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A Survey on Home Energy Management and Monitoring Devices

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Abstract

Electric power grid is facing various challenges due to its aging infrastructure while it is still required to meet the growing demand and maintain high power quality. In order to address these concerns, consumers can manage their energy consumption using energy management systems (EMS). These EMS control the energy consumed while electric utilities can provide incentives through demand side energy management programs. The important aspect of this system would be to monitor the energy consumption of individual appliance and transmit this information to a remote metering system for easy access between utility and consumer. This constitutes implementing appropriate load disaggregation techniques to non-intrusively monitor the electric energy consumption while ensuring that the whole system is at an affordable price. This paper aims to review the energy monitoring and management products currently available in the market for residential sector. Within these products, various technologies featured are reviewed and a comparative study among these technologies is presented.

Keywords: Home energy management, Energy monitoring, Wireless sensor, Energy saving products, Smart meter and Remote control.

1 Nomenclature

EM	Energy Management
HEMS	Home Energy Management System
HEM	Home Energy Management
HEC	Home Energy Controller
HEG	Home Energy Gateway
NIALM	Non Intrusive Appliance Load Monitoring
RECAP	Recognition of Electrical Appliance and Profiling in Real- Time
CT	Current Transformer/ Transducer
ANN	Artificial Neural Network
AC	Alternating Current
IR	Infrared Ray
AMI	Advanced Metering Infrastructure
AMR	Advanced Meter Reading
ERT	Encoder Receiver Transmitter
MTU	Measuring Transmitting Unit
SMPS	Switching Mode Power Supply

2 Introduction

Power demand has been steadily growing over the last few decades because of the natural expansion in the residential and industrial sectors. Moreover, it is expected to steeply increase in the near future with the integration of Electric Vehicles (EVs). This growing demand alerts utilities, system operators and consumers regarding possible impacts on the electricity grid in terms of protection, control, efficiency and power quality issues if proper actions are not taken to reduce the energy consumption and to ensure efficient monitoring. In addition, the concerns over climate change due to pollutant energy sources have led to consensus to limit or even eliminate fossil-fuel based generation sources from the energy portfolios of many North American jurisdictions. Moreover, most of the power system assets suffer from aging as many of them are in service for more than 50 years ago, which may not qualify them to accommodate the expected growing demand of 20% according to North American Electric Reliability Council (NERC), [1], since they are close to be retiring hence their performance will be reduced. As a result, transmission lines congestion, overall power system performance degradation, poor reliability and poor power quality will be the consequences unless necessary steps are taken to monitor the energy usage and to reduce the energy consumption especially during the time of peak demand.

A first insight into the energy management process requires efficient monitoring of electric quantities such as voltage and current in real-time, then processing these data using signal processing techniques to provide the consumers with useful information regarding their energy consumption and energy bills which will help them changing their energy consumption pattern according to for example the time of use (TOU) in which customer is charged at high energy rates during peak time demand and lower rates during off peak time demand [2].

Recent developments in energy saving devices and integration of smart meter technologies have shown promising results in terms of reducing the energy consumption to up to 20% in the residential sector [3]. Despite this fact, the cost of energy monitoring systems along with energy saving devices still hamper full implementation of this technology in every home in all jurisdictions, keeping in mind that old homes represent the largest consumers of energy in the residential sector. This paper provides a comprehensive review of the energy saving products available in the market and presents the technologies used in developing these devices. Moreover, the paper introduces a cost-effective comparative study of these energy saving devices while it highlights the technical aspects of each product regarding the monitoring and the management of the electric energy consumption in the residential sector.

3 Overview of Energy Management Products

Energy management and monitoring products categorized into three groups: Portable plug-in energy monitor, Full house energy monitor, and Full house energy management with individual device control. The following subsections outline the technical aspects upon which there groups are based on.

3.1 Portable Plug-in Energy Monitoring Products:

"Belkin conserve insight" [4] shown in Fig.1 is a very simple energy monitoring device that can measure the power usage of any electronic device connected to a 3-pin Alternating Current (AC) outlet. Through this portable device consumers can monitor: power usage of any single appliance in watts, cost during the operation in dollars per KWh and also, the amount of carbon dioxide produced. It measures the power usage directly from the AC line in both instantaneous and average modes. During the instantaneous mode it takes current and voltage measurements from AC outlet at certain time and calculate the instantaneous power consumption. While in average mode, it calculates the average of voltage and current samples over a time period determined by the instant the device was plugged in till the end of the measurement period.

"P3 International" [5] also introduced "Kill-a-Watt" energy monitoring products (Figs.2-4) from large load monitoring power strips, to single appliance monitoring power meters, and wireless sensors & display panel. “Kill-a-watt PS-10” power strip monitors the cumulative power usage of devices connected such as PC, home theater and TV. “Kill-a-Watt EZ”, GT and “Save-a-Watt” models connect directly to the appliance and its power usage is displayed on the power meter. “Kill-a-Watt P4200” has single display panel that monitors power usage up to eight traceable wireless sensor activated appliances [30]. All “Kill-a-Watt” models measures power consumption using the RMS voltage and current samples from the 3-pin AC wall outlet. Wireless sensor connected appliances transmit the power usage information to display panel using the 433 MHz radio frequency channel. “Watts Up? .Net” [6] shown in Fig. 5 works in similar way to “Belkin insight” and “Kill-a-Watt EZ”, “GT” & “Save-a-Watt” models but, unlike these plug-in products “Watt Up? .Net” has the capability to control and access power usage data of the appliance through any internet enabled and elink monitoring software installed Portable Computer (PC).

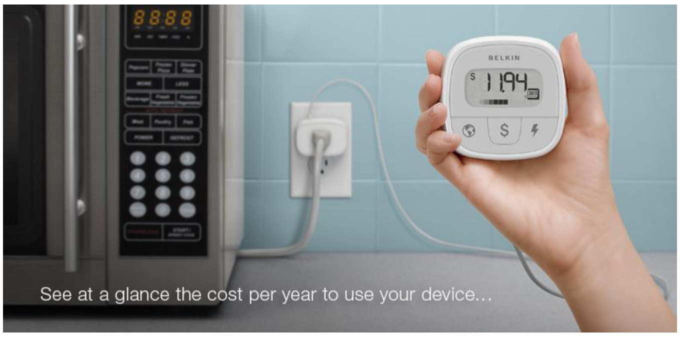

Fig. 1 Conserve Insight

Fig. 2 PS-10

Fig. 3 Kill A Watt EZ

Fig. 4 Kill A Watt Wireless

Fig. 5 Watts Up? .Net

3.2 Full House Energy Management Products:

“Blueline” Innovation’s “PowerCost” Monitor [7], “Black & Decker” Power Monitor [9], and “Watt-vision’s” Energy Sensor [8] Energy Management (EM) devices shown in Figs. 6-8 use a passively connected IR pulse sensor technology to read the power consumption data from the smart meter and relay information on close loop signal to display panel using the 433 MHz frequency band. Most analog and digital meters are compatible with the IR sensor technology that has either visible ‘disc’ or optical port that generates watt pulse on the meter [24]. The sensor has 2 LEDs which either sends out IR pulse or detects an IR pulse. For analog meters, sensor needs to align with spinning disk and black mark inside the meter where it measures the total power consumption. While, for digital meters IR sensor aligns with optical port on the meter and measures power usage through the red light flashing once per revolution of disk. Since, the sensor depends on the type of electricity meter installed in the house the sampling and transmission time varies depending on the meter.

Fig. 6 PowerCost Monitor

Fig. 7 Power Monitor

Fig. 8 Wattvision

“PowerCost” Monitor and “Wattvision” Energy sensor also have WiFi connectivity feature which allows the home users to access the energy usage information from anywhere on the internet enabled PC.

“Efergy e2” [10]/ “Cent-a-Meter” [11]/ “Owl” [12]/ “Current Cost Envi” [13] energy management products (Figs. 9-12) employ a single phase Current Transformer (CT) clamp or current sensing technology to detect and monitor the change in magnetic field around the smart meter power feed cable, remote transmitter for wireless communication and energy monitor display panel. The CT measures the current being used in amperes and uses nominal system voltage to calculate the cumulative power consumption [22]. The remote transmitter unit then transmits this information to an energy monitor display panel on a 433 MHz frequency channel.

Fig. 9 Efergy e2

Fig. 10 Cent A Meter

Fig. 11 Owl

Fig. 12 Current Cost Envi

3.3 Full House Energy Management with Individual Device Control:

“TED 5000 series” [14]/ “eMonitor” [15]/ “Eyedro” [16] (Figs. 13-15) has single electricity sensor i.e. CT similar to “Efergy e2”/ “Cent-a-Meter”/ “Owl”/ “Current Cost Envi” products but provides additional capability of RECAP. Current Transformer (CT) sensor captures the required parameters for each appliance such as, signature ID, real power, power factor, RMS voltage & current, sampling rate and machine state (ON/OFF), and transmits these data to a database location such as, local PC or remote server through Ethernet gateway, Wi-Fi or Power line for consumer action. These power components and their profiling to individual appliance help differentiate a unique appliance signature. Once these parameters are transmitted to database it is trained using a biological training model like, ANN built within the provided software for recognition of appliances. When the individual appliance is trained with enough data, load profile for that particular appliance is created to monitor and control with greater accuracy and performance [27].

Fig. 13 The Energy Detective (TED)

Fig. 14 eMonitor

Intel low-power Z5xx series atom processor based HEMS [17] shown in (Fig. 16) is the latest Intel's concepts designed to monitor, control and manage power usage information with smart appliances, smart plugs, smart meters and wireless sensor activated devices throughout the house. It is the most complete energy management product which informs the home users with relevant and detail information regarding power consumption of full house to individual appliance and also, suggest power saving solutions.

Fig. 15 Eyedro

Intel HEM monitors the power consumption of full house and individual appliances using a low cost single point wireless sensor shown in (Fig. 17) which can be plugged-in to any electrical outlet in the house. Single point energy sensing is related to NIALM which is based on analyzing changes in voltage measurements [23]. These voltage measurements are taken as load identification and appliance actions such as, device turning ON/OFF. Load identification involves NIALM approach for disaggregated energy sensing by using high frequency voltage noise FFT of the transient signals when devices are turned ON/OFF [29]. These continuous voltage noise signatures provides unique voltage recognition pattern which can be used to differentiate energy usage among the installed appliances.

Fig. 166 Intel Dashboard

Fig. 17 Cisco HEC

“Cisco HEC (Fig.18) [18], FreeScale HEG” (Fig.19) [19], and Control4 EMS (Fig. 20) [20] collects power consumption data from various sources such as, appliances, solar panel, and smart meters, and establishes a 2-way communication between utility and consumer in order to monitor, control and manage power consumption. Each of these sources has a Zigbee enabled wireless sensor which allows the HEMS to communicate with individual appliances, smart meters, thermostat control, and so on [30]. Within the HEMS, HEM is connected to the gateway through Wi-Fi, Ethernet or PLM where the data is sent over the internet for remote data access and control. Smart electricity meters with AMI, AMR or ERT send power usage information to utilities through power line communication. Through this 2-way communication utilities and consumers can have complete control over the energy management of the whole house to individual appliances [28].

Fig. 18 FreeScale HEG

Fig. 19 Control4 EMS

3.4 Products Comparative Study:

Table I plug-in energy monitoring devices

Product Characteristics	Product Name			
	Belkin Conserve Insight F7C005q / P4460 P3 International Kill A Watt	P3 International P4200 Kill A Watt Wireless	Watts Up?	ThinkEco Modlet/ Freelux/ Watts Clever/ BITS Limited/ kill a watt PS-10
Power Monitoring technology	Direct sensing through AC line in both instantaneous and average (RMS) mode	Direct sensing through AC line for instantaneous power, current, active power	Active power, RMS voltage and current measurements through AC line	Direct sensing through AC line
Component Breakdown	Single appliance	Individual wireless activated sensor appliance (track up to 8 appliances) / large load	Single appliance	large load (total power usage of connected appliances)
Software Compatibility	-	-	Google power meter	-
Network Communication	-	Wireless sensor to display panel: ZigBee (IEEE 802.15.4)	Access data wirelessly or remotely: Ethernet interface	ZigBee/WiFi/ Wireless
Update Time	1 sec	Real time	15 min	-
Price	$30-60	$100	$219	$15-50

Table II Full house Energy Monitoring devices

Product Characteristics	Product Name	
	Power Cost Monitor PCM28000 + WiFi gateway/ EM100 Black and Decker/ Wattivision	Efergy e2/ centameter/ OWL/ Current cost
Power Monitoring technology	Infrared ray pulse sensor/ digital IR sensor/ analog sensor	CT clamps/ current sensors
Component Breakdown	Full house energy monitor	Full house energy monitor with circuit by circuit categorized load
Individual Load Identification method	-	Adding additional CT/ transducers for each circuit wire
Installation	Sensor clamped to Electricity meter	Clamps on to Electric meter feed cable
Software Compatibility	Hohm	Elink/built-in
Network Communication	Sensor to Display communication:433.92 MHz wireless transmitter Remote data access: WiFi	Sensor to Display communication:433.52 MHz wireless transmitter
Update Time	30 sec	6-18 sec
Price	$100-270	$145- 250

Table III Full house energy monitoring devices with break down to individual loads

Product Characteristics	Product Name		
	TED 5000 series / eMonitor/ Eyedro	Intel HEM Dashboard	Cisco HEC/ Freescale HEG/ Control4 EMS-100
Power Monitoring technology	MTU with a set of CT's	AC line Single point wireless (Zigbee enabled) sensing using NIALM	Zigbee enabled, smart plugs, smart meter with advanced metering infrastructure (AMI) +ERT reading
Component Breakdown	Full house energy monitor with circuit by circuit categorized load	Full house EM with breakdown to Individual devices using SMPS or other electronic load controls	Full house EM and control with breakdown to individual systems and appliances
Individual Load Identification method	RECAP using electrical sensor (CT)	Voltage recognition pattern using continuous voltage noise	Zigbee enabled appliances/ smart plugs

		SIGNATURE	
INSTALLATION	INSTALLS ON CIRCUIT BREAK BOX WITH NETWORK	PLUG-IN ANYWHERE IN THE HOME 3-PIN ELECTRICAL OUTLET	SMART METERS/ AMI/ AMR
SOFTWARE SUPPORT	GOOGLE POWER METER	BUILT IN ENERGY MANAGER	HOHM
NETWORK COMMUNICATION	ETHERNET GATEWAY + WIRELESS	DEVICE TO DEVICE COMMUNICATION: ZIGBEE (IEEE 802.15.4) WIRELESS HEM CONTROL: WIFI (IEEE 802.11 B/G/N)	COMMUNICATING WITH CLOUD-BASED DEVICE MANAGEMENT SYSTEM: WIFI/ETHERNET COMMUNICATION WITH SMART METERS & OTHER INDIVIDUAL DEVICES: ZIGBEE
UPDATE TIME	1 SECOND	REAL TIME	REAL TIME
PRICE	$200-1300	CHECK WITH LOCAL UTILITY	$300- 1000

4 Conclusions

In this paper, a review of the currently available energy monitoring and saving devices in the market is presented with comprehensive overview of various technologies implemented in the three categories of energy monitoring and management products identified in this paper namely; portable plug-in energy monitoring, Full house EM, and Full house EM with breakdown to individual appliances.

The products reviewed has shown that single appliance load monitoring and whole house energy management power usage data may not suffice to significantly managing the energy consumption in a holistic perspective since there is not much scope for consumers to take any enough action over energy management, nevertheless electric utilities. Therefore, it is necessary to find stable individual load identification techniques that will allow both the utilities and consumers to better manage and control the way energy is being consumed and utilized using a holistic approach.

There have been many methods proposed by the authors till now to identify individual appliance load monitoring but, each method comes with its own problems of classifying and sensing individual loads such as, transient power signature for similar load identification. Recently, artificial neural networks with combination of other load identification have caught much of interest with improved accuracy and load detection.

In implementing these techniques it is also important to foresee other factors such as, cost of whole system setup, hardware requirements, ease of implementation and as such. While, the price of the product increases with its ability to manage, monitor and control energy in the house, most of these products can be installed by any regular consumer but few may need an electrician to setup the system. For example, "TED 5000 series"/ "eMonitor"/ "Eyedro" shown in (Figs. 13-15) require an experienced electrician to open the main panel of the circuit board to correctly install the CT clamps for each circuit.

Based on this proposed study of these products HEMS are able to generate energy savings for both utility and consumer by engaging them to make energy saving decisions through various communication protocols such as, ZigBee, Power Line Communication (PLC) etc. For instance, through PLC utility can alert consumer to reduce/increase the temperature of the thermostat to reduce power consumption during peak time. This will ensure energy losses are reduced for utility companies and at the same time reduce energy bills for the customer.

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