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Energy Management of End Users Modeling their Reaction from a GENCO's Point of View

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Outline

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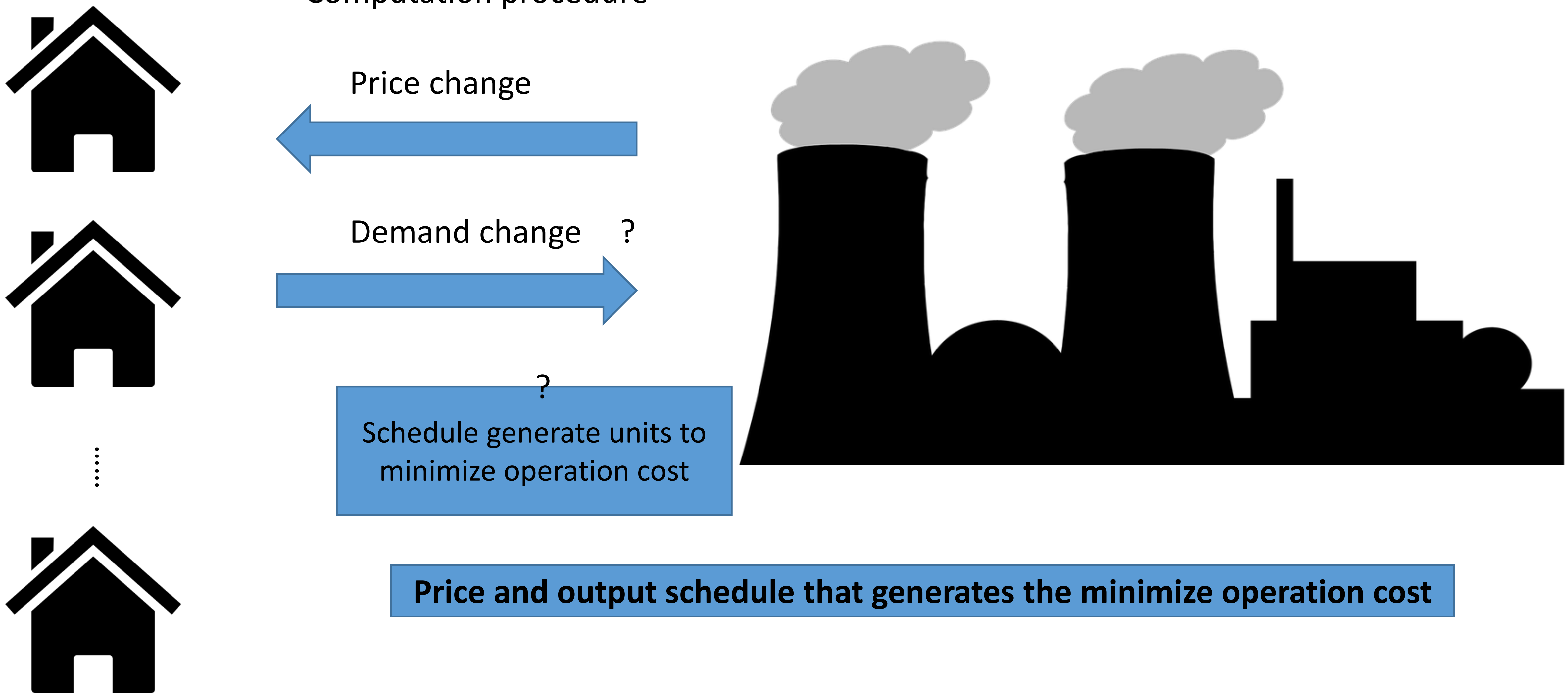
Literature Review

Computation procedure



Introduction

- The energy scheduling problem of generation units involves finding the least-cost dispatch of available power plants to meet the electrical load demand.

- Energy management is considered as the first priority in all the energy policy decisions due to its benefits from economic and environmental viewpoints.

- Energy management is able to reduce overall costs of energy supply, increase reserve margin, and mitigate electricity price volatility.

- Also, it achieves environmental goals by deferring commitment of polluted units, leading to increased energy efficiency and reduced greenhouse gas emissions.

Literature Review

- Previous work
  - Investigate potential of energy management.
  - Determine value of demand for shifting from the peak period to other periods by direct load control for congestion management and increasing utilization of wind power.
  - Investigate energy management in the generation scheduling problem by modeling the reaction of end user customers with respect to the value of incentive for demand reduction at peak period.
- However, in the above mentioned studies, different behaviors of end users with respect to electricity price changes has not been modeled in the generation scheduling problem.
- In this study, price-controlled energy management of end users is investigated in the generation scheduling problem of generation units.
  - Different mathematical models (linear, power, exponential, and logarithmic) are considered for the end users behavior.
  - The behavior of end users is modeled based on the social welfare of end users and their price elasticity of demand.
  - The values of electricity prices in the valley and peak periods are decreased and increased, respectively, to encourage the end users to shift their demands from the peak period to the valley period.
  - Therefore, the demand profile of the system becomes more flat and the overall cost of generation system is decreased, since fuel consumption and emission level of the generation units are polynomial functions.

Proposed Technique

- **Price-Controlled Energy Management Modeling**

- Price elasticity of demand is defined as the demand sensitivity respect to the price

$$E = \frac{\partial \widetilde{D} / D}{\partial \tilde{\pi} / \pi} = \frac{\partial \widetilde{D}}{\partial \tilde{\pi}} \times \frac{\pi}{D} \qquad (1)$$

  - D is the initial demand level, $\widetilde{D}$ is the demand level after introducing the new price, π is the initial price, and $\tilde{\pi}$ is the value of new price.

- If the electricity price varies at different periods (valley, off-peak, and peak periods), the reactions of an end users are as follow:
  - One part of demand of the end user (such as lighting or cooling/heating demands for every type of end users) cannot be transferred to other periods and it can be only "on" or "off" in the same period. Elasticity of such demand does not have any sensitivity to the electricity prices in other periods.
  - Another part of demand of the end user (such as demand of cleaning appliances) can be transferred from one period to other periods. Elasticity of this part of demand, which has sensitivity to the electricity prices of other periods, is called "cross elasticity".

Proposed Technique

- *End User with Linear Behavioral Model:*

$$\widetilde{D}_t^{Lin} = D_t^{Lin} \times \left(1 + \sum_{t'=1}^{24} \frac{\tilde{\pi}_{t'} - \pi_{t'}}{\pi_{t'}} \times E_{t,t'}\right) \qquad (12)$$

- *End User with Power Behavioral Model:*

$$\widetilde{D}_t^{Pow} \cong D_t^{Pow} \times \prod_{t'=1}^{24} \left(\frac{\tilde{\pi}_{t'}}{\pi_{t'}}\right)^{E_{t,t'}} \qquad (17)$$

- *End User with Exponential Behavioral Model:*

$$\widetilde{D}_t^{Exp} = D_t^{Exp} \times e^{\sum_{t'=1}^{24} \frac{\tilde{\pi}_{t'} - \pi_{t'}}{\pi_{t'}} \times E_{t,t'}} \qquad (20)$$

- *End User with Logarithmic Behavioral Model:*

$$\widetilde{D}_t^{Log} = D_t^{Log} \times \left(1 + \sum_{t'=1}^{24} \left(ln\left(\frac{\tilde{\pi}_{t'}}{\pi_{t'}}\right)\right) \times E_{t,t'}\right) \qquad (23)$$

- Electricity prices at peak and valley periods are changed using ρ^{EM}, as can be seen in (24).

$$\tilde{\pi}_t = \begin{cases} \pi_t - \rho^{EM} & t \in Valley \\ \pi_t & t \in Off-peak \\ \pi_t + \rho^{EM} & t \in Peak \end{cases} \qquad (24)$$

Proposed Technique

❑ Optimization Technique

- ➢ Genetic algorithm (GA) is applied to solve the optimization problem.

	G1	G2	…	G10
1	0/1	0/1	0/1	0/1
2	0/1	0/1	0/1	0/1
⋮	⋮	⋮	⋮	⋮
24	0/1	0/1	0/1	0/1

- ➢ The value of objective function (the total cost of generation system over the operation period (one day)) is defined as the fitness of a chromosome.
- ➢ The outputs of GA include:
  - ▪ Minimum value of total cost of generation system over the operation period (one day),
  - ▪ Optimal generation level of units
  - ▪ Optimal demand level of the end users with a behaviour model.

Proposed Technique

❑ Finding Optimal Scheme of Energy Management

TABLE II
The pseudo code for finding the optimal scheme of energy management of end users.

1: Set the value of $\rho^{EM} = 0$.
2: $\rho^{EM} = \rho^{EM} + 1$.
3: Update the electricity price at every period ($\tilde{\pi}$) using (24).
4: Update the system demand ($\widetilde{D}^{Model}$) using (12), (17), (20), and (23) for und users with linear, power, exponential, and logarithmic behaviors, respectively.
5: Solve the optimization problem and determine the minimum daily operation cost of GENCO using GA.
6: Go to Step 2, if $\rho^{EM} < \rho^{EM}_{MAX}$. //$\rho^{EM}_{MAX}$ *is determined based on the initial electricity price at valley period.*
7: Determine optimal value of ρ^{EM} based on the minimum daily operation cost of GENCO.

Problem Formulation

- **Objective Function of the Problem**

$$OF = \sum_{t=1}^{Nt}\left[Cost_t^{EM} + \sum_{g=1}^{Ng}\left[\begin{array}{c} Cost_{g,t}^{F} + Cost_{g,t}^{E} \\ +Cost_{g,t}^{STU} + Cost_{g,t}^{SHD}\end{array}\right]\right] \qquad (25)$$

- *Cost of energy management of end users:* Energy management of end users may result in cost or profit for the GENCO when the income of sold electrical energy decreases or increases after energy management, respectively, as can be seen in equation (26).

$$Cost_t^{EM} = \sum_{Model}\left[D_t^{Model} \times \pi_t - \widetilde{D}_t^{Model} \times \tilde{\pi}_t\right] \qquad (26)$$

- *Fuel cost of generation units:* The fuel cost of every generation unit ($Cost_{g,t}^{F}$), which is in “on” status ($x_{g,t}^{G} = 1$), is a quadratic polynomial. In other words, the generation unit consumes more fuel per power unit when its power is in the upper level of power compared to the value of consumed fuel per power unit in the lower level.

$$Cost_{g,t}^{F} = \left(\alpha_{1,g}^{F} \times \left(P_{g,t}\right)^2 + \alpha_{2,g}^{F} \times \left(P_{g,t}\right) + \alpha_{3,g}^{F}\right) \times x_{g,t}^{G} \qquad (27)$$

- *Greenhouse gas emissions cost of generation units:* The greenhouse gas emissions cost of every generation unit ($Cost_{g,t}^{E}$), which is in “on” status ($x_{g,t}^{G} = 1$), is a quadratic polynomial.

$$Cost_{g,t}^{E} = \beta^{E} \times \left(\alpha_{1,g}^{E} \times \left(P_{g,t}\right)^2 + \alpha_{2,g}^{E} \times \left(P_{g,t}\right) + \alpha_{3,g}^{E}\right) \times x_{g,t}^{G} \qquad (28)$$

- *Start-up cost and shut down cost of generation units:*

$$Cost_{g,t}^{STU} = C_g^{STU} \times \left(1 - x_{g,t-1}^{G}\right) \times x_{g,t}^{G} \qquad (29)$$

$$Cost_{g,t}^{SHD} = C_g^{SHD} \times x_{g,t-1}^{G} \times \left(1 - x_{g,t}^{G}\right) \qquad (30)$$

Problem Formulation

- **Constraints of the Problem**

- *System power balance constraint:* This constraint is applicable for the problem with ($x^{EM}=1$) and without ($x^{EM}=0$) energy management of end users.

$$\sum_{g=1}^{Ng} P_{g,t}\times x_{g,t}^{G} = \sum_{Model}\left(D_t^{Model}\times(1-x^{EM})+\tilde{D}_t^{Model}\times x^{EM}\right) \quad (31)$$

- *System minimum generation constraint:*

$$\sum_{g=1}^{Ng} P_g^{min}\times x_{g,t}^{G} \le \sum_{Model}\left(D_t^{Model}\times(1-x^{EM})+\tilde{D}_t^{Model}\times x^{EM}\right) (32)$$

- *System maximum generation constraint with spinning reserve:*

$$\sum_{g=1}^{Ng} P_g^{max}\times x_{g,t}^{G} \ge \sum_{Model}\left(D_t^{Model}\times(1-x^{EM})+\tilde{D}_t^{Model}\times x^{EM}\right)+SR_t \quad (33)$$

- *Generation units' power constraint:*

$$\left(P_g^{min}\le P_g(t)\le P_g^{max}\right)\times x_{g,t}^{G} \quad (34)$$

- *Ramp-up rate and ramp-down rate constraints:*

$$\left(\left(P_{g,t+1}-P_{g,t}\right)\le RUR_g\right)\times x_{g,t}^{G} \quad (35)$$

$$\left(\left(P_{g,t}-P_{g,t+1}\right)\le RDR_g\right)\times x_{g,t}^{G} \quad (36)$$

- *Minimum "off time" and minimum "on time" constraints:*

$$OFFT_{g,t}\ge MDT_g \quad (37)$$

$$ONT_{g,t}\ge MUT_g \quad (38)$$

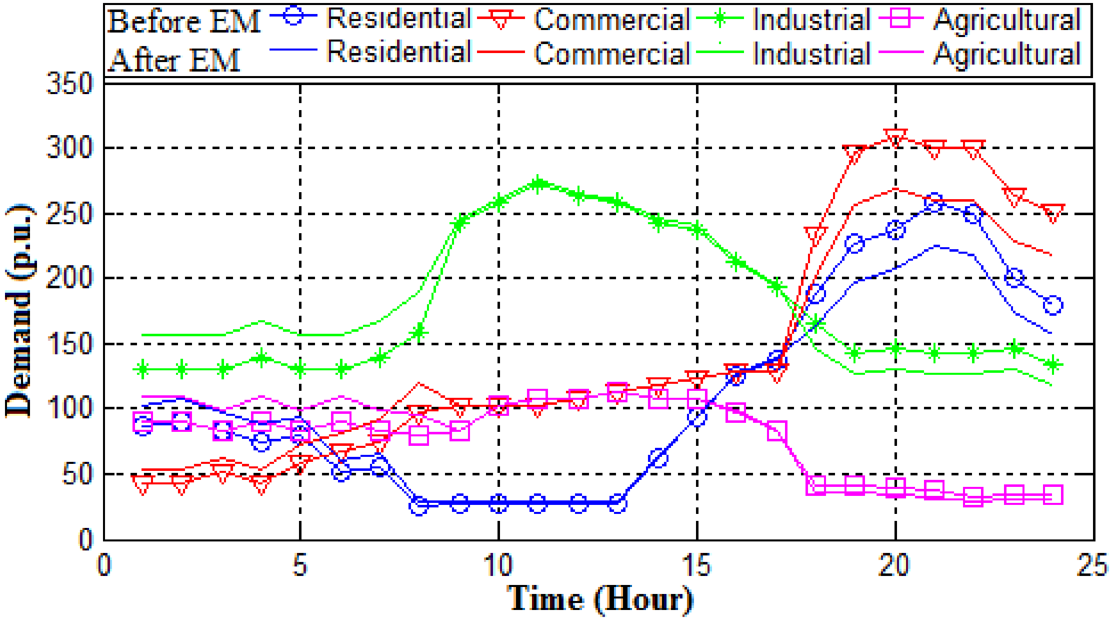
Problem Simulation

TABLE VI
RESULTS OF THE PROBLEM SIMULATION WITH AND WITHOUT ENERGY MANAGEMENT OF END USERS.

-	Before EM	After optimal EM	Reduction
Generation cost ($/day)	377,290	361,793	15,497
Energy management cost	0	-5,543	-
Total cost of system	377,290	356,250	21,040
Total emissions (Ton/day)	6,538	6,358	180

TABLE VII
THE OPTIMAL SCHEME OF PRICE-CONTROLLED ENERGY MANAGEMENT OF THE END USERS.

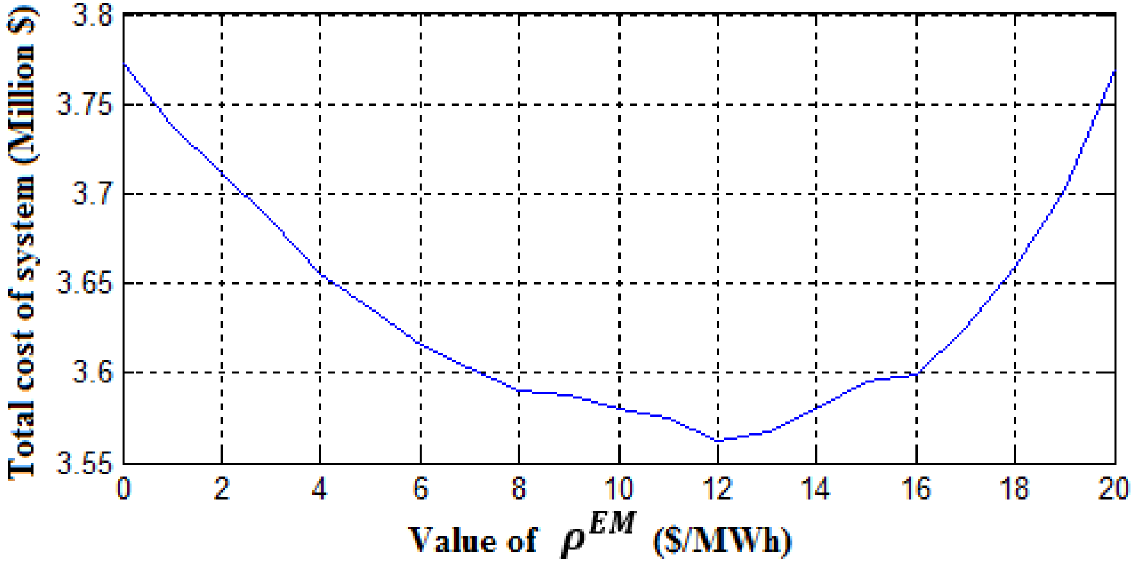
	Valley period	Off-peak period	Peak period
Electricity price before EM ($/MWh)	21.3	23.1	27.3
Electricity price after optimal EM ($/MWh)	9.3	23.1	39.3



Problem Simulation

TABLE VIII
THE POWER LEVEL OF UNITS (MW) WITH OPTIMAL SCHEME OF PRICE-CONTROLLED ENERGY MANAGEMENT OF END USERS.

Hour	G1	G2	G3	G4	G5	G6	G7	G8	G9	G10
1	203	75	65	65	15	0	0	0	0	0
2	208	75	65	65	15	0	0	0	0	0
3	198	75	65	65	15	0	0	0	0	0
4	198	75	65	65	15	0	0	0	0	0
5	203	75	65	65	15	0	0	0	0	0
6	190	75	65	65	15	0	0	0	0	0
7	204	75	65	65	15	0	0	0	0	0
8	216	75	65	65	15	0	0	0	0	0
9	230	86	65	65	15	0	0	0	0	0
10	230	121	65	65	15	0	0	0	0	0
11	230	141	65	65	15	0	0	0	0	0
12	230	136	65	65	15	0	0	0	0	0
13	230	141	65	65	15	0	0	0	0	0
14	230	162	65	65	15	0	0	0	0	0
15	230	192	65	65	15	0	0	0	0	0
16	230	194	65	65	15	0	0	0	0	0
17	230	172	65	65	15	0	0	0	0	0
18	230	175	65	65	15	0	0	0	0	0
19	230	230	65	65	18	10	0	0	0	0
20	230	230	65	65	40	10	0	0	0	0
21	230	230	65	65	46	10	0	0	0	0
22	230	230	65	65	34	10	0	0	0	0
23	230	190	65	65	15	0	0	0	0	0
24	230	149	65	65	15	0	0	0	0	0



Conclusion

- Price-controlled energy management of the end users in the generation scheduling problem is noticeably advantageous, since it can decrease the total cost of system and the greenhouse gas emissions level of the generation units.

- In order to minimize the total cost of system managed by the generation company, we proposed and implemented optimal scheme of price-controlled energy management.

- In addition, we realistically modeled the behavior of end users since the end users with different behavioral models have dissimilar reactions to the energy management schemes, and consequently different value for the total cost of system will be obtained.

- Our numerical studies confirm the effectiveness of the proposed approach in minimizing the total cost of system.

Thank you!
Questions & Comments?

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