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Integration of Steam Power Plant with Process Utility System

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The purpose of steam power plant usually is power production; however, it can work as dual purpose plant with production of steam and power simultaneously. The aim of this paper is evaluation of the integration between steam power plant as source and a site utility system as sink of steam. In this regard, a systematic methodology was applied to integration of steam power plant and process site utility system based on total site analysis and economic evaluation. In this regard, the Total Site Analysis has been performed for better understanding of both plants integration. Also, the new cogeneration targeting method has been proposed for accurate estimation of cogeneration potential for integration of steam power plant and site utility system. Furthermore, the techno-economic .evaluation of separate and coupled plant has been performed. As shown in the result, the Total Annualized Cost of coupled plant has been decreased by1.78 % rather than separate plants.

1. Introduction

The chemical process usually requires steam at different pressure and temperature values for heating and non-heating purposes. In order to provide steam at the required condition, the designer has to decide whether to provide steam at the extreme condition and then let it down to the different levels or produce steams separately at different boilers. Many industrial processes operate within Total Sites (Dhole and Linnhoff, 1993; Raissi, 1994), where they are serviced and linked through a common central utility system. This utility system meets the demands for heat and power of the individual process units by their indirect heat integration. However, greater benefits in terms of energy and capital cost can be obtained by looking at the entire site. Total site integration addresses the task of optimizing each process and the utility system in the context of the overall site (Sorin and Hammache, 2005). One of the important tasks for the utility systems design is targeting d shaftwork production ahead of design. A number of models have been proposed for the early estimation of cogeneration for utility systems using steam turbines. Dhole and Linnhoff (1993) proposed an exergetic model based on the site source-sink profiles. Raissi (1994) proposed the T-H model based on the Salisbury (1942) approximation to assume power be linearly proportional to difference between the inlet and outlet saturation temperatures. Mavromatis and Kokossis (1998) introduced the non-linear model of THM (Turbine Hardware Model) based on the principle of the Willans' line to incorporate the variation of efficiency with turbine size and operating load. Harell (2004) introduced a graphical technique to estimate the cogeneration potential that utilizes the concept of extractable power and header efficiency to establish cogeneration potential.Varbanov et al. (2004) developed the improved turbine hardware

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model. Sorin and Hammache (2005) developed an exergetic model based on thermodynamic insights for the Rankine cycle which shows that power is not linear to saturation temperature differences. Mohan and El-Halwagi (2007) developed a linear algebraic approach based on the concept of extractable power and steam main efficiency. Bandyopadhyay et al. (2010) developed a linear model based on the Salisbury (1942) approximation and energy balance at steam mains. Ghannadzadeh et al. (2011) presented a new shaftwork targeting model, termed the Iterative Bottom-to-Top Model (IBTM). Kapli et al. (2011) introduced a new method to estimate cogeneration potential of site utility systems by a combination of bottom-up and top-down procedures.

2. New Targeting Method

In this section the new model is presented in detail to target the cogeneration potential for site utility systems. The method uses the Site Utility Grand Composite Curve (SUGCC), which represents another form of the site composite curves. The SUGCC are obtained from the site composite curves by representing on temperature–enthalpy axes each steam main by its saturation temperature and steam generation and usage loads, respectively from the source and sinks profiles of the site composites. The differences between steam generation and steam usage will set the VHP demand or the supply heat available at each main. The new model calculates the minimum required flow rate from a steam generation unit and the levels of superheat at each steam main based on the heat loads specified by SUGCC. The L given steam mains are indexed by i from highest pressure steam main. This means i is equal to 1, 2, 3 and 4 for very high pressure (VHP), high pressure (HP), medium pressure (MP) and low pressure (LP) steam mains, respectively. There is an expansion zone between two steam mains. Zones are indexed by Z starting from top, i.e. Z=1 is for VHP-HP, and one single steam turbine is placed at each zone. Figure 1 shows a thermodynamic expansion of steam at two different pressure levels on a Temperature-Entropy diagram. The step S1-S'2 shows an isentropic expansion. An isentropic process is an ideal case where there is not any kind of irreversibilities such as mechanical friction and heat losses. Step S1-S'2 is a better representation of what happens in reality. The outlet of the turbine is shifted to the right which indicates increase of entropy (state of disorder) caused by losses. The isentropic efficiency is basically the ratio of the enthalpy difference of step S1-S'2 to that of step S1-S2. The isentropic efficiency is a function of the load and for fixed values of flow rates, it would be better to consider the highest efficiency assuming using turbines for which the calculated flow rate will be the full load. In this study thermodynamic model has been used to estimate the isentropic efficiency as Al-Azri (2008) has been proposed.

$$\eta_{is} = \frac{W_{\max}}{W_{is,\max}} \tag{1}$$

$$W_{\max} = \frac{W_{is,\max} - A}{B} \tag{2}$$

Where A and B are constants that are dependent on the turbine and are functions of the saturation temperature. A and B are calculated by Eqs. (3) and (4), respectively. The values of these constants are given in Kapli et al. (2011).

$$A = b_0 + b_1.\Delta T_{sat} \tag{2}$$

$$B = b_2 + b_3.\Delta T_{sat} \tag{3}$$

At the boiler exit, for a given pressure and steam temperature, the enthalpy can be obtained with the aid of steam tables. The actual input enthalpy of steam mains are usually provided from the calculations of the previous steam main. The input isentropic enthalpy of steam main in the superheated region can be obtained. Then the efficiency is calculated. The actual enthalpy which will serve as the input enthalpy for the next zone is then calculated using the isentropic enthalpies and efficiency by Eq. (5).

$$h_{i,actual}=h_{i-1,isentropic}-\eta(h_{i-1,isentropic}-h_{i,isentropic}) \tag{4}$$

In this study the calculation of superheat temperature at each steam level is made, with iterative procedure based on certain desirable amount of superheat in the LP steam main. This superheat needs to be set to 10 to 20°. If the degree of superheat in the resulting LP steam main is less than required, then operating conditions of VHP is updated and then iterates until the acceptable superheated conditions for LP steam main is met. The mass flow rate of steam expanding through the Z-th turbine ($\dot{m}_z$) can be calculated by the mass balance for i-th by Eqs. (6) as shown in Figure 1:

$$\dot{m}_{z}=\dot{m}_{z-1}+\dot{m}_i^{DEM}-\dot{m}_i^{GEN} \quad (5)$$

Where $\dot{m}_i^{GEN}$ is flow rate of steam generated by process and $\dot{m}_i^{DEM}$ is flow rate of steam demanded by process which can be calculated by Eqs. (7) and (8), respectively.

$$\dot{m}_i^{DEM}=\frac{\dot{Q}_i^{DEM}}{h_i^{Actual}-h_{f\,i}} \quad (6)$$

$$\dot{m}_i^{GEN}=\frac{\dot{Q}_i^{GEN}}{h_i^{Actual}-h_{f.i}} \quad (7)$$

where,

$h_{f,i}$= The enthalpy of the saturated liquid enthalpy at the pressure of i-th steam main.

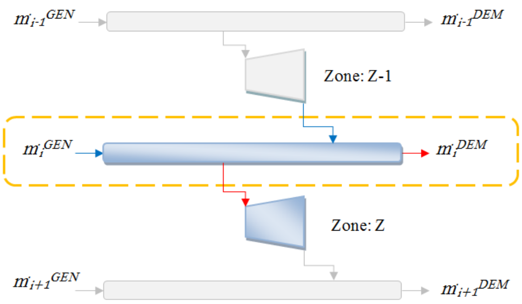

Figure 1: Mass load balance for i-th steam main

The procedure of cogeneration targeting for a given site utility systems (Fig.4) is presented as follows:
Step 1: The incoming streams from power plant are distributed such that each stream will go to the steam main whose pressure is the same or just below the pressure of the stream.
Step 2: calculate heat load of incoming streams from power plant
Step 3: Plot Sink and source profiles for a steam network
Step 4: Plot Sink and source profiles for a steam network by adding incoming streams from power plant
Step 5: preparation of a model in SUGCC
Step 6: initial estimates of boiler superheat temperature.
Step 7: Find initial estimates of mass flow rates passing by each zone assuming isentropic expansions throughout the levels by Eq. (9).

$$m_{z,initial}=\frac{\dot{Q}_{net,i}}{h_i-h_{f.i}} \quad (8)$$

$$\dot{Q}_{net,i}=\dot{Q}_i^{DEM} - \dot{Q}_i^{GEN} \quad (9)$$

Where,

$\dot{Q}_{net,i}$=Net load for at given level

h_i=Steam main isentropic enthalpy at the given level

h_f=Saturated liquid enthalpy at the given level

Step 8: Correct the efficiency by using equation (1).
Step 9: For Given steam levels Correct h_i and $\dot{m}_i^{NET}$
Step 10: From the second iteration through convergence, the steps are repetitive in manner until they meet the stopping criterion (Eq. (11)).

$$\sqrt{\sum_{i=1}^{z}(m_z - m_{z,new})^2} \le \varepsilon \qquad (10)$$

Step 11: When the first loop of algorithm terminates, the LP superheat temperature is checked. If it falls below the allowed minimum, the superheat temperature of boiler is increased and repeats the steps until meet desirable amount of superheat in the LP steam main.

3. Case cstudy

A 315 MW gas fired conventional steam power plant has been considered as a case study (similar to RAMIN power plant that is located in southwest of Iran in Ahvaz city). The scheme of this plant and its steam turbines has been shown in Figure 2. Also, The type of fuel is natural gas that its Low Heating Value (LHV) is 48,748 kJ/kg and the net plant efficiency based on LHV is about 38.5 (one purpose plant). The properties of steam requirements for total site have been determined in Table 1. In addition, the site profile of steam network has been demonstrated in Figure 3. Also, the cogeneration potential of site utility system obtained from new method has been shown in Figure 4.

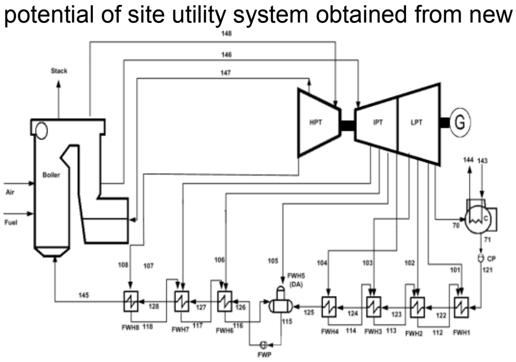

Figure 2: The scheme of conventional gas fired steam power

Table 1.The properties of steam requirements

Parameter	VHP	HP	MP	LP
Pressure (bara)	101	20.6	4.1	2.7
Saturation Temperature (°C)	312	214	144.5	130
Net Heat Load (MW)	110.8	21.4	9.3	73.6

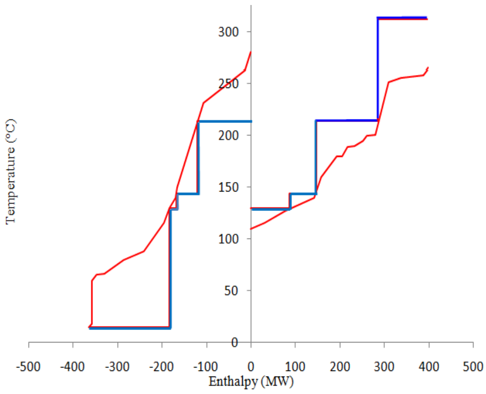

Figure 3: Site source and sink composite curve

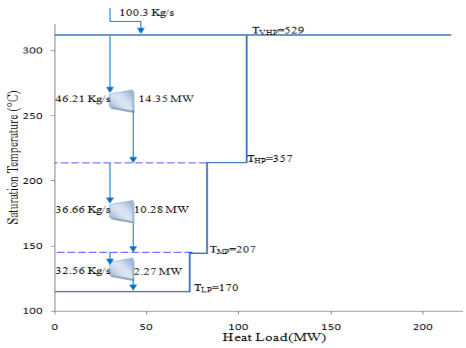

Figure 4: Cogeneration potential from the new method

4. Results

The schematic of coupled plant has been illustrated in Figure 5. The properties of steam requirements of site utility in coupled plant were determined in Table 3. The steam generation and used in coupled plant for site utility (coupled) has been determined in Table 4 . Also, the site profile relevant to site utility was shown in Figure 6. The cogeneration potential of site utility in coupled plant has been shown in Figure 7. The economic evaluation of coupled plant for power plant section has been demonstrated in Table 5. As shown, the break even electricity price of coupled plant decreased by 0.0301 USD/kWh. However, the Total Annualized cost and operating cost of power plant have been increased. Moreover, economic evaluation of site utility for coupled plant illustrated in Table 6. As determined, the Total Annualized Cost of site utility has been decreased by 22 %.In addition, the economic evaluation of separate and coupled plant has been shown in Table 7. Also, the Total Annualized cost of coupled plant decreased by 1.78 % rather than separate plants.

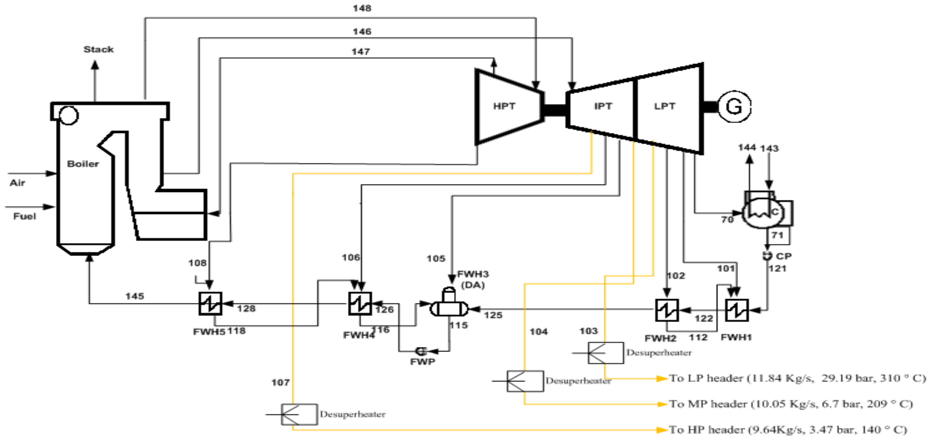

Figure 5: The scheme of Steam Power Plant (Coupled)

Table 3.The properties of steam requirements

Steam level	PSG	PSD
VHP	0	110.8
HP	144.94	141.4
MP	70.39	57
LP	42.54	89

Table 4.Steam generation & used (coupled)

Parameter	VHP	HP	MP	LP
Pressure (bara)	101	20.6	4.1	2.7
Sat Temperature (°C)	312	214	144.5	130
Net Heat Load (MW)	110.8	-3.54	-13.39	46.5

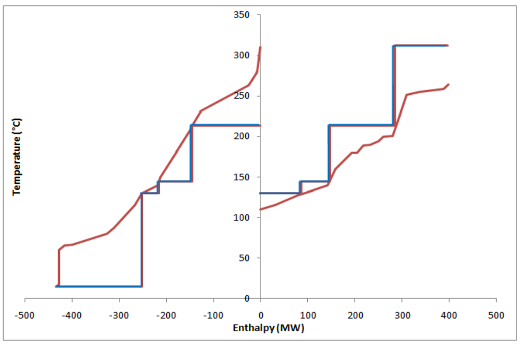

Figure 6: Site source and sink composite curve (coupled)

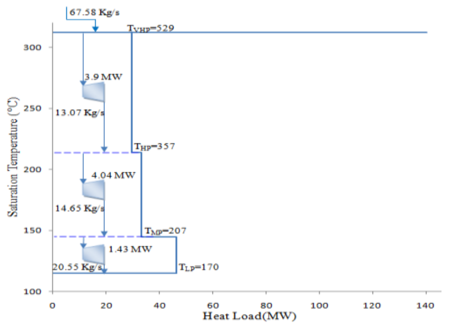

Figure 7: Cogeneration potential from the new method (coupled)

Table 5. Economic evaluation of Integrated power plant with site utility (Power Plant Section)

Parameter	Base	Coupled
Operating cost (USD)	33,878,000	35,612,000
Electricity price USD/kWh	0.0327	0.0301
Years of payback	1.899	1.725
Total Annualized Cost $/y	5,479,155	1,2016,836

Table 6. Economic evaluation of Integrated site utility with power plant (Site Utility Section)

Parameter	Base	Coupled
Power ($/y)	10,770,229	3,747,426
Fuel ($/y)	40,956,920	27,446,665
Boiler ($/y)	1,445,120	1,032,578
Turbines ($/y)	802,693	493,631
Total Annualized Cost ($/y)	32,439,491	25,225,481

Table 7. Economic evaluation of separate and coupled plant

Parameter	Total (Power Plant +Site Utility) Separately	Total (Power Plant +Site Utility) coupled
Total Capital Cost ($/y)	27,535,608	27,395,845
Total Operating Cost ($/y)	10,378,051	-9,846,439
Total Annualized Cost	37,918,646	37,242,317

References

Al-Azril N.A., 2008, Integrated Approaches To The Optimization Of Process-Utility Systems, Ph.D. Thesis, Texas A&M University, Texas, USA.

Bandyopadhyay S., Varghese J., Bansal V., 2010, Targeting for cogeneration potential through total site integration, Applied Thermal Engineering, 30, 6–14.

Dhole V.R., Linnhoff B., 1993, Total site targets for fuel co-generation, emissions, and cooling, Computers and Chemical Engineering, 17(Suppl), 101-109.

Ghannadzadeh A., Perry S., Smith R., 2011, A new shaftwork targeting model for total sites, Chemical Engineering Transactions, 25, 917–922.

Harell D.A., 2004, Resource Conservation and Allocation Via Process Integration, Ph.D. Thesis, Texas A&M University, Texas, USA.

Kapil A., Bulatov I., Smith R., Kim J.-K., 2010, Site-wide Low-Grade Heat Recovery with a New Cogeneration Targeting Method, Chemical Engineering Research and Design, doi:10.1016/j.cherd.2011.09.001.

Khoshgoftar M.H., Amidpour M., Comparison of Combined Cycle and Conventional Steam Power Plant through Energy Level and Thermoeconomic Analysis, ASME International Mechanical Congress and Exposition, (IMECE 2008), October 31-November 6 2008, USA, Boston, Massachusetts, USA.

Klemeš J., Dhole V.R., Raissi K., Perry S.J., Puigjaner L., 1997, Targeting and design methodology for reduction of fuel power and CO_2 on total sites, Applied Thermal Engineering, 17 (8–10), 993–1003.

Mavromatis S.P., Kokossis A.C., 1998, Conceptual optimisation of utility networks for operational variations - I. Targets and level optimisation, Chemical Engineering Science, 53(8), 1585-1608.

Mohan T., El-Halwagi M.M., 2007, An algebraic targeting approach for effective utilization of biomass in combined heat and power systems through process integration, Clean Technology and Environment Policy, 9 (1), 13–25.

Raissi K., 1994, Total site integration, PhD Thesis, UMIST, Manchester, UK.

Salisbury J.K., 1942, The Steam-Turbine Regerative Cycle - An Analytical Approach, Trans ASME, 64, 231-245.

Sorin M., Hammache A., 2005, A new thermodynamic model for shaftwork targeting on total sites, Applied Thermal Engineering, 25, 961-972.

Varbanov P.S., Doyle S., Smith R., 2004, Modelling and optimization of utility systems, Chemical Engineering Research and Design. 82(5), 561-578.