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An Efficient Algorithm for Energy Management in Smart Home Including Renewable Energy

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***Abstract*– Energy management strategies are instrumental in the performance and economy of smart homes integrating renewable energy and energy storage. Home energy management system (HEMS) in the smart home allows the customer to control, optimize and monitor the energy consumption and the energy conservation. In this paper, a brief overview on the architecture and functional modules of smart HEMS is presented. Then, the advanced HEMS infrastructures and home appliances in smart houses are thoroughly analyzed and reviewed. For management and monitoring the energy consumption of home appliances and lights is used ZigBee based energy measurement modules while for renewable energy is used a Power Line Communication (PLC) based renewable energy gateway. The home server monitors and controls the energy consumption and generation and controls the home energy use to reduce the energy cost. The remote energy management server aggregates the energy information from the home servers, compares them and creates statistical analysis information. We propose the control algorithm to efficiently manage the renewable energy and storage to minimize grid power costs at individual home. The proposed HEMS architecture is expected to optimize home energy use and result in home energy cost saving.**

***Index Terms*– Home Energy Management, Home Server, Renewable Energy**

I. INTRODUCTION

ELECTRICAL energy demand has been increased all over the world for past decades. Renewable energy sources (RES), such as wind power, solar power and fuel cell etc., should be utilized to fulfill energy demand as well as conventional energy sources based mainly on fossil fuels. Challenges is by integrating RES into the grid and increasing power demand causes the redesigning of the conventional power system architecture and infrastructure. The features of this power system should be more attractive, secure, reliable and intelligent comparing to the existing systems. The most well-known term used to define this next generation power system is smart grid.

With the increased concerns on global energy security and environmental emissions, more and more distributed renewable energy generations, such as wind turbines, solar panels, and plug-in electric vehicles (PEVs), etc., would be grid-integrated into the active distribution networks. Coupled with the rapid development in advanced power electronics and alternative energy technologies, building renewable and stored energy sources installed at the residential premises can be incorporated in smart HEMS to improve the home efficiency of energy conversion and utilization [1].

The smart grid concept refers the electrical power grid merged with communication infrastructure which is able to utilize the electrical energy efficiently, sustainably, reliably and safely. One of the main research areas in the smart grid is energy management applications. Energy management applications provide several benefits to both utilities and consumers. Utilities are able to improve power with higher reliability and stability, and lower operational costs while consumers can utilize the energy in cost saving way. Another important valuable benefit with respect to environmental issues is reducing the greenhouse gas emission.

Several demand response (DR) programs are widely implemented on the commercial and industrial side [2].

Smart HEMS is an essential home system for the successful demand-side management of smart grids [3]. It monitors and arranges various home appliances in real-time, based on user's preferences via the human–machine interface in smart houses, in order to conserve electricity cost and improve energy utilization efficiency [4]–[6].

Smart Home energy management (HEM) system which is responsible for monitoring and managing the energy consumption of home appliances is the most popular demand side response automation type for residential customers. HEM system, an important part of smart grid, provides a number of benefits such as savings in the electricity bill, reduction demand in high rate and meeting the demand side requirements.

In this paper, a smart HEMS architecture that considers both energy consumption and generation based on ZigBee, WiFi and PLC-based renewable energy gateway (REG), respectively.

The home server gathers both the energy consumption data through ZigBee, WiFi and energy generation data through the REG. By taking into account both consumption and generation, the home server optimizes home energy use.

Several HEM algorithms by which consumers are able to manage their electricity consumption have been proposed in the literature [7]-[9]. These algorithms are based on different methods such as: load shifting, optimal scheduling, charges the battery from renewable sources and from the grid during low rate period etc. Operating and duration time of home appliances can be shifted by load shifting and optimal scheduling methods [10]. Many of HEM system consider only grid supply. In [11], is proposed an optimal model for HEM in which wind and solar power sources are considered.

II. ARCHITECTURE OF HOME ENERGY MANAGEMENT SYSTEM INCLUDING RENEWABLE ENERGY

A) System Architecture

Although numerous efforts are taken for energy-efficient home appliances [12]-[15], energy management can achieve more energy-efficient home. It provides an opportunity for economic benefits of smart home to manage the demand-side resources by shifting their electricity usage during peak-load periods in response to the changes in electricity prices. The economic incentives include the saving in electricity bill, the improvement in utilization efficiency of household appliances and residential energy conservation [16]. For an efficient smart home energy management, we use a new architecture, which, in terms of energy management, consists of two parts: the part of energy consumption and the part for energy generation. A considerable number of home appliances belong to the energy consumption part. A smart home consumes energy, but it can also generate energy from renewable resources, therefore to manage the consumed and generated energy, in terms of minimizing energy consumption, a controlling device such as home server is necessary. Fig. 1 shows the smart HEMS architecture, where home appliances and lights belong to the energy consuming part, while wind and solar resources belong to the energy generation part.

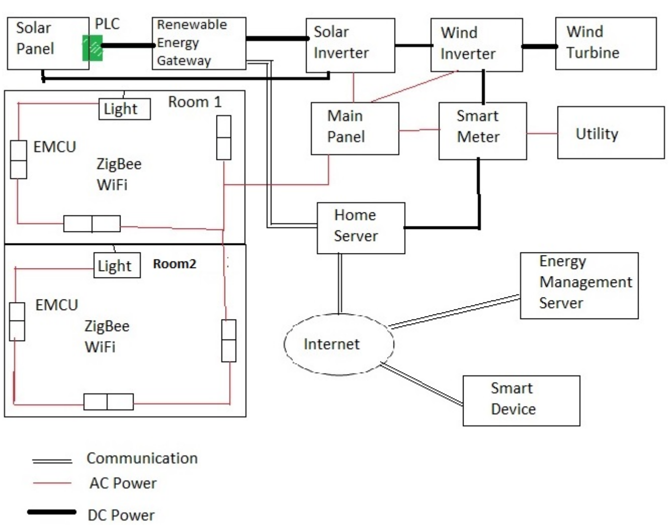

Fig. 1: Architecture of smart home energy management system (HEMS)

Regarding energy consumption, the consumed energy by the home appliances and lights is managed and controlled by energy and communication unit (EMCU), which is installed in every appliance and light. EMCU periodically measures the consumed energy by the home appliance and lights, and transfers these measured values to the home server. EMCU communicates with the home server via ZigBee, Wi-Fi or cable, which are low power communication medium [17] . The home server analyzes the gathered data by all EMCUs and it provides an overview of energy consumed by home appliances and lights for a specific period of time. Thus, home server users can find data related to the state of energy in a smart home, data related to energy consumption by home appliances and lights as well as data about the generated energy.

As for the energy generation, the energy generation from wind and solar sources, is monitored through renewable energy gateway (REG). In this structure, the solar system of the energy is consisted of: solar panels, PLC modems, solar inverters and an REG. The solar panel operation is controlled and monitored by PCL modem, which communicates with REG. The PLC modem monitors and controls the status of each solar panel and the gathered data from all panels are sent to REG. The generated DC energy by solar panels is converted to AC energy by the inverter, and it also monitors the accumulated energy.

The system of wind power consists of wind turbines and inverters. The accumulated DC energy by wind turbines is converted to AC energy by the wind inverter, and it also monitors the accumulated energy. The wind inverter communicates with REG through serial communication. REG gathers data about the solar panel and wind inverter status and transfers them to the home server via Ethernet. The home server analyzes the data and makes a power generation profile. As a smart device of the HEMS system, the home server aggregates all information regarding the consumed and generated energy. It has both, the consumed and generated energy profile at over time. At any time, it estimates the potential amount of energy that can be generated by taking into account the atmospheric conditions obtained from Internet, such as: air temperature, fog, air humidity, wind speed. As a smart device, it saves the previously generated energy due to atmospheric conditions, and it can also predict the potential generated energy based on weather forecast.

The real price of the electricity can be set by utility. The home server manages and controls energy consumption based on generation estimation. Considering the optimization of consumed energy, various aspects can be considered from various analyses and control plans which are based on different algorithms. But in all these systems, the user is interested to access the home server through their smart phones for detailed information on their home energy balance.

If every home individually sends information related to energy via the home server, then remote energy management server (REMS) aggregates that information from the home server. REMS analyzes the gathered information and creates new information in numerous aspects. Based on the new information, REMS provides a service to the energy portal and helps client-homes compare their energy use with that of others.

B) Home Appliances

Various household appliance and energy storage devices - batteries, can be fully analyzed and modeled based on device characteristics and its usage preferences. To implement optimal or coordinated planning strategies of devices, smart home appliances should be divides into two groups:

- Non-schedulable home appliances, e.g. fridge, printer, microwave, TV, hair dryer, lights, computers;
- Schedulable home appliances, which can be scheduled for an optimal function or switched on/off at any time, e.g., washing machine, air conditioner, iron, boiler, electric vehicle (EV)

Devices which can perform their work in an automated form, such as the air conditioner and boiler, are schedulable. Whereas, non-schedulable devices, such as: lights, computers and TVs, rely on manual control to complete their operation and are needed only when users are at home. The users' comfort is quite sensitive towards services of non-schedulable devices at a real time.

In terms of continuity of operation time [18], the schedulable appliances can be further classified into interruptible and non-interruptible. In general, interruptible appliances are most often schedulable. Non-interruptible appliances are characterized by fixed operating period called "hold-time". As a unique load, EV becomes more important and is taking on wider dimensions in HEMS.

Energy management researchers predict that the amount of EV will increase in a near future, which would help reduce air pollutants and greenhouse gas emissions (GHG) [19]. Since EV can be charged or discharged when connected to the power grid, an increasing number of practical services can now be realized in the power grid [20]. Vehicle-to-grid, as a new concept, enables the transmission of the stored power in the EV battery to the power grid [21]-[23]. In a smart HEMS, EV are able to balance the energy at high rates, which means that EV can supply energy during high rates, while consumer consume energy during low rates period.

C) Home Server

The home server manages all EMCUs installed on each outlet and on the light switch via ZigBee, Wi-Fi, UTP/ FTP cable. It also controls and monitors the performance of all EMCUs through control elements. The control table manages the home appliances and lights connected to the EMCU. Through this control table, the home server identifies home appliances and lighting. The data related to power consumption of appliances and lighting are stored in the database, so the aggregated data are accumulated at every moment. The energy consumption manager (ECM) continuously analyzes the data collected on a daily, weekly and monthly basis. Using the data, it creates information on the consumed energy such as, for example, creates an energy consumption pattern for each appliance and lighting, as well as an energy consumption pattern for the whole house. This pattern is used by the home server.

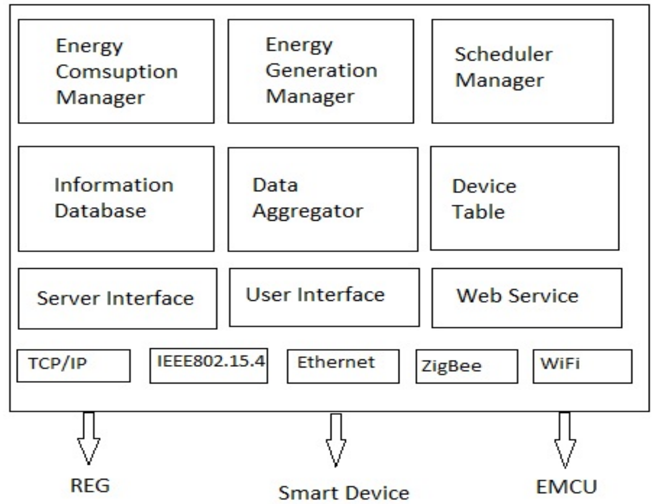

Fig. 2: Function blocks of a home server

Data from solar panels, solar inverters and wind inverters are collected in the REG, then REG transmits them to the home server. The transmitted data in itself contains information about the performance of each solar panel, solar power system and wind power system. This classified data is gathered and stored in the database. Weather forecast data is used to estimate the amount of potential energy generated. The energy generation manager (EGM) analyzes the renewable energy generation. The solar energy generation is based on the solar radiation, amount of fog and the surface of solar panels, whilst wind energy generation relates to the wind speed. Accordingly, EGM can estimate renewable energy generation based on the weather conditions. As a result, based on the estimated energy generation, the home server can modify the home appliances schedule so that the energy cost is reduced. For example, during the time of the low renewable energy generation and in high rate time, the load of several home devices can be postponed to low rate time. The home server decides this based on the priority of the operation.

The user interface (UI) in smart homes provides sufficient information to home users about energy consumption and generation. The UI shows the energy consumption and generation information over time. Users can check and browse energy usage of each appliance and each light. They can also find information about much energy is being generated during that time, and how much cost is saved. The web application enables smart devices to access the home server where they get home energy. The home server provides information to smart devices on request, and they access it through smart applications. The home server transfers the home energy information to the REMS, which manages several client-homes.

D) Energy Management and Communication Unit (EMCU)

EMCU belongs to the energy consuming devices and consists of measurement and communication blocks. The measurement device block measures the consumed energy and the power factor of home appliances. The power measurement is carried with UI measuring factor. The UI factor measures the voltage and current and continuously multiplies them. The power factor is measured according to the phase difference between voltage and current. The measurement block stores the information about the accumulated energy and calculates the power and power factor on demand. The measurement block, in its content, includes also the power control block which enables switching on or blocking the electric appliance to the connection to the electric energy. The communication device block enables the transfer of aggregated information between the EMCU and the home server. This communication is enabled by ZigBee, Wi-fi or UTP/STP cable and it transfers data about the voltage, current, power and power factor.

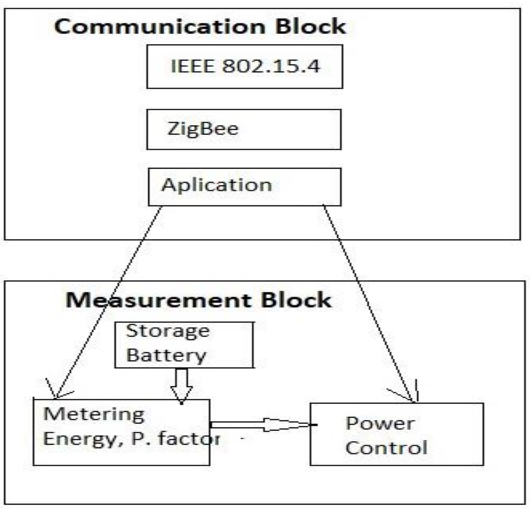

Fig. 3: Function block of Energy measurement and communication unit (EMCU)

The REG, as a key component in the energy generation part, communicates to the PLC modems, the solar and the wind inverters. The PLC modems communicate through TCP/IP protocol, actually, and IP address is assigned by the router. The connection controller controls and monitors the connections in the REG. The measuring devices of the control block continuously measure voltage and current in the solar panels. These read data are transferred from the PLC modem to the REG. Here, the REG has three communication interfaces: PLC for each solar panel, Ethernet for the home server, and an RS 485 for the inverter [24]. The PLC modems and Ethernet communicate through TCP/IP protocol. The connection controller controls the connection of each PLC modem to aggregate data. The solar and wind inverters are connected through RS 485 interface. The data aggregator sends a request message to each PLC modem and inverter, regarding their data status. Thus, the aggregated data are periodically sent to the home server.

E) Renewable Energy Gateway and PLC Modem

The REG, as a key component in the energy generation part, communicates to the PLC modems, the solar and the wind inverters. The PLC modems communicate through TCP/IP protocol, actually, and IP address is assigned by the router. The connection controller controls and monitors the connections in the REG. The measuring devices of the control block continuously measure voltage and current in the solar panels. These read data are transferred from the PLC modem to the REG. Here, the REG has three communication interfaces: PLC for each solar panel, Ethernet for the home server, and an RS 485 for the inverter [24]. The PLC modems and Ethernet communicate through TCP/IP protocol. The connection controller controls the connection of each PLC modem to aggregate data. The solar and wind inverters are connected through RS 485 interface. The data aggregator sends a request message to each PLC modem and inverter, regarding their data status. Thus, the aggregated data are periodically sent to the home server.

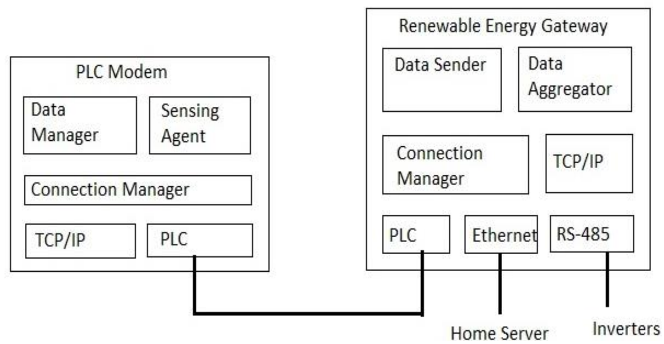

Fig. 4: Function block of PLC modem and Renewable energy gateway

F) Remote Energy Management Server (REMS)

The home server from each home transfers the aggregated home energy information to the REMS. The REMS aggregates all energy information from each home server, from which it aggregates data on the energy generation, energy consumption by home appliances and lights. All aggregated information is stored in the information database, from where, the REMS calculates the average, maximum, minimum of every home appliance. These calculated values help create a standard energy usage pattern, which serves as a comparing pattern related to energy consumption by different clients.

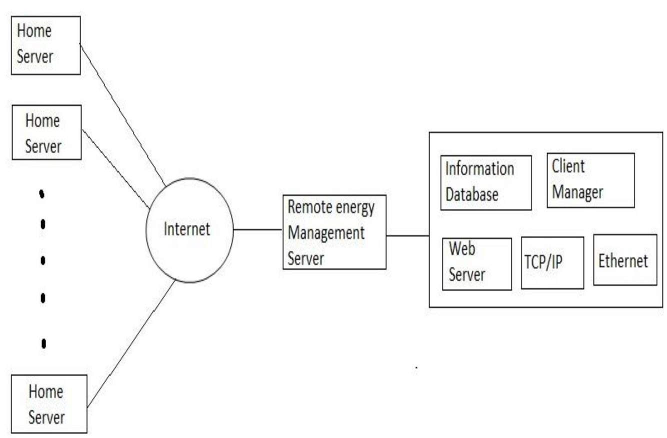

Fig. 5: Function block of Remote energy management server

III. AN EFFICIENT HEM CONTROL ALGORITHM

The Fig. 6 represents the HEM and RES algorithm diagram. PL(t) represents the overall load by all home appliances during time t. In the time t, the energy used by power grid is PG(t), while the generated energy by the RES system is PR(t). The accumulated energy by the RES system in the battery, in the time t is PB(t), Pi denotes the working power of appliance i. The goal of the algorithms is minimizing the cost of electric energy consumed from power grid, therefore the main condition of the algorithm is that the generated energy has a higher priority of use over the power grid. The operating time of the device which submits a power connection demand is determined depending on the type of device and the demand submission time, managed by the home server.

If appliance i submits power connection demand and, if the generated energy amount PR(t) by the RES system is sufficient for the operation of this appliance as well, then it can be directly connected into operation by the RES system, namely, PR(t)> PL(t) + Pi

If appliance i submits power connection demand and, if the generated energy amount PR(t) and the accumulated energy PB(t) by the RES system is sufficient for the operation of this appliance as well, then it can be directly connected into operation, namely, PR(t) + PB(t)> PL(t) + Pi

If any non-schedulable appliance submits power connection demand and, the amount of the actually used energy by the power grid and the needed energy for requested appliances, is lower than the limited power P0, then the requested appliance is given connection permission, i.e., PG(t) + Pi<P0

If any schedulable appliance submits power connection demand during high rate and, the amount of the actually used energy by the power grid and the needed energy for requested appliances, is higher than the limited power P0, then the demanded appliance operation will be postponed, respectively, PG(t) + Pi>P0.

If any schedulable appliance submits power connection demand during low rate and, the amount of the actually used energy by the power grid and the needed energy for requested appliances, is higher than the limited power P0, then the demanded appliance connection will be postponed for a specified time during low rate. The allowed delay time (t) for the device connection depends on its type and it is found in the mapping function on the home server i.e. PG(t) + Pi>P0.

If a demand for the connection of air conditioning arrives, it is approved without delay. During high rate, the air conditioner cannot exceed the maximum temperature (T*) set by the home server in order to reduce the cost. During low rate, if PG(t)+Pi >P0 (available power is exceeded), then, in order to avoid the maximum limit of the energy, the air conditioner should be set at T, where 22oC>T>T*. On the contrary, to provide a comfortable home environment, the air conditioner is set at 22^{o}C.

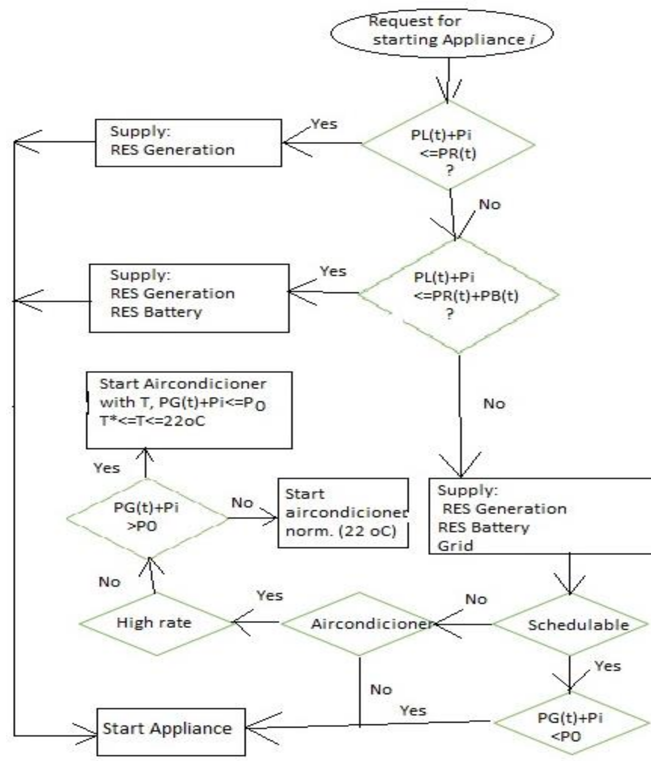

Fig. 6: Home energy management (HEM) algorithm flowchart

IV. CONCLUSION AND FUTURE STUDIES

This study presents a new home energy management (HEM) algorithm for houses with renewable sources implemented in the description system architecture. The algorithm helps reduce electric energy cost at home. In this paper, a theoretic detailed description of the algorithm for home energy management is done, where RES is connected or not (without RES system) in the system. The practical implementation of the algorithm will be realized in the future since it presents a very complex system, especially the architecture of the control system. The architecture of the control system, which we have chosen for the implementation of the HEM algorithm, is also described in this paper. We will have closer values of cost reduction after the practical implementation of the algorithm.

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