Microcontroller based Wireless Control for Future DSM networks

Manash Pratim Boro, K.Bhawin Pattnaik, Akhilesh Kumar

Abstract— The information collected by a smart meter can be implemented in many applications for a smart grid design. One such area of concern is Non Intrusive Load monitoring (NILM) to aid Demand Side Management (DSM) program. In this paper a system is proposed for optimization of energy consumption in future smart grids based on grid integrated near real time communications between a modified version of smart metering unit and the control grid. The communication protocol IEEE 802.15.4. is used for dedicated message exchange. In addition to it, the various shortcomings of the present power management in smart grid are discussed and innovative solutions are suggested.

Index Terms— Automated Metering Infrastructure (AMI),Control Grid (CG), Demand Side Management (DSM), Load Forecasting, Non Intrusive Load Monitoring (NILM), Controlled Outage, Peak Load, Smart Grid, Smart Metering Unit (SMU). .

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1   INTRODUCTION

Sometimes there can be a link between two totally different entities belonging to totally different fields. A problem encountered in one field can provide a solution for another. The various technologies developed in communication networking can help to solve various problems in energy management [2].

One of the main problems currently faced by the energy suppliers is the fluctuations in energy demand. And, in the modern world our dependence on electricity needs no explanation. In near future this dependence is likely to increase manifold which require new innovations in distribution automation techniques [4]. In situations like this, the approach traditionally adopted by the energy supplier is to take the peak consumption into account and create enough reserve energy supply (potentially upgrade existing infrastructure) to meet this uneven energy demand. Even though this approach addresses the problem of meeting the demand, it results in inefficiencies by creating a waste in the system since the demand on average is much less than the (estimated) peak energy requirement or Peak Load (PL). The installation of new power plants to fulfill the rising demand seems like a possible solution but it is not only expensive, but also may not be practical. The demand of power fluctuates rapidly and, in most cities, keeps on increasing much more than the available supply. Also electricity generated has to be used or consumed instantaneously as storage of such large amount of power is practically more expensive than setting up of the power plant itself. And in countries like India where the demand-supply relationship is much more complex because of complexities in governance, population and development, we have to resort

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to efficient management strategies rather than increasing the capacity. In this paper the focus is on a coordinated effort to shift the power load from peak to off peak times and to identify how to determine the demand at the consumer level, distribution system level, and the average demand taking into account all the distribution systems [3]. This requires bi-directional communication mechanisms between the grid and the consumer premises facilitating the consumers to notify their demand requirements to the grid and for the grid to feedback availability/pricing information to the consumers. This is achieved by Automated Metering Infrastructure (AMI) [1]. Based on the information obtained from the consumer side, the utility providers can ascertain demand per distribution system and hence the average demand. The method of balancing the load so as not to exceed the available capacity is similar to the traffic engineering problem in the Internet where traffic load balancing is analogous to electrical load balancing. The mechanisms to estimate the demand are analogous to available bandwidth estimation and the concept of a traffic engineering management server spreading traffic across different paths is analogous to the energy management system distributing the available supply appropriately to the different distribution systems.

Finally, as the current situation is, the demand outpaces the supply such that it is impossible to satisfy the demand. In such cases we may have to resort to controlled (partial) outage or rolling blackouts. In controlled outage or rolling blackouts the energy provider e.g. the state electricity board, discontinues the supply to a particular area for a specific time period. This procedure is repeated for all the areas of the concerned distribution system. Such measures are effective in managing low supply capacity but it makes the consumers suffer. The possible solution is to design a distribution network which offers the consumer to choose from different levels of priority. This is analogous to the message switching or token passing techniques in communication networks where some of the traffic is dropped or delayed (using the priority assigned to the packets) due to lack of bandwidth [2]. The decision of who does and doesn't encounter outage could be based on the different preferences and priorities of the different consumers depending on their roles in the grid. It is envisaged that the prioritization could be done in a hierarchical manner wherein the consumers are grouped into different service classes at the time of registration (initiation of service). Load shedding

should happen in such a way so that loads are disconnected according to the service classes assigned to them. The consumer in each service class could further prioritize their appliances according to their preferences which help the scheduler to make scheduling decisions for the consumer in an outage event where the outage can be avoided by merely re-scheduling non-critical loads in the lowest priority service class (e.g. residential). Different classes of priorities could be assigned to different types of buildings according to their perceived importance. Further, having subclasses can facilitate more granular load scheduling decisions.

1.1 Load Scheduling

There are similarities between the load scheduling problem in smart grids and scheduling and resource allocation problems in communication networks [7], mathematical optimization algorithms are used to determine optimum power allocation and frequency band selection to satisfy different data rate requirements for various users. This has similarities in smart grids where loads need to be allocated to various users at different time slots to optimize resource utilization and to improve energy efficiency. To summarize, the lessons learned and the optimization approaches adopted in communication networks can be used in energy management problems in smart grids. The concept of congestion pricing in Internet traffic control has been applied to smart grid demand response. The burden of load leveling can be shifted from the grid (or supplier) to the end users via a pricing mechanism.

The following paper is organized as follows. In section 2 we describe the system design and architecture. In section 3 the salient features of the proposed system are discussed. And we finally conclude the paper in section 4.

2 SYSTEM DESIGN AND ARCHITECTURE

2.1 Functional Layers

The system consists of the following functional layers:

1. Priority line home network.
2. Interface layer between the consumer premises and grid (control centre)i.e. smart metering unit
3. Communication layer
4. Control software and systems in control centre.

2.2 Hardware

The hardware components required by the system are:

1. A network of priority supply lines for each group of devices or appliances as preferred by the consumer
2. A set of control switches or relays which can be operated by a microcontroller
3. Current and Voltage transformer, display devices
4. Wireless communication modem – IEEE 804.15.4 or IEEE 802.11 etc.
5. Control centre computer
6. Software required : MPLAB, visual basic etc

The communication layer acts as an interface between the distribution and control layer. The distribution layer consists of the network in consumer's premises, the SMU, and the wireless transmitter receiver unit. The control layer consists of the control computers and controlling software. Control layer is located in the control centre of the supplier grid.

For demonstration purpose of how the proposed system fits into the smart grid architecture we designed a hybrid system with a modification on the present smart meters in terms of programming and circuit design.
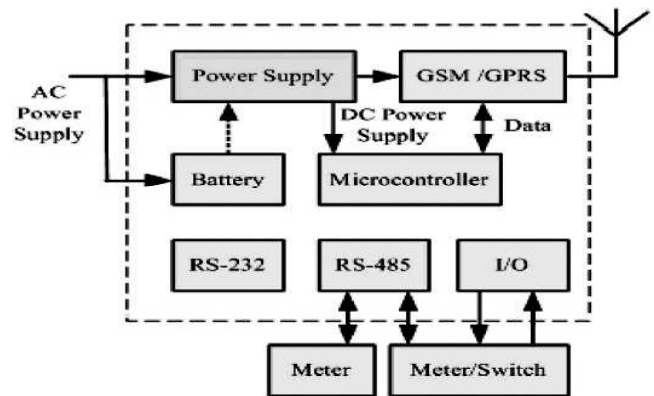

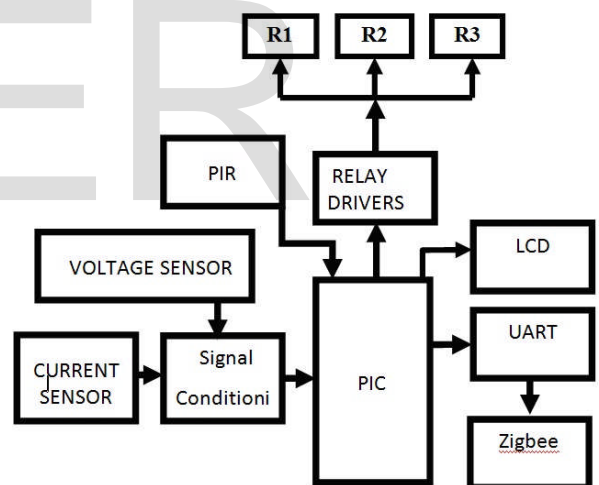
Fig.1. Diagram of presently used Smart Meters

Fig.2. Diagram of new modified Smart Meter

In the new design we are combining the PIC microcontroller with a network of relay circuit. We are replacing the bulky Energy meter with a Current Transducer and a Voltage transducer which are directly interfaced with the Microcontroller unit via a signal conditioning circuit. This whole circuit is coupled with a wireless communication modem. We are using the IEEE 802.15.4 communication protocol.

3 ANALYSIS AND SALIENT FEATURES

The layer by layer analysis of the system is as follows. The lowest level of the system is the distribution network in the consumer dwelling. The main supply line from the supplier is divided into a number of priority lines, connected to the home appliances in a parallel network. A solution to have more defined control is by having the main

supply line into well defined division of a network of supply lines such that each line carries a fixed amount of load.
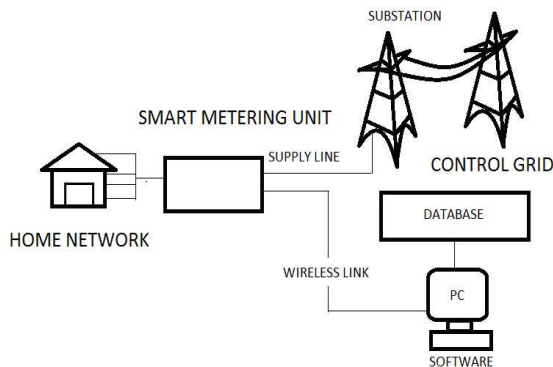

Fig.3, Simplified system architecture

The option of deciding the range and number division for one house is given to the user. The advantage of these divisions is that it increases the aresolution and control of the entire system. A large number of divisions may appear cumbersome but the initial implementation cost is reasonable when compared with the amount of savings.

3.1 Smart Metering Unit

The second layer consists of the Automatic metering unit and wireless communication. This consists of a MCU, USART modem, Current and Voltage Transformers, In Home Displays (IHD) and final control relays on a single compact circuitry. The function of this unit is to gather accurate consumer usage readings, and send this data wirelessly to the concerned control centre [1]. The need for Analog to digital conversion, error detection, modulation of the data signal is handled at the equipment level itself. Finally the data is received by the modem at the control centre. This data represents the complete consumption pattern of the user. Use of this data is to track the energy consumptions and operating statuses of major home appliances. The total output of the SMU unit can be analysed using a Simulator framework [5],[9]. This simulator can predict the power dissipation profiles of individual appliances as well as the cumulative energy consumption of the house in a realistic manner. The results will enable homeowners to make sound decisions on how to save energy and how to participate in demand response (DR) programs [11].

3.2 Control Layer

The third layer uses a computer system in the control centre to wirelessly monitor and control the SMU. Softwares like Visual Basics work as an user interface in the control grid. Continuous real time updates of the energy usages are received from the SMU and control signals to control the relay network can be sent via the wireless communication modem, both manually or automatically by the system. This also incorporates automatic billing mechanism in software.
As already discussed earlier when the gap between demand and supply is very large and it is impossible to satisfy the demand, the supplier resorts to methods like controlled or partial power outage. A consumer is deprived of electricity for a limited amount of time periodically. The time ranges from a few hours on daily basis to a

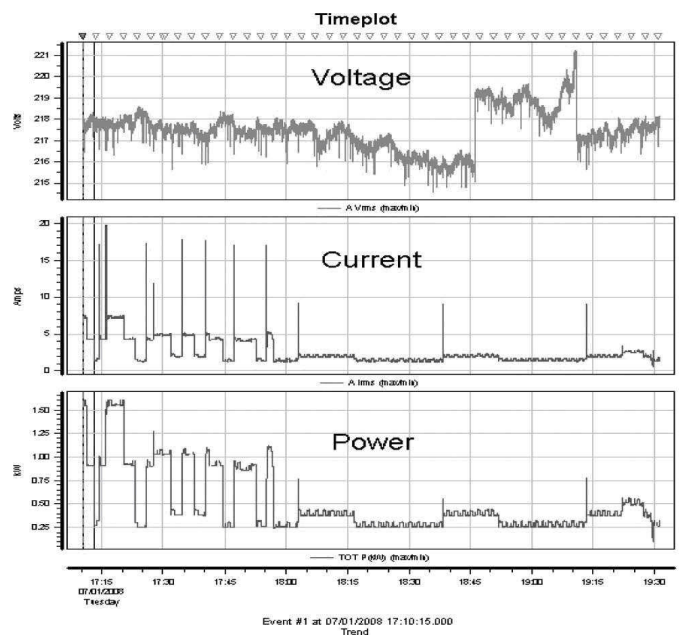few days of outage on weekly basis depending on the availability in the grid.

Fig.4. Real time consumption patterns recorded by smart meter

This method is applied to large areas on rotating basis. i.e. suppose a grid supplies around 75MW of power to a region. The requirement of the region is 100 MW. The region is divided into (say) 4 areas: A,B,C and D. Each region requires approx. 25MW. But due to shortage, the grid supplies only 3 areas A, B, C at a time. Supply to area D is compromised. After some time the next 3 areas B, C, D are supplied while supply to area A is cut. This method is repeated periodically. In the proposed system, instead of cutting off supply of one area completely, only the supply to the low priority service class is compromised. The low priority supply line chosen by each end user is cut off. Depending on the time of cut off and the shortage of power any number of priority supply lines can be cut off, starting from the lowest priority lines and the lowest service class. During this period the high priority lines remain active and the consumers can still use their high priority line (basic appliances). So what the system does is instead of shutting down supply to an entire area completely, it reduces the supplied power to the area. So during the period of power outage a consumer can still get a continuous supply. The decision of who does and who does not encounter outage is based on the preferences and priorities of the customer and their respective role in the grid. E.g. hospitals/ emergency services should never encounter outage whenever possible, whereas services to low priority consumer can be compromised.

One of the important topics in power management research is that of Demand Side Management (DSM) when the consumer is included in the power management process the efficiency in implementing the process increases manifold. So by letting the end user participate in the decision making process by letting them to choose and state their preferences, the decision of distribution is shared. In the proposed system, the SMU continuously transmits

the user consumption information to the control grid. Thus there is a pool of information of consumption patterns of any particular area of concern. This information can be used to determine the peak load timings, thus enabling the control grid to take sound decisions on the appropriate resource allocation. DSM techniques are primarily concerned about management of available power, achieving minimum wastage, and maximum efficiency of usage. DSM requires the user to understand his/her role in the distribution system, and aid in management process. The system will enable crucial decision making process of load forecasting of an area for future efficient smart grids [8].

3.3 Additional Features of NILM.

Load signature is the unique consumption pattern intrinsic to each individual electrical appliance/piece of equipment [9],[10]. Millions of electrical appliances are in operation today. The information provided by the SMU can be used to extract load signatures of equipments used by a consumer. With an increasing number of electronically controlled and automated devices, it is infeasible and impractical to obtain a complete and "personalized" database for all equipment. But, a set of generalized and critical features can be extracted from conventional measurements (e.g., current and voltage waveforms).
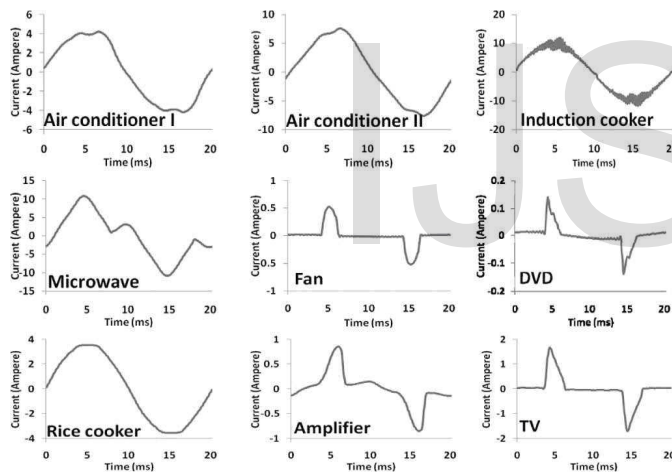

Fig.5. load signatures of individual appliances

The output of a SMU can be represented as current and voltage waveforms. The system or computer at the control grid receives real time updates on the waveforms, from which load signatures can be extracted by using mathematical modeling techniques [10].

NILM needs a customized signature database to realize identification since appliance characteristics are usually different from house to house. Convenient creation of signature database for ordinary householders is really important. By creating a signature database tailed for each home utilizing a device called appliance register. An appliance register is a device inserted between the appliance to be registered and the electric outlet the appliance is plugged in originally [10]. The device contains a current sensor and a wireless transmitter. Once a current change is de-

tected (an event), the device will send a signal to the smart meter. Hence based on the requirement the database can be created using the data collected by the SMU.

4 CONCLUSION

Real-time demand response and management strategies for lowering peak demand and overall load, through appliance control and DSM is proposed in this paper. The communication of the lowest level (end user) to the highest level (grid) is emphasized and a direct wireless control between the two levels is established. Our proposed system provides the flexibility of preference as well as manages to safeguard customer comfort, while encouraging consumers to participate in DSM in a positive way for better power management.

ACKNOWLEDGMENT

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