Application of Two-Phase Simplex Method for an Efficient Home Energy Management System to Reduce Peak Demand and Consumer Consumption Cost

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Abstract

Superabundant utilization of electricity in the residential sector is one of the major reasons for frequent peak demand. Hence, power sector necessitates an appropriate solution to control and monitor the peak demand. In this regard, implementation of an appropriate home energy management system becomes mandatory at customer premises to have an effective control over peak demand. In this situation, Two Phase Simplex Method is proposed with an objective to (i) reduce peak demand, (ii) reduce consumer consumption cost, and (iii) conserve consumer comfort level. For simulations, different load scenarios are considered

and the results are compared with the existing benchmarks available in the literature. On validations, the proposed TPSM method is found simple, reliable and efficient. More importantly, the multipurpose objectives has certainly given better results in consumer consumption cost that can give better control to peak demand. Furthermore, the usage of this two phase simplex method has almost reduced the computational complexity to fasten the response time.

Introduction

Modernization with recent technology driven by the advancement in power electronics has made the common mankind to utilize the electronic home appliances in regular routines. Excess power usage via modernized and conventional electric home appliances results in an increase in power demand and periodic peak demand. The productive advancements in electric vehicle technology is considered as one of the probable inclusions in home energy management for battery charging. This again increases the burden on utility to raise the power demand and peak demand. Hence, burden on utility becomes monumental to supply the actual power demand for consumers. This uncertain power demand forces the utility to create frequent power outages for consumers. To attenuate the problem, an effective Home Energy Management (HEM) system is needed. In particular, the self automated HEM is more appropriate to serve for this purpose. Note that HEM is not only beneficial for utility but also to the consumer from an economic perspective. Implementation of much effective HEM can be achieved with the assistance from smart grid technology. Smart grid system has the provision to merge distributed renewable energy sources with conventional power grid. Wise usage of smart grid technology and HEM system, balances the ratio between power demand and available power generation to attain bidirectional communication feature.

System Model

In order to present an accurate system model, an actual real time pricing scheme was considered to implement the proposed TPSM based HEM. A smart grid infrastructure at consumer premises is needed to implement the automated demand response program. An HEM systems with Wireless Home Area Network (WHAN) and cloud computing is considered at the consumer's premise for applying the proposed TPSM. The infrastructure is designed to execute the proposed algorithm by getting input from utility and consumer. Central Control System (CCS) acts as a brain for the entire system. For communication, the Ethernet is connected between CCS and utility. Common day-ahead electricity cost for the different time slot is generated by the utility and transmitted to its entire consumer's CCS. It is important to note here that CCS connects all home appliances in every individual home to an individual wireless switch via ZigBee to facilitate wireless ON/OFF control of home appliances.

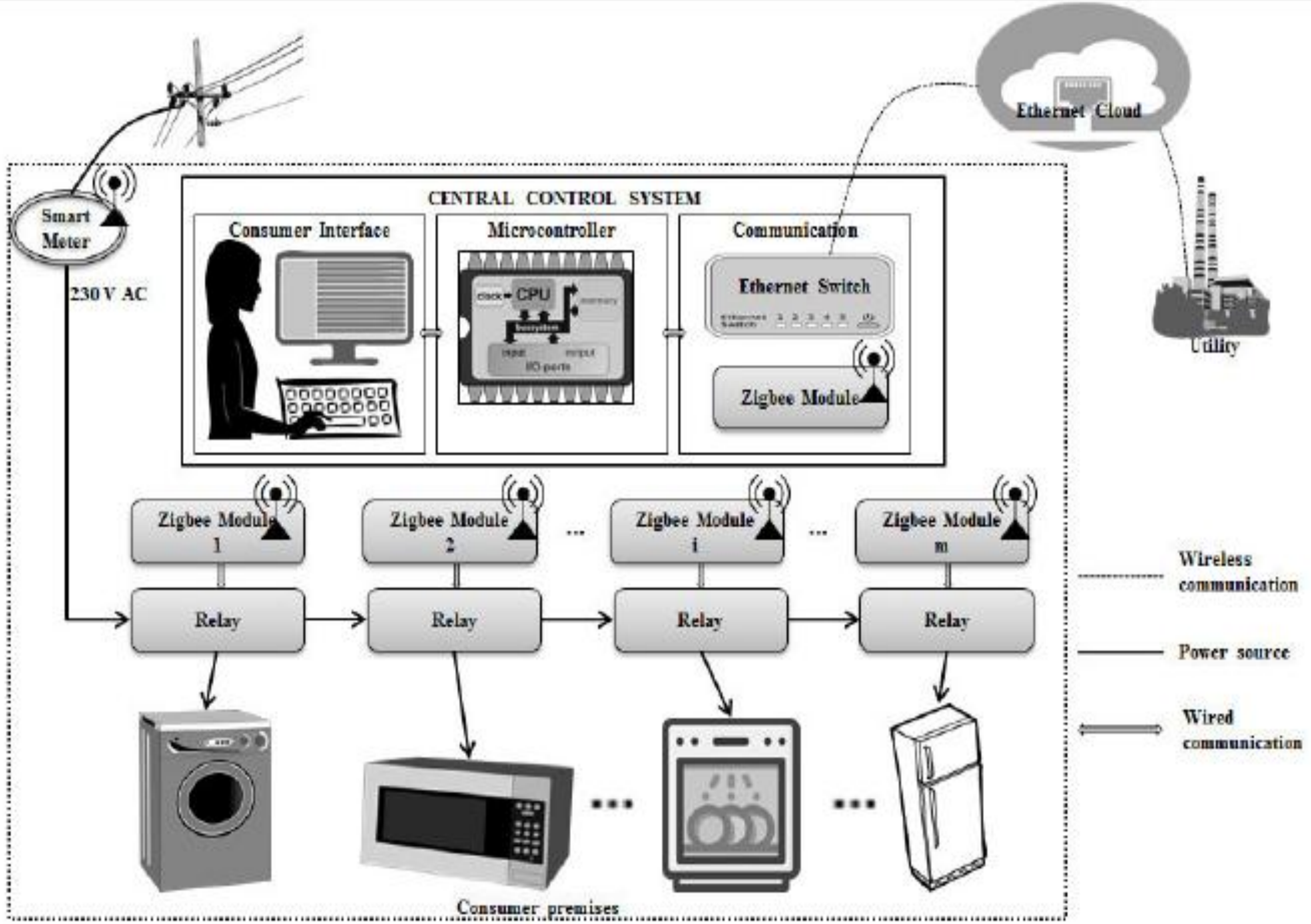


FIGURE 1. Proposed home energy management system.

Problem Formulation

The problem formulation is made to reduce power consumption cost of customers without compromising the consumer comfort. Reduction of cost in peak demand is wisely handled to resolve the burden impound on utility and consumers. The power consumption cost is reduced by shifting the residential electrical load from peak to the off-peak time slot. This is an existing scheme implemented in real-time pricing of the consumers connected to smart grid technology. To maintain demand in limits, load shifting must be carried out in such a way that all necessary appliances are ensured to not get affected during its working process. It is important to avoid consumer dissatisfaction. One of the usual problems that arise in the implementation of real time- demand response program is that every consumer tends to shift their electric load from a high-cost time slot to a low-cost time slot to reduce the power consumption cost. But then, new peak demand is created due to the aforementioned load shifting. And thus it is necessary to allot total electrical demand within a limited range to neglect the needless peak demand. To accomplish the task, a target value constant E is assigned to maintain peak to average ratio in a limited range and hence the peak demand is restricted. This ensures the maximum electrical load per house is limited and not getting exceeded to the target value E. It is important to note that the target value is assigned by the electric utility depending upon the climate or seasonal or festival condition of their consumer. This target value E may not change frequently hence, the authors considered E as constant.

By considering the prerequisite objectives and constraints, the authors formulated a mathematical model for a residential consumer. Let, set (A) = {A(1); A(2); A(3);…; A(i);…; A(M)}, be the set of M number of home appliances, where Ai denotes the ith appliance. Set (D) = {DA(1); DA(2); DA(3);...; DA(i);...;DA(M)}, be the set of the rated power of appliances, where DA(i) denotes the rated power of ith appliances in kW. The total demand needed by individual appliances to complete its 100% task per day is given in set (L) = {L(1); L(2);L(3);…; L(i);…;L(M)},
such that the total power consumed by DA(i) of the appliance must be equal to L(i) to complete its 100% task. Set (T) = {T(1); T(2); T(3);…; T(j);…; T(N) }, be the set of `N' number of time slots and cost set

(C) = {C(1);C(2);…;C(j);…;C(N)} in cents/kW for time slots. For mathematical formulation, M*N decision variable (V(i,j)) are introduced in (1). In equation (1), the variables ‘i’ denote appliances and ‘j’ represents respective time slot. If the ith appliance is scheduled to ‘ON’ at jth time slot then (V(i,j)) =1, otherwise V(i,j)) =0.

$$
\begin{matrix}
V_{1,1} & V_{1,2} & \cdots & V_{1,j} & \cdots & V_{1,N} \\
V_{2,1} & V_{2,2} & \cdots & V_{2,j} & \cdots & V_{2,N} \\
\vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\
V_{i,1} & V_{i,2} & \cdots & V_{i,j} & \cdots & V_{i,N} \\
\vdots & \vdots & \cdots & \vdots & \cdots & \vdots \\
V_{M,1} & V_{M,2} & \cdots & V_{M,j} & \cdots & V_{M,N}
\end{matrix} \qquad (1)
$$

Power consumed by the ith appliance at jth time slot can be found by using (DAi)*(Vi,j) and the total power consumed by all appliances at jth time slot (PTj) can be referred in equation (2). The total power consumed by the ith appliance at day-end (PAi) is given in equation (3).

$$PT_j = \sum_{i=1}^{M} (DA_i) \times (V_{i,j}) \tag{2}$$

$$PA_i = \sum_{j=1}^{N} (DA_i) \times (V_{i,j}) \tag{3}$$

To meet out the objective of consumer comfort, all appliances must complete 100% of the task by day-end. Therefore, the power consumed by ith appliances must be equal to (Li) as given in the constraint equation (4). To accomplish the comfort, various loads allotted for a single time slot must be lesser than or equal to the target value E. This will confirm that the demand is shared within the limit for all the time slots. Thus, the demand curve is under control and it will not lead to a peak demand. The constraint for maximum allowed power per time slot by all the sum of appliances per house is given in equation(5).

$$PA_i = L_i, \quad \forall (i = 1, 2, \cdots, M) \tag{4}$$

$$PT_j \leq E, \quad \forall (j = 1, 2, \cdots, N) \tag{5}$$

The consumption cost at j^{th} time slot (CC_j) is given in equation (6)

$$(CC_j) = (C_j) \times (PT_j), \quad \forall (j = 1, 2, \cdots, N) \tag{6}$$

Therefore, the total cost at the day-end (Z) is given in (7)

$$Z = \sum_{j=1}^{N} CC_j \tag{7}$$

Set of Appliance (M Numbers)	Set of time slots per day (N Slots)					Total power consumed per appliance at end of the day
	T_1	T_2	T_3	$\cdots$	T_j	
A_1	$(DA_1)\times(V_{1,1})$	$(DA_1)\times(V_{1,2})$	$(DA_1)\times(V_{1,3})$	$\cdots$	$(DA_1)\times(V_{1,j})$	$PA_1=\sum_{j=1}^{N}(DA_1)\times(V_{1,j})$
A_2	$(DA_2)\times(V_{2,1})$	$(DA_2)\times(V_{2,2})$	$(DA_3)\times(V_{3,3})$	$\cdots$	$(DA_2)\times(V_{2,j})$	$PA_2=\sum_{j=1}^{N}(DA_2)\times(V_{2,j})$
A_3	$(DA_3)\times(V_{3,1})$	$(DA_3)\times(V_{3,2})$	$(DA_3)\times(V_{3,3})$	$\cdots$	$(DA_3)\times(V_{3,j})$	$PA_2=\sum_{j=1}^{N}(DA_3)\times(V_{3,j})$
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
A_i	$(DA_i)\times(V_{i,1})$	$(DA_i)\times(V_{i,2})$	$(DA_i)\times(V_{i,3})$	$\cdots$	$(DA_i)\times(V_{i,j})$	$PA_i=\sum_{j=1}^{N}(DA_i)\times(V_{i,j})$
	$PT_1=\sum_{i=1}^{M}(DA_i)\times(V_{i,1})$	$PT_2=\sum_{i=1}^{M}(DA_i)\times(V_{i,2})$	$PT_3=\sum_{i=1}^{M}(DA_i)\times(V_{i,3})$	$\cdots$	$PT_j=\sum_{i=1}^{M}(DA_i)\times(V_{i,j})$	Total power consumed per time slot by total appliance
	C_1	C_2	C_3	$\cdots$	C_j	Price in Cents/kW for different time slot.
	$CC_1=PT_1\times C_1$	$CC_2=PT_2\times C_2$	$CC_3=PT_3\times C_3$	$\cdots$	$CC_j=PT_j\times C_j$	Consumed cost per time slot
	$Z=\sum_{j=1}^{N}CC_j$					Total cost at end of the day

FIGURE 2. Calculation table for the stated problem statement in equation (1)-(7).

With the obtained mathematical formulation from equations (1)-(7), the problem statement is limited as, “*To minimize the consumption cost by finding optimum values for all decision variables, without violating the stated constraints*”. *The same problem statement can be* mathematically represented as shown in equation (8).

$$\begin{aligned} & min(Z) = \sum_{j=1}^{N} (C_j) \times (PT_j) \\ & Subject\ to: \\ & \qquad PA_i = L_i, \quad \forall (i = 1, 2, \cdots, M) \\ & \qquad PT_j \leq E, \quad \forall (j = 1, 2, \cdots, N) \end{aligned} \tag{8}$$

APPLICATION OF TWO-PHASE SIMPLEX METHOD FOR DEMAND RESPONSE SYSTEM

As the problem formulation made in equation (8) is a Binary Linear Programming Problem (BLPP), it is much better to solve the problem efficiently via simplex method. Simplex method in general finds the optimum value for a Linear Programming Problem (LPP) by using the systematical approach with less computational effect. Equation(8) has equality and inequality constraints and thus it may not be solved by a conventional simplex method. Considering the non-linearity with mixed constraints, here Two-Phase Simplex Method (TPSM) is used. The utilized TPSM handles the LPP problem in two phases as phase-I and phase-II.

In Phase-I results pertinent to initial basic feasible solution is evolved and later, in phase-II the obtained solution is utilized to obtain an optimal solution. Detailed explanations with mathematical expressions of TPSM method is discussed in the following.

TWO-PHASE SIMPLEX method(TPSM)

Since TPSM is an extended version of simplex method, the problem formulation to be made is almost identical to problem formulation made in equation (8). Hence, standard notation of the simplex method is used hereafter for simplicity, and further it is ensured to not affect the original problem statement. The minimization is converted to maximization with `negative' such that, Max = -(Min).

$$\max z = -(c_1x_1 + c_2x_2 + \ldots + c_nx_n)$$

Subject to

$$\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n &= b_1 \\
a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n &= b_2 \\
&\vdots \\
a_{m1}x_1 + a_{m2}x_2 + \ldots + a_{mn}x_n &\leq b_m \\
\forall x_1, \ldots, x_n \geq 0. & \qquad (9)
\end{aligned}$$

The above LPP should be in Standard Form (SF). Hence, the LPP in equation (9) can be converted into SF by adding slack variable *for the constraints equation having* '$\leq$' type. Same slack variables are added to objective function with a product of `zero', such that `0 *Xs' to make sure that the* impact of slack variables is zero with an objective function. Then the SF of the LPP is given in equation (10).

$$
\begin{aligned}
&max\ z = -(c_1x_1 + c_2x_2 + 0x_{si} + \ldots + c_nx_n) \\
&Subject\ to \\
&\qquad a_{11}x_1 + a_{12}x_2 + a_{1s1}x_{s1} \ldots + a_{1n}x_n = b_1 \\
&\qquad a_{21}x_1 + a_{22}x_2 + a_{2s2}x_{s2} \ldots + a_{2n}x_n = b_2 \\
&\qquad \vdots \\
&\qquad a_{m1}x_1 + a_{m2}x_2 + a_{msi}x_{si} + \ldots + a_{mn}x_n = b_m, \\
&\qquad \forall x_1, x_{si} \ldots, x_n \geq 0. \qquad (10)
\end{aligned}
$$

Equation (10) in SF, has the vectors *x; b; c, and from which* matrix *`A' can be introduced as follows.*

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{m1} & a_{m2} & \cdots & a_{mn} \end{bmatrix}_{m\times n} .$$

The authors assume that the slack variables are present in the vectors *x; c, and matrix A. Hence, the variables are denoted* as *x = col(x1,x2,...,xn), b= col(b1, b2,..., bn); c =col(c1, c2,..., cn). Where, `x' is the decision variable of* the objective function and *`b' in LHS* of equation (10) is the constraint. The coefficient of the decision variable of the objective function is *`c0 and its* coefficient matrix of the constraints equations is *A. The* condition for the aforesaid vectors are given as follows:

$x \in \mathbb{R}^n$, $b \in \mathbb{R}^n(\forall b \geq 0)$, $c \in \mathbb{R}^n$, $A = (a_{ij}) \in \mathbb{R}^{m \times n}$, $x_j \geq 0, \forall j = 1, 2, \cdots$, and Rank $A = m(< n)$.

Some of the basic notation used for TPSM are given below for understanding the implementation procedure with actual problem formulation. Let, $A = [a^{(1)}, a^{(2)}, \ldots, a^{(j)}, \ldots, a^{(n)}]$ and $a^{(j)} = col(a_{1j}, a_{2j}, \ldots, a_{mj})$, then $a^{(j)}$ is j$^{\text{th}}$ column of matrix A. Basic matrix $B = [b^{(1)}, b^{(1)}, \ldots, b^{(m)}]$, where $b^{(1)}, b^{(2)}, \ldots, b^{(m)}$ are basic columns. The $(m \times 1)$ vector $x_B = B^{-1}b$ gives m basic variables $x_{B1}, x_{B2}, \ldots, x_{Bm}$. To find the basic feasible solution for the basic variable, $x_{Bi} = B^{-1}b_{i,}$ the value for objective function $z(x_B)$ is calculated by $z(x_B) = c_B^T x_B$. Where c_B is coefficient column of basic variables $c_B = col(c_{B1}, c_{B2}, \ldots, c_{Bi}, \ldots, c_{Bm})$.

STEPS INVOLVED IN TPSM

1) INITIALIZATION

The initialization process starts with obtaining the constraints. To obtain basic matrix B, the constraints in equation (10) should contain *M*M identity matrix*. *However*, equation (10) is a mixed constraint type, and hence there is no possibility of getting the initial identity matrix. Therefore, artificial variables are added to the constraint in equation (10) such that matrix A contains *M*M identity matrix to select* it as a basic matrix B.

2) TPSM PHASE I

The objective function of phase-I should contain only artificial variables by keeping all main constraints equations with slack and articial variables. The mathematical expression for phase-I objective function and constraints are given in (11).

$$max\ z_a = -(x_{a1} + x_{a2} + \ldots + x_{ai})$$

Subject to

$$\begin{aligned}
a_{11}x_1 + a_{12}x_2 + \ldots + a_{1n}x_n &= b_1 \\
a_{21}x_1 + a_{22}x_2 + \ldots + a_{2n}x_n &= b_2 \\
&\vdots \\
ann_{m1}xnn_1 + a_{m2}xn_2 + a_{ms}x_s + \ldots &+ a_{mn}xn_n \\
+ x_{ai} = b_m \quad \forall x_1, x_s \ldots, x_n, x_{ai} &\geq 0. \qquad (11)
\end{aligned}$$

where:

z_a–is the objective function of phase I.

x_{ai}–is the artificial variables.

a: FIRST ITERATION

From equation (11), identify the matrix A, basic matrix B (identity matrix) and calculate the values $\forall x_{Bi,} yn^{(j)}, z(x_B)$. The value of $y^{(j)}$ in Table 1 is given by $B^{-1}a^{(j)}, \forall(j = 1, 2, \ldots, n)$ and the scalars $(z_j - c_j)$ is relative cost coefficients $(z_j - c_j) = c_B^T y^j - c_j$. As simplex tableau is given in Table 1 with the calculated values. After filling the simplex tableau, the sign of relative cost coefficient $(z_j - c_j)$ will help the method to wisely select the current basic feasible (optimal) solution x_{Bi}. However, the search for existence of a new $\widehat{x_{Bi}}$ such that $z\left(\widehat{x_B}\right) > z(x_B)$ is also performed. The conditions for optimal value and existing optimal value are given below.

TABLE 1. **Simplex tableau.**

x_B	$y^{(1)}$	$y^{(2)}$	$\cdots$	$y^{(j)}$	$\cdots$	$y^{(n)}$
$x_{B1} = (B^{-1}b)_1$	y_{11}	y_{12}	$\cdots$	y_{1j}	$\cdots$	y_{1n}
$x_{B1} = (B^{-1}b)_2$	y_{21}	y_{22}	$\cdots$	y_{2j}	$\cdots$	y_{2n}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$x_{B1} = (B^{-1}b)_i$	y_{i1}	y_{i2}	$\cdots$	y_{ij}	$\cdots$	y_{in}
$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$	$\vdots$
$x_{Bm} = (B^{-1}b)_m$	y_{m1}	y_{m2}	$\cdots$	y_{mj}	$\cdots$	y_{mn}
$z(x_B)$	$(z_1 - c_1)$	$(z_2 - c_2)$	$\cdots$	$(z_j - c_j)$	$\cdots$	$(z_n - c_n)$

(i) If all $(z_j - c_j) \geq 0$ then the current x_{Bi} is optimal.

(ii) If some $(z_j - c_j) < 0$ and for that some $yij > 0$ then there exists a new $\widehat{x_{Bi}}$ such that $z(\widehat{x_B}) > z(x_B)$. If the second condition is satisfied, then go for pivoting iteration to obtain the new $\widehat{x_{Bi}}$.

b: PIVOTING ITERATION 1

The new $\widehat{x_{Bi}}$ is obtained by pivoting the simplex tableau such that, taking one column out of B and entering it by another column of A which is not already a basic column. The rule for which column $a^{(k)}$ of A, should be entered in B and which column $b^{(r)}$ of B, should be taken out by following the set of rules as given below

– Rule 1. Column to enter (pivot $a^{(k)}$)

Choose $a^{(j)}$ which has the most negative value of $(z_j - c_j)$ which at least one $y_{ij} > 0$.

Such that, $(z_k - c_k) = \min_j\{(zcj) :< 0, \textit{and some } y_{ij} > 0\}$.

– Rule 2. Column to leave the basis (pivot $b^{(r)}$)

If the pivoting column is $a^{(k)}$, then $x_{Br} = \min_j \left\{ \frac{x_{Bi}}{y_{ik}} : y_{ik} > 0 \right\}$

After calculating the $(z_k - c_k)$ and x_{Br} values, update the $\widehat{B}$ matrix. Later using $\widehat{B}$ compute $\forall x_{Bi,} yn^{(j)}$, $z(x_B)$, and $(z_j - c_j)$.

The above pivoting iteration must be continued until the optimal solution is reached.

3) TPSM PHASE II

In phase I, the optimal solution must be 'zero' since the objective function only has artificial variables. Hence, the value of 'x_B' at the final iteration of phase-I must be the basic feasible solution for the first iteration of phase-II of TPSM. Thus, by keeping the original objective function and final $\widehat{\mathrm{B}}$ in phase-I, compute $\forall x_{Bi,} yn^{(j)}$, $z(x_B)$, and $(z_j - c_j)$ by following the same procedure of phase-I. Repeat the procedure until optimal solution in phase-II is arrived. Now, the resultant solution in phase-II is the optimal value of the original objective function given in equation (9). The TPSM can be applied to equation (8) for getting an optimized scheduling scheme without violating the formulated constraints. For better understanding, the flowchart for TPSM applied for home energy management system is given in Fig. 3.

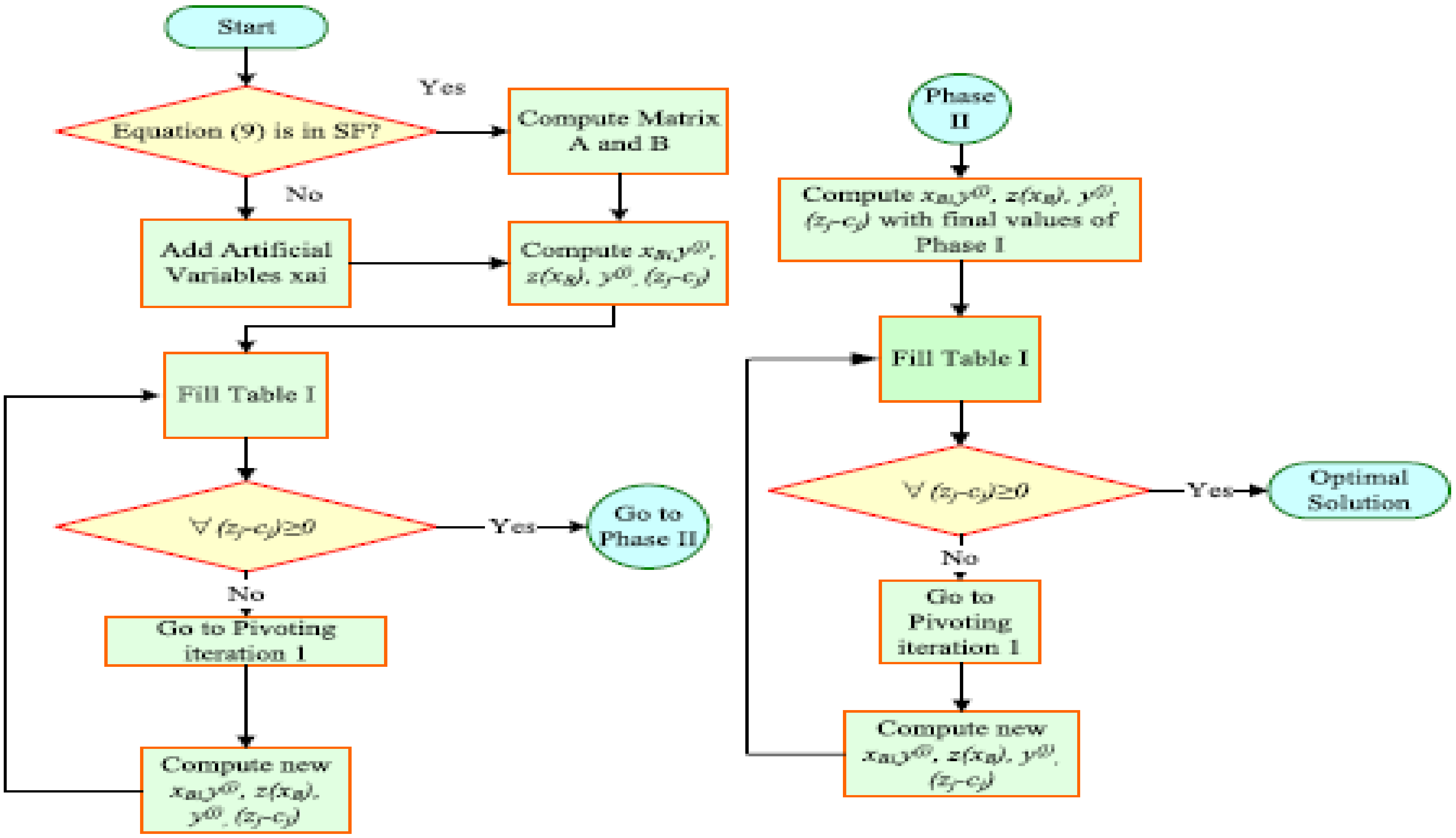


FIGURE 3. Flowchart for TPSM applied home energy management system.

SIMULATION RESULT

- To validate the efficiency of the TPSM, a mathematical problem is simulated.
- We take load profile i.e. household LS1,LS2,LS3,LS4
- Each uses 10 appliances A1,A2,…,A10
- Number of time slots required for each of the appliances are in the table below.
- Here each slot is of 3 hours.

Appliances	(No. of Time slots)			
	LS1	LS2	LS3	LS4
A1	8	8	8	8
A2	8	8	8	8
A3	3	3	3	2
A4	3	3	3	4
A5	5	4	5	4
A6	5	4	3	2
A7	6	4	4	2
A 8	6	4	4	3
A9	2	4	3	2
A10	2	3	5	4

Based on the appliance parameters the rated power of various appliances are given in the table beside

- Here there are 8x10=80 decision variabes and we will try ti schedule the appliances' operating time so that they can have 100% of their task done.

Appliances	LS1	LS2	LS3	LS4
A1	1.5 kW	1.5 kW	1.5 kW	1.5 kW
A2	1.5 kW	1.5 kW	1.5 kW	1.5 kW
A3	1.5 kW	1 kW	1 kW	0.5 kW
A4	0.5 kW	1 kW	0.5 kW	1 kW
A5	1 kW	1 kW	0.5 kW	1.5 kW
A6	1 kW	1.5 kW	1 kW	1 kW
A7	1 kW	1.5 kW	0.5 kW	1 kW
A8	2 kW	1 kW	0.5 kW	0.5 kW
A9	1 kW	1 kW	0.5 kW	1 kW
A10	1.5 kW	1 kW	1.5 kW	0.5 kW

DEMAND FOR APPLIANCES FOR DIFFERENT SCENARIOS

As the demand of electricity varies over the slots the cost of electricity per kW is shown in the table beside:

The table below is for the required power consumptions for each of the performance .If the appliance get the required amount of electricity the we say that the appliances are working at at their100%

Time Slot	Price in Cents/kW			
	LS1	LS2	LS3	LS4
T1	4	8	5	4
T2	5	3	3	9
T3	6	9	7	5
T4	7	4	9	8
T5	6	6	8	6
T6	8	5	4	7
T7	2	7	4	4
T8	5	6	6	6

cost at different time slot

Starting the optimization process:

Appliance	Total power (kW)			
	LS1	LS2	LS3	LS4
A1	12	12	12	12
A2	12	12	12	12
A3	4.5	3	3	1
A4	1.5	3	1.5	4
A5	5	4	2.5	6
A6	5	6	3	2
A7	6	6	2	2
A8	12	4	2	1.5
A9	2	4	1.5	2
A10	3	3	7.5	2
Total power for 100 % task.	63	57	47	44.5

Whatever the optimization method we choose it is desired to fulfil the typical power for 100% task

TPSM Scheduling:

We use TPSM to find the optimized allocation that :

- Minimize the cost for electricity
- Provide 100% power for the task
- Manage peak demand and peak-to-average ratio reduction

TPSM SCHEDULING :

Here we have the TPSM scheduling That gives the optimum allocation for the scheduling of the operating time :

Now we will investigate the merits and demerits of this allocation in comparison to other methods such as,

- COMPARISON OF APPLIANCES TASK COMPLETION
- COST COMPARISON
- RESPONSE TIME COMPARISON
- PEAK DEMAND AND PEAK-TO-AVERAGE RATIO REDUCTION COMPARISON

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

1) COMPARISON OF APPLIANCES TASK COMPLETION

As we can see from here that TPSM allocation fulfils the 100% power requirement for each appliances for LS1

Similarly this happens for all the other load profile LS2,LS3,LS4

Time Slot	Total power consumed by all appliances at jth time slot Equation (2) for LS1 in (kW)					
	TPSM	SOPCol	LCSol	OPTSol	PRDSol	PSO
T1	11	5	5	9	5	5
T2	10	6	5	8	12	5
T3	8	8	6	6	8	6
T4	3	9	8	5	9	8
T5	6	8	8	8	6	9
T6	3	12	9	5	5	9
T7	12	5	9	12	8	12
T8	10	9	12	9	9	8
Total Power (kW) at day end	63	62	62	62	62	62

COMPARISON OF APPLIANCES TASK COMPLETION FOR EACH OF THR LOAD PROFILE

Time Slot	Total power consumed by all appliances at jth time slot Equation (2) for LS1 in (kW)					
	TPSM	SOPCol	LCSol	OPTSol	PRDSol	PSO
T1	11	5	5	9	5	5
T2	10	6	5	8	12	5
T3	8	8	6	6	8	6
T4	3	9	8	5	9	8
T5	6	8	8	8	6	9
T6	3	12	9	5	5	9
T7	12	5	9	12	8	12
T8	10	9	12	9	9	8
Total Power (kW) at day end	**63**	**62**	**62**	**62**	**62**	**62**

Time Slot	Total power consumed by all appliances at jth time slot Equation (2) for LS2 in (kW)					
	TPSM	SOPCol	LCSol	OPTSol	PRDSol	PSO
T1	3	7	2	4	2	7
T2	11	2	4	11	8	11
T3	3	11	5	2	7	8
T4	11	4	6	9	11	2
T5	10	9	7	6	4	6
T6	11	6	8	8	9	4
T7	3	8	9	5	5	9
T8	5	8	11	7	6	5
Total Power (kW) at day end	**57**	**55**	**52**	**52**	**52**	**52**

Time Slot	Total power consumed by all appliances at jth time slot Equation (2) for LS3 in (kW)					
	TPSM	SOPCol	LCSol	OPTSol	PRDSol	PSO
T1	6	7	3	5	3	7
T2	9	3	4	9	9	9
T3	3	6	5	5	6	5
T4	3	9	5	3	7	8
T5	3	8	6	4	4	4
T6	9	4	7	8	8	5
T7	9	5	8	7	5	6
T8	5	5	9	6	4	3
Total Power (kW) at day end	**47**	**47**	**47**	**47**	**46**	**47**

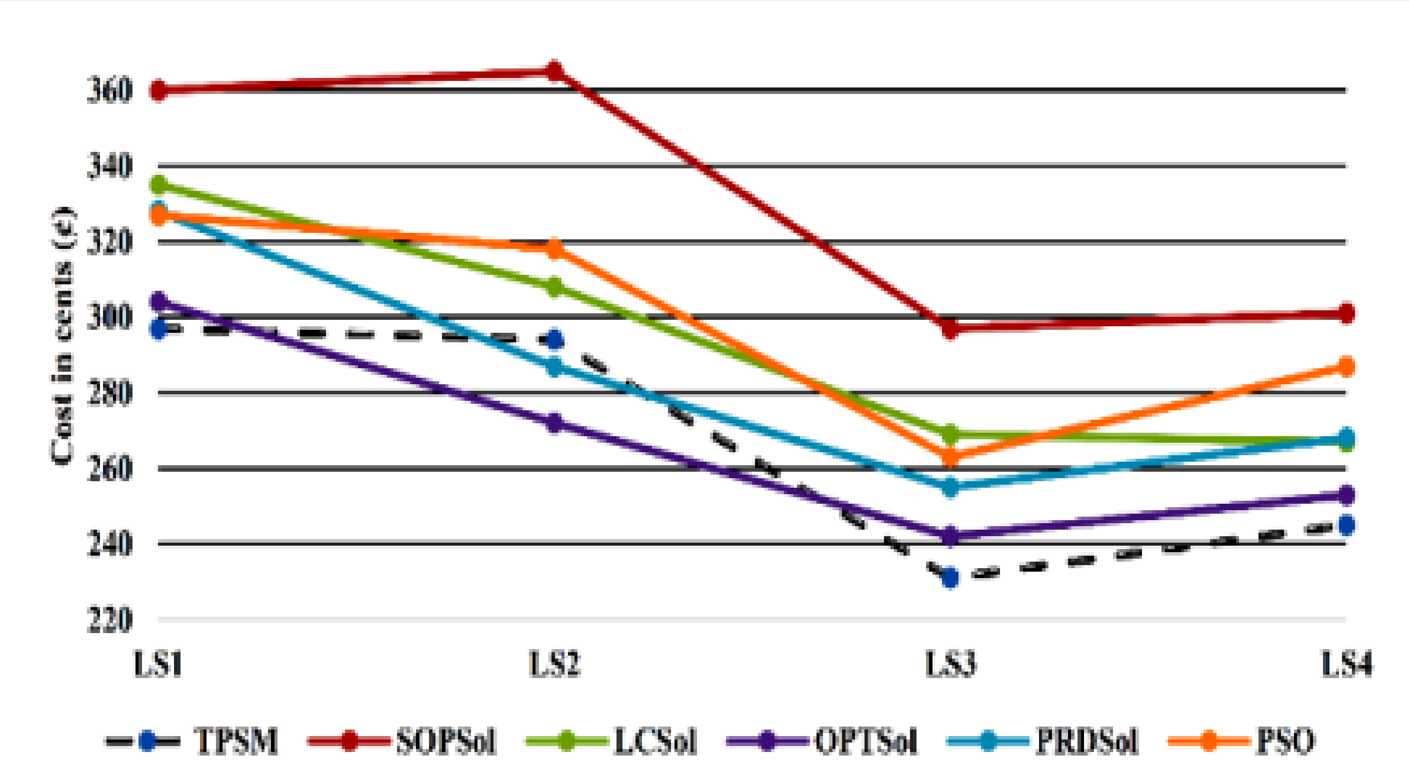
Time Slot	Total power consumed by all appliances at jth time slot Equation (2) for LS4 in (kW) in (kW)					
	TPSM	SOPCol	LCSol	OPTSol	PRDSol	PSO
T1	8	3	3	5	4	8
T2	3	8	4	3	3	7
T3	8	5	5	7	6	2
T4	3	7	5	4	8	6
T5	8	7	6	6	5	4
T6	3	6	6	5	5	8
T7	8	4	7	8	6	6
T8	3.5	6	8	6	7	5
Total Power (kW) at day end	**44.5**	**46**	**44**	**44**	**44**	**46**

INTERPRETATION FROM THE ABOVE TABLES:

Here we get that TPSM allows the required amount of power for each of the appliances A1,…,A10 for each of the load profiles but the other methods sometimes fail to allocate in such a way that the appliances get 100% power.

2) COST COMPARISON:

The cost of allocation for TPSM is very much low except for LS2 ,but we also note that the other methods also fail to allocate to fulfil 100% power requirement



3) RESPONSE TIME COMPARISON

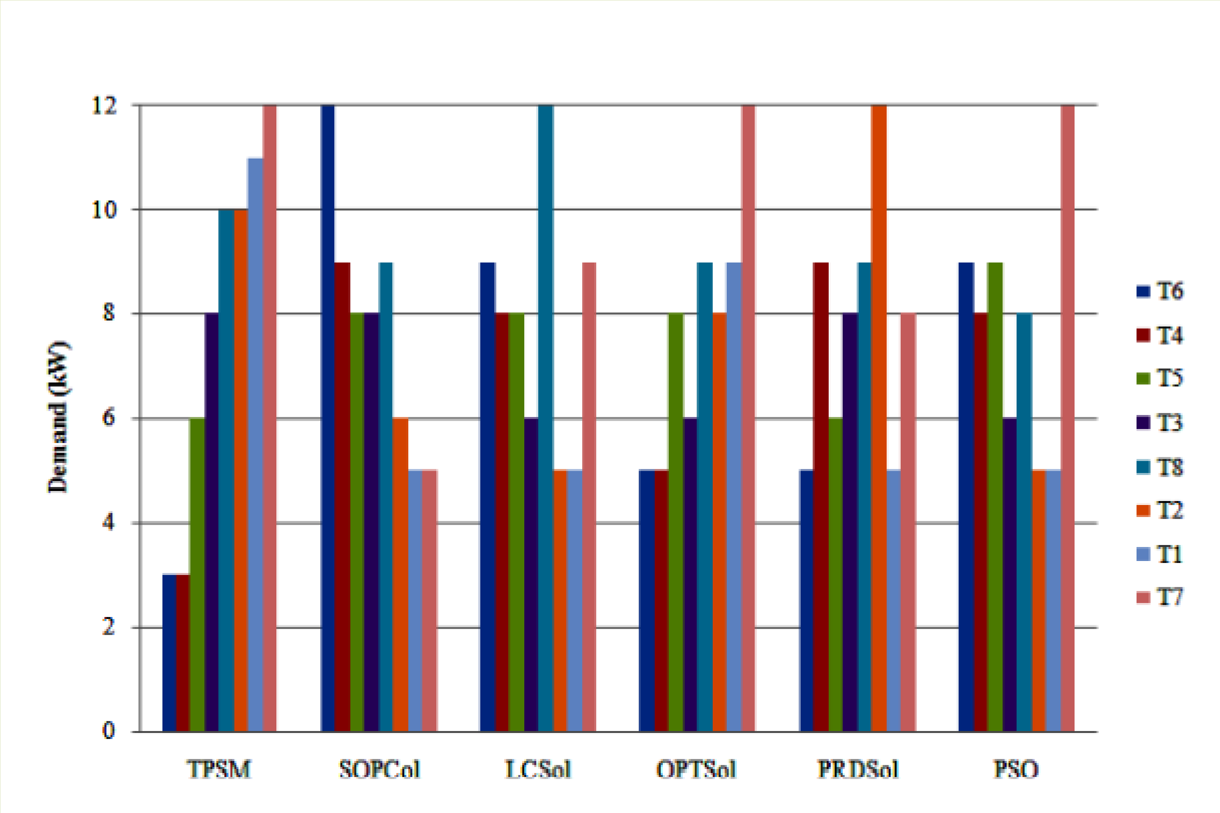
System response time is one of the important factors for HEM. So the response time of the proposed TPSM is compared with the existing algorithm and the results are tabulated in Table . The response time of the proposed TPSM is 0.047s, which is the lowest response time compared to any other algorithms in comparison

Response time comparison (LS1-LS4).

Algorithm	Computational Time (s) for LS1
TPSM	0.047
SOPSol	0.534
LCSol	0.483
PRDSol	8.599
OPTSol	179
PSO	18.58

Conclusions:

To experiment the ability of TPSM in handling peak demand and reduction in peak to average ratio, the case study of peak demand is performed by considered only TPSM and other existing algorithms for LS1. For better clarity, the peak demand reduction comparison of LS1 pertinent to TPSM ann other algorithms are shown in Fig. 6. In general, the cost of electricity is high during peak hours and low during offpeak hours. Therefore, the peak demand can be reduced by shifting the load from a high-cost time slot (peak hours) to low cost time (off-peak hours).



Peak demand for LS1 . The demand increases after T6.Here we see that the demand for electricity in the TPSM allocation is low in each of the time slots

CONCLUSION

This project proposes a new TPSM based demand response program for residential customers

- to reduce peak demand
- to reduce the electricity consumption cost,
- to maintain consumer comfort,
- to reduce the computational time.

Acknowledgement

- We are thankful to Prof. S.K. Neogy for giving us this opportunity to make a presentation on this topic.
- We are thankful to numerous researchers who worked on optimization problems. Going through their works really helped us.

Thank You!!