Optimal Demand Response for PV-Integrated Households

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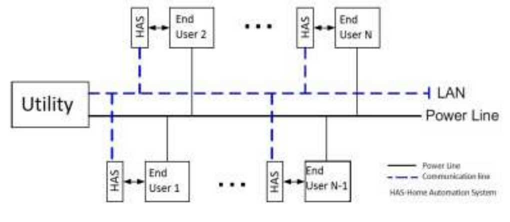
1. Motivation

- With increasing energy demand, setting up new power plants and transmission systems are time consuming and costly affairs.
- There is need for better utilization of alternative forms of energy such as solar energy, which is available in abundance and also doesn't cause any pollution.
- The peak loading on the system creates additional stress on the power network. The cost of operating peak load power plants is also very high.
- There is a need for better demand side management which also considers household photovoltaic (PV) generation.

2. Introduction

- The rooftop solar PV can be used to supply household loads in grid-connected mode and the excess generation can be sent back to the grid.
- Demand response programs are an effective solution for reducing or shifting the peak demand.
- A user-friendly algorithm which also considers PV generation to schedule the household loads is essential.
- The proposed algorithm caters to the customers load preference to arrive at the optimum schedule for the controllable appliances, while considering the generation from solar PV system.
- By the use of battery storage system, uninterrupted power supply is ensured during power failures or load shedding by the utility.

3. Optimal Demand Response Algorithm



- The Home Automation System (HAS) can be viewed as a system that can perform the following functions: metering, monitoring, communication, scheduling and controlling.
- The proposed demand response (DR) algorithm is executed and implemented by the HAS.
- For each appliance $a \in \mathcal{A}$, an appliance energy scheduling vector $\mathbf{x_a}$ is defined as follows.
  - $\mathbf{x_a} \triangleq [x_a^1, x_a^2, \ldots, x_a^H]$
- The daily energy requirement for each appliance a in the interval $[\alpha_a, \beta_a]$ should satisfy the following condition.
  - $\sum_{\alpha_a}^{\beta_a} x_a^h = E_a$

where α_a, β_a are the user specified time limits for appliance a.

- The maximum and minimum energy level are denoted by γ_a^{max} and γ_a^{min} respectively for each a
  - $\gamma_a^{min} \le x_a^h \le \gamma_a^{max}, \quad \forall h \in [\alpha_a, \beta_a]$
- Let E_{pv}^h be the solar energy generation at each hour h from the solar panels installed at the household.
- Let E_{grid}^h be the energy supplied by the grid to the house at hour h. Hourly grid power supply can be defined as,
  - $E_{grid}^h = \sum_{a \in \mathcal{A}} x_a^h - E_{pv}^h$
- Let p^h be the hourly price at hour h.
- Let c be the selling price factor for selling power back to the grid.
  - $p^h = cp^h, \quad when\ E_{grid}^h < 0$
- The objective is to minimize the per day cost function. The objective function is defined as follows.
  - $\underset{x \in X}{\text{minimize}} \sum_{h=1}^{H} p^h E_{grid}^h$
- The optimization problem can now be completely defined along with all its constraints as,

$$
\begin{aligned}
&\underset{x \in X}{minimize} \sum_{h=1}^{H} p^h E_{grid}^h \\
&E_{grid}^h = \sum_{a \in \mathcal{A}} x_a^h - E_{pv}^h \\
&p^h = cp^h, \quad when\ E_{grid}^h < 0 \\
&\mathcal{X} = \{\mathbf{x} | \sum_{\alpha_a}^{\beta_a} x_a^h = E_a, \quad \forall h \in [\alpha_a, \beta_a] \\
&\gamma_a^{min} \le x_a^h \le \gamma_a^{max}, \quad \forall h \in [\alpha_a, \beta_a] \\
&x_a^h = 0 \quad \forall h \notin [\alpha_a, \beta_a]\}, \forall a \in \mathcal{A}
\end{aligned}
$$

4. Solar PV and Battery Integration

- The PV-grid connection (Figure 2) is two-stage high-frequency power conversion in cascaded configuration with dc link in the middle.
- In this configuration, the DC-DC (buck) converter tracks the maximum power point and the DC-AC converter (full bridge inverter) performs the grid current control.

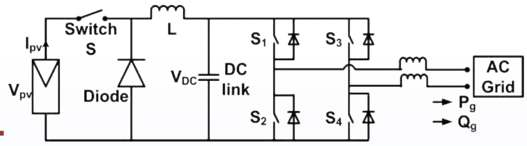


Figure 2: PV-Grid interface circuit

- To facilitate an efficient charging and discharging mechanism, single phase bidirectional AC-DC converter and bidirectional DC-DC converters is used in cascaded configuration (Figure 3).

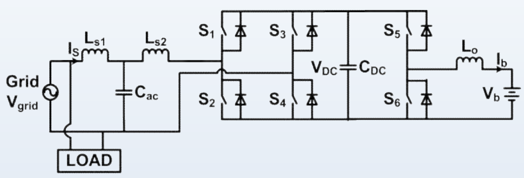


Figure 3: Battery-Grid interface circuit

5. Simulation Results

- A generic load profile for a residence with 10 typical household appliances is considered for the simulation.
- Proposed DR algorithm is solved in MATLAB.
- Without DR, cost per day is Rs.53.39 and with DR, it day is Rs.45.64. Savings is Rs.7.75 on a typical day without the use of PV array. (Figure 4)
- With the use of a 3kW solar array, and a selling price factor of c = 1.5. It is found that cost per day for the customer is Rs.-3.78. Savings is Rs.57.18. (Figure 5)

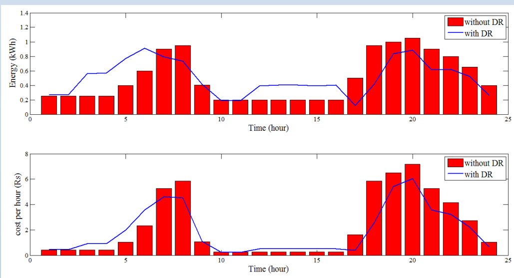


Figure 4: The energy profile and cost with and without demand response program for 10 appliances.

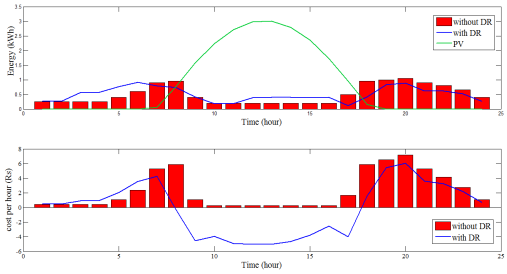


Figure 5: The energy profile, PV generation and cost with and without demand response program for 10 appliances.

- Real Time Digital Simulator (RTDS) simulations are carried out with IEEE 13 node feeder as the test system.
- Solar PV and battery circuits shown in figure 2 & 3 are connected to node 645 along with 10 household appliances.
- Energy is fed back to the grid during times of excess PV generation (Figure 6).
- Battery charges when grid is connected and supplies power to essential loads during off grid mode

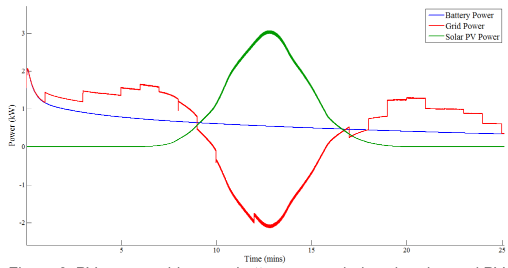


Figure 6: PV power, grid power, battery power during charging and PV operation.

6. Conclusion

- The main objectives of reducing and shifting peak loading on system are achieved with the proposed demand response algorithm.
- Customer is able to save on the electricity bill. Since customer load preference is considered, customer satisfaction is not compromised.
- With the use of PV, multiple objectives are satisfied, such as ease of stress on the system to generate more energy, clean energy without any pollution, monetary benefit for the customer for the excess energy sold back to grid.
- Battery is used as a backup power source during powercut situations. This ensures that the customer is able to enjoy uninterrupted supply during short power outages.
- Even during intermittent power supply conditions, it is seen that, continuous power supply is maintained, without having to switch off any of the essential loads.

Selected References

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