International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 8, August 2018, pp. 67–76, Article ID: IJMET_09_08_007
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=8
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

IMPROVING PERFORMANCE (MERIT ORDER) OF COAL BASED THERMAL POWER PLANTS BY OPTIMISING FUEL TRANSPORTATION USING GOAL PROGRAMMING

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ABSTRACT

In India, approximately 60% of electricity is generated by coal based power plants. The power tariff has two components: Fixed charge and variable charge. The fixed charge is dependent on the mainly initial investment but the variable component depends on fuel charges and type of machine (heat rate). The load dispatch centre gets information of variable charges of each plant and gives priority to plants for scheduling of power having low variable charges (this is called Merit Order Generation). Coal mines are allocated to power plants as and when plants are conceived; so that plants can be designed according to type of quality of its coal (GCV, moisture, ash, Sulphur etc.) available from the allocated mine. The impact of coal cost (Coal cost + transportation cost) on variable component of the tariff is phenomenal. A power generating company can have many plants and their allocated mines, in this case coal swapping is an option to optimize overall variable cost and plants can be in merit order generation and get adequate scheduling for power generation. The goal programming technique is used for optimizing the coal cost for reducing variable charges.

Keywords: Thermal power plants, transportation, variable cost, merit order generation, Goal programming, coal mine

Cite this Article: Revti Raman, Dr JK Sharma and Skandh K Tyagi, Improving Performance (Merit Order) of Coal Based Thermal Power Plants by Optimising Fuel Transportation Using Goal Programming, International Journal of Mechanical Engineering and Technology, 9(8), 2018, pp. 67–76.
http://www.iaeme.com/IJMET/issues.asp?JType=IJMET&VType=9&IType=8

1. INTRODUCTION

Indian power sector has made a significant change since independence. In 1947, the installed capacity was 1362 MW and increased to 340527 MW (Ministry of Power, 2018) as on 31.03.2018. The power supply and distribution system has changed from isolated system to National Grid. Electricity generation, transmission and distribution were prime responsibility of State Electricity Boards. It is well established and acknowledged by all that electricity is the prime mover for growth. In India, demand always exceeds supply and people had to bear with long power outages. For giving a major boost for power sector, Government of India has implemented many improvements in last 30-35 years. To name a few:

a. Entry of Central Generating and transmission companies
b. Unbundling of Generation, Transmission and distribution in State Electricity Boards
c. Set up of CERC and SERC's
d. Electricity Act 2003
e. Ultra-Mega Power projects

The power generation in India has a mix of thermal, hydro, Nuclear and renewable technologies for power generation and State Govt, Central Govt and Private sector players are involved in power generation. The category wise details as on 31.03.2018 are as follows-

A. Sector Wise Details-

Sector	MW	% age
State	84517	24.82
Central	103968	30.53
Private	152042	44.65
Total	340527	100

Source: Ministry of Power, India

B. Technology Wise Details-

Fuel	MW	% age
Thermal total	222907	65.46
Coal	197172	57.90
Gas	24897	7.31
Oil	838	0.25
Hydro (Renewable)	45293	13.30
Nuclear	6780	2.00
Others	65547	19.24
Total	340527	

Source: Ministry of Power, India

In India, maximum power generation is through coal based power technology although there is continuous improvement in steam parameters and higher efficiency. The basic input for the power generation is coal. For a total capacity of app. 197000 MW and considering a Plant load factor of 75% and specific coal consumption of 0.65 kg/kwh, the coal requirement will be app. 900Million ton/annum. This coal is to be supplied from coal mines to power plants. Generally, (KwakandSchniederjans, 1983) the transportation model can be used when transportation cost are the dominating factor for decision making but it is a part of the solution when there are other factors equally important as transportation cost. For the case under study, goal programming is being used as there are conflicting constraints for finding the solution.

In India, following methods are used for coal transportation

- Railways
- Merry-go-round system
- Coal conveyors

2. COAL BASED POWER PLANTS

In a thermal power station steam turbines which are prime mover are driven by steam. The steam is generated in the boiler by heating water and then through high pressure pipes taken to turbine and these turbines rotate electric generator at a specific speed. The electro-mechanical generators are coupled with the turbine through which electricity is generated at a particular voltage and frequency. The generated power is set-up by installing transformer and is transmitted to load center by high voltage line.

The steam generation is a closed cycle. The steam after doing the work is condensed in a condenser and recycled to the boiler drum for heating; this is known as a Rankine cycle. The thermal power plants use coal as primary fuel and the due to variation in the coal properties, the greatest variation in the design of thermal power stations is due to the different fossil fuel resources generally used to heat the water. Globally, fossil-fuel power stations produce a large part of man-made CO_2 emissions to the atmosphere.

3. COSTING OF POWER GENERATION

The power is sold to consumers by Power Purchase Agreement (PPA) route or spot market purchase (Power trading). In India, Central Electricity Regulatory Authority (CERC, website www.cercind.gov.in) makes tariff regulation every five years. The tariff regulation has normative values for different operating norms and based on these norms tariff to be charged by generators is calculated.

The tariff has mainly two components-

- Fixed Charges or Capacity charges-
- Variable charges of Fuel Charges.

The tariff is the algebraic sum of these two components. The fixed charges has components – Return on Equity, Interest charges, O&M charges, Depreciation and Interest on working capital and these fully recovered at 85% plant load factor. The variable charges is fuel cost which is based on normative heat rate of the machine, auxiliary power consumption, Coal cost and Coal GCV.

In the whole exercise, most of the parameters are fixed with the type of machine and capital cost of the Power plant. The variable part which is dependent on the fuel becomes important as it will go on increasing with the cost of the fuel. The coal cost is dependent on the coal GCV and mining cost plus the coal transportation cost. The coal transportation cost plays a very important role for overall cost of the power generation price and sometimes it is a significant portion in the cost of power. Now, coal swapping has become a reality.

The facility location problems (Current et al 1990) were traditionally considered only for minising cost of transportation but other objectives will also affect the decision. The problem is considered as multi objective in nature.

4. LOCATING A POWER PLANT

The coal based thermal plant is to be located based on the siting conditions prescribed by Environmental Ministry (IL&FS, (2010) guidelines which are as follows-

- Location of Thermal stations (TPS) should be avoided within 25 kms. of the outer peripheries of the following
- Metropolitan cities.
- National Parks and wild life Sanctuaries, Ecologically sensitive area like Tropical Forests, Biosphere Reserves, Important Lakes and Coastal Areas rich in Coral Formations.

- In order to protect the coastal areas above 500 m of HTL a buffer zone of 500 m should be kept free of any TPS.
- MOEF in its notification declaring coastal stretches as Coastal Regulation Zone (CRZ) have stipulated as follows:
- The Central Govt. declares the coastal stretches of sea, bays, estuaries, rivers and backwaters which are influenced by tidal action upto 500 meters from the High Tide Line (HTL) and the land between Low Tide Line (LTL) and the HTL as Coastal as Coastal Regulation Zone and impose restrictions on the setting up and expansion of industries. The distance from the HTL to which the regulation will apply in the case of rivers, creeks and backwaters may be modified on a case basis, however, this distance shall not be less than 100 meters or the width of the creek, river or backwater whichever is more.
- The site (Chimney) should not fall within the approach funnel of the runway of the nearest airport.
- The site should be at least 500 m away from the Flood Plain of the Riverine Systems.
- The site should be also at least ½ km away from Highway.
- Location of TPS should be avoided in the vicinity (say 10 kms.) of places of archaeological, historical, cultural, religious or tourist importance and defence installations.
- No forest or prime agricultural land should be utilized for setting up of TPS or for ash disposal.
- Project should be avoided in coal bearing areas.

The plant requires two major inputs – Coal and water. The plant should be located near the water source and it takes app. 25 cusec of water for a 1000MW plant. The coal requirement will be around 5.0 MT per annum for operating the plant of 1000 MW at 85% plant load factor.

5. COAL AVAILABILITY

In India, coal was mined by Coal India Ltd., a Government Controlled company but in the last 15 years reforms in coal sector allowed mine allocation to Generating companies also. The generating company can plan their power plants based on coal from their own mines. Considering the development of new mines which takes a long time, still the generating companies have to depend on coal from Coal India mines. For getting the coal, the generating company has to apply to Coal Company. The coal company allocates coal to generators in the SLC meeting which looks into demand of all the generating companies (Central, State and Private utilities). Based on the data of coal allocated, the generating company designs their boilers for efficient operation.

The location of power plant and mine has different considerations. While plants are to be located near water sources and satisfying many conditions laid down in the guidelines, mines are located in the geographical locations where coal is physically available. This requires transporting coal to power plants and sometimes the distances are quite long and costs are also high. Most of coal reserves in India are in Eastern part of the country but thermal power plants are located in all the parts of the country.

In this background, the coal transportation becomes important for optimizing the cost of power and its availability. This paper focuses allotment of 4 mines which can feed coal to 6 plants so that coal as per requirement and required quality can be made available by optimizing the fuel cost.

6. MERIT ORDER GENERATION

Load Control Centre (LDC) is focal point to keep a balance between demand and supply of electricity and manage the grid. All the power stations are supposed to inform Control Centre regarding availability of power generation and Variable charges of generation for next 24 hours. Based on this data, Control Centre will decide which power stations will generate electricity for meeting the demand. To take an example, it is considered that there are 5 stations in the region and demand is 1800MW. The stations intimate following data to Control Station.

Plant	Power Generation (MW)	Variable charges (Rs/kwh)
A	700	2.10
B	500	1.90
C	200	1.65
D	300	2.20
E	800	1.80

In this case, the generation schedule based on merit order generation will be-

a. Plant C : 200MW
b. Plant E : 800MW
c. Plant B : 500MW
d. Plant A : 300MW only
e. Plant D : No schedule

It is important to reduce variable charges for getting the schedule and be competitive in the Generation market.

7. THE MODEL

In order to demonstrate linear programming model for optimizing the coal cost, four mines (1,2,3,4) and six power stations (A,B,C,D,E,F) are considered.

a. Mine Capacity

Coal Mine	GCV Range (Kcal/kg)	Capacity (MTPA)
1	4000- 4600	6
2	3200- 3800	7
3	3800-4400	15
4	4000-4600	12

b. Power Plants

The capacity of plants

1. A,C,D & F : 1600MW (2 X 800MW)
2. B : 1000MW (2 X 500MW)
3. E : 1320 MW (2 X 660MW)

c. Present Allocation

From mine 1 to plant A, mine 2 to plant C, mine 3 to plant E and F, mine 4 to plant B and D.

d. Optimization Model

For finding the optimum cost of fuel to power station, goal programming model is developed. The coal cost at mine end and transportation cost from each mine to each power station is calculated as follows-

Coal Cost from Mine end to Power plant (Rs /MT)				**Power Plant**	**Total Demand**
1	2	3	4		(MTPA)
4548	2836	3946	3417	A	7.40
3029	2214	3403	3417	B	5.53
3774	3298	2539	4244	C	6.91
3544	2992	4101	4007	D	7.40
4396	2214	3779	2942	E	5.70
3544	2371	2403	3929	F	7.40

The Goals

a. Satisfy 100% demand requirement of plant A
b. Minimize coal transportation from mine 4 to plant A to 3.0 MTPA
c. Fulfill 83% demand of all plants
d. Total fuel cost less than Rs 11600 crore per annum
e. No coal from mine 1 to plant C and from mine 2 to plant A
f. No coal from mine 3 to plant B and mine 4 to plant D and F
g. Minimize fuel cost for the generation

Variables-

- Xij = Amount to be transported from ith mine to jth plant
- Cij = Price of coal from ith mine to jth plant

Deviational Variables-

- di^+ = Overachievement of constraints for ith equation
- di^- = Underachievement of the constraints for ith equation

Goal Constraints-

The LPG model constraints are formulated as follows-

a. The supply from the mine is restricted by the amount that can be mined so the positive deviations can be excluded from the supply constraint. The LPG constraint for the supply can be given as –

$$\sum_{J=1}^{6} X1j + d1- = 6$$

$$\sum_{J=1}^{6} X2j + d2- = 8$$

$$\sum_{J=1}^{6} X3j + d3- = 15$$

$$\sum_{J=1}^{6} X4j + d4- = 12$$

b. The power plants will receive coal from mines as per the requirement but mine will not give coal more than its demand.

$$\sum_{i=1}^{4} Xi1 + d5- = 7.40$$

$$\sum_{i=1}^{4} \text{Xi2} + \text{d6}- = 5.53$$

$$\sum_{i=1}^{4} \text{Xi3} + \text{d7}- = 6.91$$

$$\sum_{i=1}^{4} \text{Xi4} + \text{d8}- = 7.40$$

$$\sum_{i=1}^{4} \text{Xi5} + \text{d9}- = 5.70$$

$$\sum_{i=1}^{4} \text{Xi6} + \text{d10}- = 7.40$$

c. Due to transportation problem and congestion on route, the coal from mine 4 to plant A is restricted to 3 MTPA.

X41 + d11- = 3.0

d. In the tariff structure, full fixed charges as chargeable to the consumers when plant load factor is equal or more than 83%. The goal constraints for this conditions are as follows-

$$\sum_{i=1}^{4} \text{Xi1} + \text{d12} + +\text{d12}- = 6.14$$

$$\sum_{i=1}^{4} \text{Xi2} + \text{d13} + +\text{d13}- = 4.59$$

$$\sum_{i=1}^{4} \text{Xi3} + \text{d14} + +\text{d14}- = 5.73$$

$$\sum_{i=1}^{4} \text{Xi4} + \text{d15} + +\text{d15}- = 6.14$$

$$\sum_{i=1}^{4} \text{Xi5} + \text{d16} + +\text{d16}- = 4.73$$

$$\sum_{i=1}^{4} \text{Xi7} + \text{d17} + +\text{d17}- = 6.14$$

e. Minimise total fuel cost which includes coal cost and transportation cost with a target of Rs. 11600 crore which is Rs. 12500 crore based on present allocation-

$$\sum_{i=1}^{4} \sum_{J=1}^{6} CijXij + d18 + +d18- = 11600$$

f. Considering the coal quality problems, design of boilers and route not available, coal from some of the mines cannot be transported to few plants-

$$X_{13} - d19+ = 0$$

$$X_{21} - d20+ = 0$$

$$X_{32} - d21+ = 0$$

$$X_{44} - d22+ = 0$$

$$X_{46} - d23+ = 0$$

g. If Cij is the cost of transportation of one ton of coal from ith mine to jth plant then total cost will CijXij for all i and j. The company wants to minimize the cost then one goal will be to set it to zero and attempt is made to minimize the positive deviation-

$$\sum_{i=1}^{4}\sum_{j=1}^{6} CijXij - d24- = 0$$

Objective Function- The objective function based on the constraints will be to find the coal transportation from each mine to each plant so that the total cost is minimized and less than from the already allocated single mine to the plant which is the existing system prevailing for the power sector.

Minimize Z = P1 d10- + P2 d11- + P3 (d12- + d13- + d14- + d15- + d16- + d17-) + P4 d18- + P5 (d19+ + d20+ + d21+ + d22+ + d23+) P 6 d24-

For solving the optimization problem MATLAB is used. The goal for objective function is considered as Rs 12800 crore for cost of coal to 6 power plants from 4 mines based on goals and constraints. The fgoalattain function is used for optimization-

8. ANALYSIS

On running the optimization model for the objective function and goal constraints following is the amount of coal to be transported from each mine to every plant has been found-

Plant → / Mine ↓	A	B	C	D	E	F
1	1.34	1	0	1.33	1	1.33
2	0	0	3.4	1.77	0	1.77
3	3.06	0	2.33	3.04	1.23	3.04
4	3	3.59	0	0	2.5	0

Deviational Variables

Variable	Value	Variable	Value	Variable	Value
d1-	0	d9-	0	d17+	0
d2-	0.06	d10+	1.26	d18+	907
d3-	2.3	d11+	0	d19+	0
d4-	2.91	d12+	0	d20+	0
d5-	0	d13+	0	d21+	0
d6-	0.94	d14+	0	d22+	0
d7-	1.18	d15+	0	d23+	0
d8-	1.26	d16+	0	d24-	11593

Based on the optimization for coal transportation, the coal transportation from mine 1 will be 6.0 MT, from 2 it will be 6.94 MT, from mine 3 the coal of 12.70 MT and from mine 4 the coal will be 9.09 MT. The attain factor is (-) 0.1591. On optimization coal cost will reduce from Rs 12500 to Rs 11593 crore which is a reduction of 7.56%. The optimization model has reduced variable charges considerably for 5 plants (app. 15%) which will bring these in merit order scheduling.

9. CONCLUSION

The price of electricity has two components i) Fixed or capacity charge ii) Fuel or variable charge. The fixed charge is dependent mainly of initial investment but variable charge is dependent on coal price and heat rate of the machine. Once the machine is finalized, the price of electricity will vary with the coal which is a primary fuel for power generation. The generation scheduling (merit order) of the plants is based on variable charges .i.e the plant with least variable charge will get priority for running the units in case of oversupply of electricity in the grid.

It is seen that variable charge has a considerable portion in the overall price of electricity. The efforts are required to optimize the coal price and select the source for reducing the electricity price. The swapping of coal is a good exercise for coal price optimization.

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