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New Demand Management Scheme for Smart Grid with Potential Use of Wireless Sensor Networks

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Abstract. Smart grid provides vast opportunities in demand response field. The demand response solutions target both peak load reduction and consumer expense reduction. Furthermore, in the smart grid, the demand response is extended to demand management since the consumers are also able to generate energy. Energy generation at the demand-side requires intelligent control and coordination algorithms. In addition to those, widespread adoption of Plug-in Hybrid Electric Vehicle (PHEV) will impose tight operation constraints for the power grids. PHEV will be charged from the grid and their energy consumption rating may be as high as a households' daily consumption. One of the promising demand management techniques is employing Wireless Sensor Network (WSN) in demand management. In this paper, we suggest a fuzzy demand management scheme for the smart grid with a focus on the potential uses of the WSN in the building blocks of the smart grid.

Keywords: Smart grid, fuzzy system, Plug-in Hybrid Electric Vehicle (PHEV), in-Home Energy Management (iHEM)

1 Introduction

Demand management schemes for the smart grid are grouped as communication-based demand management, incentive-based demand management, real-time demand management, and optimization-based demand management. Communication-based demand management techniques have been studied in [3]. Demand management schemes that employ WSNs have been presented under communication-based techniques, as well. Incentive-based demand management techniques have been studied in [5]. These schemes try to shift the consumer demands to off-peak hours, and in the meanwhile they provide incentives to the consumers by configuring the prices based on a game theoretic approach. Incentive-based schemes can shape consumer behavior according to the needs of the smart grid. Thirdly, real-time demand management has been studied in [4]. In this paper, we represent a broad perspective on the possible utilization of wireless sensor network (WSN) in the smart grid. Then, we focus on in-Home Energy Management (iHEM) among communication-based demand management schemes. One of the promising demand management techniques is employing WSN in demand management. A WSN is a group of small, low-cost devices that are able to sense some phenomena in their

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surroundings, perform limited processing on the data and transmit the data to a sink node by communicating with their peers using the wireless medium. Scheduling is one of the most essential bases of iHEM demand management. A fundamental approach to solve this problem is applying fuzzy sets.

2 WSN and iHEM

In [3], they have used WSNs and smart appliances for residential demand management. This residential demand management scheme is called in-Home Energy Management (iHEM). iHEM employs a central Energy Management Unit (EMU) and appliances with communication capability. EMU and appliances communicate via wireless links where their packets are relayed by a WSN. iHEM is based on the appliance coordination scheme that was proposed in [2]. EMU communicates with the smart meter regularly to receive the price updates of the TOU tariff applied by the grid operator. The authors assume that the smart home is also able to produce energy by solar panels or small wind turbines. Therefore, upon receiving a START-REQ packet, EMU communicates with the storage units of the local energy generators and retrieves the amount of the available energy by sending an AVAIL-REQ packet. Upon reception of AVAIL-REQ, the storage unit replies with an AVAIL-REP packet where the amount of available energy is sent to the EMU. After receiving the AVAIL-REP packet, EMU determines the convenient starting time of the appliance by using crisp Algorithm. EMU computes the waiting time as the difference between the suggested and requested start time, and sends the waiting time in the START-REP packet to the appliance. The consumer decides whether to start the appliance right away or wait until the assigned timeslot depending on the waiting time. The decision of the consumer is sent back to the EMU with a NOTIFICATION packet. Afterwards, EMU sends an UPDATE-AVAIL packet to the storage unit to update the amount of available energy on the unit after receiving the consumer decision.

3 Fuzzy demand management system

In iHEM, typical scheduling algorithm works as follows. First, EMU checks whether locally generated power is adequate for accommodating the demand. If this is the case, the appliance starts operating, otherwise the algorithm checks if the demand has arrived at a peak hour, based on the requested start time of appliance i, S_i. If the demand corresponds to a peak hour, it is either shifted to off-peak hours or mid-peak hours as long as the waiting time does not exceed D_m, i.e. maximum delay. The computed delay of appliance i, d_i is returned to the consumer as the waiting time. D_m parameter limits the delay, hence it guarantees a maximum delay for the consumers, and at the same time it prevents the requests to pile up at certain off-peak periods.

There are stochastic versions of scheduling problems, but they are hard to compute in practice, because some deterministic scheduling problems are already very hard. Resorting to fuzzy set may help building a tradeoff between the expressive power and the computational difficulties of stochastic scheduling techniques while tackling uncertainty and accounting for local specifications of preferences. In iHEM, when fuzzy variable S_i has three membership functions InPeak, InMidPeak and OffPeak, and fuzzy variable Start has two membership functions Immediate and Delayed, a scheduling rule based on fuzzy logic works as follows.

Fuzzy Scheduling Rules

R1: **if** (S_i is InPeak and $d_i > D_m$) **then** Start is Immediate
R2: **if** (S_i is InPeak and $d_i <= D_m$) **else** Start *is* Delayed
R3: **if** (S_i is InMidPeak and $d_i > D_m$) **then** Start is Immediate
R4: **if** (S_i is InMidPeak and $d_i <= D_m$) **else** Start is Delayed
R5: if (S_i is OffPeak) then Start is Immediate

4 Simulation

For comparison, we use very soon Time of Use (TOU) data which is activated by most of the utilities in North America. TOU rates will be applied to the metering operations by the help of smart meters and the AMI. Figure 1 denotes the accumulated loads by using fitting network to fit an input-output relationship. The hours of high consumer activity, i.e. high load durations, is called on-peak periods, while moderate and low load durations are called mid-peak and off-peak periods, respectively

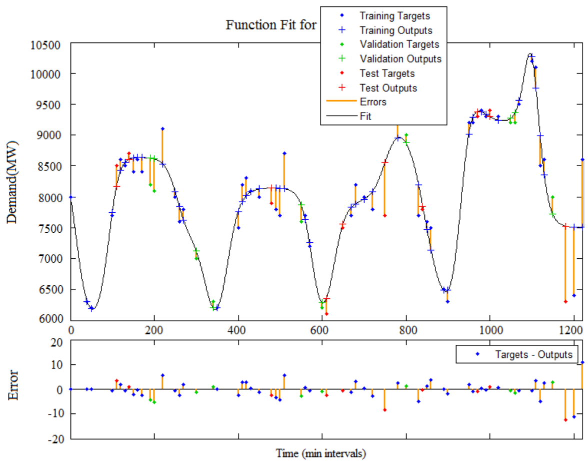

Fig. 1. Comparison of electricity load on the grid for four days in winter

The rate chart of an Ontario-based utility is given in Table 1 as an example of TOU rate and adjusted rate by fuzzy reasoning. Typical triangular membership functions are used for fuzzy variables On-Peak, Mid-Peak and Off-Peak. Note that, TOU hours and rates may vary from one utility to another based on the local load pattern and cost. For instance, cold weather conditions in northern countries increase heating demand throughout the winters, whereas, southern countries may have less heating demand during the same period of the year.

Table 1. TOU rates of an Ontario utility

	Period	*Time*	*Rate*	*Adjusted Rate*
Winter	On-Peak	7:00am to 11:00am	9.3 cent/kWh	6.1 cent/kWh
Weekdays	Mid-Peak	11:00am to 5:00pm	8.0 cent/kWh	8.0 cent/kWh
	On-Peak	5:00pm to 9:00pm	9.3 cent/kWh	9.3 cent/kWh
	Off-Peak	9:00pm to 7:00am	4.4 cent/kWh	4.4 cent/kWh
Summer	Mid-Peak	7:00am to 11:00am	8.0 cent/kWh	8.0 cent/kWh
Weekdays	On-Peak	11:00am to 5:00pm	9.3 cent/kWh	9.3 cent/kWh
	Mid-Peak	5:00pm to 9:00pm	8.0 cent/kWh	8.0 cent/kWh
	Off-Peak	9:00pm to 7:00am	4.4 cent/kWh	4.4 cent/kWh
Weekends	Off-peak	All day	4.4 cent/kWh	4.1 cent/kWh

5 Conclusion

In this paper, we discussed new demand management scheme for the smart grid with a focus on the potential uses of Wireless Sensor Network (WSN) in the building blocks of the smart grid. WSN provides promising solutions for efficient integration of intermittent renewable energy resources, low-cost monitoring of traditional power plants and high-resolution monitoring of utility transport assets. Furthermore, WSN offers vast variety of applications in the field of consumer demand management. The ultimate aim of those demand management schemes is to schedule the appliance cycles so that the use of electricity from the grid during peak hours is reduced which consequently reduces the need for the power from the peaker plants and reduces the carbon footprint of the household.

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