IORC Course - Project
Daily scheduling of a district cooling system

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1 Introduction

A district cooling system (DCS) is a centralized cooling supply system. Its main function is to cool down water and to distribute it through an underground pipe network to the buildings in the district to provide them with air conditioning. DCSs usually are much more energy-efficient than individual traditional air-cooled air-conditioning systems: using a DCS is thus a means of reducing the energy consumption, and as a consequence the environmental impact, of air conditioning.

Resources A DCS consists in a set of chillers and an ice storage tank.

A chiller is a machine that removes heat from a liquid by using a variety of techniques such as vapor-compression. We consider here electric-powered chillers which are used to cool water. These chillers can be classified into two main categories depending of their functionality. Standard chillers (denoted by STDC) only produce cooling power to satisfy the instantaneous demand of the customers. Ice chillers (denoted by ICEC) have two distinct operating modes: they either produce cooling power, but usually with a lower efficiency than the one of a STDC, or they produce ice. This ice can be stored for a few hours in an ice storage tank and be melted afterward to provide cooling power.

Within each category of chillers (STDC or ICEC), there are chillers with different production capacity levels. Each level corresponds to a predefined production range, i.e. to a minimum and maximum cooling power (or ice) it can provide per hour when turned on, and to a performance curve. A performance curve gives, for each chiller, the electric power consumed as a function of the produced cooling power or of the produced ice.

Another key resource in the system is the ice storage tank. This tank is linked to all the ice chillers of the system, can store the produced ice for a few hours and release it afterwards to produce cooling power. It has a maximal storage capacity.

Demand The demand for cooling power to be satisfied by the DCS is highly variable. First, the demand for cooling power varies throughout the day and is usually much higher at daytime than at night. There are also weekly and yearly variations: the demand pattern of a weekday thus significantly differs from the one observed during the week-end and the total daily demand varies during the year, in particular with the summer and winter seasons.

Electricity supply The chillers are powered by electricity bought from an external utility provider. The electricity price displays daily, but no weekly nor yearly variations. Thus, within a day, three types of periods, termed peak, flat and valley periods, can be distinguished. They correspond respectively to the highest, intermediate or lowest prices. Peak periods are usually at noon and in the evening, the valley periods at night and early in the morning and the rest of the day corresponds to flat periods. These price variations can be exploited to reduce the total energy cost, e.g. by producing ice at night when the demand for cooling power is low and the electricity rather cheap, storing it for a few hours and releasing ice to produce cooling power at daytime when the demand is high and the electricity more expensive.

Daily scheduling of a DCS The short-term daily scheduling of a DCS relies on an hourly time discretization: the day is divided into 24 one-hour time periods. Scheduling the DCS consists in determining for each hour of the day the number of chillers which will be turned on, the amount of cooling power produced by each chiller and the amount of stored and released ice. The objective is to ensure that the demand for cooling power is satisfied at all time while minimizing the total electricity costs.

In what follows, we will consider two cases:

1. Scheduling for a winter day
   The first (simple) case will consider a winter day in which the demand for cooling power is low. We will consider a DCS in which there are

only standard chillers. The possibility to produce ice with ice chillers and store it in a storage tank will thus not be taken into account.

2. Scheduling for a summer day
   The second (more complicated) case will consider a summer day in which the demand for cooling power is much higher. We will consider a DCS in which there are standard chillers but also several ice chillers and one ice storage tank.

2 Daily scheduling: winter day

We first focus on the daily scheduling of the DCS on a winter day in which the demand for cooling power is low. The day is divided into 24 one-hour periods numbered from $h = 0$ (period from 0am to 1am) to $h = 23$ (period from 11pm to 12pm). The demand for cooling power varies throughout the day: the total demand to be satisfied during hour h is denoted by D_h and is expressed in kW.

The DCS comprises only $LS = 2$ standard chillers of different production capacity levels. Each standard chiller corresponds to a production range and a performance curve. Let C_s^{min} and C_s^{max} be the minimum and maximum cooling power (expressed in kW) that the standard chiller of level s can produce. As for the performance curve, it provides the electric power consumed by a chiller of level s as a function of the produced cooling power. For the sake of simplicity, we will consider in this project that this performance curve is linear. Let a_s and b_s be the slope and constant value of this curve: the electric power consumed by the chiller of level s producing a cooling power equal to C is thus computed as: $E = a_s C + b_s$. Note that a turned off chiller (i.e. a chiller not producing any cooling power) does not consume any electric power.

As mentioned in the introduction, the electricity price varies throughout the day. Let EP_h be the price (in euro per kW) of electricity during hour h.

1. **Formulate the DCS daily scheduling problem for this first simplified case. You should be careful about precisely defining the decision variables and clearly explaining the meaning of all the constraints introduced in your model.**

2. **The numerical data relative to this first case are provided in the file 'DailySchedulingWinter.dat'. Use the mathematical programming solver CPLEX12.8 to solve your MILP. Give the optimal schedule in this case.**

3 Daily scheduling: summer day

We now focus on the daily scheduling of the DCS on a summer day in which the demand for cooling power is much higher. In order to be able to satisfy this demand, we will consider a DCS comprising both standard and ice chillers.

Regarding the standard chillers, we consider again LS production levels and use the same notation to describe the corresponding production range and performance curve. However, contrary to the first case, we now have several chillers in each production level. Let NS_s be the number of standard chillers of production level s available.

The available ice chillers correspond to LI production level. An ice chiller of level i can produce a cooling power comprised within the production range $[\Gamma_i^{min,cold}; \Gamma_i^{max,cold}]$ (in kW). Its performance curve is a linear function given by: $E = \alpha_i^{cold}\Gamma^{cold} + \beta_i^{cold}$ where E is the electric power consumed (in kW) and Γ^{cold} is the output cooling power (in kW). Similarly, its ice production (in kW) should be within the production range $[\Gamma_i^{min,ice}; \Gamma_i^{max,ice}]$ and its performance curve is a linear function described by $E = \alpha_i^{ice}\Gamma^{ice} + \beta_i^{ice}$. Finally, the number of chillers of production level i is given by NI_i. Recall that a turned on ice chiller is either production cooling power or producing ice but cannot do both at the same time.

As for the ice storage tank, its storage capacity is denoted by $IceStoCap$. The ice inventory at the beginning of the day is assumed to be equal to 0.

1. **Show the following two properties:**

   - For a set of n_s identical standard chillers of level s turned on and producing cooling power, equally distributing the total output power C_s between these active chillers, i.e. in having each chiller producing a cooling power of $\frac{C_s}{n_s}$, is an optimal load allocation.
     NB : The load allocation corresponds to sharing/allocating the total cooling power C_s to be produced amongst the n standard chillers of a given level s which are currently turned on to produce cooling power. The overhead cost b_s does not come into play here as we assume that the number of turned on chillers and the total amount of cooling power they have to produce are already determined.

   - When n_s identical standard chillers of level s are simultaneously producing cooling power (or ice), the relation providing the total amount of consumed electricity as a function of the total amount of output power can be described by a linear aggregate performance curve. Its expression is given by: $E_s = a_s C_s + b_s n_s$.

2. **Use these two properties to formulate the DCS daily scheduling problem for this second case. You should be careful about precisely defining the decision variables and clearly explaining the meaning of all the constraints introduced in your model.**

3. **The numerical data relative to this first case are provided in the file 'DailySchedulingSummer.dat'. Use the mathematical programming solver CPLEX12.8 to solve your MILP. Give the optimal schedule in this case.**

DOCUMENTS TO BE HANDED IN:

- **a report describing the problem modeling, the formulation of the mixed-integer linear programs and the optimal schedule for each case.**
- **the files .mod used for the resolution by ILOG CPLEX.**

Send your documents by mail to celine.gicquel@lri.fr before November 7th, 2021