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A survey on behind the meter energy management systems in smart grid

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ABSTRACT

Over the last few years, the fast-growing energy needs across the world have intensified a central challenge: how to reduce the generation and operation costs in power systems and, in parallel, to minimize the hydrocarbon emissions. Moreover, one-quarter of world's population still lacks access to electricity, as the cost of building conventional power grids is not affordable by third world countries. On the other hand, behind-the-meter (BTM) energy systems offer cost-effective solutions to aforementioned challenges, as they enable end-users to satisfy their energy needs with distributed energy generation and storage technologies. To that end, this paper presents a detailed survey of BTM energy management systems. The paper starts with the classification of the electrical loads with respect to their physical properties, priority ranking, and sizes. Next, the literature on BTM energy management systems is systematically classified into three main categories: technology layer, economic layer, and social layer. The technology layer spans the studies related to power systems including distributed generation and storage technologies, whereas the economic layer shows how economic incentives along with optimization and scheduling techniques are employed to shape the energy consumption. The social layer, on the other hand, presents the recent studies on how to employ social sciences to reduce the energy consumption without requiring any technological upgrades. This paper also provides an overview of the enabling technologies and standards for communication, sensing, and monitoring purposes. In the final part, a case study is provided to illustrate an implementation of the system.

1. Introduction

1.1. Motivation

Over the last decade, the power grid operations have become more stressed due to growing customer demand and less secure with the integration of intermittent renewable resources. Moreover, the usage of fossil fuels in the electricity generation raises environmental concerns all over the world. Such issues become more intense during peak hours, as the power grid runs up against its operating limits, hence becomes more fragile. One effective way to alleviate the challenges mentioned above is the deployment of smart energy management systems which integrate communication, control, and sensing technologies to shape the electricity consumption efficiently [1,2]. To that end, in this paper, we present a holistic survey on behind meter energy management systems.

The term *behind the meter* (BTM) refers to a renewable energy system located in a single building or at multiple facilities (depicted in Figs. 1 and 2) owned by a single entity i.e., university campuses, usually operated with distributed generation and storage units to supply all or some portion of the end user‘s energy demand [3,4]. Due to the uncertainties involved in distributed generation units, the critical part of BTM system is the orchestration of loads through efficient optimization and scheduling algorithms. Moreover, BTM systems are usually not connected to the bulk generation, but typically are connected to end user's meter allowing the customer to sell energy back to the utility. In this regard, behind the meter energy management systems refers to a system which fulfills the end users energy needs while realizing certain objectives such as reducing operation cost, improving energy efficiency, balancing demand and supply, and reducing carbon emissions.

1.2. Benefits

The multifaceted benefits of the BTM energy management systems are ultimately linked to the current power system operations. Power grids are large complex networks designed to deliver resources from centralized power generators (e.g., nuclear, hydro, natural gas, coal) to distributed demand. Since large-scale energy storage is still not a viable option, the generation should be aligned with the demand at every instant. To that end, utility operators dispatch their generation assets

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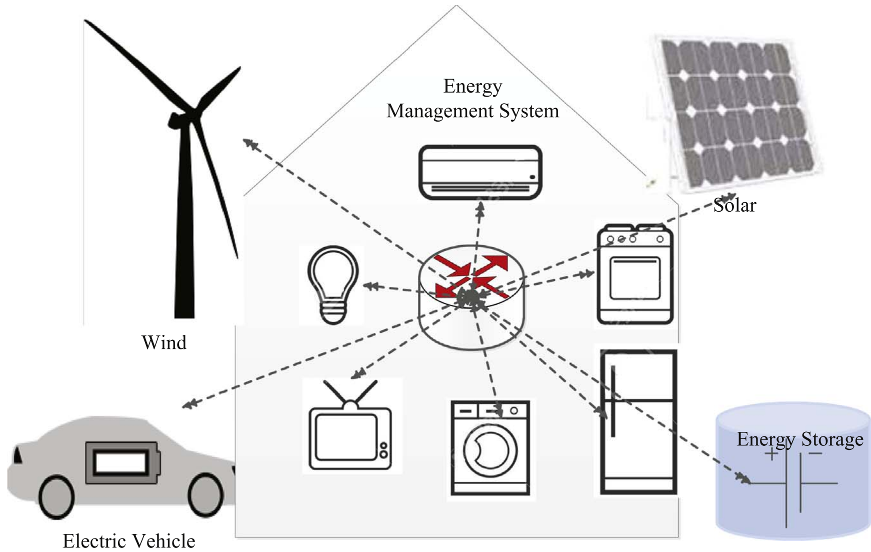

Fig. 1. Behind the meter system: case for single household.

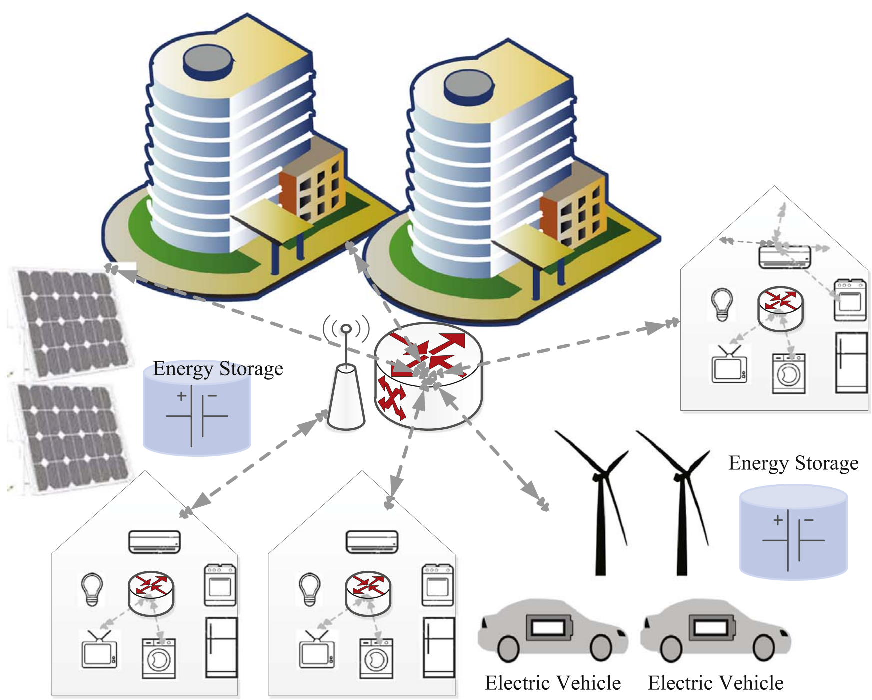

Fig. 2. Behind the meter system: case for a campus.

by considering their cost, flexibility, environmental "head-room", and distance to load. Traditionally, power system operators plan the system capacity (e.g., generation portfolio, transmission capacity, transformer ratings) according to the peak energy demand plus additional reserve margin which is typically set as 15%. Even though, this approach enables power grid to serve the customer demand with a very high reliability, it leads to inefficient use of resources as the peak generation typically occurs only around 10–12% of the time [5]. Hence, the adoption of energy management systems is aiming to reduce the usage of fast start, high cost, and usually environmentally unfriendly peak generators and promises the following benefits:

(1) *Economic Benefits:* Today, almost 40% of the residential energy is wasted due to lack of awareness in the U.S. [6]. By promoting customer-utility interaction, users can enjoy incentives and differentiated tariffs for shifting peak hour demand and they can even make a profit by selling excess local generation back to the grid. Regulators and utilities can benefit from increased utilization of grid components and lessened investments. Obviously, exact calculation of benefits depends on the assumptions made. The work in [7] shows how demand-shaping with energy storage units leads to monetary savings under different scenarios (e.g., varying utility tariffs, consumption patterns). Fig. 3 shows the average residential electricity consumption in 2014. The early adoption of BTM systems are likely to take place in regions like GCC, North American, Nordic countries, and Western Europe, as the average household consumption is relatively high compared to the world average .
(2) *Reduced Green House Gas* (*GHG*) *Emissions*: The electricity generation sector in the U.S. accounts for 32% of GHG emissions