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Self Powered Wireless Sensors for Fault Diagnosis of Wind Turbine Planetary Gearbox

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ABSTRACT: This project deals with smart sensing: a second-generation Smart Meters replacing traditional metering device, and the first generation of electronic meters, in order to extract a richer and near real-time information. This information is then transferred on a fast communication network where is needed. In other words, the Smart Meters deployed over the distribution grid create a Sensor Network used for grid control and management. The intelligent unit employed in the proposed system is able to communicate using standard metering protocols like DLMS/COSEM, allowing high-level integration with systems that use this information for both billing and customer relationship management

KEYWORDS: Smart Meters, DLMS/COSEM, Sensor Network, grid control.

I. INTRODUCTION

Smart meter is an advanced energy meter that measures the energy consumption of a consumer and provides added information to the utility company compared to a regular energy meter. Smart meters can read real-time energy consumption information including the values of voltage, phase angle and the frequency and securely communicates that data. The ability of smart meters for bidirectional communication of data enables the ability to collect information regarding the electricity fed back to the power grid from customer premises. A smart meter system includes a smart meter, communication infrastructure, and control devices. Smart meters can communicate and execute control commands remotely as well as locally. Smart meters can be used to monitor and also to control all home appliances and devices at the customer's premises. They can also collect diagnostic information about the distribution grid, home appliances, and can communicate with other meters in their reach. They can measure electricity consumption from the grid, support decentralized generation sources and energy storage devices, and bill the customer accordingly. Data collected by smart meters is a combination of parameters such as a unique meter identifier, timestamp of the data, and electricity consumption values. Smart meters can be programmed such that, only power consumed from the utility grid is billed while the power consumed from the distributed generation sources or storage devices owned by the customers are not billed. Smart meters can limit the maximum electricity consumption, and can terminate or re-connect electricity supply to any customer remotely.

A smart meter system employs several control devices, various sensors to identify parameters and devices to transfer the data and command signals. In future electricity distribution grids, smart meters would play an important role in monitoring the performance and the energy usage characteristics of the load on the grid. Collection of energy consumption data from all customers on a regular basis allows the utility companies to manage electricity demand more efficiently and also to advise the customers about the cost efficient ways to use their appliances. In light of this, smart meters can be used to control light, heat, air conditioning and other appliances. Smart meters can be programmed to maintain a schedule for operation of the home appliances and control operation of other devices accordingly. In addition, integration of smart meters helps utility companies in detecting unauthorized consumption and electricity theft in view of improving the distribution efficiency and power quality. Transient stability simulation tools are essential for enabling safe and reliable operations of power systems. In real life large scale systems with thousands of buses, transient stability studies often



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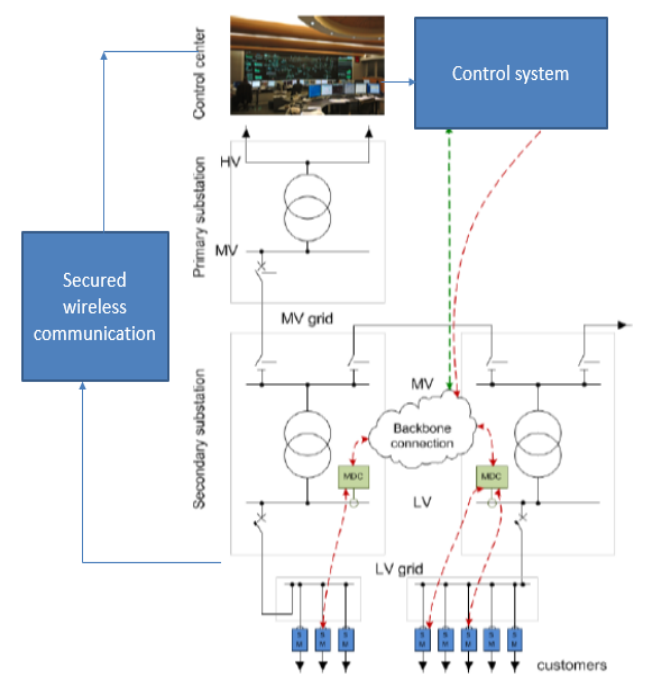
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generate gigantic volumes of data. This poses a significant challenge to power system planners to analyze the overall system response and identify portions of the system which might be displaying “abnormal” behavior. An exhaustive analysis being prohibitively inefficient, it is of critical importance to develop methods to automatically extract such information from transient stability data. This paper addresses the above need by applying clustering techniques on transient stability data, more specifically, voltage and frequency response signals. Common features are extracted and outliers characterized by uncommon features are also identified. Furthermore, a visualization method is presented to infuse geographic information in the display of the results. Feature extraction from other power system quantities such as bus voltages poses greater challenges and has been addressed here. In the previous work, the choice of parameters for applying clustering techniques was not discussed. These have been addressed in this current paper. The second part of this work focuses on visualization of the information extracted from transient stability data, which is time-varying in nature. Traditionally strip-charts have been used for this purpose. Such an approach can be quite effective provided one is only interested in showing a few signals. The architecture of an electronic SM is similar to the architecture of an electronic data acquisition system: sensors, the sensor conditioning stage, the data acquisition block (ADC), an elaboration blocks (Elab) and a communication stage (Comma). The simplified block diagram of a single phase SM is shown in Fig. The sensors stage is composed of voltage and current sensors, which are directly connected to the LV grid. In LV application, resistive voltage divider sensors are used to acquire the voltage from the grid. Resistive voltage divider sensors use voltage divider to scale down the voltage of the grid so that it can be acquired by the ADC block of the SM. These sensors offer the best compromise between the cost and measurement performance (good accuracy and linearity). Considering the current sensors, several solutions are available in literature. Resistive shunts are the cheapest, and the most commonly used solution for residential and LV applications. Shunt sensors use allow-value resistor to produce a low-voltage drop that can be used to estimate the current. Current Transformers (CTs) represent an alternative to shunt-based sensors in applications requiring higher accuracy, higher current ranges and isolation.

II. OPERATIONAL ANALYSIS



Circuit diagram of proposed system



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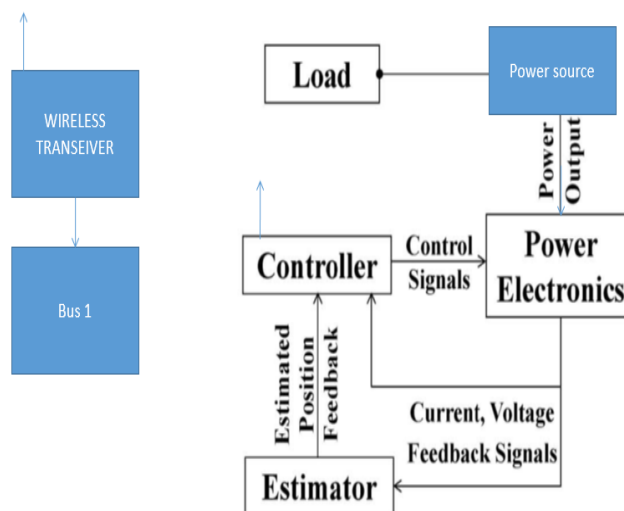
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In the proposed work, clustering techniques on transient stability data, more specifically, voltage and frequency response signals. Common features are extracted and outliers characterized by uncommon features are also identified. The second part of this work focuses on visualization of the information extracted from transient stability data, which is time-varying in nature. Traditionally strip-charts have been used for this purpose. The area selected for the test is the LV network connected to MV/LV substation located in the city of Brescia (North of Italy). This area has been selected because of the high photovoltaic (PV) penetration, which is about 40 % of the peak demand. This grid is composed of eight LV feeders; five of them have been partially equipped with the sensor network made of SMPS.

- Passive customers with no generation which have been equipped with a SM to monitor the power flow between the grid and the load;
- Active customers with a PV plant which have been equipped with a SM to monitor the power flow between the grid and the load;
- Active customers with a PV plant, which have been equipped with two SMs. The first one (red) to monitor the power flow between the grid and the load and the second one (green) to monitor the PV production.

LV backbones are three-phase, while the connection to the residential customers is single-phase. An Ethernet port and is connected to a LV Broadband Power Line (BPL) modem (API-2000-GW by Ormazabal Current), operating in the 2-32 MHz band. Data are collected in the MV/LV substation where the master node of the LV-BPL network is installed. A repeater is present in any street cabinet to boost the signal strength. A communication model for connecting the smart meters is to be designed using a high data rate QAM system with better security.

- Wireless based feedback is given the control section, assuming that the grid and control section is at a distance of 100m.
- Along with that an encrypted signal is given to the control panel, with speed monitoring and control through wireless sensor networks. Also we prove that the delay introduced by the wireless feedback does not affect the motor speed settling time.
- Hardware module may designed(optional) using a load for about 100w, with 802.15.4 point to point communication



Block diagram of wireless system



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A. Communication Technologies

Of all design considerations, selection of the communication network and design of the communication devices are very important and must satisfy multiple complex requirements. As discussed earlier, utilization of the smart meter system involves a huge amount of data transfer between the utility company, smart meter, and home appliances in the network. This data is sensitive, confidential and access to this data should be restricted to a few personnel. With these restrictions on data, security guidelines are formulated for transmission, collection, storage, and maintenance of the energy consumption data. The communication standards and guidelines were formulated to ensure that data transfer within the network is secure. It is equally important that this data must represent the complete information regarding the energy consumption by the customer and status of the grids without any potential manipulations or miscalculations. So, this data must be authenticated and should reflect information about the target correct devices. The directionality of communication between the devices at the customer premises, utility, and neighbor's smart meters, and other power system components. In this devices in the transmission sector ensure proper transmission of generated energy, control systems in distribution sector ensure monitoring and controlling faults, communication devices like protocol gateways, data collectors and repeaters and network operations coordinates data and control signals between all the devices in the communication network. A smart meter or an appliance that belongs to a customer can be identified by a unique identity assigned to it. In general, identities given to all components are secured by cryptographic techniques. The communication network selected has to support operation of the smart meter system even on power outage detection and support distribution automation. In addition, the selected network and its components must be cost effective and must support "traffic prioritization" i.e., prioritize the delivery of data based on its time and direction sequence.

Communication technologies to be chosen have to be cost efficient, should provide good transmittable range, better security features, bandwidth, power quality and with least possible number of repetitions. Bluetooth technology can be a possible option for communication of control signals and to transmit energy consumption data. In view the of implementing this technique, B.S. Koay *et al.* proposed a Bluetooth based energy meter that can collect and transmit the energy consumption data wirelessly to a central base station. Power Line Carrier (PLC) and Broadband Power Line (BPL) communication are the other possible options of data transfer supporting the higher level communication suites such as TCP/IP. One of the popular communication technologies is PLC, which uses the existing electricity grid, cellular/pager network, and mesh network, combination of licensed and unlicensed radio, wireless modem, existing internet connection, power line communication, RS-232/485, Wi-Fi, WiMAX, and Ethernet with protocol to upload data using IEC DNP. PLC technology is highly efficient for automation of data in smart meter applications. In spite of substantial overhead caused by the large IPv6 header, this protocol can be applied even at low PHY layer data rates. This technology, with the combination of the MAC algorithm can achieve satisfactory delay times and throughput. Though this combination might slightly reduce the usable data transfer rate, it will not affect the overhead at MAC layer. IP based network protocol would be another promising option for communication because of its advantages over other technologies while satisfying the security standards of the smart grid communications. In addition, TCP/IP technology can also be used as a common platform for multiple communication devices. In addition to above options, Session Initiation Protocol (SIP) is a text-based signaling protocol that is used for controlling multimedia sessions such as video and Voice over Internet Protocol (VOIP). SIP can be used on Transmission Control Protocol (TCP), User Datagram Protocol (UDP), or Stream Control Transmission Protocol (SCTP). SIP incorporates several elements of HTTP and Simple Mail Transfer Protocol (SMTP). SIP is an open and standards-based technology, which provides a robust communication medium for the smart grid applications. T. Mander *et al.* proposed a communication architecture that uses DNP3 to produce the protocol discontinuity between the DNP3 devices for regulated power system operations and TCP/IP devices for the smart load and demand management. This discontinuity in protocols limits the number of vulnerable attacks from other TCP/IP devices. Some security enhancements such as data object security and a security layer to DNP3, as this protocol by itself is not adequately safe for collaborative operations. Data object security provides several rules for accessing the data in order to avoid unauthorized access that manipulates the data and device operations. S. Rusitschka *et al.* proposed an energy meter that communicates using a Peer-to-Peer (P2P) based network.

A smart meter that employs P2P network can enhance the range of operations of the appliances. In addition to such advantages, several value added services can also be implemented with less capability requirement. As the P2P based



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communication uses internet, this can lead to cost effective design of smart grid communication network. In addition, the P2P network utilizes the resources of participating homes optimally. Zigbee [19] network is another important and potential communication network for transfer of data and control signals. As many industrial and household entities maintain a computer with 802.11.x, Zigbee protocol can be used with Home Area Networks (HAN) for data transfer over 802.11.x. Using this technology, instead of increasing the operating clock frequency in the crypto core in order to reduce the response time and verification delay, J. Kim *et al.* proposed the mode toggling approach on the design process for AES-CCM module. They have also adopted the optimal security material management module. These design methodologies and the obtained response time allow the cryptographic core to maintain the minimum clock frequency, while staying within the constraints, ensuring the reduction in total dynamic power consumption. GPRS technology can be a potential communication medium for transferring both the data and control signals wirelessly over long distances. In contrary to other communication network technologies, only a few communication characteristics that represent GPRS communication network have been assessed. In view of this, lack of tools for detection of a network failure would be major setback for implementing GPRS network in many geographical locations. Before deploying a GPRS based communication system in a specific location, availability and quality of the signal has to be determined. Parallel processing and implementation of field-programmable gate array (FPGA) hardware can reduce the total computation time for interpreting the data and to obtain the status of the distribution network. Adoption of reconfigurable logic for processing of data minimizes the amount of data to be generated by a smart meter. Of all proposed and available possibilities of communication technologies, GPRS and PLC technologies are currently implemented because of the ease in maintenance and economic factors.

B. Issues & Challenges

In general view, efficient management of the grid can be an alternative solution instead of revamping the existing grid. But, in view of technical advantages and enhancements to operation capability, integration of the smart grid stands as a valuable solution in managing the existing grid. However, the design, deployment and maintenance of the smart meter system involve many issues and challenges. Implementation of smart meter system in the distribution system involves several billion dollars of investment for deployment and maintenance of the network. Indeed justifying the investment is difficult. So, this investment has to be realized as a function proportional to the projected increase in the energy demand and portion of the distributed generation. Initially, the process of replacing the existing energy meters with a smart meter system will be a challenge for utility companies. Lack of proper infrastructure for synchronizing this new technology with the existing ones might interrupt the introduction of smart meters. Though several devices are integrated with the smart meter system, they can be used to their fullest extent only when all the appliances and devices in the distribution and metering network are included in the communication network. Integration of the devices becomes even more complicated with an increasing number of customers.

Deployment of communication network in some localities might be difficult due to terrestrial difficulties. In the USA, utility companies receive incentives for selling more electricity, which might not drive them to encourage their customers to conserve energy. Collection and transmission of energy consumption data is a continuous process that is done automatically, but it is a tedious and expense job. In this context, a common notion might arise in several customers is that, smart meters they might essentially create some privacy and security risks as the data and signals are being transmitted. Additionally, this data might also reveal the information about presence of people at their residence, when they were present, and what appliances are in use. In view of this, some customers might be unwilling to communicate their energy consumption data with their neighbor's meter. Fundamentally, it would be an issue about the choice of parameters to be transmitted and administrator authentication to access that information.

In addition to communicating the data and control signals with the base station, smart meters must execute these control commands from the utility companies. Operation of a smart meter system involves a huge quantity of data transfer between a smart meter and the server located at the base station. Maintenance, management and storage of data could be a tedious job. There are many technical issues that might be considered during selection of communication network. For instance, DNP3 does not provide sufficient security for collaborative operations, so some security enhancements to DNP3 are proposed by T. Mander *et al.* using data object security and a security layer. In addition, most of the smart meter



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communication networks use low bandwidth, which generates high traffic and limits the quantity of data to be transmitted. Integration of devices for modulation, demodulation and additional memory for storing the data logs could increase the overall deployment costs. Energy consumption data transmitted through public communication networks like cellular networks might involve security risks. Other possible security vulnerabilities might be weak authentication, quality of implemented software, error handling, weak protocols, and improper session management. In spite these issues, though deployment and maintenance of some communication networks are cheap, utility companies might encounter some challenges in the form of limitations in network coverage, data capacity, and propagation issues. In addition, data concentrators may lead to accommodation and safety issues. In case of wired communication, physical damage to the cable might also cause discontinuity in data transfer.

C. Applications

Smart Grid System determines the need of aspects such as daily workflow, workforce management, asset management, call center philosophy, billing systematic etc. Smart meters can enhance the operation of SCADA system. As smart meter system provides several benefits such as efficient power system control and monitoring, operational decisions those are taken timely to minimize outages and losses. Particularly in micro-grids, smart meters can perform energy cost allocation, fault analysis, demand control and power quality analysis. Smart meters can schedule preventive maintenance, and support the operation of check meters for accurate billing. In addition, smart meters can detect the presence of unwanted harmonic component in current supplied from the de-centrally generated sources, which helps in identification and rectification of the source of the problem. Micro generators integrated into the distribution network must be registered, so that they are under the access and control of the smart meter system. Pattern recognition techniques can also be employed as part of the smart metering system in order to gain access to the performance information of the devices and financial incentives to the customer. Manual energy meter reading is a tedious, continuous and an expensive job. In conventional metering system, meter reader has to go and take the reading manually to generate and issue the bill. This whole process can be simplified with the help of a smart meter and proper communication mechanism. Increased energy security as well as energy saving drives the installation and adoption of smart meters. Smart meters encourage consumers to conserve energy by helping them maintain the quantity and cost of their energy consumption.

There are several models of smart meters proposed by several researchers. Of which a few models are discussed in this section. Power strip smart meters can be employed to monitor and control the appliances of customers. These meters provide data, identity and location of home appliances under operation. Generally, unbalanced loads cause fluctuations in the voltage profile of a distribution feeder located far-away from the substation. Smart meters can analyze and control these fluctuations in low voltage grids. Information about the load at the customer end and control of the maximum load demand helps utility companies in maintaining a flat voltage profile on the power supplied. Smart meters control the maximum load demand of a customer during peak load, and if any customer exceeds their limit, the supply of electricity will be disconnected to that customer. Present electricity grids are designed for large scale generation, centralized control, transmission, and distribution of electricity. As such, these devices and system might not be efficient for housing intermittent power generation sources such as wind turbines and PV panels without compromising on the overall power system stability. In addition, present grid systems are designed for unidirectional power flow. Integrating additional devices to the smart meter system enhances the capabilities of smart metering technology. Geographic Information System (GIS) can be integrated to the smart meter system in order to obtain specific information regarding the geographical location of a potential fault. Quick identification and rectification of faults and other issues that demand the attention of utility company reduces the overall power outage duration. In addition, smart meters reduce the average power outage duration to 4 to 6 minutes due to their fast response and rectification to power outages and faults. C. Claudio and R. Emilia proposed a smart total harmonic distortion (THD) meter that monitors the quality of the power Supplied from the grid and evaluates the THD. Particularly, when the distribution grid is integrated with wind turbines, occurrence of a fault similar to sudden disconnection of a generation unit or large load can alter the supply frequency. Smart meter system can quantify and maintain these parameters within desirable range even under high wind circumstances.



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In a smart meter system, a central control station at the utility company directs the smart meter at a customer premises to control the home appliances based on the preselected schedule for operation of devices that the customer opts for. Implementation of smart meters enables the utility companies to change or introduce new tariff schemes. Apart from the discussed advantages, other major arguments for introducing smart meters are the possibility of introducing new and dynamic tariff schemes that allow benefits for the end customer. This would enable the possibility to provide demand response by shifting loads which helps in flattening the energy usage profile. In addition to time of use tariff and real-time pricing schemes, introduction of pre-paid smart card system will allow utility companies to impose a reasonable tariff for the benefit of consumers. A smart card can be bought based on the consumer's load requirement and it can be recharged after consumption of the prepaid amount of energy. The prepaid smart card system reduces the possibility of billing irregularities. Smart meters can be designed such that they can control illegal consumers from bypassing or tampering with the meter. They can manage the denial of service, hijacking, hacking, and control introduction of malware into the metering system. Billing for the energy consumed by the customer is done with human intervention, which can be avoided using mobile agents to access the energy meters remotely. Each agent can be assigned a particular task for a particular location. Multiple mobile agents can be employed to overcome difficulties in accessing large amounts of data. C.D. Suriyakala and P.E. Sankaranarayanan proposed intelligent congestion controlling software that facilitates the operation of multiple mobile agents. V.V. Das proposed a new communication system for existing energy meters, in which, the billing software is integrated with the communication mechanism so that the utility company can access any energy meter in the network and generate the bill remotely.

HAN technology can integrate load control devices with the target load and equipment to display the data related to overall energy consumption and other power quality parameters. HAN technology supports plug-in hybrid electric vehicles (PHEVs) and distributed energy generation facilities in the communication network. Penetration rate of PHEVs is expected to grow very high in future, which implies great ease for numerous smart meter applications. Environmental savings because of utilizing the energy from renewable energy sources can be calibrated and displayed on smart meters. Displaying such information might encourage some customers to use PVs and wind energy technologies instead of consuming energy generated from fossil fuels based generation units. Energy web ecosystem proposed by D. Tuan allows consumers to monitor the parameters of distributed generation units and their load on grid. This might acquire attention of consumers and involve them in operation of the power systems while encouraging large scale integration of renewable energy sources.

III. INFERENCE ANALYSIS

In many developing countries, conventional energy meters are used for billing the energy consumed by customers. For ease of operation of the home appliances, monitoring the grid, improving the power quality, improved load sharing, detecting non-technical losses, and other implied advantages, smart meters are to be introduced in developing countries. Power utility companies worldwide lose about 20 billion dollars each year because of non-technical losses. In addition, growing non-technical losses because of theft and billing irregularities force the utility companies to implement a transparent and genuine metering system. However, deployment of smart grid and smart meter system involves huge budgets. It would be very difficult for utility companies to invest billions of dollars on an infrastructural upgrade that has no direct return on the investment. So, smart meters with minimum required, but essential features may be designed for implementation in countries with weaker economy. So, smart meters might not be implemented for luxury in operation, but they must be introduced in order to fight the basic problems that power utility companies and its customers face. Smart meters with great networking capability and advanced software tools are difficult to tamper and hack, which improves the distribution efficiency. Integration of smart meters enhances facilitation of decentralized generation and power storage devices. In the near future, total energy demand is expected to become double the current demand. In view of this situation, many developing countries do not have resources for the additional capacity addition. To fill this gap, apart from increasing the installed generation capacity, controlling the electricity theft and regularizing the existing electricity customers can manage the load within demands.



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A. Status of smart meters

In view of the advantages and applications, smart meter systems are being under large scale deployment worldwide. For instance, Austin Energy, one of the largest electric utility companies in the US with about 400,000 customers, has begun deploying smart meters to about 260,000 residential customers in 2008. Center point Energy, a Houston based utility company will have deployed smart meters to about 2 million customers by the year 2012 in the Houston-Metro and Galveston service locations. In US, targeted implementation of smart meters requires an investment of about \$50 billion. In North America, penetration rate of smart meters was about 6% in the year 2008 and is expected to reach 89% by 2012. By the year 2014, worldwide deployment of smart meters is expected to reach about 212 million units. In Italy, Enel, the third-largest energy provider in Europe has started deploying smart meters to about 27 million customers, which is the world's largest smart meter deployment project. In Canada, the government of Ontario has planned to deploy smart meters to about 800,000 consumers including both residential and small businesses by the year 2007.

In Korea, Korea Electric Power Corporation (KEPCO) started implementation of AMR based energy metering system for its industrial customers in 2000. Currently, these meters automatically transmit the energy consumption information from about 130,000 high voltage consumers. Using these smart metering systems, KEPCO provides value added services for about 55,000 of their low-voltage customers. In Australia, the Essential Services Commission has mandated installation of interval meters for 2.6 million electricity consumers in Victoria. In 2007, the Dutch government has proposed a policy that mandated the adoption of smart meters to 7 million residential consumers by the year 2013. Later, the government went back on its policy and left the decision about installation to the consumer's interest because of the privacy and security concerns.

IV. SIMULATION RESULTS

Simulation has become a very powerful tool for industrial application as well as in academics, nowadays. It is now essential for an electrical engineer to understand the concept of simulation to study the system or circuit behavior without damaging it. The tools for doing the simulation in various fields are available in the market for engineering professionals. Many industries are spending a considerable amount of time and money in doing simulation before manufacturing their product. In most of the research and development (R&D) work, the simulation plays a very important role. Without simulation it is quiet impossible to proceed further. It should be noted that in power electronics, computer simulation and a proof of concept hardware prototype in the laboratory are complimentary to each other. However computer simulation must not be considered as a substitute for hardware prototype. MATLAB provides extensive documentation, in both printed and online format, to help you learn about and use all of its features. If you are a new user, start with this Getting Started book. It covers all the primary MATLAB features at a high level, including many examples. The MATLAB online help provides task-oriented and reference information about MATLAB features. MATLAB documentation is also available in printed form and in PDF format. MATLAB online help is used to view the online documentation, by selecting MATLAB Help from the Help menu in MATLAB.

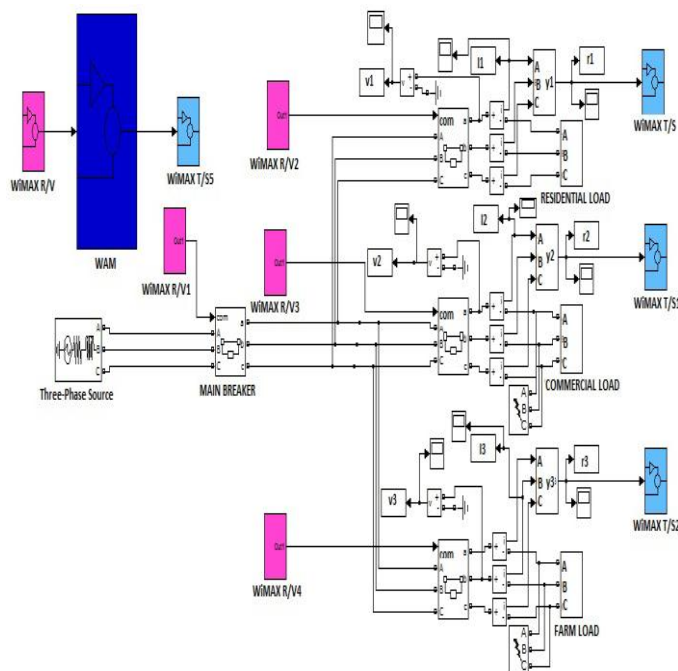


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Power system load protection SIMULINK diagram.

The complete scenario of the above mentioned smart grid architecture along with its flow charts is shown in Fig, which briefly explains the wide area power system load protection, consisting of three area loads and are controlled by a wide area manager (WAM) in MAT-LAB/SIMULINK. The system given below has primary protection on the main line along with transmitter and receiver. If the secondary protection on the distribution line fails or if the fault occurs on the main primary line of the generating station then it's the primary protection to trip all the loads. While intelligent protection is one which isolates only the faulty portion, which is also implemented in all loads. The below system also shows five areas which are industrial, commercial, farm, agricultural and residential along with their sub-systems which are explained in Fig.

V. CONCLUSION & FUTURE SCOPE

This project reviews several important aspects of smart metering. It explains the advantages of a smart meter system in a utility company as well as from the customer's point of view. Various potential communication networks for smart meter communication are presented in detail. In addition, several challenges, requirements and issues in design, development, deployment, and maintenance of smart meter systems are illustrated. Finally, the need for smart meters in developing countries and the status of worldwide installation of smart meters are discussed in detail.

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