OPEN ACCESS

1st International e-Conference on Energies
14 - 31 March 2014

http://sciforum.net/conference/ece-1

Conference Proceedings Paper - Energies „Whither Energy Conversion? Present Trends, Current Problems and Realistic Future Solutions"

Demand Response on Pumping Systems of Commercial Buildings under Real-time Pricing

Minh Y Nguyen[1,*], Ngoc Thang Pham[1] and Huy Toan Nguyen[1]

1 Faculty of International Training, Thai Nguyen University of Technology, Thai Nguyen, Vietnam; E-Mail: phamngocthang@tnut.edu.vn, toannguyen@tnut.edu.vn

* Dept. of Electrical Engineering, Faculty of International Training, Thai Nguyen University of Technology, Thai Nguyen, Vietnam; E-Mail: minhy@tnut.edu.vn;
Tel.: +84-966996399; Fax: +84-2803847403.

Received: 19 December 2013 / Accepted: 13 March 2014 / Published: 14 March 2014

Abstract: Under market environments, electric customers are offered choices to manage and pay for their electricity usage corresponding to the wholesale price; this is referred to as demand response. This paper presents a framework for the demand response of commercial sector, particularly applies to the pumping systems of tall buildings. The problem is to control the pumping system in response to the market price to minimize the electricity charge. The idea is to utilize the tank on the top as an energy storage component to manage the electricity consumed for pumping, i.e., from on-peak to off-peak hours, at the same time, to maintain sufficient water in the tank for usage. The problem is formulated and solved by dynamic programming method. Then, it is tested in a case study assuming markets for real-time pricing.

Keywords: Demand response, real-time pricing, pumping systems, dynamic programming

---

1. Introduction

Smartgrid applies advanced automation and communication technologies into the existing grid in order to improve the security, reliability and economics of the production, transmission, and consumption of electricity. One of the key components of smartgrid is Advanced Metering Infrastructure (AMI) which enables the real-time information to exchange between provider and consumer, e.g., real-time price of electricity. It creates opportunities for the end-users to reduce electricity charge by responding accordingly to the condition of the wholesale market; i.e., Demand Response (DR). Today, DR becomes a growing resource base that system operators rely on maintains the reliability and economics on the power grid.

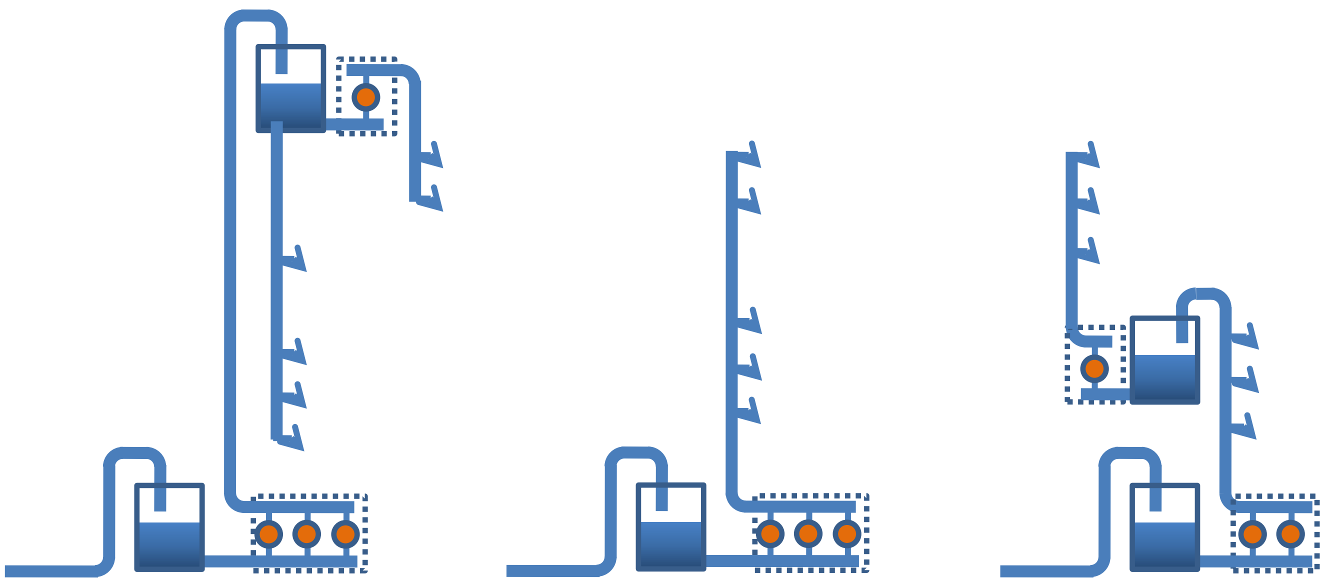
Generally, DR program can be applied to the loads which are associated with the capability of storing energy: batteries, hydro-pumped storage, etc. or the loads with slow dynamics: heating or air conditioning systems, etc. In this work, we realize a common load which naturally provides the capability of energy storage: the water supply system of buildings with a roof tank. Consequently, DR can be applied that the pump should be managed to pump and store water into the tank when the electricity is cheap, at the same time, to avoid running during high price time. Thus, we propose a framework to schedule and control the pumping system in building under real-time pricing environments. The problem is to minimize the electricity charge to pumping system, while subject to the constraint of tank capability, pump capacity and also, the demanded water. The problem is formulated in Dynamic Programming (DP) framework and solved by DP backward algorithm.

2. Water Supply Systems in Buildings

2.1. Water Supply System Configuration

The use of roof tanks to store and maintain adequate amount of water with certain pressure in buildings is very common. The simplest structure consists of a water tank, i.e., break tank, in front of the pump to ensure water supply to the demand when the mains are not available, and another tank on the top to ensure adequate pressure for usage [Figure 1].

Figure 1. Water supply system configurations: (a) A single roof tank system. (b) A single pressurized system. (c) Combined system with two tanks (in series).



(a) (b) (c)

The break tank is filled with water during low consumption periods and ensures the availability of water. The pumping system consists of a booster pump to elevate water to the roof tank and a pressure pump to ensure adequate pressure for the top floors (e.g., about six upper floors).

This configuration takes advantage of simplicity, technology maturing, and space saving. However, the disadvantage includes insufficient and excessive pressure on the uppermost floors and the lowest floors, respectively, consequently, requiring higher pressure grade of pipe, and microbiological growth in the tank, etc. Of course, there are many other configurations of water systems in buildings such as multiple tank systems, single pressurized systems, zonal pressurized systems, and the combination of those (tanks and pressurized pumps), etc.; each of them has its own pros and cons. In the scope of this paper, we will focus on the single roof tank system to respond to the variation of the market price and believe that the other types can be treated with not much modification.

2.2.Energy Consumption of Pumping Systems

Normally, the pump is controlled automatically to keep the water level of the tank within a certain range: when the water drop down to a certain lower level, the pumps will be activated by a floating switch to refill the tank up to a predetermined upper level. The energy consumed can be calculated by the following formula.

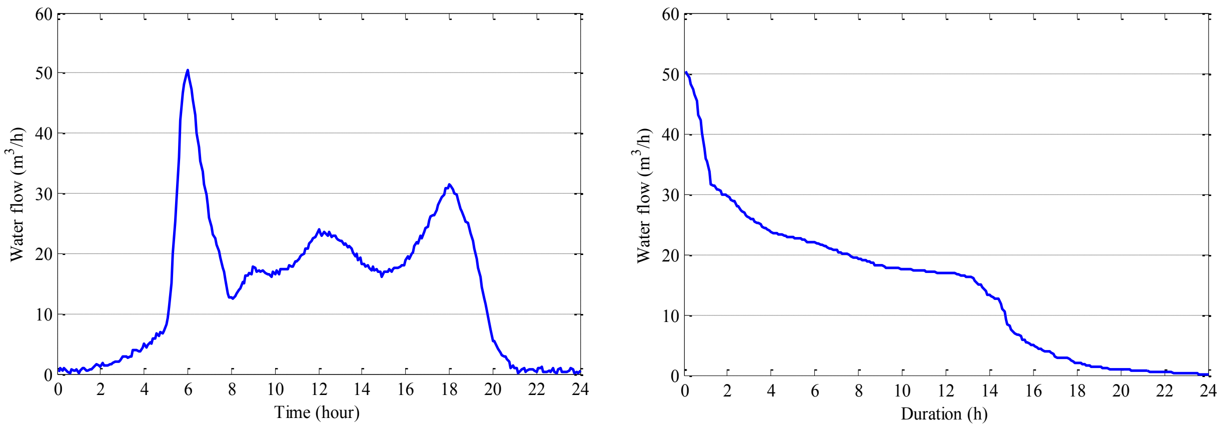
$$E = \frac{Q \cdot H \cdot T}{\eta}, \quad [kWh] \tag{1}$$

Where, E is the energy consumption, [kWh], Q is the amount of water flow through the (booster) pipe, [m^3/s], H is the pressure height, [kPa], T is the pumping duration, [h], and η is the efficiency of the pump, [p.u.].It is noted that H is expressed in term of pressure, [kPa], which is proportional to the geometrical distance between the lower and upper tank.

2.3. Consumption Profiles

It is obvious that the water stored in the upper tank has to be available for users when needed. Hence, the load profile (i.e., water usage) is very important when scheduling and operating pumping system. In this work, we consider commercial (and office) buildings in which the water usage varies greatly during the day. The largest water flow occurs in the morning with the start of service activities such as cleaning, coffee making, cooking and washing, etc. Then, the flow fluctuates in the rest of day, but does not reach as high as in the morning. There is virtually no consumption in late evening and overnight in these building. The load profile can be expressed in term of the flow during 24-hour period and the duration showing hours per day the flow is above an indicated amount.

Figure 2. Load profile of the water usage. (a) The water flow. (b) The duration curve.



(a) (b)

3. Problem Formulation

The problem is to schedule the pumping system of buildings according to the real-time price to reduce the daily charge of electricity (i.e., corresponding to day-ahead hourly electricity market). Therefore, the objective is to minimize the sum of electricity payment in each stage of a day. The problem is subject to some constraints such as the tank capability, the pump capacity, etc.

$$\min_{P_k} \sum_{k=1}^{K} \rho_k^{RT} \cdot P_k \cdot \Delta T \tag{2}$$

s.t.

$$x_{k+1} = x_k + u_k - w_k \tag{3}$$

$$P_{\min} \le P_k \le P_{\max} \tag{4}$$

$$x_{\min} \le x_k \le x_{\max} \tag{5}$$

$$u_k = \frac{\eta \cdot P_k \cdot \Delta T}{H} \tag{6}$$

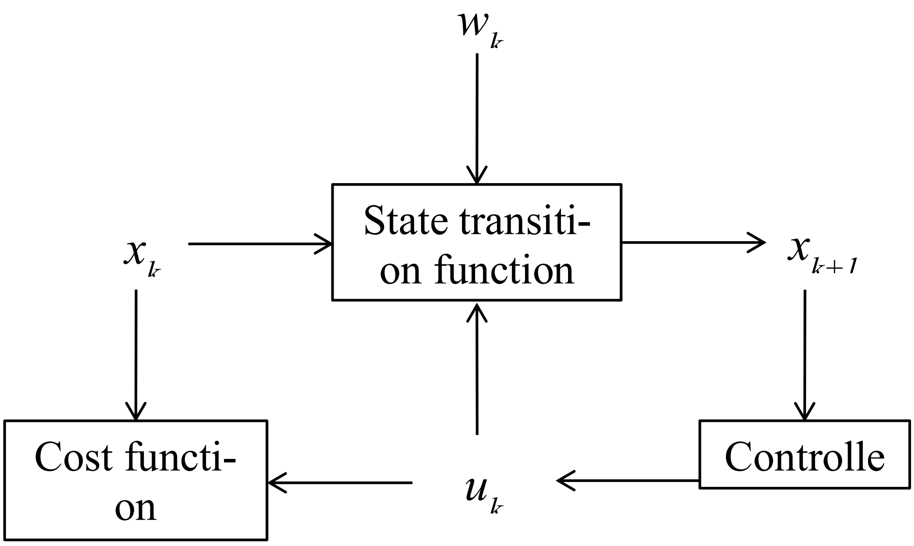
where, ρ^{RT} is the real-time price, [¢/kWh]; P_k is operating power of the pumping system during stage k, [kW]; ΔT is the time basis of the real-time market, which is $^1/_{12}$ hours (i.e., 5 minutes); K is the number of stage in a day (which is 288 in this paper); x_k is the amount of water stored in the tank in the beginning of the stage k, [m^3]; u_k is the water pumped into the tank during stage k, [m^3]; w_k is the output flow (i.e., consumption) during the stage k, [m^3]; P_{min} and P_{max} are the capacity limits of the pumping system, [kW]; and x_{min} and x_{max} are the limits of the tank capability, [m^3].

In the above formulation, (2) indicates the sum of payment in each stage which is calculated base on the market price and the usage. Equation (3) expresses the water amount in the tank in each stage which is driven by the pumping system and usage of the last stage. Equation (4) and (5) show the constraints of the tank capability and the pumping capacity. Equation (6) is the water amount and the operation power.

4. Dynamic Programming Method: the Backward Algorithm

In this paper, we introduce Dynamic Programming (DP) method to solve the problem. In DP framework, the state variable is defined as the amount of water in the tank in the beginning of each stage. Discretizing the state variable and breaking down the time horizon, the problem becomes the so-called deterministic finite problem, thus, the DP backward algorithm can be applied. The DP framework is shown in Figure 3.

Figure 3.DP framework for deterministic finite state problems.



The DP backward algorithm is to find the solution of sub-problems, i.e., optimizing the process in the following stage given the current state. The algorithm starts from the last stage and goes through every possible state, at each state, the algorithm will find the control variables (i.e. input) which optimize the objective function of the sub-problem. After going through every state, the algorithm will move backward to the previous stage and the computation is repeated, and so on. The algorithm terminates once the initial stage is reached and, again, all possible states are scanned through.

The DP backward algorithm can be formulated as the following formulation:

$$\begin{cases} J_{K+1}\left(x_{K+1}\right)=0 \\ \min\limits_{P_k}\left(J_{k+1}\left(x_k+\dfrac{\eta\cdot P_k\cdot\Delta T}{H}-w_k\right)+\rho_k^{RT}\cdot P_k\cdot\Delta T\right) \\ k=K,K-1,\ldots,1 \end{cases} \tag{7}$$

5. Case Study

In this section, the above framework for scheduling and operation scheme of pumping system is tested in a commercial building assumed that the real-time market has been implemented. It is a 120-floor building equipped with a roof tank and controlled pumping system. Parameters of the system are in Table 1. The load profile is given both water flow and duration [Figure 2].

Table 1. The pumping system of the commercial and office building.

Tank capability (m^3)		Pumping capacity (kW)		Pump efficiency (p.u.)	Height (kPa)
x_{max}	x_{min}	P_{max}	Control level		
150	30	50	10	0.85	2897

The real-time price is displayed in Figure 4. The proposed framework for scheduling and operation of the pumping system is applied and compared with the traditional operation scheme was done. The traditional scheme is that the pump is turn on/off whenever the water in the tank drops down or is filled up to pre-specified levels. Figure 4(a) shows the real-time price which is referred from JPM electricity market. Figure 4(b) shows the cost per stage (5 minutes) between two schemes. Figure 5 shows the comparison in details with respect to operating power of the pump and states of the water tank. The daily cost of the proposed scheme is $7.78, while which is as high as $11.26 with the traditional scheme.

Figure 4. (a) Real-time price in a day. (b) Cost per stage between two schemes.

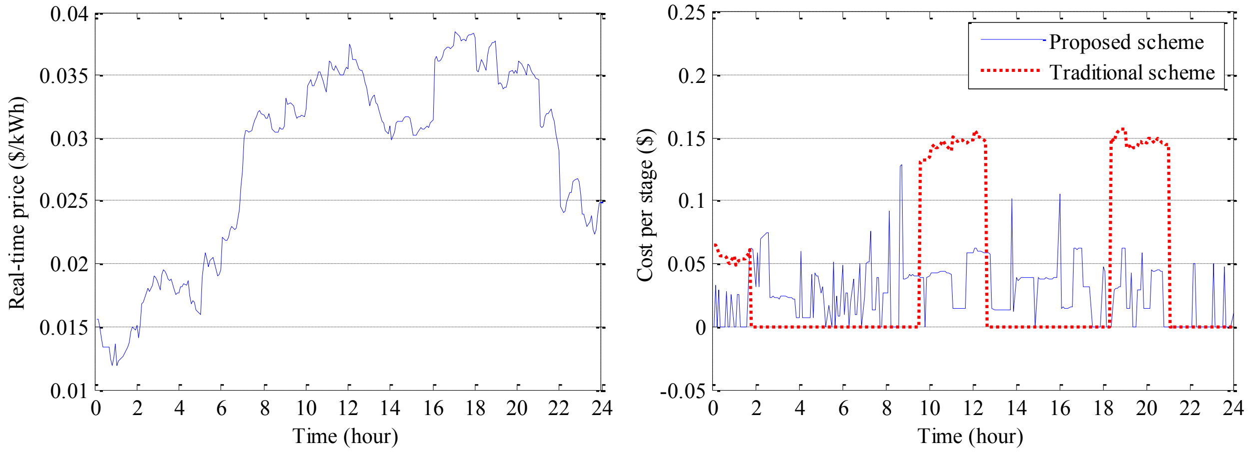
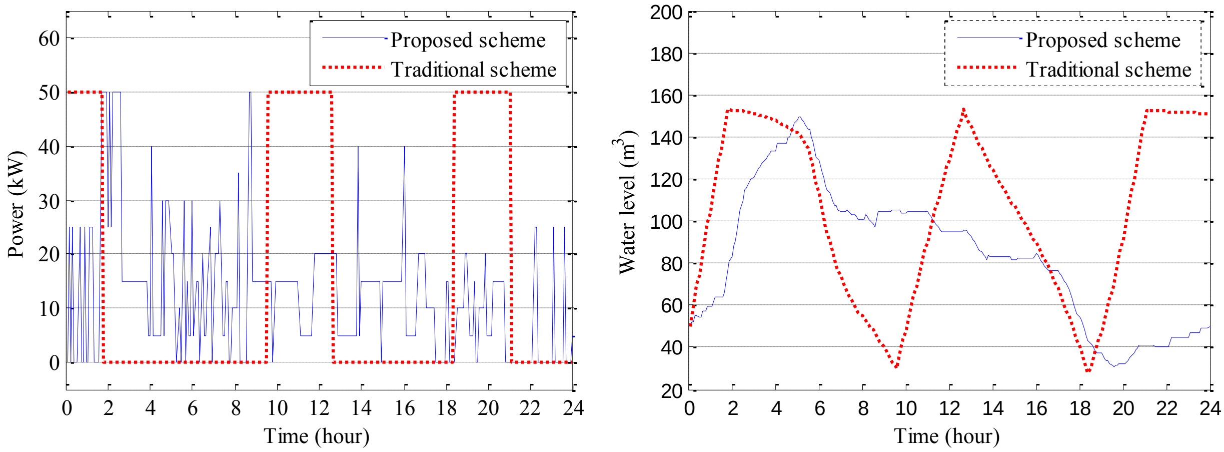


Figure 5. Comparison between two schemes. (a) Operating power of the pumping system. (b) State of the tank.



6. Conclusion

This paper has discussed a possible DR applied to pumping systems of commercial buildings under real-time market. The idea is to take advantage of the roof tank as an energy storage device that is naturally provided. Then, the paper has presented formulation to minimize the cost associated with electricity usage in a day. The problem is subject to constraints like tank capability, pump capacity, etc. The test in a case study and the comparison with the traditional scheme performed in the end of the paper showed that the proposed scheme significantly changes the operation of the system which lets to the saving in this case is about 30.9%.

In this paper, the problem is formulated for single boost water supply systems with roof tank (i.e., tank on the top). In future work, we expect to generalize this problem to other types, e.g., multiple tanks, etc.

Acknowledgments

This work was supported by Thai Nguyen University of Technology as parts of its project on Demand Response in Smartgrid.

Conflicts of Interest

The authors declare no conflict of interest.

References and Notes

1. R. Yu, W. Yang, S. Rahardja. A statistical demand-price model with its application in optimal real-time price. *IEEE Trans. Smartgrid* **2012**, *3*, 1734-1743.
2. G. T. Costanzo, G. Zhu, M. F. Anjos, G. Savard. A system architecture for autonomous demand side load management in smart buildings. *IEEE Trans. Smart Grid* **2012**, *3,* 2157-2166.

3. Y. He, B. Venkatesh, L. Guan. Optimal scheduling for charging and discharging of electric vehicles. *IEEE Trans. Smart Grid* **2012***, 3,* 1095-1106.
4. Z. Chen, L. Wu, Y. Fu. Real-time price-based demand response management for residential appliances via stochastic optimization and robust optimization. *IEEE Trans. Smart Grid* ***2012****, 3,* 1822-1832.
5. M. Y. Nguyen, N. H. Choi, Y. T. Yoon. Dynamic programming formulation of micro-grid operation with heat and electricity constraints. *IEEE T&D Conf. and Exhibitions: Asia and Pacific,* Seoul, Korea, 2009.
6. M. Y. Nguyen, V. T. Nguyen, Y. T. Yoon. A new battery energy storage charging/discharging scheme for wind power producer in real-time market. *Energies* ***2012****, 5,* 5439-5452.
7. M. Y. Nguyen, Y. T. Yoon. Battery modeling to economic operation of energy storage systems in electricity markets. *International Review of Electrical Engineering,* ***2013****, 5, 1000-1007.*
8. Bertsekas, D.P. *Dynamic Programming and Optimal Control*; Athena Scientific: Belmont, MA, USA, 1995.
9. J. Nørgaaard, A. Nielsen. Water supply in tall buildings: Energy efficiency of roof tanks vs. pressurized systems. Grundfos Water Boosting. Available online: http://www.cbs.grundfos.com/CBS_Master/...Files/Roof_Tank_Whitepaper.pdf (accessed on 1st Feb 2014).
10. PJM Electric Market. Available online: http://www.pjm.com (accessed on 1st Feb 2014).