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Steam CHPP site level optimal integration into a refinery / petrochemical plant

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Abstract

Petrochemical plants generate from their process products that can be burned, and are important consumers of process heat, work and power. This paper purpose a method for better integration of a steam CHPP into plant sites. For efficiency reasons we assume that power will be produced only with backpressure steam turbines. The authors build a methodology for generation, computation and analyses of energy supplying system, integrated into plant structure. That allows restriction check, sorting the viable options and prognosis of energy performances. Authors present a case study for an existing refinery / petrochemical plant.

Keywords: Combined Heat and Power / Work Generation, Steam Cycles, Energy Auto Production, Process Integration, Numerical Modeling.

1. Introduction

Refineries / petrochemical plants have important requirements of **a)** process heat, **b)** work for large and variable speed compressors, and **c)** power for low and medium electrical drives. They are suitable for steam turbines CHP applications [1-3] because some residual products from the processes can be burned into boilers*, and steam can be the main heat vector and work fluid into

* But they are not appropriate for gas turbines combustion chambers.

compressors driving turbines [4]. We will consider a refinery / petrochemical plant site with process energy requirements optimized and known. Will be accepted changes only in large process compressors drive solutions. Into improved design, those will be exclusively driven by electric motors or backpressure steam turbines. Beside Combined Heat and Work (CHW), assured by process turbines, Combined Heat and Power (CHP) with extraction and backpressure steam turbines will be introduced. The general CHW / CHP design is based on high parameters steam production, expansion in steam turbines for electricity or work generation and use of exhaust (extractions and backpressure) for covering heat demands.
The scope of CHW / CHP is to minimize energy acquisition, plant's energy bill and primary fuel consumption, respectively CO_2 emissions. This paper, based on thermodynamic modeling of the cogeneration processes, follows energy and mass flows optimization for better integration of a steam CHW / CHP into sites.

2. Methodology

Authors build a methodology for generation, computation and analyses of system layouts witch allows: **a)** restriction check and sort the viable options, **b)** annual energy consumption prognosis for the chosen schedule. Due to the complexity, the problem can be solved only numerical and for given data.
First step is analyzing electricity and heat consumption (those will be grouped on maximum three pressure levels). After statistical evaluation, demand curves for electricity and heat (by levels) will be assigned, and energy demand correlations between electricity and heat will be established.
The second step is the process compressor drives analyses for their energy rationalizes. Condensing steam turbines drives will be eliminated and only electrical and backpressure steam turbines options will be retained.
One important step is the generation of steam links schedule packages for the CHW / CHP generation. For simplification, the number of steam feeders will be limited to 4. The highest-pressure level will be at live steam feeder for CHP. Main steam for CHW turbines will be ensured by a steam feeder having a pressure higher or equal to the maximum pressure required by process heating. CHW turbines will ensure links between their live steam feeder and heat user's feeders. Backpressure and extractions CHP turbines, backpressure CHW turbines and, peak or emergency steam boilers will balance heat demand.
Process cogeneration restrictions check for generated schedules begin with exclusive steam backpressure compressors drives case. If computed heat flow on a feeder from CHW exceeds needed level, the schedule is rejected. If in all the schedules we have exceeding heat flows on heat consumer's feeders, we accept electrical drive for at least a compressor*. In consequence, new steam

* For given plants existing electrical drive will be maintained. For new plants, the process will begin with the smallest compressor.

links schedule packages will be generated[*]. The schedule generation process will stop when a valid solution is obtained. This is the maximal CHW solution.
Once the CHW schedule is fixed we select the CHP schedule and determine the thermal loads for CHP turbines. CHP steam turbines number must be at minimum two. After that we can compute electrical power obtained for a reference load.
The final step is system modeling of stationary off design running, for various loads. The purpose is energy consumption calculus, through numerical integration of load curves.

3. Case study

The case study is realized for an existing 2,500,000 tones per year oil capacity refinery. This plant is in operation average 11 months yearly. Historical electrical and heat load curves are presented in the figures 1 and 2.

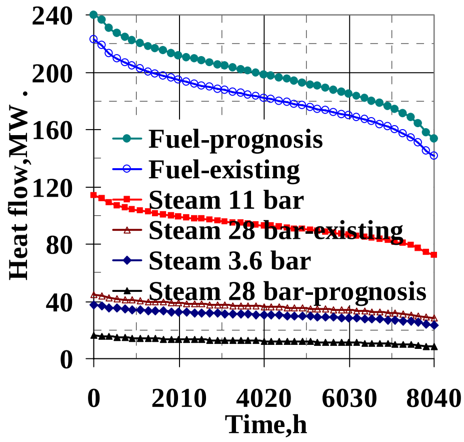

Figure 1. Heat load curves.

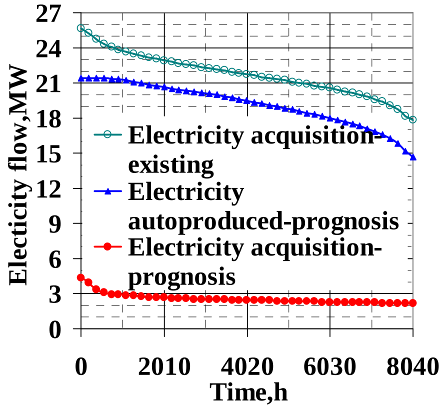

Figure 2. Power load curves.

This refinery has 3 main compressors: C#1 with P_{mk} = 1.8 MW (maximal mechanical power demand) at n = 12,400 rpm (rotation speed) and driven by a backpressure steam turbine; C#2, P_{mk} = 3.6 MW at n = 7,350 rpm, driven by a condensing steam turbine and C#3 with P_{mk} = 3.8 MW at n = 7,150 rpm, electrical driven. On the existing schedule (see figure 3) we find 3 steam feeders supplied by boilers. Boiler's feed water has a temperature of 104 ºC.
Maximal pressure of steam boilers is equal to maximal consumed steam pressure and equal to motor steam pressure for process turbines. Others heat

[*] For low heat demands, successive elimination process can be with no CHW solution, only electrical compressor drives.

consumers are grouped on two thermal levels: intermediate and low pressure. CHP do not exist into present installation and CHW is used only for C#1. Annual fuel and electricity consumption for present situation is given on the first column of table 1.

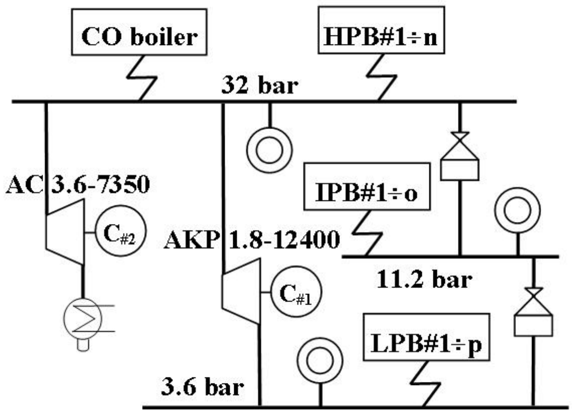

Figure 3. Existing CHW schedule.

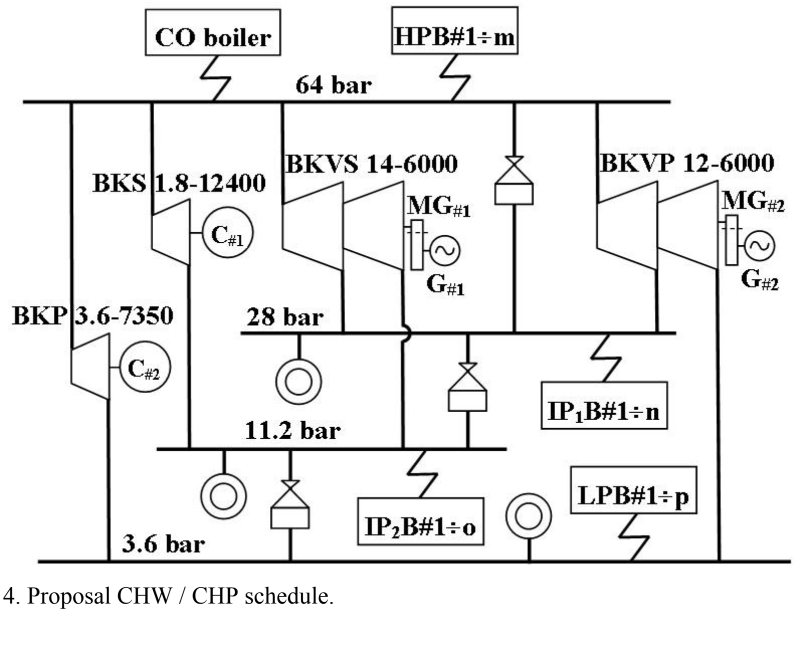

Figure 4. Proposal CHW / CHP schedule.

First proposed package of generated schedules was with existing live steam pressure and development of CHW for C#2. Heat delivery being bigger then minimum of thermal load for existing two pressure levels, restriction check eliminated all variants, unaffected by pressure combinations of the CHW backpressure levels. This think eliminated any interest for electricity cogeneration for these live steam parameters.
For CHP implementing, next step brings 4 steam feeder schedules (see figure 4) with higher live steam pressure for energy boilers (64 bar) and feed water preheating temperature 210 ºC. The driving solution with backpressure steam turbines of 1.8 MW / 11.2 bar, for C#1, and 3.6 MW / 3.6 bar, for C#2, satisfy exhausted heat restriction check.
The two CHP backpressure and extraction turbines were calculated for base and semibase coverage of 28, 11.2 and 3.6 bar steam feeders. Existing steam boilers will be maintained as peak and emergency units. Nominal power of the two CHP steam turbines resulted 14 and respectively 12 MW.
Modeling of the CHW /CHP and peak steam sources system for 44 off-design regimes, based on load curves, permitted the calculation of fuel and electricity consumption. For an easy comparison with existing situation, new electrical and heat load curves are presented together with the old ones in figures 1 and 2. Annual fuel and electricity consumption for the improved schedule are presented on second column of table 1.

Table 1.Economical and ecological results

	Existing	Future	Difference
Electricity acquisition, MWh / year	174,571	20,444	-154,128
Electricity cost, EURO / MWh	55	55	
Electricity bill, Euro / year	9,601,429	1,124,400	-8,477,029
Fuel consumption, MWh / year	1,461,912	1,591,642	129,730
Heat cost, EURO / MWh	25	25	
Fuel bill, EURO / year	36,547,800	39,791,062	3,243,262
Energy bill, EURO / year	46,149,229	40,915,462	-5,233,767

The case study demonstrated that proposed solution, due to CHP / CHW efficiency, reduces ten times the electricity acquisition comparing with existing situation and growth the fuel consumption with less then 10 %. Because burned fuel heat's cost is lower then electricity cost [5], operational energy expenses of the plant are diminishing with a factor of 1.13[*].

[*] The prices in table 1 correspond to the Romanian ones.

4. Conclusions and future work

The main conclusion of the paper is that use of CHW / CHP generation into a petrochemical / refinery plant brings positive economical effects through operational expenses diminish. From sustainable development point of view [6, 7], if electricity consumed in present by the plant is generated in Romania, with condensing steam turbines at 32 %* global efficiency, the solution brings 99,768 tones CO_2 emission reduction per year. Even if electricity is produced with advanced thermodynamic conversion cycles, these can't achieve global efficiency of cogeneration cycles. So these conclusions remain, only the figures will be others.

Into a future stage, the authors will examine exclusive CHP generation schedules using high steam parameters and electrical drives for process compressors.

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* This includes plants efficiency and transport losses.