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Development of AMI for Efficient Distribution and Control of Electrical Energy for Smart Grid

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Abstract: Energy crisis is increasing day by day. Its main reasons are lack of electricity generation, inefficient distribution and theft of electricity as cited by Bhatti *et al.,* (2012). The concept of Smart grid overcomes such problems and provides efficient distribution of electricity as cited by Anas *et al.,* (2012). One of the key components of smart grid is AMI (Advanced Metering Infrastructure). The main aim of this research is to develop a prototype model for AMI and observe its performance. Research methodology applied in this paper is to develop a smart meter, centralized server and communication link between smart meters and a server. The developed AMI system can perform three major functions, i.e. Automatic meter reading (Telemetry), Pole Mounted Transformer protection (Controlling) and Theft Detection (Monitoring). This AMI model can be used in smart grids to provide efficient and cost effective electricity.

Keywords: Smart Gird, Telemetering, Arduino, AMI.

I. INTRODUCTION

Telemetry is the process of measuring physical quantities and transmitting the information to the remote locations automatically. Conventional method of electricity measurement requires a lot of meter readers to manually record the meter reading. This is more tedious job and as well as more prone to corruption but telemetry resolves this problem. Telemetry is possible because of smart meters which are capable to measure electricity and transmit that information to the centralized server. These meters use microcontrollers, sensors and a communication system as cited by Benzi *et al.,* (2011) for interfacing smart meters with households and also cited by Gungor *et al*., (2011) about communication technologies and standards that can be used in such systems.

Some scientists are working on Energy Management System. So many models are developed for effective distribution and utilization of electrical energy using smart systems, with that some computer-aided tools are used to monitor, control and optimize the performance of generation and transmission as cited by Chakraborty *et al.,* (2007) and also cited by Tushar *et al*., (2015) discusses the energy management with distributed energy resources.

Smart grid is also an example of energy management system; in which smart meters and smart appliance are used to control the distribution of electricity as cited by (Farhangi, 2010) the transformation of traditional grids in to the smart grids and energy management systems as cited by (Brown, 2008) describe the impact of such system on distribution of electricity. In smart grid, there is two-way communication as cited by (Devidas and Ramesh, 2010) communication protocol for optimizing the distribution, consumption information of users is transmitted to utility servers and any command from utility server will be transmitted to smart meters for reducing the load in peak hours. That is why Advanced Metering Infrastructure becomes the core component for Smart Grids as cited by (Abdulla, 2015) and Jiang*et al.,* (2014). AMI requires a complete communication system. The development of a new communication system is quite costly, therefore existing communication systems can be used such as cellular mobile network as cited by (Ladarat and Naetiladdanon 2015). Cellular Network is widely spread network which can save the cost of developing a complete new system as cited by Fang *et al.* (2012).

In this research a prototype model of such an advanced metering infrastructure is developed to work in conjunction with cellular mobile network. Using this model consumption of energy is efficiently controlled and monitored. Current sensors and potential transformers (PT) are used in this research to measure the electricity of individual user and then the real time information of power consumption is transmitted to centralized location (Grid) by using existing cellular mobile network. The established system is a two way communication system, in which each user's connection can be controlled from centralized server and billing information is also shared with each user using messaging service.

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This model performs automatic meter reading, pole mounted transformer protection and theft detection. Pole mounted transformer protection is done by restricting each user to use electricity as per his allocated installed capacity, as this load exceeds, it results in tripping of the connections. Aurdino measures power consumption of each user and compares it with that specified limit. If the power consumption exceeds that specified limit, Aurdino sends command to relay module to terminate the connection. System model is designed in such a way, so that theft detection is become possible. For theft detection, total power delivered from PMT is also measured and it is compared with sum of the power of each user. If the total power exceeds the sum of power of each user, it means and an unauthorized load is connected in between, than arduino generates an instruction of theft detection, which is transmitted to centralized server. Afterwards the theft detection LED turns on.

The organization of this article is as follows: Section II describes Literature Review. Research Methodology is described in section III which is divided in to three parts, Power Measurement and Theft Detection, Communication with centralized server and centralized server. Section IV describes Software and Hardware Design and Development. Section V is Results and Discussions.

2. RELEVANT RESEARCH

Various designs and network topologies are proposed for AMI i.e. PLC (Power Line Communication), Mesh Topology, WiMAX and M2M (Machine to Machine). But still there are many challenges that need to be overcome as cited by Lopez *et al.*(2011). There is more focus on developing the communication infrastructure for AMI. Korea is developing AMI using ZigBee and power line communication as cited by Yang *et al.*(2009). ENEL (Ente nazionale per l'energiae lettrica) means National Entity of Electricity in Italy. It is a gas and electricity distribution company that developed the "Telegestore project" in 2001 for AMI. The PLC (Power line communication) was used for communication between smart meters but now they are looking for another infrastructure to improve the efficiency. Energy and climate change department in the UK (United Kingdom) aims to deploy smart meters in all homes by 2020. In this research project rather than developing different communication infrastructure, cellular mobile network is used. There are lot of concerns for using cellular network for communication among smart meters. Increasing number of distributed smart meters result in high data traffic, which requires either more bandwidth or some changes in protocols to accommodate this traffic. How GSM/GPRS and LTE cellular system performance behaves with current generation need to be discussed as cited by Nielsen *et al.,* (2015). In this proposed research GSM technology is used which proved efficient for less number of users but if numbers of users are increased, it results in little delay. Problem is optimum utilization of cellular network which can easily accommodate this traffic with disturbing telephony traffic as cited by Inga *et al.* (2014).

However for controlling system an efficient smart meter needs to be developed. The design of KWH (Kilo Watt Hour) meter developed in a research project, which was based on microcontroller. The CT (Current Transformer) sensors are used which generates continuous pulses and the rate of these pulses is directly proportional to the load of electricity. Power is calculated by microcontroller based on this rate of pulses as cited by Jamil *et al.*, (2004). Each meter is connected with a computer having an assigned address. Then the computer sends MAC (Media Access Control) address which is transmitted to all the meters and then corresponding meter responds to computer. Then computer may enquire for the power consumption data which is stored in that meter. This system is wired based and very much slow. The efficiency and reliability of the established system has been improved by using wireless technology. In the reported research, a meter sends consumption data whenever there is change in load. By using old microcontrollers and sensors that generate continuous pulses to measure the power are very slow and it is not an intelligent system. Another methodology is proposed to measure the power using Arduino with current transformer and potential transformer as cited by Srividyadevi *et al.* (2013). A voltage and current conditioning card is used for power measurement. The purpose of using Arduino was just to monitor the load level and if it exceeded certain specified limit than the load was tripped.

The discussed project, as cited by Jamil *et al.* (2004) was wire based, very much slow and it required to send the command from computers for power measurements. The efficiency and reliability of the system has been improved by using wireless technology. In this project, a meter sends consumption data whenever there is change in the load, this happens in real time. However the purpose of another discussed project as cited by Srividyadevi *et al.* (2013) was just to measure the power using Arduino and restricting each user not to exceed the specified limit. Where as in the undergoing research, the developed system is interfaced with cellular mobile network and a centralized server has also been established.

3. RESEARCH METHODOLOGY

Research methodology is split into three parts including the ways to calculate power & control theft, to

establish the communication link between smart meter and the centralized server and the utilization of the central server. (**Fig. 1)** represents the discussed prototype model in which AVR ATmega16 Microcontroller Based Control Circuit is Arduino, which is measuring the power consumption of each load and total power at PMT using current sensors (CT). The Arduino monitors power consumption of each user, if it exceeds specified limit than it disconnects the load via a relay module as shown in figure, it also compares the total power at PMT transformer with sum of power of each user. If total power exceeds the sum than the instruction of theft detection is generated. Arduino is connected with Cellular Network Connecting Module. This module is basically a GMS modem which connects this smart meter (Aurdino circuit) with centralized server and mobile (handset) of customer using cellular network. The Arduino microprocessor-based prototype can transmit the consumption information as well as it may receive any command from Control Room.

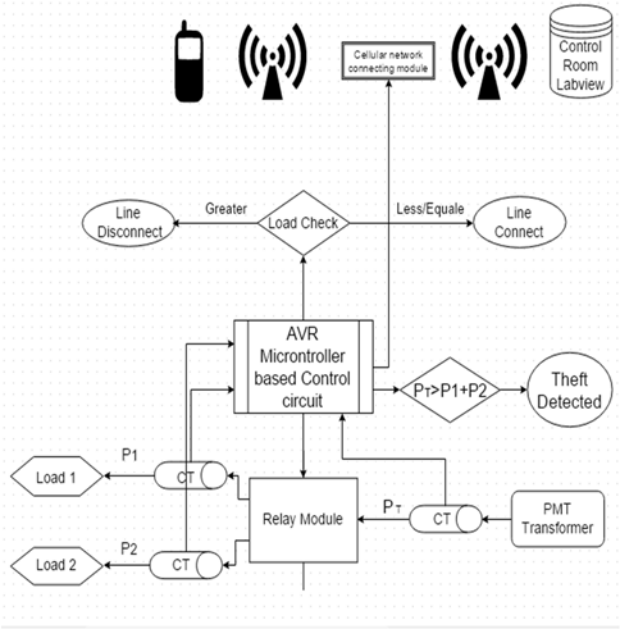

Fig. 1 System Model

a. Power measurement and Theft Detection

Current sensors sense the magnetic field generated around the wire due to flow of electric current. Current sensor converts this magnetic field into and electric signal which is fed to Arduino. Arduino calibrates the magnitude of this electric signal to find the power delivered to load. Than Arduino compares this measured power with the specified limit of the power for each user to decide whether to trip the load or not. Another current sensor is used at PMT to measure total power. Imbalance in sum of power delivered to each user and total power at PMT result in theft detection.

b. Communication with user and centralized server

Consumption infromation of all the users is tranmitted to to centallized server which keeps on updating its data comsumption pattren of each user Moreover when user is approaching the maximum specified limit of power consumption, a message is generated and sent to user's mobile to inform him/her. If user crosses that specified limit, load is tripped and another message is generated on user's mobile informing him/her for the reason of tripping.

c. Centralized server

A graphical user interface is developed at centralized server using LabVIEW software. From where, one can monitor the consumption pattern of each user, billing history and control connection. Load can be connected or disconnected just by clicking a button. A message can also be sent to user from centralized server. This user interface consists of three window described following.

4. SOFTWARE AND HARDWARE DESIGN AND DEVELOPMENT

This section is divided in to two parts software development and hardware development. In software development, LabVIEW software is used for GUI and data acquisition on server. In hardware development Arduino, current sensor and potential transformer are used to develop a smart meter.

a. Software Development

GUI (Graphical User Interface) of server is designed using LabVIEW (Laboratory Virtual Instrumentation Engineering Workbench) which is a platform and development environment for a visual programming language from National Instruments. Execution is determined by the structure of a graphical block diagram on which the programmer connects different function-- ‑ nodes by drawing wires. These wires propagate variables and any node can execute as soon as all its input data become available, this is done by using VISA. This VISA program is tool for performing all data acquisition and processing all the received information from GSM (Global System for Mobile Communication).

The complete GUI (Graphic User Interface) is divided into three windows, Home Window, Feeder Window and User Window as shown in following (**Fig. 2)**. The home window allows user to select the GUI of a particular feeder a menu ring. Feeder window includes a menu ring to select user for bill history, LED (Light Emitting Diode) to indicate theft detection, two graph plotters on this screen show the recent power consumption (in KWH Kilo Watt Hour) of users, two

buttons to disconnect connection of user A and user B manually. The user window consists of buttons of previous months to show the monthly bill in String indicator. The string control is used to send the message to user.

All the updated consumption information of users is automatically displayed on these windows. Moreover LED on this window blinks when theft is detected.

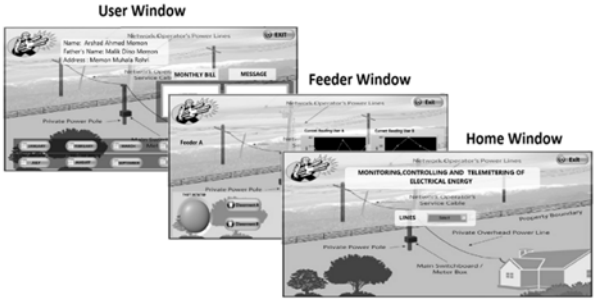

Fig. 2 Graphical Windows

GSM module acts as both transmitter and receiver. LabVIEW receives data from the GSM module of system in the form of coded signals using AT Commands. Data Acquisition into LabVIEW is done by USB-to-UART converter from GSM.

The data transmitted from serial port of USB-to-UART Converter is interfaced with NI-LabVIEW using VISA (Virtual Instrument Software Architecture) protocol. It is a standard for configuring, programming, and troubleshooting instrumentation systems comprising GPIB, VXI, PXI, Serial, Ethernet, and/or USB interfaces. VISA provides its own functions to configure write and read to serial port. In order to disable the echo from the GSM modem ATE0 command is used. AT+CMGF=1 is used to set modem in text mode. In text mode SMS messages are represented as readable text. AT+CNMI=1,1,0,0,0 is used to make the GSM modem attentive so that when message is received it gives indication to LabVIEW program. The LabVIEW program is continuously reading the data from serial port until indication of message is read. When indication received the program will read the message.

In order to communicate with GSM AT commands (VISA program) are used as shown in **(Fig. 3)**. It is graphical programming; each node in this figure is a function which is processing the data. i.e. Open, Read and Write functions. When message arrives at centralized server it is received by USB-to-UART port. Open function imports this message in VISA software than this message is read using Read function. This Message is decoded and based on information GUI Display is updated. The received message is identified to check what information is sent from system (Smart Meter placed on remote location). On the basis of that result LabVIEW VISA program will take the decision to indicate the conditions such as updating the power consumption graph or blinking the LED.

b. Hardware and Prototype Development

In the hardware development, a smart meter is developed using Arduino, GSM module, Current sensor and Potential sensor and relays as shown in following **(Fig. 4)**. Current sensors sense the current passing through line and produce current signal which is measure and calibrated by arduino and same with voltage which is sensed by potential transfer. Using this current and voltage information arduino calculates power and performs some operation i.e. transmitting this information to centralized server using GSM module, tripping the load if current level exceeds the certain specified limit using relays and comparing the power at main line and sum of power consumed by individual user to detect the occurrence of theft.

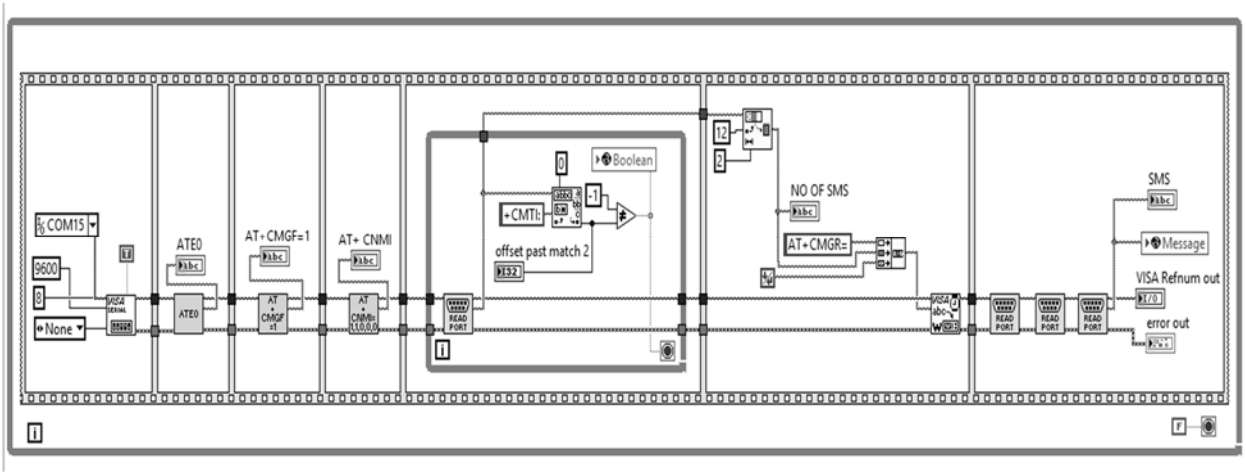

Fig. 3Visa Program

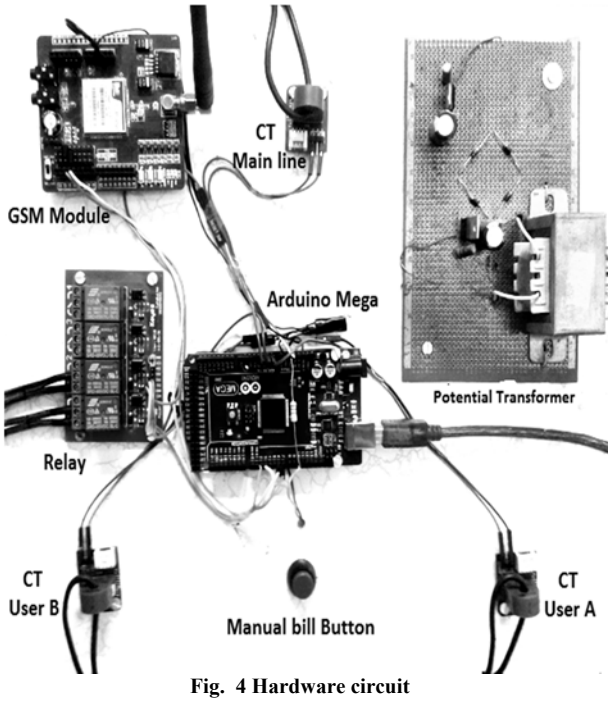

Fig. 4 Hardware circuit

5. RESULTS AND DISCUSSIONS

Results can be divided into three parts, i.e. Telemetering, Control and PMT Protection and Monitoring & theft detection.

a. Telemetering

Consumption information is conveyed to centralized server and user via cellular network. Whenever load changes, Arduino generates a message which is sent via GSM module to the centralized server. Message is also sent to user for warning and billing purpose. In following **(Fig. 5)** and **(Fig. 6)**, generated messages are shown at user's mobile and server screen. In **(Fig. 5)**, a billing message at user's mobile is shown.

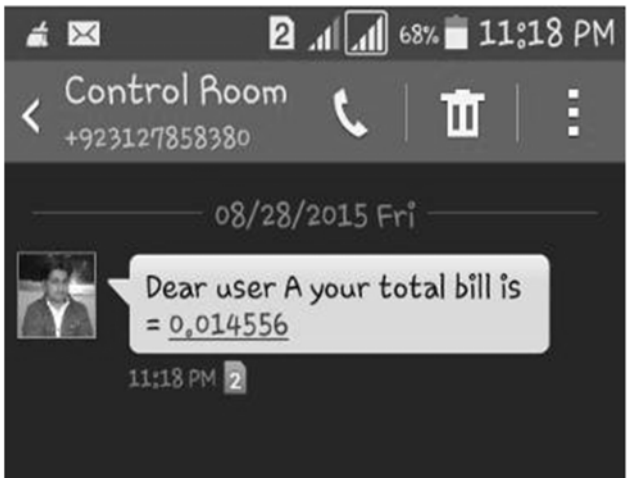

Fig. 5Message to user

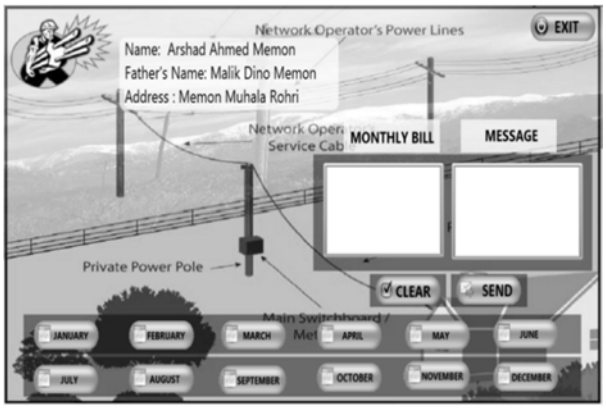

Fig. 6 message to control room

b. Control and PMT Protection

A load limit is specified for PMT protection. In this prototype we have used three 100W bulbs for each user. Load of one bulb is normal. If two bulbs turn on at the same time, it is specified as maximum load, at this load a warning message is sent to user as shown in following **(Fig. 7)**. Turning on third bulb crosses the maximum specified limit that's why load is tripped and an alert message is sent for informing user about the reason of load tripping as shown in following **(Fig. 8)**.

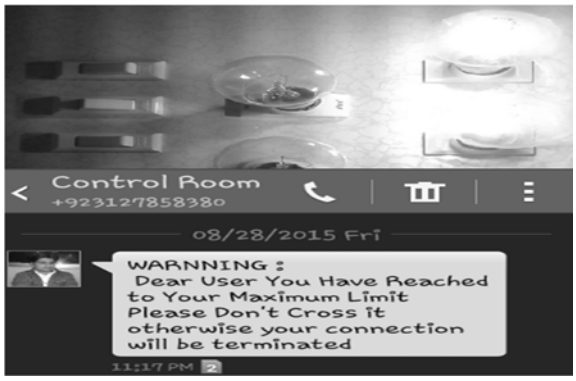

Fig. 7 warning message

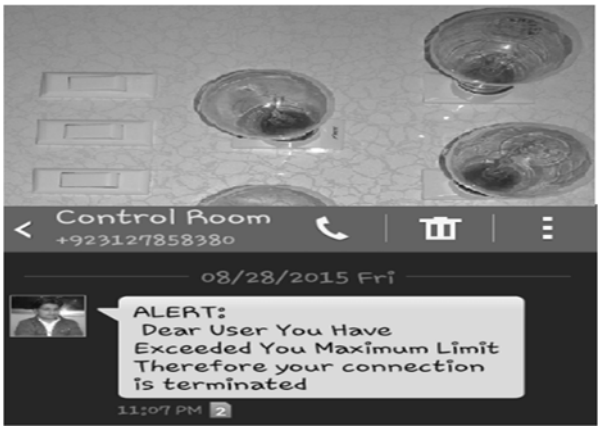

Fig. 8 Alert Message

c. Monitoring and Theft Detection

Centralized system continuously monitors the status of each user and record the meter reading. Power consumption of each user is graphically displayed as shown in following **(Fig. 9)**. Theft detection is also monitored from centralized server. If unauthorized load is connected, Arduino sends theft detection message to centralized location then LED turns on as shown in same **(Fig. 9)**.

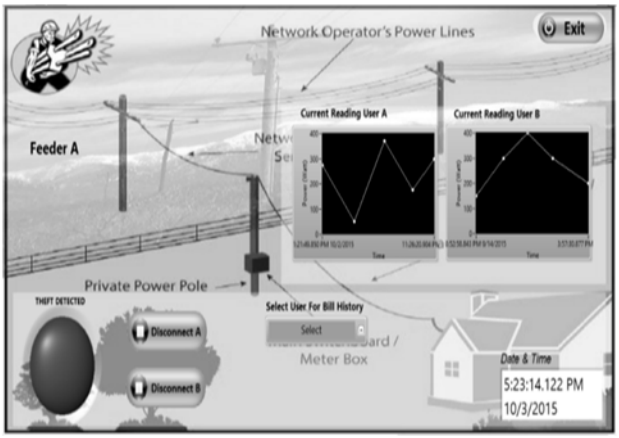

Fig. 9 Theft Detection

(Table 1) shows the line status of smart meters when load changes.

Table 1 Line Status

Sr. No	Load level	Message sent to user	Message sent to control room	Load status
01	Normal	----------	update	connected
02	Approaching maximum	warning	update	connected
03	Crossed maximum	alert	Power 0	disconnect

(Table 2)shows the occurrence of theft detection on centralized server. Column 1 and 2 show the current variation of user 1 and 2. In this prototype, one user can operate maximum two appliances and each appliance draws one ampere current, that's why current limit in column one and two is 1 to 2 ampere. Where the third column is showing total current in main line, which should be sum of currents drawn by both users. Maximum current in third column should be 4 ampere but one unauthorized load of one ampere is attached for theft detection. When this unauthorized load is attached, current of main line reaches 5 ampere which is greater than the sum of currents drawn by both users. When Arduino finds current limit of main line is greater than sum of the currents of user one and two, it generates an instruction and transmits it to centralized server for turning on the theft detection LED.

Table 2 Current Values

Current at user 1	Current at user 2	Current main line	Theft Detect LED
1 A	1 A	2 A	off
2 A	1 A	3 A	off
2 A	2 A	4 A	off
2 A	2 A	5 A	on

6. CONCLUSION

A prototype has been developed to reduce the theft of electricity and protect the transformer from overloading. This research reports three functions i.e. telemetering, monitoring and control of the usage of electricity. By using cellular network the data can be transferred from smart meter to the centralized server and vice versa. As the cellular system is abundantly available and it is reliable for communication therefore this system is chosen as the communication link in this research. This research also suggests to restrict the users to a certain amount of electricity that reduces the overloading problems of transformer. This is the major in summer season in this area. The Theft of electricity is a major problem and causes revenue loss. By effectively monitoring consumption of electricity at both the load and PMT sides, the theft detection becomes possible, that is the one of the main features of this research project. By utilizing two-way communication any instruction to load can be monitored and commanded accordingly. At the end the product will provide an autonomous and robust solution of the problems of automatic meter reading, theft detection and PMT protection. This research also addressed few issues of Smart Grid and smart metering and proposed their comprehensive solution.

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