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A Model for Multi-Objective Programming for Power Generation Corporate Unit

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ABSTRACT

For real life situations, Model building is a complex process. Every real life situation has its own strengths and weaknesses. The model should try to inculcate all the factors that are relevant to the current problem. It should relate to actual problem, should be accurate, logical and practical in application. With the application of a GP model, we have discussed how the corporate power manufacturing unit, a thermal power plant, can reduce the costs of fuel and furnace oil consumption and how they can maximize their utilization capacity and minimize their cost of power generation per unit. The model has addressed many issues and provided solutions for them in this paper.

Key Words: Power generation, Goal programming, Corporate manufacturing unit

INTRODUCTION

Power is the basic and most crucial requirement for any nation, especially like India which requires it in abundance to fuel its growth as an emerging world power. Adequate power is required for the domestic use, agriculture use, industrial and commercial use. Since independence, Government's thrust has been to build many hydro and coal operated power projects to fulfil the ever increasing demand. Inspite of massive increase in the installed capacity in the last few years, India is reeling under severe power shortage. There are severe power cuts and trips due to poor maintenance, transmission losses and theft. Peak power shortage is up to 15% in urban areas and 30% in rural areas. The gap between demand and supply is increasing despite the fact that power generation has been increased substantially over the years. Thermal power is the largest producer of electricity in India followed by Hydro, Gas, Oil and nuclear generated power. The operational performance of a Thermal power plant is affected by many factors like shortage of coal, operational maintenance, breakdown, labour unrest, accidents and other constraints.

There are several Thermal, Hydro, Gas, Wind and Nuclear power based power generation corporate units in India. The installed capacity of electricity is 254 Gigawatt till August 2014. India has become the world's third largest producer of electricity in the year 2013 with 4.8% global share in electricity generation surpassing Japan and Russia. Inoperational power plants have an additional capacity of 39.375 GW. Non Renewable Power Plants constitute 87.55% of the installed capacity and Renewable Power Plants constitute the remaining 12.45% of total installed Capacity. India generated around 967 Tera Watt-hours (TWh) or (967,150.32 GWh) of electricity (excluding electricity generated from renewable and captive power plants) during the 2013–14 fiscal. The total annual generation of electricity from all types of sources was 1102.9 TWh in 2013. As of March 2013, the per capita total electricity consumption in India was 917.2 KWh. The per capita average annual domestic electricity consumption in India in 2009 was 96 KWh in rural areas and 288 KWh in urban areas for those with access to electricity in contrast to the worldwide per capita annual average of 2,600 KWh and 6,200 KWh in the European Union. Electric energy consumption in agriculture is highest (18%) in India. The per capita electricity consumption is lower compared to many countries despite cheaper electricity tariff in India.
The core aim of any corporate unit is to minimise the cost and maximise the profits. Likewise in power sector the main thrust of every power generating corporate unit is to minimise the losses which in turn will maximise the output, thus profits. Very few studies have been conducted on the scientific norms for optimisation of power

generation at thermal power stations so far. Efficiency is often lost in the absence of scientific norms as the decisions are based more on perception rather than technology. Rarely a performance factor is taken into consideration to cut down the downtime level. The various efficiency parameters like heat rate, oil consumption and motive power consumption are not taken into account in operation scheduling of these units. Due to a system of part loading operation is used, the unit cost rises steeply causing high power generation cost per Kilowatt. This results in the observation that there exists no optimum scheduling in the thermal power stations.

In this research paper, we have taken the study of a Super Thermal Power Plant located in North India. It's first coal-fired unit was commissioned in October 1991 and the last unit was commissioned in July 2010. The gas-based generating units were commissioned between 1992 and 1997.

The coal is sourced from Piparwar Mines, Jharkhand. The gas is sourced from GAIL Hazira-Bijapur-Jagdishpur (HBJ) Pipeline. The water source for the thermal power station is the Upper Ganga Canal.

Ganapathy et. al. (2009) in their study did energy analysis of lignite fired Neyveli thermal corporate power generating unit and recorded energy losses and the exergy destructions of the steam power plant components. Exergy is the energy that is available to be used. Their findings show that over 57% of exergy losses take place within the boiler system only. Out of which 42.7% of exergy loss occurs in the combustor only. They found that this loss was occurring due to the irreversibility inherent in the combustion process, heat loss, incomplete combustion and exhaust losses. Their study pinpointed that the combustor requires necessary modifications to reduce its exergy destructions to improve the plant performance and thus profits. Reddy et. al. (2010) and Sarang et. al. (2013) did research on corporate power generating unit losses and concluded that proper insulation in turbine improves its efficiency and minimises losses. They found that condensers play a pivotal role in back pressure thereby improving efficiency. Better efficiency will help in maximising the profits. Dutta et. al. (2007) observed in their study that the major source of irreversibility in the power cycle is the boiler, which destroys exergy upto 60%. Exergy efficiency is decreased when condenser back pressure increases . Furthur, withdrawal of the high pressure heaters show a gradual increment in the exergy efficiency for the control volume excluding the boiler, while a decrease in exergy efficiency when the whole plant including the boiler is considered. Keeping the main steam pressure before the turbine control valves in sliding mode improves the exergy efficiencies in case of part load operation. Ansari et. al. (2011) did study and claimed to harness the potential of bulk utilization of thermal plant waste and to answer the problem of land uses and food security. Ghodke et. al. (2012) reiterated that the quality of coal (from different sources) differs over a wide range. As the mixing ratio of different quality of coal cannot be specified, a single quality standard cannot be adhered to for a particular corporate power generating unit. At the same time, the mixture remains non-homogenous. Moreover, the quantity of coal and oil requirement varies in accordance with their calorific value to meet a specific electrical demand. Singh et. al. (1991) and Ghodke et. al. (2012) studied the Green House Gas Emission impact on the environment, from Indian Coal Based corporate power generating unit. Sodha and Chandra (1992) commented on the ideal size, location and other aspects while erecting a corporate power generating unit in India. Wani et. al. (2012) did coal accident analysis, risk quantification and suggestive scheme improvements in coal bunkers of abstract thermal corporate power generating unit in India. Singh and Tiwari (2012) did a performance analysis of electrostatic precipitator in a corporate thermal power generating unit. Yao et. al. (2006) did research on use of stationary and mobile measurements to study power plant emissions in a corporate thermal power generating unit.

PROBLEM DATA

In this study, we have used a super thermal power plant which is located in north India. We have not disclosed the name of the plant due to confidentiality concerns. This power station has an installed capacity of 2000 MW that comprises of 5 units of 200 MW and 2 units of 500 MW. As per requirement, these units operate at different load conditions of 40% to 100%. Coal and oil comprise the main fuel cost for this power plant.

Difference in the costs of coal and oil is marginal but at stipulated loads, there is a significant variation in the use of these two fuels. The performance parameters of the power plant are predefined that include turbine heat rate, boiler efficiency at full and part loads. The operating conditions of the unit show that load is generally maintained above normal levels. A summary of data is presented below:

(i) Hours of operation:
200 MW units at 100 to 40% load = 35,000
500 MW units at 100 to 40% load = 14,500

(ii) Partial load hours due to station problems:
200 MW units at 100 to 60% load = 35,275
500 MW units at 100 to 60% load = 14,045

(iii) Partial load hours due to Grid:
200 MW units at 100% load = 25,000
200 MW units at 100 and 80% load = 31,525
500 MW units at 100% load = 11,500
500 MW units at 100 and 80% load = 15,775
200 and 500 MW units at 100 to 40% load = 1,52,540

Table 1: Data for 200 MW Units

CONDITIONS	Load 100%	Load 80%	Load 60%	Load 40%
1. Power Generation (P_G) ₹/KW	2.50	2.00	1.50	0.90
2. Contribution Margin (C_M) ₹/KWh	200.75	165.25	115.30	65.45
3. Oil Consumption (O_C) ₹/KWh	1.00	0.20	2.00	4.00
4. Cost of Fuel (C_F) ₹/KWh	56.20	64.75	55.55	37.25
5. Cost of Coal (C_C) ₹/KWh	123.60	100.60	73.08	46.72

Table 2: Data for 500 MW Units

CONDITIONS	Load 100%	Load 80%	Load 60%	Load 40%
1. Power Generation (P_G) ₹/KW	6.00	4.50	3.50	2.00
2. Contribution Margin (C_M) ₹/KWh	540.50	425.15	270.15	110.50
3. Oil Consumption (O_C) Kl/KWh	0.00	2.00	10.00	20.00
4. Cost of Fuel (C_F) ₹/KWh	165.70	135.00	126.74	169.25
5. Cost of Coal (C_C) ₹/KWh	299.50	245.64	168.90	24.80

GOAL PROGRAMMING MODEL

Goals set by the management as per their importance:

(i) To maximize capacity utilization generation to achieve the maximum reward of ₹13,70,000.
(ii) To maximize contribution margin of energy generated at given cost of ₹80,00,000.
(iii) To minimize furnace oil consumption within a given limit of 4,000 Kl.

(iv) To minimize generation cost within a given limit of ₹95,00,000.
(v) Limit the supply of coal to not more than 80,000,000 metric tons.

Decision Variables

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 of 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
PG = Power Generation per KW
CM= Contribution Margin per KWh
OC = Oil Consumption Kl per hr.
CF= Cost of fuel per KWh
CC= Cost of Coal per KW
d_i^- = Under-achievement of constraints in the ith equation
d_i^+ = Over-achievement of constraints in the ith equation.

Goal Constraints

The LGP model constraints for the power generation problem are formulated as follows:

(i) The objective of management is to operate at optimum capacity level to maintain maximum reward achievable.

This LGP constraint can be expressed as follows:

$$\sum_{i=1}^{8} \sum_{G=1}^{8} P_G\, x_i + d_1^- - d_1^+ = 13{,}70{,}000 \qquad \ldots(1)$$

(ii) The goal is to maximize contribution margin with the given cost. The LGP constraint is given as follows:

$$\sum_{i=1}^{8} \sum_{M=1}^{8} C_M\, x_i + d_2^- - d_2^+ = 80{,}00{,}000 \qquad \ldots(2)$$

(iii) The management goal is to minimize total oil consumption in a year with given resources. This can be expressed as follows:

$$\sum_{i=1}^{8} \sum_{C=1}^{8} O_C\, x_i + d_3^- - d_3^+ = 4{,}000 \qquad \ldots(3)$$

(iv) The fuel cost for a one year period is determined according to load contributions. The constraint is given as:

$$\sum_{i=1}^{8} \sum_{F=1}^{8} C_F\, x_i + d_4^- - d_4^+ = 95{,}000{,}000 \qquad \ldots(4)$$

(v) Coal supply for the given period should not exceed the maximum estimated output. The constraint can be expressed as follows:

$$\sum_{i=1}^{8} \sum_{C=1}^{8} C_C\, x_i + d_5^- - d_5^+ = 80{,}000{,}000 \qquad \ldots(5)$$

(vi) That operation hours for 200 MW and 500 MW units should not exceed 35,000 and 14,500 respectively. The constraints are given as follows:

$$\sum_{i=1}^{4} x_i + d_6^- - d_6^+ = 35{,}000 \qquad \ldots(6)$$

$$\sum_{i=5}^{8} x_i + d_7^- - d_7^+ = 14{,}500 \qquad \ldots(7)$$

(vii) That hours devoted to station problems should be minimized. The constraints can be expressed as follows:

$$\sum_{i=1}^{3} x_i + d_8^- = 35{,}275 \qquad \ldots(8)$$

$$\sum_{i=5}^{7} x_i + d_9^- = 14{,}045 \qquad \ldots(9)$$

(viii) The goal of management is to minimize as much as possible the hours devoted to grid. The constraints are given below:

$$x_1 + d_{10}^- = 25{,}000 \qquad \ldots(10)$$

$$x_1 + x_2 + d_{11}^- = 31{,}525 \qquad \ldots(11)$$

$$x_5 + d_{12}^- = 11{,}500 \qquad \ldots(12)$$

$$x_5 + x_6 + d_{13}^- = 15{,}775 \qquad \ldots(13)$$

$$\sum_{i=1}^{8} x_i + d_{14}^- = 1{,}52{,}540 \qquad \ldots(14)$$

Objective Function

The rank of goals is based on the range of importance as P1 to P5.

The complete GP model for the power generation problem is given as follows :

Minimize

$Z = P_1 (d_1^- + d_1^+) + P_2 (d_2^- + d_2^+) + P_3 d_3^+ + P_4 d_4^+ + P_5 d_5^+$

subject to the equations (1) - (14) and x_i , d_i–, $d_i^+ \geq 0$.

RESULTS

The present GP problem contains 27 variables, 14 constraints, 5 priorities and an objective function. The solution generated using QSB+ software took 33 iterations of the modified simplex method. The solution of the problem indicates that the first and the third goal is under-achieved. The possible generation from the thermal power plant is 1,184.88 MW with the oil consumption of 273,445 Kl at 80% load. The achievement of goals at different priority levels are given in Table 3.

Table 3: Summary of Achievement of Goals

Priority	Goal	Achievements
1	Maximize capacity utilization	Under-achieved
2	Maximize contribution margin	Achieved
3	Minimize furnace oil consumption	Under-achieved
4	Minimize total generation cost	Achieved
5	Limit the supply of coal	Achieved

CONCLUSION

In the present study, GP technique was employed to determine the optimal power generation for a power plant in India. We tested five objectives in this model. Three showed optimum results and two showed under-achievement. Therefore the goal of maximizing power generation remains to be achieved given the limitations imposed by the grid restrictions. Another limitation was that due to inadequate supply of coal by Coal India Ltd., oil has to be used as supplement fuel.

The solution of the GP model suggests that units should run at a desired minimum capacity of 80%. Thus, if the units that are inoperable are maintained to run at the capacity load of 80%, then oil and fuel consumption costs could be minimized. From the results in this study, we believe that the GP technique is a useful planning tool especially in providing solution to multiple criteria's objectives.

With application of this GP model, power generation sector companies can reduce the costs of fuel and furnace oil consumption. They can maximize their utilization capacity and minimize their cost of power generation per unit thus saving a lot of resources which could add to their net revenues.

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