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Capital Cost Assessment for Total Site Power Cogeneration

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Abstract

Industrial regions consume large amounts of energy. A lot of research effort is targeted at improving energy efficiency. Heat recovery on Total Site level can provide a considerably high potential for energy saving for industrial areas. It offers opportunities for heat recovery and cogeneration in addition to individual processes. This work deals with estimation of capital cost for power co-generation, evaluating the potential steam turbine placement for various steam pressure levels. The methodology uses the basic principles of Total Site Integration and adds estimation of capital cost for steam turbines with different capacity, inlet and outlet of steam pressure. It also allows evaluating the trade-off between capital cost and energy consumption for the Total Site Integration.

Keywords: Total Site Integration, Cogeneration, Capital Cost, Energy Efficiency.

1. Introduction

Currently energy consumption by both residential and industrial users worldwide is very high. A major factor for this is the rapid industrial growth in China and India. In addition, the there is still significant scope for reducing energy use in Central and especially Eastern Europe.

Heat recovery at Total Site level can provide a considerable potential for energy saving. It is important for utility system development and optimisation as shown by Smith (2007). It offers additional opportunities for heat recovery, cogeneration and heat engine usage as highlighted by Klemeš and Varbanov (2012). Ghannadzadeh et al. (2012) considered a methodology of targeting for cogeneration of heat and power, updating a previous one by Klemeš et al (1997). Ghannadzadeh et al. (2012) presented an Iterative Bottom-to-Top Model (IBTM) as a shaftwork targeting model which facilitates the targeting stage. Sorin and Hammache (2005) introduced a targeting model based on a thermodynamic insight on cogeneration in general and Rankine cycle in particular. An approach for the optimisation of steam levels of total site utility systems with different utility demands was presented by Shang and Kokossis (2004).

The target for cogeneration of power in addition to heat is an important item of Total Site integration. To enable the optimal choice of site specifications, such as ΔT_{min} values in heat recovery networks, the capital cost of power cogeneration also needs to be accounted for. This would enable to evaluate the complete trade-off between investment and operating costs of a site at the targeting stage.

The significance of the selection of ΔT_{min} specifications have been investigated in a recent work by Varbanov et al. (2012). The heat transfer area target evaluation of Total Site utility use and generation has been considered in the work by Nemet et al. (2012). However, heat exchangers represent only one of the important equipment types incurring capital cost. Another important investment cost item is associated with installing steam turbines in the utility system. The capacity for power co-generation for a Total Site can be targeted employing the Utility Grand Composite Curve - UGCC (Klemeš et al., 1997).

Thermodynamics-oriented approach for identification of a cogeneration plant that completely satisfies process heat and power demand was presented by Goršek and Glavič (2003). The effect of including both sensible and latent heat of steam in the Balanced Composite Curve is investigated by Botros and Brisson (2011). It is shown that including sensible heating allows for better thermal matching between the process and steam system which results in improving the overall efficiency while minimising cost.

Some works also tried to estimate the economics of steam turbine usage. Poullikkas (2005) presented an economic evaluation of the operating cost and the water economy of the various commercial mixed air-steam turbine technologies. Stoppato et al. (2012) presented a procedure aimed at evaluating this extra cost related to flexible operation, and at assisting the management decision about power plant operation and maintenance scheduling. The procedure predicts on the basis of the historical data the residual life of the most critical components, considering the effects of creep, thermo-mechanical fatigue, welding, corrosion and oxidation.

But there is still the need to predict the investment for Total Site cogeneration. The current paper deals with capital cost estimation for cogeneration and utility usage on site level with by employing an extension of the R-curve analysis (Varbanov et al., 2004). The extension is based on evaluating the investment cost for varying generation power-to-heat ratio of the generation on the site. In the current work this targeting is developed via allocation of potential steam turbines and letdown stations to expansion zones in the utility system.

2. Methodology

2.1. General approach.

The targeting model for capital cost for power cogeneration on site level is based on the Total Site heat recovery targets estimating the overall needs for heat and power as well as energy losses, also incorporating the R-curves analysis initially developed by Kimura and Zhu (2000). Typical Total Site Composite Curves can be seen elsewhere (Klemeš et al, 2010). They show heating/cooling requirements and placement of utility for various levels. Capital investments of power cogeneration are the function of power production. This function depends on inlet and outlet temperature of steam in the turbine, efficiency, capacity and turbine construction. To estimate the power production, the Total Site Sink and Source Profiles should be plotted. Then the heat recovery for the Total Site integration is targeted. For the Source Profile cooling water capacity, hot water generation, refrigeration needs are estimated. For Sink Profile temperatures of possible steam levels are identified. It makes possible to evaluate the need for boiler steam or flue gas consumption and build profile of flue gas and to compose the overall heat balance of Total Site levels. Flue gas profile satisfies heat energy demands and possible for power cogeneration. It is easy to estimate steam flow to process, steam flow through turbines and power generated based on temperature levels of steam (Smith, 2005). Process steam flow is:

$$G_{PROCESS} = \frac{Q_{EXH}}{H_V - H_L}, \qquad (1)$$

where Q_{EXH} – turbine exhaust heat flow, kW; H_V and H_L – saturated vapour and liquid enthalpy, kJ·kg^{-1}. Steam flow trough turbine is determined from the following equation:

$$G_{TURBINE} = \frac{G_{PROCESS}}{1 - X'}, \qquad (2)$$

where X' - wetness fraction, %. Power generated by steam turbine calculated from the approach developed by Varbanov et al. (2004). Willan line approximation is used for this calculation. Generated power should be calculated for each expansion zone. Total capital cost for power cogeneration on the Total Site level is calculated from the Eq (3):

$$Total\ capital\ cost = A \times N_{min} + B \times \sum_{i=1}^{n} W_i \qquad (3)$$

where A – coefficient of turbine installation, USD, B – coefficient of 1 kW power generation, USD/kW N_{min} – minimum number of turbines based on the overall power target; n – number of expansion zones; W_i – power generated by expansion zone, kW.
The capital cost is depended on numbers of steam turbine it has a big installation cost. Each next installation will have an intermittent growing of total investments. Fig. 1 illustrates the minimum units number prediction for steam turbine installation.
It based on power generated and low and upper bounds of power for steam turbine installation. If the power cogeneration target is less than the lower bound threshold (W_{LTHR}) it is not efficient to install steam turbine. When this value will from low bound to upper bound threshold (W_{UTHR}) it is possible to install steam turbine. The possibility of installation of other next unit will be the same and the total numbers of steam turbine for Total Site will be as shown on Fig. 1.

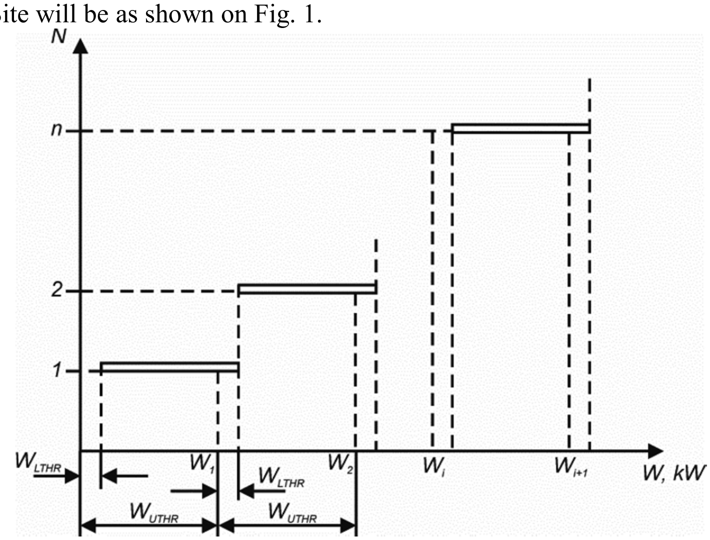

Fig. 1. Prediction of number of steam turbines

2.2. R-curve analysis.

The described model can estimate the capital cost for a fixed power cogeneration capacity, usually identified from the pinched condition of the UGCC and use of only backpressure steam turbines. However, more power than this capacity may be needed for a larger site. In this case cogeneration efficiency for different power to heat ratios has to be investigated by gradually increasing power generation by employing condensing steam turbines.

Varbanov et al. (2004) analysed cogeneration efficiency on Total Site by the R-curve methodology (Kimura and Zhu, 2000). They obtained dependence of cogeneration efficiency upon the power to heat ratio. This method may be used also for capital cost evaluation for varying power to heat ratio and cogeneration efficiency. Power-to-heat ratio is defined as follows:

$$R = \frac{W_{PRC}}{Q_{PRC}}, \tag{4}$$

where W_{PRC} – site process power demands, kW; Q_{PRC} – site process heating demands, kW. With use of Eq. 3, the Capital-R Profile depicting capital cost versus power-to-heat ratio can be build. It can be jointly placed with the cogeneration efficiency R-curve (Varbanov et al., 2004). Cogeneration efficiency and capital cost curves are presented on Fig. 2.

3. Case study.

The case study presented the results of capital cost assessment for Total Site power cogeneration. It is considered the system with 4 expansion zones. The steam parameters are presented in Table 1.

Table 1. Parameters of steam levels

	VHP steam	HP steam	MP steam	LP steam	Condensate
Pressure, bar	120	50	14	3	0.85
Saturation temperature, °C	325	264	195	134	95

The flow rate of VHP steam is changed from 32.65 t/h to 559 t/h with step 50 t/h. Coefficient of steam turbine installation (A) is 100,000 USD and coefficient of 1 kW power generation (B) is 1,000 USD·kW^{-1}. In Table 2 presented parameters of Total Site power cogeneration.

Table 2. Case study summary

	VHP steam, t/h										
	33	83	133	183	233	294	344	394	459	509	559
Total heat usage, MW	75	75	75	75	75	75	75	75	75	75	75
Total power, MW	2	8	15	23	30	39	46	53	63	70	78
Fuel heat load, MW	33	83	133	183	233	294	345	395	460	510	560
Total supplied heat, MW	118	168	218	268	318	379	430	480	545	595	645
Utilised energy flow, MW	77	83	90	98	105	114	121	128	138	145	153

Fig. 2 shows the joint placement R-curve and cogeneration capital cost. Increasing power and heat ration reduces the cogeneration efficiency with rising of cogeneration capital cost. Constant *A* shows the value of installation cost of steam turbine and angle of curve 2 is the specific cost of power generation (*B*).

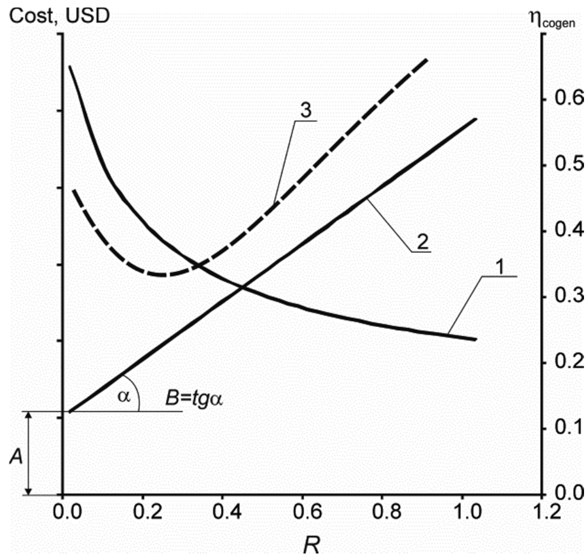

Fig. 2. R-curves for cogeneration efficiency and cost for cogeneration cost. 1 – R-curve for cogeneration efficiency Varbanov et al. (2004), 2 – cogeneration capital cost versus power and heat ratio, 3 – total cost versus power-to-heat ratio.

4. Results and discussion

The approach presented in this work allows estimating the cogeneration capital cost on Total Site level. It shows the general methodology main pathway for targeting. The use of R-curve analysis lets cogeneration capital cost function prediction for different power and heat ratio. It is useful if there is target for power cogeneration on Total Site level.

But really the cost functions are not as linear as shown on Fig. 2 and the Total Cost Curve will be different from also. Behaviour of these curves is depends on unit number and nonlinearity of specific capital cost for power 1 kW generation. On the other hand behaviour of these curves is depend on coefficients in Eq. 3 which have low and upper bounds. Definition of these bounds defines the curves position and optimum placement.

Further work should concentrate on definition of low and upper bounds of values sited above. It allows determination of Cost Curves position and selection of optimal power and heat ratio for Total Site power cogeneration. Validation on industrial data will help to identify accuracy of optimal solution and error analysis of the study method. estimation.

5. Conclusion

Developed approach lay out the ground for a procedure evaluating the capital cost targets for power cogeneration on a Total Site level. Using these results, the basic capital energy trade-off can be evaluated and an optimisation of power cogeneration for Total Sites can be estimated. It lets to determine compromise between capital cost and energy consumption for the Total Site Integration.

Results of this paper may be used for the advanced capital cost targeting of Total Site. Other important points which has significant contribution to Total Site capital cost should be determined and estimated. It allows reducing the overall cost and identified the optimal distance between hot and cold side of Total Site profile. This will increase heat recovery and improve utility usage as well as decrease the pollution that will have environmental and social impact. The results can ground for further development in Total Site approach to estimate overall capital cost on site level.

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