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Energy Utility Fuel Allocation Model for Non-Linear Revenue and Regulatory Tariff Implications

by

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Abstract

The primary motivation for this paper is based on the challenge faced by a utility firm that generates its electricity through multiple coal fired thermal power plants. The utility firm operates in a regulated market

(including interest expenses). To encourage maximum generation of power, the regulatory authority allows this cost to be fully recovered only from a particular level of plant capacity utilization by having a scaled capacity component of unit tariff till this target level. This implies that any production below this target level would result in the utility firm not recovering fully its capacity cost. As an incentive for production beyond the target utilization, the regulatory authority permits the firm to charge the same capacity component of unit tariff for generation beyond the target level. The energy component of unit tariff is independent of plant utilization or fixed costs and is based on the technology used by the plant and a weighted average coal cost based on a bundle of different coal types. Older plants are allowed to charge a higher energy component to compensate for the higher amount of coal required per unit output of electricity. The total cost incurred by the utility firm is based on the coal, coal freight and variable costs of a bundle of different types of coal and the utility firm could improve its profitability by using a higher proportion of cheaper coal.

The secondary motivation for this paper is to address the regulatory tariff issue and explore whether the integer non-linear power-generation expansion planning problem as one of the most complex optimization problems. They propose a GA-heuristic based method to solve their problem. Though there is sufficient information in the internet and industry reports (Wikipedia Contributors, n.d.) on utilization based utility tariffs, scholarly articles on same considering fuel shortages in regulated markets appears to be sparse. This paper attempts to contribute to literature in this area.

2. The Utility Firm: Relevant Data and Current Fuel Allocation

The utility firm studied produces its electricity through six coal fired thermal power plants located in five different geographic locations. Let $I = \{i|i = 1, 2,\ldots, I\}$ indicate the set of electricity generation plants. Let $J = \{j|j = 1, 2,\ldots, J\}$ indicate the set of coal sources. The utility firm annually negotiates with coal companies and the railroad company before the beginning of a financial year. Thus, the coal cost, freight charge and coal availability are information available before the start of the year and are not subject to volatility. Let A_j denote the annual availability of coal from source j, c_j denote the unit coal cost for procuring from source j and f_{ij} denote the unit coal freight charge for transporting coal from source j to plant i. The remaining notations are C_i the peak load of plant i; q_{ij} the unit coal requirement at plant i using coal from source j; r_i the unit tariff energy component at plant i; s_i the capacity charge slope at plant i; t_i the target plant output (available for sale after factoring internal consumption) at plant i for realizing peak tariff capacity component; u_i the yield at plant i as a proportion of generation (amount available for sale after factoring internal consumption), 0 ” u_i ” 1; and v_{ij} the unit other variable cost at plant i using coal from source j. Let the decisions variables be denoted by x_{ij} the optimal electricity generation at plant i using coal from source j and X_i the optimal electricity generation at plant i. The relevant data are shown in the following tables.

Table 1A: Coal freight charges (f_{ij}), Coal Cost (c_j) and Annual Availability (A_j)

Coal Source	Coal freight charges (Rs./MT)						Coal Cost (Rs./MT)	Availability (mi MTs per year)
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6		
A1	350	110	110	100	212	300	2225	4.15
A2	350	110	110	100	212	300	4640	3.00
B	300	190	190	190	300	300	1274	1.30
C	350	110	110	100	250	300	1235	2.53
D	479	517	517	500	300	818	763	9.15
Imports	550	550	550	550	550	550	5000	Unlimited

Table 1B: Coal requirement for unit power generated (q_{ij})

Coal Source	Coal requirement per unit power generated (MT/MWH)					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
A1	0.70	0.68	0.68	0.65	0.72	0.65
A2	0.65	0.65	0.65	0.63	0.72	0.65
B	0.70	0.70	0.70	0.70	0.72	0.70
C	0.80	0.75	0.75	0.75	0.82	0.76
D	0.90	0.90	0.90	0.85	0.95	0.88
Imports	0.65	0.63	0.63	0.64	0.68	0.63

Table 1C: Other variable cost (v_{ij})

Coal Source	Other variable costs (Rs./MWH)					
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
A1	500	500	500	550	500	500
A2	500	500	500	550	500	500
B	700	700	700	700	700	700
C	550	550	550	580	550	530
D	630	650	650	650	800	650
Imports	500	450	450	500	500	480

Table 1D: Other details

Detail	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6
Peak Load, C_i, (MW)	1260	630	420	150	450	600
Energy Charge, r_i, (Rs/MWH)	1784.3	1581.3	1581.3	1581.3	2044.2	1581.3
Capacity charge slope, s_i, (Rs./MW-MWH)	0.68	1.56	1.94	5.49	2.22	1.36
Target, t_i, (MW)	886	487	325	115	279	464
Yeild, u_i	0.893	0.890	0.890	0.883	0.883	0.886

The firm currently allocates coal to the different plants that result in electricity generation as shown in the table below. This allocation enables the firm to operate at 90.66% of its peak load but results in a deficit of Rs. 6,754 million. The weighted average tariff per MWH turns out to be Rs. 2,082.

Table 2: Current Allocation of Coal and Overall Utilization

Coal Source	Electricity Generation (MW)						Coal Required (mi MTs per year)
	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5	Plant 6	
A1	90	100	68	70	190	176	4.15
A2	147	63	42	22	95	148	3.00
B	82	20	13	65	16	16	1.30
C	90	114	76	0	56	38	2.53
D	539	244	163	113	36	71	9.15C
Imports	74	55	36	0	0	54	1.22
Total	1022	596	398	270	393	503	Firm Utilization
Peak Load	1260	630	420	150	450	600	90.66%

amount of electricity that should be generated at a particular plant using coal of a particular coal source. The firm in question operates in a region of electricity shortages and, hence, we assume that it is capable of selling all the electricity that it generates. At plant i, the capacity component of unit tariff is $s_i u_i X_i$ up to electricity generation of t_i / u_i and $s_i t_i$ for electricity generation above t_i / u_i. Hence, the hourly revenue can be described as $s_i [u_i X_i \quad u_i X_i \quad t_i \quad] \quad r_i \; u_i X_i$, where $u_i X_i$

non-negative. The lower bound of X_i, X_i^L, is the X_i value for which surplus is zero and increasing from there onwards. From Lemma 2, the surplus at plant i will be positive only if $W_i \quad u_i \; s_i t_i \quad r_i$ and the hourly surplus becomes non-negative at $X_i \quad t_i / u_i$. As W_i is the average unit cost based on coal sourced from different sources, $w_{ij}^{\min} \; d W_i \quad u_i \; s_i t_i \quad r_i$. Hence, hourly surplus becomes non-negative at $X_i \quad t_i / u_i$ when the coal is exclusively supplied from source j_i^l.

For $X_i \quad t_i / u_i$ while using coal from source j_i^l, the hourly surplus $\acute{} s_i u_i X_i \quad r_i \; \grave{u}_i \quad w_{ij}^{\min} \; X_i$ is zero at $X_i \quad w_{ij}^{\min} \quad r_i u_i \; / s_i u_i^2$. Hence, for $w_{ij} \; (r_i u_i$ and $w_{ij} \; ! \, r_i u_i$ the lower bounds of X_i are zero and $w_{ij}^{\min} \quad r_i u_i \; / s_i u_i^2$, respectively.

Lemma 4: The linear function $\;_{i\;i} \quad \hat{}_{i} \;_{i} \;_{i} \quad \sum_{j} \; / \;_{j} \; \grave{} \;_{ij} \;_{ij} \;_{ij} \;_{ij}$

Heuristic Solution:

Step 1: Determine the X_i^L values for all i as per Lemma 3.

Step 2: Set x_{ij} = 0 for all i and j. Determine solution for the model including constraint in (8) using a solver like GRG nonlinear solver in Microsoft® Excel. Let $X_i^{/}$ indicate optimal X_i

5. Conclusions

The heuristic solution arrived at improves the functioning of the firm significantly. The current allocation of coal followed by the firm results in a deficit of Rs. 6754 million. Our heuristic solution enables the firm to have a surplus of Rs. 6834 million though it would operate only at 59.06% of its peak load capacity. This is owing to regulatory tariff pricing that makes it more profitable to shut-down a power plant rather than operate it at low utilization levels when the firm is faced witha io5.w[( )sources..9(a7]TJ10.909 52.300