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Research Article

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Coordination of Demand Response and Energy Efficiency for Load Reduction in a Smart Home

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Abstract Increasing demand on electrical energy coupled with lack of new distribution facilities create a potential threat that can eventually sprawl to jeopardize the distribution system reliability. Smart grid provides electricity consumers with opportunities to manage their electricity usage for the purpose of reducing their electricity bills and alleviating the power peak-average-ratio. The recent advancement in smart grid technology such as advanced metering infrastructure (AMI) has made it possible for both utility and consumers to interact automatically through bi-directional digital communication. Effectiveness of the load reduction with demand response and energy efficiency is validated through a time sequence analysis over a 24-hourly simulation period using Open Distributed System Simulation (Open DSS) Com Matlab. Test results show that the demand response and energy efficiency tools cause load reduction in in the building. This enhances the benefits of demand response and energy efficiency such as security of the network system, reduction in electricity bill for energy usage and voltage profile improvement.

Keywords Demand response, Energy efficiency, Load reduction, Peak period, Smart grid

Introduction

Energy is a vital factor in nation building and it should be well managed. Electricity consumption and production must balance at all times in electricity grid; any significant imbalance could cause severe voltage fluctuations or grid instability, and cause failures within the grid. Tremendous efforts must be made to ensure development of its (grid) sustainability via demand response (DR), energy efficiency (EE) and reduction of energy wastage among key energy sectors as well as encouraging the deployment of distributed generation (DG) as an alternative energy source.

Smart grid (SG) is defined differently by utility stakeholders, engineers, businesses, politicians and academics. In general terms, SG refers to improved electricity supply originating from main power plant generating centers and delivered to end users. SG techniques is also multifaceted due to the infrastructure that produces and delivers energy and the various loads that consume energy [1]. The development of SG is to be an automated, digitalized and widely distributed energy delivery network. SG applies the use of digital technology to improve reliability, security and efficiency (both economy and energy) of the electric system from large generation, through the delivery system to electricity consumers and a growing number of DG and storage devices. The basic concept of SG is to apply monitoring, analysis, control, information and communication capabilities to the conventional grid system, to maximize the output of the system and minimize the energy consumption [2].

The advancement of SG provides electricity consumers with opportunities to manage their electricity usage for the purpose of reducing their electricity bills and alleviating the power peak-average-ratio. The recent advancement in SG technology such as advanced metering infrastructure (AMI) has made it possible for both utility and consumers to interact automatically through a bi-directional digital communication. (DR is one of SG tools that empowers customers in effective management of their own electricity usage in response towards changes in energy price overtime or incentive base payment provided by the utility company). It is a potent technique that can take care of a potential threat that can ultimately sprawl to jeopardize the grid's reliability; especially with the advancement of SG technologies instead of constructing more power plants to meet the increasing demand [3]. It has the potential to postpone the need for network upgrades and reduce overall plant and capital cost investments [4].

Smart grid applications enable two-way communication between electricity producers and consumers to make decisions about when and how to produce and consume electricity. This emerging technology will enable customers to shift from an event-based DR where the utility requests the shedding of load, towards a more 24/7-based DR where the customer sees incentives for monitoring load all the time[4]. Although this bi-directional communication increases the opportunities for DR, customers are still basically influenced by financial incentives and are unenthusiastic to give up total control of their assets to distribution companies(DISCOs) [5]. Users participating in DR program can defer (shift the load to off-peak period) or reduce their energy usage when the energy price is high during peak period to when the energy price is low at off-peak period [6]. DR such as consumer’s electricity scheduling mitigates the urgency of power plant construction, facilitates the integration of DGs and alleviates supply pressure of DISCO [7-8].

Energy efficiency (EE) is a technological solution for eliminating energy losses in the existing system. EE refers to using less energy to produce the same amount of service or useful output [9]. This can be carried out by the installation of EE technologies with the objective of reducing load levels in the long-run, while maintaining customer comfort or level of service [9]. DR and EE as well as energy conservation, advanced metering, and DG technologies are offered as elements of an integrated solution that supports energy and carbon reduction.

The effect of incentive-based DR on distribution system voltage profile was carried out in [10]. A demand-price elasticity matrix was modeled for customers. However, the model lack control option to carry out the incentive-based DR program. In [11], a power system where customers manage their energy consumption by playing games among one another in response to DISCO 24-hour electricity price scheduling is presented. Due to customers’ participation in the dynamic pricing DR, there was improvement in voltage profile and the cost of energy was reduced while keeping customers’ satisfaction at a high level. However, the proposed algorithm required customers to update their energy usage scheduling asynchronously with the assumption that each customer has full information of generation cost function. This proposal is hard to realize in practice. In [12], a genetic algorithm (GA) approach to exert a day-ahead peak demand control for a commercial building considering central air conditioners is developed. The direct load control employed on the central air conditioners in the commercial building is effective in system performance improvement and energy cost reduction. However, the percentage of load reduction is small. A wider application could have been better.

This paper presents the coordination of DR and EE programs for load reduction in a smart building. This will enhance the benefits of DR and EE such as security of the network system, reduction in electricity bill for energy usage and voltage profile improvement.

Potential Synergies and Conflicts between Demand Response and Energy Efficiency

Demand response and EE affect customer end-use of electrical energy. DR programs and technologies have been presaged in recent years as a great advancement in providing customers new options for managing their energy usage along with providing energy suppliers new options for guaranteeing reliable supply at reasonable costs. DR and EE programs are commonly operated independently and simultaneously by DISCOs. However, these two programs are not mutually exclusive. Although, DR and EE accomplish different but complementary electrical power system objectives, DISCOs could couple DR and EE programs in order to leverage the different strengths of each for an optimum resource plan. DR and EE program can be coordinated together to defer new plant construction, flatten DISCO load curves and lower prices for power and gas. The coordination may also be obliging for producing an adequate value package for the electricity users. For instance, participating in DR programs could cause inconvenience; however, coordinating DR with EE, could reduce the effect felt by electricity users when DISCOs call on them to shift, curtail or reduce their load.

DR programs seek to reduce peak demands during times when reliability may be endangered or electricity price is high. However, demand reduction is not the same as energy saving, although there are clear relationships between peak power demand (kW) reduction and energy saving (kWh). Yet DR and EE relationship is vitally significant because there are many potential synergies, as well as potential conflicts, between DR and EE programs.

Potential synergies include[13]:

- Energy demand can be reduced permanently, at peak as well as off-peak times with application of EE;
- Focusing on peak-demand reductions can help identify inefficient and non-essential energy uses that could be reduced at other times, thus resulting in broader energy and demand savings;
- Technologies that can allow DR also can be used efficiently to manage energy usage year-round;
- DR activities can lead to greater cognizance of energy savings opportunities through improved EE;
- Participating customers of DR programs may be prime customers for participating in EE (and vice versa);
- Electricity aggregators could be more effective at communicating with customers about their energy usage through integrated approaches to energy management.

Energy Efficiency Strategies

The following can be employed to reduce energy and demand in existing redeveloped building:

a. Install interlock or proximity switches in windows and patio doors that will turn off the air conditioning when windows and patio door are opened for more than a pre-set period of time. This could be integrated with a security/fire alarm system.
b. For the solar/thermal-assisted water heaters in the units:

   i. Disconnect the lower heating element and let the system run on the top element only. This would allow the lower part of the tank to be heated primarily by solar and if the tank empties to less than 1/3, the upper element will come on.

   ii. Alternatively, set the lower thermostat to 10°F to 20°F degrees cooler than the upper thermostat. Either of these strategies could net a 10% to 40% increase in solar-driven water heating with a similar decrease in electric resistance water heating.
c. The following number of strategies can be deployed for improved building EE and DR:

   i. Install high-quality, light-emitting diode (LED) recessed can/down-lighting technology. Replace incandescent lamps with energy saving tubes.

   ii. Correctly size the air conditioners (A/C) commensurate with any additional energy/load saving strategies.

   iii. Install LED streetlights and walkway lights in neighbourhoods.

   iv. Consider "solar tubes" (natural light transmission via reflective tubes) in areas that are normally dark due to the house layout and lack of windows.

   v. Implement SG appliances/technologies and thermostats with potential control features of a smart chip such as:
   - Refrigerator that will only defrost when truly required and only in off-peak times;
   - Hot water tank that will learn usage pattern and delays heating water during on-peak times;
   - Dishwasher that will delay start-up until off-peak times;
d. Thermostat that delays activating the A/C during or near on-peak periods, and dryer that will only heat during off-peak times that allow automatic control based on load and/or instability and that is communicated via the SG architecture [1].

Coordination of Demand Response and Energy Efficiency

Coordinating DR and EE is worth exploring because it could provide customers with increased tools to understand, manage and reduce their electricity usage. Coordinating DR and EE provides customers an opportunity to make better use of their time and consider operational changes and investments that reduce their total energy usage.

While DR targets reducing loads during a few brief periods over the course of a year, peak-periods or when reliability is endangered due to supply constraints; EE targets energy savings at all times throughout the year. This dissimilarity can cause some confusion as energy decision-making strategies, program equipment and different building systems are involved. Most EE technologies also will produce at least some peak-demand reduction benefits. By coordinating DR and EE elements in program design, customers could benefit from integrated solutions to their needs for energy cost reduction and related benefits, such as improved building management and control[13].

Effective coordination of DR and EE by DISCOs, policy-makers, and third-party program providers is an essential step to increase the effectiveness and utilization of energy management resources. While progress has been made in recent years, more work is needed to achieve the full promise and potential of the synergy between EE and DR[14].

Test Result

The effect of load reduction in a smart residential building supplied with 415V, 50Hz, 9.5 kW load is carried out with DR and EE. Energy purchased by DISCO is sold to customers at whichever price they choose. Flat price is mostly used which is designed to cover long-run average cost. However, DISCO depends on bilateral contracts including wholesale spot market to purchase the energy they supply to customers. The underlying cost structure is therefore difficult to be estimated. Hence, publicly available wholesale market data as shown in Fig. 1[15] is used in this paper to estimate the system-level costs incurred by the DISCO.

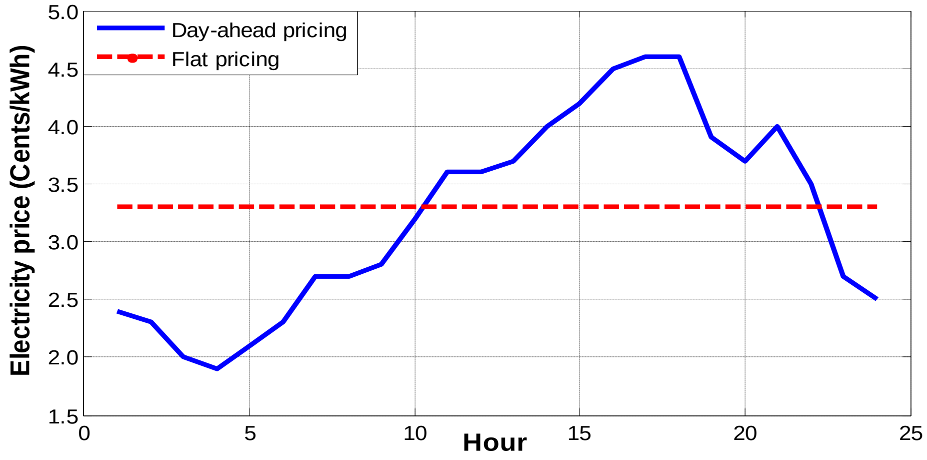

Figure 1: 24-hour electricity price released by DISCO

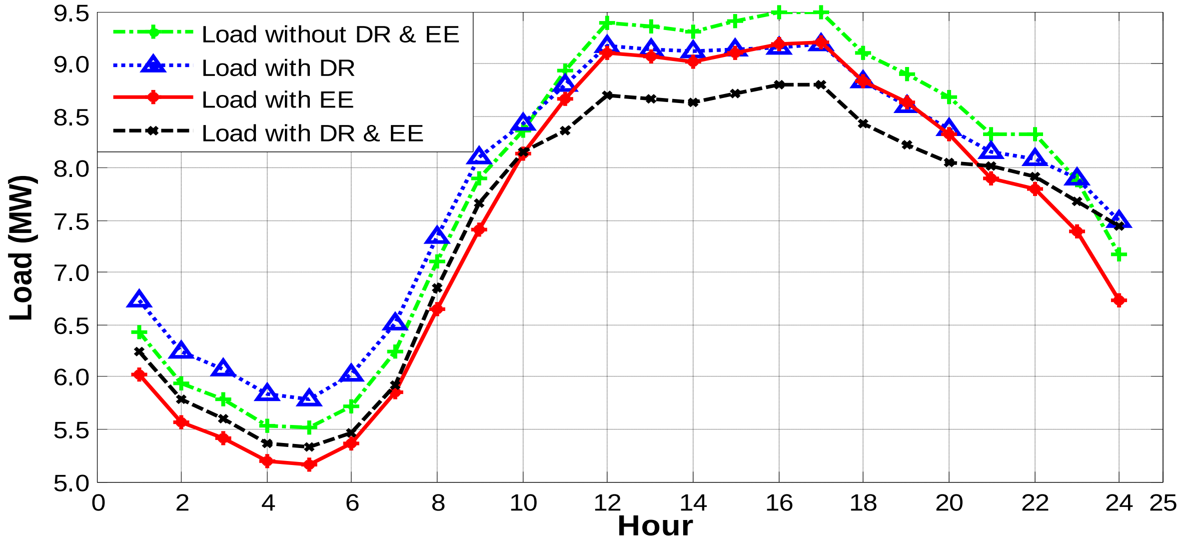

Figure 2: The feeder load curve with and without DR and EE

A day-ahead pricing is introduced. The elastic loads in the building is controlled based on the 24-hour electricity price released by DISCO. Some of the elastic loads are curtailed, reduced and some load such as washing machines, pumping machine are shifted from day to night. A 24-hourly simulation using Open Distributed

System Simulation (OpenDSS) Com Matlab with peak load of 9.5 MW is carried out to verify load reduction with DR. The result of the building load curve with DR is as shown in Fig. 2 with dotted line. EE is implemented following the instructions in section 3 as applicable. The result of the building load curve with EE is as shown in Fig 2 with solid line. Coordination of DR and EE result is shown dashed line in the figure. The more the customer participated in the DR, the more the benefits of DR. Energy efficiency targets energy savings at all times throughout the day/year, it did not take cognizes of peak period or off peak period. The coordinated result brings more load reduction which is a good benefit to both DISCO and customer. Customers could benefit from integrated solutions to their needs for energy cost reduction and related benefits, such as improved building management and control. Test results show that the demand response and energy efficiency tools cause load reduction in a smart building. This boosts the benefits of demand response and energy efficiency such as security of the network system, reduction in electricity bill for energy usage and voltage profile improvement.

Conclusion

Tremendous efforts must be made to ensure development of energy sustainability via demand response, energy efficiency and reduction of energy wastage among key energy sectors as well as encouraging the deployment of distributed generation as an alternative energy source. The advancement of SG provides electricity consumers with opportunities to manage their electricity usage for the purpose of reducing their electricity bills and alleviating the power peak-average-ratio. Effective coordination of DR and EE by DISCOs, policy-makers, and third-party program provider is an essential step to increase the effectiveness and utilization of energy management resources. While progress has been made in recent years, more work is needed to achieve the full promise and potential of the synergy between EE and DR.

Demand response and energy efficiency tools cause load reduction in the building as demonstrated in this paper. This increases the benefits of demand response and energy efficiency such as security of the network system, reduction in electricity bill for energy usage and voltage profile improvement. Further studies will examine the effect of the load reduction caused by demand response and energy efficiency on energy loss reduction and voltage profile improvement.

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