CHAPTER VI

COGENERATION IN A OF PULP AND PAPER PLANT

6.1 Description of the Pulp and Paper Production Process

In the pulp and paper production process, a large amount of energy is consumed such as mechanical energy for chipping logs, heating steam for the digestion of chipped log with sodium hydroxide, etc.

The pulp and paper process is described briefly as follows.

The logs are slashed and debarked, and conveyed to the chippers to reduce the wood to small chips.

The chips are screened on either rotary or vibrating screens to separate the oversized chips, the desired product and the sawdust.

The digesters are charged with the screened chips; the cooking white liquor containing essentially sodium sulfide and caustic soda is added. The cooking period lasts about 3 hours.

The pulp, is separated from the cooking liquor andwashed.

The spent cooking liquor (black liquor) is pumped to storage to await recovery of the chemicals by evaporation and combustion of dissolved organic matters in the recovery furnace for reused in the process.

The washed pulp is passed to the screening chamber to sieve out any small slivers of uncooked wood, and finally to the filters and thickeners.

The thickened pulp is next bleached, using at least one chlorine dioxide stage, followed by neutralization and calcium hypochlorite treatment.

After bleaching, the pulp is washed and rethickened. It then runs into the charging chest of a paper machine to give dried pulp.

6.2 Description of the Cogeneration Process

As shown in Fig.6.1 the cogeneration system of the present pulp and paper plant was as following.

Feed water, oil and combustion air were fed into 4 boilers. The steam produced had a pressure about 860 lb/in^2G and a temperature of 800 ^oF. The superheated steam was divided into two streams. One flowed directly in turbogenerator no.3 while the other flowed through pressure reducing valve and became high pressure steam. Electricity that was produced by turbogenerator no.3 was supplied to the process. Medium-pressure steam and low-pressure steam coming out of turbogenerator no.3 was also used in the process.

Part of the above high pressure steam flowed into turbogenerator no.1 and turbogenerator no.2 to produce more electric its for use in the process.

The outputs from turbogenerator no.1 were besides electricity, medium-pressure steam and low pressure steam. The outputs from turbogenerator no.2 were low-pressure steam and condensate.

Another part of the high-pressure steam flowed directly to the digesters (P1).

The medium-pressure steam flowed to the process via 3 routes.

In the first, it flowed directly to the process. In the second, it flowed to the process through a mechanical power generating turbine (M1) that drived the forced draft fan unit. Sometimes the some unit was driven by electric power. In the third,it flowed to another mechanical power generating turbine (M2) that drived other mechanicalunits. Sometimes these units were also drived by electric power.

The low pressure steam flowed directly to the process and after usage became condensate, part of which was recycled to the feed water tank.

6.3 Problem Formulation

In the present pulp and paper plant, steam was produced from the boilers and electricity was produced by the steam-driven turbogenerators. A part of electricity was purchased. Major mechanical units were powered dually using both steam and electricity.

The objective of the present optimization work was to find an optimal operating condition that minimized the costs of utility production while satisfying all the constraints.

6.3.1 Definition of Variables and Parameters

The variables in this work were as follows (see Fig.6.2) :

y(1) - Total flow rate of medium-pressure steam that was extracted turbogenerators no.3 and no.1 (lb/h).

y(2) - Total flow rate of low-pressure steam that was exhausted from turbogenerators no.1, no.2 and no.3 and combined with low-pressure steam from the dual-powered process drive (M1) before entering the process (lb/hr).

y(3) - Flow rate of condensate from turbogenerator no.2 that entered the condensate line (lb/hr).

y(4) - Purchased electric power (KW).

y(5) - Flow rate of the medium-pressure steam that split from y(1) and flowed into M1, M2 (lb/hr).

y(6) - Total electric generation by all three turbogenerators (KW).

y(7) - Electric power requiree to run the unit process. (KW)

y(8) - Total load of drive and process that required steam driving. (HP)

y(9) - Total load of drive and process that required electric driving. (HP) y(10) - Total flow rate of steam that flowed from dual powered-process and drive to process (lb/h)

y(11) - Total flow rate of steam from dual-powered process and drive that flowed to the condensate line.

<u>The parametric constants were as follows</u> :

X2 - high-pressure steam that flowed directly to the process.

X7 - total medium-pressure steam requirement of the process (50 lb/h)

X8 - Total low-pressure steam requirement of the process (250 lb/h)

X13 - Condensate return from the process (lb/h)

W18 - Total electricity requirement of the process (34 KW)

6.3.2 The Mathmetical Model

The model for cogeneration in the pulp and paper plant was as follows :

<u>The objective function</u>

The problem is defined as minimizing the fuel cost ($/hr) plus electricity cost ($/hr), that is the total utility cost.

From [24] the total cost of fuel was given by $0.0006 \ (y(1)+y(2)+y(3))^2+2.6(7(1)+y(3))-12$. And the cost of purchased electricity was given by 6.74+12.1 y(4).

So the objective function was,

$$\text{minimize } f(y) = 0.0006(y(1)+y(2)+y(3))^2 \\ +2.6(y(1)+y(2)+y(3))-12 \\ +6.74+21.1\ y(4)$$

<u>The equality constraints and their physical meaning</u>

h(1) : Relationship between steam input to the turbogenerators and electricity generated.

$h(1) = 0.125\ y(1)+0.25y(2)+0.222y(3)-30.4-y(6) = 0$

h(2) : Electric power balance in the process

$h(2) = y(4)+y(6)-y(7)-34 = 0$

h(3) : Load demand relation for dual process and drives.

$h(3) = y(8)-y(9) -6.56 = 0$

h(4) : Relation between steam power and load of dual process and drive.

$h(4) = 9.55\ y^2(8)+0.4y(8)+1-y(5) = 0$

y(5) : Relation between electric power and load of dual process and drive

$h(5) = y(7)-0.027y^2(9)-0.88y(9)-2.6 = 0$

h(6) : Mass balance of dual process and driver.

$h(6) = y(5)-y(10)-y(11) = 0$

h(7) : Mass balance of steam flow conduits (medium-pressure steam).

$h(7) = y(1)-50-y(5) = 0$

h(8) : Mass balance of steam flow conduits (low-pressure steam).

$h(8) = y(2)+y(10)-250 = 0$

The upper limits of some variables were as follows :

$y(1) \leq 260$

$y(2) \leq 280$

$y(3) \leq 80$

$y(6) \leq 44.6$

Further details of the model may be found in [24].

6.3.3 Experiment of Optimization

In this optimization work the three starting points were experimented.

To compare with the answer given in [24] starting point no.1 (SP1) was the same starting point used in [24]

Starting point no.2 (SP2) was the optimal point given in [24]. This experiment was to find out whether the optimal objective function in [24] can further be improved or not.

Starting point no.3 (SP3) was an arbitary starting point used to see whether the same optimal point would be obtained.

6.4 Results of optimization

The results of optimization are shown in Table 6.1

Table 6.1 revealed that all three starting points SP1, SP2 and SP3 gave the same optimal operating condition. Referring to starting point no.1, the present optimization results may be explained as follows :

Since y(1) was slightly reduced, it means that the medium-pressure steam extracted turbogenerations no.3 and no.1 should be reduced.

Since y(2) was increased, it means that the low-pressure steam exhausted from turbogenerators no.1, no.2 and no.3 should be increased.

Table 6.1 Result of optimization for cogeneration of pulp and paper plant.

Variable	Starting point			Optimal conditions			Remark
	SP1	SP2	SP3	SP1	SP2	SP3	
y(1)	60.0	59.8	45	55.0	55.0	55.0	
y(2)	240.0	244.0	230	249.9	249.9	249.9	
y(3)	6.0	17.2	100	17.1	17.1	17.1	
y(4)	4.0	0.0	5	0.0	0.0	0.0	
y(5)	10.0	9.81	20	5.0	5.0	5.0	
y(6)	38.0	42.3	40	42.7	42.7	42.7	
y(7)	8.0	8.36	10	8.7	8.7	8.7	
y(8)	0.96	0.939	5	0.62	0.62	0.62	
y(9)	5.6	5.62	5	5.93	5.93	5.93	
y(10)	10.0	5.47	10	0.0	0.0	0.0	
y(11)	0.0	4.33	5	5.0	5.0	5.0	
objective function ($/hr)	930.92	891.16	889.97	894.46	894.46	894.46	

Since y(3) was increased, it meaned that the flow rate of condensate from turbogenerator no.2 should be increased.

Furthermore, y(4) was reduced to be zero, meaning that purchased electricity should be zero because at the optimal condition this factory did not need to purchase electric from the outside.

The overall effect of reducing y(1) while increasing y(2) and y(3) was to increase electricity generation to fully meet the electricity demand of the plant, as reflexted by y(6).

Since y(5) was reduced, it means that the flow rate of medium pressure steam that by-passed from y(1) and flowed to dual-powered process and drive (M1, M2) was reduced. This occurred because more electricity was generated and the surplus electricity was used to drive the units, thus reducing the steam consumption.

As mentioned earlier, y(6) was increased so that purchased electricity was no longer needed.

As mentioned in relation to y(5), y(7) was increased because there was surplus electricity to drive the units.

Similarly, y(8) was reduced because surplus electricity was available to reduce steam consumption.

Similarly, y(9) was increased because there was surplus electricity from y(6) to meet the load of drive and process.

y(10) was reduced to be zero meaning that the flow rate of steam that flowed through the dual powered process and drive to the process was reduced to be zero. This resulted from the increase in y(2) along with the process requirement that y(2)+y(10) should be kept constant.

Since y(11) was increased, it meaned that the flow rate of condensate from dual powered process and drive into the condensate line was increased because y(10) was reduced to zero.

6.5 Conclusions

In the present cogeneration problem for the pulp and paper plant it can be concluded as little electricity as possible should be purchased which can be accomplished by generating as much electricity as possible. The surplus electricity could then be used to drive the mechanical units. In addition, it is seen that the amount of medium-pressure steam and low-pressure steam that were extracted and exhausted from the turbogenerators were related to the amount of electricity produced. this relationship depended on the characteristic of the turbogenerators.

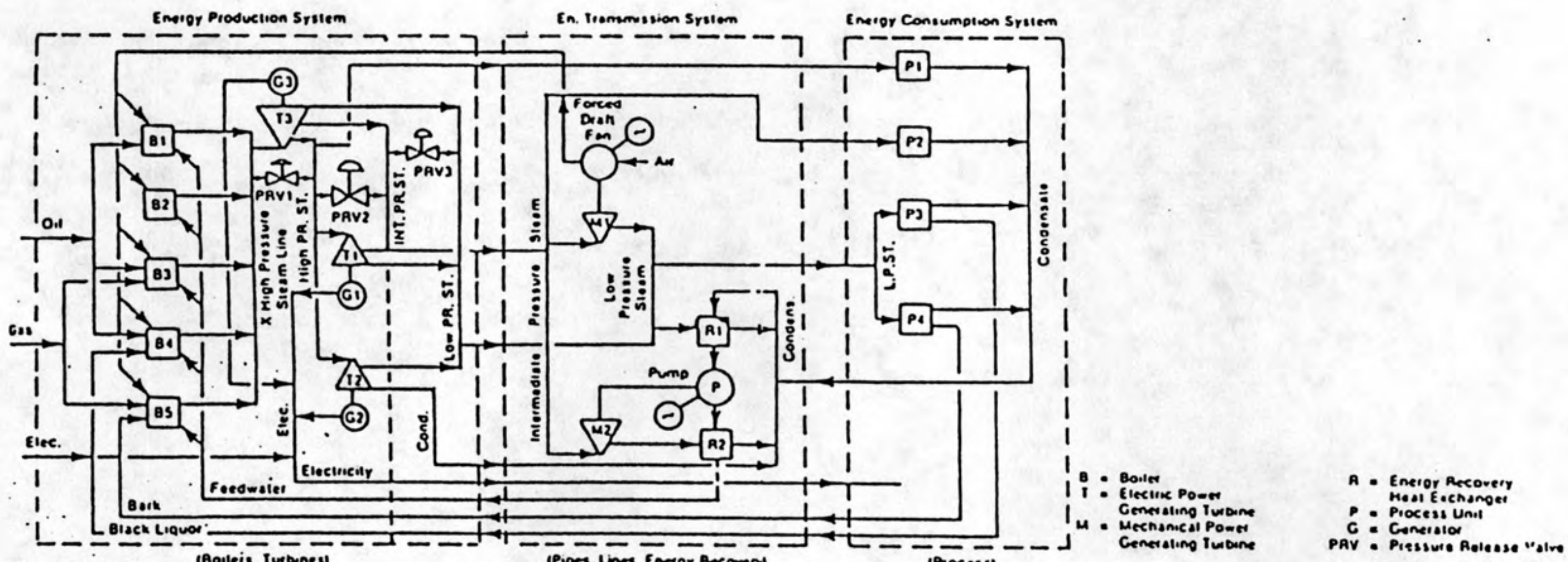

Fig 6.1 Energy Management System Model for Pulp and Paper Plant.

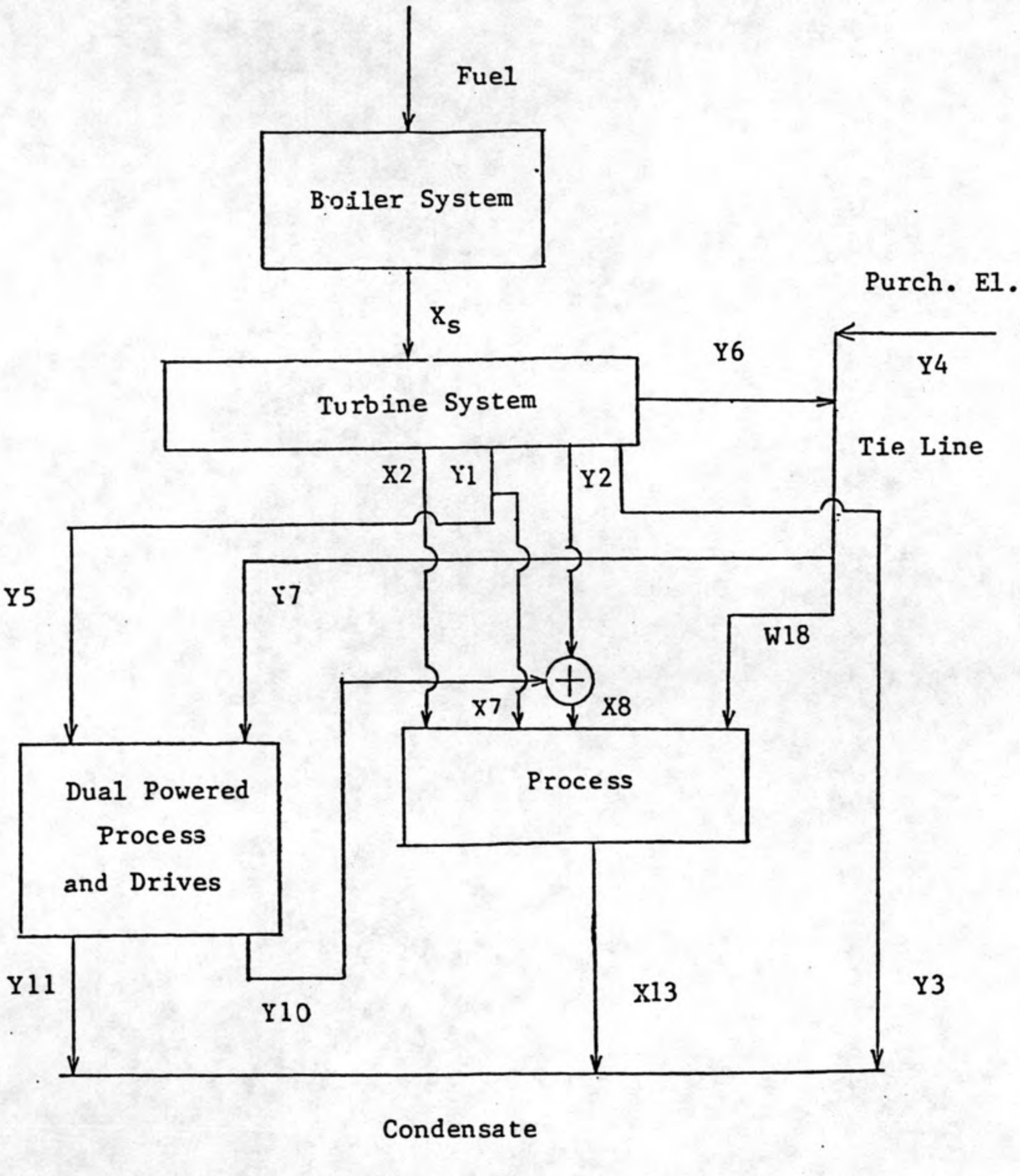

Fig 6.2 Global Description of Cogeneration in a Pulp & Paper Plant.