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Multi-Objective, Multi-Period Optimization of Renewable Technologies and storage system Using Evolutionary Algorithms and Mixed Integer Linear Programming (MILP)

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Abstract

In the present work a systematic procedure, including process design and integration techniques, for sizing and operation optimization of a poly-generation plant integrated with heat storage systems is presented.

The storage system is used to balance energy demand fluctuation during 24 hours of a day. Adding thermal storage capacity allows for better utilization of equipments and avoiding over estimation of installed capacity. The integration of heat storage systems with poly-generation technologies in a multi objective and multi-period optimization model is the novelty of this work.

Keywords: Heat storage, Mixed Integer Linear Programming, Evolutionary algorithm, Renewable conversion technologies, CO_2 mitigation

1. Introduction

Poly-generation technologies, joined with the storage system, have a good potential for CO_2 emissions reduction in the district heating networks. A systematic optimization procedure is needed to select and size equipments and storage tanks.

The optimization of energy systems that include one or more technologies is extensively studied by many authors. It is referred to D.Connolly et al. (2010) for a detailed review. Most of these publications carried out only simulations, while system design optimization is neglected. For a detailed overview, the role of optimization modeling techniques in power generation is reviewed in Bazmi and Zahedi (2011). However, most of these optimization models only consider a mono economic objective function, completed with environmental and energetic targets as constraints.

On the other side, the integration of heat storage devices and conversion technologies in the energy system is studied in several publications. Soderman and Pettersson (2006) proposed a mixed integer linear model with mono objective function to integrate the storage tank with the cogeneration units in a district energy system. The MIP optimization model for sizing the heat storage tanks and a combine heat and power plant with mono

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objective function is presented by Christidis et al. (2011) and Collazos et al. (2009), while long-term thermal storage is studied by Tveit et al. (2009).
To sum up, the energy system optimization with storage systems are studied by many authors. However, a systematic procedure including the heat storage systems and energy integration techniques with simultaneous consideration of multi-periods and multi-objectives aspects for optimizing a district energy system is needed. A multi-objective optimization model with evolutionary algorithms (EMOO) and MILP based on the decomposition approach was developed by Fazlollahi and Marechal (2011). It is extended with the integration of the thermal storage optimization model in the present work. The goal is to integrate heat storage system with other conversion technologies for optimizing a district energy system design.

2. Methodology

The multi-objective optimization techniques are used in order to investigate sizing and operating effects of poly-generation technologies and heat storage systems on CO_2 emissions. The basic concept of the developed model is the decomposition of the problem into several parts, as illustrated in Figure 1. Three major parts (Weber et al. (2006)) are; a **Structuring phase** in which required data will be collected and manipulated. Secondly the **Multi-objective nonlinear optimization phase** will solve the system configuration and produce results in the form of a Pareto frontier. In the third step, the **Post-Processing phase**, the Pareto frontier and associated results will be studied in details by doing a more details process operation simulation.

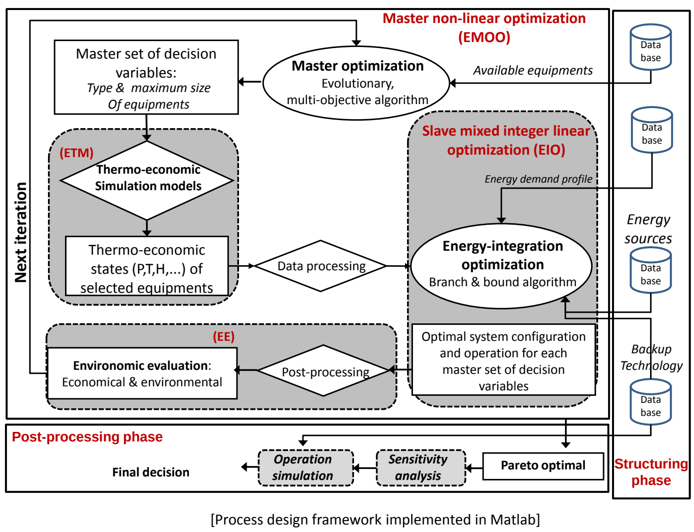

Figure 1. Illustration of the process optimization strategy

2.1. Multi-objective nonlinear optimization phase

The optimization algorithm has the aim of solving a complex non linear problem consisting of minimizing the investment costs (CAPEX), operational costs (OPEX) and CO_2 emissions simultaneously. The goal of this step is to optimize the system configuration and size the selected equipments including the storage system. This phase is decomposed in four major parts, a **master optimization (MOO)**, a **thermo-economic simulation (ETM)**, a **slave optimization (EIO)** where the best usage of equipments in the selected superstructure is calculated, and the **environomic evaluation (EE)**. For detail explanation on these steps, it is refer to the previous work of authors Fazlollahi and Marechal (2011). In the present work the slave optimization is extended by adding the heat storage model (Part.3). The storage model is considered as an equipment option to optimize the operation schedule.

3. Storage optimisation model

Heat for the district heating can be stored in heat storage tanks. The storage is used to manage the energy demand fluctuation during 24 hours of a day. Adding thermal storage capacity allows for better utilization of equipments and avoiding over estimation of installed capacity. There should be a trade off between the investment cost of additional capacity of conversion technologies and the storage system. Economical data of storage system were taken from Becker and Marechal (2012).

In the present work the thermal storage is divided into several temperature intervals, $S = 1,...,N_S$, between its maximum and minimum temperature limits. Each intervals is going to charge with the available excess heat by considering its corresponding temperature level during each time periods. When there is a heat deficit in the district networks the tank will be discharged to supply the heat requirement. For the heat storage tanks, it has been assumed that the total volume of the storage tanks is constant (Q^{max}) and the losses from radiation are negligible. Charging or discharging flow are activated throw the following two equations:

$$Fmin_S * \mathbf{y}_{S_c,t} \leq \mathbf{f}_{S_c,t} \leq Fmax_S * \mathbf{y}_{S_c,t} \qquad \forall S = 1,...,N_S \quad , \quad \forall t = 1,...,T \tag{1}$$

$$Fmin_S * \mathbf{y}_{S_h,t} \leq \mathbf{f}_{S_h,t} \leq Fmax_S * \mathbf{y}_{S_h,t} \qquad \forall S = 1,...,N_S \quad , \quad \forall t = 1,...,T \tag{2}$$

Where $Fmin_S$ and $Fmax_S$ are two parameters for showing the minimum and the maximum available capacity of each interval S. $\mathbf{y_{S_c,t}}$ and $\mathbf{y_{S_h,t}}$ are binary variables for activating the inlet flow and outlet flow of each storage's interval S in time t. $\mathbf{f_{S_c,t}}$ and $\mathbf{f_{S_h,t}}$ are continuous variables for showing the filling rate and discharging rate of each interval S in time t.

Input and output flows of each interval S should not be activated at the same time, as the heat content in the storage can vary. Eq.3 is used to present this condition:

$$1 - \mathbf{y}_{S_h,t} - \mathbf{y}_{S_c,t} >= 0, \qquad \forall S = 1,...,N_S \quad , \quad \forall t = 1,...,T \tag{3}$$

The net heat flow into each storage interval S at time t is shown by $(\mathbf{f}_{S_c,t}\dot{Q}^{-}_{S_c,t} - \mathbf{f}_{S_h,t}\dot{Q}^{+}_{S_h,t})$. Where $\dot{Q}^{+}_{S_h,t}$ is a parameter for representing the reference heat discharging of each storage interval, while $\dot{Q}^{-}_{S_c,t}$ shows the reference heat charging of the storage interval S at time t. The total charging load of the storage in the interval S is shown by $\mathbf{f}_{S_c,t}\dot{Q}^{-}_{S_c,t}$.

In this work a daily storage with 24 operating hours is defined. The heat content in the storage must be the same at the beginning and the end of a day. This cyclic constraint is shown as following:

$$\sum_{t}^{N_t}\sum_{S}^{N_S}(\mathbf{f}_{S_c,t}\dot{Q}^{-}_{S_c,t} - \mathbf{f}_{S_h,t}\dot{Q}^{+}_{S_h,t}) * \triangle t = 0 \qquad (4)$$

The heat load available in each storage interval S during each time period t, should be positive:

$$\mathbf{Q^0_S} + \sum_{p=1}^{t}(\mathbf{f}_{S_c,t}\dot{Q}^{-}_{S_c,t} - \mathbf{f}_{S_h,t}\dot{Q}^{+}_{S_h,t}) * \triangle t >= 0, \qquad \forall S = 1,...,N_S \quad , \quad \forall t = 1,...,T \qquad (5)$$

Where $\mathbf{Q^0_S}$ shows the initial heat load (MWh) of each storage interval S. It is optimized by the optimization model. As mentioned before, the maximum size of the storage is constant and set by the user as an input data, while the size of each interval S is optimized through the optimization model.

$$\sum_{S}\mathbf{Q^0_S} =< Q^{max}, \qquad (6)$$

3.1. Illustrative example

The proposed model is demonstrated by means of a case study, where the district heating demand should be supplied by a central plant. Available equipments in the central plant are; fuel-oil, biomass, coal and natural gas boilers, gas turbine and incinerator. Economical and technical data of each technology were taken from Fazlollahi and Marechal (2011). The first graph in Fig.2 gives the optimal outlet power of each equipments with-

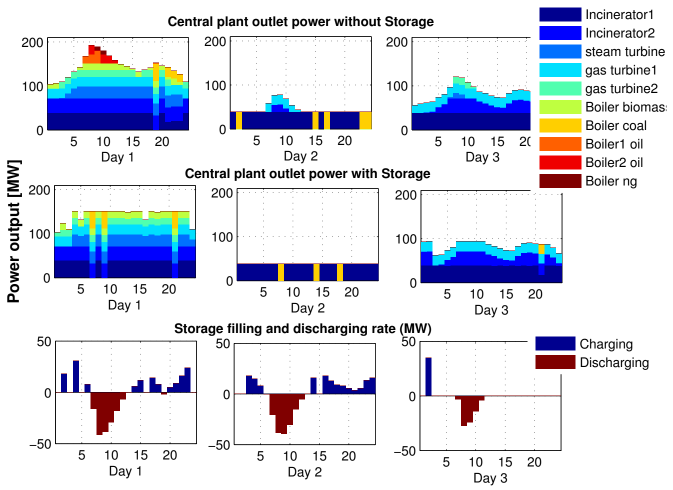

Figure 2. Comparison between a plant's operation condition with and without storage tank

out storage tanks for 3 typical days of a selected year. While the second graph shows the optimal outlet power of each equipments integrated with storage tanks. Finally, The third graph gives the storage tank level for the second situation. The number of tanks, the volume and the initial level of storage tank are optimized by using the developed model. From the results it appears adding thermal storage capacity allows for better utilization of equipments, avoiding over estimation of installed capacity and managing the energy demand fluctuation during 24 hours of a day.

4. Conclusion

A systematic procedure including the storage system, process design and energy integration techniques with simultaneous consideration of multi-periods and multi-objective aspects, economic and environment targets, for energy system design and operation is explained. A decomposition approach is used to deal with this complexity. The heat storage optimization model is introduced in the optimization phase in order to manage the energy demand fluctuation during 24 hours of a day. Adding thermal storage capacity allows for better utilization of equipments and avoiding over estimation of installed capacity.

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