Power Systems - Term Project

Reducing Electricity Cost of Smart Appliances

DRM-1

A.D.V.M.S. Nikhil – 2022EEB1165

J Naveen Prasad – 2022EEB1176

K. Sethu Madhav – 2022EEB1186

Objective

(i) To reduce peak demand and consumer consumption cost

(ii) To satisfy consumer comfort level

(iii) To minimize the mismatch in power in each slot

(iv) To simulate a real-time scheduling model

Methodology

The methodology implemented addresses an energy scheduling problem using Mixed-Integer Linear Programming (MILP). It formulates the scheduling of appliances with varying power demands, energy requirements, and priority levels across discrete time slots, aiming to minimize total cost while constraining energy limits. The core approach involves defining an objective function that combines energy costs and a penalty for mismatch between available and consumed energy, subject to constraints ensuring each appliance's energy demand is met and the total power consumption at each time slot remains within a specified limit. The MILP is solved using “intlinprog”, and the resulting binary variables give an optimized schedule and analyse power usage and mismatch.

Simulation Results

- *Original Results from the base paper*

TPSM Resultant Scheduling scheme for LS1

Appliance	Time Slot T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	1	1	0	0	0	0	1	0
A4	1	1	0	0	0	0	0	1
A5	1	1	1	0	0	0	1	1
A6	1	1	1	0	0	0	1	1
A7	1	1	1	0	1	0	1	1
A8	1	1	1	0	1	0	1	1
A9	1	0	0	0	0	0	1	0
A10	0	0	0	0	0	0	1	1

TPSM Resultant Scheduling scheme for LS2

Appliance	Time Slot T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	1	1	0	0	0	0	1	0
A4	1	1	0	0	0	0	0	1
A5	1	1	1	0	0	0	1	1
A6	1	1	1	0	0	0	1	1
A7	1	1	1	0	1	0	1	1
A8	1	1	1	0	1	0	1	1
A9	1	0	0	0	0	0	1	0
A10	0	0	0	0	0	0	1	1

TPSM Resultant Scheduling scheme for LS3

Appliance	Time Slot T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	1	1	0	0	0	0	1	0
A4	1	1	0	0	0	0	0	1
A5	1	1	1	0	0	0	1	1
A6	1	1	1	0	0	0	1	1
A7	1	1	1	0	1	0	1	1
A8	1	1	1	0	1	0	1	1
A9	1	0	0	0	0	0	1	0
A10	0	0	0	0	0	0	1	1

TPSM Resultant Scheduling scheme for LS4

Appliance	Time Slot T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	1	1	0	0	0	0	1	0
A4	1	1	0	0	0	0	0	1
A5	1	1	1	0	0	0	1	1
A6	1	1	1	0	0	0	1	1
A7	1	1	1	0	1	0	1	1
A8	1	1	1	0	1	0	1	1
A9	1	0	0	0	0	0	1	0
A10	0	0	0	0	0	0	1	1

- ❖ This represents the amount of power consumed by each appliance in all slots for different load scenarios.

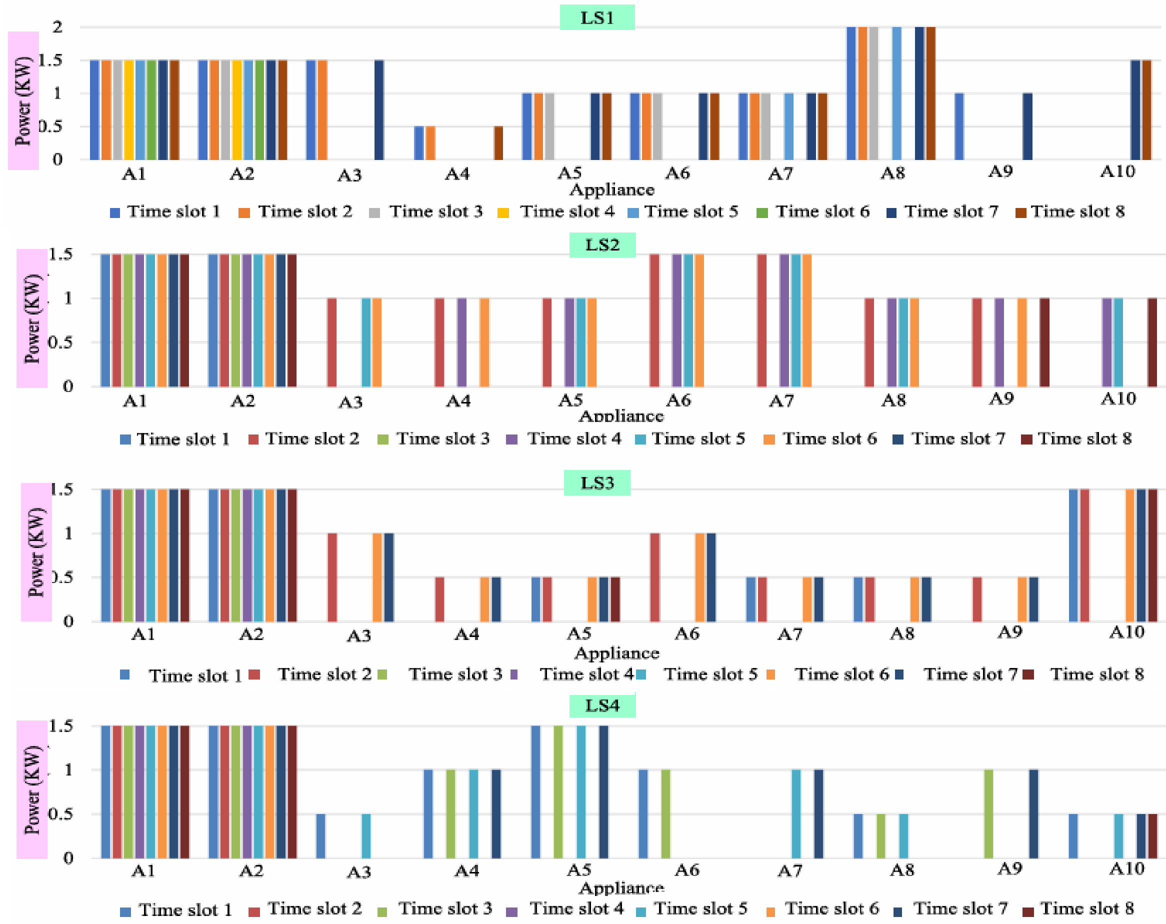


FIGURE 4. **Appliances scheduling split-up (scheme) by TPSM for LS1-LS4.**

- ➢ ***Simulation Results from interim-demo implementation***

Optimized Appliance Scheduling:

LS1

Appliance	T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	1	0	0	0	0	0	1	1
A4	1	0	0	0	0	0	1	1
A5	1	1	0	0	1	0	1	1
A6	1	1	0	0	1	0	1	1
A7	1	1	1	0	1	0	1	1
A8	1	1	1	0	1	0	1	1
A9	1	0	0	0	0	0	1	0
A10	1	0	0	0	0	0	1	0

LS2

Appliance	T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	0	1	0	1	0	1	0	0
A4	0	1	0	1	0	1	0	0
A5	0	1	0	1	0	1	0	1
A6	0	1	0	1	0	1	0	1
A7	0	1	0	1	0	1	0	1
A8	0	1	0	1	0	1	0	1
A9	0	1	0	1	0	1	0	1
A10	0	1	0	1	0	1	0	0

LS3

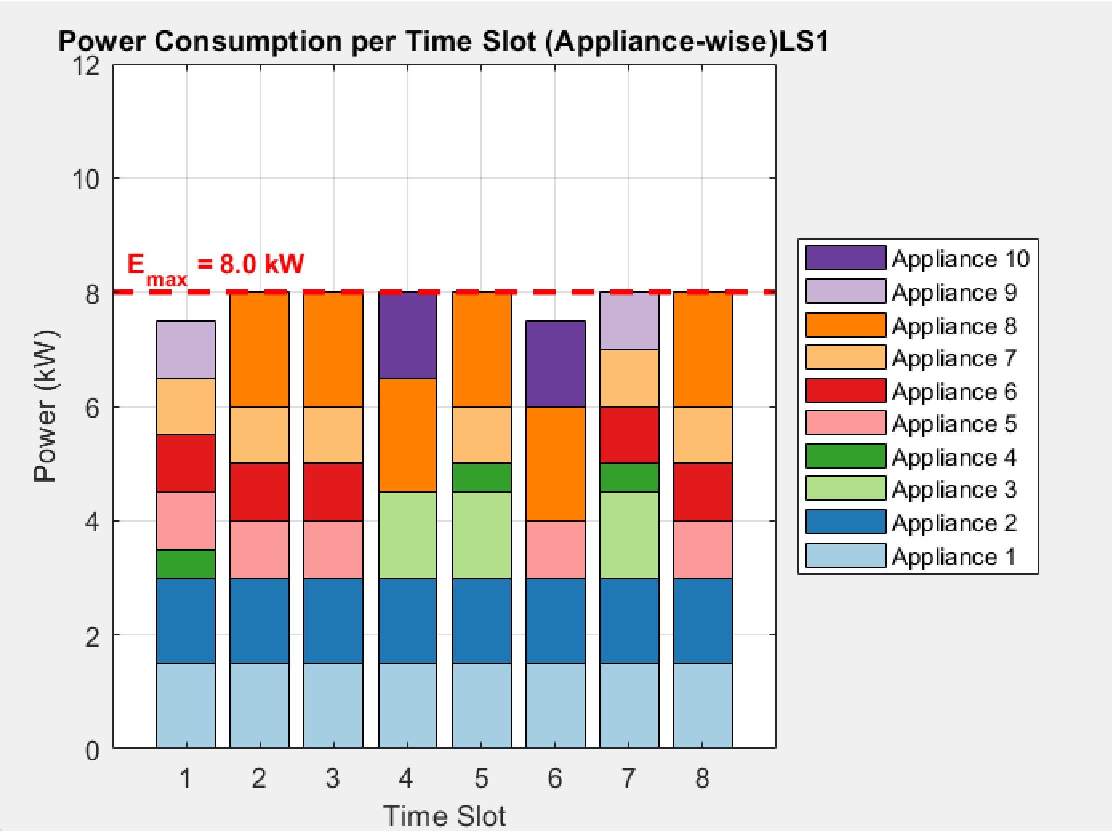
Appliance	T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	0	1	0	0	0	1	1	0
A4	0	1	0	0	0	1	1	0
A5	1	1	0	0	0	1	1	1
A6	0	1	0	0	0	1	1	0
A7	1	1	0	0	0	1	1	0
A8	1	1	0	0	0	1	1	0
A9	0	1	0	0	0	1	1	0
A10	1	1	0	0	0	1	1	1

LS4

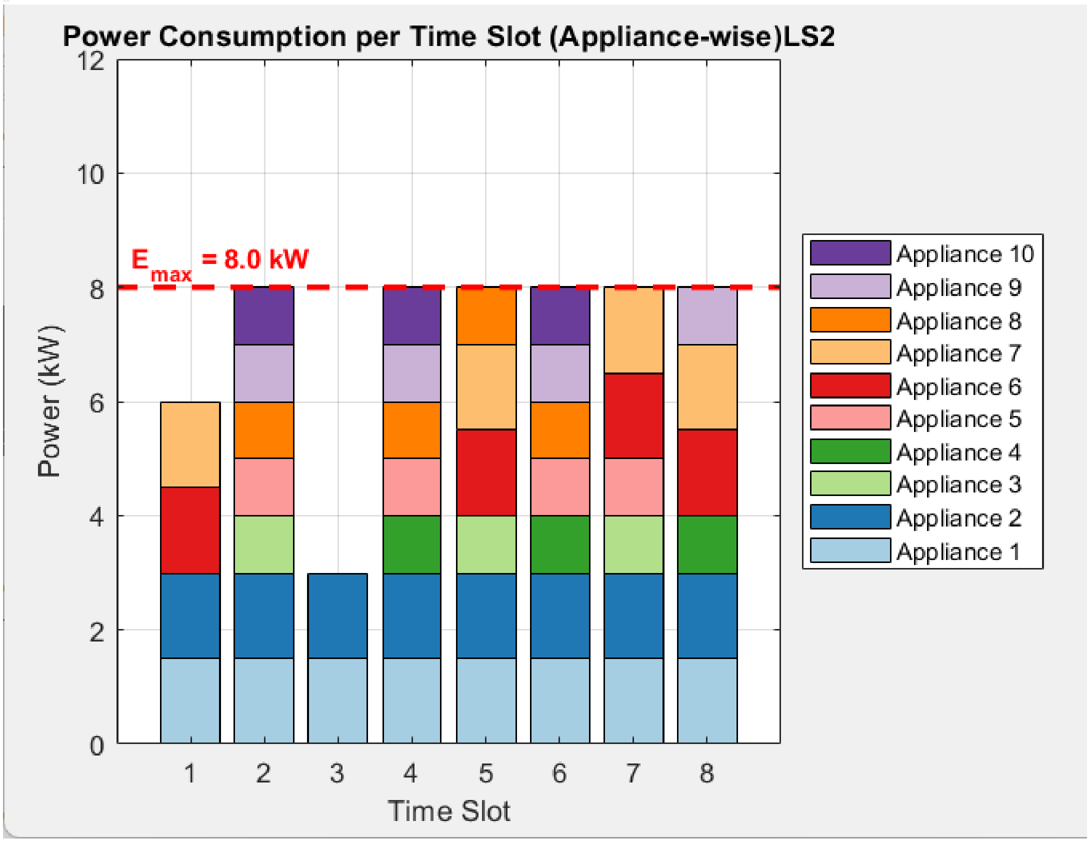
Appliance	T1	T2	T3	T4	T5	T6	T7	T8
A1	1	1	1	1	1	1	1	1
A2	1	1	1	1	1	1	1	1
A3	1	0	0	0	0	0	1	0
A4	1	0	1	0	0	0	1	1
A5	1	0	1	0	0	0	1	1
A6	1	0	0	0	0	0	1	0
A7	1	0	0	0	0	0	1	0
A8	1	0	1	0	0	0	1	0
A9	1	0	0	0	0	0	1	0
A10	1	0	1	0	0	0	1	1

➢ *Simulation Results of Final and Improved version*

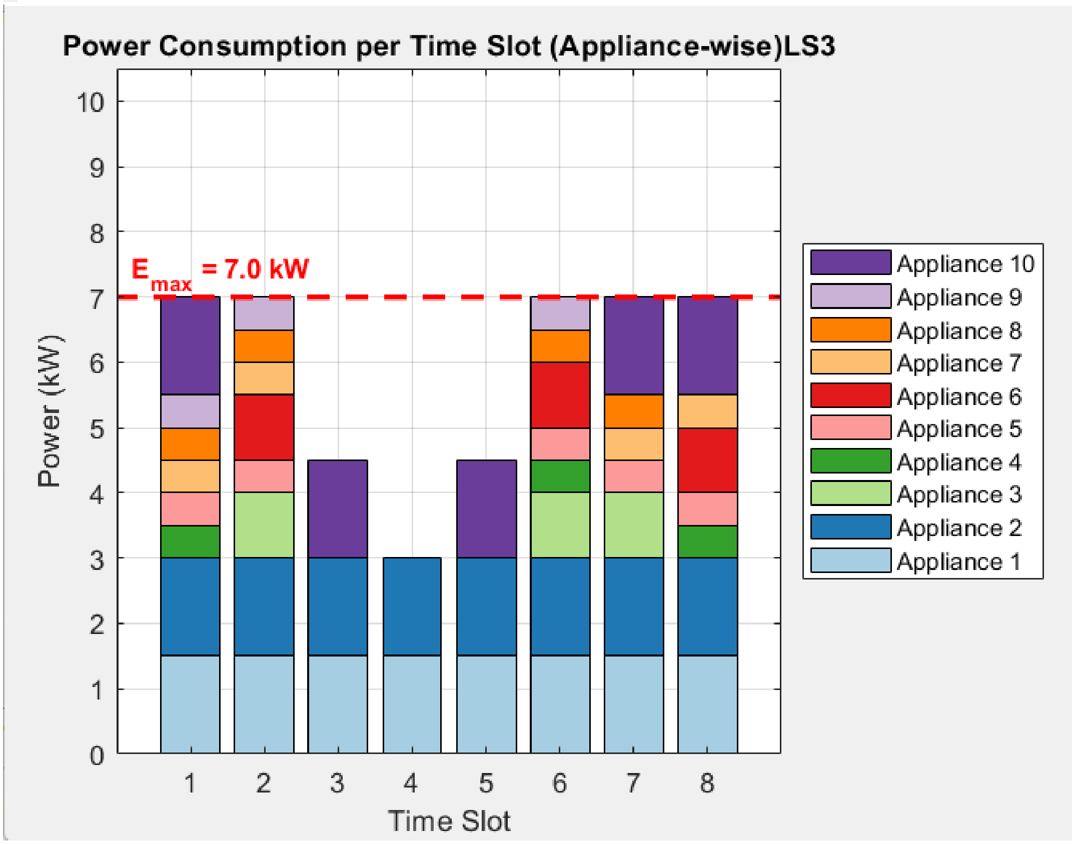
```
Optimized Appliance Scheduling LS1(1=ON, 0=OFF):

                T1    T2    T3    T4    T5    T6    T7    T8
Appliance 1      1     1     1     1     1     1     1     1
Appliance 2      1     1     1     1     1     1     1     1
Appliance 3      1     0     0     0     1     0     1     0
Appliance 4      1     0     0     0     1     0     1     0
Appliance 5      1     1     1     0     0     1     0     1
Appliance 6      0     1     1     1     0     0     1     1
Appliance 7      1     1     1     0     1     0     1     1
Appliance 8      0     1     1     1     1     1     0     1
Appliance 9      1     0     0     0     0     0     1     0
Appliance 10     0     0     0     1     0     1     0     0
     Energy:    8.0   8.0   8.0   7.5   8.0   7.5   8.0   8.0
   Mismatch:    0.0   0.0   0.0   0.5   0.0   0.5   0.0   0.0

Consumed Cost: 32.0  40.0  48.0  52.5  48.0  60.0  16.0  40.0
  per slot

Utility Cost:   4.0   5.0   6.0   7.0   6.0   8.0   2.0   5.0
  per slot

   E_max:       8

Total Power Consumption Cost = 249.00
```



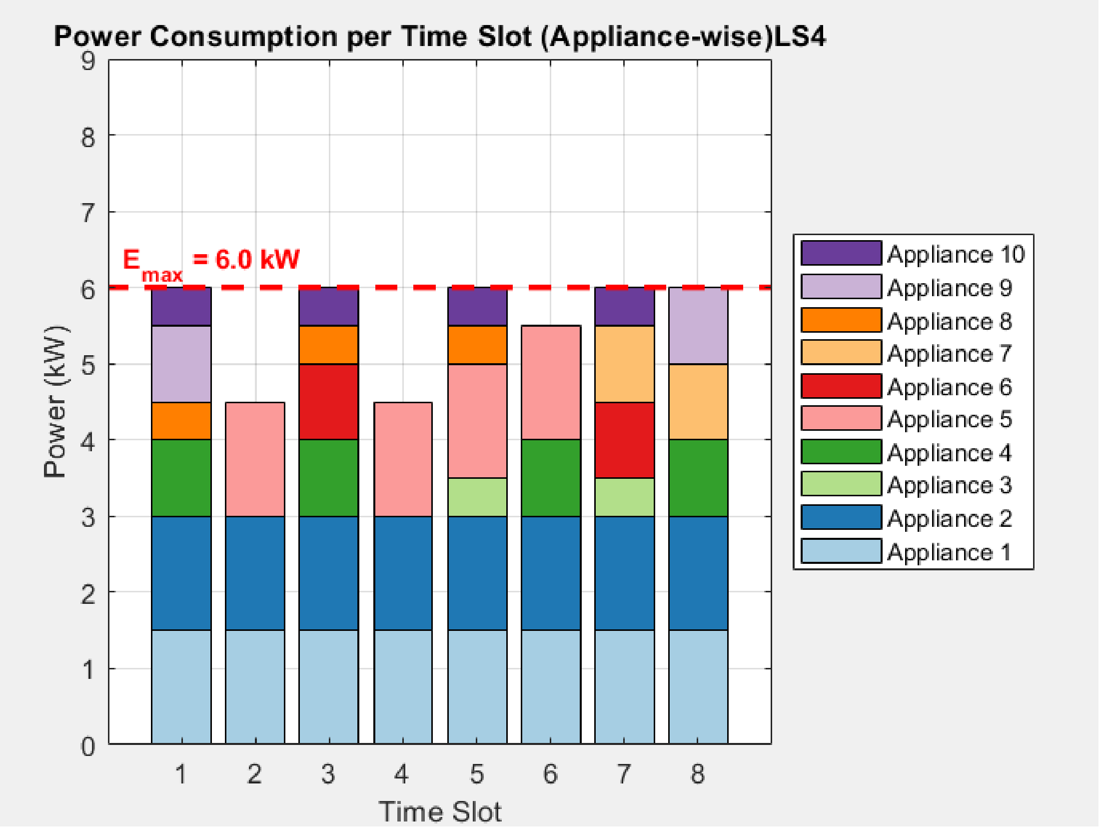
```
Optimized Appliance Scheduling LS2(1=ON, 0=OFF):

                 T1     T2     T3     T4     T5     T6     T7     T8
Appliance 1      1      1      1      1      1      1      1      1
Appliance 2      1      1      1      1      1      1      1      1
Appliance 3      0      1      0      0      1      0      1      0
Appliance 4      1      0      0      0      0      1      0      1
Appliance 5      0      1      0      1      0      1      0      1
Appliance 6      0      0      1      1      1      0      1      0
Appliance 7      1      0      0      0      1      0      1      1
Appliance 8      0      1      0      1      1      1      0      0
Appliance 9      1      1      0      0      0      1      0      1
Appliance 10     0      1      0      1      0      1      0      0
     Energy:     6.5    8.0    4.5    7.5    8.0    8.0    7.0    7.5
   Mismatch:     1.5    0.0    3.5    0.5    0.0    0.0    1.0    0.5

Consumed Cost:  52.0   24.0   40.5   30.0   48.0   40.0   49.0   45.0
  per slot

Utility Cost:    8.0    3.0    9.0    4.0    6.0    5.0    7.0    6.0
  per slot

   E_max:        8

Total Power Consumption Cost = 254.00
```



```
Optimized Appliance Scheduling LS3(1=ON, 0=OFF):

              T1    T2    T3    T4    T5    T6    T7    T8
Appliance 1    1     1     1     1     1     1     1     1
Appliance 2    1     1     1     1     1     1     1     1
Appliance 3    0     1     0     0     0     1     1     0
Appliance 4    1     0     0     0     0     1     0     1
Appliance 5    1     1     0     0     0     1     1     1
Appliance 6    0     1     0     0     0     1     0     1
Appliance 7    1     1     0     0     0     0     1     1
Appliance 8    1     1     0     0     0     1     1     0
Appliance 9    1     1     0     0     0     1     0     0
Appliance 10   1     0     1     0     1     0     1     1
     Energy:  7.0   7.0   4.5   3.0   4.5   7.0   7.0   7.0
   Mismatch:  0.0   0.0   2.5   4.0   2.5   0.0   0.0   0.0

Consumed Cost: 35.0  21.0  31.5  27.0  36.0  28.0  28.0  42.0
  per slot

Utility Cost:   5.0   3.0   7.0   9.0   8.0   4.0   4.0   6.0
  per slot

   E_max:      7

Total Power Consumption Cost = 229.00
```



```
Optimized Appliance Scheduling LS4(1=ON, 0=OFF):

                T1    T2    T3    T4    T5    T6    T7    T8
Appliance 1      1     1     1     1     1     1     1     1
Appliance 2      1     1     1     1     1     1     1     1
Appliance 3      0     0     0     0     1     0     1     0
Appliance 4      1     0     1     0     0     1     0     1
Appliance 5      0     1     0     1     1     1     0     0
Appliance 6      0     0     1     0     0     0     1     0
Appliance 7      0     0     0     0     0     0     1     1
Appliance 8      1     0     1     0     1     0     0     0
Appliance 9      1     0     0     0     0     0     0     1
Appliance 10     1     0     1     0     1     0     1     0
     Energy:    6.0   4.5   6.0   4.5   6.0   5.5   6.0   6.0
   Mismatch:    0.0   1.5   0.0   1.5   0.0   0.5   0.0   0.0

Consumed Cost: 24.0  40.5  30.0  36.0  36.0  38.5  24.0  36.0
  per slot

Utility Cost:   4.0   9.0   5.0   8.0   6.0   7.0   4.0   6.0
  per slot

   E_max:       6

Total Power Consumption Cost = 223.00
```



❖ ***Cost Comparison among different methods***

Load Scenarios	TPSM (base paper)	Interim demo	Final demo
LS1	297	294	249
LS2	294	288	254
LS3	231	231	229
LS4	245	238.5	223

❖ ***Response Time Comparison between different methods***

METHODS	Time
TPSM (base paper)	0.047 seconds
intlinprog	0.015175 seconds

Discussion

The model was implemented in MATLAB using `intlinprog`, with each decision variable representing whether a particular appliance is active at a specific time slot. The results showed that the system effectively respects both individual appliance requirements and energy capacity limits, offering a flexible tool for smart and efficient energy management.

From this method we have observed that we are able to achieve cheaper operations compared to the method in base paper, also by introducing parameters like alpha and beta, and setting the value of maximum power per slot to be less than sum of power rating of each appliance in a slot, so inclusion of the above points led to significant decrease in the total cost.

In addition to that we observed better utilisation of power in each slot, that is minimising the mismatch, along with that our method is computationally less intensive compared to the two-phase simplex method proposed in the base paper.

Conclusions

In this project, we designed an advanced home energy management system by enhancing the base model with multiple new features to better optimize electricity usage and cost. Using Mixed-Integer Linear Programming solved through MATLAB's `intlinprog` function, we achieved efficient scheduling of appliances by considering power demands, required active time slots, and dynamically assigned priority levels. Compared to the base model, our modified approach successfully reduced the total cost, and improved power slot utilization, while still meeting user comfort levels.
In addition to static scheduling, we developed a real-time scheduling model that allows priority values to be updated dynamically based on user inputs during operation. This real-time flexibility ensures that unexpected user preferences, appliance demands can be accommodated immediately without violating energy constraints. Features like mismatch minimization between available and used energy per slot, tuneable cost functions with priority and energy usage weights α and β, and binary ON/OFF scheduling for appliances make the system more robust, user-adaptive, and practical for real-world smart home scenarios.

References

1. *Base Paper* (click here) - **A. Singaravelan, K. M. D, J. P. Ram, G. B., and Y.-J. Kim, "Application of Two-Phase Simplex Method (TPSM) for an Efficient Home Energy Management System to Reduce Peak Demand and Consumer Consumption Cost,"** ***IEEE Access*****, vol. 9, pp. 63591-63601, May 2021.**

2. *Input Parameters for different load scenarios(from pp922-923)* (click here) - **A. Basit, G. A. S. Sidhu, A. Mahmood, and F. Gao, "Efficient and autonomous energy management techniques for the future smart homes", IEEE Trans. Smart Grid, vol. 8, no. 2, pp. 917 - 926, Mar. 2017.**

Modifications and Extensions

The base paper used the Two-Phase Simplex Method (TPSM) to optimize **cost minimization** and **peak demand reduction** in a residential energy management system. The key constraints maintained were ensuring 100% task completion of home appliances and limiting the maximum demand per time slot to a target value **E**. Optimization was performed using a standard linear programming approach without any priority consideration or mismatch penalty.

In our modified and improved version of the work, several enhancements were made.
First, **priority-based scheduling** was introduced. Appliance priorities were taken as input from the user, and the cost function was modified to penalize lower-priority appliances. Specifically, the cost function was changed to:

$$\textbf{Effective Cost} = \textbf{Base Cost} - \boldsymbol{\alpha} \times \textbf{Priority}$$

where **α** is a tuneable weight for priority influence. Higher-priority appliances are thus encouraged to be scheduled earlier, offering better flexibility based on user needs.

Second, **mismatch minimization** was added as another objective. Here, the model additionally minimized the difference between the maximum allowed slot energy (E) and the actual energy used. The new combined objective function became:

$$\textbf{Objective Function} = \textbf{Effective Cost} - \boldsymbol{\beta} \times \textbf{Energy Used}$$

where **β** is a reward factor to encourage fuller utilization of power in a time slot. This helped achieve better slot-wise load balancing while reducing wastage.

Next, the input flexibility was improved. The user now provides inputs for Emax (maximum energy per slot), appliance priority matrix, and the weights **α** and **β**. This makes the system much more dynamic and adaptable to real-world requirements compared to the fixed setup in the base TPSM model.

Next, we maintained **binary scheduling** (appliance ON/OFF states) using MATLAB’s intlinprog solver instead of manually solving using TPSM phases. This made the model faster, more reliable, and simpler to implement.

Finally, in addition to flexible user inputs and enhanced objective functions, we further extended the work by developing a dynamic rescheduling function "**reschedule".**

This functions allow selective turning **off** or **on** of a specific appliance at a particular time slot and dynamically **re-optimize the *remaining* schedule**.

This function rebuilds the optimization problem considering the updated ON/OFF constraint while satisfying appliance time requirements and the overall energy capacity limits.

The updated schedules are then printed and visualized using a custom **printer** function.

This dynamic rescheduling framework makes the system highly **interactive, user-driven, and real-time adaptable**, which was not supported in the base TPSM method.