Paper mill energy optimisation at SPB : A mathematical programming approach

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ABSTRACT

The cost of energy in the paper industry is of the order of 25 to 30 percent of the total cost of the paper made. The cost of energy is the sum of the cost of fuel burnt in the power and recovery boilers, cost of diesel used in diesel generating sets, and the cost of purchased power from grid Increasing cogeneration power will increase the cost of fuel and decrease the cost of purchased power and vice versa. By efficient loading of turbo generators tne generated power can be maximised by judicious extraction of steam from two different turbines. All these and the options of running/shutting of a particular recovery boiler and a particular steam turbine etc, determine the cost of energy in a typical paper mill. This paper presents the use of Mixed-integer Linear programming model for determining the operating strategies to be adopted for achieving minimum total energy cost per ton of paper. The appropriateness of the model is illustrated for the case of M/s. Seshayee Paper and Boards Ltd. Erode, Tamilnadu.

Introduction :

The cost of energy in an integrated pulp and paper mill depends upon the price of fuels, price of the purchased power and methods followed in operating the power plant. While the price of fuels and power are not under the control of the decision maker, the methods followed in operating the power plant plays an important role in deciding the cost of energy. The methods adopted in operating the power plant include the following.

(i) quality and quantity of fuels burnt in power boilers
(ii) proportion of power generated and power purchased
(iii) energy conservation efforts
(iv) running/shutting of a particular recovery boiler
and (v) running/shutting of a particular steam turbine

Energy conservation efforts include arresting of steam leaks, maintaining proper insulation on hot surfaces, maintaining higher power factor, use of energy efficient proces technology and energy efficient equipments, maintaining ideal process parameters for minimum consumption of energy, maximum utilisation of plant capacity, etc. The strategy adopted in managing plant operations have greater influence on the energy cost. Optimum utilisation of existing plants and equipment is the most attractive approach.

Mathematical modelling approaches have been used in many paper mills for energy management through either on-line computer control or for off-line decision making (see for example (1), (5), (6), (7), (15) and (16)). The tasks that were modelled in these cases include the following :

(i) fuel allocation to boilers to minimise fuel cost (fuels considered include coal, brown coal, natural gas, oil etc. mostly for individual burning).
(ii) allocation of load to boilers so as to maximise the load on the boiler for which the cost is minimum.

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(iii) setting of steam flow through turbine extractions so as to maximise power generations for a given steam demand.

(iv) determination of optimal power mix

and (v) coal procurement.

The solution techniques that were used include incremental cost analysis based on equipment efficiencies, on line modular optimisation, linear programming and mixed-integer linear programming. Both modular optimisation control and incremental cost analysis require sophisticated instrumentation with on-line computer control. Such systems are higly capital intensive and can not make a dent in the present conditions prevailing in the Indian paper industry. For off-line decision making linear programming has been mostly used for modelling paper mill energy systems (see for example references (3), (5) to (7), (9), (12), (14), and (16)).

There are only very few references ((1) and (16)) which talk about the mixed-integer linear programming. P. Mukari etal (16) has indicated the use of mixed-integer linear programming technique for modelling a Scandinavian corporate electric network system comprising six major paper mills, six hydro power plants, one nuclear power plant and seven theremal power plants to decide on power generating unit commitments. F. Cavalieri etal[1] illustrated the use of mixed-integer progrmming technique to minimise the quantity of steam generated in the power boilers of a paper mill with out considering purchased power. Boolean variables were used for expressing minimum outputs from boilers, minimum flow of steam extracted and minimum flow of steam condensed in mixed flow steam turbines.

This paper presents a mixed-integer linear programming model for determining (a) optimum quantity of steam to be generated in power boilers, (b) optimal power mix under various power cut levels which are imposed by the state owned power supply agency, (c) running/shutting of a recovery boiler and/or a steam turbine so as to achieve always minimum possible cost of energy per ton of paper product by meeting steam and power demand at the maximum process equipment production. Section 2 describes the paper mill energy plant modelled. Section 3 describes development of the complete mathematical model. Section 4 describes a case study for illustrating the appropriateness of the model for M/s Seshasayee Paper and Boards Ltd, Erode Tamilnadu.

Description of the Plant.

The block diagram of the steam and power plant of M/s Seshasayee Paper and Boards Ltd is shown in Fig. 1. The system consists of the following :

(i) Five numbers of power boilers

(ii) one number medium pressure oil fired package boiler

(iii) one high pressure recovery boiler

(iv) one medium pressure recovery boiler

(v) two numbers of extraction cum condensing turbines

(vi) two diesel generating sets

and (vii) 110 KV substation connected to Tamilnadu Electricity Board Grid

There are three major steam pressure levels namely 400 psi, 150 psi, and 50 psi. Both the steam turbines receive steam at high pressure i.e. 400 psi. Desuperheaters are installed at 150 psi and 50 psi levels. Process equipment which consume 150 psi steam are stationary digesters, continuous digester. papermachine drive turbines, recovery boilers auxiliaries. Equipment which consume 50 psi steam are evaporators, stationary digesters, papermachine drying cylinders, deaereators, and causticising section.

The Mathematical Programming Model

Assumptions

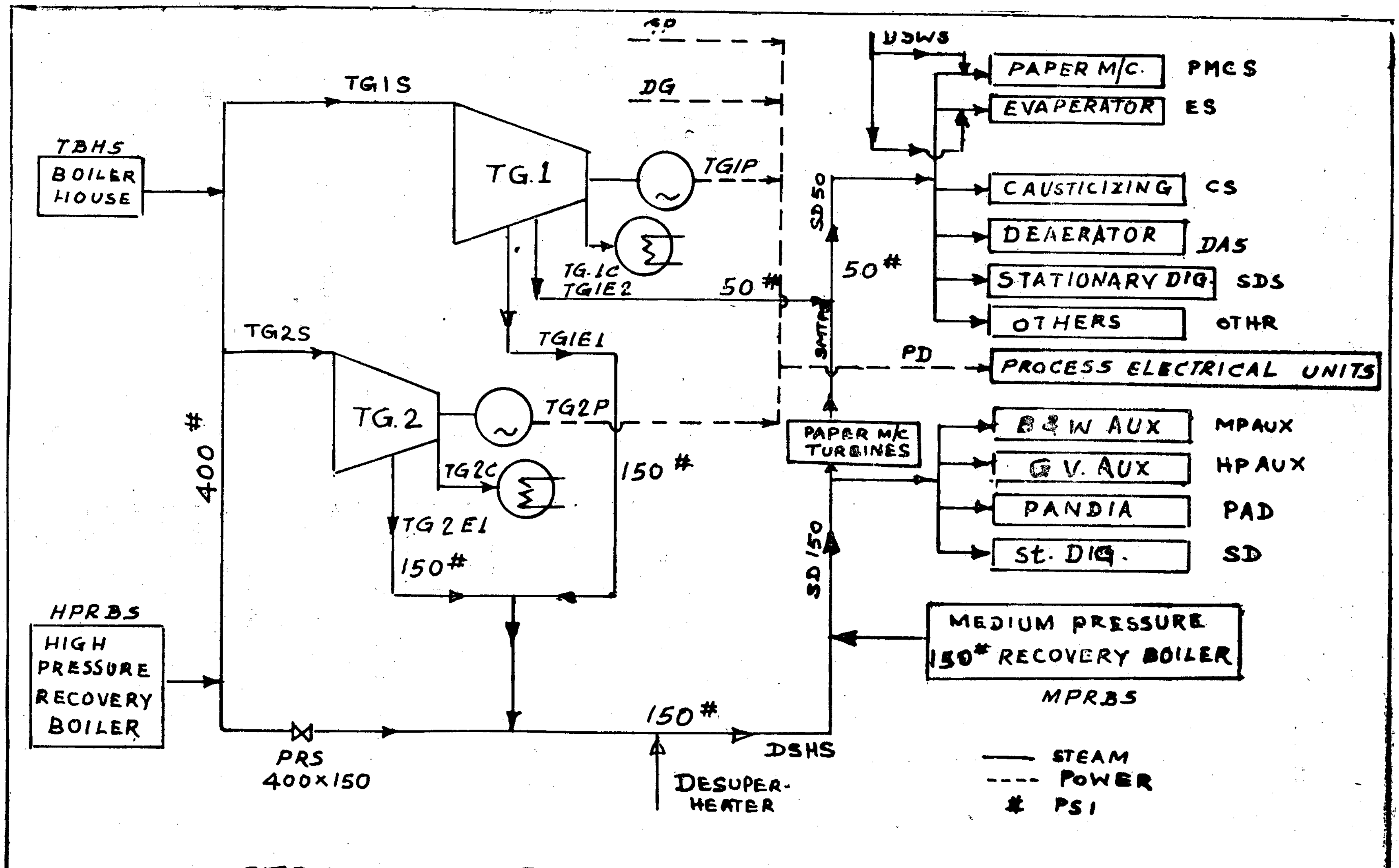
(i) the time unit for the model will be one day

(ii) all the process units are operating at their respective maximum capacity

(iii) the power and steam demand by the process units is at a constant rate throughout the day

(iv) in the turbogenerators minimum condensation is assumed and the same will be constant throughout the day

and (v) the cost of steam from recovery boilers is assumed as 0



STEAM AND POWER NETWORK

FIG. 1

The model described below is applicable for a general system similar to the one described in section 2. The relationship between the quantity and quality of fuels fired in power boilers and the steam generated in power boilers is not included in the model. Instead the cost of steam from power boilers is used as a parameter.

For steam the unit is in tons per day. For power it is represented in MW. For electrical energy it is represented in KWH.

The following notations are used for describing the known state parameters in developing the model.

Let

G	the total steam generating capacity of the power boilers in tons per day
C	cost of fuel per ton of steam from power boilers in Rs per ton of steam
PPT	paper production in tons per day
M1HPRB	steam that is generated in high pressure recovery boiler in tons per day when medium pressure recovery boiler is in operation
M2HPRB	steam that is generated in high pressure recovery boiler in tons per day when medium pressure recovery boiler is not in operation
MPRB	steam that is generated in medium pressure recovery boiler in tons per day if in operation
HPAUX	auxiliary steam consumption in high pressure recovery boiler in tons per day at 150 psi
PAD	steam consumption in Pandia digester in tons per day at 150 psi.
SD	steam consumption in stationary digester in tons per day at 150 psi
MPAUX	steam consumption in medium pressure recovery boiler in tons per day at 150 psi (auxiliary)
DSWS	water spray in the desuperheater at 50 psi
PMCS	steam consumption in papermachine drying cylinders in tons per day at 50 psi
ES	steam consumption in evaporators in tons per day at 50 psi
CS	steam consumption in causticising plant in tons per day at 50 psi
SDS	steam consumption in stationary digester in tons per day at 50 psi
OTHR	steam consumption in other process equipments in tons per day at 50 psi levels
a_1	the power generated by 150 psi extraction steam in turbine 1 in KWH/ton
b_1	the power generated by 50 psi extraction steam in turbine 1 in KWH/ton
c_1	the power generated by condensing steam in turbine 1 in KWH/ton
TG1M1	maximum steam flow in tons/day for turbine 1 150 psi extraction
TG1M2	maximum steam flow in tons/day for turbine 1 50 psi extraction
TG1MC	maximum steam condensed in tons/day for turbine 1
TG1MP	maximum power that can be generated in turbine 1 in MW
T1MC	minimum condensation flow in turbine 1 to prevent fluctuation in frequency of power generated in tons/day
a_2	the power generated by 150 psi extraction steam in turbine 2 in KWH/ton
c_2	the power generated by condensation flow in turbine 2 in KWH/ton
TG2M1	maximum steam flow in tons/day for turbine 2 150 psi extraction
TG2MC	maximum steam condensed in turbine 2 in tons/day
TG2MP	maximum power that can be generated in turbine 2 in MW

T2MC	minimum condensation flow in turbine 2 to prevent fluctuation in frequency of power generated
P	electrical energy consumed in the mill in KWH per ton of paper at full production
MDGP	maximum power generated by diesel generating sets in MW
MGP	maximum power available from the Tamilnadu Electricity Board (TNEB) grid supply in MW
MGPU	maximum energy available from TNEB grid in KWH per day
q_1	cost of energy from TNEB grid supply in Rs per unit (KWH)
q_2	cost of energy from diesel generating sets in Rs. per unit (KWH)
MPRBP	Power consumed by medium pressure recovery boiler auxiliaries in KWH per day.
PCTG2	Power consumed by turbine 2 auxiliaries in KWH/day.

The Decision variable are as follows :

CEPT	cost of energy per ton of paper in Rs. per ton
CFPT	cost of fuel per ton of paper in Rs per ton
CPPT	cost of power per ton of paper in Rs per ton
TBHS	the total amount of steam that is to be generated in power boilers.
TG1S	amount of steam going into the turbine 1 in tons per day.
TG2S	amount of steam going into the turbine 2 in tons per day
PRS	amount of steam passing through the 400×150 psi pressure reducing station in tons per day
HBRBS	amount of steam generated in high pressure recovery boiler in tons per day
MBRBS	amount of steam generated in medium pressure recovery boiler in tons per day at 50 psi
SD150	steam demand at 150 psi in tons per day
DSHS	amount of desuperheated steam at 150 psi in tons per day
SMTPR	amount of steam flowing through the papermachine steam turbine and 150 X 50 psi pressure reducing station in tons per day
SD50	steam demand at 50 Psi in tons per day
DAS	steam consumed in the deaerators in tons per day
TG1E1	amount of steam passing through 150 psi extraction in turbine 1 in tons per day
TG1E2	amount of steam passing through 50 psi extraction in turbine 1 in tons per day.
TG1C	amount of steam condensed in turbine 1 in tons/day
TG1PU	amount of electrical energy that is to be generated in turbine 1 in KWH per day
TG1P	amount of power that is generated in turbine 1 in MW
TG2E1	amouns of steam passing through 150 psi extraction in turbine 2 in tons per day
TG2C	amounr of steam condensed in turbine 2 in tons per day
TG2PU	amount of electrical energy that is to be generated in turbine 2 in KWH per day.
TG2P	amount of power that is generated in turbine 2 in MW
IIMP	= 1 if medium pressure recovery boiler is in operation = 0 otherwise
IITG2	= 1 if turbine 2 is in operation = 0 otherwise

PD	total electrical energy demand for the mill in KWH per day
DG	amount of power to be generated in diesel generating sets inMW
GP	amount of TNEB grid power to be consumed in MW
GPU	amount of electrical energy used from TNEB grid in KWH

The objective function is to minimise the energy cost in Rs per ton of paper. This is represented by a single variable as shown below :

$$\text{Min } CEPT \qquad (1)$$

The model incorporates 35 constraints as described below.

The cost of energy per ton of paper in equal to the sum of the cost of fuel per ton of paper and the cost of power per ton of paper. This is given by the following expression.

$$CEPT-CFPT-CPPT = 0 \qquad (2)$$

The cost of fuel per ton of paper is equal to the cost of steam generated in the power boilers in a day divided by the amount of paper produced per day. This is given by the following expression.

$$\frac{C * TBHS}{PPT} - CEPT = 0 \qquad (3)$$

The steam generating capacity of the power boiler is limited to G tons per day. This is represented by the following expression.

$$TBHS \le G \qquad (4)$$

There should be a steam balance in the 400 psi header. This is represented by the following expression :

$$TG1S+TG2S+PRS-TBHS-HPRBS = 0 \qquad (5)$$

The steam generated in the high pressure recovery boiler depends on the operation or stoppage of the medium pressure recovery boiler. This is represented by the following expression.

$$HPRBS-(M1HPRB)* \; IIMP-M2HPRB* \; (1-IIMP)=0 \qquad (6)$$

This is inview of the fact that higher amount of black liquor solids are burnt in high pressure recovery boiler when medium pressure recovery boiler is not in operation.

There should be a steam balance across the steam turbines. For turbine 1 this is given by

$$TG1S-TG1E1-TG1E2-TG1C=0 \qquad (7)$$

For turbine 2 this is given by

$$TG2S-VG2E1-TG2C=0 \qquad (8)$$

There should be a steam balance across the 150 psi desuperheater. This is given by

$$1.08* \; (PRS+TG1E1+TG2E1+TG2E1)-DSHS=0 \qquad (9)$$

Equation (9) arises inview of the fact that the DM water spray at desuperheater is equal to 8% of the total steam flowing into the desuperheater.

There should be a steam balance in the 150 psi steam header. This is given by

$$DSHS+MPRBS-SD150=0 \qquad (10)$$

The steam generating capacity of the medium pressure recovery boiler is represented by

$$MPRBS-MPRB* \; IIMP=0 \qquad (11)$$

The sum of the individual process steam demand at 150 psi is equal to SD 150. This is given by

$$SD150-SMTPR-(MPAUX)* \; IIMP=(HPAUX+PAD+SD) \qquad (12)$$

Equation (12) ensures that steam is consumed in medium pressure recovery boiler auxiliaries only when the unit is in operation.

The steam balance in the 50 psi header is given by

$$TG1E2+SMTPR-SD50=DSWS \qquad (13)$$

The sum of the individual process steam demand at 50 psi level is equal to SD50. This is given by

$$SD50-DAS=PMCS+ES+CS+SDS+OTHR \qquad (14)$$

Deaerator steam consumption is equal to 8.5% of the total steam generated by all the boilers. This is given by

$$0.085* \; (TBHS+HPRBS+MPRBS)-DAS=0 \qquad (15)$$

Power generation by the turboalternators is represented as follows. For turbine 1 this is given by

$$a_1 * \mathrm{TG1E1} + b_1 * \mathrm{TG1E2} + c_1 * \mathrm{TG1C} - \mathrm{TG1PU} = 0 \tag{16}$$

The upper limit on the extraction and condensation flows is represented by the following expressions

$$\mathrm{TG1E1} <= \mathrm{TG1M1} \tag{17}$$

$$\mathrm{TG1E2} <= \mathrm{TG1M2} \tag{18}$$

$$\mathrm{TG1C} <= \mathrm{TG1MC} \tag{19}$$

There should be a minimum steam condensation in turbine 1 to prevent fluctuation in frequency of power generated. This is given by

$$\mathrm{TG1C} >= \mathrm{T1MC} \tag{20}$$

The maximum electrical energy that can be generated in turbine 1 is given by

$$\mathrm{TG1PU} - 24000 * \mathrm{TG1P} <= 0 \tag{21}$$

$$1000\ \mathrm{TG1P} <= \mathrm{TG1MP} \tag{22}$$

Similar equations for turbine 2 is as given below.

$$a_2 * \mathrm{TG2E1} + c_2 * \mathrm{TG2C} - \mathrm{TG2PU} = 0 \tag{23}$$

$$\mathrm{TG2E1} - \mathrm{TG2M1} * \mathrm{IITG2} <= 0 \tag{24}$$

$$\mathrm{TG2C} - \mathrm{TG2MC} * \mathrm{IITG2} <= 0 \tag{25}$$

$$\mathrm{TG2PU} - 24000\mathrm{TG2P} = 0 \tag{26}$$

$$\mathrm{TG2P} - \mathrm{T2MP} * \mathrm{IITG2} <= 0 \tag{27}$$

$$\mathrm{TG2C} - \mathrm{T2MC} * \mathrm{IITG2} >= 0 \tag{28}$$

Electrical energy demand by the process should be equal to the electrical energy supplied. This is given by

$$\mathrm{TG1PU} + \mathrm{TG2PU} + 24000\mathrm{DG} + 24000\mathrm{GP} - \mathrm{PD} = 0 \tag{29}$$

$$\mathrm{PD} + \mathrm{MPRBP} * (1 - \mathrm{IIMP}) + \mathrm{PCTG2} * (1 - \mathrm{IITG2}) = (\mathrm{P} * \mathrm{PPT}) \tag{30}$$

The upper limit on the availability of diesel power and grid power are given by the following three expressions.

$$1000\mathrm{DG} <= \mathrm{MDGP} \tag{31}$$

$$1000\ \mathrm{GP} <= \mathrm{MGP} \tag{32}$$

$$24000\ \mathrm{GP} - \mathrm{GPU} = 0 \tag{33}$$

$$\mathrm{GPU} <= \mathrm{MGPU} \tag{34}$$

The cost of power is given by the following two expressions.

$$24000 * q_1 * \mathrm{GP} + 24000 * q_2 * \mathrm{DG} - (\mathrm{CPPT}) * \mathrm{PPT} = 0 \tag{35}$$

Equations (1) to (35) describe the MILP model.

Case Study

The model was run using a Mixed-integer Linear programming software on a PC for the case of M/s Seshasayee paper and boards Ltd. The input data used for the model are given in TABLE—1. Three sets of runs were made for 20%, 30% and 40% powercuts for the TMEB grid. For each set four runs were made for four values of cost of fuel per ton of steam from power boilers namely Rs. 170, Rs. 180, Rs. 190 and Rs. 200 per ton of steam. The optimal solutions are shown in Table 2, Table 3 and Table 4 respectively for the 20%, 30% and 40% powercuts

As seen in these tables, the cost of energy is minimum when the 2.5 MW turbine is in operation for all three levels of powercuts with the 150 psi extraction at the maximum level. Also it is profitable to increase 2.5 MW condensation than 5 MW condensation. Condensation in 5 MW is always to be kept at the minimum level. The running of the medium pressure recovery boiler is economical only when the power cut is 20% and cost of steam is Rs. 190 or Rs. 200 per ton. For all the cases the total power boiler steam demand is in the range of 1428 to 1680 tons per day.

At 20% powercut running of diesel generating set and medium pressure recovery boiler is economical when the cost of steam is Rs. 190 or Rs. 200 per ton. At 30% powercut running of diesel generating set is economical when the cost of steam is Rs. 190 or Rs 200 without the medium pressure recovery boiler. At 40% powercut diesel set is to be run always irrespective of the cost of steam without the medium pressure recovery boiler.

TABLE 1

INPUT DATA FOR THE MILP MODEL OF M/S SPB LTD

S. NO.	DESCRIPTION	UNITS	VALUE		IN NOTATION
1	PAPER PRODUCTION PER DAY	TONS/DAY	160		PPT
2	FUEL COST OF STEAM	RS/TON	170 TO 200		C
3	HIGH PRESSURE RECOVERY BOILER STEAM	TONS/DAY	380 OR 410		(M1HRB/ M2HRB)
4	MEDIUM PRESSURE RECOVERY BOILER STEAM	TONS/DAY	170		MPRB
5	PROCESS STEAM AT 150 PSI	TONS/DAY	324		(PAD+SD +HPAUX)
6	MPRBAUX STEAM CONS	TONS/DAY	70		MPAUX
7	PROCESS STEAM AT 50 PSI	TONS/DAY	1394		(PMCS+ES+ CS+SDS+ OTHER)
8	MAX POWER BOILER STEAM CAPACITY	TONS/DAY	2000		G
			NO. 1	NO. 2	
9	TURBINES POWER CAPACITY	MW	5	2.5	(TG1MP/ TG2MP
	EXTRACTION 1	KWH/TON	24.39	33.26	a1/a2
	EXTRACTION 2	KWH/TON	54.054	—	b1
	CONDENSATION	KWH/TON	117.5	160.5136	c1/c2
	MAX STEAM FLOW				
	EXTRACTION 1	TONS/DAY	1200	700	TG1M1/2M1
	EXTRACTION 2	TONS/DAY	550	—	TG1M2
	CONDENSATION	TONS/DAY	660	544	TG1MC/2MC
	MINI CONDENSATION	TONS/DAY	84	48	T1MC/T2MC
10	DIESEL SET	MW	1.2		MDGP
11	GRID POWER	MW	10.032		MGP
	AT 20% POWERCUT	KWH	187559		MGPU
12	MPRBAUX POWER CONSUMPTION	KWH/DAY	7730		MPRBP
13	TURBINE 2 AUX POWER CONSUMPTION	KWH/DAY	1720		PCTG2
14	pROCESS POWER	KWH/TON	1700		P
15	COST OF GRID POWER	RS/KWH	1		q_1
16	COST OF DIESEL POWER	RS/KWH	1.21		q_2
17	50 PSI DE SUPER HEATER SPRAY WATER	TONS/DAY	20		DSWS

TABLE 2

Optimal Solution For 20% Power Cut

Grid=10.032 MW And 187559 KWH

S. No.	Description	Units	Cost Of Power Boiler Steam			
			C=170	C=180	C=190	C=200
	A. COST					
1	Energy Cost	Rs/T	2696.75	2789.5	2879.11	2968.37
2	Fuel Cost	Rs/T	1576.78	1669.53	1695.81	1785.06
3	Power Cost	Rs/T	1119.97	1119.97	1183.31	1183.31
	B. POWER					
4	5 MW Load	MW	2.1703	2.1703	2.0829	2.0629
5	2.5 MW Load	MW	1.2911	1.2911	1.2911	1.2911
6	Diesel Load	MW	0	0	0.0609	0.0609
7	Grid Load	MW	7.4664	7.4664	7.8149	7.8149
8	Total Load	MW	10.9278	10.9278	11.2498	11 2498
9	5 MW Units	KWH	52088	52088	49991	49991
10	2.5 MW Units	KWH	30986	30986	30986	30986
11	DG Units	KWH	0	0	1672	1461
12	Grid Units	KWH	179195	179195	187559	187559
13	Total Units	KWH	262269	262269	270208	269997
	C. STEAM					
14	Total Boiler House Steam	Tons	1484	1484	1428	1428
15	HP Recovery Boiler Steam	Tons	410	410	380	380
16	Total Steam To Steam Turbines	Tons	1894	1894	1808	1808
17	400×150 PRS	Tons	0	0	0	0
18	5 MW Extract 1	Tons	512	512	426	550
19	5 MW Extract 2	Tons	550	550	550	426
20	5 MW Condens	Tons	84	84	84	84
21	2.5 MW Extract	Tons	700	700	700	700
22	2 5 MW Conden	Tons	48	48	48	48
23	LP Recovery Boiler System	Tons	0	0	170	170

TABLE 3

Optimal Solution For 30% Power Cut
Grid = 8.778 MW And 164114 KWH

S. No.	Description	Units	Cost of Power Boiler Steam			
			C = 170	C = 180	C = 190	C = 200
	A. COST					
1	Energy Cost	Rs/T	2709.46	2808.5	2902.05	2994.8
2	Fuel Cost	Rs/T	1685.75	1782.79	1762.28	1855.03
3	Power Cost	Rs/T	1025.71	1025.71	1139.76	1139.76
	B. POWER					
4	5 MW Load	MW	2.1783	2.1783	2.1703	2.1703
5	2.5 MW Load	MW	1.9114	1.9114	1.2911	1.2911
6	Diesel Load	MW	0	0	0.6283	0.6283
7	Grid Load	MW	6.8381	6.8381	6.8381	6.8381
8	Total Load	MW	10.9278	10 9278	10.9278	10.9278
9	5 MW Units	KWH	52281	52281	52088	52088
10	2.5 MW Units	KWH	45874	45874	30987	30987
11	DG Units	KWH	0	0	15080	15080
12	Grid Units	KWH	164114	164114	164114	164114
13	Total Units	KWH	262269	262269	262269	262269
	C. STEAM					
14	Total Boiler House Steam	Tons	1584	1584	1484	1484
15	HP Recovery Boiler Steam	Tons	410	410	410	410
16	Total Steam To Steam Turbines	Tons	1994	1994	1894	1894
17	400 × 150 PRS	Tons	0	0	0	0
18	5 MW Extract 1	Tons	519	519	512	512
19	5 MW Extract 2	Tons	550	550	550	550
20	5 MW Condens	Tons	84	84	84	84
21	2 5 MW Extract	Tons	700	700	700	700
22	2 5 MW Condens	Tons	141	141	48	48
23	LP Recovery Boiler Steam	Tons	0	0	0	0

TABLE 4

OPTIMAL SOLUTION FOR 40% POWER CUT

GRID = 7.524 MW AND 140669 KWH

S. NO.	DESCRIPTION	UNITS	COST OF POWER BOILER STEAM RS/TON			
			C = 170	C = 180	C = 190	C = 200
	A. COST					
1	Energy Cost	RS/T	2733.51	2838 53	2936.37	3033 18
2	Fuel Cost	RS/T	1785 24	1890.25	1839 39	1936.2
3	Power Cost	RS/T	948 27	948.27	1096 98	1096.98
	B. POWER					
4	5 MW Load	MW	2.186	2 186	2.1755	2.1755
5	2 5 MW Load	MW	2.5	2.5	1.6912	1.6912
6	Diesel Load	MW	0 3806	0 3806	1 2	1.2
7	Grid Load	MW	5.8612	5.8612	5.8612	5.8612
8	Total Load	MW	10.9278	10.9278	10.9279	10.9279
9	5 MW Units	KWH	52464	52464	52212	52212
10	2.5 MW Units	KWH	60000	60000	40588	40588
11	DG Units	KWH	9134	9134	28800	28800
12	Grid Units	KWH	140669	140669	140669	140669
13	Total Units	KWH	262267	262267	262269	262269
	C. STEAM					
14	Total Boiler House Steam	TONS	1680	1680	1548	1548
15	HP Recovery Boiler Steam	TONS	410	410	410	410
16	Total Steam to Steam Turbines	TONS	2090	2090	1958	1958
17	400 × 150 PRS	TONS	0	0	0	0
18	5 MW Extract 1	TONS	527	527	517	517
19	5 MW Extract 2	TONS	550	550	550	550
20	5 MW Condens	TONS	84	84	84	84
21	2 5 MW Extract 1	TONS	700	700	700	700
22	2.5 MW Conden	TONS	228	228	108	108
23	LP Recovery Boiler Steam	TONS	0	0	0	0

Conclusion

The paper mill energy system is modelled as a Mixed-integer Linear Programming model and the model was illustrated for the case of M/s. Seshasayee Paper and Boards Ltd. Optimal strategies for operating the plant at various levels of powercut and for various values of cost of steam have been developed. The model can also be used to answer various what-if 'analysis (some of these are currently being investicated) such as studying the effect of

- (i) installation of additional steam turbine
- (ii) reduction in process steam and power demand due to conservation efforts
- (iii) replacing conventional evaporater and recovery boiler system by black liquor gassification, gasturbine and wasteheat recovery boiler in to a high pressure recovery boiler
- and (v) installation of steam accumulators in the 150 psi and 50 psi comman steam headers

The MILP model described in this paper can also be used as a basic model for the development of a production planning model for an integrated pulp and paper mill by including the process plants in the model- Such a model is being currently developed.

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