DEVELOPED CONCEPTS OF SMART GRID

A Project report submitted in partial fulfillment of the
requirements for the degree of B. Tech in Electrical
Engineering By
SANDIPAN MUKHERJEE (11701617039)
SRIPARNA CHOWDHURY (11701617030)
SUPROBATH SARKAR (11701617023)

...
Under the supervision of
MR. NIJAM UDDIN MOLLA
ASSISTANT PROFESSOR
DEPARTMENT OF ELECTRICAL ENGINEERING

Department of Electrical Engineering
RCC INSTITUTE OF INFORMATION TECHNOLOGY
CANAL SOUTH ROAD, BELIAGHATA, KOLKATA – 700015,
WEST BENGAL
Maulana Abul Kalam Azad University of Technology
(MAKAUT)

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1. SANDIPAN MUKHERJEE (11701617039)

Sandipan Mukherjee

2. SRIPARNA CHOWDHURY (11701617030)

Sriparna Chowdhury

3. SUPROBATH SARKAR (11701617023)

Suprobath Sarkar

Name and Signature of the Students

RCC INSTITUTE OF INFORMATION TECHNOLOGY
GROUND FLOOR, NEW BUILDING,
CANAL SOUTH ROAD, BELIAGHATA, KOLKATA -700015 , WEST BENGAL

CERTIFICATE

To whom it may concern

This is to certify that the project work entitled **DEVELOPED CONCEPTS OF SMART GRID** is the bona fide work carried out by **SANDIPAN MUKHERJEE (11701617039), SRIPARNA CHOWDHURY (11701617030) & SUPROBATH SARKAR (11701617023)** students of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year **2020-21**, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and that this project has not been submitted previously for the award of any other degree, diploma or fellowship.

Nijam uddin molla.

____
Signature of the Guide

Name: MR. NIJAM UDDIN MOLLA

Designation: ASSISTANT PROFESSOR,
ELECTRICAL ENGINEERING

HoD, Dept. of EE
RCC Institute of Information Technology
Kolkata-700015

____
Signature of the HOD

Name: DR. DEBASISH MONDAL

Designation: ASSOCIATE PROFESSOR,
HEAD OF THE DEPARTMENT,
ELECTRICAL ENGINEERING, RCCIIT

____

Signature of the External Examiner

Name:

Designation:

ABSTRACT

Due to a significant increase in electricity consumption globally, governments have to look and to identify better, more efficient and effective alternatives and sustainable energy sources to meet this high demand. This becomes more and more important in the context of implementing modern approaches such as those that might be applied in cases of smart cities and cultural and creative communities.

Electricity can be produced based on conventional sources, but also on an emergent use of renewable sources. The electricity grid is usually designed as unidirectional. We consider that in case of smart cities and creative-innovative communities there is a need to implement mostly new smart grids that are bi-directional. This may allow and support the emergency of a new type of electricity user, called "prosumers", who produces electricity from renewable sources, next uses & shares them smartly within the smart grid and finally stores them.

A smart allocation and use of energy resources (mostly of the alternative one) can be facilitated based on the application of smart grid concept. Smart grid facilitates and improves communication and the flow of information regarding smart networks. Smart Grid is a technological transformation that illustrates a shift from a conventional electric grid, electro-mechanically controlled system, towards a smart, intelligent, and electronically controlled system. It may solve multiple issues like power failures and waste of energy. The smart energy-controlling devices installed within households from smart cities and creative-innovative communities facilitate an effective monitoring of energy usage through, for instance, a smart phone-based application.

The Smart Grid is not just about utilities and technologies; it is about providing the information and tools people need to make choices about how they use the energy. Many people already manage activities such as personal banking from their own home on computer. Thus it is not too difficult to imagine how people will soon manage their home electricity in a similar way.

A smart grid will enable an unprecedented increase of the level of consumer participation. A Smart Grid consists of millions of pieces and parts-controls, computers, power lines, and new technologies and equipment.

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Chapter 1: INTRODUCTION TO SMART GRID

Electric grid is considered to be the biggest engineering achievement of the 20th century. We built large power plants that generate electricity which is transported over high voltage transmission networks to long distances and distribute the electricity at low voltage to millions of customers. The power system consisting of limited number of power stations injecting electricity in to the grid and millions of customers drawing electricity from the grid remained as the basic model of electrification for over a century. However in the past few years we see the emergence of a distinct trend with proliferation of distributed generation resources which has put the electric grids on the threshold of a paradigm shift. After 100 years of focus on centralized power generation, the shift is now towards de-centralized generation.

In the recent past (from 2010), the picture of the grid has changed dramatically in many geographies. Some of the visible characteristics of this shift are:

- With the increasing share of generation resources being added at the distribution end, the traditional boundaries between generation, transmission and distribution are fast disappearing.

- With consumers becoming “prosumers”, the grid that is built for one-way flow of electricity is now experiencing bi-directional flow of electrons.

- With decreasing cost of energy storage solutions, there is already a debate on whether to invest in transmission or in storage – the choice between “Generation + Transmission + Distribution” AND “Distributed Generation + Storage + Distribution” is becoming real. This is even more relevant in regions where T&D losses are very high as with distributed generation there are fewer network losses.

- The nature of loads have changed – Incandescent lamps and induction motors that could accommodate frequency and voltage excursions comprised majority of the load on the grid in the past. The present day digital loads require quality power at constant frequency and voltage.

- Power purchase is moving from Volumetric Tariffs to Transanctive Tariffs as Inflexible Demand has become Price Responsive Demand.

- The “Merit Order Dispatch” has graduated towards an “Energy Efficient and Environmentally Responsible Dispatch” regime.

- Solar PV has already achieved grid parity in many parts of the globe which is about to unleash a rooftop PV revolution and with increasing quantum of wind power being added the power mix on the grid is changing more towards intermittent generation resources.

- Large fleets of Electric Vehicles that can be aggregated as virtual power plants which could support short term supply-demand balancing will make the grid even more dynamic and complex.

In the traditional electric grid, the ability to monitor power flows and control it in real-time is limited to high voltage networks which are equipped with automation systems. In the low voltage network, the power system operator has no visibility on who is consuming how much electricity when and where. In a smart grid equipped with sensors and smart meters which are connected to computers in the control room, it is possible to remotely monitor and control the flow of electricity in real time to every customer or even to every smart appliance inside a customer’s premise. So the evolving smart grid of the 21st century will be drastically different – the grid will soon emerge as the “grid of things” like how the internet is evolving as “internet of everything”.

1.1. CHANGING PICTURE OF THE ELECTRIC GRID

Some of the disruptive changes taking place in the power systems are described in detail below:

- **Integrated Grid**: Traditionally the power system was vertically divided in to three segments as Generation, Transmission and Distribution. In the recent years, increasingly larger share of new generation resources such as rooftop PV, micro-wind turbines, energy storage devices (batteries and electric cars etc) are being connected to the low voltage grid. This is leading to the fast disappearance of the traditional boundaries between generation, transmission and distribution. It is a very disruptive trend for electric utilities as their organizational structures and functions are also segregated in to Generation, Transmission and Distribution silos. Traditionally all generation from the power plants flowed in to the transmission department which accounted for total receipts from generation. With rooftop PVs connected at customer premises to the distribution grid on a net-metering scheme which department of the utility will account for the total monthly generation and energy inputs, energy balance etc. Similarly, the System Operations group forecast the demand and generation department will schedule the available plant capacity for next day. With distributed generation assuming larger share in the energy mix, there is a need for forecasting potential generation from the distributed resources connected to the grid at customer premises in order to accurately schedule and dispatch. But neither the customers who own these resources have any capability nor the distribution department of the utility which deal with this segment of the grid has any expertise and lastly but not the least the generation department has no visibility of distributed generation.

In order to manage a grid with distributed generation resources connected at all voltage levels in the grid, utilities need to invent new organizational structures, new skills and operating rules which will require new investments. Management and operation of the evolving integrated grids are going to be major challenge in the transitional term.

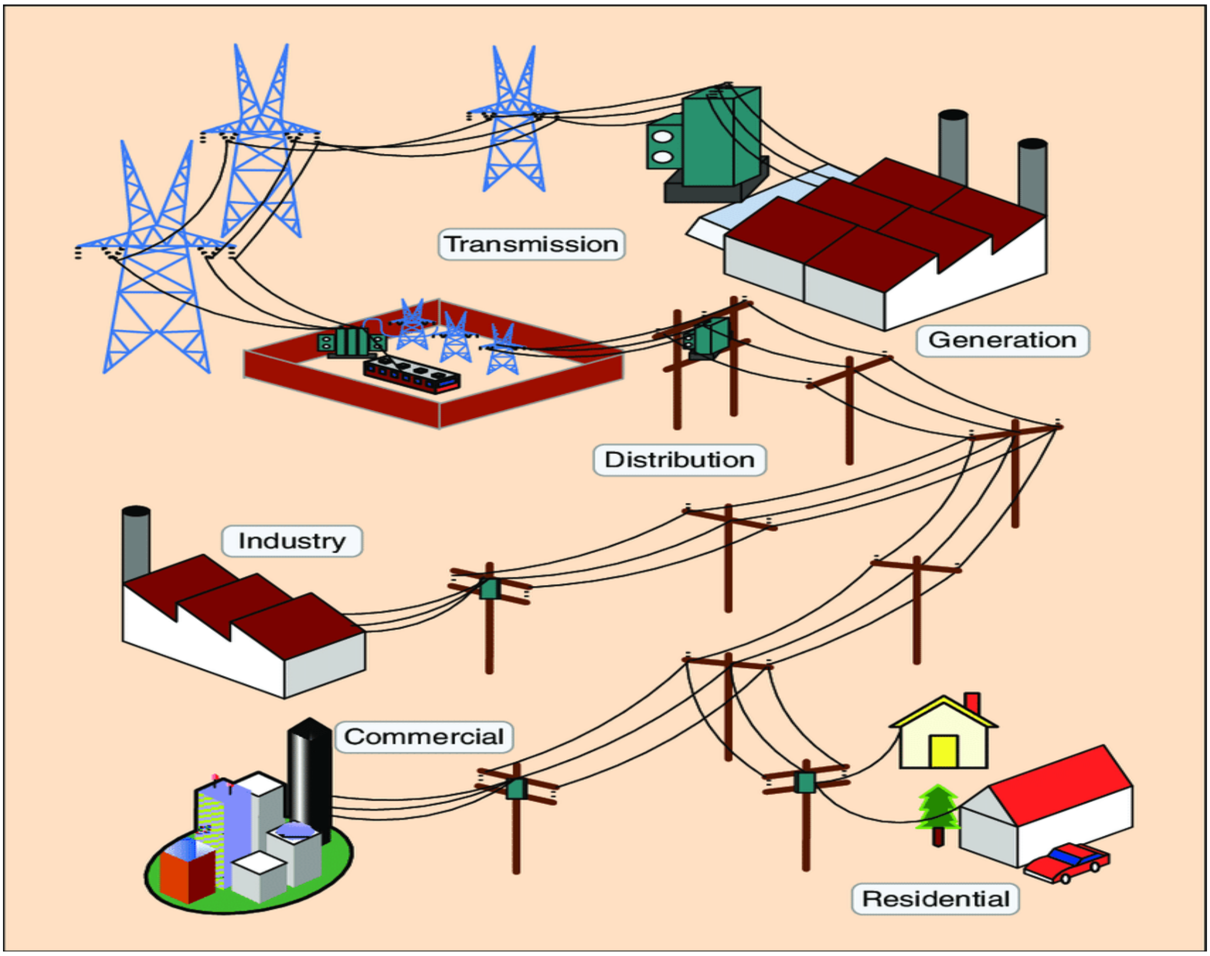


Figure 1.1: Typical traditional electric Grid

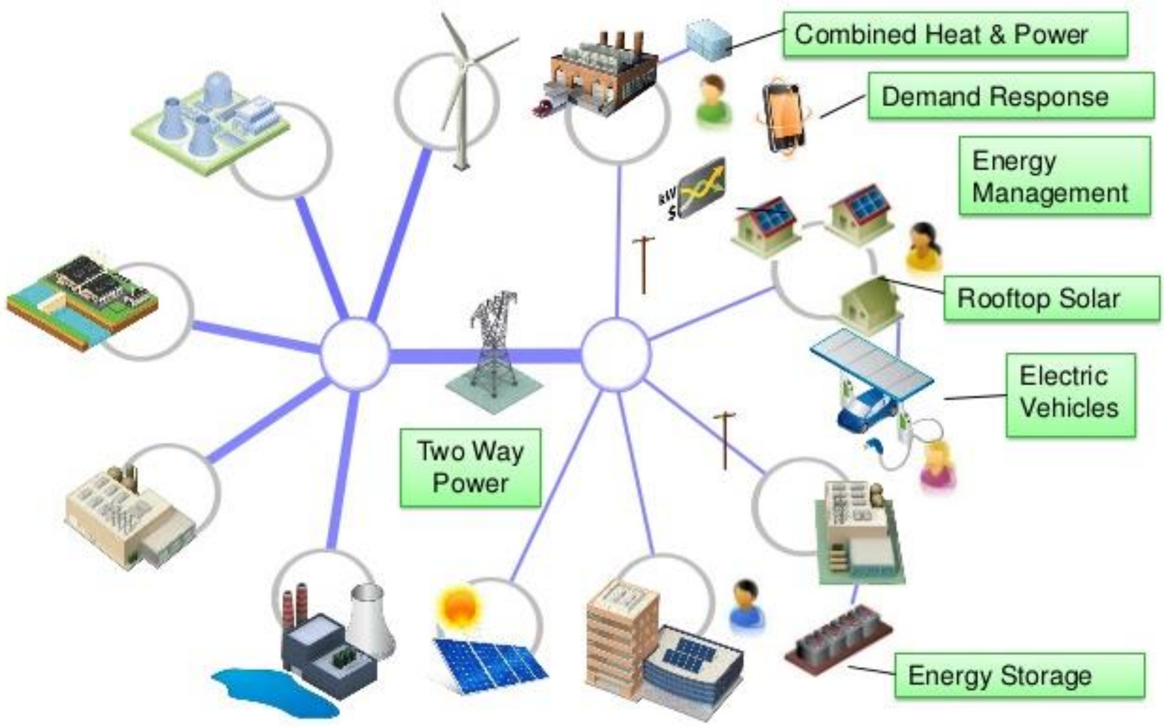


Figure 1.2: Emerging Integrated Grid

- **Prosumers**: The existing grid is designed for one way flow of electrons from generating stations to loads at the customer premises. And it was operated in that fashion for over a century. All equipment, systems, processes and operating procedures are designed to facilitate this one-way flow of electricity. However, now with rooftop PV or Micro Wind Turbines on customer premises being connected to the grid, a customer can inject electricity in to the grid that the utility can sell to any customer on the network. So the traditional customer who was only a buyer of electricity has become a producer and a consumer – “prosumer” now. This again brings out both engineering challenges as well as business process challenges. In engineering terms it need to be assessed how much “reverse power flow” from a customer premises can be accommodated in the low voltage grid; and in terms of business challenges, the utility need to put in place new/smart metering and control systems as well as policies for accounting and payment mechanisms. Utility need to constantly evaluate the capacity of the last mile network before approving connectivity for rooftop PV systems which require network models and load flow studies. Yet another challenge for utilities!

- **Transmission v/s Energy Storage**: A host of energy storage technologies are fast approaching commercialization and already MW-scale lithium ion and Sodium Sulphur (NaS) batteries are commercially deployed for certain grid applications. In many geographies, building transmission lines has been a herculean task as people dislike high voltage transmission lines passing through their habitations. In USA and several other countries, it takes well over a decade to establish the right of way for a high voltage transmission line and the cost of right of way is often higher than the actual line construction cost. In the emerging paradigm of distributed generation coupled with energy storage, utilities could avoid bringing high voltage transmission lines to congested urban areas or expensive neighbour hoods. In this scenario, large capacity battery storages (other storage technologies may also be relevant according locational considerations) and distributed generation can be designed to service the local load.

This model of “distributed generation + energy storage + distribution /consumption” is a challenge to the traditional model of “generation + transmission + distribution”. In the distributed generation model, network losses are also lower compared to the traditional model. This is highly relevant in regions with high transmission and distribution losses. So we can expect to see in the coming years, many regions and pockets opting for distributed generation and storage instead of bringing electricity through high voltage transmission lines and building substations and distributing it.

- **Changing nature of Loads**: Incandescent lamps and induction motors comprised of majority of the loads in the traditional grid. Both of them could accommodate frequency and voltage excursions to certain extent. If the voltage drops even by 50% still an incandescent bulb could burn with lower luminosity. But in the present day digital word, majority of the new loads require quality power at constant frequency and voltage. In the traditional grid, majority of the generation resources (large hydro and thermal stations) could accommodate load fluctuations to certain extent and could keep the voltage and frequency constant; but in the emerging grid with larger share of renewable generation resources which are intermittent, sudden drop in generation can take place any time and balancing the grid is becoming a nightmare for power system operators. When the share of renewables exceed the limit of spinning reserve maintained in a power system, it can cause serious fluctuations anytime. Hence we are now exploring demand-side controls. When sudden loss of generation happens, utility should be able to switch off certain loads (water pumping, air conditioning etc) at customer premises so that supply-demand equilibrium is achieved to ensure grid stability. The changes in the nature of loads have further complicated this grid balancing.

- **Electric Vehicles**: Electric Vehicles (EVs) are becoming an integral part of the electric grid. The globally accepted model for low carbon development is "electrification of all human activities including transportation and agriculture to the extent possible".

In India, Government has launched a National Mission on Electric Mobility in 2013 with the target of 2 million four wheelers and 4-5 million two wheelers by 2020. Although this mission was moving slowly owing to a variety of teething issues including availability of charging stations, now, Government of India has accorded priority for faster roll out of EVs to address the pollution in cities reaching dangerous levels.

EVs are big loads on the grids as car batteries are 10kWh to 100kWh whereas bus batteries can be from 100kWh to 300kWh. These will have unprecedented impacts on the distribution grid as it is not a stationary load for which the grid up-gradation can be made at any particular location. EVs may be charged from different locations with in a city based on where the EV owner is driving on a particular day. Huge investments are required to setup charging stations city wide as well as to upgrade the capacity of transformers and cables to accommodate the new loads from EVs. Even if a separate commercial tariff is applied on EV charging stations, cost recovery from necessary grid upgrades will not be viable. EV batteries can act as an energy storage device which can pump electricity back to the grid. Large fleets of EVs connected to the grid can be aggregated as virtual power plants which could support short term supply-demand balancing. This could help the distribution grid to tackle the intermittency of rooftop PV generation at street level.

All the above factors are going to affect the grid operations in a profound manner in the coming days leading to a paradigm shift. So the evolving 21st Century Grids are going to be drastically different than the one that we are used to for over a century.

1.2. NEW TECHNOLOGIES

Several emerging technologies are expected to be commercially viable before the end of this decade which include:

- Energy storage systems
- New generation technologies:
  - I. Next Generation Solar Cells
  - II. Wave Energy
  - III. Next Generation Wind Turbine

IV. Waste to Energy

- Solid State Transformer (SST)
- Micro Grids and DC Grids
- V2G Technologies
- Hybrid Concepts (Solar & Wind)

1.2.1. ENERGY STORAGE SYSTEMS (ESS)

During the past two decades billions of dollars have been invested in research, development and deployment (RD&D) of energy storage systems. Several types of energy storage systems are under development. Some of the technologies shown promises are:

- Batteries: Different battery chemistries are being tried and tested for different applications – Sodium Sulphur (NaS) batteries, Lithium-Ion batteries, Flow batteries, Advanced Lead Acid batteries etc.
- Compressed Air Energy Storage
- Flywheels
- Super Capacitors

1.2.2. NEW GENERATION TECHNOLOGIES

Some of the promising new generation technologies are briefly mentioned here:

I. NEXT GENERATION SOLAR CELLS:

The solar cells made of crystalline silicone had cell efficiencies below 15% in the 1970s has now improved to 24% by 2014. Yet most commercially available cells are below 20% efficiency with panels/module efficiency of 16-18%. The next generation cells in laboratories have efficiencies above 30% and expected to be commercially available by turn of this decade. Similarly the efficiency gains in solar inverters has also been very marginal in the past decades. Yet the prices of PV modules have been falling constantly at much greater pace as can be seen from Figure 1.5. During 2009-14 period the PV module prices fell by 75%. The deployment of solar PV has grown in geometrical proportions from 2.6 GW in 2004 to 177 GW by 2014.

According to Prof. Ray Kurzweil, solar PV has been doubling its share every two years for the past 25 years.

In 2012 solar PV was producing 0.5% of world's total energy supply which has now doubled twice in 4 years to reach 2% - another 6 doublings or 12 years only to make it 100% theoretically – yet we will be using only 1/10,000 of the sun light we get on earth!

II. WAVE ENERGY:

Wave energy from the ocean waves has been a slow starter for several decades. The traditional approaches to tapping the energy from wave revolved around water turbines on floating buoys. The main challenge was to create regular output of energy from ocean swells which are 5-10 seconds apart. Other challenges included materials that can survive the high corrosion of sea water and weather shocks from high waves and storms. In the last 5-6 years we have witnessed few ground breaking developments. Particularly the designs and pilot projects of Wavestar Energy (Denmark), Eco Wave Power (Israel) and Carnegie Wave Energy (Australia) are worth mentioning. Wavestar commissioned the test section of a 600kW wave energy unit at Roshage Pier near Hansthlom in Denmark in 2009 and is connected to the Danish grid since February 2010. This test section with a capacity of 100kW has two floats of 5 meter diameter which are installed in sea depths of 5-8 meters and wave heights of 6 meters. The 600kW commercial model will have 20 floats of 6 meter diameter which will be installed in sea depths of 10-20 meters and wave heights of 8 meters. The design involves kinetic energy harvesters called floats which move up and down with the kinetic

III. NEXT GENERATION WIND TURBINES:

Next generation wind turbines with Multiple Rotors and Floating Wind Turbines are already in trial operations and expected to revolutionise the wind energy domain. These inventions are expected to be commercially viable by end of this decade.

Globally, while there has been much written about the precipitous drop in the price of solar PV, less has been written about the drop in wind prices. While the recent record low prices for wind in auctions in Peru, Morocco and Mexico will not be replicable everywhere in the short term, we can expect prices to continue to come down, and unlike solar, they were already low to begin with. Although it may seem like wind and solar are in a 'race' to get the lowest cost, as will be seen below, at a certain point, that is no longer the question. There is plenty of room for both technologies in most systems for the foreseeable future, and the local resource, demand curve and system characteristics will determine the relative amounts of each technology that are optimal in each system.

IV. <u>WASTE TO ENERGY:</u>

Power generation from waste, particularly municipal solid waste (MSW) is attracting acceptance around the world. With ever increasing urbanization, average daily generation of MSW is about 1kg per person and it keep increasing with GDP growth and at a much higher level of GDP (>US$5000 per capita) that growth of waste generation gets decoupled from GDP growth – otherwise the trend has been more prosperity, more waste! Developed world addressed the problem of MSW with segregation of waste in to different categories such as recyclable, bio-degradable, non-degradable etc. In most developing countries the practice been to dump all kinds of waste together and rag pickers sort out what is valuable for them and the rest is used as landfill.

Instilling a culture of segregation of waste in to different categories at user end look highly impractical in India (and most other developing countries) owing to a variety of factors. With latest incineration technologies, the MSW can be efficiently burnt to produce electricity and industrial heat. India did several experiments with waste-to-energy plants in the last 3-4 decades, starting with a pilot plant in Delhi in the 1980s which never functioned. A modern design plant constructed at Okhla in the 2000s again has technical issues. A more recent plant was built in Ghazipur (on the outskirts of Delhi) recently by IL&FS. Even this plant has technical issues.

1.2.3. SOLID STATE TRANSFORMER (SST)

This is another interesting technology under development. First patent for Solid State Transformer (SST) was filed in 1980s but owing to availability of suitable materials the technology remained in the labs only.

Now with breakthroughs in material sciences, SST is fast approaching commercialization. An SST can take both AC and DC inputs as well as give AC and DC outputs; and enable bi-directional power-flows. It can also improve power quality – reactive compensation and harmonic filtering. SST will be only 1% in size and weight of a comparable distribution transformer. SSTs of 11-15kV ratings are expected to be commercialized in next 5-7 years. This will radically change the electric grid where AC and DC will merge.

1.2.4 MICROGRIDS AND DC GRIDS

Micro grid is top on the list of smart grid technologies in the developed countries - reason: critical infrastructure (airports, military bases, hospitals etc) have no stand-by power supply systems. At the heart of a micro grid is an intelligent control centre that can island the local grid (micro grid) from the utility grid and can control and curtail (if required) the load within that micro grid to match the emergency demand with the available generation and storage facilities.

Smart micro grids that can island from the grid is considered as a fall back safety net against cyber attacks. While it is easy for an attacker to target the control centre of a large utility, it will be impossible to attack thousands of micro grids with each of it having its own control centres. In case of an attack and breakdown of the utility control centre, the micro grids can island from the main grid and can serve critical loads till main grid is back in operation.

Today the electricity generated from solar PV is converted from DC to AC and distributed which is again converted to DC for the digital appliances such as computers, LED lights, LCD/LED TVs, flat screen monitors, security cameras, cell phones etc. Almost half the energy generated is lost in these two conversions (DC to AC and again AC to DC). As the share of DC generation and DC consumption both are increasing steadily, it makes business sense to have DC distribution system in parallel to AC distribution in offices and homes. Already in certain hotels and office buildings there is 5V DC distribution system on which USB connections are provided. Several teams around the world are working on standards for DC Grids. In India, ISGF facilitated the creation of a Low Voltage Direct Current (LVDC) Forum in 2013 which has been adopted by IEEE. This LVDC Forum has selected 48V DC for indoor applications in India and standards for the same has been issued by Bureau of Indian Standards (BIS) in November 2017 (IS 16711:2017 - 48 V ELVDC Distribution Systems – Guidelines). DC Grids could also facilitate reliable rural electrification with solar PV, batteries and DC appliances – LED lights, Brushless DC (BLDC) motors, LED TVs etc.

1.2.5. V2G TECHNOLOGIES

The Electric Vehicle (EV) batteries could act both as load as well as generation resources. Millions of EVs connected to the grid can be aggregated as virtual power plants (VPP) and support_the grid during supply demand imbalances. This is again becoming increasingly relevant with proliferation of rooftop PV which is intermittent. Vehicle to Grid (V2G) technologies are ready for commercialization.

However EV manufacturers are reluctant to facilitate V2G functionality in EVs owing to warranty on the batteries. The V2G trials in past few years in several research centres indicate that if the depth of discharge of the EV battery is limited with in specified limits during V2G operations, there will be little or no impacts on the battery life. We expect V2G to play a major role in the 21st century grids with major share of renewable generation resources.

1.2.6. HYBRID CONCEPTS

An ideal wind-solar hybrid system is one that generates electrical energy by using an optimal combination of wind turbines and solar photovoltaic (PV) panels, along with shared infrastructure that allows for greater economic and social utilisation of both the resources. Primarily, there are three types of wind-solar hybrids – smalls scale hybrids, co-located hybrids and true hybrids.

Small-scale hybrids include various small-scale watt-class and kilowatt class projects, which are deployed for off-grid renewable energy-based generation.

A co-located hybrid comprises two independent generating systems located in close proximity to each other. This allows them to share large transmission equipment such as a common substation and grid infrastructure.

Meanwhile, in a true hybrid system, the two technologies, wind and solar, work in tandem and use common components to produce a single electricity output more efficiently. In such systems, the output of the entire network is capped at rated output of the bigger system.

1.3. WHAT IS SMART GRID

The smart grid is the evolving electric grid with advanced automation, control, IT and IOT systems that enables real-time monitoring and control of power flows from sources of generation to sources of consumption. A set of technologies enable these functionalities and help manage electricity demand in a sustainable, reliable and economic manner. Smart grids can provide consumers with real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers exercise choices in terms of usage of energy.

“Smart grid is an electricity grid with communication, automation and IT systems that enable real time monitoring and control of bi-directional power flows and information flows from points of generation to
points of consumption at the appliances level.

SMART GRID - ANALOGY WITH HUMAN BRAIN

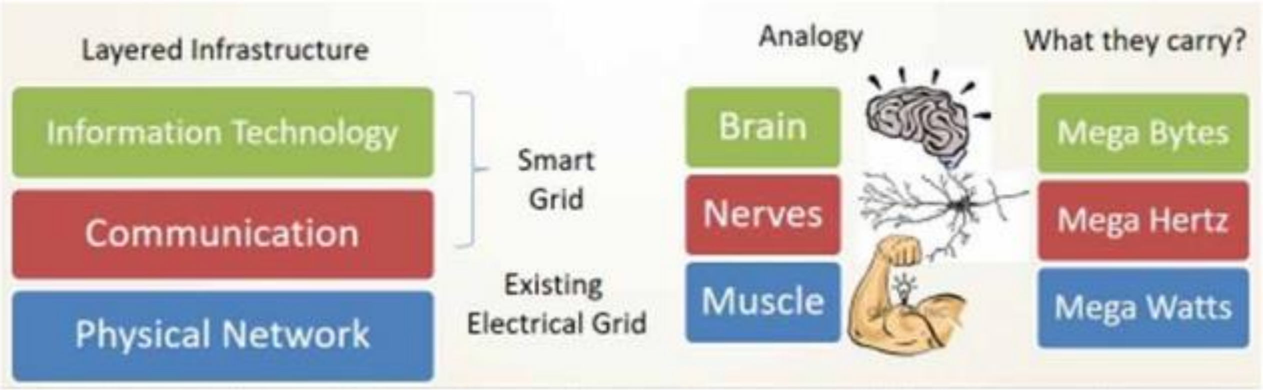


Figure 1.2: Smart grid – Analogy with human brain

The picture above depicts the analogy of a smart grid with human body. Key components to make an existing grid smarter is to have two way communicable sensors to monitor and control power flows in real time and IT systems to process the data captured and issue commands and alerts.

1.4. DRIVERS FOR SMART GRID:

Since the early 21st century, advancement in electronic communication technology is being used to resolve the limitations and costs of the electrical grid. Technological limitations on metering no longer force peak power prices to be averaged out and passed on to all consumers equally.
Key drivers for smart grids for different stakeholders in the Indian context are:

I. UTILITIES:

- Reduction in Aggregate Technical and Commercial (AT&C) losses.
- Peak load management – multiple options from direct load control to price incentives to customers.
- Reduction in power purchase cost.
- Better asset management.
- Increased grid visibility.
- Self-healing grid- faster restoration of electricity after fault or disturbances.
- Renewable energy integration.

II. CUSTOMERS:

- 24x7 Powers for All.
- Improved reliability of supply to all customers – no power cuts, no more DG sets and inverters for back up.
- Improved quality of supply – no more voltage stabilizers.
- User friendly and transparent interface with utilities.
- Increased choice for customers – including green power.
- . “Prosumer” enablement – can produce own electricity and consume or sell.
- Options to save money by shifting loads from peak hours to off-peak periods.

III. GOVERNMENTS AND REGULATORS:

- Satisfied customers.
- Financially sound utilities.
- Tariff neutral system upgrade and modernization.
- Reduction in emission intensity.

Chapter 2: KEY FUNCTIONALITIES AND COMPONENTS OF SMART GRIDS

Following are the key functionalities and components of smart grids:

- Supervisory Control and Data Acquisition (SCADA) and Energy Management Systems (EMS) at
  Transmission level and SCADA and Distribution Management Systems (DMS) at distribution level
- Distribution Automation
- Substation Automation
- Advanced Metering Infrastructure (AMI)
- Geographical Information System (GIS) Map
- Peak Load and Power Quality Management
- Outage Management System
- Distribution Transformer Monitoring System
- Mobile Crew Management System
- Enterprise IT Systems
- Application Integration
- Wide Area Monitoring Systems (WAMS)
- Smart Street Lights (with noise and pollution sensors)
- Energy Storage
- Electric Vehicles
- Distributed Energy Resources and Renewable Energy Integration
- Common Command Control Room
- Customer Engagement
- Social Media for Utility
- Cyber Security

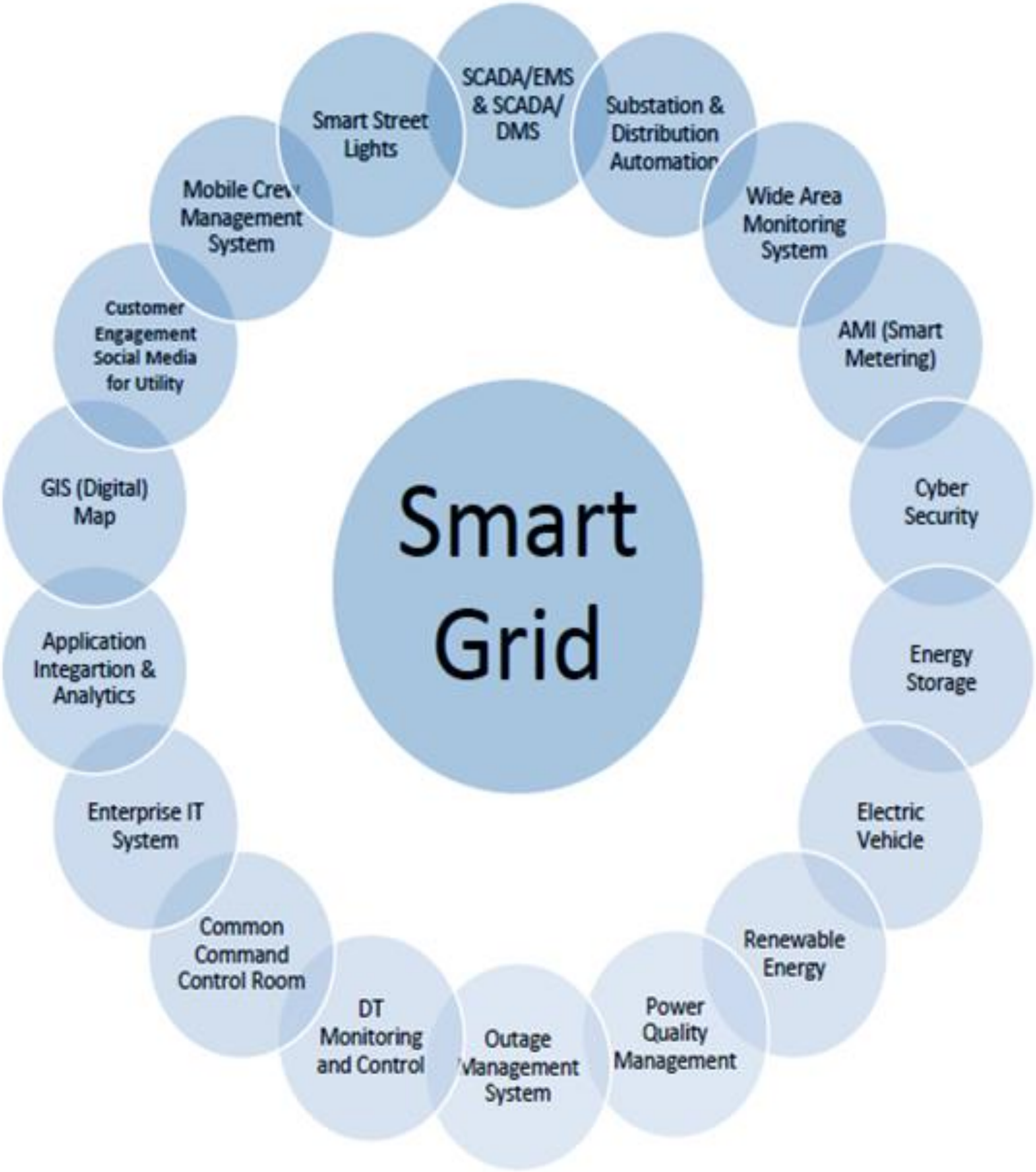


Figure 2.1: Smart Grid Functionalities

The Smart Grid will likely employ a variety of communications technologies, many of which will have multiple applications. A particular technology's characteristics can best be reviewed in the context of where it may be used within the Smart Grid. Based on survey it is determined that there are six functional categories into which most, if not all, Smart Grid applications fall: advanced metering infrastructure, demand response, wide-area situational awareness, distributed energy resources and storage, electric transportation, and distribution grid management.

2.1. SMART GRID COMPONENTS FOR TRANSMISSION SYSTEM

2.1.1. SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM (SCADA):

Extra High Voltage (EHV) transmission network (110kV and above) was traditionally smart or intelligent with automation and real-time communication systems integrated for system operations. The load dispatch centers or control centers of EHV systems have Supervisory Control and Data Acquisition (SCADA) and Energy Management System (EMS) which helps monitor and control the power flows in real-time. In order to facilitate the functioning of SCADA/ EMS, the EHV network has dedicated communication systems between the control center and all generating stations and EHV Substations. From the control center, the operators can control generation as well as loads at the substations.

<u>SCADA OVERVIEW:</u>

SCADA refers to a system that collects data from various sensors at a factory, power plant, transmission system or in other remote locations and then sends this data to a central computer which then manages and controls the system. SCADA has the ability to monitor an entire system in real time and can run with relatively little human intervention. This is facilitated by data acquisitions from various sensors and meters.

SCADA collects all the information related to the operation of the grid from various sensors placed in different points and sends those data to master computer and data such collected will be analyzed in real time.

An SCADA system should have all of the infrastructure elements to support the multifaceted nature of distribution automation and the higher level applications of a DMS. A smart grid SCADA system’s main function is in assisting of distributed generation operations, alarming, telemetry, event logging recording, and remote control of outstation field equipment.

A modern SCADA system should support the engineering planning and budgeting functions by providing entrance to power system data without having to have procurement of an operational workstation. Historically, SCADA systems have been known for their surplus support for the importation, and more importantly, the exporting of power system data values. The evolving changes in recent power system operational needs demand a distributed control center that is decentralized, flexible, integrated, and opened. Present-day control centers are moving in that direction with varying degrees of success [5-10]. The SCADA technologies utilized in today's control centers to enable them to be more distributed are briefly reviewed. With the rising of the Internet age, the trend in information and communication technologies is moving toward micro grid and grid computing and web services, or micro grid services. A micro grid service-based future control center is specified.

Renewable energy systems have gained more popularity over the years because of the incessant failure and general unreliability of the power grids and micro grids.

Renewable energy forms a major source of energy in distributed generation systems; the energy generated can be integrated into the existing power grid or it can be used for domestic micro grid consumption. Even though renewable sources are in abundance and inexhaustible, their occurrence at a quantity enough for power generation at all times is not guaranteed because of variations in climatic conditions, thereby jeopardizing the chances of relying on them as the only source of energy. This prompted research and development in the areas of power generation and storage of energy in order to increase the efficiency of such systems. Such researchers have seen a drastic reduction in the cost of systems, which convert renewable energy into electrical energy. The increasing size of PV power plants all over the world has made their operation and maintenance (O&M) tasks much more complex than they were a few years ago. Many of these PV plants are equipped with advanced SCADA systems in order to collect the necessary information to assess their performance, such as meteorological data, information from the PV farm field, PV inverters, etc.

However, the great amount of data provided those SCADA systems makes necessary the development of new procedures capable of handling all this data and providing accurate information about the performance, failures, long-term trends etc. In the literature available, there is a lack of information and experiences in the automatic failures detection and performance evaluation of large-scale solar PV plants.

SCADA systems are essentially Process Control Systems (PCS) that are used for gathering, monitoring, and analyzing real-time environmental data from a simple residential building or a complex large scale PV or wind far power plant. PCSs are designed for micro grid automation or power distribution systems based on a predetermined set of data and conditions, such as generated/consumed energy or power grid management. Some PCSs consist of one or more remote terminal units (RTUs) and/or Programmable Logic Controllers (PLC) connected to any number of actuators and sensors, which relay data to a master data collective device for analysis.

SCADA systems are composed of the following components:

COMPONENTS OF SCADA:

1. Outstations hardware: state of charge (SOC), Current transformer CT, Voltage transformer VT, fuel valves, conveyors, and Circuit breakers CB that can be controlled locally or remotely.
2. Local substations processors: which collect data from the site’s instruments and hardware equipments. This includes the Remote Terminal Unit (RTU), Programmable Logic Controller (PLC). Intelligent Electronic Device (IED) such as digital relays and digital meters. The local processor will be responsible for dozens of analog and digital inputs/outputs from IEDs and switchgear equipment.
3. Digital Instrument: It is usually installed in the field or in a facility that sense conditions such as current, voltage, irradiance, temperature, pressure, wind speed, and flow rate.
4. Communications devices: It could be either short-range communications or Long-range communications. The short-range communications are installed between local RTUs, instruments, and operating equipment These are relatively short distance cables or wireless connections carry digital and analog signals using electrical properties such as voltage and current or using other settled industrial communications protocols. The Long-range communications are installed between local processors RTU/PLC and host serves. This communication typically is using methods such as leased telephone lines, microwave, satellite, frame relay network, and cellular packet data.
5. Host computers/servers: Host computers, like Data acquisition server DAC, engineering/operation workstations. It acts as the central point of monitoring and control. They will be in the control room or master station. The operation workstation is where an engineer or operator can supervise the process, as well as receive system alarms, review data, and exercise remote control.

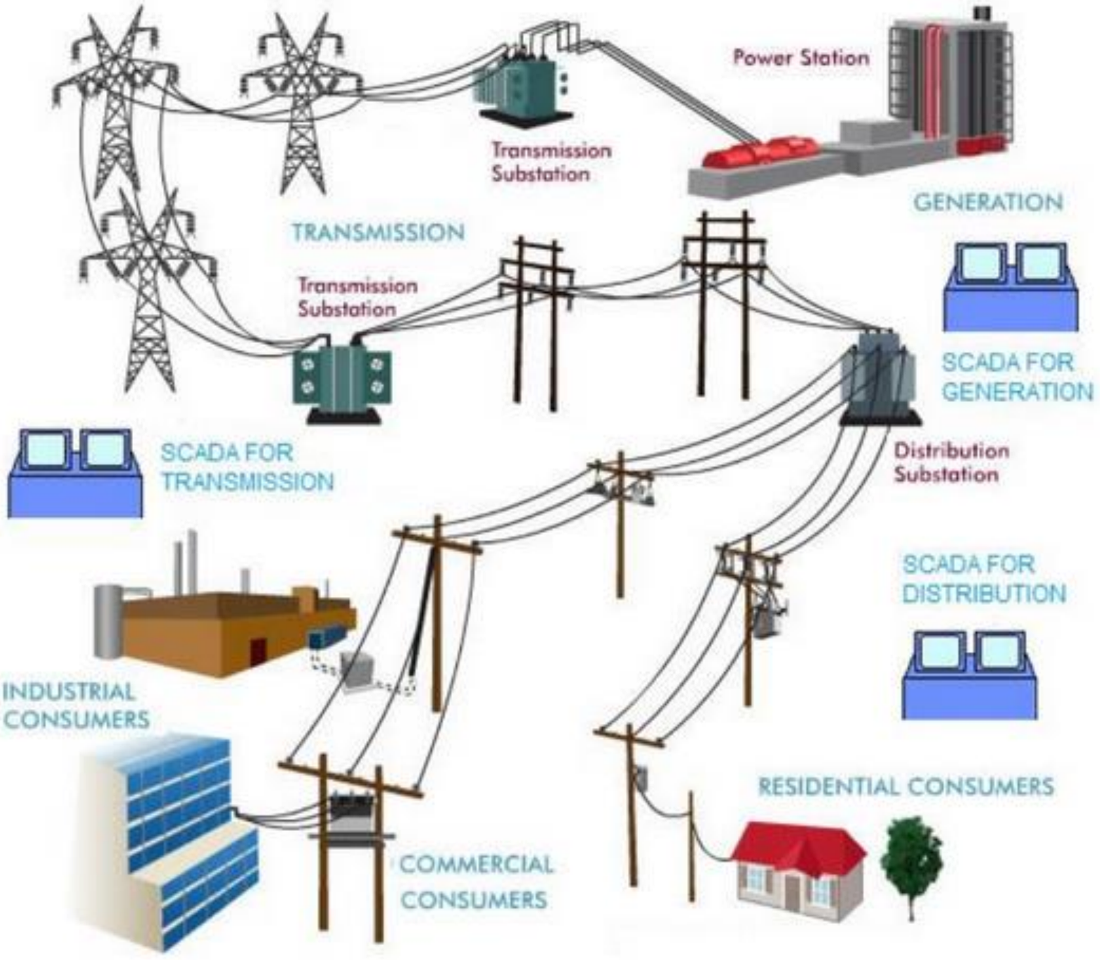


Figure 2.2: SCADA for electrical power industry

With the progress in the digital computing area, the integration of digital intelligent electronics devices play a substantial role in the industrial manufacturing, wherein manufacturing factory utilize PLCs/RTUs to control the devices, and develop distributed and large complicated systems in which intelligent systems are part of the manufacturing plant control systems.

Most often, an SCADA system will monitor and make slight changes to function optimally; SCADA systems are considered closed loop control systems and operate with comparatively little human interference. One of the key processes of SCADA is the ability to supervise a whole system in real time environment. This is simplified by data acquisitions including meter reading, checking statuses of sensors, etc. that are communicated at regular small time intervals depending on the system. An SCADA system as an industrial automation system is used to acquire data from instruments and sensors located at remote sites and to receive/transmit data at master station central site for either controlling or monitoring purpose. The collected data from sensors and instruments is usually viewed on one or more SCADA host computers that are located at the central site. Based on the data received from the remote substations, automated or operator-driven supervisory commands can be pushed to remote substation control devices, which are usually referred to as outstation or field devices.

COMMUNICATION SYSTEM FOR SCADA:

SCADA require dedicated and reliable communication systems between various field devices (RTU) and the Master Station. Traditionally electric utilities used Power Line Carrier (PLC) communications in the past. The analog PLC could support limited bandwidth. PLC based SCADA are still in operation in many places.

Other communication options for SCADA are:

- Fiber Optic Cables- Optic Fiber Ground Wire (OPGW) can be used as earth wire on EHV lines
- Microwave Communication
- Satellite Communication
- Public Telecom Network can also be leveraged by leasing dedicated communication links from telecom operators (MPLS networks)

MAJOR FUNCTIONS OF SCADA:

- Acquisition from RTUs and storage of data in online database
- Processing of data for converting the raw values to engineering values and checking quality
- Historical data storage and retrieval
- Sequence of events recording, reconstruction and replay of events
- Protective and informative tagging of power system devices
- State estimation and load management
- Generalized calculations – for adding and removing operator’s defined calculations
- Providing user interface to operators
- Inter control center communication
- Real time and historical trends
- SCADA works in combination with Energy Management System.

ADVANTAGES AND DISADVANTAGES OF SCADA:

Advantages

- Flexible, simple, reliable
- Increased efficiency - less manpower
- Self-checking and reliable

Disadvantages

- High initial capital investment
- Lack of trained persons in utilities
- False alarms at times
- Cyber Security threat

2.1.2. ENERGY MANAGEMENT SYSTEM (EMS):

Energy Management System (EMS) is a tool used by grid operators for monitoring, controlling and to optimize the characteristics of generating/transmission systems.

FUNCTIONS OF EMS:

- Real-time network analysis and contingency analysis
- Study functions like power flow, power factor, security enhancement etc
- Real-time generation functions allows the operator to monitor, analyze and control real-time generation and automatic generation control (AGC)
- Economic dispatch directs the dispatcher to set economic base point for a set of units selected.
- Reserve monitoring for calculating spinning reserve, operating reserve and regulating reserve
- Production costing calculates the current cost of generating power of online units
- Load forecasting
- Transaction scheduling.

ADVANCED FUNCTIONALITIES:

- Enhanced grid reliability
- Increased grid capacity
- Advanced contingency awareness
- Decreased system support cost
- Secure system that meets regulatory requirements

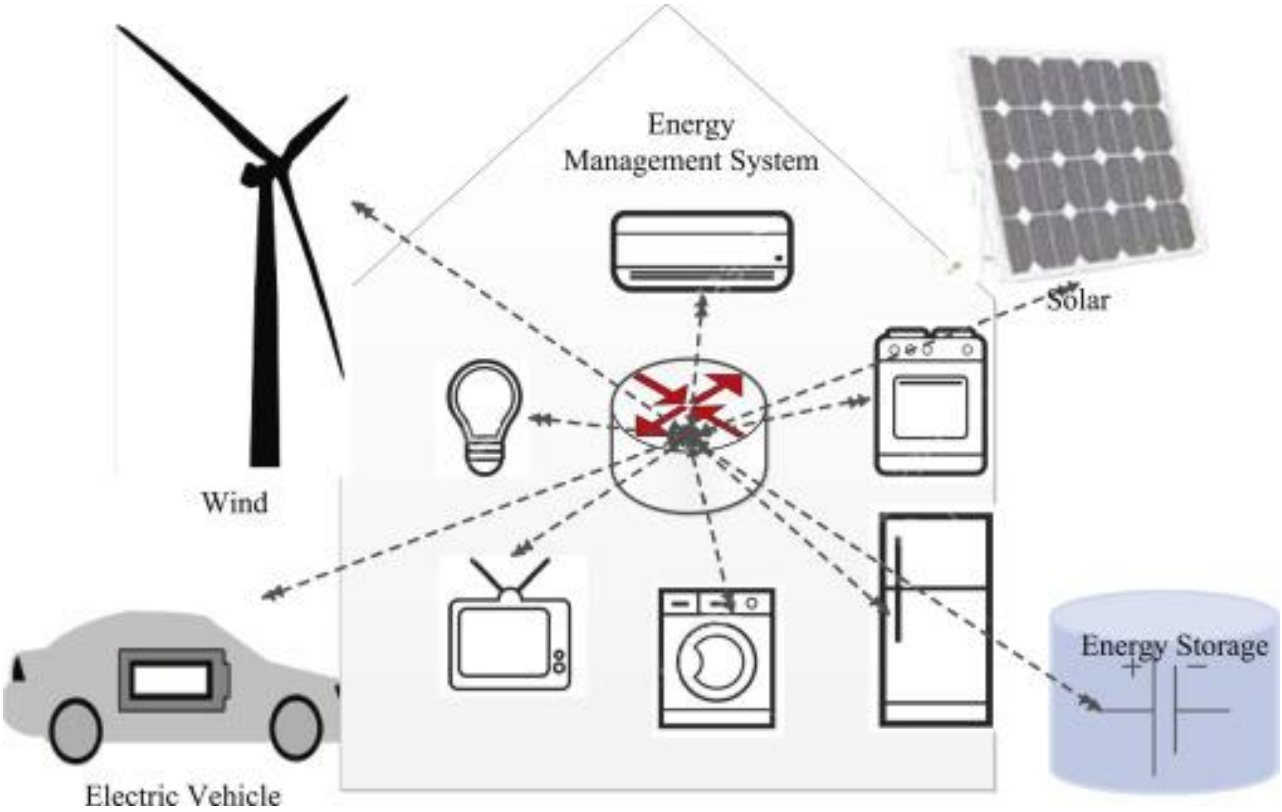


Figure 2.3: Energy Management System

EMS works along with a SCADA system and EMS helps the control room operator to manage the transmission system operation efficiently and economically.

2.1.3. WIDE AREA MONITORING SYSTEM (WAMS):

With the deployment of Phasor Measurement Units (PMU), a fast and accurate measurement of grid equipment is possible. Real-time wide area monitoring applications have strict latency requirements in the range of 100 milliseconds to 5 seconds. A fast communication infrastructure is needed for handling the huge amounts of data from PMUs. Smart grid applications are designed to exploit this high through put real-time measurements. While SCADA data is collected in 1- 5 seconds, PMU data is captured in milliseconds. SCADA data has no timestamps but PMU data is accurate time stamped. While SCADA is like an X-Ray, PMU Data is like an MRI scan of the grid.

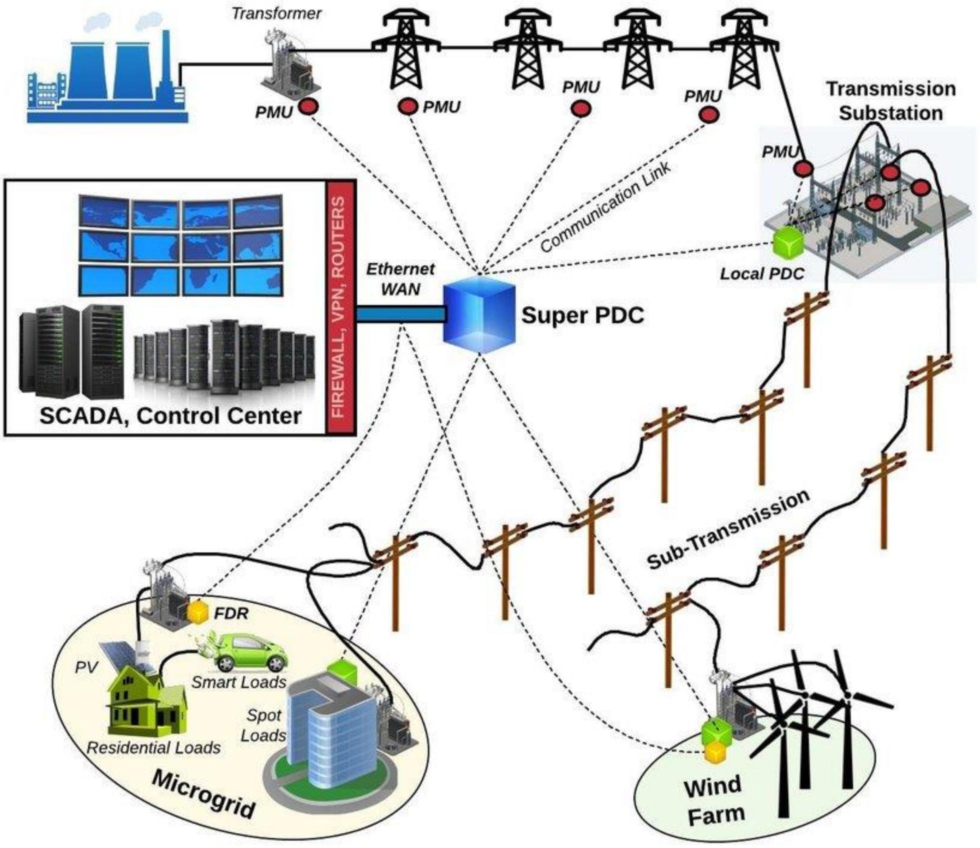


Figure 2.4: Layout of smart grid WASN comprising Synchrophasors

2.2. SMARTGRID FUNCTIONALITIES AT DISTRIBUTION LEVEL

The distribution grid comprises of medium voltage (33 & 11kV) and low voltage (415/230V) network which traditionally had limited automation systems. Main reason for this was the cost of communication system for automation. Distribution grid in large utilities runs in to hundreds of thousands of kilometres and establishing reliable communication system between all end points and the control centre was way too expensive. So there is no visibility of power flows in the low voltage network. Faults are also not automatically detected. Only when customers complain about an outage the crew is dispatched to locate the fault and repair it. Hence, the key objective of smart grid initiatives are focused on modernizing the distribution grid with advanced automation and control features. The main technologies in this domain are:

- Supervisory Control and Data Acquisition (SCADA) and Distribution Management Systems (DMS)
- Distribution Automation

- Substation Automation
- Advanced Metering Infrastructure (AMI) or Smart Metering
- Geographical Information System (GIS)
- Peak Load Management (PLM)
- Power Quality Management (PQM)
- Outage Management System (OMS)
- Distribution Transformer Monitoring System
- Mobile Crew Management System
- Enterprise IT Systems
- Application Integration
- Smart Street Lights (with noise and pollution sensors)
- Energy Storage
- Electric Vehicles
- Distributed Energy Resources and Renewable Energy Integration
- Customer Care Centre
- Customer Engagement
- Social Media
- Cyber Security
- Analytics
- Smart Homes, Buildings Energy Management Systems /Home Energy Management Systems (BEMS/HEMS)

2.2.1. SCADA AND DISTRIBUTION MANAGEMENT SYSTEMS (DMS):

Features of SCADA system explained under previous section are similar for distribution SCADA as well.

While all RTUs for transmission SCADA are placed in high voltage substations, in case of distribution SCADA besides RTUs in substations, there may be Field RTUs (FRTUs) in distribution network at power transformer
and distribution transformer locations. Communication options for transmission SCADA and distribution
SCADA are also same – utilities select what is appropriate depending upon local considerations.

<u>DISTRIBUTION MANAGEMENT SYSTEM (DMS):</u>

DMS is a collection of software applications designed to monitor and control the entire distribution network efficiently and reliably. Distribution management systems deal with electric power from distribution substation to the different loads with the use of medium and low voltage cables and transmission lines. Most of the power distribution or utility companies rely on manual labor to carry out the distribution tasks like interrupting the power to loads, all the parameter hourly checking, fault diagnosis, etc. The implementing SCADA to the power distribution not only reduces the manual labor operation but also facilitates smooth automatic operations with minimizing disturbance. Following fig. shows the structure of SCADA in power distribution system where it collects the whole data from various electrical substations, even at remote locations, and does the corresponding data and status processing.

DMS FUNCTIONS:

- Network Visualization and Support Tools
- Applications for Analytical and Remedial Actions
- Utility Planning Tools
- System Protection Schemes

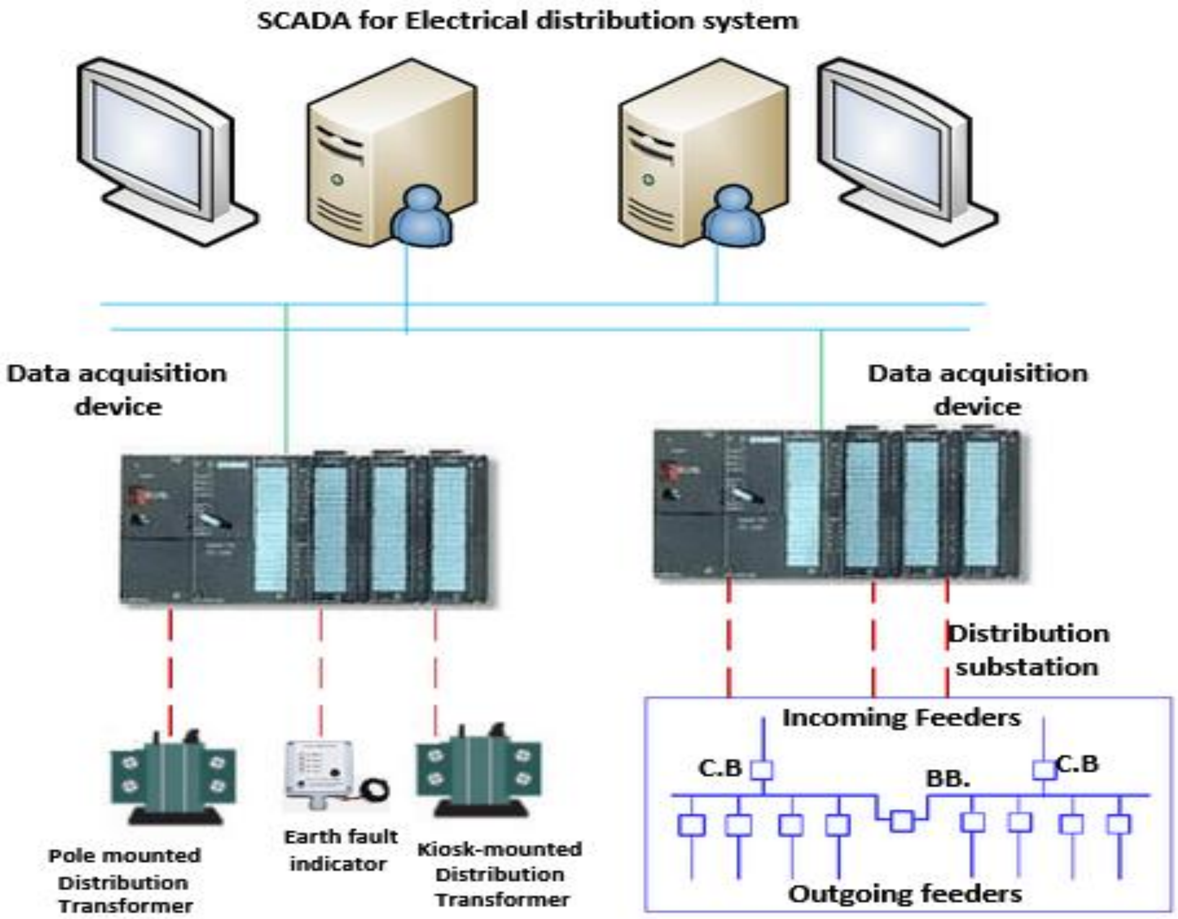


Figure 2.5: SCADA and DMS architecture for distribution at smart grid

2.2.2. DISTRIBUTION AUTOMATION (DA):

Distributed Automation (DA) eludes to different computerized control strategies that upgrade the execution of energy dispersion organizes by enabling individual gadgets to detect the working states of the lattice around them and influence changes in accordance with enhance the general energy to stream and stream line execution. In the present situation, lattice administrators in concentrated control focuses recognize and break down their energy framework physically and intercede by either remotely enacting gadgets or dispatching an administration expert. DA can be a basic part in blackout counteractive action. The sensors and inter-changes related with DA can give early recognition of the gadgets that won't not work legitimately, consequently enabling the utility to supplant those gadgets previously a through and through disappointment happens. DA is viewed as the center piece of a brilliant lattice, connecting with all other savvy framework applications and making the network more proficient and solid. DA empowers Renewable Energy (RE) by progressively changing appropriation controls to suit fluctuation, control inclining and bi-directional power streams.

Figure 2.6: Typical Distribution Automation system at smart grid

Other key components of DA are: Ring Main Unit (RMU), Sectionalizer, Reclouser, Fault Locator and Capacitor Banks which are described below:

SECTIONALIZER is a protective device, used in conjunction with a reclouser, or breaker and reclosing relay, which isolates faulted sections of the distribution lines. The sectionalizer cannot interrupt fault current.	
RECLOUSERS are designed to operate like a station breaker and can interrupt fault current and reclose a pre-set number of times before going to lockout the faulted section. Sectionalizer counts the breaker and reclouser operations during a fault sequence and open when they reach their pre-set count limit while the breaker or reclouser is still open.	
FAULT LOCATOR: The DA system and its automated distribution devices enable faulted load blocks to be quickly identified, isolated and power is re-routed to downstream load blocks. However, the actual fault still has to be found and repaired by field crews before all customers can be restored.	
RING MAIN UNITS (RMU) are installed in strategic locations on every feeder to monitor and control the Sectionalizers, Reclousers and other equipment in the network	

CAPACITOR BANKS: DA system helps in controlling the capacitor banks for controlling the voltage and power factor.	

Figure 2.7: Components of Distribution Automation Systems

2.2.3. SUBSTATION AUTOMATION:

Substation Automation (SA) system enables an electric utility to remotely monitor, control and coordinate the distribution components installed in the substation. SA has been focused on automation functions such as monitoring, controlling, and collecting data inside the substations. SA overcomes the challenges of long service interruptions due to several reasons such as equipment failures, lightning strikes, accidents and natural catastrophes, power disturbances and outages in substations. The main component of SA is digital (or numeric) relays and associated communication systems which can be operated remotely.

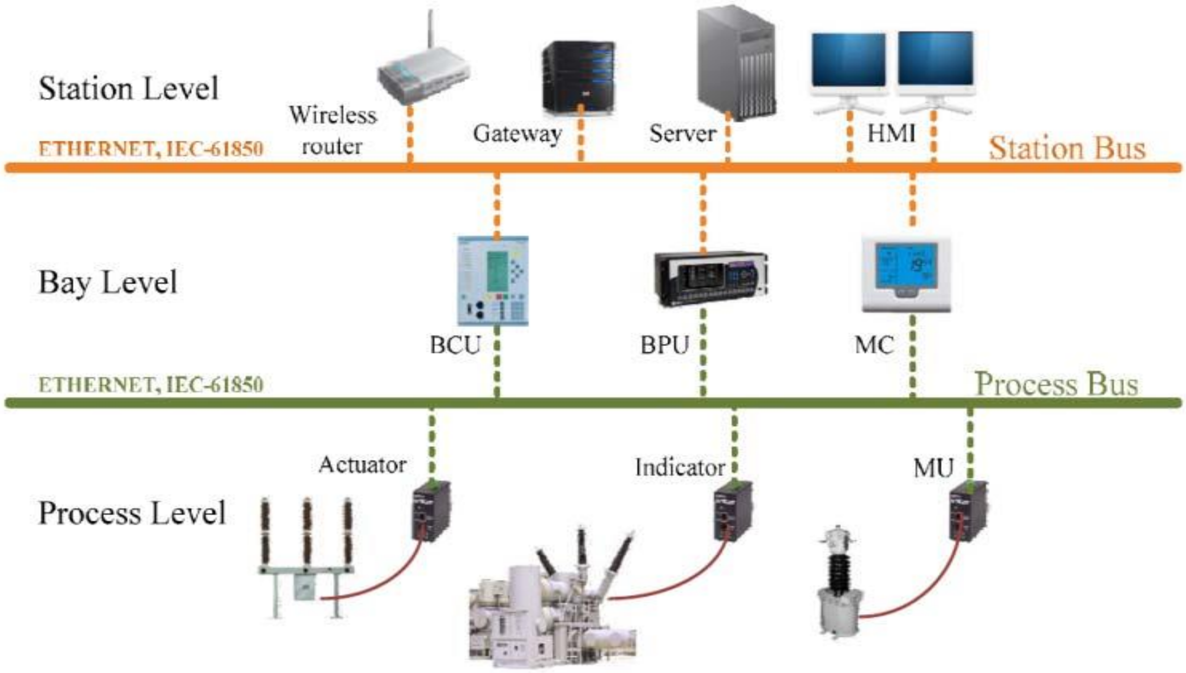


Figure 2.8: 3 level substation automation layout diagram

2.2.4. ADVANCED METERING INFRASTRUCTURE (AMI):

Advanced Metering Infrastructure (AMI) allows utilities to collect, measure, and analyze energy consumption data for grid management, outage notification, and billing purposes via two-way communications. While a predecessor technology called Automatic Meter Reading (AMR), still prevalent and in use today, uses one-way communications to accomplish meter readings primarily for monthly billing purposes, AMI can be leveraged to provide consumers with historical energy consumption data, comparisons of energy use in similar households, dynamic pricing information, and suggested approaches to reducing peak load via in-home displays. For certain applications, such as near-real-time data feedback and full energy management analysis, AMI will likely be required. AMI networks, however, still require a significant investment to build out fully, and are not required to enable most consumer-facing applications. Several alternatives to AMI are therefore discussed below in the context of home and office applications.

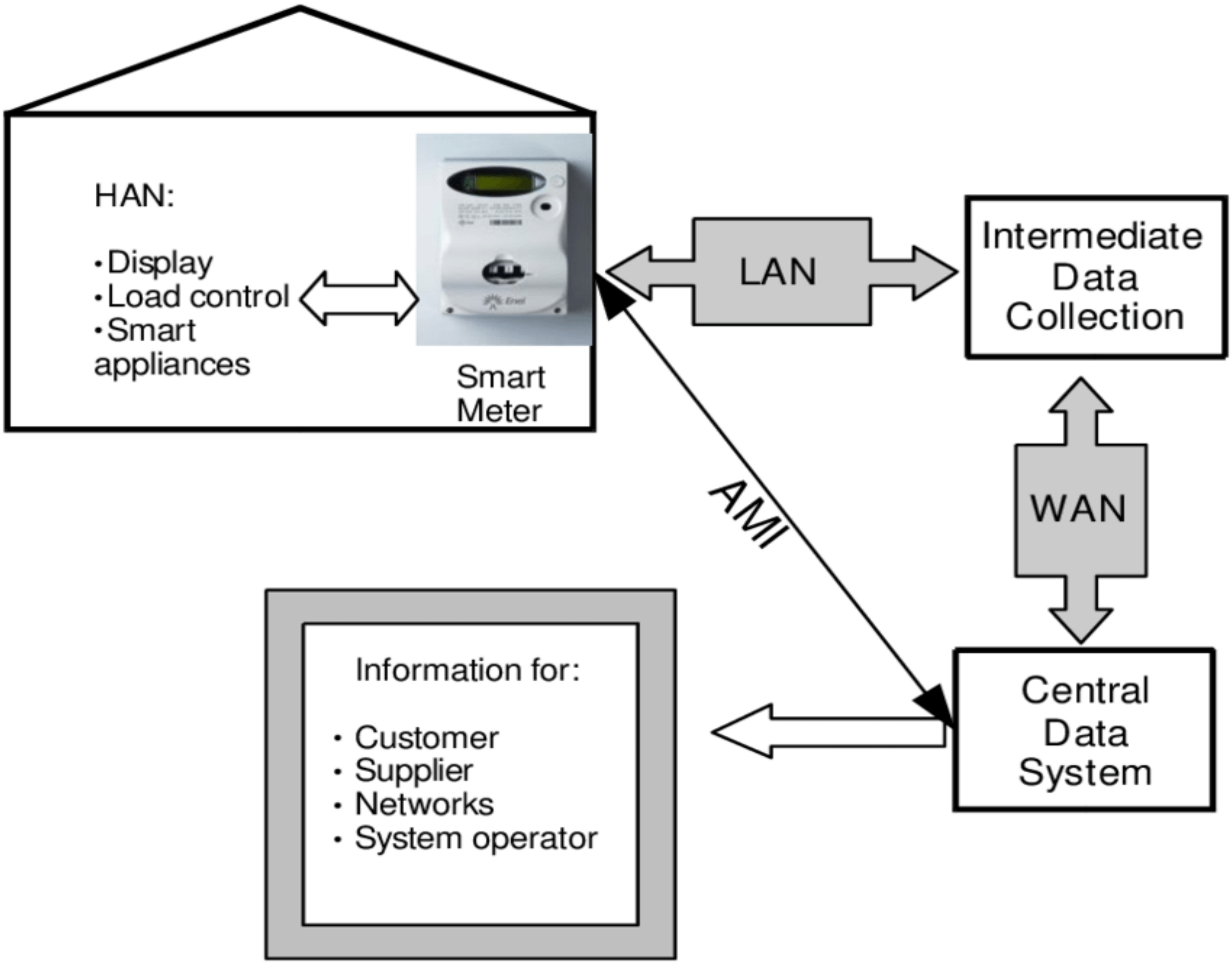


Figure 2.9: Typical architecture of AMI

1. Technologies for on-premises networking

The vision for Home Area Networks (HANs) is to connect the smart meter, smart appliances, electric vehicles, and on-site electricity generation or storage, both for in-home displays, controls, and data uploads, and to allow for automated modulation of energy loads during peak demand periods. For most in-home applications, communications needs are modest. The amount of data being transferred at any one moment will likely consist only of the instantaneous electricity use of each device, measured in watts, and thus commenter's state that the bandwidth needs to accomplish this will likely fall between 10 and 100 kbps per node/device. This requirement could scale up quickly, however, for large homes or office buildings, so the networking technology selected should be suitably scalable as well. Because in-home applications are primarily intended to inform consumers of their energy use, such applications are not likely to be considered "mission critical," and the required level of reliability may fall into the 99 percent to 99.99 percent range, with the possible exception of demand response and distributed generation, discussed later in this paper. Likewise, latency, in this case the delay between the moment instantaneous energy uses is measured and the moment at which that information is reported on the display, is not critical. UTC and Verizon assert that the ideal latency for in-home applications should be between 2 and 15 seconds. Voluntary reduction in energy use, one of the anticipated outcomes of in-home displays, does not depend on instantaneous information, so clearly much higher latencies might be reasonable. Reasonable timeliness of information is still important, however, if consumers are expected to change behaviors based on the information. Furthermore, such delays may affect the value of information for upstream applications that depend on the information, such as demand response. The communications needs of on-premises applications can be handled by low-power, short-distance technologies designed with consumer uses in mind.

Technologies currently being used or considered for on-premises communications include 2.4 GHz WiFi, the common 802.11 wireless networking protocol, ZigBee, which is based on the wireless IEEE 802.15.4 standard and is a close technological cousin of the ubiquitous Bluetooth protocol, and Home Plug, a form of power line networking that carries data over the existing electrical wiring in the home. While the industry has not yet converged on a standard, the predominant technology used in installations today is ZigBee, followed by Home Plug. ZigBee offers the advantage of being wireless while requiring very little power, and both technologies, despite being relatively low-bandwidth, are cost-effective and flexible, although each is accompanied by their individual challenges. These characteristics will be critical if the HAN is to communicate with myriad smart appliances, large and small, in the home, which will in turn allow various consumer applications, such as remote monitoring and control of a home's thermostat or appliances via smart phone.

Ultimately, a key goal for in-home networking communications maybe interoperability between Smart Grid communications technologies. While a thorough analysis of the various benefits and drawbacks of network technologies is beyond the scope of this report, it is worth noting that a number of stakeholder shave recommended standardizing on the use of the internet protocol(IP) for Smart Grid communications.

As noted above, in-home applications can leverage AMI networks, but can also exist separately from such utility-driven systems. For instance, both traditional meters and AMR meters can be connected to the HAN via bolt-on technologies. For example, products may leverage a website working in concert with a WiFi-enabled sensor that reads traditional meters to allow consumers to monitor their energy use, compare their energy consumption with neighboring homes, and learn how to improve energy efficiency. Other approaches will involve a more extensive suite of hardware and software products to enable additional Smart Grid consumer applications. For example, consumers might view their home energy consumption and electricity pricing in real-time via a wall-mounted device, control certain appliances and thermostats remotely via smart phone, and shut off conventional appliances through the use of ZigBee-connected outlets. As the National Cable & Telecommunications Association notes, these applications, whether they use an existing meter or a smart meter, allow consumer-facing functions without the need for any communications technologies beyond those already installed in an Internet-connected home.

2. Technologies for hand off of information from the premises

The utility network would have four tiers in the Smart Grid architecture: (1) the core backbone –the primary path to the utility data center; (2) backhaul distribution –the aggregation point for neighborhood data; (3) the access point –typically the smart meter; and, (4) the HAN –the home network. Communications between the smart meter and the other devices on the HAN was discussed in the previous section. The next step in the network is to carry this information away from the premises to an aggregation point, which will often be a substation, a utility pole-mounted device, or a communications tower. Bandwidth requirements will be similar to those for in-home networking, in the 10-100 kbps range per device in the home or office, although this will scale up quickly if appliance-level data points as opposed to whole-home data are transmitted to the aggregation point. As with on-premises communications, UTC and Verizon suggest that the required latency will be in the range of 2 to 15 seconds for some types of data traffic, and reliability requirements will be in the 99 percent to 99.99 percent range. The availability of emergency power backup at the meter will not be critical because in-home metering services are not needed during outages, although backup power at aggregation points in varying sizes is used depending on specific needs.

Determining the appropriate communications technologies for AMI applications will depend on the level of AMI functionality desired. Early AMI installations traditionally had been serviced by power line carrier (PLC) technology, which is used for relaying meter data and other internal communications over a utility's power lines. PLC is still the most common conduit for AMI functions in rural, low-density areas, where wireless coverage is less available. While PLC is low cost and can reach all utility customers in a territory, it has very low bandwidth (often below 20 kbps) and requires hopping of the PLC signal around transformers by using a bridge, for instance via a wireless connection, that bypasses this grid element that would normally scramble the PLC signal. The bandwidth provided by PLC may not be adequate to meet the requirements of real-time AMI at the per-device level (up to 100 kbps per device). Many AMI deployments, particularly in urban areas, use 900 MHz wireless mesh networks. In a mesh network, each endpoint has the ability to function as a router, and connectivity between meters and collection points is typically achieved via a dedicated network using unlicensed radio spectrum, run either by the utility or a subcontractor. Fixed point-to-multipoint radio frequency networks, also known as star, radial, or spoke networks, are also common in current installations, using licensed spectrum and communications towers or other sources of elevation. Commenter's note that it is quite possible that greater demands for bandwidth will emerge over time, meaning that new technologies may be required to connect homes and businesses to aggregation points. Some industry representatives contend that traditional PLC and wireless mesh may well be replaced by broadband communications such as the IEEE 802.16e mobile WiMAX standard, broadband PLC, or next-generation cellular technologies.

The backhaul of information from aggregation points to the utility typically functions over private networks. Backhaul can be accomplished using a variety of technologies, such as fiber, T1, or microwave networks. Star networks may also be used for backhaul of data from the hub to the utility, often utilizing commercial wireless connectivity.

To enable more advanced applications such as real-time pricing, which would bill for electricity at the current rate, a two-way communications system is required, and lower latency may be necessary as well. The backhaul of aggregated data from an aggregation point to a utility is likely to have bandwidth requirements in the 500 kbps range. Current AMI networks may be strained by such applications. In fact, many AMI networks only have intermittent connectivity to the utility, as data is aggregated at a neighborhood node and only sent to the utility periodically. An open question remains, however, whether such two-way communications must be truly “real-time”; such consumption data may be of more use if limited to the HAN, which can act locally to manage energy consuming devices and appliances, with only aggregated data being backhauled to the utility, perhaps on an hourly or less frequent basis. Indeed, in the opinion of many experts, backhauling real-time or near-real-time data from the billions of devices that may eventually be connected to the Smart Grid would require not only tremendous bandwidth, but also data storage capacities well beyond the current installed base, making the undertaking economically infeasible.

2.2.5. PEAK LOAD MANAGEMENT:

DEMAND RESPONSE (DR):

One of the most common steps taken by utilities toward creating a smarter power grid has been the increasing implementation of demand response (DR). Demand response is the reduction of the consumption of electric energy by customers in response to an increase in the price of electricity or heavy burdens on the system. Demand response can significantly reduce peak loads. Demand response programs can be implemented at both the wholesale and retail levels. Wholesale demand response programs are typically operated by independent service operators (ISO) and regional transmission organizations (RTO), while retail programs are run by utilities.

Retail demand response can take various forms. With direct load control (DLC), customers agree to have their consumption of electricity automatically curtailed at times of peak load, via the powering down of appliances. A more advanced version of DR is automated DR, which allows on-premises equipment to respond to dynamic conditions on the grid, shifting load consumption in near-real-time.

The DR device can be an energy management system or a smart appliance, the latter referred to as "prices to devices" because it sends pricing information directly to the appliance, which responds accordingly without an explicit control command. Another variation of DR would have the electricity usage at the premises offloaded to distributed generation sources at the customer's location.

A fourth variation of demand response is the delivery of dynamic pricing to the customer. With such pricing, the customer has the option to curtail electricity use manually.

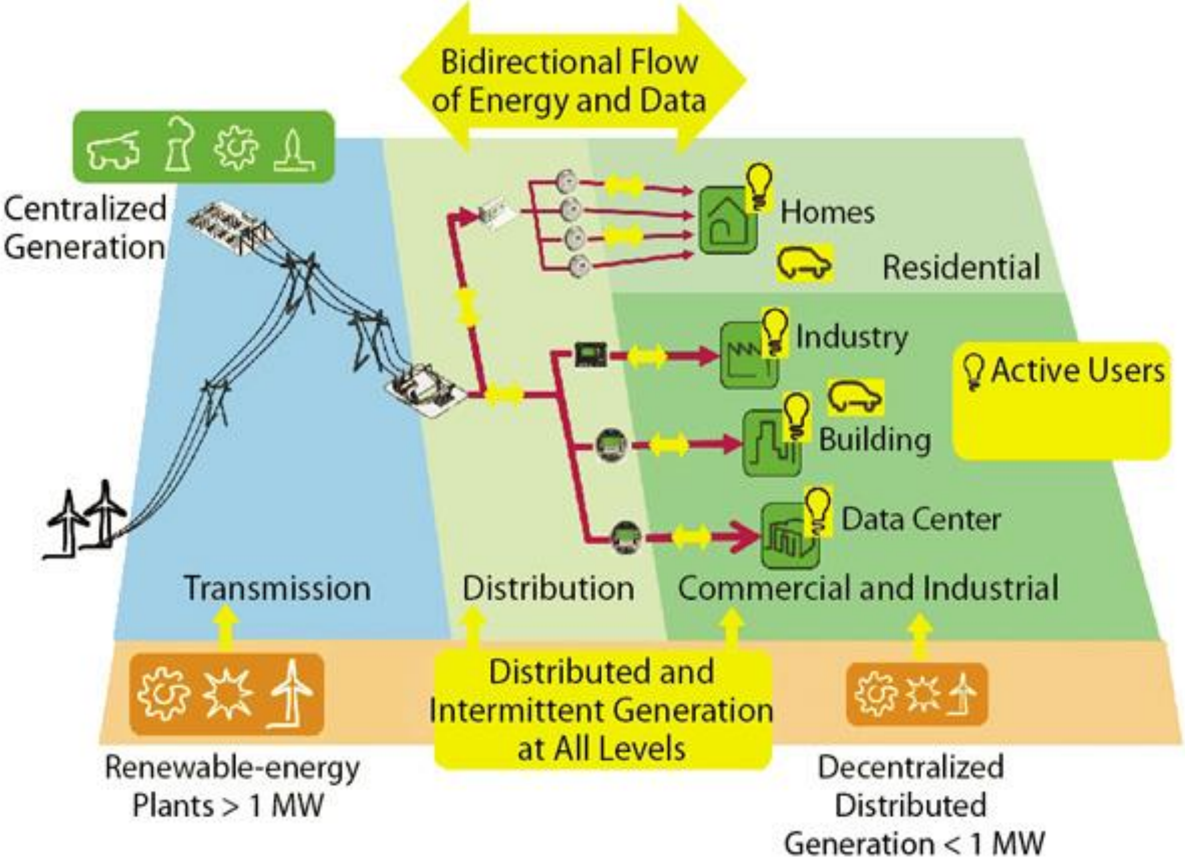


Figure 2.10: Demand response diagram for smart grid

The communications requirements of DR applications may vary depending on the sophistication of the system desired; at its most basic (for example, DLC), DR simply sends a shut-off command to an appliance, such as an air conditioner or hot water heater, and bandwidth requirements for this type of application are quite low and are easily handled by today's infrastructure. Some experts have estimated future bandwidth requirements to range from 14 kbps to 100 kbps per node/device, similar to AMI, or perhaps even higher. Other experts have estimated bandwidth requirements to be lower than AMI, on the order of 120 bytes per message. If next-generation DR systems work in tandem with AMI, however, the total bandwidth requirements of DR would likely be at least as high as AMI. At least as important as bandwidth for DR purposes is consistent latency. Estimates of the latency requirements of DR fall into a wide range, from as little as 500ms to 2 seconds, up to several minutes. The difference in perspective of various experts on this issue is likely due to the various potential applications of DR. certain iterations of DR may be considered “mission critical,” in that failure to reduce energy use will lead to a system overload situation. If DR is truly intended to avert imminent emergencies such as an overload, relatively lower latencies may be necessary. If DR is used as a load balancing tool, however, the responsiveness of the system may not be critical, and thus latency could be higher. Either way, because utilities using DR will likely depend on it as a grid management tool, reliability will be important, and experts have provided estimates of reliability ranging from 99 percent to 99.99 percent level. The delay of a significant number of DR commands due to high latency would greatly impact effectiveness of the system. Several commenters’ note that unlike AMI and certain other Smart Grid functions; DR is likely to be implemented only on the order of 30 to 35 days per year, corresponding with periods of peak energy usage. As with AMI, demand response systems typically do not needs back up power, as the load management functions of demand response are not necessary if the electrical system is not operational. Communications technologies capable of providing these services include standard paging systems or PLC, sometimes not connected to AMI systems at all. Communications would be passed along to the in-home network, which could utilize the ZigBee networking protocol or others to distribute commands to appliances and devices. Other implementations of DR may use more modern communications technologies, such as broadband (via cable, DSL, fiber, etc.), next-generation cellular such as LTE, WiFi, or WiMAX. Using such higher 24bandwidth systems will allow for two-way communications and the implementation of more time-sensitive applications.

2.2.6. WIDE AREA SITUATIONAL AWARENESS (WASA):

Wide-Area Situational Awareness with increasing demand on the power supply system, as well as the need for improved reliability, prevention of power supply disruption is one of the key goals of the Smart Grid. Because of the inherently interconnected and interdependent nature of the grid, improving wide area monitoring and situational awareness is necessary to achieve this objective. A disturbance in the power supply in one area can quickly translate into a widespread problem, with cascading and deleterious consequences. Additionally, information about the power supply in neighboring areas can help utilities optimize the economic operation of the grid. Wide area situational awareness (WASA) refers to the implementation of a set of technologies designed to improve the monitoring of the power system across large geographic areas –effectively providing grid operators with a broad and dynamic picture of the functioning of the grid.

25frequently as 60 times per second –with time stamps synchronized to a common clock. The frequency of the readings, coupled most importantly with the fact that readings from disparate locations can be time-tagged and compared to form an aggregate snapshot of the state of the power supply at any one time, enable real-time wide area monitoring of the power system. Data from synchrophasors are sent to phasor data concentrators, and then subsequently distributed to end users for various power monitoring applications.

According to the commenter –many of whom have begun implementing synchrophasor technology –synchrophasors have a long list of specific benefits, including, among others, obviating the need for construction of additional transmission lines, facilitating integration of intermittent and renewable resources, and improving system modeling and planning. Synchrophasors also assist with contingency analysis, which analyzes security through simulating the effect of removing equipment, and post-event analysis of power disturbances. Notably, synchrophasors will not supplant SCADA systems.

The focus of synchrophasors is widespread grid situational awareness, whereas SCADA systems will continue to be used for local monitoring and control, and synchrophasors may be used as a backup mechanism in the event that local control and management technologies fail.

The communications requirements of synchrophasors vary depending on the nature of data being transmitted. For real-time monitoring and control, latency requirements are very low. Alcatel suggests that the maximum latency for these applications is 20 milliseconds, although UTC and Avista states that it is below 200 milliseconds. For post-event, historical data, low latency is less imperative.

In terms of data requirements, it is noted that that phasor measurement data will be continuous, rather than variable. UTC and Avista estimate that synchrophasors will require between 600 kbps and 1500 kbps. GRE characterizes synchrophasors as requiring “high speed, high throughput communications,” pointing specifically to the IEC standard 61850, which is applicable for these types of communications. Over time, with the proliferation of devices, the increased use of distributed generation, and the introduction of new applications for phasor data, the aggregate bandwidth demands will increase.

There are several communications network technologies for networking synchrophasors. They include: fiber optics, microwave, and even broadband over power line (BPL). The NASPI net architecture envisions a private Wide Area Network, consisting of Local Area Networks, using open network architecture “to allow the addition of future functionality and the replacement of hardware without disruption” to normal operation.

There is abundant information in the relevant technical literature on standards and quality of service requirements for synchrophasors. While these technical issues are beyond the scope of this report, it is clear that these parameters are still evolving. Given the stringent technical requirements for these types of communications, however, the issue relevant for our inquiry is how supporting the stringent communications needs for these devices will impact the way in which utilities meet the communications requirements for other Smart Grid devices. That is to the extent that the increasingly ubiquitous implementation of synchrophasors is driving the utilities to ramp up and invest in low latency communications platforms the communications needs for synchrophasors might be coupled with or drive the communications choices for other Smart Grid technologies. At this time, the implementation of synchrophasors is still in the relatively nascent stage and it is therefore not possible to do a more detailed analysis. This issue, however, is one worthy of continued exploration and review.

2.2.7. POWER QUALITY MANAGEMENT:

Voltage variation beyond stipulated limits and interruptions are major power quality issues faced by customers. With proliferation of distributed and variable generation resources such as solar PV and wind turbines which operates intermittently, it is increasingly difficult to maintain quality of supply. On the other hand, modern loads with switch-mode power supply (SMPS) such as computers, television, washing machines, air-conditioners, refrigerators, LED lights, furnaces, inverter, UPS etc inject harmonic distortion on the power system. Voltage and current are in sinusoidal wave form whereas the above category loads with power electronics in them are in square wave form which lead to generation of harmonics.

2.2.8. DISTRIBUTION TRANSFORMER (DT) MONITORING SYSTEM:

In most distribution utilities in India, hundreds of Distribution Transformers (DTs) get burned during every summer owing to over loading or phase imbalances of the DTs. Remote monitoring of DTs will prevent overloading, phase imbalance and burn outs of DTs. This will transform into huge financial savings taking into account the high technical losses that occur in the system owing to phase-imbalances - one phase gets overloaded while other two phases are low on load. With monitoring systems in place the loads can be redistributed to remove such imbalances on transformers. With DT Monitoring Systems, overloaded DTs can be identified and replaced with higher capacity DTs as load in the locality increases.

2.2.9. DISTRIBUTED ENERGY RESOURCES AND RENEWABLE ENERGY INTEGRATION:

Distributed Energy Resources (DER) are small, modular, energy generation and storage devices such as rooftop PV systems, micro wind turbines, energy storage batteries such as batteries in UPS, Inverters and EVs etc. DER systems may be either connected to the local electric power grid or isolated from the grid in stand-alone applications. Renewable Energy Integration focuses on incorporating renewable energy, distributed generation, energy storage and demand response into the electricity transmission and distribution systems. A systems approach is being used to conduct integration development and demonstrations to address technical, economic, regulatory, and institutional barriers for using renewable and distributed systems. In addition to fully addressing operational issues, the integration also establishes viable business models for incorporating these technologies into capacity planning, grid operations, and demand-side management.

2.3. TARIFF DESIGN FOR SMART GRID CONSUMERS:

Regulators all over the World have introduced tariff based incentives to customers who save Energy, when the Utility is facing problems, for avoiding purchase of High cost Power and also to use more energy, at off peak periods, when the system more generation is available (high frequency period)

2.3.1. NEED FOR DYNAMIC PRICING MECHANISM IN INDIAN CONTEXT:

Indian Utilities' load curve experiences the morning and evening peak hours, with increased load compared to the Average Load. Utilities need to purchase High Cost power, during Peak hours and have excess availability during off peak. The load curve flattening can be obtained through the Dynamic Pricing Programs.

2.3.2. TIME OF DAY (TOD) / TIME OF USE TARIFF (TOU):

In this method, the electricity tariff to consumers varies with the Time of the day (and also Day of the week). The tariff is higher during Peak Periods and lower during Off Peak periods. The TOD/TOU tariff is decided by the Regulators along with the ARR and is known to the consumers, at least a year before; hence

TOD/TOU is practically not the Dynamic rate Option. It offers consumers the least potential reward at the lowest risk. TOD/TOU tariff is very easy to implement and incentivizes the consumers to shift their nonessential load from peak period to off peak period, for efficient resource allocation.

2.3.3. CRITICAL PEAK PRICING (CPP):

In Critical Peak pricing mechanism, the system operator captures the true cost of power generation during the Peak Demand period. It is in fact the crest of Load duration curve. This period normally ranges between 1-3% of the year (75-225 Hours in a year). If the consumers are ready to pay for the actual cost of power during this period (i.e. CPP Period, which is much higher than TOD tariff), they are offered a discounted rate, for all remaining hours of the year.

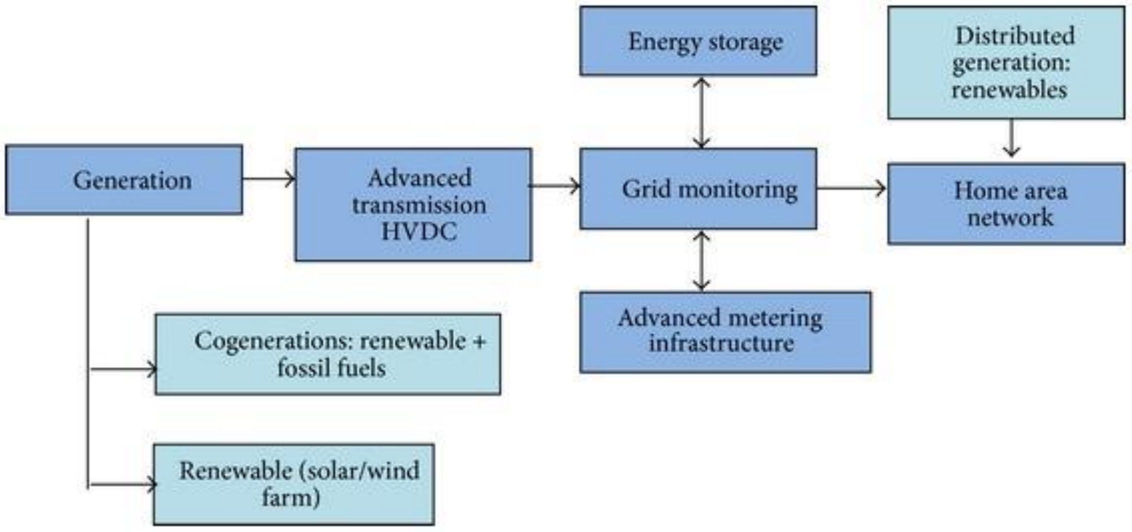
CPP tariff is charged for the number of days on which the peak crosses a particular limit. The actual time block during which, the CPP will be in effect is identified on a day-ahead basis, depending on the demand– supply balance.

2.3.4. EXTREME DAY PRICING:

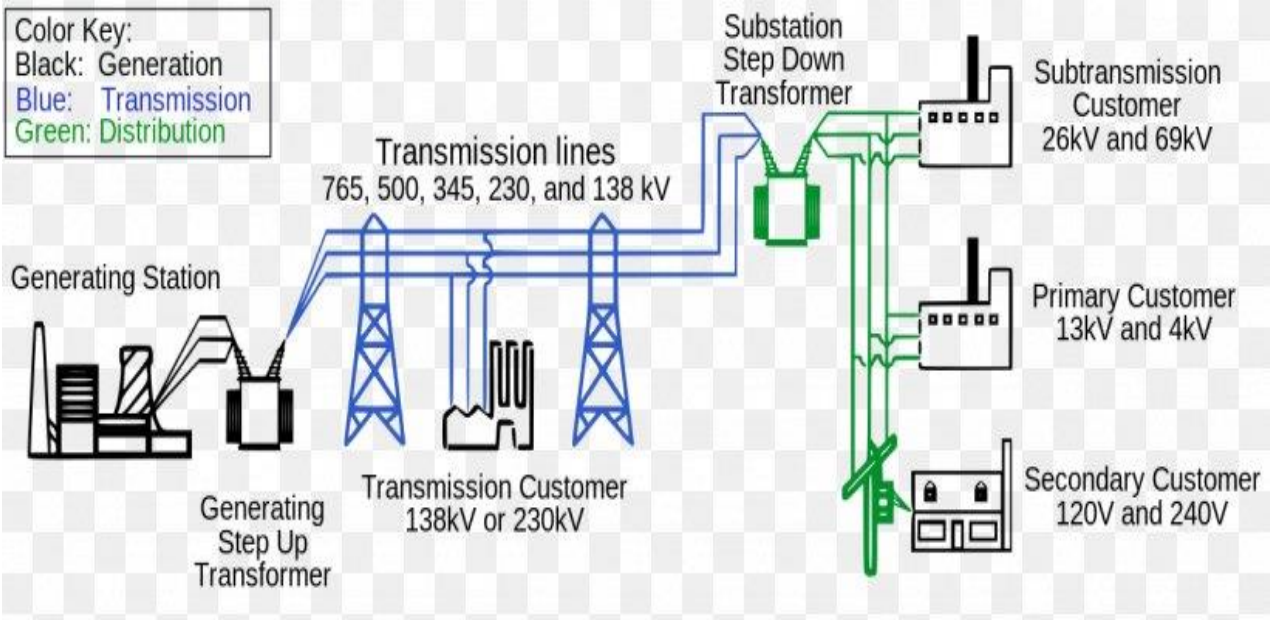
Extreme Day pricing is similar to the Critical Peak Pricing. The basic difference is that in CPP the peak pricing is for the limited peak period in the critical day. But in Extreme Peak pricing has the higher price in effect for all 24 hours of critical days.

Chapter 3: IMPLEMENTATION

3.1. BLOCK DIAGRAM:



3.2. PROTOTYPE:



3.3. SOFTWARE EXPERIMENTS:

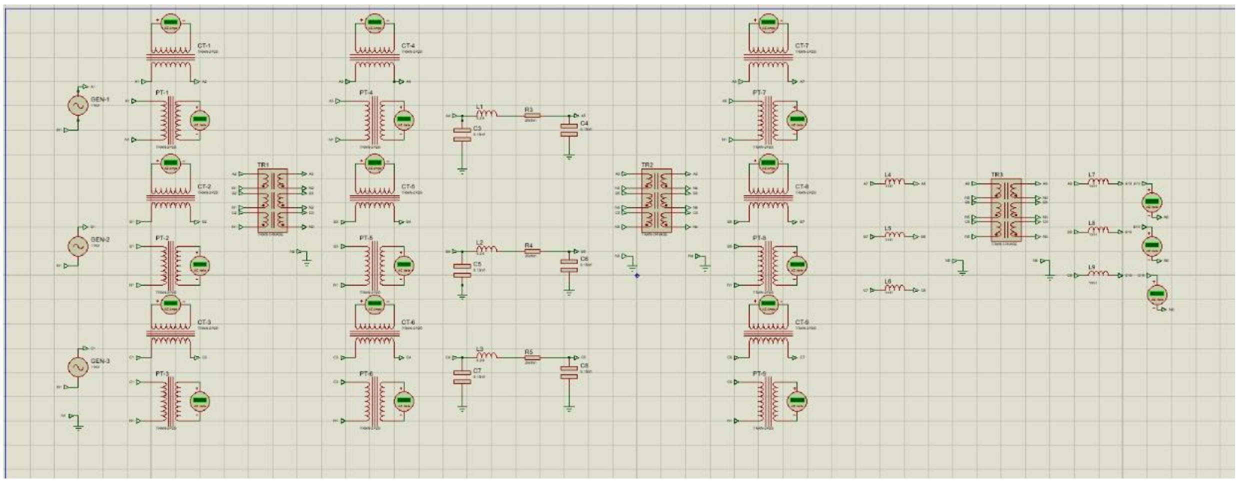
3.3.1. SOFTWARE USED:

Proteus 8 Professional is a simulation software program that offers unlimited possibilities for that offers unlimited possibilities for project planning and automation of projects. It has been used to implement this project.

3.3.2. EXPERIMENT 1:

In this experiment a proposed 3 phase transmission line has been shown for a smart grid system.

3.3.2.1. SIMULATION DIAGRAM:



3.3.2.2. OBSERVATION AND RESULT:

At first, Electric power is generated by the 11 kV generators. This generating voltage is then stepped up by 3 phase step up transformer TR1 to 132kV.

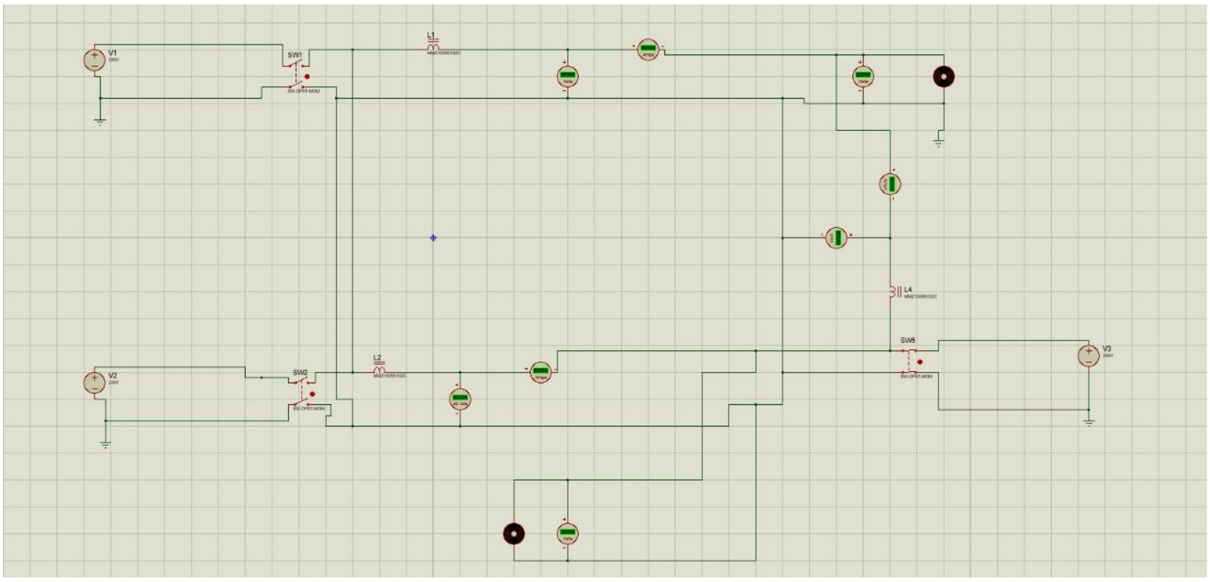
Then the power is transmitted by primary transmission line and stepped down to 33kv or 66kv by transformer TR2. Secondary transmission lines emerge from this receiving station to connect substations located near load centers.

The voltage is stepped down again to 11kV at a substation by step down transformer TR3. Large industrial consumers can be supplied at 11kV directly from these substations. Finally, the voltage is stepped down to 415 volts by a pole-mounted distribution transformer and delivered to the distributors.

3.3.3. EXPERIMENT 2:

In this experiment a grid distribution system has been shown by a miniature of single phase DC system for hardware implementation.

3.3.3.1. SIMULATION DIAGRAM:



3.3.3.2. OBSERVATION AND RESULT:

Here, 2 DC motors as loads are supplied by a grid system of 3 single phase DC source.

The following observations are made by this experiment:

1. When the three switches SW1, SW2 & SW3 are on all the voltage sources V1, V2 & V3 are supplying power to the load equally.
2. When any one of the voltage sources is off (V1, V2 or V3) then other 2 voltage sources will deliver power to the loads.
3. When any two of the voltage sources is off (V1 & V2 or V2 & V3 or V3 & V1) then other one voltage sources will deliver power to the loads.

OBSERVATION TABLE:

When V1, V2, V3 is on

V1 (Voltage across Line 1) (Volt)	V2 (Voltage across Line 2) (Volt)	V3 (Voltage across Line 3) (Volt)	Vm1 (Voltage across motor1) (Volt)	Vm2 (Voltage across motor2) (Volt)	I1 (Current across Line 1) (Amp)	I2 (Current across Line 1) (Amp)	I3 (Current across Line 1) (Amp)
221.9	227.6	221.9	221.9	227.6	10.5	7.98	2.52

When V1 is off so, V2 & V3 is on

V1 (Voltage across Line 1) (Volt)	V2 (Voltage across Line 2) (Volt)	V3 (Voltage across Line 3) (Volt)	Vm1 (Voltage across motor1) (Volt)	Vm2 (Voltage across motor2) (Volt)	I1 (Current across Line 1) (Amp)	I2 (Current across Line 1) (Amp)	I3 (Current across Line 1) (Amp)
222	227	222	222	227	0	12.0	25.4

When V1 & V2 both is off so, only V3 is on

V1 (Voltage across Line 1) (Volt)	V2 (Voltage across Line 2) (Volt)	V3 (Voltage across Line 3) (Volt)	Vm1 (Voltage across motor1) (Volt)	Vm2 (Voltage across motor2) (Volt)	I1 (Current across Line 1) (Amp)	I2 (Current across Line 1) (Amp)	I3 (Current across Line 1) (Amp)
218	226	218	218	226	0	0	37

Chapter 4: OVERVIEW OF SMART GRID

The Smart Grid framework is composed of and concerned with distributed intelligence including data decentralization, renewable distributed generation and energy storage, and distribution system automation. Customer partnership and interaction are a regard, as are micro-grids, and high-demand electric devices. The Smart Grid is by definition about real-time data monitoring and active micro grid management via rapid two-way digital communications through the implementation of technological solutions to the power delivery infrastructure. Integration exists between micro grids and within the electric utility, renewable power generating devices; consumer loads devices, and third-party entities either as consumers, vendors, or regulatory organizations. Smart Grid comprise an intelligent monitoring system that observes the flow of electrical energy throughout the power network and incorporates the use of cables or transmission lines to manage power fluctuations, losses, and co-generation integration from solar, fuel cell and the wind. Generally, most effective Smart Grid can monitor/control residential home devices that are non-critical during peak power consumption times to reduce power demand, and return their function during non-peak hours. Proposals for optimization include smart micro grids, smart power grid, and intelligent grid. In addition to normalizing electric demand, the ability to manage power consumption peaks can support in avoiding brown-outs and black-outs when power demand exceeds supply, and allow for maintaining critical loads and devices under such conditions. The following Figure displays a high-level communication flow between different components in a Smart Grid.

The Smart Grid initiative has produced a significant progress toward the Modernization and growth of the electric utility infrastructure and aims to integrate it into today’s advanced communication era both in function and in architecture. That evolution comes with a number of organizational, socio-economic, technical, and cyber security challenges. The expansion and depth of those challenges are significant, and a number of regulatory organizations have taken up the initiative to bring their own standards and requirements into alignment with these new challenges.

The initiative has also offered many opportunities to explore new areas for taking advantages of data communication among distributed and remote electric networks and their devices.

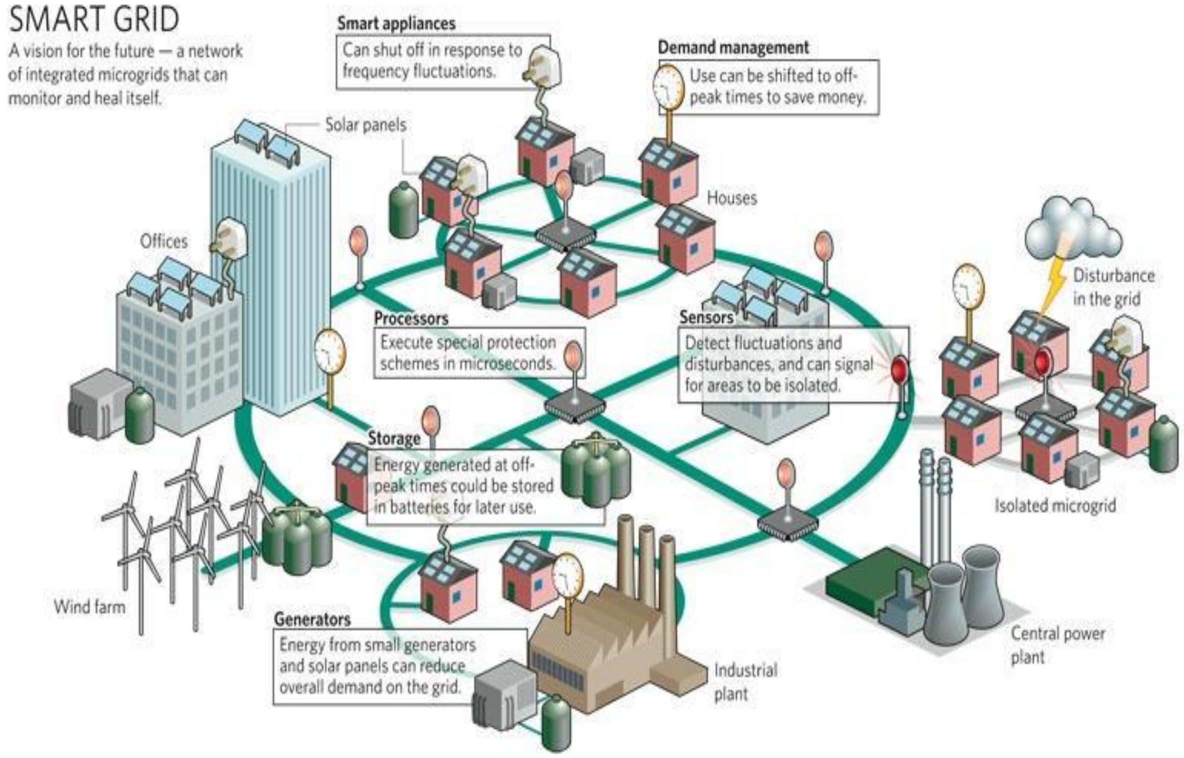


Figure 4.1: An overview of a smart grid system

4.1. SMART GRID MATURITY MODEL

The Smart Grid Maturity Model (SGMM) is a management tool that utilities can leverage to plan their smart grid journey, prioritize their options, and measure their progress as they move towards the realization of a smart grid. The SGMM was founded by utilities for utilities when the Global Intelligent Utility Network Coalition, a smart grid collaboration of 11 utilities, saw the need in the industry for such a tool. The model describes eight domains, which contain logical groupings of incremental smart grid characteristics and capabilities that represent key elements of smart grid strategy, organization, implementation, and operations. Utilities use the SGMM framework to assess their current state of smart grid implementation, define their goals for a future state, and generate inputs into their road mapping, planning, and implementation processes.

SMR	**Strategy, Mgmt & Regulatory** *Vision, planning, governance, stakeholder collaboration*	TECH	**Technology** *IT architecture, standards, infrastructure, integration, tools*
OS	**Organization and Structure** *Culture, structure, training, communications, knowledge mgmt*	CUST	**Customer** *Pricing, customer participation & experience, advanced services*
GO	**Grid Operations** *Reliability, efficiency, security, safety, observability, control*	VCI	**Value Chain Integration** *Demand & supply management, leveraging market opportunities*
WAM	**Work & Asset Management** *Asset monitoring, tracking & maintenance, mobile workforce*	SE	**Societal & Environmental** *Responsibility, sustainability, critical infrastructure, efficiency*

Figure 4.2: Domains of Smart Grid Maturity Model

4.2. SMART GRID VISION AND ROADMAP FOR INDIA

Ministry of Power with the inputs from India Smart Grid Forum (ISGF) and India Smart Grid Task Force (ISGTF) have issued Smart Grid Vision and Roadmap for India in August 2013. Smart Grid Vision for India in
this document is to “Transform the Indian power sector into a secure, adaptive, sustainable and digitally enabled ecosystem that provides reliable and quality energy for all with active participation of stakeholders”
In order to achieve this vision, stakeholders are advised to formulate state/utility specific policies and programs in alignment with following broad policies and targets which are in line with MoP’s overarching policy objective of “Access, Availability and Affordability of Power for All”

4.2.1. DISTRIBUTION:

- Appropriate policies and programs to provide access to electricity for all with uninterrupted life line supply (8 hours/day minimum, including the evening peak) and electrification of 100% households by 2017. Also, continuous improvement in quality and quantum of supply.
- Completion of on-going programs which will lay the building blocks of smart grids such as system strengthening, consumer indexing, asset mapping as part of RAPDRP, and planning for integration of such systems into future smart grid deployments.
- Enabling programs and projects in distribution utilities to reduce AT&C losses to below 15% by 2017, below 12% by 2022, and below 10% by 2027.
- Integrated technology trials through a set of smart grid pilot projects by 2015. Based on outcome of the pilots, full rollout of smart grids in pilot project areas by 2017; in major urban areas by 2022 and nationwide by 2027.
- Availability of an indigenous low cost smart meter by 2014. After successful completion of pilots, AMI roll out for all customers in a phased manner based on size of connection (and geography and utility business case), starting with consumers with load >20 KW by 2017, 3- phase consumers by 2022 and all consumers by 2027 by deploying smart meters and necessary IT and communication infrastructure for the same. Innovative and sustainable financing/business models for smart meter roll outs may be developed.
- Working with other stakeholders, building the National Optical Fiber Network (NOFN) by connecting 2,50,000 village Panchayats in the country by Optical Fiber Cable and extending the fiber link to all the 33/11 kV and above substations to build a backbone communications network for the power sector by 2017.
- Modernisation of distribution sub-stations and conversion of sub-stations in all urban areas (starting with metro cities) to Gas Insulated Substations based on techno-commercial feasibility in a phased manner through innovative financing models.
- Development of Micro grids, storage options, virtual power plants (VPP), solar photovoltaic to grid (PV2G), and building to grid (B2G) technologies in order to manage peak demand, optimally use installed capacity and eliminate load shedding and black-outs.
- Policies for mandatory roof top solar power generation for large establishments, i.e., with connected load more than 20kW or otherwise defined threshold.

- EV charging facilities may be created in all parking lots, institutional buildings, apartment blocks etc; and quick/fast charging facilities to be built in fuel stations and at strategic locations on highways.
- Micro grids in 1000 villages/industrial parks/commercial hubs by 2017 and 10,000 villages/industrial parks/commercial hubs by 2022, which can island from the main grid during peak hours or grid disturbances.
- Optimally balancing different sources of generation through efficient scheduling and dispatch of distributed energy resources (including captive plants in the near term) with the goal of long term energy sustainability

4.2.2. TRANSMISSION:

- Development of a reliable, secure and resilient grid supported by a strong communication infrastructure that enables greater visibility and control of efficient power flow between all sources of production and consumption by 2027.
- Implementation of Wide Area Monitoring Systems (WAMS, using Phasor Measurement Units, or PMUs) for the entire transmission system. Installation of a larger number of PMUs on the transmission network by 2017 or sooner, as guided by the results of initial deployments. Indigenization of WAMS technology and PMU development and development of custom made analytics for synchrophasor data by 2017.
- Setting up of Renewable Energy Monitoring Centre’s (REMCs) and Energy Storage Systems to facilitate grid integration of renewable generation.
- 50,000 Kms of optical fiber cables to be installed over transmission lines by the year 2017 to support implementation of smart grid technologies.
- Enabling programs and projects in transmission utilities to reduce transmission losses to below 4% by 2017 and below 3.5% by 2022.
- Implement power system enhancements to facilitate evacuation and integration of 30 GW renewable capacity by 2017, 80 GW by 2022, and 130 GW by 2027 – or targets mutually agreed between Ministry of New and Renewable Energy (MNRE) and MoP.

4.2.3. POLICIES, STANDARDS AND REGULATIONS:

- Formulation of effective customer outreach and communication programs for active involvement of consumers in the smart grid implementation.
- Development of state/utility specific strategic roadmap(s) for implementation of smart grid technologies across the state/utility by 2014.

Required business process reengineering, change management and capacity building programs to be initiated by 2014. State Regulators and utilities may take the lead here.

- Finalization of frameworks for cyber security assessment, audit and certification of power utilities by end of 2013.
- Policies for grid-interconnection of captive/consumer generation facilities (including renewables) where ever technically feasible; policies for roof-top solar, net-metering/feed-in tariff; and policies for peaking power stations by2014.
- Policies supporting improved tariffs such as dynamic tariffs, variable tariffs, etc., including mandatory demand response (DR) programs, starting with bulk consumers by 2014, and extending to all 3-phase (or otherwise defined consumers) by 2017.
- Policies for energy efficiency in public infrastructure including EV charging facilities by 2015 and for demand response ready appliances by 2017. Relevant policies in this regard to be finalized by 2014.
- Development/adoption of appropriate standards for smart grid development in India–first set of standards by 2014; continuous engagement in evolution of applicable standards relevant to the Indian context. Active involvement of Indian experts in international bodies engaged in smart grid standards development.
- Study the results of the first set of smart grid pilot projects and recommend appropriate changes conducive to smart grid development in the Indian Electricity Act / National Power Policy by end of 2015.
- Development of business models to create alternate revenue streams by leveraging the smart grid infrastructure to offer other services (security solutions, water metering, traffic solutions etc.) to municipalities, state governments and other agencies.
- Development of Skill Development Centers for smart grid development in line with the National Skill Development Policy 2009 for Power Sector by 2015.

4.2.4. OTHER INITIATIVES:

- Tariff mechanisms, new energy products, energy options and programs to encourage participation of customers in the energy markets that make them “prosumers” – producers and consumers – by 2017.
- Create an effective information exchange platform that can be shared by all market participants, including prosumers, in real time which will lead to the development of energy markets.

- Investment in research and development, training and capacity building programs for creation of adequate resource pools for developing and implementing smart grid technologies in India as well as export of smart grid know-how, products and services.

While many of the targets envisaged by 2017 are yet to be achieved, While many of the targets envisaged by 2017 are yet to be achieved, some of the targets have been steeply raised by Government of India (as in the case of renewable energy, smart metering etc). However the approach of this road map is still relevant and it is time for an updated version of the roadmap.

CONCLUSION

This project report presents a discussion on various technical requirements and key components with an organized approach to evolve the conceptualization of Smart Grid. An overview of roadmap of smart grid in India along with different rules, policies and regulations to be adopted for power system distribution and transmission has also been described. A smart grid consists of many different state-of-the art information and communication technology (ICT) and sensory devices and offers a wide range of advantages to both the utilities and the customers, which are, for example, lowering the utility bills; reduction of the peak demand; economic and job growth; Integration of more renewable energy resources; self-governing control, which increases the system reliability; enhancing capacity and efficiency; enhanced resilience against malicious attacks; integration of different types of energy storages including plug-in electric vehicles; the communication between the service provider and customers is two-way; improved market effciency; better power quality and reliability; better utilization of facilities and deferring building of new power stations; empower predictive maintenance and self-curing; accommodation of decentralized power generations; automated maintenance and operation; reduce GHG emission; several varieties for consumer; providing opportunities for new services, products and markets. The features of the SG which individuates itself from conventional grids, are the sophisticated devices that it uses and the services that it provides in return which are unattainable in conventional grid systems.

Power market in India is generally characterized by the poor demand side management and response for lack of proper infrastructure and awareness. Smart Grid Technology can intuitively overcome these issues. In addition to that, it can acknowledge reduction in line losses to overcome prevailing power shortages, improve the reliability of supply, power quality improvement and its management, safeguarding revenues, preventing theft etc.. In this connection, the paper should act as advocate to bring forth the significance and fortification of Smart Grid philosophy and implanting it on the basis of proposed ideology in Indian subcontinent.

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