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HEMSs and enabled demand response in electricity market: An overview

Aftab Ahmed Khan*, Sohail Razzaq, Asadullah Khan, Fatima Khursheed, Owais

COMSATS Institute of Information Technology (CIIT), Abbottabad, Pakistan

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ABSTRACT

Traditional electricity grid offers demand side management (DSM) programs for industrial plants and commercial buildings; there is no such program for residential consumers because of the lack of effective automation tools and efficient information and communication technologies (ICTs). Smart Grid is, by definition, equipped with modern automation tools such as home energy management system (HEMS), and ICTs. HEMS is an intelligent system that performs planning, monitoring and control functions of the energy utilization within premises. It is intended to offer desirable demand response according to system conditions and price value signaled by the utility. HEMS enables smart appliances to counter demand response programs according to the comfort level and priority set by the consumer. Demand response can play a key role to ensure sustainable and reliable electricity supply by reducing future generation cost, electricity prices, CO_2 emission and electricity consumption at peak times. This paper focuses on the review of HEMSs and enabled demand response (DR) programs in various scenarios as well as incorporates various DR architectures and models employed in the smart grid. A comprehensive case study along with simulations and numerical analysis has also been presented.

Contents

1. Introduction

Traditional Electrical Grid has generation, transmission, distribution and control capabilities, but there is a lack of information and communication technology (ICT) element, particularly at the consumer side. The existing grid is radial, built for centralized generation and generally depends upon manual restoration [1]. Most power plants use fossil fuels to generate electricity as a bulk in central power stations but are less efficient, cause CO_2 emissions and other harmful effects. Integration of ICTs into the grid makes it possible to take fast and accurate decisions [2] and consequently, forms an efficient electrical network of all connected components to deliver reliable, sustainable, and secure electricity to the consumer. CO_2 emission can be reduced significantly by using

* Corresponding author. Tel.: +92 3229937637.
E-mail addresses: aftabjadoon@ciit.net.pk, aftabjadoon@hotmail.com (A.-n. Khan).

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renewable energy resources for electricity generation. These resources are distributed throughout the grid, and have the ability to generate electricity in the range of kilowatts (for residential buildings) up to some megawatts (for commercial buildings and factories) [3]. Efficient control and management of the renewable resources is an important element of smart grid. Many techniques like, active and reactive load improvements, reducing line losses and distribution optimization etc were used in the past in order to improve energy efficiency. Due to the recent advancements in ICT technologies, energy efficiency has improved significantly by efficient load management [4]. Power quality is another important aspect of power system that determines fitness of the supplied electricity for the consumer devices. Ideally the electric supply should have a constant amplitude and frequency. However, this is seldom the case in practice due to nonlinear effects of power electronics, impedance mismatch etc. This leads to reduced efficiency and life time as well as increased running cost of the appliances. Solutions to power quality related problems involve advanced control methodologies. A lot of effort has been made by researchers in order to overcome power quality issues; see for instance [5] and [6]. Advanced control and ICTs give us an opportunity to achieve reliable and efficient power system, as well as efficient power consumption and reduced energy cost by employing demand-side energy management.

The term, demand-side energy management, demand-side load management or load management, in short, refers to the adjustment of demand to match supply. It is the planning, monitoring and implementation of those utility actions, designed to influence customer electricity usage by introducing dynamic load management programs. A lot of work is being done to match the supply and demand by various load management schemes so that we could have reliable, sustainable, economical and secure power system. It is stated in [7] that worldwide residential energy consumption is about 27%. Hence it is imperative to improve energy efficiency on consumer part. A Key concept used for this purpose is demand side management (DSM) [8]. Most of the DSM programs are utility driven in which consumers are not active, but current research work in this area has highlighted need of DSM programs involving active consumers. In this context DSM programs have following four elements, depending upon the applied measures and timings as a consumer process: Energy efficiency, time of use (ToU), demand response (DR), and spinning reserve [9]. Spinning reserve is back-up energy production capacity which can be made available for a transmission system within 10 min and can operate continuously for at least 2 h, once it is brought online.

According to US Federal Energy Regulatory Commission (FERC), Demand Response (DR) is defined as incentives offered to electricity users on reducing their electricity consumption in response to a utility's need for electricity due to a high, system-wide demand for electricity or emergencies that could affect the transmission grid [1,10].

Typically, DR events may occur in the range of 1 to 4 h depending on duration of peak load in a given area and includes dimming or turning off of lighting, shutting down a portion of a manufacturing process or adjusting controllable heating, ventilation and air conditioning (HVAC) levels. Alternatively, onsite generation can be used to shift load drawn from the power grid. Improving energy efficiency and system reliability are the main objectives of DR. Customers can participate in the DR program competition offered by the energy market to change the consumption pattern in response to the price variations [11,12]. DR is becoming the essential task of grid operators and utilities in order to manage peak demand for industrial/commercial and residential sectors. It is estimated that about eleven million households are subscribed to DR programs all over the globe. This rate will be extended up to 32.5 million by 2018 [13]. DR programs are developed to provide incentives to the residential customers and work under the umbrella of HEMSs. A HEMS usually consists of smart appliances, smart meters, advanced control systems and in-home displays. HEMS focuses on power management; home appliances are monitored and controlled to optimize difference in electric supply and demand [14].

Remaining paper is structured as follows. Section 2 describes the basic functions and evolution of HEMS. HEMSs based on various technologies and standards, particularly residential applications, are presented in Section 3. Research work and analysis on residential energy consumption management at peak hours (DR strategies) through a home energy management system (HEMS) at the distribution level, as well as DR architectures and models have been described in Section 4. Section 5 consists of numerical analysis based on the data of a local grid station in Pakistan (Abbottabad 132KV feeder). Section 6 concludes the paper.

2. Basic functions and evolution of HEMS

A home energy management system encompasses any product or service that monitors, controls, and analyzes electrical energy at home. This definition includes residential utility demand response programs, home automation services, personal energy management, data analysis and visualization, auditing, and related security services [15]. The end goal of HEMS is to reduce energy cost, conserve energy and improve consumers' comfort level. HEMSs are in operation for decades and their key function is to optimize, monitor and control the flow of electricity. HEMS have many applications in transmission, distribution and generation of electricity such as supervisory control and data acquisition (SCADA) with HEMS functionalities.

In the beginning analog meters were the main source of energy consumption information, but due to lack of incorporated ICTs, their scope and applications were limited. Most of the energy management systems were based on Xerox Sigma 5 and Sigma 9 [16]. The performance of HEMSs has further improved with the advent of personnel computers in 1980s. Software like UNIX, LINUX, and Windows has added more possibilities in the HEMSs, in the early 2000s. Advancements in system on a chip design and embedded systems have improved the functionality of HEMS by replacing bulky solid state technologies. During 1900s, workable thermostats were used as an automated energy control system at residential level. In the current decade, developments of ICT like low-power wireless sensors networks, ZigBee and power line communication (PLC) etc, have improved home energy management evolution exponentially. The basic components of a HEMS include;

- Sensing devices
- Measuring devices
- Smart appliances
- Enabling ICT
- Energy management system

HEMSs have been implemented in many countries in several different ways. In the US, the growth of DR programs is on a high, due to numerous initiatives and reforms [17]. As a result, the number of companies offering DR programs under the umbrella of smart grid networks is growing [18,19]. The US government and utilities have made noteworthy development in incorporating DR programs in energy markets such as NYISO, ISONE, CAISO, and ERCOT. The FERC order 719 "ARRA" (American Recovery and Reinvestment Act) [17] is an important initiative by the US government that is contributing highly in the success of HEMS in the US market [20]. According to public information by