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Energy Management Algorithm for Smart Home with Renewable Energy Sources

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***Abstract*– One of the major attributes of the smart grid is to integrate renewable and storage energy resources at the consumption sides. This paper presents the design, implementation of an embedded system that integrates solar and storage energy resources in smart home. 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. 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 integrated renewable energy resources and the energy from the power system in aspect to minimize grid power costs at the individual home. The proposed HEMS architecture is expected to reduce user's electricity cost significantly.**

***Index Terms*– Home Energy Management System, Renewable Energy and Control Algorithm**

I. INTRODUCTION

TO reduce energy consumption several authors had proposed various energy management systems for smart homes including renewable energy. The main purposes of energy management systems are to reduce the energy consumption during high rate, and user's electricity cost. 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. A challenge is to integrate RES into the power grid. 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 appears as a next generation grid and incorporates distributed generation, advanced bidirectional communication, cyber security, and advanced metering infrastructure. This feature is able to utilize the electrical energy efficiently, sustainably, reliably and safely. 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], [5], [6].

The home server gathers both the energy consumption data through ZigBee, WiFi and energy generation data through the REG. Several HEM algorithms by which consumers are able to manage their electricity consumption have been proposed in the literature [7], [8], [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. In this paper we propose a new HEM algorithm using load shifting for smart homes. Proposed algorithm uses the predefined criteria which include grid on/off situation, two rate electricity tariffs and the state of charge (SOC) of batteries.

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 high-rate 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 [17]. Fig. 1 shows the smart HEMS architecture, where home appliances and lights belong to the energy consumption part, while wind and solar resources belong to the energy generation part [17].

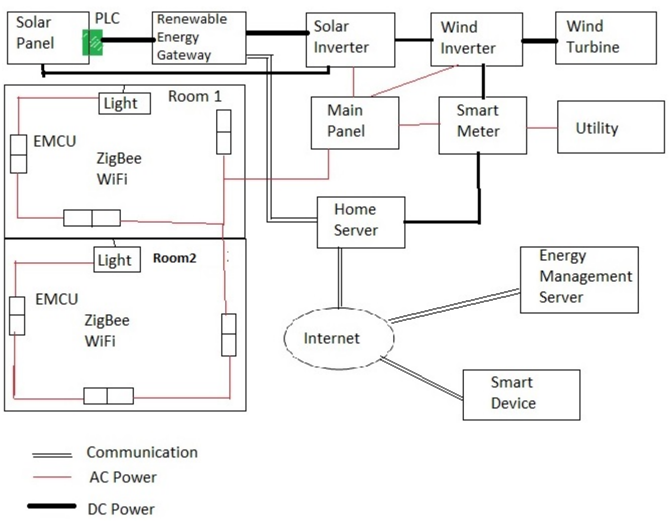

Fig. 1: Architecture of smart home energy management system (HEMS) [17]

In the energy generation part, 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 transfer the gathered data from all panels to the 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. REG gathers data about the solar panel and wind inverters and transfers them to the home server via Ethernet. 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.

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 this information from the home server. REMS analyze the gathered information and creates new information in numerous aspects

B) Home Appliances

To implement optimal or coordinated planning strategies of devices, smart home appliances are divided 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) [17].

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 user’s comfort is quite sensitive towards services of non-schedulable devices at a real time.

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) [18]. 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 [19]. Vehicle-to-grid, as a new concept, enables the transmission of the stored power in the EV battery to the power grid [20]-[21]. 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 is 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 [17].

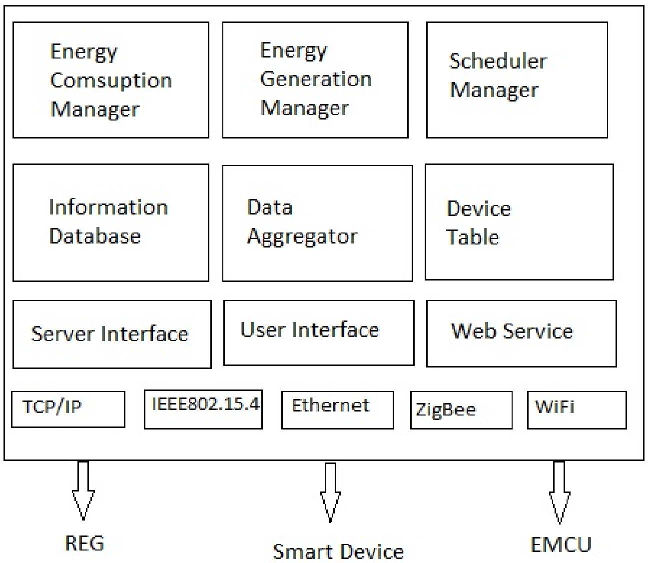

Fig. 2: Function blocks of a home server [17]

Data from solar panels, solar inverters and wind inverters are collected in the REG, and 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. 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.

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 [17]. 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 energy. The communication device block enables the transfer of aggregated information between the EMCU and the home server.

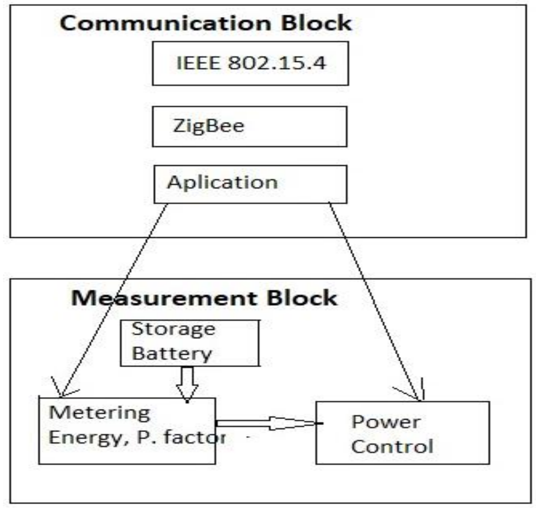

Fig. 3: Function block of Energy measurement and communication unit (EMCU) [17]

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. 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 [22]. The PLC modems and Ethernet communicate through TCP/IP protocol. 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 periodically are transferred 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 [17]. The PLC modems communicate through TCP/IP protocol, actually, and IP address is assigned by the router. The measuring devices of the control block continuously measure voltage and current in the solar panels. These 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 [22]. 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 transferred to the home server.

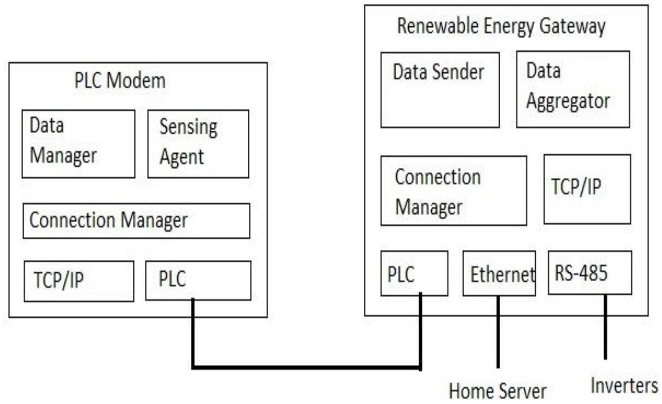

Fig. 4: Function block of PLC modem and Renewable energy gateway [17]

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, where the REMS calculate the average, maximum, minimum of every home appliance. These calculated values help to create a standard energy usage pattern, which serves as a comparing pattern related to energy consumption by different clients.

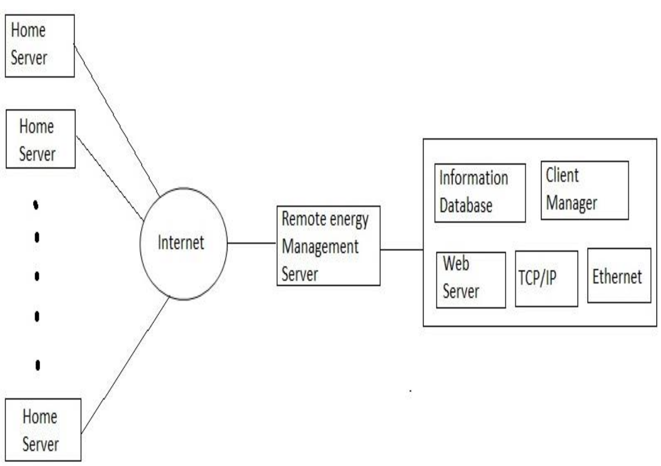

Fig. 5: Function block of Remote energy management server [17]

III. EFFICIENT HEM CONTROL ALGORITHM

Fig. 6 shows a block diagram of the proposed algorithm for home energy management. As can be seen from the figure, the state of charge (SOC) parameter represents the main part of the algorithm. The main purpose of the HEMS system is to reduce consumer bills, then at the time of high rate to make the most of renewable energy. For this reason, the algorithm works based on SOC battery levels, which vary depending on renewable resources. In the home-generated power structure, the battery is only charged by renewable energy sources. Only the SOC level is not enough for the algorithm to work, so the parameter L is added as an indicator that indicates whether the RES is charging the battery or not.

The parameter L is defined as the change of SOC level during operation and is calculated by the successive difference of SOC level every 15 min (our decision). If the value of L is positive, then we find that the battery is charged, and in case of negative value, the battery is discharged. For successful execution of the algorithm, home appliances are categorized according to the priority list with values from 0 to n. A lower value from the priority list indicates that the device is more important i.e. has a higher priority and vice versa. This determines which work equipment function will be relocated for later, depending on the situation.

When the algorithm starts running, it first checks the power grid functionality. If the grid is operational, the SOC battery level is first checked. If the SOC level is higher than the specified level, e.g., 80%, then all appliances whose work has been relocated will be turned on. If the SOC level is lower than the defined level, e.g., 25%, then it is considered that the battery is out of use and at that moment the only power source is the grid. In this case, some electrical appliances are relocated at the low rate tariff in accordance with their priority. Currently, in the Republic of North Macedonia there are two electricity tariffs: the expensive (high rate) and cheap (low rate) tariffs. Thus, the room temperature drops from normal due to the expensive tariff as a result of reducing the air conditioner work in order to reduce the cost. When the SOC level is between defined values e.g., greater than 25% and less than 80%, then the index L comes to expression. If the value of L is negative, then the work of some schedulable appliances is delayed until L reaches a positive value.

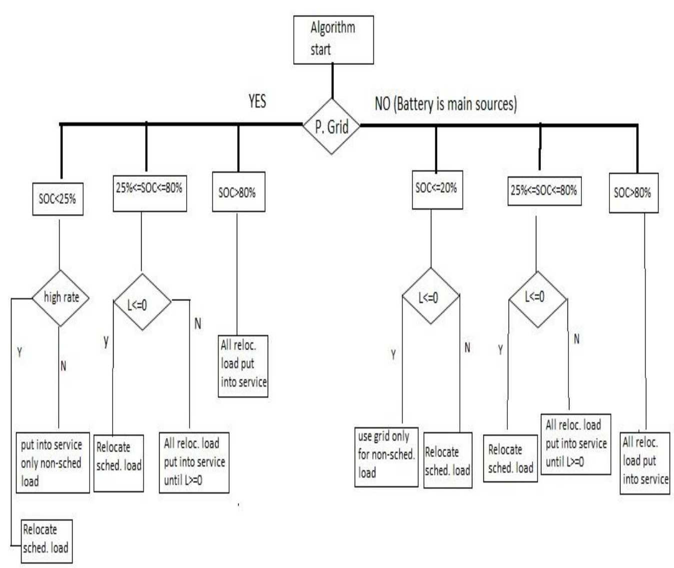

Fig. 6: Home energy management HEM control algorithm flowchart

The working process of the algorithm is similar when the primary source is the battery. The only difference is when the

SOC level is lower than the value set, e.g., 20%, then for non-schedulable appliances will use grid electricity, otherwise if parameter L>0, the loading of these appliances will be from battery. The prerequisites set by the SOC level and the grid are the same. The proposed algorithm can also be used for homes without SOC levels. Because there are no SOC and L parameters in that case, it has been undoubtedly found that the electricity grid tariffs are the only index used in the algorithm.

IV. CONCLUSION AND FUTURE STUDIES

This paper presents a new home energy management (HEM) algorithm for reducing the electricity cost in smart home with renewable energy sources implemented in the description system architecture. The algorithm helps to reduce 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.

In future work, we plan to develop a multi-agent management algorithm that schedules the energy consumption of multiple smart homes with distributed energy resources and appliances. A key challenge for this is designing the efficient communication scheme between multiple smart homes for reducing the energy cost and maintaining the consumer comfort level.

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