Optimal Design of a District Cooling System Design by Mixed Integer Linear Programming

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1 Problem presentation

In a district cooling system, chillers convert electricity to cooling power which is distributed through an underground pipe network to the buildings in the district. Designing such a system involves choosing the type and number of chillers to be installed as well as the ice storage capacity. These decisions should take into account not only the construction costs, but also the operations costs of the system during its whole lifetime. In order to accurately compute these operations costs, a detailed schedule describing, on a hourly basis, the on/off status, the load allocation of each chiller and the ice inventory management should be built for an horizon spanning a whole year. Furthermore, the deployment of a district cooling system is usually not a one-shot decision but rather a process in which investment decisions are made step by step, following the development of the district over the years. This implies that a multi-year strategic deployment plan should be built.

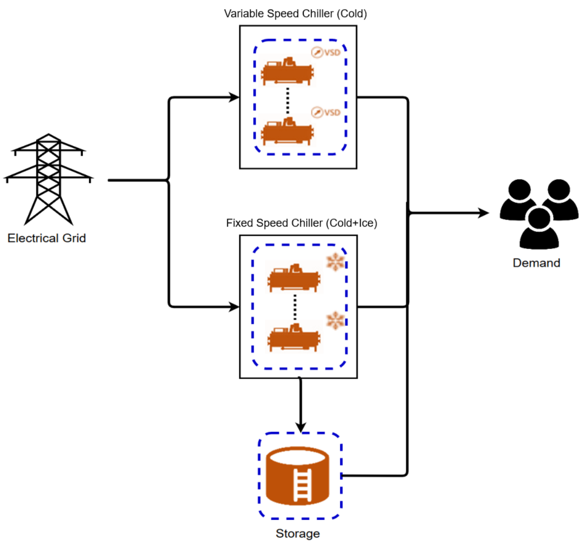

Figure 1: Diagram of a local cooling system

This optimization problem can be formulated as a mathematical program. However, several difficulties emerge. Firstly, the performance curve of a chiller describing how much cold will be produced as a function of the input electricity is not linear due partial load efficiency. Secondly, the huge size of the model makes it intractable for current MILP solvers. Thirdly, decomposition methods such as the Benders decomposition are not well-suited for this problem since the sub-problems to be solved at the operational level also contain integer variables.

2 Solution approach and preliminary computational results

In order to tackle this problem, we propose the following solution approach.
- The nonlinear performance curve of each type of chiller is approximated by a piecewise linear function. This piecewise linear function is managed in the problem formulation by the incremental method (see e.g. [1]).
- In order to obtain a mixed-integer linear program (MILP) of tractable size, we consider a deployment plan involving a limited number of investment periods, some of which correspond to several years. Moreover, we use the clustering approach described in [2] to select a small set of typical and extreme days to represent as best as possible the various conditions under which the system will be operated. This allows us to significantly reduce the problem size at the expense of some loss of accuracy in the design and operational costs evaluation.
- The resulting MILP is then solved by a customized Branch & Cut algorithm, recently proposed by Yokoyma et al. [2], which exploits the hierarchical relationship between the construction and operation variables. At the upper level, a relaxation of the initial problem in which the system design variables are integers and all scheduling variables are continuous is solved by a standard Branch & Cut algorithm. Each time a potential incumbent design solution is found during this tree search, the corresponding values of the design variables are used as input data to solve a series of independent scheduling sub-problems (one for each investment period and each representative day). This gives an accurate estimation of the feasibility and value of the potential design solution. If this solution is found to be feasible and better than the current incumbent solution, it is accepted as the new incumbent solution. Otherwise, it is rejected. When all the branches are searched in the upper level Branch & Bound search tree, the current incumbent solution gives the optimal solution of the original problem.

We provide preliminary computational results based on a real-life case study in China. These results show that the customized algorithm significantly outperforms the generic Branch & Cut algorithm embedded in CPLEX solver in terms of computation time.

References

[1] Correa-Posada C M, Sánchez-Martín P. Gas network optimization: A comparison of piecewise linear models. *Optimization Online*, 2014.

[2] Zatti M, Gabba M, Freschini M, et al. k-MILP: A novel clustering approach to select typical and extreme days for multi-energy systems design optimization. *Energy*, 2019, 181: 1051-1063.

[3] Yokoyama R, Shinano Y, Taniguchi S, et al. Optimization of energy supply systems by MILP branch and bound method in consideration of hierarchical relationship between design and operation. *Energy Conversion and Management*, 2015, 92: 92-104.