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# Integration of Process Site Utility Systems

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**Abstract**

Process utility systems consume fuel, generate power and distribute steam. The heating and cooling requirements of the site dictate the site-wide fuel demand and cogeneration of the utility system. New tools have been developed for the design of cogeneration and total site utility systems. In addition, utility systems are always designed with significant spare capacity to allow for the constantly changing demands and to allow for maintenance and breakdown. The amount and type of spare capacity and its operation are critical to the performance of the overall system. This paper will review the design of such systems under the conditions of uncertainty that prevail.

**Keywords** Process Integration, Site utility systems

Most processes operate in the context of a site infrastructure in which a number of processes are linked to the same utility system. In order to meet the energy demands from industrial processes, utility plants must convert fuel and water into steam, electricity, and rotational power. The heating and cooling requirements of the site dictate the site-wide fuel demand and cogeneration of the system. The utility systems of most sites have evolved over a period of many years without fundamental questions being addressed as to the design and operation of the utility system.

Excessive spare capacity is usually a feature of the design of utility systems. This arises from the many uncertainties in the operation of utility systems. Load changes can occur at short notice, electricity tariffs can change and components can need preventive maintenance or break down. Maintaining the integrity of site operation is important, but the penalty is a significant amount of utility equipment redundancy. However, this redundancy also presents opportunities to improve performance by managing its operation more effectively. Thus, utility systems offer the opportunity of substantial savings given their large investment requirements and operating costs.

New tools have been developed for the optimization of the operation of existing systems. These take account of the necessity to use spare capacity in the utility systems optimally. Account must be taken of part-load performance, changing tariffs and maintenance requirements. The performance of different units will translate into different quantities of overall fuel and water requirements, electricity import/export, and emissions for each operating scenario. The mathematical formulation employs continuous variables to define, for example, equipment sizes and loads, and binary variables used to select the units of the plant and designate whether they operate or not during a certain scenario. Discrete decisions relate to the operational status (on/off) of the different devices. For example, it might be possible to switch between a steam turbine or an electric motor on a particular drive. The major constraints for the objective function are energy and mass balances, together with equipment performance equations. Although the problem by nature becomes a mixed integer non-linear programming problem, it can be solved robustly by adopting an iterative mixed integer linear programming approach. Performing such an optimization for an existing system is often capable of reducing energy costs by 5 to 10%.

The design of a utility system should also make allowances for equipment being unavailable due to maintenance and unexpected failure. As a result, plants operate with some redundant equipment (i.e. spare or oversized units) most of the time. In conventional design approaches a discretionary number of additional units or oversizing factors are assumed to cope with these concerns. However, given the possibility of simultaneous structural and operational optimization, the proposed methodology can establish an optimum use of spare equipment capacity. For instance, users can define several scenarios and specify failure conditions so that the final design will cope with all anticipated situations at minimum cost.

If the operating horizon of a plant is divided into maintenance time intervals and each unit is forced to be shutdown during one of these periods, then the optimizer can establish at the same time the operational planning (scheduling) and the redundancy due to maintenance that will minimize cost. In addition, since two units failing independently at the same time is very unlikely, optimal redundancy due to unexpected failures can be also obtained by forcing the shutdown in certain periods of the two largest units of each type (i.e. one of them fails while the other one is receiving maintenance). Hence optimization might cope with such situations by adding new equipment, increasing the size of some units or by importing/exporting more/less utilities (e.g. electricity). It is worth mentioning that the size or the types of units that will be employed as redundant equipment is not known beforehand, so the procedure will determine the optimal equipment redundancy without the use of any heuristic or rule of thumb.

*Under variable conditions, such as different electric power tariffs, changing load in processes and variable ambient temperature, different operating scenarios can be proposed. But there are transient periods in which utility systems transfer from one scenario to another. Flexible utility systems should transfer between such scenarios smoothly and safely. Transient models have been developed for 'slow' utility equipment. For fast-response equipment, steady and quasi-steady models can give adequate representation. Such transient analysis can help to design a flexible utility system. Firstly, an optimisation problem is set up, including, identification of constraints and objectives. Then steady state operating scenarios can be obtained from conventional procedures based on steady state models, including the site configuration, equipment design and operating scenarios. Transient analysis can be applied to check the feasibility of utility system design, analyze the flexibility and reliability of utility systems and propose the operating strategies in both steady operation and transient periods. Understanding transient better can lead to cost savings through less standby capacity.*

While such simulation and optimization tools are useful in reducing operating costs, they have a number of other uses. First, the cost of steam on sites is far from straightforward to determine at the various levels. Realistic steam prices are necessary for the efficient operation of a site, both to allocate realistic costs to the different businesses on the site and to provide a true economic incentive for energy conservation. Once a model has been developed it can be used to determine the true cost of steam either for fixed steam loads to allocate costs to the various businesses on the site, or to determine the value of steam saving in energy conservation projects. To determine the value of steam saving simply requires the model to be re-optimized after making decreases in the steam load on each level in turn. The marginal changes to costs then allow the true value of steam saving to be established. The cost of steam then depends not only on the cost of fuel and power, but also on the performance of the individual items of equipment at part-load, the network structure and the constraints on the system.
Finally, the simulation and optimization tools can be used to evaluate changes to the configuration of the utility system. This can be carried out by the user suggesting changes based on experience, or more systematically by the construction and optimization of a superstructure.