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Wireless Smart Grid Design for Monitoring and Optimizing Electric Transmission in India

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***Abstract*— Electricity losses in India during transmission and distribution are extremely high and vary between 30 to 45%. Wireless network based architecture is proposed in this paper, for monitoring and optimizing the electric transmission and distribution system in India. The system consists of multiple smart wireless transformer sensor node, smart controlling station, smart transmission line sensor node, and smart wireless consumer sensor node. The proposed software module also incorporates different data aggregation algorithms needed for the different pathways of the electricity distribution system. This design incorporates effective solutions for multiple problems faced by India's electricity distribution system such as varying voltage levels experienced due to the varying electrical consumption, power theft, manual billing system, and transmission line fault. The proposed architecture is designed for single phase electricity distribution system, and this design can be implemented for three phase system of electricity distribution with minor modifications. The implementation of this system will save large amount of electricity, and thereby electricity will be available for more number of consumers than earlier, in a highly populated country such as India. The proposed smart grid architecture developed for Indian scenario, delivers continuous real-time monitoring of energy utilization, efficient energy consumption, minimum energy loss, power theft detection, line fault detection, and automated billing.**

Keywords-smart grid; wireless sensor networks; electric grid; single phase system ; three phase system

I. INTRODUCTION

Power grid constitutes electricity generation system, electric power transmission system, and electricity distribution system. Grid may imply the entire electrical network or a regional electrical network or a sub network such as a local utility's transmission grid or distribution grid. Electricity in a remote location is carried by a simple distribution grid linking a central generator to homes. The traditional paradigm for electricity transmission and distribution in a wide area, in developing countries, is a complex phenomenon. Generating plants are usually located near a source of water, and away from heavily populated areas. The electric power which is generated is stepped up to a higher voltage which is connected to the transmission network. The transmission network will move the power to a long distances until it reaches its wholesale customer. Upon arrival at the substation, the power will be stepped down in voltage from a transmission level voltage to a distribution level voltage. As it exits the substation, it enters the distribution wiring. Finally, upon arrival at the service location, the power is stepped down again from the distribution voltage to the required service voltage. Existing power system in India faces lot of problems such as intermittent power supply, varying voltage levels with respect to varying load, power theft. In [4], the smart grid technologies such as advanced metering, automated controlling, distributed energy resources are described. In many developing countries, including India, power grids have not been fully built out.

Smart grid technology gives an opportunity for the developing countries, in the growth of their power sector to more manageable, reliable, and scalable designs. An overview of smart grid, its development and researches in smart grid are explained in detail in [3]. A model for smart grid with sensors throughout is proposed in this paper. The system proposed in [1] utilizes a private high speed access network whereas, the sensors associated with the grid in the proposed system communicate wirelessly and thus form a wireless sensor network suitable for smart grid application.

Section 2 describes the related work. Section 3 discusses in detail, the need for smart grid in India. Section 4 describes with the proposed architecture for single phase electric distribution system. Section 5 details the working of the smart wireless network and the methods designed to solve the problems faced by India. Section 6, provides the future method of implementation. Conclusion and future work are described in Section 7.

II. RELATED WORKS

Reid describes the Oncor Smart Grid Initiative, aimed to provide remote meter reading capability, and systems which function without operator intervention [1]. This system described in [1] utilizes a private high speed access network to connect the substation/switchyard to the corporate network. The construction of the access network is scheduled to begin in 2010.

In [2], J. Momoh gives an outline of smart grid intelligent functions that help to achieve adaptability, self-healing,

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efficiency and reliability of power systems. The author also presents a special case for the development of Dynamic Stochastic Optimal Power Flow (DSOPF) technology; however the implementation of DSOPF is not described in the paper.

In [3], H. Farhangi discusses the evolution of the smart grid, transition to the smart grid, coexistence of the two generations of electricity grids, emerging smart grid standards, smart grid research, and development and demonstration of smart grid. The paper gives an overview on all aspects of smart grid.

R. E. Brown describes the potential impact of the smart grid technologies such as advanced metering infrastructure, distribution automation, and distributed energy resources on distribution system design [4]. The design and the implementation of the smart grid is not explained in [4], whereas, the new architecture proposed in this paper solves the main problems faced by Indian electrical system.

III. NEED OF SMART GRID IN INDIA

India is world's 6th largest energy consumer. Due to India's economic rise, the demand for energy has grown at an average of 3.6% per annum over the past 30 years. The total demand for electricity in India is expected to cross 950,000 MW by 2030. About 75% of the electricity consumed in India is generated by thermal power generation plants, 21% by hydroelectric power generation plants and 4% by nuclear power generation plants. More than 50% of India's commercial energy demand is met through the country's vast coal reserves. The country has also invested heavily in recent years on renewable sources of energy such as wind energy.

Electricity losses in India during transmission and distribution are extremely high and vary between 30 to 45%. In 2004-05, electricity demand outstripped supply by 7-11%. Due to shortage of electricity, power cuts are common throughout India and this has adversely effected the country's economic growth. Theft of electricity, common in most parts of urban India, amounts to 1.5% of India's GDP. Despite an ambitious rural electrification program, some 400 million Indians lose electricity access during blackouts. While 80 percent of Indian villages have at least an electricity line, just 44 percent of rural households have access to electricity. The total installed generating capacity in the country is over 147,000MW and the total number of consumers is over 144 million.

Apart from an extensive transmission system network at 500kV HVDC, 400kV, 220kV, 132kV and 66kV which has developed to transmit the power from generating station to the grid substations, a vast network of sub transmission in distribution system has also come up for utilization of the power by the ultimate consumers. However, due to lack of adequate investment on Transmission and Distribution works, the T and D losses have been consistently on higher side, and reached to the level of 32.86% in the year 2000-01.The reduction of these losses was essential to bring economic viability to the State Utilities. High technical losses in the system are primarily due to inadequate investments over the years for system improvement works, which has resulted in unplanned extensions of the distribution lines, overloading of the system elements like transformers and conductors, and lack of adequate reactive power support. The commercial losses are mainly due to low metering efficiency, theft and pilferages. This may be eliminated by improving metering efficiency, proper energy accounting and auditing and improved billing and collection efficiency. Fixing of accountability of the personnel / feeder managers may help considerably in reduction of Aggregate Technical and Commercial loss.

Smart grids increase the connectivity, automation and coordination between the suppliers, consumers and networks that perform either long distance transmission or local distribution tasks. A smart grid delivers electricity from suppliers to consumers using two-way digital technology to save energy, reduce cost and increase reliability and transparency. A smart grid includes an intelligent monitoring system that keeps track of all electricity flowing in the system. Features of smart grid compared to existing power grid are: digital, two-way communication, sensors throughout, self-monitoring, self-healing, automated billing, and power theft detection.

IV. ARCHITECTURE FOR SMART GRID IN INDIA

In this paper, the distribution side of electrical grid is highlighted assuming that need for intelligent grid is much important in consumers' side to save energy. The existing power distribution system in India has distribution transformer, distribution lines and consumers. In two types of distribution services – Three Phase and Single Phase; here we speak on Single Phase distribution service.

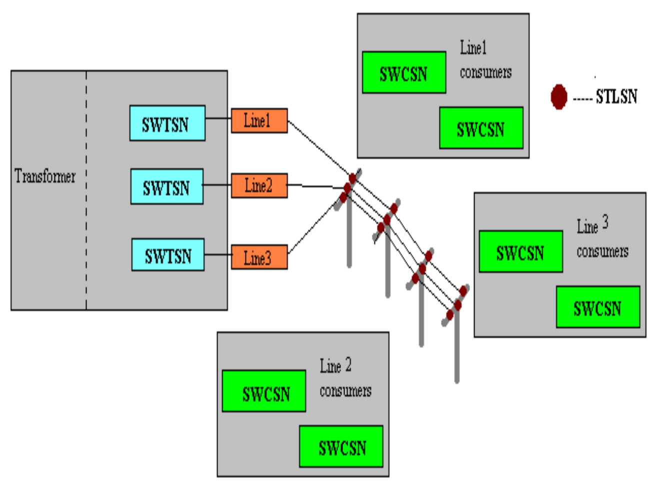

Figure 1: Architecture for Smart Grid

The whole system architecture is based on integrating wireless network with existing electrical grid. The architecture consists of four modules namely, Smart Controlling Station (SCS), Smart Wireless Transformer Sensor Node (SWTSN), Smart Transmission Line Sensor Node (STLSN), Smart Wireless Consumer Sensor Node (SWCSN). The proposed architecture is shown in Figure1. SWCSN is a consumer power metering device that measures the power consumed by the consumer and send the data periodically to the SWTSN. In India, 11KV arrived at primary of the distribution transformer is stepped down to 230V, 50Hz for Single Phase distribution. Each feeder of the transformer has a SWTSN which monitors power through each line and collects data from SWCSN aggregate it and send to the SCS. STLSN is another module associated with distribution line, mounted in each distribution line posts. Each module details is shown in Figure2

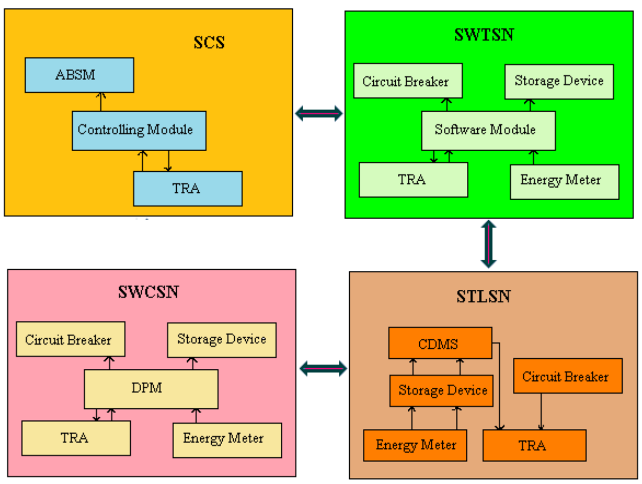

Figure2: Description of each module

A. *Smart Controlling Station (SCS)*

SCS collects the aggregated data from all the SWTSN associated with the distribution transformers. Transmission and Reception Antenna receives the data, the controlling module checks the data and Automatic Billing and Storage Module (ABSM) stores the data for each consumer and performs billing.

B. *Smart Wireless Transformer sernsor Node (SWTSN)*

This device monitors the line associated with it and measures the power consumption of the entire line and it also collects the data from SWCSNs' and STLSNs' of that line. SWTSN consists of an energy meter, software module, storage device and Transmission and Reception Antenna (TRA). Software module inside SWTSN aggregates the data from SWCSNs and compares this with the measured data and make decisions accordingly. The comparison of data can be resulted in the triggering of Circuit Breaker or transmission of data to STLSN or SWCSN or to controlling station.

C. *Smart Transmission Line Sensor Node (STLSN)*

STLSN is mounted in the transmission line posts for each line. It constitutes of energy meter, storage device, TRA and Comparison, Decision Making and Software (CDMS) module and Circuit Breaker. This will be at sleeping mode unless a wake up message is received from SWTSN. When it gets a wake up message, measurement is taken by energy meter and at the same time it receives data from SWCSNs'. Then the two values are compared and take necessary steps by CDMS module. Storage device stores the values needed for calculation. STLSNs' main job is to detect power faults

D. *Smart Wireless Consumer Sensor Node*

SWCSN is a consumer power metering device. It consists of energy meter, Data Processing Module (DPM), Storage device, Circuit breaker and TRA. SWCSN measures the power consumed by the consumer and send it to the SWTSN. If the consumed power exceeds the allowable power for consumption, it warns SWCSN to reduce the power consumption or trigger the Circuit breaker. The DPM process the data measured by the energy meter, compares it with the previous value stored in the storage device, and send the data to SWTSN accordingly.

V. WORKING OF SMART WIRELESS NETWORK

The problems faced by the existing grid in India are inefficient usage of energy, power theft, manual billing and high cost for maintenance. By the proposed architecture the above mentioned problems can be solved.

The sensor network monitors the electrical grid for a specified period of time, which may be daily, monthly or yearly. Thus the SWTSN stores the maximum demand for each consumer including the losses. This value is updated only when a new consumer becomes the part of the network. If all the apparatus and outlets are used simultaneously to full extent, the maximum demand will be equal to the connected load [5].

If the maximum demand for one distribution line is M_{dl} and the losses in distribution line may be denoted as D_{Ll}. Then the measured demand D_m should always less than or equal to the sum of M_{dl} and D_{Ll}. These values are stored in the storage device. Figure3 shows the network topology.

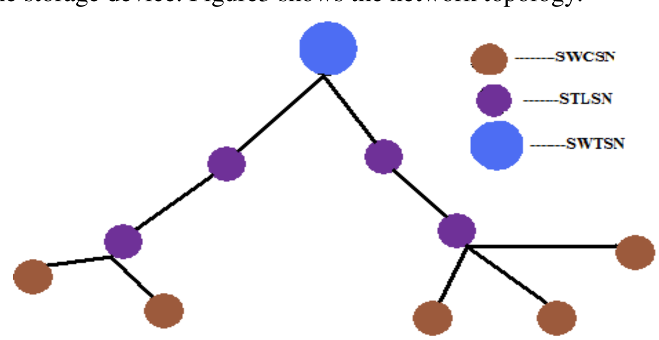

Figure3: Network topology

A. *Energy Saving*

The SWCSNs send data measured by its own energy meter periodically to SWTSN. SWTSN checks whether the collected data from each consumer exceeds the allowable power for the consumer. It also checks the measured power by its energy meter is equivalent to the collected data from all the SWCSNs that takes power from the same line associated to the SWTSN. At peak time only less amount of power is allowed to taken from the grid. This is done by the transformer. If any consumer made an attempt to draw greater power a warning signal is send to the consumer node. Even then the load is large then send message to the consumer node to cut the power to that consumer only. Thus at peak demand time only certain devices in the consumers' home are allowed to be ON, thereby we can save a large amount of energy.

B. *Line Fault and Power Theft Detection*

Line faults may be caused due to over current or earth fault. If there happens to be a connection between two phase lines then over current fault occurs. Earth fault occurs due to the earthing of phase line through cross arm or any other way. Now in India, there is not any technique to detect the specific location of the fault immediately. Power theft is another major problem faced by Indian electrical system. These two problems can be solved effectively through this architecture.

The measured data from each SWCSN is send to the neighboring STLSN. The aggregated data is then send to the next nearby SWLSN. Thus the data transfers from SWCSN to the corresponding SWTSN through STLSN. The collected data is compared with the measured data by the energy meter plus D_{Ll} in each STLSN. Normally these two data are almost same. If there is any difference (d_{mc}) in the collected data and the measured data, there may be a line fault or a power theft in that segment. Large value of d_{mc} indicates a line fault and small value of d_{mc} indicate a power theft.

C. *Automated Billing*

Existing billing system in India is manual and it wastes manpower and reduces accuracy. The proposed system presented an automated billing system. The SWTSN aggregates the data from all its corresponding SWCSN and send to the SCS. The ABSM in SCS stores the data and billing of consumed power is done. Thus we can check our payment status at any time. Monthly each user has to pay for the consumed electric power.

VI. IMPLEMENTATION

The proposed system will be implemented, tested and validated in multiple regions in India, and its performance will be evaluated. Experiments will be performed to determine the systems performance with varying loads, varying voltage levels, theft, and with line fault. The data aggregation and synchronization algorithm will be implemented by nesC language in TinyOS platform. TinyOS is an event-driven operating system designed for sensor network nodes that have very limited resources. TinyOS supply a series of components which can be used to program conveniently and easily to acquire and process data acquired by sensors. The TinyOS system, libraries, and applications are written in nesC, a new language, which is an extension to C. The proposed hardware will be developed in our University in two phases. In the first phase we will plan to design a prototype of the system. In the second phase we will enhance the system to perform the field test. Testing and validation will be performed to determine the performance of the proposed system.

VII. CONCLUSION

This research proposed an architecture based on wireless sensor network for monitoring and optimizing the electric transmission system in India. The system design mainly concentrates on single phase electric distribution system, especially suited for Indian scenario. The proposed system provides the solution for some of the main problems faced by the existing Indian grid system, such as wastage of energy, power theft, manual billing system, and transmission line fault. In future, we plan to implement this design and validate it in our remote area. We will also incorporate future enhancements to suit the system for three phase electric distribution system in India. Along with all these new architectural components will be incorporated, so that the system can be completely used for optimizing the energy consumption. This method will reduce the energy wastage and save a lot of energy for future use.

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