Demand-Response-Enabled Thermostat

Control Strategies and Simulations

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Price Generator

Motivation

When testing our control strategies, utility price signals are used. The Price Generator generates electricity price signals to simulate the price signals sent by a utility company. We are not attempting to replicate utility pricing procedures. This model just produces a reasonable-looking pattern for us to use. The price generator simulates two types of price signals:

► **Static Time-of-Use Rate with Dynamic Critical-Peak-Price (TOU with CPP)**

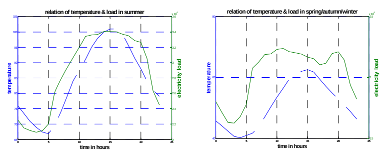
Fixed rate that changes seasonally for low, medium and high time periods with an additional "Critical Peak" price (CPP), which is dispatched during medium and high periods, with several hours advance notice for a maximum of 50 hours per year.

► **Dynamic Four-Level Rate**

Non-fixed low, medium, high and critical peak time periods, dispatched depending on the ratio between electricity demand and supply, with several hours advance notice.

Procedure

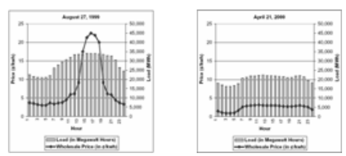
1.Forecast electricity load from weather data, in particular, temperature.
Because the electricity load shape varies between seasons, different models are developed for different seasons.



Relation of temperature and electricity load

2. Generate electricity supply signal.
Percentage of power capacity is used to demonstrate the actual supply. Negative impulses represent the electricity shortage because of equipment maintenance, malfunction or other situations that interrupt the supply. These interruptions might happen on schedule or unexpectedly. The supply signal changes every 30 minutes.

3. Generate wholesale spot price of electricity.
From results of first and second step, ratio of electricity demand and supply can be calculated. The price model is based on nonlinear relationship between price and the ratio, which references the real wholesale price data from "California Power Exchange wholesale electrical power prices".



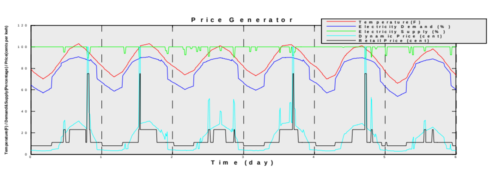
California power exchange wholesale electrical power prices

4. Define retail price policies and generate retail price signals.

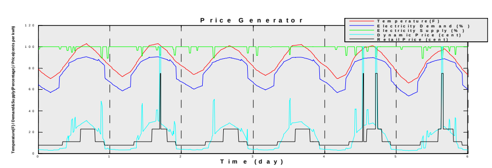
a. Based on time of use (TOU) schedule, additional critical peak price is generated from the wholesale dynamic prices. Set fixed rate that changes seasonally for low, medium and high time periods; when the wholesale dynamic price is bigger than a threshold, "Critical Peak" price happens.

b. Set thresholds and get discrete prices. Set three threshold values to get four price level. Apply thresholds and generate discrete prices with wholesale spot price.

5. Flexible notification time for price.
The notification time (ranging from one hour ahead to one day ahead) can set and the control strategy tested for different settings.



Dynamic Four-level Price



TOU with CPP

Price Generator Procedure Simulation

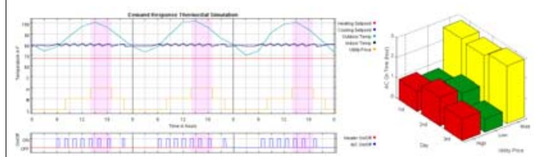
Application

► In order to compare different control strategies, an identical weather and price time sequence should be used. Therefore, price signals generated by the Price Generator can be saved into a database, together with the concurrent weather information.

► This July and August, we will feed price sequences into the test house to examine the response of the real house. The price is based on weather data forecasted hourly by weather station and data measured by sensors at the same time.

Precooling Strategy

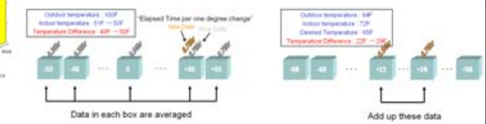
Precooling has been mostly used in commercial buildings to reduce peak energy consumption. In this case we wish to use it in residences. The key in precooling strategy is to decide when cooling should start. A fixed precooling start point, although simple and commonly used, can cause either overcooling or undercooling since the house size and efficiency of cooling devices are not considered. To maximize comfort as well as to minimize utility usage in high price, an adaptive cooling start point should be used.

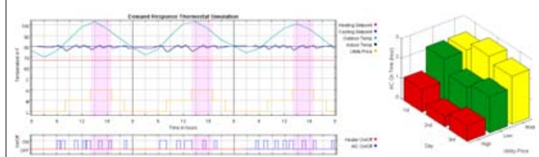


(a)Three day simulation without precooling

► Self-Learning Algorithm

During a precooling period, the elapsed cooling time is stored in an array along with the temperature differences between outdoors and indoors . The data in the array is updated (averaged) after every precooling cycle. The next precooling start point is predicted from the prior data based on outdoor, indoor, and desired temperatures.



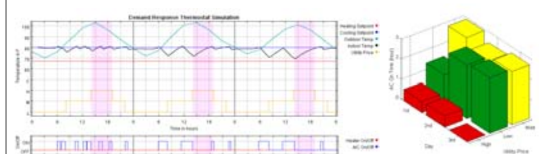


(b)Three day simulation with fixed precooling start point

► Compensation of Error with Feedback Gain

When the cooling time is either too short or too long, the data in array will be compensated based on the error (last indoor temperature – precooling setpoint)

By using the adaptive precooling start point algorithm, the indoor temperature almost reaches the desired precooling setpoint (67F) after four precooling cycles. Although total energy consumption increases with precooling, the total cost (energy consumption times utility price) decreases.

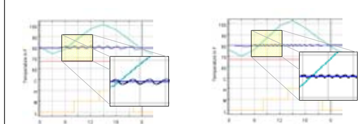


(c)Three day simulation with dynamic precooling start point

Anticipator Control

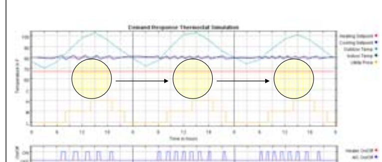
One way of improving temperature control performance of a thermostat is to use anticipator control. The control function is often used to turn equipment on/off prior to reaching the actual cut-in and cut-out points of the thermostat, and therefore can reduce the magnitude of the temperature swing. To have accurate equipment on/off timing, the DR thermostat uses feedback control.

For simulation, the setpoint tolerance was set at $\pm$ 0.5 F. The first plot shows that either system overshoot or system lag is approximately 1.5F when the anticipator was not used. This problem, however, was solved with the programmed anticipator.


Simulations without anticipator and with anticipator

Cycle Rate Control

The cycle rate indicates how often heating or cooling equipments is turned on during a certain period of time. If the cycle rate is high, equipment life and energy efficiency are reduced. If the cycle rate is low, room temperature is not well controlled, which makes the house uncomfortable. After the end user decides the proper range of cycle rate, the DR thermostat calculates the cycle rate after every cooling period and increases or decreases the setpoint tolerance in a certain amount so that the cycle rate is always inside the range. In simulation, the initial cycle rate is 0.2 cycle per hour (CPH). We want the cycle rate to be ranged between 0.4 CPH and to 0.5CPH. From the plots, it can be shown that cycle rate increases up to the desired range. The settling time (how quickly the setpoint tolerance is adjusted) mainly depends on the increment and decrement value. In the current simulation, it takes five cooling cycles to meet the desired condition.



Air conditioner cycle rate control

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