6 Hours to 12 Hours	1200 / 0.9283 = 1292.69
12 Hours to 6 Hours	1400 / 0.9283 = 1508.13

Weighted average load = [(1293 x 6) + (1508 x 18)] / 24 = 1454 MW

(d) Considering all Units available Partial Loading at full Load Generation Capacity

Load factor (%) = (1508 x 100) / 2000 = 75.4%

Partial loading = 24.6%

(e) Average Load Factor at 80% Generation Capacity

Average Load Factor (ALF) = (1454 x 100) / 1600 = 91%

Hence partial loading = 9%

2. Partial Loading due to Station Problems

(a) 200 MW Units:

Particulars	2003-04	2004-05	Average
Milling System	8	40	24
Boiler Miscellaneous	32	20	26
Scrapper conveyor / Bottom Ash	44.75	50.87	35.5
Draught System	16	40	28
Boiler Feed Pumps	3	6	3.5
Unit Start Up	50	58	54
Turbine Total	15	14	14.5
Coal Systems	1350	600	975
Total	1497	824	1160

(b) Partial Loading Hours at 40% Load

i.. Equivalent full Load (hours) at 40% Load = 1160 / 3 =387

ii. Partial Load (hours) at 40% Load = 387 / 0.4 = 967

(c) 500 MW Units:

Particulars	2003-04	2004-05	Average
Milling System	4	10	7
Boiler Miscellaneous	29	15	22
Scrapper conveyor / Bottom Ash	7	42	24.5
Draught System	12	3	7.5
Boiler Feed Pumps	2	6	4
Unit Start Up	52	39	45.5
Turbine Total	5	6	5.5
Coal Systems	920	350	635
Total	1013	471	751

(d) Partial Loading Hours at 40% Load

i.. Equivalent full load (hours) at 40% load = 751 / 3 =250

ii. Partial load (hours) at 40% load = 250 / 0.4 = 625

Designed Parameters and Oil Consumption

1. **Heat Rate**

(a) 200 MW Units

Load	Designed Heat Rate at 330C (KCAL / KWH)	Boiler Efficiency	Designed Heat Rate of Unit	Heat Rate Unit at 5% Generation Loss due to Deviation (KCAL / KWH)
100	2253	82.32	2340	2565
80	2354	82.70	2035	2474
60	2146	81.65	2395	2570
40	2240	84.51	2025	2450

(b) 500 MW Units:

Load	Designed Heat Rate at 330C (KCAL / KWH)	Boiler Efficiency	Designed Heat Rate of Unit	Heat Rate Unit at 5% Generation Loss due to Deviation (KCAL / KWH)
100	2086	81.81	2380	2541
80	2121	83.05	2309	2633
60	2009	82.51	2186	2411
40	2331	82.32	2363	2474

2. **Average Calorific Value**

	2003-04	2004-05	2005-06	Average Calorific Value
i. Coal Kcal / Kg	4395	4272	4395	4110
ii. Oil Kcal / Liter	10,000	10,000	10,000	10,000

The average calorific value of coal has been considered as 4000 Kcal /Kg due to deterioration on coal quality.

3. Oil Consumption

Oil Gun Capacity : 1 KL / Hour

Total number of Guns : 12

Total number of Elevations : 3

(a) 200 MW Units:

Load %	Furnace Oil Consumption (KL / Hour)	Specific Oil Consumption (ML / KWH)	Remarks
100	Nil	Nil	No Oil Support
80	0.2	0.734	Oil Consumption for 2 Mills. Change over Considered for Average Time 30 Minutes With 4 Oil Guns
60	2.0	16.67	An Average 50% of the Time 4 Guns are Required for Oil Support
40	4.0	50.00	Oil Support, 4 Oil Guns at an Elevation all the Times

(c) 500 MW Units

Load %	Furnace Oil Consumption (KL / Hour)	Specific Oil Consumption (ML / KWH)	Remarks
100	Nil	Nil	No Oil Support
80	0.4	1.0	Oil Consumption for 2 Mills. Change over Considered for Average Time 30 Minutes With 4 Oil Guns
60	10.0	33.33	An Average 4 Oil guns Considered for Oil Support at one Elevation
40	20.0	100.00	Oil Support With 8 Oil Guns Considered in View of Large Odd Combination of Mills

Cost Data

(a). 200 MW Units

Particulars	Load			
	100%	80%	60%	40%
Heat Rate Kcal /KWH	2322	2379	2691	2894
Specific Oil Consumption ML / KWH	Nil	1.2	16.67	50
Heat input of Oil Kcal / KWH	Nil	12.5	166.67	500
Heat input of Coal Kcal / KWH	2472	2499.5	2437.5	2337
Specific Coal Consumption	0.639	0.656	0.664	0.673
Cost of Oil per KWH	Nil	0.714	9.46	28.40
Cost of Coal per KW	33.18	34.02	33.00	32.04
Sales Price	139.02	139.02	139.02	139.02
Contribution margin	108.12	106.65	100.12	82.64

(b). 500 MW Units

Particulars	Load			
	100%	80%	60%	40%
Heat Rate Kcal /KWH	2496	2505	2598	2802
Specific Oil Consumption ML / KWH	Nil	1.0	33.33	100
Heat input of Oil Kcal / KWH	Nil	10	333.33	1000
Heat input of Coal Kcal / KWH	2398	2457	2243	1696
Specific Coal Consumption	0.602	0.632	0.594	0.463
Cost of Oil per KWH	Nil	0.576	18.93	56.79
Cost of Coal per KW	33.06	33.89	31.62	26.75
Sales Price	139.02	139.02	139.02	139.02
Contribution margin	105.91	108.90	90.04	59.50
Cost of Fuel	33.04	34.62	50.06	84.15

i. Cost of Coal per Metric Ton : Rs 535.80

ii. Cost of Furnace Oil per KL : Rs 5679.00

iii. Calorific Value of Coal Kcal / Kg : Rs 4000.00

iv. Calorific Value of Oil Kcal /Liter : Rs 10,000.00

Goal Programming Model

The four main objectives (goals) of the organization given the, pre-emptive priorities P_1,P_2,P_3 and P_4 are listed below:

i) **Maximization of Generation:** Since the station had capacity utilization of 7383 KWH/KW installed per Year in the previous year in order to get reward from ministry of energy in group a level II, step II, it must at least have the same capacity utilization.

ii) **Maximization of Contribution Margin:** The generation cost is calculated at different loads, which varies according to the operation load. This can be maximized when energy is generated efficiently. Rs. 2100 crores have been fixed as goal which give 119.80 P/KWH contribution margin at full capacity utilization.

iii) **Maximization of Oil Consumption:** The goal is kept to minimize total oil consumed in a year, which is taken as low as 5000KL. The actual oil consumption can be worked out by solution of the model.

iv) **Minimization of Fuel Cost:** The fuel cost for a year worked out according to load contributions.

System Constraints

i). **Coal Supply Constraint:** Keeping in view the coal supply position for previous years, the contract has been fixed with the Coal Company as 10 million mtrs.by all means due to various problems at the mine end \ MGR and at station end.

ii) **Availability Constraints:** In order to keep the units in healthy conditions, the planned maintenance norms have been framed. Secondly, forced outage norms have been worked out from previous year and the down time is calculated. The total availability of units is limited which is termed as availability constraints.

iii) **Partial Loading Constraint:** This has been worked out due to restrictions of grid and station problems. Considering that all the units are available at particular time and the maximum evacuation is available as per grid, the maximum availablehours at full load are constraints to this extent.

iv) **Generation Constraint:** Due to power evacuation problem the generation of the year is limited. This has been worked out on daily average loading.

Mathematically the Goal Programming Model can be Developed as follows:

Minimize $Z = P_1 d_1^- + P_2 d_2^- + P_3 d_3^+ + P_4 d_4^+$

Subjects to the Constraints:

I. Generation for Reward Constraints:

$2X_1 + 1.6\,X_2 + 1.2\,X_3 + 0.8\,X_4 + 5\,X_5 + 4\,X_6 + 3\,X_7 + 2\,X_8 + d_1^- - d_1^+ =$ 1,47,66,000.00

II. Contribution Margin Constraints:

$216.24\,X_1 + 170.64\,X_2 + 120.15\,X_3 + 66.12\,X_4 + 555.7\,X_5 + 424.88\,X_6 + 284.01X_7 + 127.5\,X_8 + d_2^- - d_2^+ =$ 2,28,900.00

III. Oil Consumption Constraint (KL)

$0.2\ X_2 + 2\ X_3 + 4\ X_4 + 0.4\ X_6 + 10\ X_7 + 20\ X_8 + d_3^- - d_3^+ = 5000.00$

IV. Fuel Cost constraint (Rs)

$66.36\ X_1 + 54.43\ X_2 + 39.60\ X_3 + 25.63\ X_4 + 165.30\ X_5 + 135.56\ X_6 + 94.86\ X_7 + 53.50\ X_8 + d_4^- - d_4^+ = 43{,}00{,}000.00$

V. Coal Supply Constraint

$127.80\ X_1 + 104.96\ X_2 + 79.68\ X_3 + 53.84\ X_4 + 301.00\ X_5 + 252.80\ X_6 + 178.20\ X_7 + 92.60\ X_8$

$- \quad d_5^+ = 1{,}00{,}00{,}000.00$

VI. Hours Availability Constraint

(a) For 200 MW Units:

$X_1 + X_2 + X_3 + X_4 + d_6^- = 37{,}840.00$

(b) For 500 MW Units:

$X_6 + X_7 + X_8 + d_7^- = 12{,}170.00$

VII. Partial Load Constraint (Hours)

(a). Due to Grid:

$X_1 + d_8^- = 28{,}531.00$

$X_1 + X_2 + d_9^- = 34{,}434.00$

$X_5 + d_{10}^- = 9{,}063.00$

$X_5 + X_6 + d_{11}^- = 10{,}938.00$

$2X_1 + 1.6\ X_2 + 1.2\ X_3 + 0.8\ X_4 + 5\ X_5 + 4\ X_6 + 3\ X_7 + 2\ X_8 + d_{12}^- = 1{,}68{,}630.00$

(b) Due to Station Problems:

$X_1 + X_2 + X_3 + d_{13}^{-} = 36,873.00$

$X_5 + X_6 + X_7 + d_{14}^{-} = 11,395.00$

Where:

X_1 = Operation Hours of 200 MW Units at 100% Load
X_2 = Operation Hours of 200 MW Units at 80% Load
X_3 = Operation Hours of 200 MW Units at 60% Load
X_4 = Operation Hours of 200 MW Units at 40% Load
X_5 = Operation Hours of 500 MW Units at 100% Load
X_6 = Operation Hours of 500 MW Units at 80% Load
X_7 = Operation Hours of 500 MW Units at 60% Load
X_8 = Operation Hours of 500 MW Units at 40% Load
d_1^- = Under Achievement of Generation for Reward of Station
d_2^- = Under Achievement of Control Margin for Station
d_3^- = Under Achievement of Oil Consumption for Station
d_4^- = Under Achievement of Fuel Cost from the Station
d_5^- = Under Achievement of Coal Consumption of Station
d_6^- = Under Achievement of Total Available Hours of 200 KW Units
d_7^- = Under Achievement of Total Available Hours of 500 MW Units
d_8^- = Under Achievement of Available Hours of Operation at Full Load of Units
d_9^- = Under Achievement of Available Hours of Operation of 200 MW Full Load
d_{10}^- = Under Achievement of Available Hours of Operation at 500 MW Units
d_{11}^- = Under Achievement of Total Available Hours of 500 MW Units at 80% Load
d_{12}^- = Under Achievement of Generation due to Grid Restriction
d_{13}^- = Under Achievement of Average Hours of Operation of 200MW Units at 60% Load
d_{14}^- = Under Achievement of Average Hours of Operation of 500MW Units at 60% Load
d_1^+ = Over Achievement of Generation from Reward of Station
d_2^+ = Over Achievement of Contribution Margin of Station
d_3^+ = Over Achievement of Oil Consumption of Station
d_4^+ = Over Achievement of Fuel Cost of Station
d_5^+ = Over Achievement of Coal Constraint of Station

RESULT AND DISCUSSION

Using the QM for WINDOWS package can solve the Goal Programming model. The Goal of maximizing generation has not been achieved fully and our effort to achieve optimum result has been limited by grid restrictions. Coal supply Station affected the performance of units and hence a part generation generation was achieved by Oil. This increased the running of 500 MW units at 40% level. The solution of the model suggests that units should run fully load to its possible extent. It follows that the thermal power unit should run at a minimum capacity of 80% load, then oil and fuel consumption costs can be minimized.

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