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Optimal Captive Power Wheeling for Industrial Load Management

C.A. Babu*[1] and S. Ashok [+]

Abstract – *Captive power plants installed in large scale industries in many developing counties like India, are intended mainly as a stand by supply source or to cater some portion of critical load, and hence remain under utilized. In the context of ongoing power system deregulation, the spare capacity of captive power plants can be effectively utilized by wheeling the captive power among the deficient industries, which will in turn reduce the utility's peak demand. In this paper, an optimization model for captive power wheeling for peak demand management is proposed. The formulation utilizes non linear programming technique for minimizing the electricity cost and reducing the peak demand, by wheeling the captive power among the industries, satisfying the system constraints. The model when applied to three large scale industries of a typical industrial belt, resulted in significant reduction in peak demand (about 39%) and electricity cost (about 11%).*

Keywords – Captive power wheeling, non-linear programming, peak load management, TOU tariff.

1. INTRODUCTION

Captive Power Plants (CPPs) are set up for generating electricity, primarily for the owner's use. CPPs are mainly owned by industries and generate power for the exclusive consumption by the owner industry. The industries generally do not sell power to the transmission entities. Almost all over the world, the electricity supply industry is moving rapidly towards a deregulated environment and electricity wheeling has become an indispensable element of it. The term "wheeling" has been defined in a number of ways in power system parlance. It may be defined as "the use of transmission or distribution facilities of a system to transmit power of and for another entity or entities" [1]. Another definition is "wheeling is the conveying of electric power from a seller to a buyer through a third party owned transmission network" [2]. Wheeling of electricity is the purchasing of electricity by a customer from a source other than its own serving utility. The wheeling utility is paid for its service and for meeting the losses.

Wheeling of power between utilities using the transmission network has widely been discussed in the literature. Industrial power wheeling involves the usage of interconnecting transmission/distribution network and all its associated equipments. Hence it may require some minor modifications like changing of the settings of the relays, reorientation/removal of some protective devices *etc.* to facilitate the power transaction between industries. An appropriate control strategy has to be developed, to oversee the desired power transfer among the industries. A pioneer attempt towards industrial power wheeling was made by integrating captive power plants of different industries of an industrial belt, to relieve the utility during its acute power shortage period [3]. Potential financial benefits derived by wheeling the captive power to the utility, such as increased utilization factor and plant load factor and improved system reliability *etc.* was demonstrated by a case study.

Different methodologies have been proposed, to assess the feasibility of power wheeling and pricing for wheeling charge, under deregulated environment of power industry [4], [5]. Considering electricity wheeling, scheduling of cogeneration plants has been developed using enhanced immune algorithm [6]. Wheeling rates based on marginal cost theory and different approaches to determine the marginal cost of wheeling transactions of independent power producers, has been discussed [7], [8]. Inter-utility power transaction in a deregulated electricity markets has been addressed as a non linear optimization problem [9]. Monte Carlo simulation method has been used to evaluate the effects of wheeling on operating cost, transmission losses, and system security of the power system [10]. A practical method for identifying wheeling paths in deregulated electricity markets based on an extended sensitivity analysis has been developed [11]. The methodology helps to decide the proper and fair wheeling rate according to the degree of burden on transmission lines by each power flow transaction. Simulation results have shown the effectiveness of the method to decide the path of any wheeling for any combination of market players in the system, easily and accurately. A real power tracing based methodology has been developed, to determine the ex-ante point-of-connection rates for the participants of decentralized market [12]. If the point charges are devised by conventional means, it is rather impossible to achieve all

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the desired qualities of point-of-connection charges such as consideration of network usage, recovery of sunk costs and provision of price signals, in a single scheme. These desired objectives have been achieved using the inherent multiplicity of solution space in tracing, rather than employing conventional proportional sharing based tracing. Most of these models reported are, focused mainly on estimating the cost of wheeled power and the available transfer capacity limits of power systems and does not generally address the peak demand problem faced by the utilities.

Since the mid 1980s, electrical power supply industry around the world has experienced a period of rapid and irreversible change [13]. The need for more efficiency in power production and delivery has led to restructuring of power sector in several countries, which were traditionally under the control of central and state governments. In line with these developments took place across the globe, the Electricity Act 2003 [14] came into force in India and the state owned utility companies are gradually being deregulated. The Act provides for open access in transmission, phased open access in distribution, license free generation and distribution, power trading *etc.* among other things. In the deregulation environment, generation, transmission, and distribution are independent activities. Industries can now freely establish CPPs and sell any excess power either to the grid or the third party directly. Almost all the industries representing producers of aluminium, cement, chemicals, fertilizers, iron and steel, paper, sugar *etc.* have their own captive power plants. During the last few years, the installed capacity of the CPPs in India has grown at a faster rate compared to that of utilities. The total installed capacity of CPPs in India at present is around 25,000 MW and accounts for about 35% of the total power requirement of the industries [15].

CPPs installed in these large industrial plants are intended mainly as an emergency supply source, or to deliver power to some critical load of the plant. In the former case the CPP remains idle for most of the time, where as its capacity is under utilized in the latter case. It remains under utilized in both the cases. With the present installed capacity of about 149,000 MW, the Indian power system is experiencing an energy shortage of 11% with a peak demand deficit of about 12% [16]. In view of the prevailing power shortage in the country, the Government of India is encouraging the larger CPPs set up by the industries to sell their surplus power to the grid by providing grid connectivity. In the background of ongoing power system deregulation process, captive power wheeling has been proposed [17] as a viable load management option for the industries and utilities to address the peak demand problem.

In order to reduce peak demand and consequent reduction in electricity cost of the industries, an optimal operating strategy of the CPPs has to be developed, which require the operation of CPP with least fuel cost and wheeling out the power to other deficient industries. This necessitates a generalised model to determine the optimal operating strategy of the CPPs to achieve the objective of peak demand reduction by captive power wheeling under the specified electricity tariff, satisfying the system constraints. In this paper, an optimization model for captive power wheeling for peak load management is proposed. The formulation utilizes non linear programming technique to minimize the utility electricity cost and fuel cost of CPP under different TOU tariffs. Non-linear fuel cost characteristics of the captive power plants have been considered in the model.

2. MATHEMATICAL FORMULATION

It is assumed that all the industries in an industrial belt are fed from a single utility company, generally from the same sub station. Most of the industries are having CPPs with specified capacity.

Fuel cost model of the captive power plant of the p^{th} industry is given by a quadratic approximation:

$$CF_p(t) = A_p * \left[PG_p(t)\right]^2 + B_p * PG_p(t) + C_p \ \text{\$/h} \tag{1}$$

where $PG_p(t)$ is power generated by the CPP in MW at any instant t and A_p (\$/MW^2 h), B_p (\$/MWh) and C_p (\$/h) are the fuel cost parameters of the p^{th} CPP.

The cost function of the utility power is approximated to piecewise linear, considering the TOU tariff followed

$$CU_p(t) = E(t) * PU_p(t) \ \text{\$/h} \tag{2}$$

where $PU_p(t)$ is the power supplied by the utility to the industry in MW and $E(t)$ is the time dependant cost parameter under TOU tariff in \$/MWh. Both the maximum demand cost and energy cost, according to the TOU tariff followed by the utility company, is accounted in the cost parameter $E(t)$.

The excess power available at each industrial plant is wheeled out (exported) to other industries, so as to optimize the total electricity and fuel cost of the industries. Captive power wheeled out from the p^{th} industry is

$$PW_p(t) = PU_p(t) + PG_p(t) - PD_p(t) \ \text{MW} \tag{3}$$

where $PD_p(t)$ is the power demand of the industry in MW.

The wheeled power $PW_p(t)$ can be a positive quantity if the power is wheeled out (export) from the industry after meeting its own demand and a negative quantity if the power is wheeled in (import) from other industries.

Total power drawn from the utility by all the industries is:

$$PU(t) = \sum_{p=1}^{N} PU_p(t) \ \text{MW} \tag{4}$$

where N is the number of industries in the industrial belt.

Total power generated by CPPs of all the industries:

$$PG(t) = \sum_{p=1}^{N} PG_p(t) \text{ MW} \tag{5}$$

Total power demand of all the industries:

$$PD(t) = \sum_{p=1}^{N} PD_p(t) \text{ MW} \tag{6}$$

Total captive power wheeled among the industries:

$$PW(t) = \sum_{p=1}^{N} PW_p(t) \text{ MW} \tag{7}$$

A small portion of the power is lost in transmission network due to captive power wheeling among the industries. Total power loss occurring due to wheeling is modelled as:

$$PL(t) = \sum_{p=1}^{N} PL_p(t) \text{ MW} \tag{8}$$

where $PL_p(t)$ is the power loss due to wheeling from/to p^{th} industry.

The constraint to ensure that, the total demand of the industries and the losses occurring due to wheeling are met by supplying power from the utility and captive power generation is

$$PD(t) + PL(t) = PU(t) + PG(t) \text{ MW} \tag{9}$$

The captive power is wheeled among the industries located close to each other in an industrial belt. Considering the losses in the network systems due to wheeling, the net power wheeled is:

$$PW(t) - PL(t) = 0 \tag{10}$$

When power is wheeled between utilities, the power transfer takes place through the interconnecting transmission lines alone and the thermal limit of the lines becomes an important parameter in deciding the power transfer capacity. In captive power wheeling among industries, the interconnecting transmission lines, the entire distribution network and all the associated equipments are involved in the transaction. All the associated equipments and network systems should have sufficient capacity to wheel the power without over heating it. The constraint to ensure that the associated equipments and network systems are not loaded to exceed the thermal limit is

$$PD_p(t) - PW_p(t) \le DL_p \tag{11}$$

where DL_p is the maximum demand limit of network systems in MW and the associated equipments of the p^{th} industry.

The active and reactive power generation of the p^{th} CPP shall be within the specified limits, so that

$$PG_p^{\min}(t) \le PG_p(t) \le PG_p^{\max}(t) \tag{12}$$

$$QG_p^{\min}(t) \le QG_p(t) \le QG_p^{\max}(t) \tag{13}$$

where $PG_p^{\min}(t)$ and $PG_p^{\max}(t)$ are the lower and upper bounds of active power in MW and $QG_p^{\min}(t)$ and $QG_p^{\max}(t)$ are the lower and upper bounds of reactive power generation of p^{th} CPP in MVAr.

The voltage magnitude $V_p(t)$ of p^{th} CPP shall be within the specified limits, so that

$$V^{\min}(t) \le V_p(t) \le V^{\max}(t) \tag{14}$$

where $V^{\min}(t)$ and $V^{\max}(t)$ are the lower and upper bounds of the system bus voltage in kV.

The objective function to minimise the electricity cost of the industries, both of the utility power and captive power generation is

$$Min. \int_0^T \left\{ \sum_{p=1}^{N} \left[CF_p(t) + CU_p(t) \right] dt \right\} \tag{15}$$

where T is the total time horizon under consideration in hours.

The solution to the above non linear formulation, for minimizing the electricity cost satisfying the constraints, provides the optimal operating and power wheeling strategy for the captive power plants. Almost all over the world, the utilities use TOU metering scheme which employs digital techniques, for the measurement of energy and maximum demand. The load variation in industries, are not necessarily continuous because of the starting and stoppage constraints. Hence a discrete time model is sufficient, to determine the optimal operating strategy of the CPPs. The proposed model is dicretised at smaller intervals during the time horizon T under consideration [18] and can be easily solved using non linear programming technique.

3. CASE STUDY

The proposed model is illustrated through a case study of typical industrial belt in Kerala, India. Three industries which are having minimum distance between them are selected for the case study, so that the network losses are negligibly small. It is ensured that, at least some of the industries have CPPs with spare capacity so that captive power can be wheeled after meeting its own demand.

Profile of the Industries

Profiles of the three industries considered for the case study are detailed below.

Industry-I is a zinc smelter engaged in manufacturing electrolytic zinc [19]. The plant has a production capacity 38,000 MTPA of zinc metal, 51,000 MTPA of sulphuric acid and 65 MTPA of cadmium metal. Industry-II is a petrochemical plant having installed capacity of 50,000 MTPA of caprolactam, 3 800 MTPA of nitric acid and 4,750 MTPA of soda ash [20]. Caprolactam is a versatile petrochemical used as a raw material in the manufacture of nylone-6, which finds extensive application in textiles, tyre cord and engineering products. Main fuel used for the CPP is LSHS. The purge gas of petrochemical process available in the plant is also used as the boiler fuel in combination with LSHS, to reduce the fuel cost.

Industry-III is a chlor-alkali manufacturing plant having an installed capacity of 57,750 MTPA of caustic soda, 24,750 MTPA of chlorine and 52,800 MTPA hydrochloric acid [21]. Caustic soda and its co product chlorine are used in large quantities in the production of organic chemicals and also in plastics, pulp and paper industries, aluminium industry, water and wastewater treatment facilities *etc*. At present the industry is not having any captive power plant. Details of the captive power plants and electrical load connected to each industry are shown in Table 1.

Electricity Tariff Rate

For the extra high tension industrial consumers, the utility follows differential pricing system for both energy and maximum demand, the details of which are given in Table 2. Response of the industries to captive power wheeling, under three different TOU tariffs, has been evaluated. Tariff 1 [22] is the prevailing tariff for the industries.

The utility is planning to revise the tariff upwards and a tariff revision petition has already been filed before the Electricity Regulatory Commission. Tariff 2 is the proposed tariff [22]. For comparison purpose, a demand flat and energy differential tariff followed by another utility [23] is also considered for the case study (Tariff 3).

The optimization model as per Equation 15 is developed, based on the data collected from the industries. The corresponding non linear programming formulation for minimizing the electricity cost has 510 variables and 835 constraints and is solved using non linear programming technique.

Table 1. Industry details.

Industry	Connected Load (MW)	Average Demand (MW)	Contract Demand (MVA)	Average Peak Demand (MW)	CPP Capacity (MW)	CPP Fuel
I	28.00	19.20	18.00	19.45	10.00	Diesel
II	20.00	11.62	16.00	11.98	16.00	LSHS
III	40.00	19.10	25.00	19.38	Nil	-

Table 2. Tariff rates.

Tariff	Base M D Charge $/kVA	Base Energy Charge $/kWh	Differential Rate	
			Demand	Energy
Tariff 1	5.3260	0.0630	1:1.8:0.75*	1:1.8:0.75*
Tariff 2	5.3260	0.0847	1:1.8:0.75*	1:3.6:0.75*
Tariff 3	4.3478	0.0728	Flat	1:1.4:0.64 #

** For normal, peak and off peak periods. Normal time: 6.00AM – 6.00PM, Peak time: 6.00 PM – 10.00 PMOff peak time: 10.00 PM -6.00 AM*
 # For normal, peak and off peak periods. Normal time: 6.00AM – 5.00PM Peak time: 5.00 PM – 11.00 PM Off peak time: 11.00 PM -6.00 AM

4. RESULTS AND DISCUSSION

Results of captive power wheeling, when applied to three industries in an industrial belt, under three different TOU tariffs are shown in Table 3.

Comparisons of load curves of three industries are shown in Figures 1 to 3. It is observed that, all the three industries are benefited out of the captive power wheeling operation, as their electricity cost has been reduced considerably.

From the load curve it can be seen that, the CPP of Industry-I is operated to about 75% of its full capacity during the peak hours. The power so generated is used for self consumption and thus reduces peak demand by about 40%. It results in an annual saving of $ 0.2426 million (1.97%) on electricity cost of the industry, under Tariff 1.The CPP of Industry-II is loaded to about 78% of its capacity during peak hours and results in peak demand reduction of 34.63%. The excess power available is wheeled out to Industry-III. It can be seen that, for the Industry-II, captive power utilization and wheeling to other deficient industry resulted in an annual saving of $ 0.4486 million (5.43%) under Tariff 1. Even though Industry-III is not having any CPP, it is also benefited out of captive power wheeling with an annual saving of $ 0.5452 million (4.45%). It is observed that, Industry-II is benefited maximum under this tariff.

All the three industries achieve significant reduction in electricity cost under Tariff 2. The captive power generation and utilization in Industry-I resulted in an annual saving of $ 2.0739 million (11.08%). Captive power utilization and wheeling resulted in an annual saving of $ 1.0330 million (8.95%) for the Industry-II. Here, Industry-III is benefited most as the captive power wheeling results in an annual saving of $ 2.2643 million (12.16%). The captive power wheeling operation resulted in a total saving of $ 5.3713 million (10.99%) per annum for all the three industries. It can be seen that, maximum savings in terms of total electricity cost is achieved under Tariff 2. This happens because under this tariff, the base energy charge has been increased from $ 0.0630 to $ 0.0847 per kWh (34.48%). Since the Tariff 2 is the proposed tariff and the upward tariff revision is impending, the substantial savings achieved assumes significance.

The total savings achieved by the industries under Tariff 3 is $ 0.9547 million (2.74%) only and is the lowest among the three tariffs. This tariff is a demand flat and energy differential tariff and the base demand charge is less compared to other three tariffs. The energy differential rate for peak hours is also less under this tariff. Hence it can be inferred that, the savings obtained due to captive power wheeling is less under demand flat TOU tariff in comparison to demand and energy differential TOU tariffs.

Table 3. Results of Captive Power Wheeling

	Existing Operation		Captive Power Wheeling Operation				
Industry	Electricity Charge/ Month $ million	Peak Demand MVA	Electricity Charge/ Month $ million	Peak Demand MVA	Peak Demand Reduction %	Savings/ Annum $ million	Annual Savings %
Tariff 1							
I	1.0241	19.96	1.0039	11.98	39.98	0.2426	1.97
II	0.6886	11.32	0.6513	7.40	34.63	0.4486	5.43
III	1.0193	19.79	0.9739	11.85	40.12	0.5452	4.45
Total	2.7321	51.07	2.6291	31.23	38.84	1.2365	3.77
Tariff 2							
I	1.5597	19.96	1.3869	11.98	39.98	2.0739	11.08
II	0.9613	11.32	0.8752	7.40	34.63	1.0330	8.95
III	1.5513	19.79	1.3626	11.85	40.12	2.2643	12.16
Total	4.0723	51.07	3.6247	31.23	38.84	5.3713	10.99
Tariff 3							
I	1.0902	19.96	1.0621	11.97	40.03	0.3365	2.57
II	0.7217	11.33	0.7065	7.39	34.77	0.1826	2.10
III	1.0847	19.79	1.0484	11.83	40.25	0.4356	3.34
Total	2.8967	51.07	2.8171	31.19	38.92	0.9547	2.74

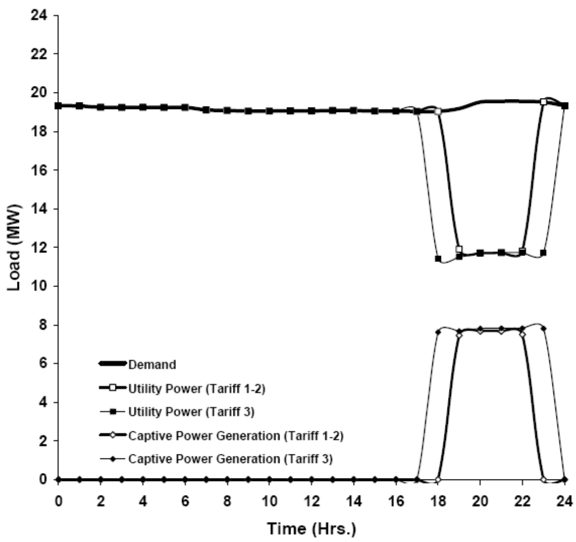

Fig. 1. Load curve - Industry-I.

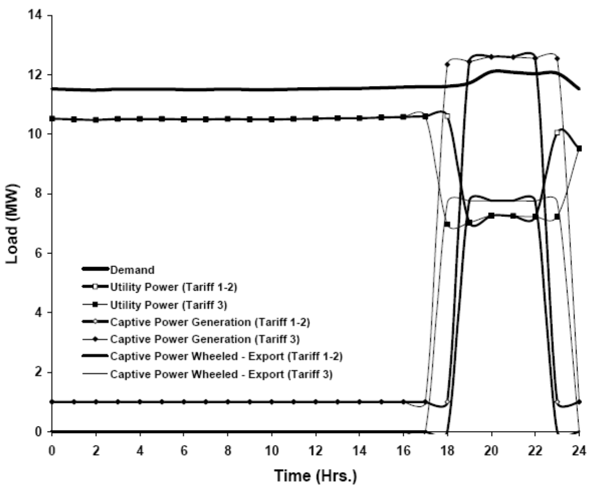

Fig. 2. Load Curve - Industry-II.

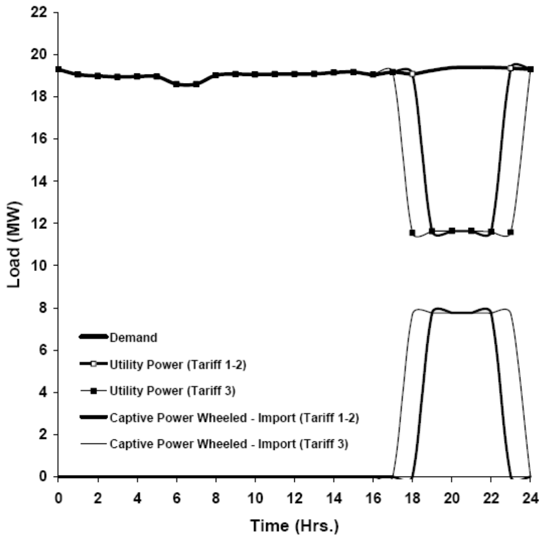

Fig. 3. Load Curve - Industry-III.

Comparison of the Results of Different Load Management Options

Different options such as load scheduling and utilization of renewable power have been used for industrial load management and reported in literature. Peak demand reduction and saving achieved in terms of electricity cost under each load management option has a definite correlation with the tariff rate employed. Hence the savings achieved by captive power wheeling can be compared only with the results obtained from the other load management applications under the same tariffs considered for this case study. Results obtained from the application of load scheduling [18] and utilization of renewable power [24], are used for comparison with the results obtained from the case study, as the tariffs followed are same.

From the Table 4, it can be seen that peak demand reduction achieved by captive power wheeling is higher than the other two methods, under Tariff 1. The savings obtained is comparable with that of load scheduling, but definitely less than that of renewable energy sources. This happens because, most of the CPPs use fossil fuels such as diesel or LSHS and naturally has higher operating cost than that of renewable energy sources such as small hydro, wind and biomass. Under Tariff 2, the peak demand reduction follows almost the same pattern as that of Tariff 1. But the annual savings achieved in terms of electricity cost has increased considerably, as this tariff charges a higher rate for base energy charge and differential energy charge during the peak hours.

Impact Captive Power Wheeling on the System Load Curve

Possible benefits the utility company can derive out of captive power wheeling have been examined. The utility's load curve on a typical day has been plotted from the data collected. The system peak demand on that particular day is 2,710 MW. It is observed that, consequent to the captive power wheeling and utilization by the three industries considered for the case study, the system peak demand gets reduced by 20.43 MW.

The impact of captive power wheeling, if all major industries connected to the utility grid resort to the optimal captive power wheeling strategy, has also been evaluated. It is estimated that, the industries coming under this category accounts for about 32% of total electrical energy consumption in the state of Kerala, India [25]. Contribution of major industries towards peak demand is about 867 MW. The effect of captive power wheeling operation on the utility's load curve is shown in Figure 4. It can be seen that, the peak demand of the utility company gets reduced by 338 MW (12.48%), when all the major industries resort to captive power wheeling. Thus the captive power wheeling operation results in considerable reduction in utility's peak demand and hence it tries to flatten the system load curve.

Table 4. Comparison of results of different load management options.

	Load Management Options		
	Load Scheduling [18]	Renewable Energy Sources [24]	Captive Power Wheeling
	Tariff 1		
Peak Demand Reduction (%)	19.30	34.24	38.84
Annual Savings in Electricity Cost (%)	3.97	6.16	3.77
	Tariff 2		
Peak Demand Reduction (%)	17.16	34.91	38.84
Annual Savings in Electricity Cost (%)	9.06	14.1	10.99

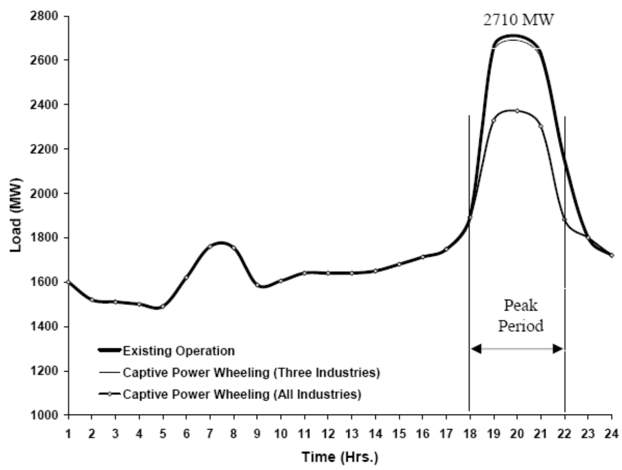

Fig. 4. Effect of captive power wheeling on system load curve.

5. CONCLUSION

An optimization model for captive power wheeling among the industries for peak demand management has been developed. The model assumes importance, in the context of ongoing deregulation of electricity supply industry across the globe. The model, when applied to three large scale industries in an industrial belt, under different TOU tariffs showed very encouraging results.

It resulted in significant reduction of electricity cost of all the industries. Coincident peak demand of the industries also got reduced considerably. It is demonstrated that, by optimally wheeling the power from hitherto under utilized captive power plants, the industries can reduce their operating cost, which in turn can result in significant reduction in peak demand of the utility companies.

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REFERENCES

[1] Merrill, H.M. and Erickson, B.W., 1989. Wheeling rates based on marginal-cost theory. *IEEE Transactions on Power Systems* 4(4): 1445–1450.

[2] Lai, L.L., 2002. *Power System Restructuring and Deregulation.* England: John Wiley & Sons Ltd.

[3] Baji, V.T. and Ashok, S., 1998. Wheeling power - a case study in India. *Electrical Power & Energy Systems* 20(5): 333–336.

[4] Li, R., Chen, L. and Yokoyama, R., 2005. Pricing for load and wheeling charge considering transmission paths in deregulated power markets. *Electrical Power & Energy Systems* 27: 496–505.

[5] Sood, Y.R., Padhy, N.P. and Gupta, H.O., 2004. Assessment for feasibility and pricing of wheeling transactions under deregulated environment of

power industry. *Electrical Power & Energy Systems* 26: 163–171.

[6] Chen S.-L., Tsay, M.-T. and Gow, H.-J., 2005. Scheduling of cogeneration plants considering electricity wheeling using enhanced immune algorithm. *Electrical Power & Energy Systems* 27: 31–38.

[7] Ma, X., El-Keib, A.A. and Haskew T.A., 1998. Marginal cost-based pricing of wheeling transactions and independent power producers considering security constraints. *Electric Power Systems Research* 48: 73–78.

[8] Yu, C.W., 1999. Long-run marginal cost based pricing of interconnected system wheeling. *Electric Power Systems Research* 50: 205–212.

[9] Ferrero, R.W. and Shahidehpour, S.M., 1996. Energy interchange in deregulated power systems. *Electrical Power & Energy Systems* 18(4): 251-258.

[10] Bakirtzis, A.G., Kim, Y.-H. and Sakis Meliopoulos, A.P., 2002. Monte Carlo simulation for evaluating retail wheeling effects. *Electrical Power & Energy Systems* 60: 137–144.

[11] Hamada, H., Marmiroli, M. and Yokoyama, R., 2009. Identification of wheeling paths by an extended sensitivity analysis. *Electrical Power & Energy Systems* 31: 79–85

[12] Abhyankar, A.R. and Khaparde, S.A., 2009. Electricity transmission pricing: Tracing based point-of-connection tariff. *Electrical Power & Energy Systems* 31: 59–66

[13] Sood Y.R., Padhy, N.P., and Gupta, H.O., 2002. Wheeling of power under deregulated environment of power system – a bibliographical survey. *IEEE Transactions on Power Systems* 17(3): 870–878.

[14] The Electricity Act-2003. 2009. Central Electricity Authority, Government of India New Delhi. Available on line, Retrieved May 2009 from World Wide Web: www.cea.nic.in

[15] Integrated Energy Policy, Report of the Expert Committee, New Delhi: Planning Commission, Government of India. 2006. Available on line, Retrieved May 2009 from World Wide Web: www.planningcommission.gov.in

[16] Annual Report 2008-09, New Delhi: Ministry of Power, Government of India. 2009. Available on line, Retrieved June 2009 from World Wide Web: http://www.powermin.nic.in

[17] Babu, C.A., and Ashok, S., 2008. Captive power wheeling for peak load management. In *Proceedings of the International Conference on Energy Security and Climate Change: Issues, Strategies, and Options (ESCC 2008)*. Bangkok, Thailand, 6-8 August. RERIC.

[18] Babu, C.A. and Ashok, S., 2008. Peak load management in electrolytic process industries. *IEEE Transactions on Power Systems* 23(2): 399-405.

[19] Data collected from M/s Binani Zinc Ltd, Cochin, India.

[20] Data collected from M/s Fertilizers and Chemicals Travancore Ltd, FACT Petrochemicals Division, Cochin, India.

[21] Data collected from M/s Travancore Cochin Chemicals Ltd, Cochin, India.

[22] Schedule of Tariff. 2008. Kerala State Electricity Regulatory Commission, Thiruvanathapuram, India. Available on line, Retrieved May 2009 from World Wide Web: www.erckerala.org

[23] Schedule of Tariff. 2009. West Bengal State Electricity Distribution Company Limited, India. Available on line, Retrieved May 2009 from World Wide Web: http://www.wbsedcl.in

[24] Babu, C.A. and Ashok, S., 2009. Optimal utilization of renewable energy-based IPPs for industrial load management. *Renewable Energy* 34: 2455–2460.

[25] Annual Report 2008–09. 2009. The Kerala High Tension and Extra High Tension. Industrial Electricity Consumer's Association Cochin, India.