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Statement of Research of the Systemic Control of PCT Networks

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A network of programmable communicating thermostats (PCT) enable manipulation of the load on an electricity grid by reducing HVAC operation in response to demand response (DR) signals dispatched to homes. This capability is potentially very powerful, because according to Roger Levy of DRRC, the controllable load under this network greatly exceeds what is necessary to balance a system imbalance in voltage, frequency, or supply; according to Mr. Levy air conditioning in California (which can potentially be controlled by PCT's) accounts for 30% or more of the system load at peak times, while reductions of 1-2% are usually sufficient to manage the system. Presently, few discussions have focused on the dispatch and load manipulation techniques, and it seems likely that the system performance can be affected significantly by how this is accomplished. It is especially important to ensure that improper operation of this network does not degrade performance to the point of system instability or failure.

We assume that the operator of the electricity distribution system (referred to here as the Utility) has a target demand (total system load) needed to meet whatever economic or reliability situation is in progress. A substantial portion of that load comes from residences, the area of our focus. After some form of demand response signal is sent out, the Utility will be able to measure the actual system load through normal distribution network instrumentation. The next time a demand response signal is sent out, either during the same demand response event or at the beginning of the next event, the dispatch parameters will be adjusted to compensate for the degree to which the target demand was missed.

This system has the structure of a feedback control system. In this project there are two important properties of feedback control systems that will be our focus:

1. The purpose of feedback control is to compensate for lack of complete knowledge about the system's dynamic behavior; the interaction between the weather, conditions of the distribution system, differences in residential HVAC equipment, and PCT settings are some of the many variables that make it nearly impossible to achieve a desired level of load reduction with a single control input.
2. When feedback control is applied to a system, depending on how it has been implemented, the resulting behavior can be better or worse than the original, uncontrolled behavior.

A basic feedback control system contains an open loop system (the target of control). Here, the open loop system consists of everything on the grid – homes, businesses, factories, etc. The set of PCT enabled homes makes up the portion of the system controllable via the PCT/DR signal system we are studying. The rest of the system can be further divided into controllable and observable components. The states and operating conditions for each house include the inside and outside temperatures, HVAC setpoint, occupant comfort, etc. The external input of interest is the DR signal. The output of the system is the power consumed.

While each house behaves in a relatively simple manner, and could be simulated and predicted if desired, no two houses are the same. Physical properties, siting issues (shade, window orientations, etc.) and many other properties differ from house to house. Furthermore, each occupant operates the house differently according to a complicated set of personal preferences, which certainly include cost and comfort among others. Thus, although an individual house could be characterized physically, essentially none are. In aggregate, therefore, the system consists of a large number of houses with properties that can, at best, be described by statistical distributions of property values.

Interestingly, this system is not an inanimate object like most classical plants: a human manages, to a larger or smaller extent, every PCT. Therefore, the control system will be acting on human behavior as well as machine behavior. Because of the desire to maintain home comfort, precooling will certainly occur when advanced notice of a DR event has been given. Even without prior notice, the possibility of people, or sophisticated thermostats, predicting DR events may also lead to precooling. Regardless of the amount of notice given, the system response will change with time due to people, and thermostat manufacturers learning how to maintain home comfort with the new DR system. Further, precooling is only one example of how human behavior could affect system response. In summary the system parameters will not be static, and the control system will likely need to adjust for this.

Thus, the ability of a feedback system to compensate for lack of knowledge arises from the tremendous expense that would be required to adequately characterize all of the houses in a Utility’s territory and the inability to predict the human behavior that governs important aspects of how the system will respond to a DR signal.

For this study, we are only interested in controlling the portion of the grid energy consumed by the climate control of PCT enabled homes. Ideally, we would have direct access to this measurement at every house under control. Since this measurement does not currently exist, this study assumes access to the measurement of energy consumed at the first power substation upstream of the homes. Each substation can be connected to many different types of energy consumers, and not all of those consumers will be under control. The entire industrial load and some of the personal residences will not be PCT enabled. Additionally, uncontrollable load exists inside a PCT enabled house in the form of any power-consuming device not part of the climate control system. For the most part, these uncontrollable loads can be modeled as background noise unaffected by DR events. The exception is industrial sites enrolled in programs that controllably reduce peak consumption. Presumably the signals that enact these changes can be monitored so that the reductions could be modeled and compensated for. In general the noise from the base load will have little effect on the control system, but a problem arises when the signal-to-noise ratio becomes too small. When the base load power overwhelms the power to the PCT enabled homes, the controllable portion of the system becomes unobservable, and the control strategy becomes much more difficult. For the purposes of this study, we are largely ignoring this potential problem and assuming that the PCT subsystem remains observable.

Currently the power consumed at the substation level (XX MW of resolution?) can be measured by the ISO or Utility with a delay (about X minutes?) and represents the least common denominator for basic feedback information. SCADA could provide as quick as 4-second response for load information, but its deployment will be rolled out over XX years and may not necessarily be available in areas where emergency dispatches could be required. Where AMI is implemented, high-resolution data for individual residences can be obtained in intervals (X minutes in PG&E's case?) within (an hour / XX minutes?). Additionally, other feedback sources exist and will continue to be developed. For instance, if two-way communications are implemented in PCT's, additional feedback such as curtailment confirmation, air conditioner on/off state, current setpoint, and whether the occupant overrode the DR event, can be sent back to the Utility and used as feedback.

The contents of the DR dispatch message also remain undefined and many options merit examination. The message structure needs definition; it could either be fully defined and hard coded into the PCT (i.e., the dispatch only sends a certain digital bit for emergency response and another for price response) or defined on-the-fly in the DR message (i.e., a flexible markup coding is used to send different information in each dispatch). On-the-fly-definition certainly will provide more system flexibility, and extensible message structures like XML are good candidates though they add considerable bandwith overhead. A fully defined structure allows a minimal message size which enhances system robustness (less chance of losing data) and security but lock the system's capabilities in place. There are many message variables possible, and a partial list follows: energy price, generic magnitude of rate or DR severity, absolute setpoint, relative setpoint change, power reduction, absolute power consumption, air conditioner maximum duty cycle, event start time, end time, duration of event, override-ability of event. A separate project, led by PIER consultant Erich Gunther, to define the PCT's manufacturer specification will attempt to identify universal functions which should be supported in such a *common information model*, and the scenarios which come out of that task can be tested as part of this research.

Additionally, the frequency at which to send the DR dispatch needs definition. Real time DR message propagation would most likely make the controls problem simpler but could annoy the consumer with too much intervention if they are trying to override setpoint adjustments. The consumer would likely prefer at most one DR message per DR event. If several DR signals are sent in the course of a DR event, the control is made more complex because the dynamics of the system would mean that the transient effects of the previous signal would still be active when the next signal is sent. Such dynamic behavior is at the heart of control system theory. On the other hand, no such dynamics are involved if only one DR signal is sent per DR event, but variations from the target system load are likely to be larger.

There are both temporal and spatial aspects to the application of the DR control signal. A well-designed control system could perform sophisticated algorithms to improve the system performance and efficiency. For instance, it could minimize occupant discomfort by rolling the DR signal over geographic areas for short periods of time in order to get the same effect as having the DR signal last for a longer time. It could randomize the start and end times or ramp the desired load-reduction in order to reduce the effect of precooling (early peaking in anticipation of DR dispatch) and postcooling (secondary peak). The system controller could modulate the length of time between when the notice is sent and when the event begins in order to effect precooling. Short-term (5 to 10 minute) events could be used to relieve the stress of bringing new generation capacity online. These temporal and spatial strategies are improved by appropriate feedback, which is resolved to geographic locations and with adequately fast time response.

The core feedback control consideration is dynamic performance of the system. In general, overcompensation leads to system oscillation or even instability; undercompensation leads to larger-than-desired variations from the target demand. Periodic DR signals sent during a DR event could potentially provide much better system load regulation, since the load would naturally vary during the event, but the compensation algorithms would have to take account of system dynamics. This is where the second key feedback control property arises: improper application of feedback control can make the behavior worse. It is crucial to ensure that feedback control of demand response does not drive the system to instability.

Initial literature research needs to be completed in order to better understand the problem. Some distribution utilities have explored and tested dynamic load-curtailment strategies in previous years, and some data may be available which will aid this research. Awareness of the desired load on the grid and non-residential load sectors is a must before the control system can be accurately designed. Research into the practice of time-of-use pricing will likely aid our comprehension. Additionally, the industrial sector uses variable contracts that will affect the response of the system. Understanding these agreements will at the minimum help us to understand how other parts of the electrical distribution system might interact with the residential component that we are studying.

Our initial research will depend heavily on simulation. This begins with creation of a model of the open loop system. The current proposal is to use multiple instances of the present PCT home model. Each instance would represent one home. In order to accurately represent the differences between homes and families, each instance would have to use different parameters, chosen randomly from appropriate distributions. Also, each instance would have to be individually addressable. Finally, to better simulate the real system, a precooling algorithm would need to be added to the PCT model.

The simulation studies would allow us to begin specification of DR signal characterization and design of feedback algorithms. Although it is premature at this time to speculate as to what types of control algorithms might work, we would first examine issues of system stability and robustness (ability of the feedback control to continue to operate satisfactorily even if the target system changes characteristics within some range). An important aspect of these studies is how different types of DR signals (see above) affect control performance. We would then extend the studies to issues of timing, spatial randomization, etc.