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Electric Energy Management in the Smart Home

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Abstract: *Smart homes hold the potential for increasing energy efficiency, decreasing costs of energy use, decreasing the carbon footprint by including renewable resources, and transforming the role of the occupant. At the crux of the smart home is an efficient electric energy management system that is enabled by emerging technologies in the electricity grid and consumer electronics. This article presents a discussion of the state-of-theart in electricity management in smart homes, the various enabling technologies that will accelerate this concept, and topics around consumer behaviour with respect to energy usage.*

Keywords: *Smart homes*

I. INTRODUCTION

A smart home may be defined as a well-designed structure with sufficient access to assets, communication, controls, data, and information technologies for enhancing the occupants' quality of life through comfort, convenience, reduced costs, and increased connectivity . The idea has been widely acknowledged for decades, but few people have ever seen a smart home, and fewer still have occupied one. A commonly cited reason for this slow growth has been the exorbitant cost associated with upgrading existing building stock to include "smart" technologies such as network connected appliances . However, consumers have historically been willing to incur significant cation technologies, such as cellular telephones, broadband internet connections, and television services.

II. SMART HOMES

A. What is a Smart Home?

A home is already a well-designed connector for power transfer between the electricity grid and energy-consuming appliances. A smart home also functions as a switchboard for data flow among appliances and participants such as the enduser, the electric utility, and a third party aggregator .This evolved capability benefits stakeholders on both sides of the interface – utility customers, utilities, and third party energy management firms – because there are strong incentives for all sides to help the others function smoothly. For instance, a homeowner may not inherently care about the peak demand issues faced by the utility, but electricity prices and supply reliability are tied to operational practices of the service provider. On the other hand, a utility may be primarily concerned with meeting the requirements of public utility commissions, but unhappy ratepayers may result in business and regulatory risks

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Looking outward, a smart residential building has two-way communication with the utility grid, enabled by a smart meter, so that it can interact dynamically with the grid system, receiving signals from the service provider and responding with information on usage and diagnostics.. This bidirectional information exchange is enabled by the rapid adoption of advanced metering infrastructure (AMI).

Looking inward, a smart home employs automated home energy management (AHEM), an elegant network that self manages end-use systems based on information flowing from the occupants and the smart meter. The value of AHEM is in reconciliation of the energy use of connected systems in a house with the occupant's objectives of comfort and cost as well as the information received from the service provider. Sensors and controls work together via a wireless home area network (HAN) to gather relevant data , process the information using effective algorithms, and implement control strategies that simultaneously co-optimize several objectives: comfort and convenience at minimal cost to the occupant, efficiency in energy consumption, and timely response to the request of the service provider.

B. Smart Home Energy Management -

Large-scale demonstration efforts have thus far approached smart home research with a strong utility focus and less homeowner focus. Currently the incentive for homeowner participation is limited to relatively small financial gain via utility pricing structures; otherwise the motivation is primarily altruistic (i.e., environmental benefits). Most utilities offer incentives for energy upgrades such as attic insulation or ENERGY STAR appliances and many have leveraged loadshedding technologies that cycle air conditioners during peak load events. Increasingly, utilities are funding more elegant efforts for on-request load reduction in the residential sector. For example, CPS Energy of San Antonio, Texas has partnered with Concert Inc. to demonstrate a load reduction system that can alter air conditioner and water heater set points and pool pump operation at the end-user facility during peak load times to enable substantial peak savings with limited impact on their customers [16]. This system is being rolled out to most residential customers in the San Antonio service territory. Some utilities such as Com Ed provide near-real time data to homeowners, along with several pricing structures and load reduction requests. Many companies have recently incorporated web-based user interfaces, so a homeowner can adjust thermostat settings or turn off lights from a smartphone.

Advanced grid measurements using AMI infrastructure are being rolled out in California and Texas . These projects have multipronged focus of better integration of renewables, enhancement of efficiency, and optimization of consumer demands with utility needs on a community scale. Emerging nonintrusive load measurement systems can provide

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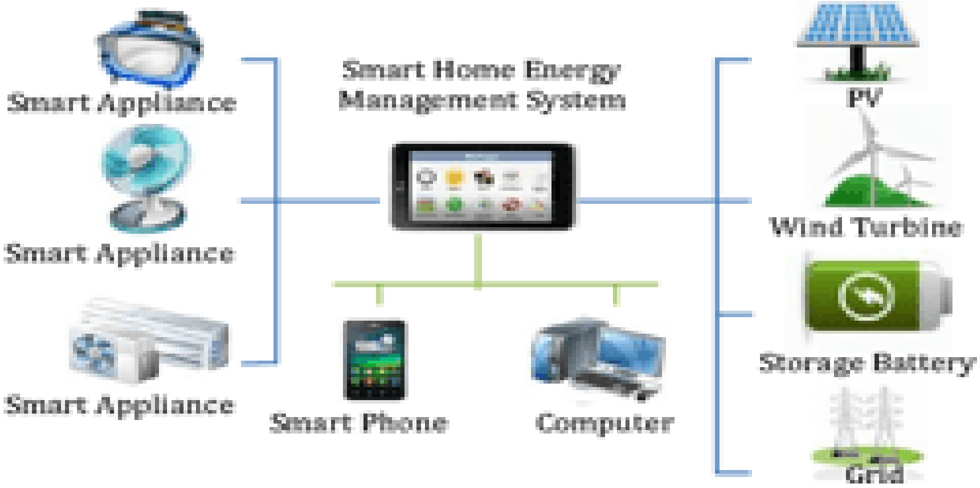
enabling data, but these modern measurement techniques are not yet robust, accurate, easy to install, or cost-effective for integration at the meter . The available legacy methods for load disaggregation use algorithms supplemented with estimation, so the results may have less relevance to a given household than across an aggregated population.



C. Economic feasibility and likelihood of widespread adoption -

Several market and technology trends are expected to accelerate the development of cost-effective AHEM systems that enable smart homes.

These include:

• Implementation of smart grids and continued growth in home offices will expand market penetration of secure HANs.

• Growth in web-based cloud computing applications will enable low-cost home energy data storage, data display, and data analysis for AHEM trend analysis .

• Advancements in smartphone technology such as batteries, user interfaces, and material , are expected to aid the development and adoption of AHEM systems.

• Manufacturers of residential equipment and appliances continue to embed additional sensors and control capabilities in new, smart home appliances that are internetready, can respond to requests from service providers, and offer advanced cycle controls such as multi-mode or variable speed controls and fault diagnostic sensors for space-conditioning equipment and "eco" modes for dishwashers, clothes washers, and other major appliances .

• Integration of energy services into other networked product offerings, such as security systems and television and telephony service. A key strategy to engaging all stakeholders may lie in changes to the end-user electricity pricing structures – from fixed tariffs to dynamic prices that may change several times over a day – that reflect the use of the assets on the grid at any given time. If these structures are implemented to provide a tangible financial incentive for customers to respond to the requests of the service providers for demand reduction, the customers can receive measurable monetary value for their participation, in addition to the increased reliability of their service. Financial incentives are but one motivating factor for the adoption of smart homes.

III. ASSETS AND CONTROLS

In smart homes, many loads can be considered as assets that can participate in the efficient use of electric energy: thermal loads, electric vehicles, and smart appliances. By intelligently controlling their behaviour in either a reactive or a coordinated manner, these assets can provide leverage for energy and cost savings .

Thermal loads, such as air conditioning, electric space heating and water heating, can be controlled by "intelligent" thermostats. Contrary to traditional thermostats operating according to the hysteresis principle, an advanced thermostat such as the Nest has a learning capability that can automatically learn from user behaviour patterns [. Then, the thermostat adapts the room temperature efficiently, e.g., by auto scheduling heating according to arrival and departure times and by detecting when the users are away. These strategies can help reduce energy consumption, especially when traditional or programmable thermostats are not configured properly, or cannot detect that users are away.

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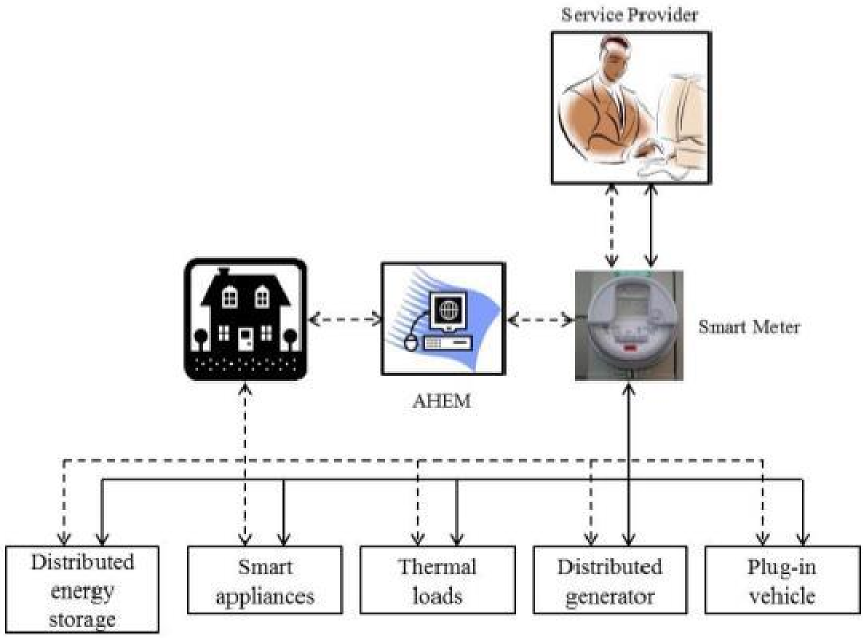
Detailed control of household loads would allow the inherent thermal inertia of smart housing stock to be used for energy storage. The controller could "learn" the thermal response of the home, including factors such as weather forecasts, weather observations, and load levels from monitored devices. The resulting model would better predict future loads, which could be used locally or aggregated or the utility to plan short-term control options.

For example, a smart home controller could pre-cool a house in the morning, before the system peak load, reducing air conditioning loads when signaled from the utility. Plug-in electric vehicles, including hybrids, are expected to represent 1.7 to 3.5% of all US light duty vehicles by 2025 . These correspond to a significant domestic load interfaced with power electronics that can also help make homes smarter. Using the vehicle-to-home technology, they can temporarily power the household, e.g., during demand peaks when power may become more expensive and the battery can provide a part of the total demand, or during outages by powering the entire household until the battery reaches its lower state-of-charge threshold . Adapting the charging schedule according to grid supply conditions offers additional possibilities, as described in section IV. The utility of such distributed storage may be improved when used together with distributed generation sources, such as photovoltaic panels



IV. CONSUMER BEHAVIOR -

The impact of technological advancement is acknowledged as an important enabler for the expansion of smart homes, an integral part of the equation is influencing the behaviour of the occupant vis-à-vis energy usage with information and education . Feedback and automation are essential features of achieving this in a smart home. However, an optimal energy efficiency strategy requires both features be designed with the end-user in mind. Numerous studies have examined the effect of diverse forms of feedback on residential electricity usage. Feedback has ranged from low-tech forms such as door hangers , to state-of-the-art in home displays (IHDs) . Feedback has usually comprised the current and past electricity usage of the end-user, but has sometimes included normative information, such as comparisons to one's neighbours . In some cases, feedback has been combined with TOU rates or other incentives . Recent reviews have concluded that real time feedback can effectively deliver durable 4% to 9% reductions in residential electricity consumption. However, utilities are challenged when predicting the energy savings that will be achieved through feedback programs because of limitations in the available data. This is critical as utilities attempt to make the case to already sceptical customers.

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Although it is beyond the scope of this paper to extensively review these feedback studies, the authors point out some important differences among them and caution the reader about extrapolating from the average energy reductions obtained in these studies to wide-scale IHD deployment. In particular, feedback studies vary in their recruitment strategies and some have methodological features that limit their generalizability.

A critical aspect of feedback studies is whether participants opt-in or opt-out, i.e., some utility pilots randomly selected a group of customers to enrol in a pilot and allowed those customers to choose not to participate (opt-out). In contrast, opt-in studies, which are more common, advertised the study and asked for volunteers . This seemingly subtle difference in recruitment can profoundly affect the results. Opt-in studies have shown relatively consistent effects of feedback.

For example, three opt-in studies have shown overall energy savings of 6% to 10% . In contrast, two opt-out studies conducted in showed no significant effect of IHDs on electricity consumption. This difference has been demonstrated across a variety of energy conservation programs showing that opt-in programs have larger participant impact but lower penetration than opt-out programs.

A major limitation to the work on feedback efficacy is the relative lack of long-term datasets that can help evaluate persistence . For smart homes to realize their potential, consumers must be engaged, which may prove challenging. For example, a recent study examined the effectiveness of electricity consumption feedback by randomly assigning participants to feedback delivered via the now discontinued Google Power meter web interface and control conditions . The feedback consisted primarily of a graph that presented 10- min interval and historical comparison data. However, other features were available, including projected electricity consumption during different time periods (e.g., night, morning) and for the whole year, a link to energy conservation tips and an email reminder.

The result

indicate that 9 This report is available at no cost from the National Renewable Energy Laboratory (NREL) at. the effect of feedback wanes over time. Reductions in energy consumption of 8% were seen in the first week. Energy consumption had returned to baseline levels by the fifth week. Concerns about the durability of behaviour change feed the belief that the real solution to energy efficiency is automation.

V. CONCLUSION

Smart homes rely on numerous enabling technologies in both the electricity grid and consumer electronics. Standardization and maturity of the technologies in each of these realms is required if smart homes are to be pervasive. Given that buy in from users is a key that will unlock the adoption of smart homes, rigorous tests with consumers must be integrated into the smart home design procedure. Without the comprehensive multi-disciplinary assessment of the smart home, an expensive system may fall short of expectations