Game Theory Based Distributed Temperature Control for Energy Saving of Smart Buildings

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Abstract: Recently, model-free distributed temperature control for multiple smart buildings within a common interest community, such as a university or corporation, received increasing attention. From a system designer's perspective, it is desirable to have the group of buildings cooperate with each other in terms of their energy consumption schedule, therefore, the total benefit can be maximized, i.e. a most beneficial behavior can be achieved.

The total benefit consists of three parts: firstly, there is a peak demand charge for the community from utility companies when the real-time power load is beyond a given limit. Thus, the real-time total power load constraint for whole community is introduced. Once an anticipated threshold is exceeded, a penalty will be added for compensation and adjustment; secondly, we would like to minimize the total energy consumption cost, which is a function of both the real-time total power load and the time-of-use rate. Here, a time-of-use rate with higher cost during peak hours is considered, so that a flatter energy consumption curve over a day with lower peak and higher valley can be achieved; last but not least, there is a requirement for the real-time indoor temperature comfort level for each building, i.e. the desired temperature should not fall below a lower limit or above an upper limit. In this paper, a global utility function is designed to describe a weighted average of the above-mentioned three parts of benefit.

This global utility maximization problem can be solved by traditional convex optimization methods in a centralized way, where a central controller is utilized to handle all the buildings. However, it is of great importance to solve the problem in a distributed manner, which has several advantages over centralized way. Firstly, a distributed control strategy makes systems more reliable. In the case of controller breaks down for some buildings, other buildings' performance is not affected or only slightly affected in a distributed system. However, if a centralized controller breaks down, all buildings will be severely affected. Secondly, a distributed control system has a better expandability. The system can be constructed with a large scale and scattered in a large area. It provides a convenient infrastructure if a new building is built and becomes part of the existing control system. Furthermore, the optimization and computation load for each controller would be significantly reduced, since no one needs to do the computation for the whole system.

In this paper, the distributed global utility maximization problem is formulated as a series of sliding window games, with each building being treated as a player, the global utility being decomposed to each player's payoff, and each game being played over a control horizon from the current time step. In each game, we apply a distributed learning algorithm such that each building can learn to play a part of the optimal solution. In the game, each player maximizes its own payoff based on the action it played and the payoff it received, without knowing others. The algorithm can achieve a sub-optimal solution, i.e. the solution converges to the centralized optimal solution with a probability approaching to one.

The effectiveness of this method is demonstrated by simulation. Both fast convergence and sub-optimal property of the methodology can be illustrated. A flatter daily energy consumption curve and a lower peak to average ratio are also shown. Moreover, since the method utilizes sliding window games, pre-cooling effect during off-peak period and autonomous cooling discharging during on-peak period can be observed.