Multi-Site Utility Integration — An Industrial Case Study

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Abstract

Mitsubishi Kasei and Mitsubishi Petrochemical merged to become Mitsubishi Chemical in 1994 making it the largest chemical company in Japan. This created an opportunity for improving their production systems especially for those production sites that are physically built next to each other. Mitsubishi Yokkaichi production site is a typical example, which consisted of three production sites in the old company structure. Each production sites consisted of a utility plant producing steam and electricity for their production. Changes have been made since the merge such as connecting steam and electricity between the plant sites for better flexibility, efficiency as well as capacity of the utility system. Beside these, there remain many other alternatives for further improvement. To explore these opportunities, a site-model were developed which consists of the three utility plants and production units. In this paper, applications on Mitsubishi Yokkaichi production site are presented to illustrate the features of the site-model.

1. Introduction

A petrochemical production site consists of two types of plants; production and the utility plants. Production plants convert raw materials into products consuming energy, mainly steam and electricity, provided from a utility plant(s). A utility plant on the other hand consumes fuel to generate utilities to maintain the production. Utility balance between the production plants and the utility plants should be maintained at all time to guarantee smoothly production. Whenever a change occurs in the production side, such as adding a new production plant, the utility plant might need to make suitable changes to maintain the balances. To obtain the best option for the changes, plant engineers are currently rely mainly on their own experiences and/or applying some simple material and energy balance calculating routines. Due to the complexity inside a production site, this approach is time-consuming and easily to miss out good opportunities. To overcome this, a mathematical programming model that contains detail energy and mass balances of the utility plant is proposed for finding the best operating conditions and/or configuration of the utility pant (Iyer and Grossmann, 1997 and 1998). An industrial application was report by Hui and Natori (1996).

Mitsubishi Yokkaichi plant site is one of the largest chemical production sites of Mitsubishi Chemical Corporation in Japan. It includes three production areas. Each area equips with its own utility plant. Steam and electricity can be exchanged among

themselves when it is desirable. Due to this special and complex configuration in Yokkaichi site, optimization of the utility system becomes a very complicated task.
To deal with this, a site-model for the Yokkaichi plant was built. This site-model is formulated as a multi-period and/or multi-scenarios model, so that production planning and scenario analysis can be studied using the same model. The model simultaneously takes into account operation conditions, product and utility demands, material prices of all planning periods, etc., in the optimization process. The model is current used for budget planning, investment decision-making, electricity contract optimization and shutdown maintenance scheduling. These applications will be discussed later in this paper.

2. Site-Model Definitions and Its Modeling Environment

A site-model is a mathematical model that contains the major material and energy balances of both production and utility system of a chemical production site. Since the main objective of our model is to study the impact of various modifications in our plant to the overall utility infrastructure, we have gone into details for modeling the power plants. Some site-wide constraints, such as, seasonal production and utility demands, fuel and electricity supply contracts, can also be included. To enable a site-model for production planning, the model has to be formulated in multi-period time frame such as days or months. Since site-models are usually used for tackling large production planning or scheduling problem, a linear model is the most suitable and sufficient. For problem like shutdown maintenance scheduling, integer variables can be imposed into the model for determining equipment on/off and/or selection.
In order to manage the site-models effectively, a site-modeling environment was developed that was tailored for modeling multi-period and multi-scenario problems. The environment integrates a graphical user interface, Access* database, Excel* and GAMS (Brooke et al., 1992) providing a flexible and power environment for handling large-scale problems. The graphical interface allows users to model plants, equipment, etc., as objects and connect them into a site-model. Every variable in the model is defined by a plant name (e.g. ETY – ethylene plant), a material name (e.g. MP – medium pressure steam) and an alternative (e.g. GEN – generation) making it easy to understand, process and manage. Other the information of the model such as equations, variables' bounds, etc., are all arranged in table format so that they can be effectively managed using a relational database (e.g. Access). Special constraints and objective function are input in a standard GAMS file, which can be modified according to the requirement of the application. An Excel file is attached with each application allowing users to customize input and report formats (e.g. tables and charts) and languages.
In summary, what we have achieved is that via this interface, we managed to put a very powerful numerical tool on the hands of our plant engineers who are not well trained in the area of numerical arena to analysis this very complicated and highly interacted system. With this tool, our engineers can focus their efforts on analysis the results physically and to understand what are their appropriate reactions to any changes in the overall system. Moreover, this interface is essential as our infrastructure is constantly changing.

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* Access and Excel are products of Microsoft Corporate, http://www.microsoft.com

3. Industrial Case Studies

To cope with the rapid emerging global economy, chemical companies have to improve their own technologies as well as their ability in managing their production plants. Mitsubishi Yokkaichi Plant is a very good example, which was merged with three old production and utility systems making it very difficult to manage. A Dynamic Matrix Control (DMC[*]) system has been implemented recently for improving the controllability of the utility system, however, potential for improvement still remain but very difficult to identify. Site-model was therefore adopted to perform the following studies and help engineers to identify potential benefits.

3.1 Budget planning

Budget planning has to be performed annually to estimate annual operating cost of the whole production site and to guarantee feasibility of all operations during the fiscal year. Although budget planning has to be done every year, it is still a very complicated and time-consuming task to be performed manually in particular when other issues such as shutdown maintenance, material purchasing contracts are considered simultaneously. So far, no commercial software is available for performing this task. With a site-model, engineers can now update the model parameters (costs/prices, production and utility demands) to perform case studies rapidly and effectively.

To make an annual budget plan, data such as product demands and material prices are predetermined. Operating cost includes raw material, fuel, water, electricity and labor cost may vary seasonally or even between day and night. The site-model optimizes the use of utilities by better balancing the supply and demand between the utility and production plant. Besides calculating annual operating cost, the site-model can also be used to optimize the importation/exportation of material, fuel, etc. For instance, the importation of electricity can be optimized at different seasons and time periods since electricity prices are fluctuated at different time periods and consumption levels. We can also select different fuel types in different seasons or time in order to meet the emission limits given by the government. By knowing all these information ahead in time allow our engineers to negotiate better fuel and/or electricity contracts.

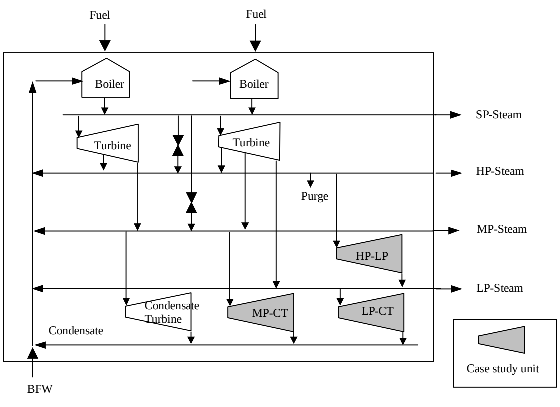

Figure 1: Simplified Shiohama South Utility Plant Configuration.

3.2 Investment decision making

Purchasing new equipment or plants are often required for improving the infrastructure of a production site. The Site-model can be used to investigate whether the investment is feasible and economical. If many options are available, the site-model can also be used to select the best option. For instance, in Yokkaichi plant, modifications on the Shiohama South production site decreased the demand of steam usage hence

[*] DMC is AspenTech's product

reduces the ability for cogeneration. A new steam turbine is proposed for Shiohama South utility plant for taking the advantage to the surplus steam. The utility plant currently contains two boilers, two back-pressured turbines and a condensing turbine, Figure 1. New turbines that take and draw steam at different levels (shaded units in Figure 1) were added into the site-model allowing it to identify the best design option taking into account the seasonal utility demands, prices and new electricity contract.

In this study, the first consideration was to add a medium pressure – condensate (MP-CT) turbine. The maximum capacity of the MP-CT turbine is set at 15MW due to the investment limit. After the site-model calculation, the electricity generation rate of the MP-CT turbine hits the maximum in some scenarios. The total cost decreases about 3.8% with respect to the original configurations, mainly from reducing the electricity purchasing cost. Although 3.8% seems to be not so much, it is already a good reference point for other alternatives.

Low pressure – condensate (LP-CT) turbine with 15MW maximum capacity is another alternative. The resulted capacity of the LP-CT turbine is 10MW. Overall saving however increases to about 4.5%. This is because the LP-CT turbine can fully utilize the existing turbines. In order to feed LP steam into LP-CT turbine, SP steam passes through the back-pressured turbine to LP level therefore produces more electricity than just letting-down from SP to MP in the case of MP-CT turbine.

While examining the LP-CT turbine study carefully, we discover that there is a purge at HP steam level in some operating periods. To prevent wasting the valuable HP steam, a HP-LP turbine is recommended together with the LP-CT. This combination eliminates the steam purge and introduces the excess steam through the HP-LP turbine to LP level for the LP-CT turbine usage. The total electricity generation is then increased by the increment in the LP-CT (increase to 13MW) and the additional amount from the HP-LP turbine (about 1MW). Finally, the total cost is saved by 6.7%, 1.5 times more than the MP-CT case.

3.3 Electricity contract optimization

Steam and electricity are the main utilities of a chemical production site produced by its utility plant. The main difference between steam and electricity is that electricity can either be produced in-house or purchased from the local electricity company but steam can only be generated locally. Instead of having a utility plant that is large enough to supply both electricity and steam for the whole production site, for reducing investment to the utility plant, a utility plant is normally designed for just guaranteeing the supply of steam. Electricity is normally backup by a local electricity company with an annually supply contract.

In an electricity contract, the cost is usually divided into two categories, variable cost and fixed cost. Variable cost depends on the total importing amount and the time period of the importation. For example, the electricity price at daytime is higher than that at night. Fixed cost is a fixed annual fee that the plant site has to pay every year, which mainly depends on the maximum importation peak on the contract period. Allowing a higher maximum import level, the production site may improve ability in production and/or maintain its productions even when utility equipment failure. On the other hand, a higher maximum importation rate increases the fixed cost. The profit gain due to higher productivity or the additional security of electricity supply may not be able to compensate the addition payment of the electricity contract. Hence, careful optimization on electricity contract is necessary. For this reason, the site-model for budget planning is modified for optimizing the electricity contract of the whole Yokkaichi plant site. Due to boilers and turbines shutdown, the electricity importation peak usually appears during the maintenance period. Prior to the availability of this total site model, the importation peak normally appears at November night-shift (maintenance period) with a value of approximately 50MW. Using the site-model, an optimum solution of 27MW (Figure 2) is predicted. Because of this, the total electricity cost (variable and fixed costs) can almost decrease by half. Although fuel cost is increased due to the increase of power generation, the total operating cost is still reduced by approximately 4%.

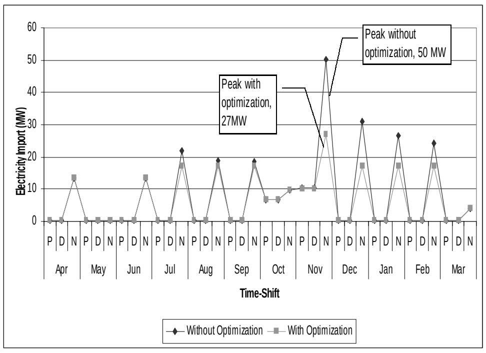

Figure 2: Electricity Importation Profiles.

3.4 Shutdown maintenance scheduling

Preventive maintenance is very important task for every chemical production site. It has to be performed regularly for preventing equipment failure and accidents. Shutdown maintenance scheduling can be classified as long-term and short-term for determining the best combination of plant shutdown and the detail schedule of the maintenance respectively. The main objective of shutdown maintenance scheduling is to reduce the overall maintenance fee and production losses.

Every process unit requires to be maintained in every 1 to 3 years. Not all the plants have to be shutdown simultaneously at each maintaining period. A good long-term schedule is therefore to guarantee the feasibility of utility and material balance at every maintenance period. The long-term schedule determines the plant shutdown frequency and combination in each maintenance period. It can also be used to determine inventory strategies for raw and intermediate materials before and during the shutdown maintenance periods. Examples of long-term maintenance scheduling were presented by Cheung and Hui (2001).

Based upon a long-term scheduling, detail timings of plant shutdown and startup are then scheduled by using a short-term scheduling model. The assigned maintenance period usually lasts for three to six weeks. Within a maintenance period, plants that require maintenance have to gone through shutdown, overhaul and startup. During these stages, the demands of utilities, materials and labor vary significantly increases the complication for optimizing the maintenance schedule. For example, plant startup will usually require a lot of steam to bring to process to a normal operating condition. Steam may not be enough to support all the production plants if they all startup at the same time. To take into account all these, a site-model is used to optimize the short-term shutdown schedule to guarantee the feasibility of material and utility balances, and to minimize production losses, labor cost, etc.

3.5 Fuel and water balances

Beside steam and electricity, fuel and water are the main elements to be considered in a budget-planning model. The usages of fuel and water are optimized together with all other utilities. In fact, the usages of utilities, water, fuel, etc., affect each other creates rooms for manipulation. For example, minimizing water regeneration from some processes may reduce the fuel consumption for the regeneration, but requiring more fresh water in overall. Using clean fuel in a furnace might reduce water usage for treating dirty flue gas. These are actually optimization problems. The trade-off between the utilities can be optimized to maintain the profitability of a plant site and/or meeting tightening environment regulations. Engineers traditionally solve these problems according to their experience and with some simple heuristics. Different engineers may turn out different results. With a site-model, the problems can be solved much faster and easier.

4. Conclusions

A general mathematical programming model, Site-Model, is developed for solving site-wide optimization problems. Yokkaichi Plant of Mitsubishi Chemical Corp. developed a site-model to deal with multi-site utility problems. This model enables our engineers to perform their normal daily functions much quicker with higher accuracy. With the model, our engineers can also be able to evaluate more scenarios and hence opportunities can be identified. So far, we have successfully used this tool in solving annual budget planning, investment decision-making, electricity contract, shutdown maintenance scheduling and fuel/water balances problems.

5. References

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