Demand Side Optimization using a Load Shifting Algorithm

A proposed load shifting algorithm for reduction of peak power consumption in residential areas

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Abstract

The Smart Grid is a concept that attempts to optimize power generation, transmission, and distribution using methods like demand side management (DSM), which consists of controlling the load on the consumer side. The traditional demand curve peaks at certain times of the day and leads to higher generation costs, more transmission losses, and higher prices for consumers. With DSM, we will attempt to reduce this peak by scheduling controllable processes at off-peak times. An algorithm was developed to optimize the shifting of loads based on the varying consumer price. This study showcases the potential and the advantages of DSM in improving the performance of the grid.

Energy Prices

Time	Price (ct/kWh)
08h–09h	12.00
09h–10h	9.19
10h–11h	12.27
11h–12h	20.69
12h–13h	26.82
13h–14h	27.35
14h–15h	13.81
15h–16h	17.31
16h–17h	16.42
17h–18h	9.83
18h–19h	8.63
19h–20h	8.87
20h–21h	8.35
21h–22h	16.44
22h–23h	16.19
23h–24h	8.87
24h–01h	8.65
01h–02h	8.11
02h–03h	8.25
03h–04h	8.10
04h–05h	8.14
05h–06h	8.13
06h–07h	8.34
07h–08h	9.35

Table 1

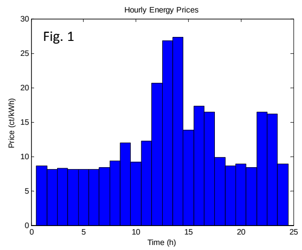


Table 1 and Figure 1 show the hourly energy prices.

Fixed and Controllable Loads

Time	Hourly consumption (kW) Residential
08h–09h	540.9
09h–10h	593.8
10h–11h	593.6
11h–12h	594.1
12h–13h	558.8
13h–14h	545.6
14h–15h	535.4
15h–16h	529.6
16h–17h	513.8
17h–18h	866.4
18h–19h	1085.6
19h–20h	1196.6
20h–21h	1229.3
21h–22h	1117.3
22h–23h	911.2
23h–24h	545.4
24h–01h	395.3
01h–02h	331.9
02h–03h	364.7
03h–04h	349.8
04h–05h	269.6
05h–06h	269.6
06h–07h	412.3
07h–08h	539.1

Table 2: Fixed Loads

Table 3: Controllable Loads

Load Type	Initial Schedule	Consumption (kW)
Dryer	17:00	226.8
Dish washer	13:00	201.6
Washing Machine	15:00	241.2
Oven	12:00	362.7
Iron	18:00	340
Vacuum Cleaner	10:00	63.2
Fan	12:00	172.8
Kettle	21:00	812
Toaster	08:00	43.2
Rice Cooker	12:00	50
Hair Dryer	08:00	87
Blender	09:00	19.8
Frying Pan	00:00	111.1
Coffee Maker	08:00	44.8

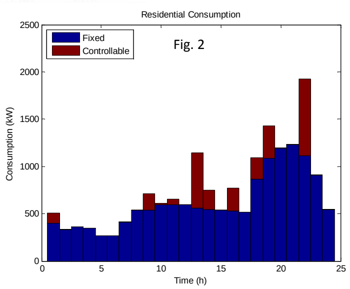


Figure 2 shows a plot of the total residential load found in tables 2 and 3. Blue represents the fixed or uncontrollable loads, and red represents the controllable (or shiftable) loads.

Objective Function

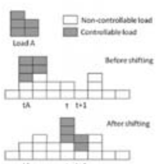
For each time interval, we can define the total load as:

$$P_{load}(t) = P_{fixed}(t) + P_{shifted}(t) + P_{unshifted}(t)$$

We will define the objective function based on the hourly prices. Notice that the hour price is in the denominator, so we are looking to minimize the consumption at times when the price is high.

$$Obj(t) = \frac{Price_{Avg}}{Price_{max}} \times \frac{1}{Price(t)} \times \sum_{s=1}^{N=24} P_{load}(s)$$

Shifting Controllable Loads



The uncontrollable loads cannot be shifted. However, the controllable loads can be shifted based on their flexibility.

We will define a flexibility parameter (m) based on the nature of the load. This indicates how many hours the load can be shifted backwards or forwards. For example, we assume that the washing machine can be shifted 6 hours while the oven can only be shifted by 3 hours.

Optimization Equation

With an expression for power and objective for each time period, we can form an optimization problem:

$$minimize \sum_{t}^{N=24} [P_{load}(t) - Obj(t)]^2$$

We are taking the square of the difference between the actual load and the objective load, and then summing them across the day. We want to minimize this parameter. So we would like to find the arrangement of the controllable loads that results in the lowest value for this parameter.

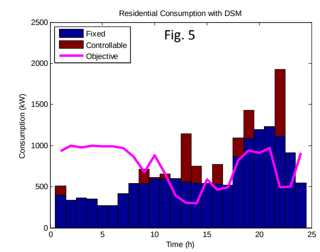
Table 4

Residential Load Type	Flexibility (m) (hr)
Coffee Maker	1
Hair Dryer	1
Vacuum Cleaner	5
Oven	3
Dish Washer	5
Washing Machine	6
Dryer	6
Rice Cooker	1

Table 4 shows some examples of the assumed flexibility of some residential load types. This parameter can be changed in the model.

Test Plans

To verify our model, we considered cases where the flexibility of the controllable loads are at extremes. When the flexibility is set to zero (figure 5), the load graph is unchanged. When the flexibility is set to 24 (figure 6), the loads can be moved freely and a more optimal arrangement can be found (with respect to the key performance parameter).



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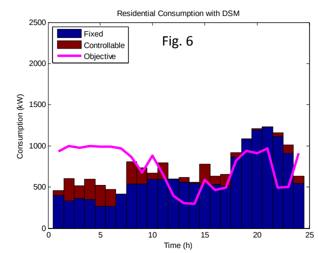

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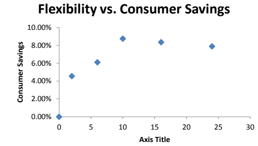
Cost Analysis

Table 5

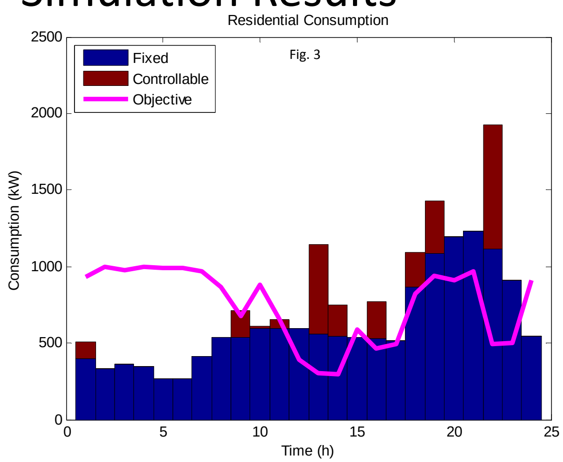
Flexibility (m)	Consumer Savings
0	0.00%
2	4.55%
6	6.11%
10	8.76%
16	8.38%
24	7.90%

Fig. 7



In table 5 and figure 7, we are assuming a static flexibility parameter for all load types and observing the resulting consumer savings. We see that the maximum flexibility does not necessarily result in the most consumer savings. This initially seems strange, but upon further inspection it can be seen that the objective function looks not only to reduce consumer price, but also to flatten the consumption curve. Thus there is actually a 'sweet spot' of load flexibility that results in the lowest consumer prices and a flat consumption curve.

Simulation Results



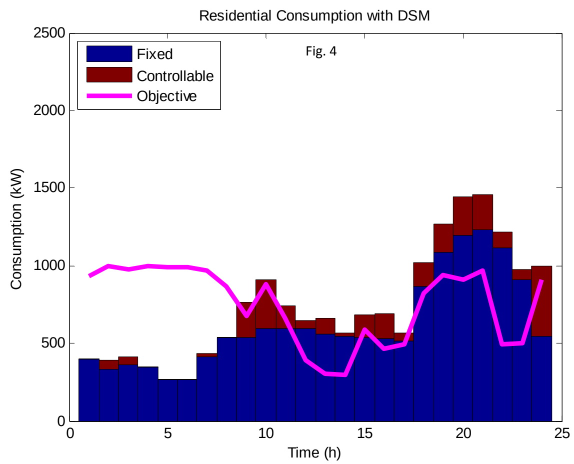


Figure 3 and Figure 4 demonstrate the result of the shifting algorithm on this set of data. The objective function is seen in magenta. We can see that the consumption peak is getting flattened out and distributed, which is what we are looking for. With this set of flexibility parameters, there was a 6.61% decrease in consumer cost.

Conclusions and Future Work

- The DSM shifting algorithm can shift controllable loads to non-peak times in order to optimize costs.
- Two critical parameters that affect the DSM performance are:
- Number of controllable loads
- Flexibility of controllable loads (m)
- With more controllable loads/more flexibility of controllable loads, we can achieve better performance.
- Demand side management will not only reduce consumer costs, but will also reduce generation cost and transmission losses.
- DSM can also allow easier implementation of renewable energy and distributed generation by shifting loads to when power is available and cheap.
- This can lead to cheaper, efficient, and more sustainable power generation and distribution.
- The algorithm developed can be improved by
  – Using a dynamic flexibility parameter (m)
  – Implementing one-way shifting
  – Adding key performance parameters and making it an n-dimensional optimization.
- Using an evolutionary algorithm (EA) to reduce the computation load of the algorithm.

References

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