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ScienceDirect
Energy Procedia 103 (2016) 195 – 200
Energy Procedia

Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid, 19-21 April 2016, Maldives

Design and Implementation of a Smart Meter with Demand Response Capabilities

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Abstract

This paper presents the design of a smart meter (SM) with demand response (DR) capabilities. The SM design is tested in a simulation that implements an advanced measurement infrastructure (AMI), which allows a bidirectional communication between the household smart meters and the distribution management system (DMS). The DMS deploys an energy management system (EMS) that runs a simple demand response program (DRP) based on time of use (TOU), consisting in peak and off-peak rates. Results from the simulation and the data collected from the SM show significant improvements in energy consumption during peak hours thanks to the load curtailment strategies.

Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.

Keywords: demand response; fuzzy control; smart meters

1. Introduction

Smart meters (SMs) are gradually replacing the traditional meters, and are also being installed in new microgrids. SMs transmit information to different information clients via SCADA systems and other networks. One of the main features that SMs offer to consumers is the possibility to read in real time rates and pricing policies, allowing the implementation of DRP. These features are being exploited by utilities in order to achieve energy efficiency. Peak load reduction through an interactive reaction of the loads installed at the customer premises, *e.g.* turn on schedulable loads when cheap generation is available, increases network reliability and produce significant economic savings to the utility and the customers [1].

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Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.
doi:10.1016/j.egypro.2016.11.272

DR may limit, in certain degree, the comfort of the consumers. Therefore, it is desirable to limit the time during they may be exposed to such discomfort. Automation, monitoring and control techniques are fundamental to correctly manage the energy-use process, making DR less hindering for the customer [2].

A report with successful results on the implementation of DRP is presented in [3]. Significant economic savings are reported, since demand peak flattening avoids the need for more generation capacity. In [4], a load scheduling algorithm is implemented through a combinatorial optimization problem constrained by the maximum demand limit on a microgrid. The utility establishes TOU rates. In [5], a DRP is proposed that enables households to participate in DR services. Half-hour-ahead rolling optimization and a real-time control strategy are combined to achieve household economic benefits. A fuzzy logic controller is utilized to determine battery charging/discharging power; proper rules are proposed to ensure benefits from operating the battery storage system under the real-time electricity price. Reference [6] presents a demand side management strategy for load shifting based on heuristic optimization. The proposed optimization algorithm aims to shape the final load curve close to the desired load curve. The restriction of this strategy is compliant in the number of shiftable loads in the system, which users are willing to use at a different time. The results of this strategy are positive and show 5-10% operational cost reduction and 14.2-18.3% peak demand reduction. Additional DR methods are overviewed in [7].

This paper presents the design of a household SM with DR capabilities. An AMI simulation scenario is developed in order to test the DR capabilities of the SM. The TOU rates method is implemented for the simulation events. Additionally, an EMS processes real time data coming from the SMs, consisting of: 1) power measurements; 2) time and date; 3) load priority; and 4) prices of the electricity. The SM in conjunction with the EMS takes decisions on loads curtailment strategies. A knowledge based fuzzy controller (KBFC) calculates dimming percentages of loads that allow these commands, and shifts schedulable loads from peak consumption hours to low price energy generation hours. The results show improvements in energy savings and successful application of the DR commands in the user premises through the SM.

2. SM design

SMs allow traditional meters capabilities as well as new features that aggregate intelligence to the grid. SMs integrate the ability to remotely manage loads at the end-user premises by monitoring and controlling the customer's devices and appliances. A dedicated communication infrastructure, sensors and control devices are required by SMs in order to effectively provide the interaction between the utility and the customer facility [8].

There are a variety of experimental setups of SMs, as detailed in [9]–[12], which are designed to provide the following features:

- To measure customer's power consumption and generation;
- To support control function commands;
- To enable demand response capabilities; and
- To enable a variety of communication capabilities.

Fig. 1 shows the block diagram of the SM design proposed in this research. The central processing unit of the SM is based on open source hardware (Raspberry Pi) due to the flexibility of programming and configuration this platform offers. The power measurement is performed through the dedicated integrated circuit AD7753, which needs an analog front-end (AFE) interface composed by a current sensing stage (Hall effect current transducer FHS-40P/SP600) and a voltage sensing stage (voltage divider). The measurements are sent via a serial peripheral interface (SPI). Fig. 2 shows the printed circuit boards (PCBs) of the implemented hardware design.