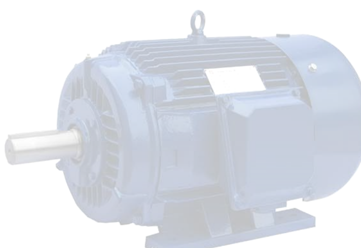
3rd International Workshop on Software Engineering Challenges for the Smart Grid
(SE4SG @ ICSE '14)

DEMAND RESPONSE ALGORITHM INCORPORATING ELECTRICITY MARKET PRICES FOR RESIDENTIAL ENERGY MANAGEMENT

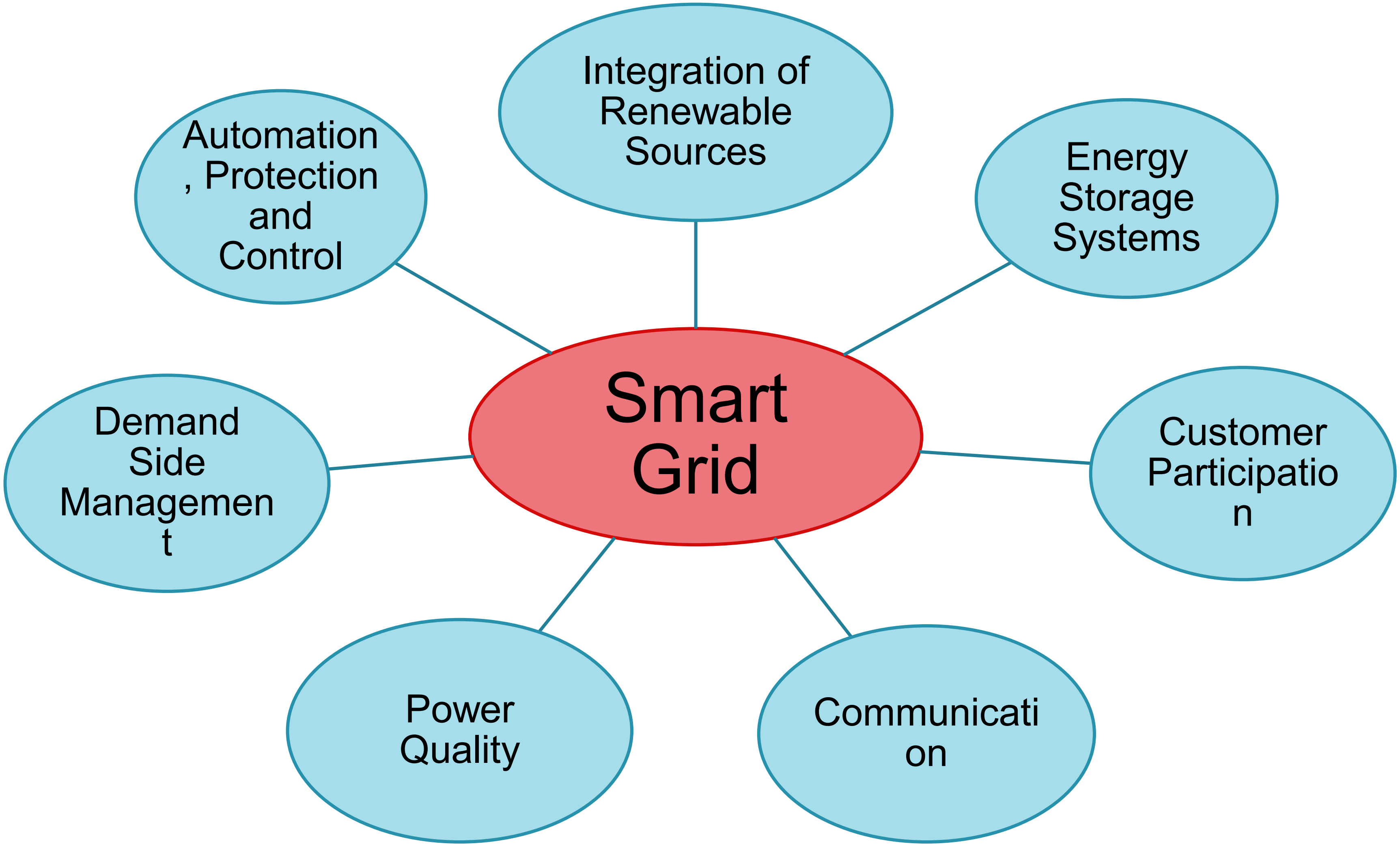


IIT Gandhinagar

Presented by: Arun Nair

Outline

Technical Challenges

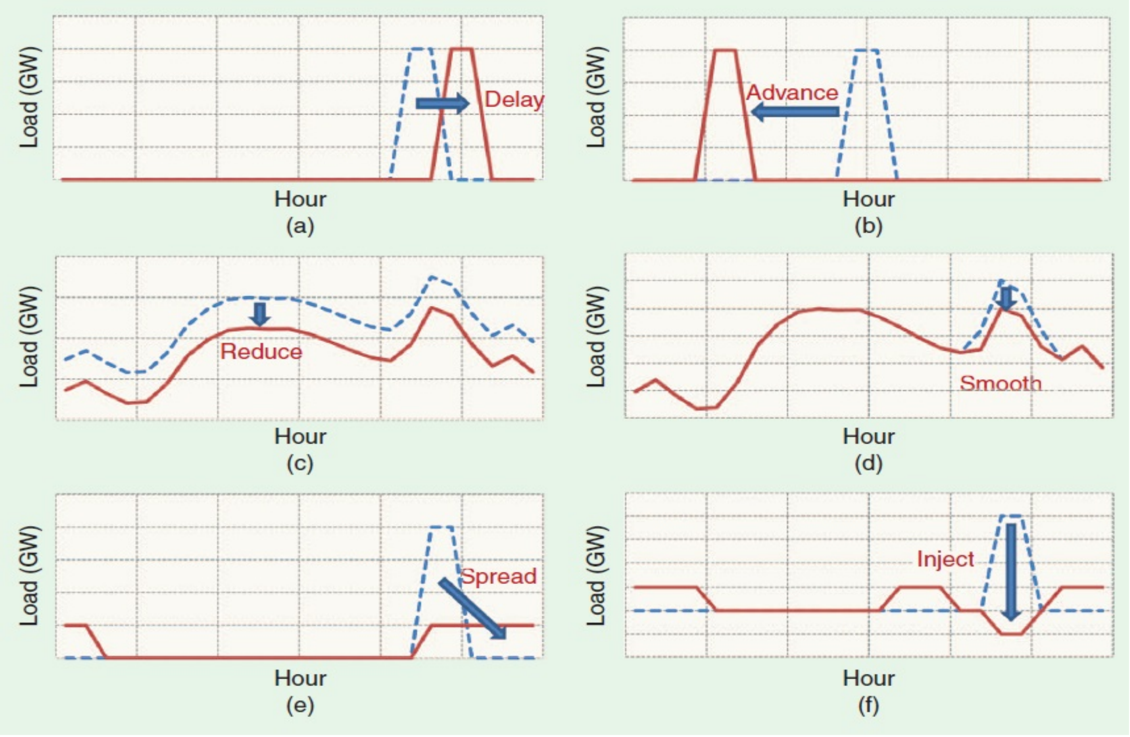


Demand Side Management

- Planning, implementation, and monitoring of those utility activities designed to influence customer's use of electricity in ways that will produce desired changes in the utility load shape

Load Shape Objectives

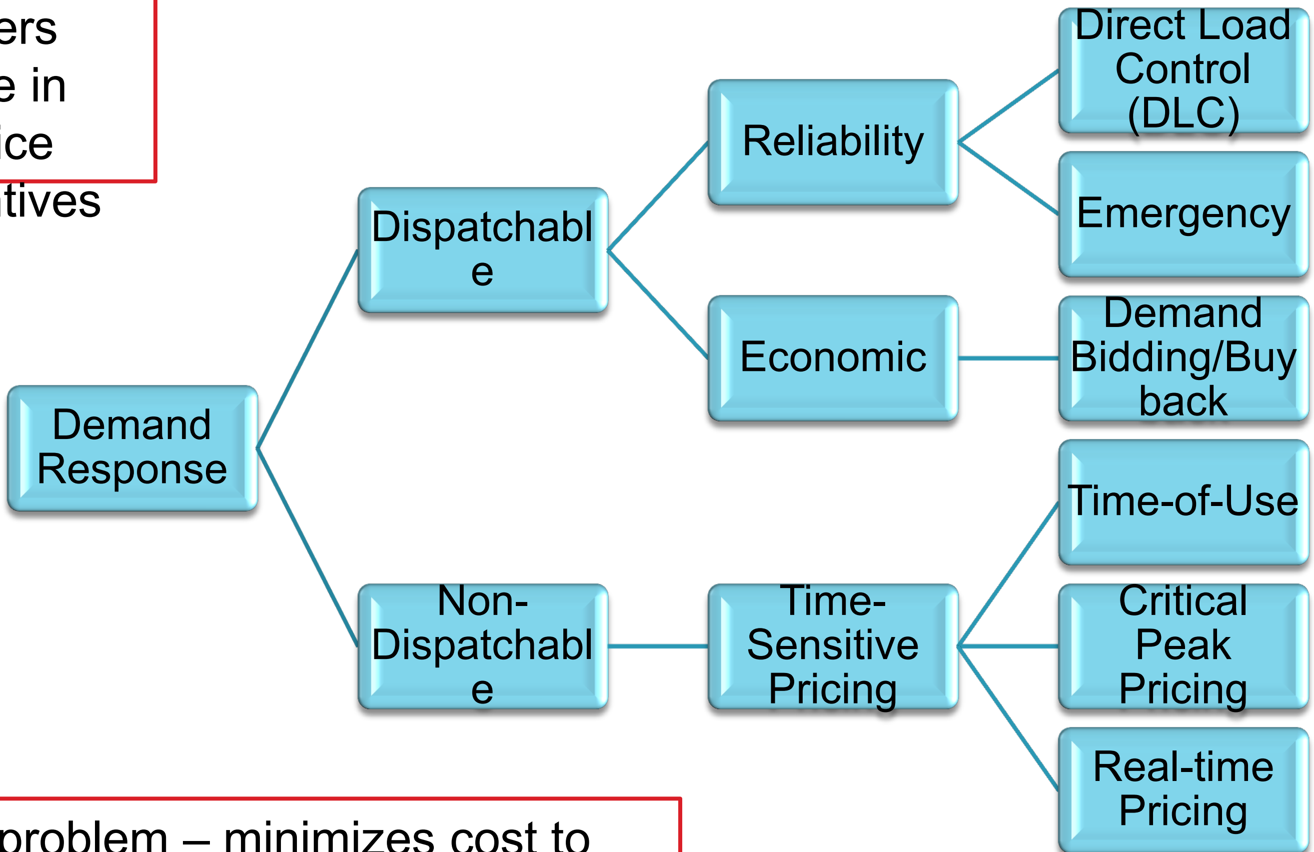
- ✓ Peak Clipping
- ✓ Valley Filling
- ✓ Load Shifting
- ✓ Strategic Conservation
- ✓ Strategic Load Growth
- ✓ Flexible Load Shape



Source: Manz, D.; Walling, R.; Miller, N.; LaRose, B.; D'Aquila, R.; Daryanian, B., "The Grid of the Future: Ten Trends That Will Shape the Grid Over the Next Decade,"

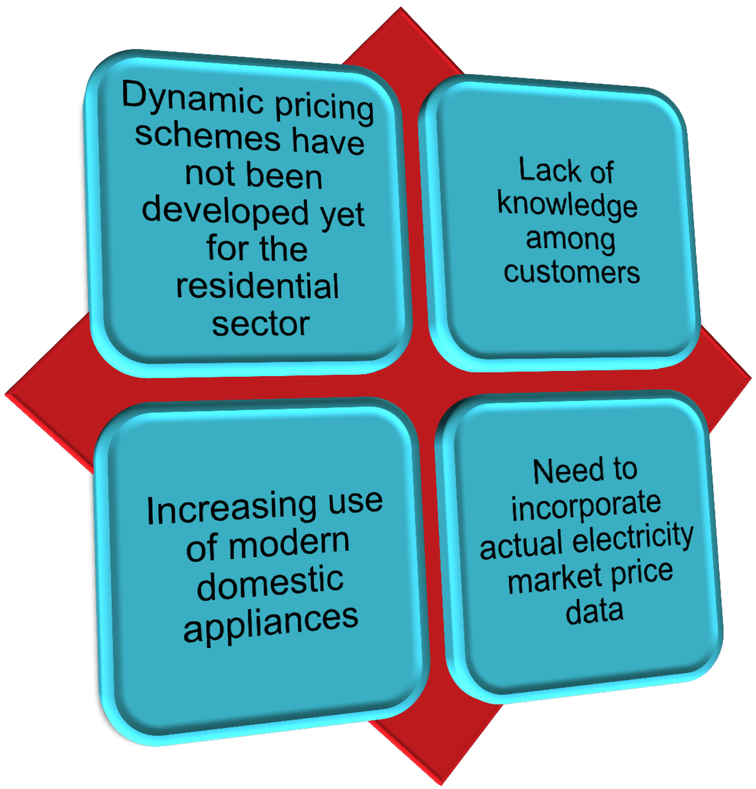
Demand Response

Modify customers electricity usage in response to price changes or incentives



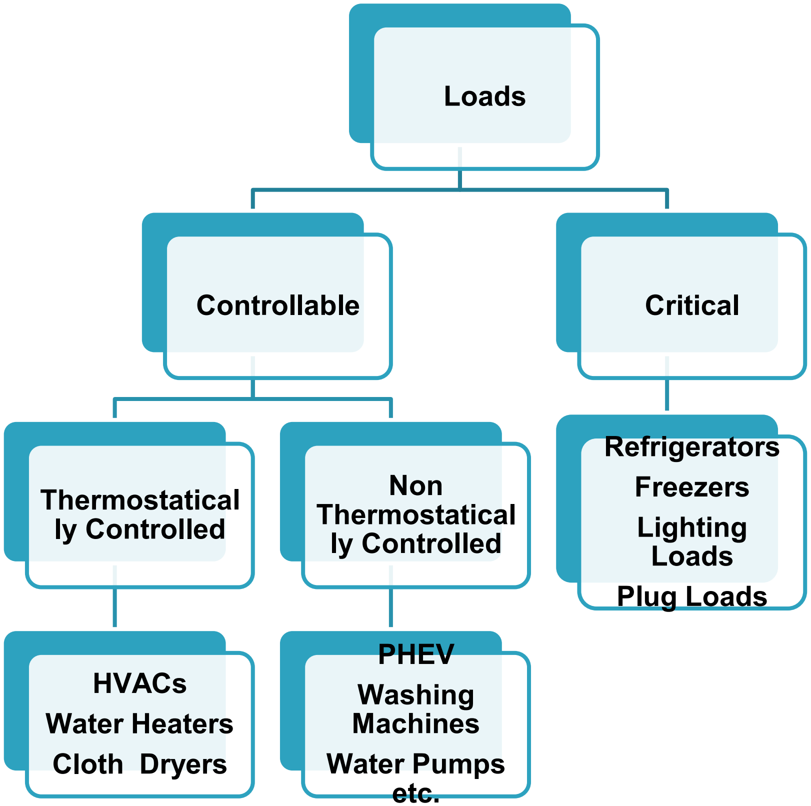
An Optimization problem – minimizes cost to customer or maximizes utility profit – subject to user priorities, comfort levels and appliance types

Motivation



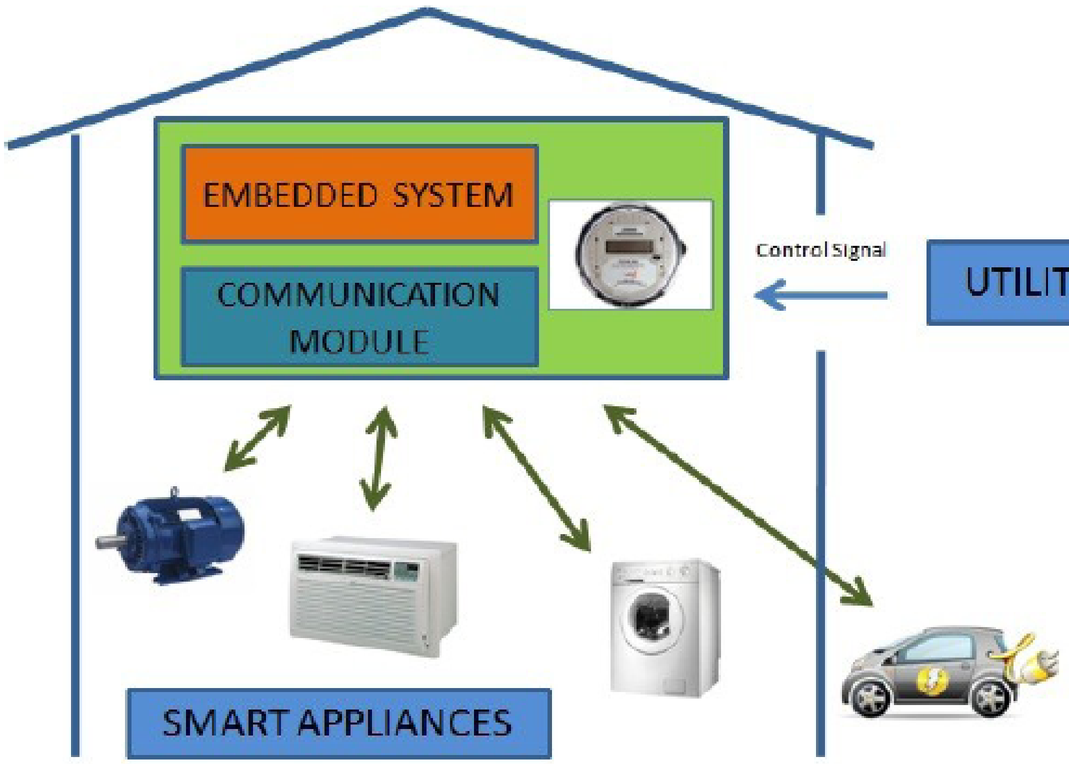
- Integer Linear Programming based
- IEX Market Price Data
- Quantifies customer and utility benefits

Appliance Classification



- Critical appliances are generally non-shiftable
- Controllable appliances
  - Power-shiftable
    - *Flexible consumption pattern*
  - Time-shiftable
    - *Fixed consumption pattern*

Residential Energy Management System



REMS consists of

- Embedded System
- Communication module

Problem Formulation

- Objective function:

  minimization of total cost of consumption of electricity

- Constraints:
  - Sum of units consumed by an appliance in a day = total requirement per day
  - Minimum limit ≤ No. of units consumed by an appliance ≤ Maximum limit
  - Sum of units consumed by all appliances in an hour ≤ Utility hourly limit

Scheduling Vector

$$X_a = \{X_{a,1}, X_{a,2}, \ldots, X_{a,24}\}$$

Scheduling Horizon

$$H = \{1, 2, \ldots, 24\}$$

$$X_{a,h} \geq 0 \quad \forall \quad h \in H$$

Constraints for time-shiftable appliances

- Time shiftable appliances have discrete levels of power consumptions
- Power consumption patterns are defined using a circulant matrix

$$P_a = \begin{bmatrix} p_{a,1} & p_{a,24} & \cdots & p_{a,2} \\ p_{a,2} & p_{a,1} & \cdots & p_{a,3} \\ \vdots & \vdots & \ddots & \vdots \\ p_{a,24} & p_{a,23} & \cdots & p_{a,1} \end{bmatrix}$$

- Binary switch vector, S_a is used to calculate the schedule vector X_a

$$S_a = \{s_{a,1}, s_{a,2}, \ldots, s_{a,24}\}$$

$$X_a = S_a \times P_a \quad \forall \quad a \in T$$

$$a \in A \equiv \text{Set of all appliances}$$

$$T \equiv \text{Set of all time-shiftable appliances}$$

Problem Formulation

$$\underset{X_{a,h}}{\text{minimize}} \quad C^T L$$

$$\text{subject to} \quad \sum_{h=1}^{24} X_{a,h} = l_a \quad \forall a \in A$$

$$\sum_{a \in A} X_{a,h} = L_h \leq U_h \quad \forall a \in A$$

$$\sum_{h=1}^{24} s_{a,h} = 1$$

$$\alpha_a \leq X_{a,h} \leq \beta_a \quad a \in A - T$$

$$X_a = P_a \times S_a \quad \forall a \in T$$

$$s_{a,h} \in \{0, 1\} \quad \forall a \in T$$

Cost Vector

$$C = \{c_1, c_2, \ldots, c_{24}\}$$

Hourly Load

$$L = \{L_1, L_2, \ldots, L_{24}\}$$

User Preferences

In the absence of a DR algorithm, the scheduling of appliances followed by a user is defined

CUSTOMER 1

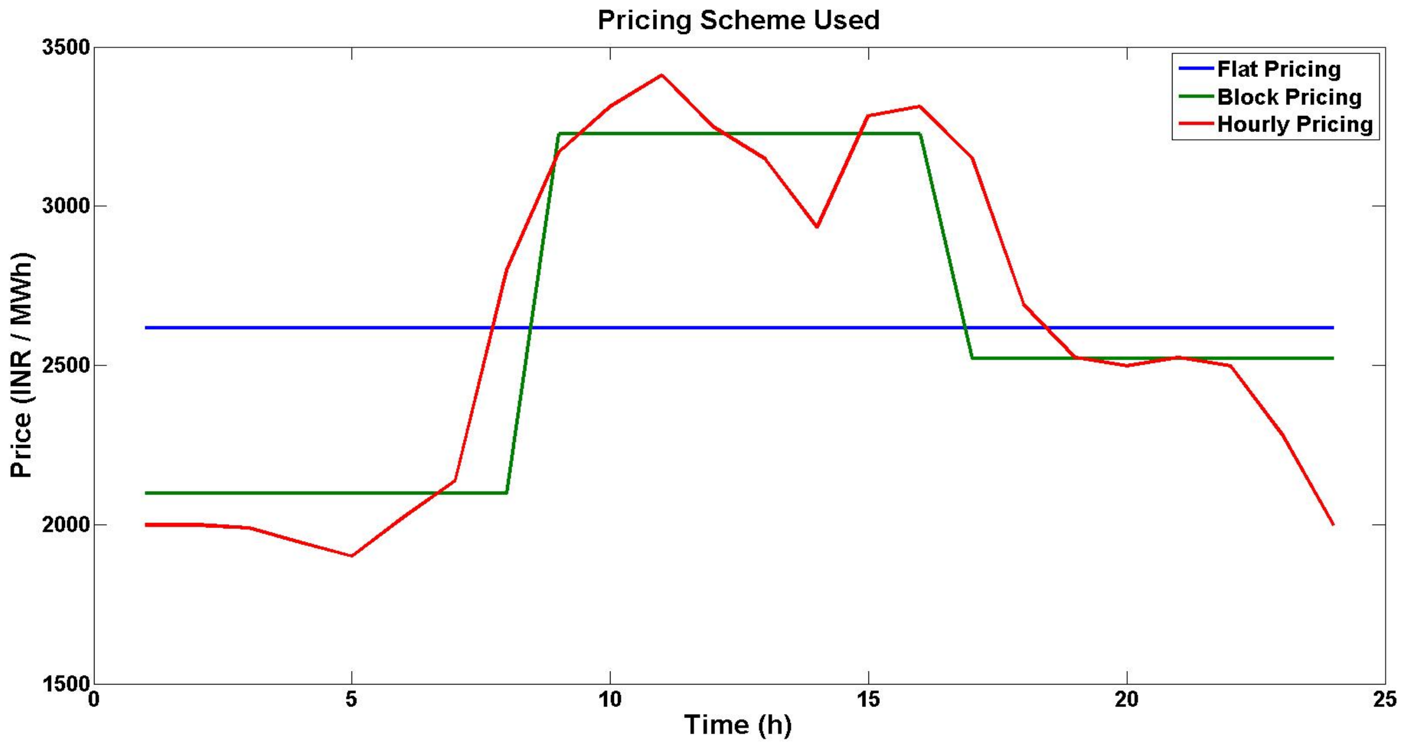
HOURS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Refrigerator	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140	140
Ceiling Fan (4)	280	280	280	280	280	280	280	280	140	140	140	140	140	140	140	140	140	280	280	280	0	0	280	280
Microwave Oven	0	0	0	0	0	0	0	750	0	0	0	0	750	0	0	0	0	0	0	750	0	0	0	0
Tubelights (5)	0	0	0	0	0	0	0	36	36	36	36	36	72	72	36	36	36	72	180	180	180	180	180	0
Television	7	7	7	7	7	7	7	7	7	7	7	70	70	70	7	7	7	7	70	70	70	70	7	7
PC	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	9	50	50	9	9
Hand Iron	0	0	0	0	0	0	250	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total fixed Consumptions	436	436	436	436	436	436	686	1222	332	332	332	395	1181	431	332	332	332	508	679	1429	440	440	616	436
Air Conditioner	0	0	0	0	0	0	0	0	0	0	0	1000	1000	1000	1000	0	0	0	0	1000	1000	0	0	0
Water Heater	0	0	0	0	500	500	0	0	0	0	0	0	500	500	0	0	0	500	500	0	0	0	0	0
EV	0	0	0	0	1000	1000	0	0	0	0	0	0	0	0	0	0	0	0	0	1000	1000	1000	0	0
Washing Machine	0	0	0	0	0	0	1200	500	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Water Pump	0	0	0	0	0	1000	0	0	0	0	0	0	0	0	0	0	0	0	1000	0	0	0	0	0
Vacuum Cleaner	0	0	0	0	0	0	0	0	0	0	0	400	400	0	0	0	0	0	0	0	0	0	0	0
Total Desired Load	**436**	**436**	**436**	**436**	**1936**	**2936**	**1886**	**1722**	**332**	**332**	**332**	**1795**	**3081**	**1931**	**1332**	**332**	**332**	**1008**	**2179**	**3429**	**2440**	**1440**	**616**	**436**

*All values are in Watts

Operating Pattern of Appliances

Appliance	Type	User Preference
Fixed Consumption Appliances	Non-Shiftable	24 h aggregate of critical loads
Air Conditioner	Non-Shiftable (user preference)	12 am-4 pm and 8 pm-10 pm Hourly consumption = 1 kWh
Water Boiler	Power-Shiftable	Hourly consumption = 0-0.8 kWh Daily Requirement = 3 kWh
EV	Power-Shiftable	Hourly consumption = 0.1-1.5 kWh Daily Requirement = 5 kWh 9pm-9am
Washing Machine	Time-Shiftable	1st hour - 1.2 kW 2nd hour - 0.5 kW once a day
Water Pump	Time-Shiftable	Hourly consumption = 1 kWh every 12 hours
Vacuum Cleaner	Time-Shiftable	Hourly consumption = 0.4 kWh 8 am to 8 pm

Pricing Schemes

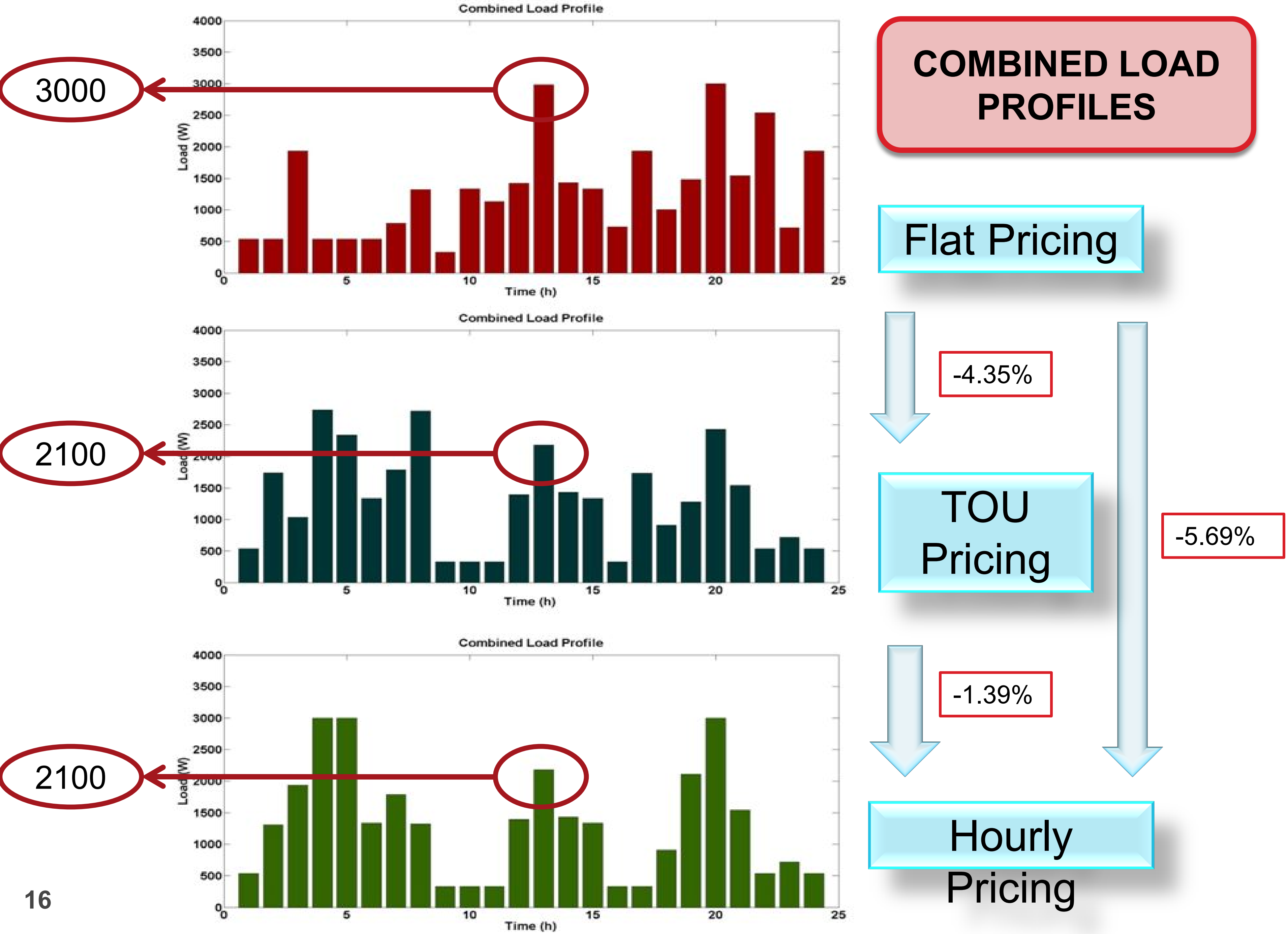


Using the actual market price data from IEX, 3 different pricing schemes are developed

Case	I	II	III
Pricing Scheme	Flat Pricing	3-Level Block Pricing (TOU)	Hourly Pricing

SIMULATION RESULTS

- 5 Customers
- 7 Appliances
- 264 variables
- 103 constraints

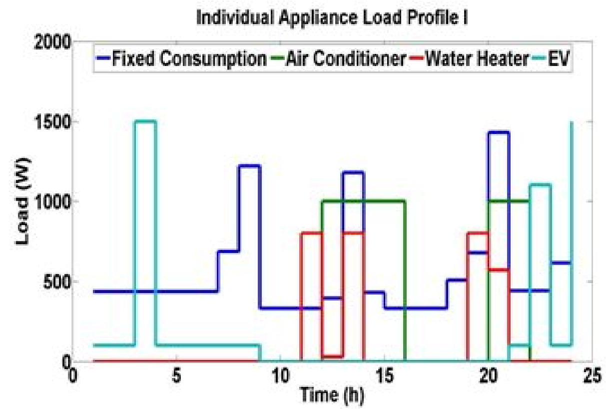

COMBINED LOAD PROFILES
Combined Load Profile
Load (W)
Time (h)
3000
2100
2100
Flat Pricing
TOU Pricing
Hourly Pricing
-4.35%
-1.39%
-5.69%

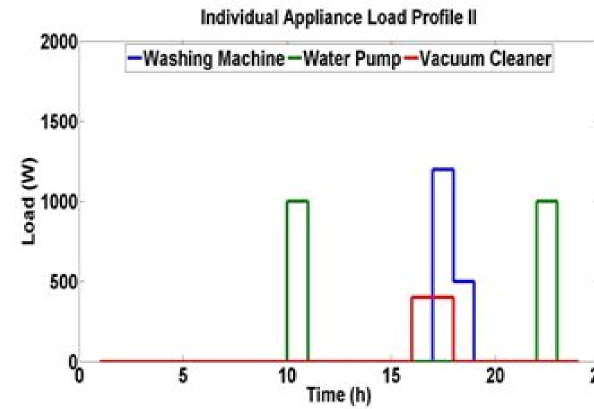
INDIVIDUAL APPLIANCE CONSUMPTION PATTERNS

Fixed consumptions and power-shiftable appliances

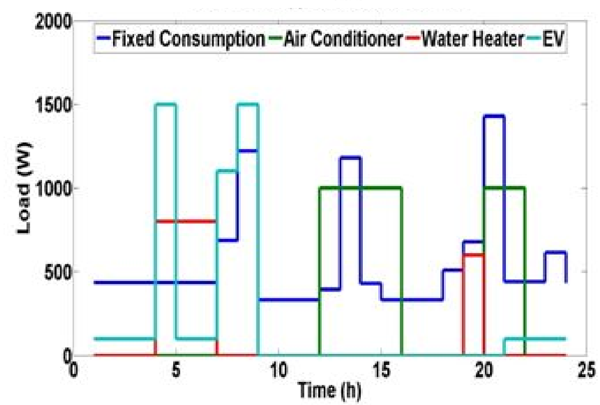
Time-shiftable appliances

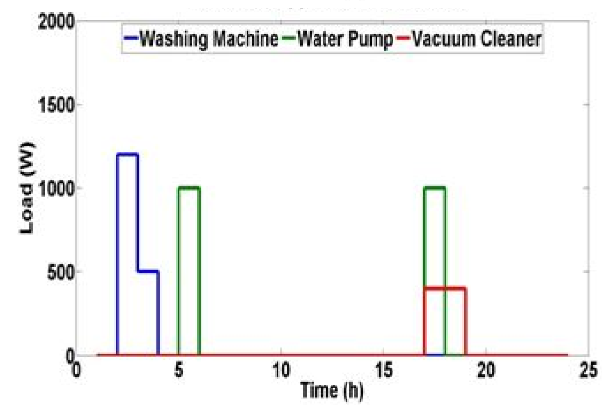
FLAT PRICING



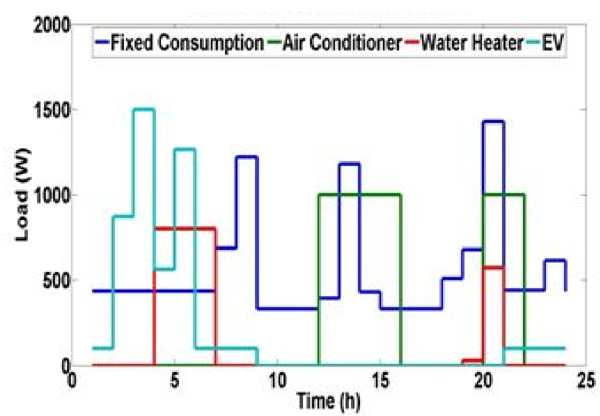


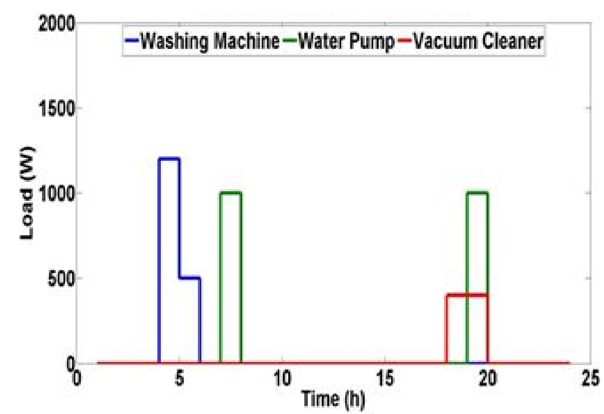
BLOCK PRICING



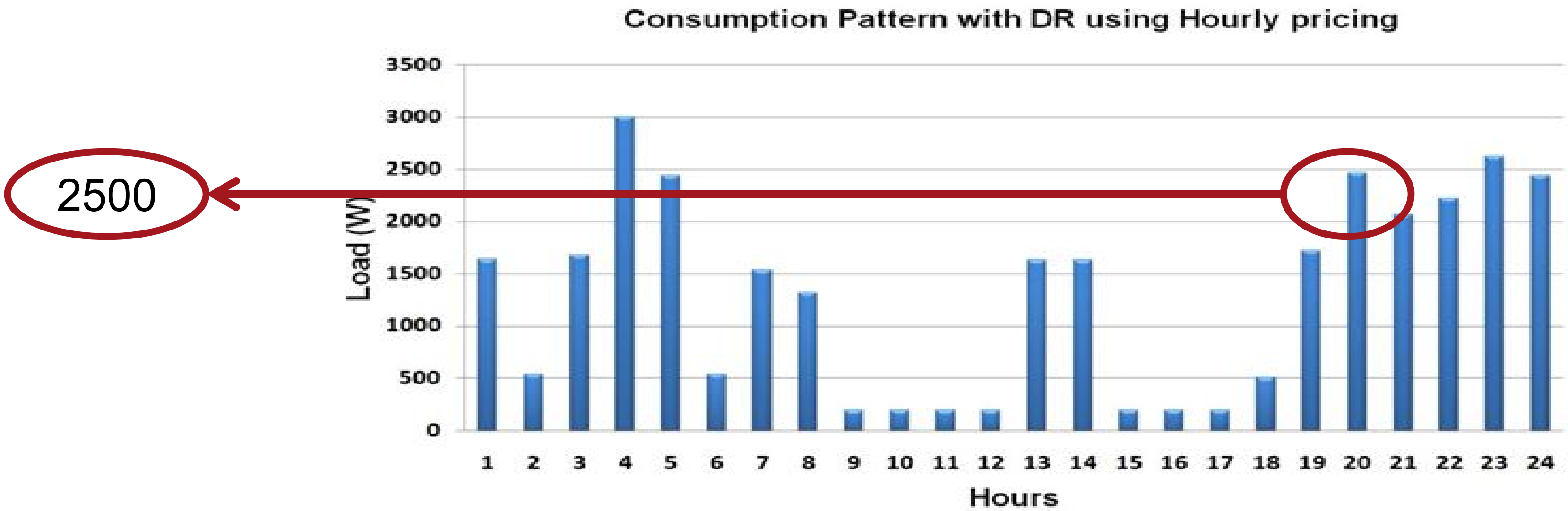


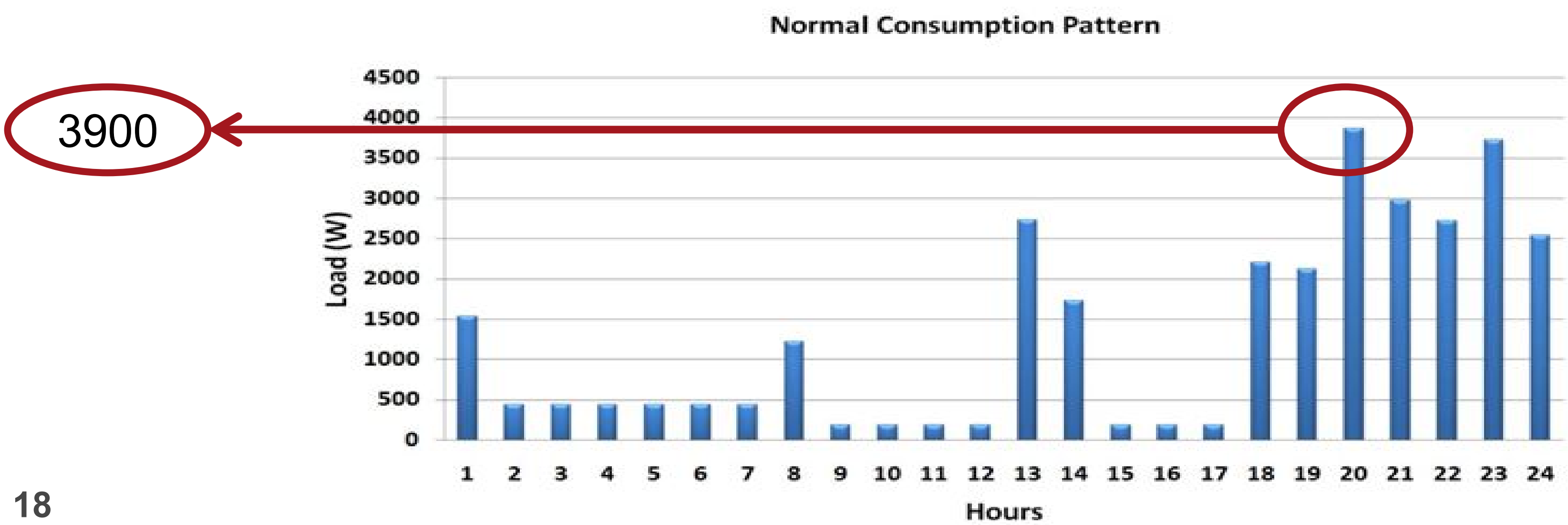
HOURLY PRICING





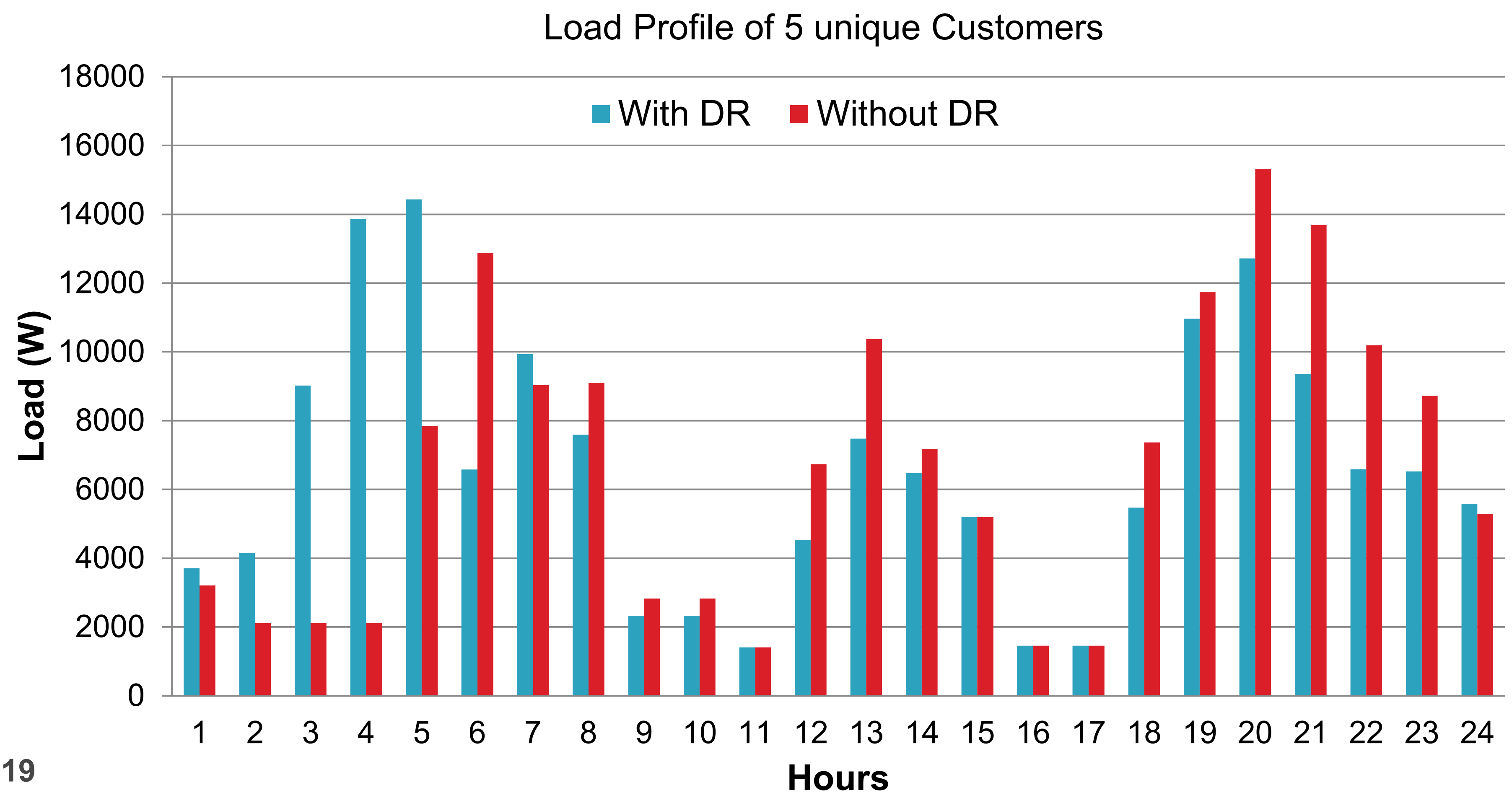
COMPARISON OF CUSTOMER LOAD PROFILE WITH AND WITHOUT DR





SYSTEM LOAD PROFILE WITH AND WITHOUT DR

- Combined load profiles of 5 different customers in a residential area



Performance gains from customer and utility perspective

Pricing Scheme	Cost/day (Rs.)				
	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Flat Pricing	82.6	74.2	87.3	90.4	82
TOU Pricing	79	65.6	84.6	87.9	76.7
Hourly Pricing	77.9	65.6	82.6	87.7	74
Savings/day	4.7	8.6	4.7	[illegible]	8
Savings/month	**141**	**2[illegible]**	**[illegible]1**	81	[illegible]

	P[illegible]		PAR
	11pm-3pm	6pm-9pm	
Without DR	10.4 kW	15.3 kW	2.30
With DR	7.5 kW	12.7 kW	2.17

Cost

- Maximum benefit is obtained by Customer 2 whose cost comes down by 11.6%

Peak Load

- Peak load on the system comes down from 15.3kW to 7.5 kW during noon

PAR

- Peak-to-Average ratio (PAR) for the entire system comes down from 2.30 to 2.17

Conclusion

- The main driver of smart grid is the carbon footprint
- Lack of knowledge among customers is why quantifying the benefits of DR has become important
- Necessity of dynamic pricing schemes
- DR algorithm developed an applied to a group of residential consumers
- Performance gains from utility and customer perspective
  - Reduced cost to customer
  - Reduced PAR

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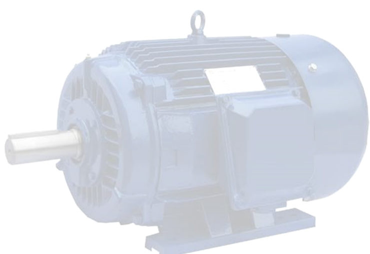

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