A Control System Framework for Privacy Preserving Demand Response of Thermal Inertial Loads

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Research Objective
A theory for operation of the load serving entity (LSE) to enable demand response by controlling the aggregate power consumption for a population of thermostatically controlled loads (TCLs) such as residential air conditioners.

Research Challenges
1. How to design the reference total power trajectory as a function of the forecasted price of energy?
2. The room temperature, setpoint, and ON/OFF binary state of any individual TCL cannot be measured for privacy reasons.
3. The LSE may have different contractual obligations for different TCLs in terms of their comfort ranges.

Key Question: What is the optimal plan for the LSE to schedule the purchase of power? Also, how to control the TCLs in real-time to track the reference total power, while respecting privacy and comfort range constraints?

Idea: Adjust setpoints to meet the optimized target consumption.

Proposed Architecture: A Two Layer Approach

Formulation
First layer: optimal planning of target consumption

\[
\begin{align*}
\min_{\{u(t)\}} & \quad \int_0^T \left( p(t) (w_1(t) + w_2(t) + \ldots + w_N(t)) \right) \, dt, \\
\text{subject to} & \\
(1) \quad & \theta_i(t) = \alpha \left( \theta_i(t) - \bar{\theta}_i(t) \right) - \beta P_{\text{ref}}(t) \quad \forall i = 1, \ldots, N, \\
(2) \quad & \int_0^T (w_1(t) + w_2(t) + \ldots + w_N(t)) \, dt = \tau = \frac{P_{\text{ref}}}{T}, \text{given}, \\
(3) \quad & L_1(t) \leq \theta_i(t) \leq L_2(t) \quad \forall i = 1, \ldots, N.
\end{align*}
\]

Second layer: setpoint control

\[
\begin{align*}
P_{\text{ref}}(t) = & \sum_{i=1}^N w_i(t), \\
\tilde{v}(t) = & \tilde{v}_0(t) + \frac{d}{dt} \left( \frac{\Delta v(t)}{\Delta t} \right) = \Delta v(t). \\
L_0 = & \left( L_{\text{low}}(t) \cap \Delta v(t) \right), \\
U_0 = & \left( U_{\text{high}}(t) \cap \Delta v(t) \right).
\end{align*}
\]

Numerical Results

Conclusions
• A simple framework for optimal demand response.
• Designs optimal target consumption using forecast.
• Tracks the designed target consumption in real-time.
• LSE does not need to know individual states ⇒ preserves privacy.

References

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