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A Smart Energy Meter Architecture in Indian Context

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***Abstract*— This paper introduces a low cost Smart Meter Architecture to suit vast and diverse Indian market. An extensive review on Smart Meters research and market has been presented. In addition, we propose a low cost add-on device for the existing electromechanical energy meters to update the customers about the billing and usage. A discussion on available and feasible communication technologies is included and the most relevant solution with cost analysis is proposed.**

Keywords-Smart Meter, ZigBee, GSM, IR sensor, Cost analysis

I. Introduction

In India, Smart Grid is perceived to be a necessity rather than a luxury. Thus for serving 1.2 billion people, cost oriented research should be the prime motive. The prices for smart meters pose a barrier for their large-scale deployment by distribution utilities in India. To overcome this, the Indian Smart Grid Task Force is working on developing a low-cost basic smart meter. This paper presents one such effort and paves a way for further research.

The contemporary energy meters in India need an upgrade to meet the future demands of the nation and to be compatible with the growing smart grid needs. The Advanced Metering Infrastructure (AMI) takes into concern and addresses the persistent issues including power theft, automatic billing, transparency, accountability and customer – utility interaction.

AMI involves two way communications between the consumer and the utility provider wherein the customer will be aware of his usage patterns and can be notified about the scheme of tariff. It provides the utility, the ability to ask users to alter load usage pattern for smoothening of load curve. Its other features include automatic billing, automatic control over consumer's usage, demand based tariff, theft detection, power quality control, detection of faults within the system [1]. AMR, abbreviated as Automatic Meter Reading, involves the development of architecture for digitizing the meter output and instantaneously communicating the data to the utility for instant billing.

A. Smart Meter Scenario in India

These are presently being installed in Delhi under a pilot project on voluntary basis by a private company [2]. Most of the houses in India are equipped with indigenous electromechanical type meters while the digital or solid state type electronic meters are rare. The former have poor configurability and they are read on a monthly basis concealing the time-to-time usage of the customer. This billing process is also quite cumbersome and needs an overhaul to a completely new metering infrastructure based on AMI at an affordable cost to everyone.

Smart meter architecture is prevalent in many countries across the world and massive roll outs are underway in US, Europe, Australia to effectively implement demand side management [3].

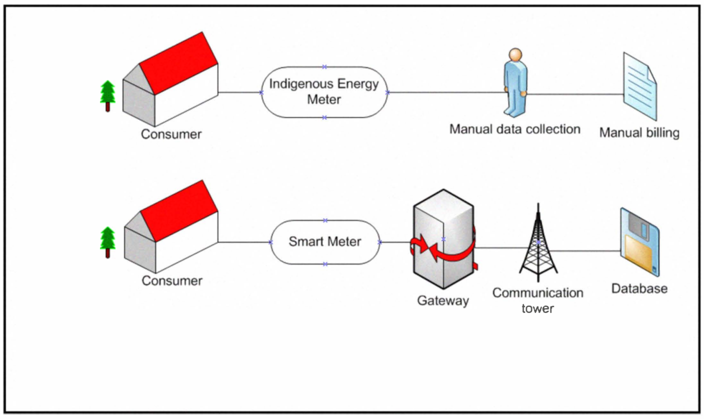

Figure 1. Difference between ordinary metering and AMI

B. State of Art

This section presents ongoing research in the area of smart meters. A comprehensive review of the AMR technologies proposed so far is given in [4]. Furthermore it also presents as a DLMS/COSEM as a communication standard and proposed SIP to handle the communication sessions between a meter and a data collection system. The necessity of a reliable and more efficient two-way communications infrastructure with less propagation delay for operation of smart meter network is stressed in [5]. Several pros and cons of smart meters were analysed in technical and social perspectives in [6]. Development of a Smart Power Meter for AMI Based on ZigBee Communication is discussed in [7]. V2G concept integration with a smart meter is presented in [8].A new idea of compressed meter reading is discussed in [9]. A method for determining location of appliances from multi hop tree structures of power strip type smart meters is proposed in [10]. The privacy issues in Smart metering were clearly put forth in [11]. A new smart apparent energy meter for Indian context was introduced in [12]. The definition of local interface along with architectures for consumer oriented implementation of smart meter network is proposed in [13]. An attempt was made in [14] to use IEC 61850, which will be the seamless standard in power system, for smart meters to achieve interoperability.

II. Proposed Add On Device

India being hugely populated cannot install Smart Meters on a single go, so a strategic planning for their implementation needs to be stressed. Majority of Indian investment still flows into generation i.e. new power plants and transmission corridors thereby allocating less priority for Smart Meters in spite of its potential to fetch returns in near future. Hence we propose an innovative and cost effective model for Smart Meter which could cater the needs of several individuals serving its purpose. Even in a phased implementation, the final phase would take at least a decade from now. So, we propose a simple add on module to the existing electromechanical meters to realize the vital features of smart meter at very low cost to compensate for the delay in mass roll out.

A. Electromechanical – Digital Add On Device

This is a typical conversion device which digitalizes the ordinary energy meter reading. The module is designed to sense the black/red strip present on the rotating disc. By sensing the strip, the device counts the no. of rotations made by the disc. Thus, the device calculates the energy consumption of the household and is made available in digital format. Fig.2 shows the design and location of module on the meter.

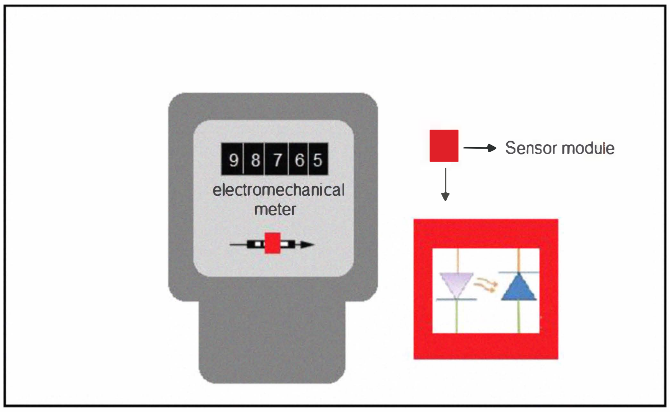

Figure 2. Basic view of meter with conversion module

This module employs an IR sensor to convert the energy consumption into a digital reading. It uses the IR sensor IC OPB706A, LM324 comparator, a counter as shown in figure 3 and its count is updated on a micro controller. It is based on the property of photo diode whose resistance changes upon incidence of light. The CD 4017 counter is used to count the number of rotations made by the disc.

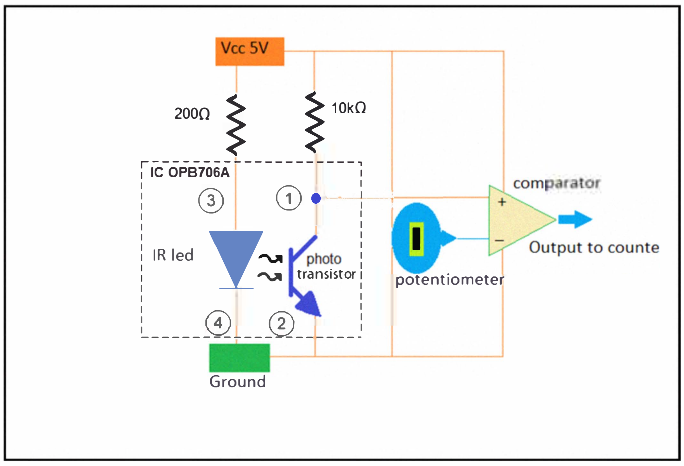

Figure 3. Circuit diagram of conversion device

Here, two sub routines can be exercised for programming on the micro controller. One routine is a constant time based energy estimation which calculates energy for every fixed time interval 'T'. The other routine is constant energy based one which calculates time for energy 'E' consumed. In either of the case, time or energy is communicated through the communication module. The circuit excluding the micro controller is simulated in MULTISIM and its screen shot is shown below in figure 4.In the simulation, a pulse generator is used to replicate the behaviour of IR receiver.

The first image in figure 5 shows the output of comparator and counter as LOW (LED OFF) when a white strip is placed. Second image in figure 5 shows the output of comparator and counter as HIGH (LED ON) when a black strip is placed.

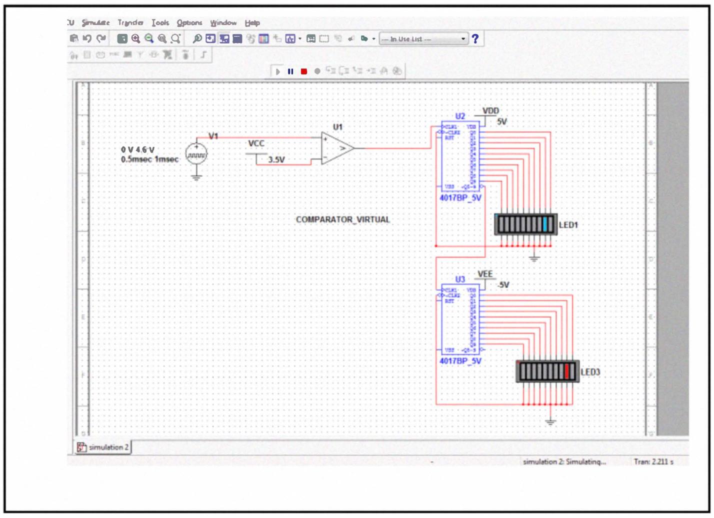

Figure 4. Simulation snapshot of convertor

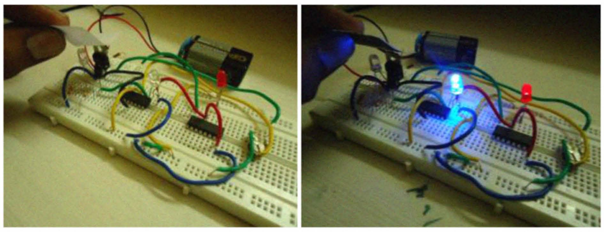

Figure 5. Prototype implementation of convertor

III. Smart Meter Architecture for India

In this section, we propose a low cost yet complete architecture for Indian Context.

A. Components

Energy Measurement is the elementary function of the energy meter. The architecture in figure 6 prescribes ICs for energy measurement and after an extensive survey on market; we are utilizing ADE7878 by Analog Devices. It is a low power device combined with high accuracy and can measure both active and reactive powers. The use of a micro controller distributes the processing and control actions over the grid reducing the burden on the systems at control centres. The choice of micro controller is difficult with hundreds of them available in the market. A 32-bit ARM Cortex M3 micro controller, specifically developed for Smart Meter application by NXP semiconductors is chosen.

Utility side control unit: In our proposed architecture, the meter communicates the usage data continually to the control unit. The usage patterns and most of the other analytics are performed at the utility control unit. So, a control unit is assigned for a group of meters and thus the control unit is optimally utilised. Thus, in Indian Context, in a densely populated area, a utility control unit can be placed close to a distribution transformer. Also, this control unit serves as the gateway between utility and customer and communicates the demand side management controls.

Load control unit- This performs the function of automatic control of the home loads in case of high demand or such similar instances. The meter on receiving a command from the Utility side control unit acknowledges by processing it. A new command specific to home is sent out by MC to load control unit which implements the control actions. Essentially, if a load control unit is embedded into a smart meter, the cost will be increased. Hence, we propose to isolate it and installed separately based on the affordability of household. For example, it is definitely not recommended to put a touch screen enabled load control terminal which controls the operation of AC's and Ovens in a middle class household. The design of this circuit specific to different households and in Indian context is a topic to be explored.
Memory chip: The memory plays a vital role in the Smart Meter functioning. Most of the data though processed and communicated to utility centre, needs to be stored on board.

The circuit employed in the present smart meter design adopts 34Kbit EEPROM, 32Mbit FLASH and stable 256Kbit FRAM.

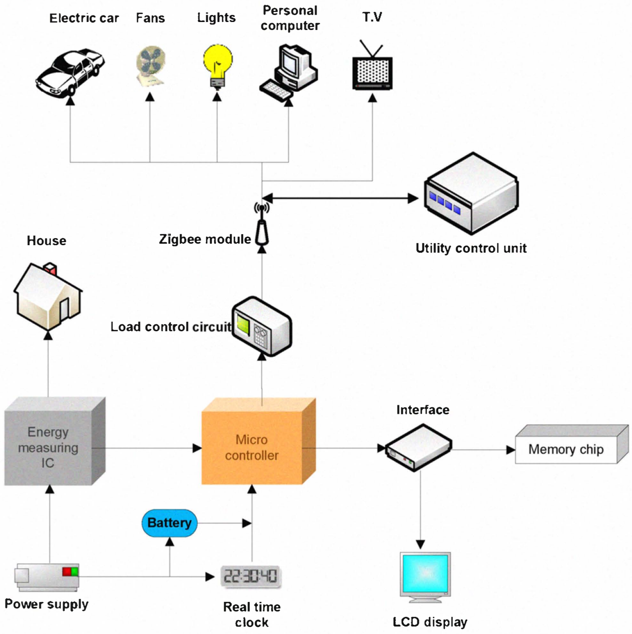

Figure 6. Architectural overview of Smart Energy Meter

The data is secured even under the condition of power failure. It has unlimited reading and writing features and low power consumption. A battery provides the required back up in case the grid is non-operational. A basic LCD display is installed to show meter data i.e. meter consumption, market pricing etc.

IV. Smart Meter Communications

Smart Meter communicates with the base station or the control centre on a bi-directional mode. It is accomplished through a module piggybacked to the meter through a channel which can be chosen based on the analysis in Indian context. Some of the important channels that are available in India for communication are: GSM, Wi-Fi, PLCC, PSTN. The type of communication available depends severely on the geographic location especially in India where not every specific mode is available throughout. A new communication topology all over the country is a costly option. Thus the communication mode used should be a combination of available options. Here we present a brief description of technology and viability in Indian context.

A. GSM (2G, 3G)

It is a second generation digital-type wireless telephone technology which can be broadly divided into two categories based on the type of multiplexing used namely TDMA and CDMA. TDMA involves allocation of time slots to the users sharing the frequency channel on a rotational method while CDMA generates a unique code for each transaction and spreads it over the available frequencies in the common spectrum. 2G uses digital encryption offering better security of the transmission content than its earlier versions. 2G engages various Compression-Decompression (CODEC) algorithms for abridging and multiplexing the data. 2G supports GPRS abbreviated as General Packet Radio Service, is based on the phenomenon of packet switching which involves transmission of data in the form of packets. It supports TCP/IP protocol enabling transmission of data over internet.

The facility of 2G GSM network is widely spread in many parts of the country and serves 900 million users. It is an economic solution for the communication of smart meters and the prices are expected to grow even cheaper. Implementation of this channel involves less extra infrastructure to be built. Its improved security standards offer great reliability on the privacy of the information being transmitted.

3G is the third generation of mobile telephony, the successor of 2G. It has better features compared to 2G like higher data transmission rates which enable the infrastructure to be of split second automation. The enhanced 3G also known as HSPA (High Speed Packet Access) offers high uplink and downlink speeds.

This technology is still in its primary phase of implementation and needs years to evolve into a complete package. They are presently available in major cities and offer full set of services. It is quite expensive and hence not an advisable option in the present.

B. Wi-Fi

Another option, Wi-Fi by Wi-Fi alliance uses IEEE 802.11 family of standards operating in the unlicensed 2.4GHz ISM band. It involves broadcast and reception of data through radio signals in an encrypted format. It works on the OFDM (Orthogonal Frequency-Division Multiplexing) or Direct-Sequence Spread Spectrum transmission scheme. It offers great bandwidths unmatched with many other wireless technologies. It uses Wireless Protected Access (WPA) as an encryption standard but it fails to offer reliability over the system.

This is the present trend of communication being implemented and deployed in many parts of the country. It cuts the cost of the cables to be run to particular houses. The establishment of this mode requires good amount of capital to make it into a full-fledged network connecting the smart meters. It involves building of Municipal Wireless Network or Municipal Wi-Fi which is in operational in many countries around the world through the concept of wireless mesh networks. It requires setting up of Wi-Fi routers all around the locality which makes it an expensive solution. This is a viable option in some of the metropolitan cities of the country as the infrastructure exists already.

C. PLCC

Power Line Carrier Communication associates the use of power conductors for communication by imposing a modulated carrier frequency signal over them. They are operational in many parts in Europe and are the prime mode of communication between sub stations in the power sector. These involve special infrastructure to be built to handle and ensure safe communication without affecting the power transmission. The carrier signal degrades gradually along the length of the line, so PLCC repeaters are used which improve the strength of the signal by demodulation and re-modulating it back on a new carrier frequency and injecting it back into the power line. It has been implemented for many applications like home automation, BPL (Broadband over Power Line) etc [15].

The power lines commissioned long ago has its roots into many remote areas where GSM isn't available. It helps in connecting many backward localities for realizing AMI all around the country. It even helps in home automation through power line networking. The high costs associated for infrastructure are a barrier.

D. Public Switched Telephone Network

It is the interconnection of the entire telephonic communication network of the planet forming a single entity. It works on the concept of circuit switching and packet switching for transmission of voice and data respectively establishing no permanent connections. Of late, PSTN is being used for data transfer too. Packet switching effectively saves money as its billing is based on the amount of data carried in packets but not on the time for which the channel is rented.

The PSTN is one of the solutions offering to cater various sectors of people since they have connectivity with every corner of the country owing to their setup decades ago. The present population shifting to wireless communication from the traditional fixed line communication has created a void in the wired telephony. This space can be used for purpose of smart metering. It is less hazardous to the environment compared to the other technologies. The issue with PSTN is with more people opting out from it due to its increased price in comparison with wireless mode of communication, it is difficult to maintain a uniform communication mode in a locality.

They require the least infrastructure to be developed and in major cities with the advent of Broadband through PSTN based on ADSL they help in faster communication.

E. Zigbee

Zigbee is a wireless technology using low-power digital radios developed as an open standard to meet the requirements of short distance data transmission with minimal cost. It operates in the unlicensed or ISM band of 2.4GHz under the IEEE 802.15.4 standard of physical radio specification which defines the Physical and MAC protocol layers. Zigbee offers enough bandwidths required for the implementation of AMI and home automation. It supports good amount of network topologies like point to point, point to multipoint and mesh architecture. Its low power consumption eliminates to change for a new battery or frequent charging thereby offering good reliability. It involves Direct Sequence Spread Spectrum modulation technique. It has very low start-on latency enabling faster response. It supports bandwidths up to 250Kbps. Its typical range is around 75m and even high (1500m) for specially designed Zigbee devices (Zigbee Pro). The Zigbee device can be made to work in three modes.

1) Coordinator

It is also known as a Full-Functioned Device (FFD) which has the features of a node and an administrator. It forms the root of the system. It has the capability to communicate with any other node connected to the network. It can even act as a bridge between two networks. It stores the information related to the network and acts as an archive for security keys.

2) Router

This performs the duties of an intermediate device which routes the information to a specified node in the network and at the same time improving the strength of the signal. It routes data based on the address information received and posts it to the respective destination.

3) End Device

It is also called Reduced-Function Device (RFD). It has very limited functionality of just communicating with the network co-ordinator. It cannot relay information from other devices connected in the network. It has long battery life compared to other types as its operations are limited uninvolving continuous data transmission.

V. Proposed Communication Architecture

In the following section, we propose the communication architecture based on the analysis presented in the previous section. As shown in the figure 7 nodes 1-7 represent the customers to whom the electricity is supplied through the distribution transformer shown in picture. Each meter is a node, equipped with a communication module to enable two way acknowledgements and data transfer between the control centre and the user.

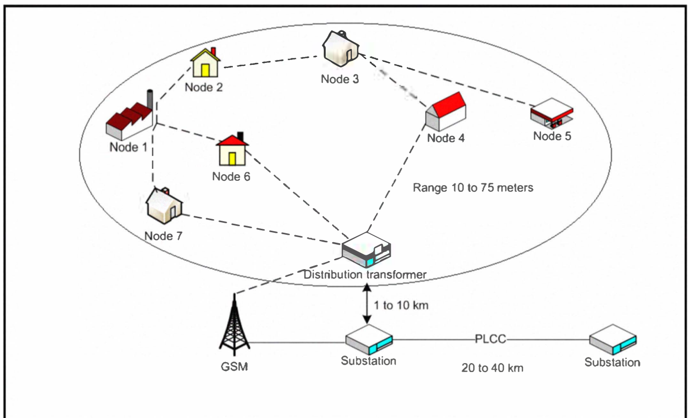

Figure 7. Network topology of AMI for data transmission

The nodes or meters are connected to a main module placed at distribution transformer through Zigbee in a wireless mesh network topology using the concept of multi-hop routing methods thereby economizing the infrastructure and improving the reliability. Employing 2G connectivity for each node is an expensive solution which can be inferred from the following analysis. An ordinary energy meter transmits data of nearly 34MB per month and according to the prevalent data charges it amounts to nearly Rs.50. Installing Zigbee module eliminates these running costs which involves only one time installation of its module whose worth is around 300-500 INR. The distance between the distribution transformer and the nearest residential customer ranges from 10-50 m which falls well in the range of Zigbee and hence it can be installed to use without loss of connectivity. The data collected at various distribution transformers is relayed to its parent substation through GSM network as the distance between the two varies from 1-10 km. Thus optimal utilisation of free and paid communications bands occurs. Thus the module at distribution transformer works as a coordinator and those at the meters as routers and nodes themselves.

The module at the distribution transformer needs to be designed such that it accumulates data from the smart meters in and around. This data is used to mitigate power theft by designing a differential type algorithm which compares the power flow in and data reported by smart meters over ZigBee network. Thus power theft detection is an added feature of this architecture. The distribution transformers update the information to the substation through GSM network which can communicate over long ranges. Thus the module at distribution transformer is equipped with both Zigbee and GSM communication capabilities. In addition, the device at distribution transformers can be devised so as to include other Smart Grid features like self healing, automatic fault detection and isolation, automated transformer protection etc.

The data received at various substations is fed to a main control centre through a data concentrator for analysis. PLCC provides the best solution for transmission of this data collected to control centre. The existing communication channels between substations can be revamped for the data transfer.

The primary purpose of different communication technologies at different hierarchical level is for optimal utilisation of resources. A direct communication link between substation and a meter node would make it difficult to detect the location of theft and is not practical. Thus our proposed architecture addresses the issues above stated in Indian scenario.

VI. Conclusion and Future Work

After extensive research on existing architecture and communication for Smart Meter, an attempt has been made to design an effective and optimum architecture for a smart meter in Indian context. An additional add-on device for immediate roll out has also been proposed. The future work can be focussed on analytics part of this architecture and further development of this architecture for different Indian scenarios.

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