A STUDY ON STANDARD GRID SUBSTATION

A thesis presented to

The Academic Faculty

By

Adham Abuiweimer (092482)
Md. Al Amin Sheikh (092468)
Nayem Uddin Chowdhury (092433)
Hassan Mohamed (092481)

In partial fulfillment
Of the requirements for the degree
Bachelor of Science (B.Sc.)
In

Electrical and Electronic Engineering

Islamic University of technology

October, 2013

A STUDY ON STANDARD GRID SUBSTATION

This is to certify that the work presented in this thesis is an outcome of the experiments, study, simulation and real time work carried out by the authors under the supervision of Prof. Dr. Md. Shahid Ullah, Head, Electrical & Electronic Engineering Department & co-supervision of Md. Rakibul Hasan Sagor, Assistant Professor of EEE Department, Islamic University of Technology (IUT).

Adham Abuiweimer	Md. Al Amin Sheikh	Nayem Uddin Chowdhury	Hassan Mohamed
(092482)	(092468)	(092433)	(092481)

Approved by:

Md. Rakibul Hasan Sagor
Thesis Co- Supervisor
Assistant Professor of EEE Department
Islamic University of Technology (IUT).

Prof. Dr. Md. Shahid Ullah
Thesis Supervisor
Head, Department of Electrical and Electronic Engineering
Islamic University of technology (IUT).

A STUDY ON STANDARD GRID SUBSTATION

ABSTRACT

Electricity the most common form of energy is the indicator of economic development of a country. The demand of safe and reliable electricity is going up in such a rate that the present grid system cannot deal with the demand response. The traditional power grid is based on centralized generation plants that supply end-users via long-established, unidirectional transmission and distribution systems. But times are changing. Today's demands for increased power supplies with higher reliability from cleaner and preferably renewable energy sources cannot be met with today's grid infrastructure. We need an intelligent system that can receive power of all qualities from all sources – both centralized and distributed – and deliver reliable supplies, on demand, to consumers of all kinds. In other word we need a *Standard Grid* or *Smart Grid*.

This thesis work is focused on this issue within a small scale grid designing which can be enlarged by proper implementation techniques. Performance analysis and data collection is done by surveying some local substations. The integration of renewable sources and other modern technologies to the grid made it more complex and time consuming to analyze the grid manually. So the use of software based simulation is the only way to perform any analysis with comparative results.

The project endeavored to study the need and analysis of the performance of present power system to identify the weakness as well as to find a way to improve it within limited resource. ETAP is such a software tool that serves the purpose of analysis and possible development of the system using the simulation to provide the result. That's why for some elementary system analysis ETAP is used with the practical data collected from substation survey.

ACKNOWLEDGEMENTS

The undergraduate thesis, ***“A STUDY ON STANDARD GRID SUBSTATION”*** has been written for the completion of Bachelor of Science degree at Islamic University of Technology, Bangladesh. This thesis work and writing has been done during the year 2013 under the supervision of ***Prof. Dr. Md. Shahid Ullah Head, Department of Electrical and Electronic Engineering & co- supervision of Md. Rakibul Hasan Sagor, Assistant Professor of EEE Department***.

We would like to pay our special thanks and express our deepest gratitude to ***Prof. Dr. Md. Shahid Ullah,*** Thesis supervisor & ***Md. Rakibul Hasan Sagor***, Thesis co-supervisor for their constant guidance, help and encouragement to our work. Without their support it would have been impossible to complete such a task successfully.

Finally, we beg pardon and apologize for the faults and any unintentional mistakes that might be recurred in this thesis paper even after all the care that was taken.

Table of Contents

CHAPTER 1

CHAPTER 2
The Smart Grid

CHAPTER 3

Performance Analysis Tools For Smart Grid

CHAPTER 4

Measurement, Control and Communication Technologies for Smart Grid.

CHAPTER 5

A Smart Substation for Smart Grid

CHAPTER 6

Substation Surveys & Simulation Results

CHAPTER 7
Our Proposals

List of Abbreviations

ADC	Analogue to Digital Conversion or Converter
AM	Automated Mapping
AMM	Automatic Meter Management
AMR	Automatic Meter Reading
AVC	Automatic Voltage Control
BES	Battery Energy Storage
BEV	Battery Electric Vehicles
CB	Circuit Breaker
CC	Constant Current
CI	Customer Interruptions
CIM	Common Information Model
CIS	Customer Information System
CSC-HVDC	Current Source Converter High Voltage DC
CT	Current Transformer
CTI	Computer Telephony Integration
CV	Constant Voltage
CVT	Capacitor Voltage Transformers
DER	Distributed Energy Resources
DES	Data Encryption Standard
DMS	Distribution Management System
DMSC	Distribution Management System Controller
DNO	Distribution Network Operators
DNS	Domain Name Server
DR	Demand Response

DSB	Demand-Side Bidding
DSI	Demand-Side Integration
DSL	Digital Subscriber Lines
DSM	Demand-Side Management
EMS	Energy Management System
EV	Electric Vehicles
FACTS	Flexible AC Transmission Systems
HAN	Home-Area Network
HMI	Human Machine Interface
HTTP	Hypertext Transfer Protocol
HVAC	Heating, Ventilation, Air Conditioning
HVDC	High Voltage DC
ICT	Information and Communication Technology
IED	Intelligent Electronic Device
IP	Internet Protocol
ITE	Information Technology Equipment
LAN	Local Area Network
LCD	Liquid Crystal Displays
LED	Light Emitting Diodes
NAN	Neighborhood Area Network
NERC CIP	North America Electric Reliability Corporation Critical Infrastructure
NOP	Normally Open Point
OMS	Outage Management System
PHEV	Plug-in Hybrid Electric Vehicles
PLC	Power Line Carrier

PMU	Phasor Measurement Units
PV	Photovoltaic
RMU	Ring Main Unit
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
SVC	Static Var Compensator
TCP	Transmission Control Protocol
WAMPAC	Wide Area Monitoring, Protection and Control
WAMSs	Wide-Area Measurement Systems
WAN	Wide Area Network

CHAPTER

1

INTRODUCTION

Electric power systems throughout the world are facing radical change stimulated by the pressing need to decarbonize electricity supply, to replace ageing assets and to make effective use of rapidly developing information and communication technologies (ICTs). These aims all converge in the ***Smart Grid*** or ***Standard Grid***. The Smart Grid uses advanced information and communication to control this new energy system reliably and efficiently. Some ICT infrastructure already exists for transmission voltages but at present there is very little real-time communication either to or from the customer or in distribution circuits. The Smart Grid vision is to give much greater visibility to lower voltage networks and to enable the participation of customers in the operation of the power system, particularly through Smart Meters and Smart Homes. The Smart Grid will support improved energy efficiency and allow a much greater utilization of renewables. Smart Grid research and development is currently well funded in the USA, the UK, China, Japan and the EU. It is an important research topic in all parts of the world and the source of considerable commercial interest.

The aim of this paper is to provide a basic discussion of the Smart Grid concept and then, in some detail, to describe the technologies that are required for its realization. Although the Smart Grid concept is not yet fully defined, this paper can provide some basic idea in describing the key enabling technologies and thus permitting the reader to engage with the immediate development of the power system and take part in the debate over the future of the Smart Grid.

Some substation surveys, data collection and computer simulation for the present grid system is provided to analyze the existing grid system and to improve it for further analysis for smart grid. In that case Etap software is used for load flow and reliability analysis. Etap is one of the most comprehensive analysis platform for the design simulation, operation, control, optimization and automation of generation, transmission, distribution and industrial power system. However, to fully capitalize on the potential benefits of smart grids, the energy sector will need to overcome two main challenges. The first is at the level of implementation: issues of standardization and certification, operation, system testing, and consumer participation. The other is financial: large amounts of funding are needed throughout the lifecycle of smart grid development. To facilitate the deployment of smart grids, the energy sector must develop a positive business case with a precise indication of how investments are paid for, reflecting the benefits for the wide range of stakeholders including consumers, utilities, information technology (IT) providers, manufacturers and the environment.

CHAPTER

2

THE SMART GRID

2.1 Introduction

Established electric power systems, which have developed over the past 70 years, feed electrical power from large central generators up through generator transformers to a high voltage interconnected network, known as the transmission grid. Each individual generator unit, whether powered by hydropower, nuclear power or fossil fuelled, is large with a rating of up to 1000MW. The transmission grid is used to transport the electrical power, sometimes over considerable distances, and this power is then extracted and passed through a series of distribution transformers to final circuits for delivery to the end customers.

The part of the power system supplying energy (the large generating units and the transmission grid) has good communication links to ensure its effective operation, to enable market transactions, to maintain the security of the system, and to facilitate the integrated operation of the generators and the transmission circuits. This part of the power system has some automatic control systems though these may be limited to local, discrete functions to ensure predictable behavior by the generators and the transmission network during major disturbances.

The distribution system, feeding load, is very extensive but is almost entirely passive with little communication and only limited local controls. Other than for the very largest loads, there is no real-time monitoring of either the voltage being offered to a load or the current being drawn by it. There is very little interaction between the loads and the power system other than the supply of load energy whenever it is demanded.

The present revolution in communication systems, particularly stimulated by the internet, offers the possibility of much greater monitoring and control throughout the power system and hence more effective, flexible and lower cost operation. The Smart Grid is an opportunity to use new ICTs (Information and Communication Technologies) to revolutionize the electrical power system. However, due to the huge size of the power system and the scale of investment that has been made in it over the years, any significant change will be expensive and requires careful justification .The consensus among climate scientists is clear that man-made greenhouse gases are leading to dangerous climate change. Hence ways of using energy more effectively and generating electricity without the production of CO2 must be found. The effective management of loads and reduction of losses and wasted energy needs accurate information while the use of large amounts of renewable generation requires the integration of the load in the operation of the power system in order to help balance supply and demand. Smart meters are an important element of the Smart Grid as they can provide information about the loads and hence the power flows throughout the network. Once all the parts of the power system are monitored, its state becomes observable and many possibilities for control emerge.

In the UK, the anticipated future de-carbonized electrical power system is likely to rely on generation from a combination of renewables, nuclear generators and fossil-fuelled plants with carbon capture and storage. This combination of generation is difficult to manage as it consists of variable renewable generation and large nuclear and fossil generators with carbon capture and storage that, for technical and commercial reasons, will run mainly at constant output. It is hard to see how such a power system can be operated cost-effectively without the monitoring and control provided by a Smart Grid.

2.2 Why implement the Smart Grid now?

Since about 2005, there has been increasing interest in the Smart Grid. The recognition that ICT offers significant opportunities to modernize the operation of the electrical networks has coincided with an understanding that the power sector can only be de-carbonized at a realistic cost if it is monitored and controlled effectively. In addition, a number of more detailed reasons have now coincided to stimulate interest in the Smart Grid.

2.2.1 Ageing Assets and Lack of Circuit Capacity

In many parts of the world (for example, the USA and most countries in Europe), the power system expanded rapidly from the 1950s and the transmission and distribution equipment that was installed then is now beyond its design life and in need of replacement. The capital costs of like-for-like replacement will be very high and it is even questionable if the required power equipment manufacturing capacity and the skilled staff are now available. The need to refurbish the transmission and distribution circuits is an obvious opportunity to innovate with new designs and operating practices. In many countries the overhead line circuits, needed to meet load growth or to connect renewable generation, have been delayed for up to 10 years due to difficulties in obtaining rights-of-way and environmental permits. Therefore some of the existing power transmission and distribution lines are operating near their capacity and some renewable generation cannot be connected. This calls for more intelligent methods of increasing the power transfer capacity of circuits dynamically and rerouting the power flows through less loaded circuits.

2.2.2 Operational Constraints

Any power system operates within prescribed voltage and frequency limits. If the voltage exceeds its upper limit, the insulation of components of the power system and consumer equipment may be damaged, leading to short-circuit faults. Too low a voltage may cause malfunctions of customer equipment and lead to excess current and tripping of some lines and generators. The capacity of many traditional distribution circuits is limited by the variations in voltage that occur between times of maximum and minimum load and so the circuits are not loaded near to their thermal limits. Although reduced loading of the circuits leads to low losses, it requires greater capital investment. The frequency of the power system is governed by the second-by-second balance of generation and demand. Any imbalance is reflected as a deviation in the frequency from 50 or 60 Hz or excessive flows in the tie lines between the control regions of very large power systems. System operators maintain the frequency within strict limits and when it varies, response and reserve services are called upon to bring the frequency back within its operating limits [1]. Under emergency conditions some loads are disconnected to maintain the stability of the system.

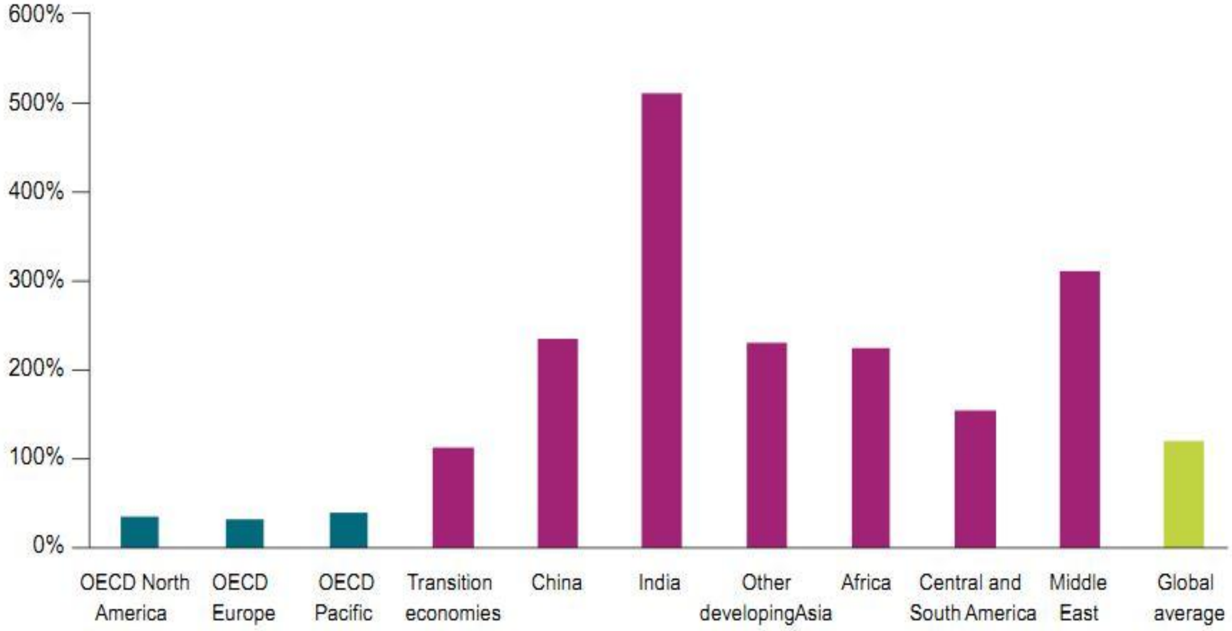
Renewable energy generation (for example. wind power, solar PV power) has a varying output which cannot be predicted with certainty hours ahead. A large central fossil-fuelled generator may require 6 hours to start up from cold. Some generators on the system (for example, a large nuclear plant) may operate at a constant output for either technical or commercial reasons. Thus maintaining the supply–demand balance and the system frequency within limits becomes difficult. Part-loaded generation ‘spinning reserve’ or energy storage can address this problem but with a consequent increase in cost. Therefore, power system operators increasingly are seeking frequency response and reserve services from the load demand. It is thought that in future the electrification of domestic heating loads (to reduce emissions of CO2) and electric vehicle charging will lead to a greater capacity of flexible loads. This would help maintain network stability, reduce the requirement for reserve power from part-loaded generators and the need for network reinforcement.

2.2.3 Security of supply

Modern society requires an increasingly reliable electricity supply as more and more critical loads are connected. The traditional approach to improving reliability was to install additional redundant circuits, at considerable capital cost and environmental impact. Other than disconnecting the faulty circuit, no action was required to maintain supply after a fault. A Smart Grid approach is to use intelligent post-fault reconfiguration so that after the (inevitable) faults in the power system, the supplies to customers are maintained but to avoid the expense of multiple circuits that may be only partly loaded for much of their lives. Fewer redundant circuits result in better utilization of assets but higher electrical losses**.**

2.2.4 National initiatives

Many national governments are encouraging Smart Grid initiatives as a cost-effective way to modernize their power system infrastructure while enabling the integration of low-carbon energy resources. Development of the Smart Grid is also seen in many countries as an important economic/commercial opportunity to develop new products and services.



Source: IEA, 2011, *Technology Roadmap Smart Grids*

Fig 2.1: National initiatives towards Smart Grid.

2.3 What is the Smart Grid?

There is no acceptable or universal definition for the Smart Grid rather it is function based. The Smart Grid concept combines a number of technologies, end-user solutions and addresses a number of policy and regulatory drivers. It does not have a single clear definition**.**

The European Technology Platform defines the Smart Grid as:

“A Smart Grid is an electricity network that can intelligently integrate the actions of all users connected to it – generators, consumers and those that do both – in order to efficiently deliver sustainable, economic and secure electricity supplies.”

According to the US Department of Energy:

“A smart grid uses digital technology to improve reliability, security, and efficiency (both economic and energy) of the electric system from large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources.”

So, Smart Grid is –

- An optimized grid with more extensive monitoring and communication system.
- Two way flow of power and information
- Grid interconnection
- Electricity storage facilities
- A large portion of distributed and renewable generation.

Smart grid system must be designed to meet four major requirements. They are –

- Capacity
- Reliability
- Efficiency
- Sustainability

2.3.1 Capacity:

As long as societal will does not limit the growth of energy consumption, it is expected that the consumption of electrical energy will grow substantially in the future. If the forecast of the International Energy Agency holds, it means that we will need to add one 1 GW power plant and related grid infrastructure every week for the next 20 years. The future electric system must cope with this capacity increase in an economic way.

2.3.2 Reliability:

Reliability of the electrical system has always been a priority to engineers and has improved dramatically over the last few decades. Nevertheless, electricity interruptions are still a real risk. Dramatic events such as massive rolling blackouts that can cut a whole country from its electricity supply are only the small tip of a far larger iceberg. It is the large number of short disturbances that contribute to significant economic disadvantages. A more reliable electrical supply not only helps the economy and improves the quality of life, but it also has a positive influence on climate change. If an electrical system can safely handle and stabilize grid disturbances, then that system will require fewer generating plants available in reserve. This means lower emissions**.**

2.3.3 Efficiency:

Energy efficiency is one of the most important requirements for the Smart Grid system. The reluctance to invest in energy efficiency is surprising. Investments can usually be recouped through lower energy costs in less than two years, and under other circumstances, businesses would normally leap at such prospects of rapid returns. A major obstacle is a lack of knowledge in private households, companies or public authorities concerning energy-efficient equipment. This challenge is further compounded by the variety of available options. In addition, energy efficient solutions are rarely photogenic, and many have obscure names. Variable-speed drives, which raise the efficiency of electric motors, sit in plain metal boxes, belying the fact that their energy saving potential is many times greater than the much touted compact fluorescent light bulb.

2.3.4 Sustainability:

Generating electricity with solar, wind, wave or geothermal energy is without doubt a powerful way to avoid CO2 emissions. There is hope that with improving technology, better conversion efficiency and sinking production costs, the contribution of such sources to the future energy mix will increase. Hydropower is the traditional CO2 free source of electrical energy and according to the IEA this will continue to be the case for the next 20 years.

Generating electricity in this way is one task; the other equally important requirement is to connect it to the electrical grid. Huge distances have to be bridged to carry electrical power from hydropower plants to the centers of consumption. Intermittent wind-power generators pose another challenge on grid stability and the need for additional reserves, but adequate technology is also required to connect them from remote places far offshore. Energy storage will ultimately help to overcome the issues of intermittency and HVDC cable technology is the way to cross the sea. The final influence, however, is the end consumer who decides how much and in which way he wants to consume energy. At the present energy costs and in view of the difference between high and low tariffs, the incentives to save energy or use it at times of lower cost are limited. Technology could provide greater transparency regarding consumption at any moment in time and its associated cost to the consumer. The resulting demand response relationship between generators and consumers makes a further contribution to the reduction of the required generating reserve.

2.4 Integrating Renewables

The integration of renewable energy is one of the most important criteria for Smart Grid. The design and development of the smart grid requires modeling renewable energy sources and technologies such as wind, PV, solar, biomass, and fuel cells, analyzing heir levels of penetration, and conducting impact assessments of the legacy system for the purpose of modernization.

2.4.1 Solar Power Technology

Solar energy harnessed by the use of photovoltaic (PV) cells was first discovered in 1839 by French physicist Edmund Becquerel. The technology can be a single panel, a string of PV panels, or a multitude of parallel strings of PV panels. Solar PV has no emissions, is reliable, and requires minimum maintenance.

The PV system generally considers:

- Insolation: The availability of solar energy conversion to electricity. Insolation levels are affected by the operating temperature of PV cells intensity of light (location - dependent), and the position of the solar panels (maximize the power tracking while maximizing perpendicular incident light rays).
- Emission: PV emission levels are environmental friendly.

To improve efficiency, the materials used for manufacturing PV cells include amorphous silicon, polycrystalline silicon, cadmium telluride, microcrystalline silicon, and copper indium selenite.

Solar power technology enhances PV output by concentrating a large area of sunlight into a small beam using lenses, mirrors, and tracking systems. Parabolic troughs and solar power towers are examples of such technologies.

Cost Implication: Manufacturers continue to reduce the cost of installation as new technology is developed for manufacturing materials. Much work is being conducted in the manufacturing of PV and the development of superior materials. Basic materials include mono crystalline and polycrystalline panels, cast polycrystalline silicon, and string and ribbon silicon, as well as amorphous silicon or thin film panels which are created by the application of amorphous silicon, copper indium dieseline (CIS), and cadmium telluride as a thin semiconductor film. This application allows for the manufacturing of panels that are less time - consuming to manufacture with lower manufacturing costs and that are applicable to varied applications, albeit with reduced efficiency.

2.4.2 Wind Turbine Systems

Fig 2.2: Wind Turbine integration System.

Wind is one of the fastest - growing sources of renewable energy throughout the world (see Fig 2.3).Turbines produce electricity at affordable cost without additional investments in infrastructure such as transmission lines. A wind turbine consists of a rotor, generator, blades, and a driver or coupling device. Compared with PV, wind is the most economically competitive renewable. Although turbines produce no CO_2 or pollutants, wind has three drawbacks: output cannot be controlled, wind farms are most suited for peaking applications, and power is produced only when there is sufficient wind.

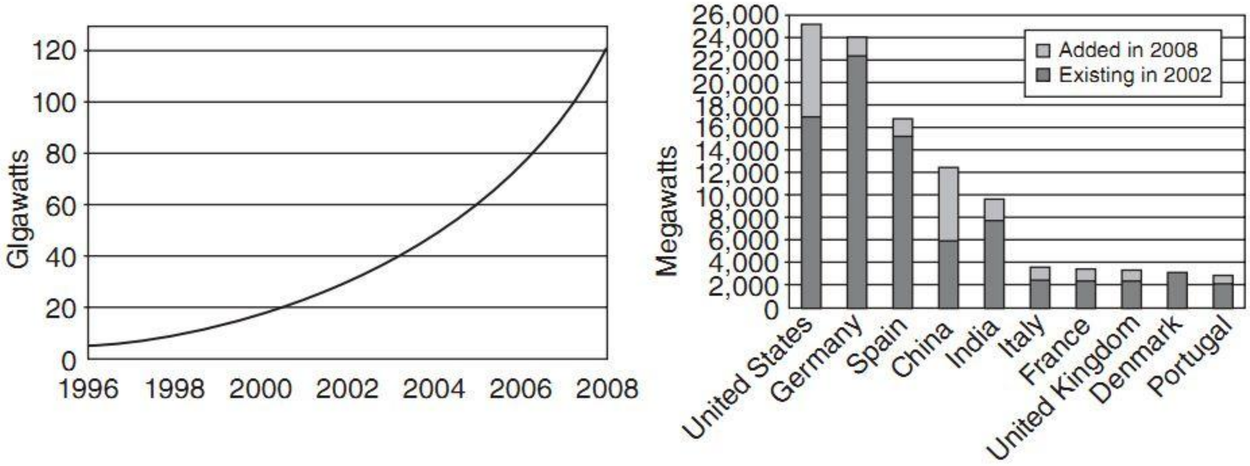


Fig 2.3: (a) Wind power, existing world capacity, 1996 –2008; (b) wind power capacity, top ten countries, 2008.

2.4.3 Small and Micro Hydropower

Hydropower is by far the largest renewable source of power/energy. Small hydropower systems vary from 100 kW to 30 MW while micro hydropower plants are smaller than 100 kW. Small hydropower generators work in variable speed because of water flow. Induction motors provide a generator for a turbine system. The hydraulic turbine converts the water energy to mechanical rotational energy. Small and micro hydropower systems are RER optimizations to enhance the smart grid. The issues of reliability and modeling are addressed as in PV and wind energy. CI technology is used for performance study and commitment.

2.4.4 Storage for Stability

One of the challenges of a smart grid is ability to cope with intermittent and variable power sources. But this is a must, since power sources such as wind and solar are becoming increasingly important. Electricity storage facilities are one of the most important criteria for Smart Grid system. It can help improve stability and power quality in grids with a greater reliance on renewable generation.

Energy Storage has some requirements

– High-energy density

– Very short response time

– High power capability both in charge and discharge

– Excellent cycling capability

– High charge retention

– Maintenance-free design

Dynamic energy storage is finding uses in a multitude of areas. Not only can it support the black start of grids, it can also bridge power until emergency generation is online and provide grid support with an optimum mix of active and reactive power. This type of storage is an alternative to transmission and distribution reinforcements for peak load support, and enables optimum pricing. It becomes possible to reduce peak power to avoid high tariffs. Dynamic energy storage can also provide power quality control in conjunction with railway electrification, and help balance power in wind and solar generation, which have stochastic behavior.

2.4.5 Demand Response Issues

Energy management involves controlling electrical and mechanical systems to reduce power needs and the associated costs. DR helps to reduce customer demand on the grid that is dependent on that demand. Abundant data, including price signals and grid conditions, allow DR technologies to play a significant role. Monitoring operating parameters such as voltage, angle, and frequency of the system are utilized through real – time sensors in addition to controllers, metering signals, and two – way digital communication, in responding to changes in the grid and electricity prices. Automatic DR in times of disruption is a key feature of the smart grid, as are smart meters, smart appliances, and distributed RER. To achieve optimal control of demand and fulfill economic and environmental goals, utilities can show customers how to adjust their consumption to off – peak time demand to assist in efficient supply.

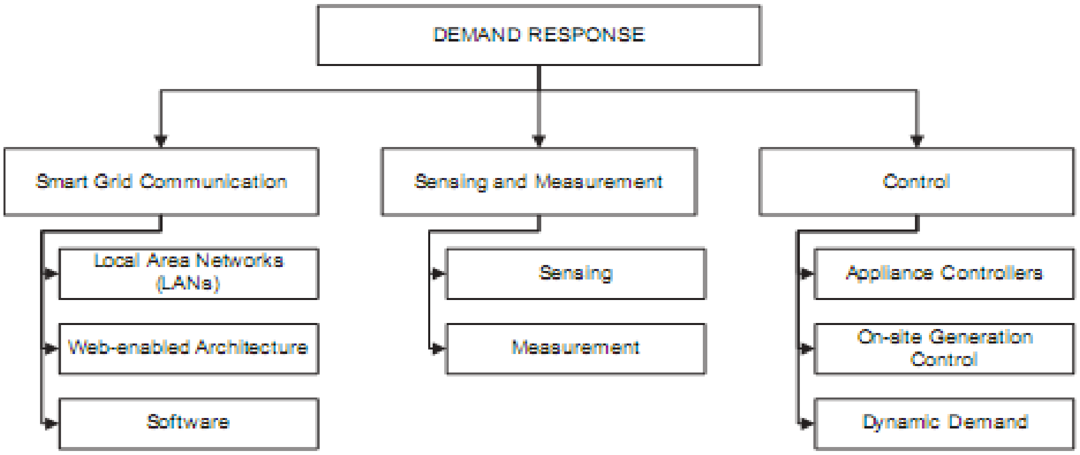


Figure 2.4: Demand Response Technology Tree.

Figure 2.4 shows the DR applications that can be categorized into four components:

A. Energy Efficiency

B. Price - based DR

a. Time - of - use (TOU)
b. Day - ahead hourly pricing

C. Incentive - based DR

a. Capacity services
b. Demand bidding buy - back
c. Direct load control

D. Time scale commitments and dispatch

a. Years of system planning
b. Months of operational planning
c. Day - ahead economic scheduling
d. Day - of economic dispatch
e. Minutes dispatch

2.4.6 Electric Vehicles and Plug-in Hybrids

The integration of electric vehicles and hybrids is another component of the smart grid system. Vehicle - to - grid power (V2G) uses electric - drive vehicles (battery, fuel cell, or hybrid) to provide power for specific electric markets. V2G can provide storage for renewable energy generation and stabilize large - scale wind generation via regulation. Plug - in hybrids can dramatically cut local air pollution. Hybridization of electric vehicles and connections to the grid overcome limitations of their use including cost, battery size/weight, and short range of application. PHEVs provide the means to replace the use of petroleum - based energy sources with a mix of energy resources (encountered in typical electric power systems) and to reduce overall emissions.

Figure 2.5: Electric Vehicles Plug-in Grid.

2.5 Operations and Control

New integrated SCADA/DMS innovations put more analysis and control functions in the hands of grid operators. As distribution systems continue to become ever “smarter” and more secure, the operations centers that control them are also changing to take on new roles in managing the evolving grids. Analytical software and other advanced applications are providing more far-reaching analyses and permit-ting automated operations.

2.5.1 Smartness in Control

Over the last decade, the electric power industry has experienced unprecedented change. This has been fueled both by technological breakthroughs and by the restructuring of the industry itself. Restructuring has seen many utilities move from a regulated environment to a more market-oriented paradigm. At the same time, the IT systems that supported transmission and distribution operations became more robust and powerful, and have now reached the point where multiple applications can be presented on a single platform. The future grid will be largely automated, being able to apply intelligence to operate, monitor and even heal itself. This smart grid will be more flexible, more reliable and better able to serve the needs of tomorrow’s world. As distribution systems continue to become ever “smarter” and more secure, the operation centers that control them are also changing to take on new roles in managing the evolving grids.

Figure 2.6: Control room for Smart grid system.

2.5.2 Network Management

Network management and utility communication technologies enable the evolution of smart grids by providing real-time management of transmission grids, distribution networks, power plants and energy trading markets. These technologies collect, transmit, store, analyze and reliably communicate critical data from thousands of data points across power networks and over large geographical areas. Large-scale integration of renewable resources, regulation of two-way distribution grids, long-distance transmission, and incorporation of electric cars and charging facilities would be impossible without these technologies.

2.6 Consumption and Efficiency

Proper condition monitoring of critical equipment can act as an early warning system against impending problems. However, condition monitoring is not used everywhere, often because of the expense of installing proper sensors and cabling, especially if the monitoring system needs to retrofitted to existing equipment. Most processes use devices that are capable of collecting and producing relevant signals which can be used for diagnostic purposes. Thus *Data enhancement* and condition monitoring can improve the overall efficiency.

2.6.1 Condition Monitoring

Intelligent transmission systems/assets include a smart intelligent network, self-monitoring and self - healing, and the adaptability and predictability of generation and demand robust enough to handle congestion, instability, and reliability issues. This new resilient grid has to withstand shock (durability and reliability), and be reliable to provide real - time changes in its use.

Wide-area monitoring improves performance of network management systems by enlarging the area the systems can see. Satellite communications can quickly access information from neighboring grids, and use it to prevent the development of widespread faults.

2.6.2 Smart Metering

Smart meter is one of the most important requirements for the Smart Grid system. Smart meter is that which gives us the reading for the consuming power as well as the reading of feedback to the grid and ensure the two way flow of power which is the main criteria for Smart Grid system.

2.6.3 Innovative Building

Commercial and residential buildings account for about 38 percent of global end-user energy demand, mainly for heating, cooling and powering electric appliances. The consumption of buildings can be reduced with energy efficient technologies such as intelligent controls that adjust the heating temperature, lighting and energy consumption of electric appliances to the actual requirements. Today, such intelligent building systems operate independently of the power grid. In a smarter network, they will interact with the grid to give consumers greater control over the amount of electricity they use as well as when they use it. For example, customers will be able to configure their building automation systems so that the heating is lowered during periods of peak demand, or they may authorize a third-party or their utility to take such action on their behalf. This would help customers lower their electricity bills as well as enhancing the overall efficiency of the system. To become fully integrated into the power supply network, buildings have to be equipped with meters capable of collecting more precise data about electricity consumption and of communicating with the utility's distribution automation or network management solutions.

2.7 The Smart Grid in Terms of Overall Vision:

Source: Smart Grid 2030 Associates, *SG2030™ Smart Grid Portfolios*

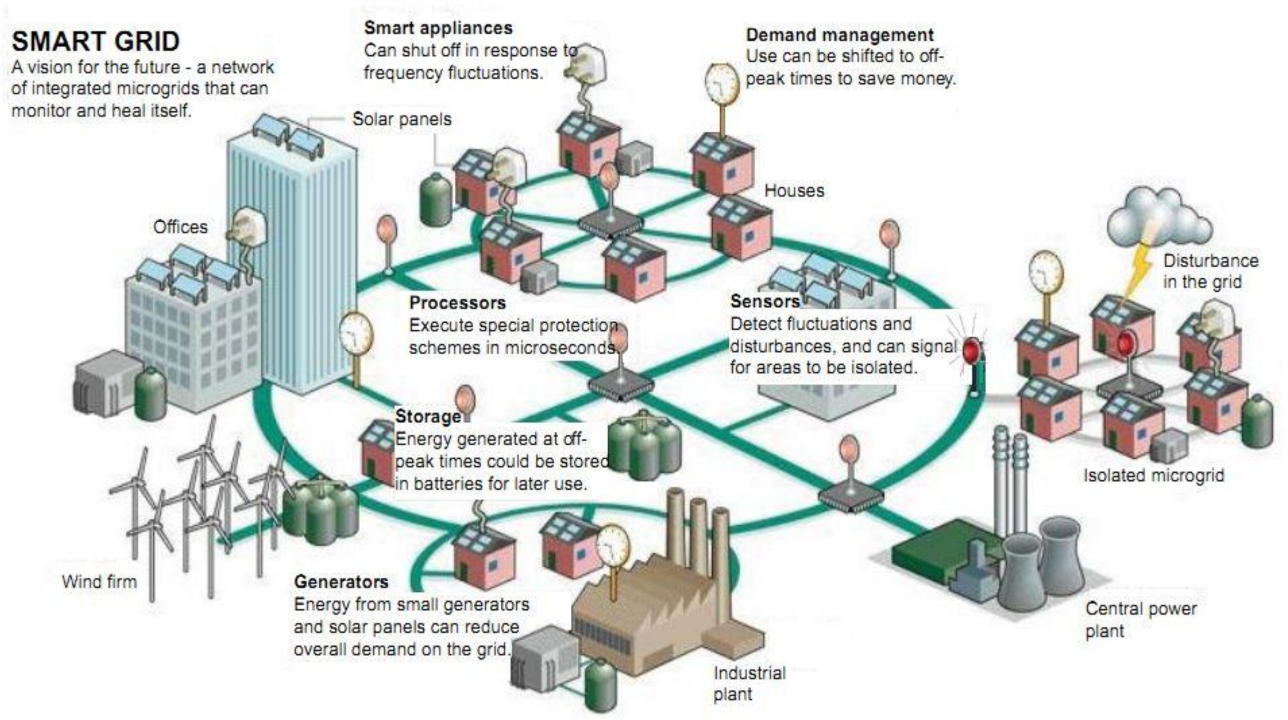


Figure 2.7: Smart Grid in Terms of Overall Vision

2.7.1 Basic differences between Current Grid vs. Smart Grid:

The basic difference between Current Grid and Smart Grid are given below:

Preferred Characteristics	Current Grid	Smart Grid
Generation	Centralized	Centralized & distributed
Metering	Electromechanical	Digital ‘Smart Meter’
Reliability	Prone to failures Cascading outages Essentially reactive	Automated, Pro-active protection And prevent outages
Restoration after disturbance	Manual	Self- healing
Communication	None or one way, typically not real time	Two way and real time

The pictorial view of basic differences between Current Grid & Smart Grid is given below:

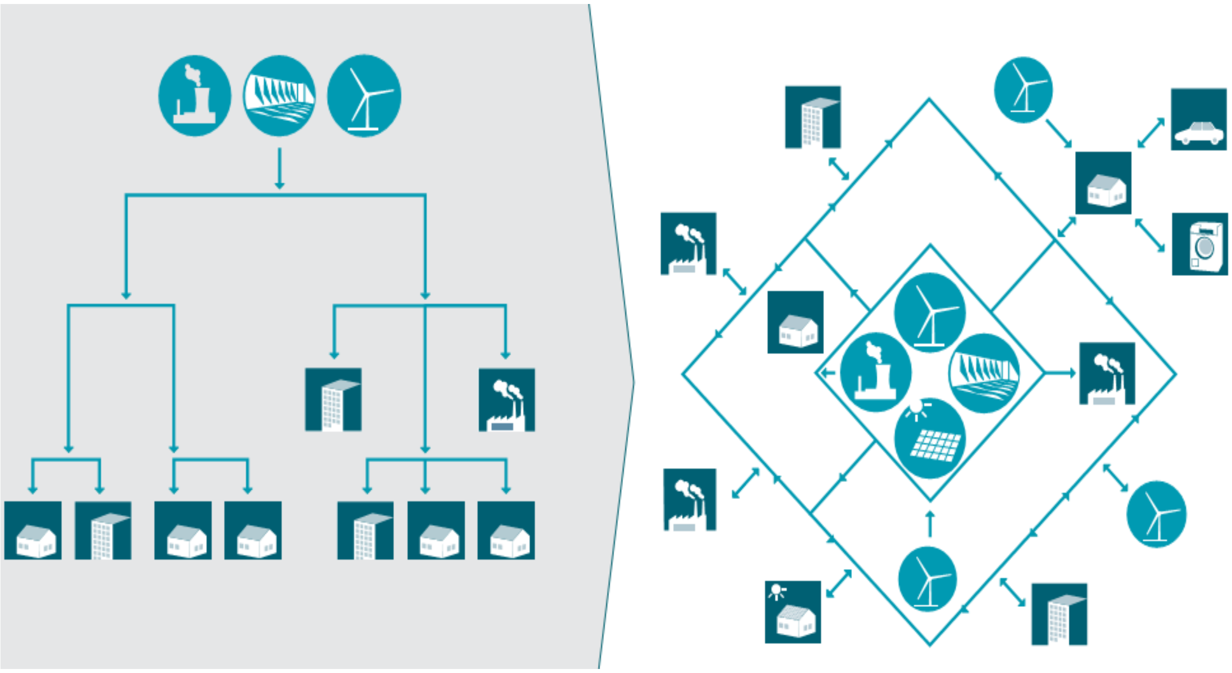


Figure 2.8: Current Grid system **Smart Grid System**

2.7.2 Benefits: what good is a smart grid?

EFFICIENCY: It is estimated that tens of billions of dollars will be saved thanks to demand-response programs that Provide measurable, persistent savings and required no human intervention or behavior change. The dramatically reduced need to build more power plants and transmission lines will help too.

RELIABILITY: A Smart Grid that anticipates, detects and responds to problems rapidly reduces wide-area blackouts to near zero (and will have a similarly diminishing effect on the lost productivity).

AFFORDABILITY: Energy prices will rise; however, the trajectory of future cost increases will be far more gradual post-Smart Grid. Smart Grid technologies, tools, and techniques will also provide customers with new options for managing their own electricity consumption and controlling their own utility bills

SECURITY: The Smart Grid will be more resistant to attack and natural disasters. So fortified, it will also move us toward energy independence from foreign energy sources, which themselves may be targets for attack, outside of our protection and control.

ENVIRONMENT/CLIMATE CHANGE: Clean, renewable Sources of energy like solar, wind, and geothermal can easily be integrated into the nation's grid. We reduce our carbon footprint and stake a claim to global environmental leadership.

GLOBAL COMPETITIVENESS: Regaining our early lead in solar and wind will create an enduring green-collar economy.

2.7.3 Smart Grid Challenges:

A common challenge among the countries and regions is the need for more public funds and tariff incentives for all stages of smart grid development: research and development (R&D), large demonstration projects (which show the impact on the system), and full deployment, in both advanced and emerging countries (Fig. 2.9). All countries, regardless of whether they are developed or emerging, face a number of challenges and government intervention can demonstrate and accelerate the deployment of smart grid technologies.

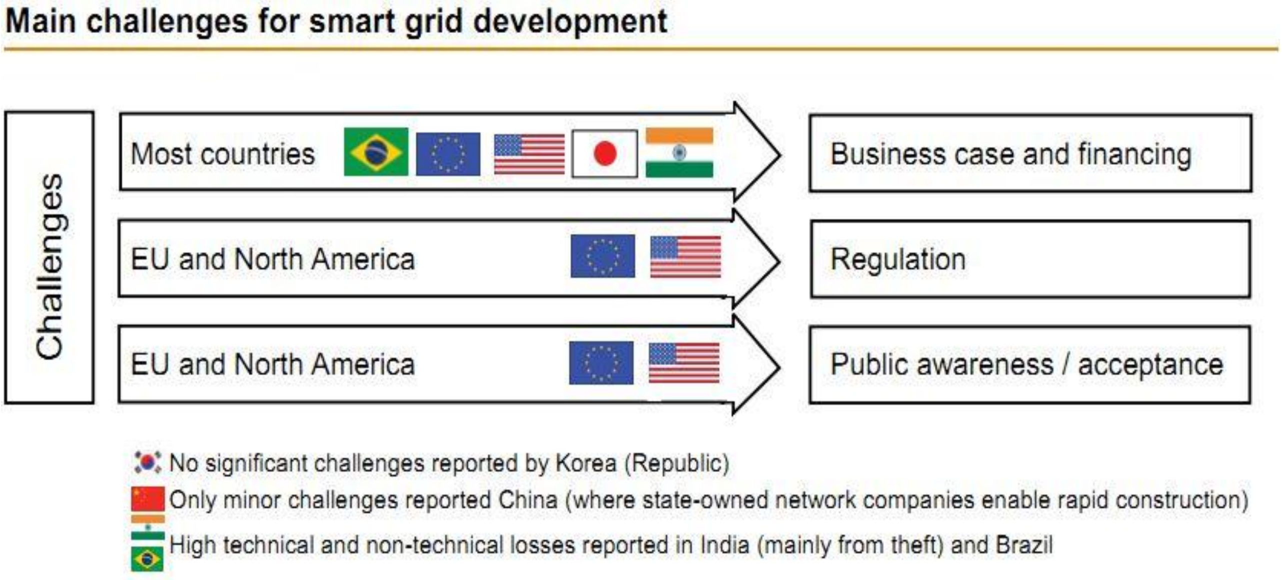


Fig. 2.9: Major Challenges for Smart Grid Development.

2.8 Summary:

Smart grid technology is not a single silver bullet but rather a collection of existing and emerging technologies working together. The transition from the grid we know today to the grid of tomorrow will be as profound as all of the advances in power systems over the last hundred years, but it will take place in a fraction of that time. The integration of smart technologies of many different kinds will be essential to a functioning smart grid, and the path to integration is lined with interoperability standards. Realizing smart grids' potential will require a new level of cooperation between industry players, advocacy groups, the public and especially the regulatory bodies that have such immediate influence over the direction the process will take. In the end, though, a fully realized smart grid will benefit all stakeholders.

CHAPTER

3

PERFORMANCE ANALYSIS TOOLS FOR SMART GRID

3. INTRODUCTION TO LOAD FLOW STUDIES:

Load flow or power flow analysis provides the steady-state solution of a power network for specific network conditions which include both network topology and load levels. The power flow solution gives the nodal voltages and phase angles and hence the power injections at all buses and power flows through lines, cables and transformers. It is the basic tool for analysis, operation, and planning of distribution networks.

System Buses	Known	Unknown
Slack Bus or, Swing Bus	|V| and δ	P and Q
Load Bus or, P-Q Bus	P and Q	|V| and δ
Regulated Bus or, P-V Bus	P and |V|	Q and δ

Table 3.1The System Buses General Classification.

In a power system, each bus bar is associated with four quantities:

- Magnitude of voltage (|V |) its angle (θ),
- Real power injection (P) and
- Reactive power injections (Q).

For power flow analysis, only two of these quantities are specified, and the remaining two are obtained by the power flow solution. Depending upon the specified and unspecified quantities, the bus bars are classified into three types as shown in Table 3.1. The power flow can be formulated as a set of nonlinear algebraic equations and then a suitable mathematical technique such as the Gauss-Seidel, Newton-Raphson, or fast-decoupled method can be chosen for the solution of the equations.

3.1 THE CLASSICAL METHODS OF STUDYING LOAD FLOW:

The traditional load flow techniques used for distribution load flow are characterized by:

1. Distribution systems are radial or weakly meshed network structures
2. High X/R ratios in the line impedances
3. Single phase loads handled by the distribution load flow program
4. Distributed Generation (DG), other renewable generation, power supplies installed in relative proximity to some load center
5. Distribution systems with many short line segments, most of which have low Impedance values.

For the purpose of load flow study we model the network of buses connected by lines or switches connected to a voltage - specific source bus. Each bus may have a corresponding load composite form (consisting of inductor, shunt capacitor, or combination).

The classical methods of studying load flow include:

1. Gauss – Sidel
2. Newton – Raphson
3. Fast Decouple

We summarize each of them here for easy reference.

3.1.1 Gauss–Sidel Method:

This method uses Kirchhoff's current law nodal equations given as Injection current at the node. Suppose I injection = current at the node of a given connected load, then

$$I_{inj(j)} = \sum_{i=1}^{n} I_{ji}$$

where $I_{inj}(j)$ is the injection current at bus j and I_{ji} = current flow from j th bus to i th bus. Rewriting, we obtain $I_{inj}(j)$ = Y bus V bus where Y bus admittance matrix is given as V bus vector of bus voltages. If we sum the total power at a bus, the generation and load is denoted as complex power. The nonlinear load flow equation is:

$$S_{inj-k} = P_g + jQ_g - (P_{LD} + jQ_{LD}) = V_k \left(\sum_{j=1}^{n} Y_{kj} V_j \right)^*$$

This equation is solved by an iterative method for V_j if P and Q are specified. Additionally, from:

$$S_{inj-k} = P_g + jQ_g - (P_{LD} + jQ_{LD}) = V_k \left(\sum_{j=1}^{n} Y_{kj} V_j \right)^*$$

Where Yij are the elements of bus admittance matrix, and P_{isch} and Q_{isch} are scheduled P and Q at each bus. After a node voltage is updated within iteration, the new value is made available for the remaining equations within that iteration and also for the subsequent iteration. Given that the initial starting values for voltages are close to the unknown, the iterative process converges linearly. Notably, the classical method performance is worse in a radial distribution system because of the lack of branch connections between a large set of surrounding buses. It should be noted that the injection voltage correction propagates out to the surrounding buses on the layer of neighboring buses for each iteration.

3.1.2 <u>Newton–Raphson Method:</u>

The Newton – Raphson Method assumes an initial starting voltage use in computing mismatch power ΔS where $\Delta S = S_{ij-i}^{sch} - (V_i^{|k|})^* (\sum Y_{ij} V_J^K)$ The expression ΔS is called the mismatch power. In order to determine convergence criteria given by ΔS ≤ ε, where ε is a specific tolerance, accuracy index, and a sensitivity matrix is derived from the inverse Jacobian matrix of the injected power equations:

$$P_i = |V_i| \sum |Y_{ij}||V_j| \cos(\theta_i - \theta_j - \psi_{ij})$$

$$Q_i = |V_i| \sum |Y_{ij}||V_j| \sin(\theta_i - \theta_j - \psi_{ij})$$

Where θi is the angle between V_i and V_j, and ψ_{ij} is admittance angle. The complex power ΔS can be expressed in polar or rectangular form

$| \Delta V| = (\Delta e + \Delta f)$ or

$\Delta V = | \Delta V| \angle\theta v$ or $\Delta S = \Delta P + \Delta Q$ respectively.

This method is excellent for large systems but does not take advantage of the radial structure of distribution and hence is computationally inefficient. The method fails when the Jacobian matrix is singular or the system becomes ill - conditioned as in the case of a low distribution X/R ratio.

3.1.3 Fast Decouple Method:

The fast decouple method simplifies the Jacobian matrix by using small angle approximations to eliminate relatively small elements of the Jacobian. The method is one of the effective techniques used in power system analysis. However, it exhibits poor convergence with a high R/X ratio system. The interaction of V and θ magnitudes with active and reactive power flows cause poor convergence as well. A variation solves current injection instead of model power injection power equations.

3.1.4 Distribution Load Flow Methods:

Due to the limitation of the fast decouple method in solving an ill - conditioned system with a high X/R ratio; the distribution load flow techniques above require alternative methods. We summarize the commonly used methods.

1. ***Forward/backward sweep methods*** solves branch current or load flow by using the forward sweeping method

2. Compute the nodal voltages using backward sweep approach

3**.** ***Newton method*** uses power mismatches at the end of feeders and laterals to iteratively solve the nodal voltage

4. ***Gauss method*** on the bus impedance matrix equation solves iteratively for the branch currents.

Method 1: Forward/Backward Sweep:

This method models the distribution system as a tree network, with the slack bus denoted as the root of the tree and the branch networks as the layers which are far away from the root nodal. Weakly meshed networks are converted to a radial network by breaking the loops and injection currents computation.

The backward sweep primarily sums either the line currents or load flows from the extreme feeder (leaf) to the root. The steps of the algorithm are:

1. Select the slack bus and assume initial voltage and angle at the root, node, and other buses

2. Compute nodal current injection at the K th iteration.

$$I_i^{(k)} = \left[\frac{S_i^{sch}}{V_i^{(k-1)}} \right]^*$$

3. Start from the root with known slack bus voltages and move toward the feeder and lateral ends

4. Compute the voltage at node j

$$V_j^{(k-1)} = V_i^k - Z_{ij} I_{ij}^{(k)}$$

Where Zij is the branch impedance between bus i and j and Vj is the latest voltage value of bus j.

5. Compute the power mismatch from and check the termination criteria using.

$$\Delta S_i^{(k)} = S_i^{sch} - V_i^{(k)} (I_i^{(k)})^* \leq \varepsilon$$

6. If step above is not reached repeat the previous steps until convergence is achieved.

Note that in Step 2 from each known load power S, the lateral voltages are computed or assumed.

This involves V_i^{k-1} as the k − 1 past iteration of bus voltage and $I_i^{(k)}$ is the Kth current iteration of injected current. We do this by starting from the last branch.

From the lateral feeder and moving back through the tree node. This is done using the Expression as before for all interconnected branches.

$$I_i^{(k)} = \left[\frac{S_i^{sch}}{V_i^k} \right]$$

Method 2: Load Flow Based on Sensitivity Matrix for Mismatch Calculation:

The distribution load flow is an improved forward/backward method utilizing a sensitivity matrix scheme to compensate the mismatch between slack bus power injection and the load flow at the feeder and lateral ends. This results in the Newton – Raphson method for distribution load flow.

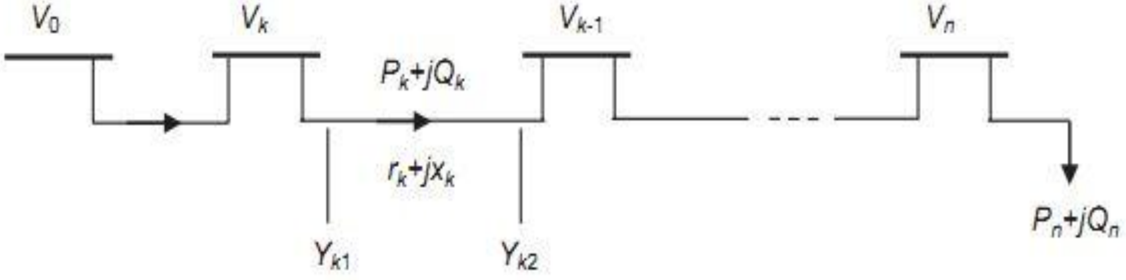


Figure 3.1. Single feeder representation.

Consider a single feeder, as shown in Figure 3.1.The steps for this method are:

1. Assume the slack bus as the root node.
2. Assume P_0, Q_0 power injection at the slack bus node equal to the sum of all of the loads in the system.
3. Load flows in each branch are equal to the sum of downstream connected loads.

At kth iteration, start from root node with known voltage at slack bus.

4. Obtain the latest = V_k, $P_{ij}k$, $Q_{ij}k$ (voltage and flows).
5. Compute power loss = $f\,(V_k, P_{ij}^*, Q_{ij}^*)$

6. From the loss compute receiving and power P_{ji},Q_{ji} ,and V_j.

7. The loads and shunt power are taken from the received power and the remaining power is sent to the next feeder at lateral branches.

8. At network solutions ΔPL, ΔQL = 0, when mismatch power is approximately 0; if load flow mismatch is less than the tolerance, ε then load flow has Converged.

9. Update the slack bus power from the sensitivity matrix .

Method 3: Bus Impedance Network:

This method uses the bus impedance matrix and equivalent current injection to solve the network equation in a distribution system.

It employs a simple superposition to find the bus voltage through the system. The Voltage in each bus is computed after specifying the slack bus voltage and then computing the incremental change ΔV due to current injection flowing into the network.

The steps are:

1. Assume no load system.

2. Initialize the load bus voltage throughout the system using the value of the slack bus voltage.

3. Modify nodal voltages due to current flow which are function of loads connected.

4. The injection current is modified in K_{th} iteration as level changes.

5. Use $I_i^{(k)} = \left(S_i^{sch}/V_i^{k-1}\right)^*$ for the first equivalent current injection until getting I_j^k at the $I_0^{(k)}$.

6. Compute the vector of voltage denoted as ΔV using $\Delta V_{bus}^{(k)} = Z_{bus} I_{inj}^{(k)}$, where Z_{bus} is η × η bus impedance matrix .

7. Determine the bus voltage updates throughout the network as $V_i^{k-1} = V_0 - \Delta V_i^{(k-1)}$ where V_0 is slack bus voltage at root node .

8. Check mismatch power at each load bus using specified and calculated values to obtain $\Delta S = S^{spec} - \sum V_i^{calc} I_{ij}^{calc}$ and stop if the value of $\Delta S \leq \varepsilon$.

9. Otherwise, go to step 3.

Note that the load flow techniques for transmission or distribution system are not sufficient for smart grid load flow. These methods can easily be implemented using
(i) sparsity techniques,

(ii) implicit bus matrix, or

(iii) computational techniques**.**

3.2 LOAD FLOW FOR SMART GRID DESIGN:

Load flow tools that incorporate the stochastic and random study of the smart grid could be modeled with the following implementation algorithm. Conditioning the load flow topology will require a new methodology and algorithm that will include feeders and the evolution of a time - dependent load flow. This method has been proven in terms of characteristics and usage in power system planning and operation. Hence, the interoperability of RER with smart grid specifications could account for adequate use of current methodology to perform analysis in both usual and alert states.

The implementation algorithm proposed will extend the following capability:

1. Model input of RER [and load will be changed to account for variability; the input will have to include some power distribution flow so as to advance the congested value of new estimate of P_f, Q_g, and P_d, Q_d. These attributes also have a unique load appropriate effectiveness in the performance Study**.**

2. Scarcity may be affected because the loads of RER may be widely distributed, that is, load and size of RER has to be considered.

3. Computational challenges in new load flow with RER for smart grid that include the stochastic model may affect the independent computation.

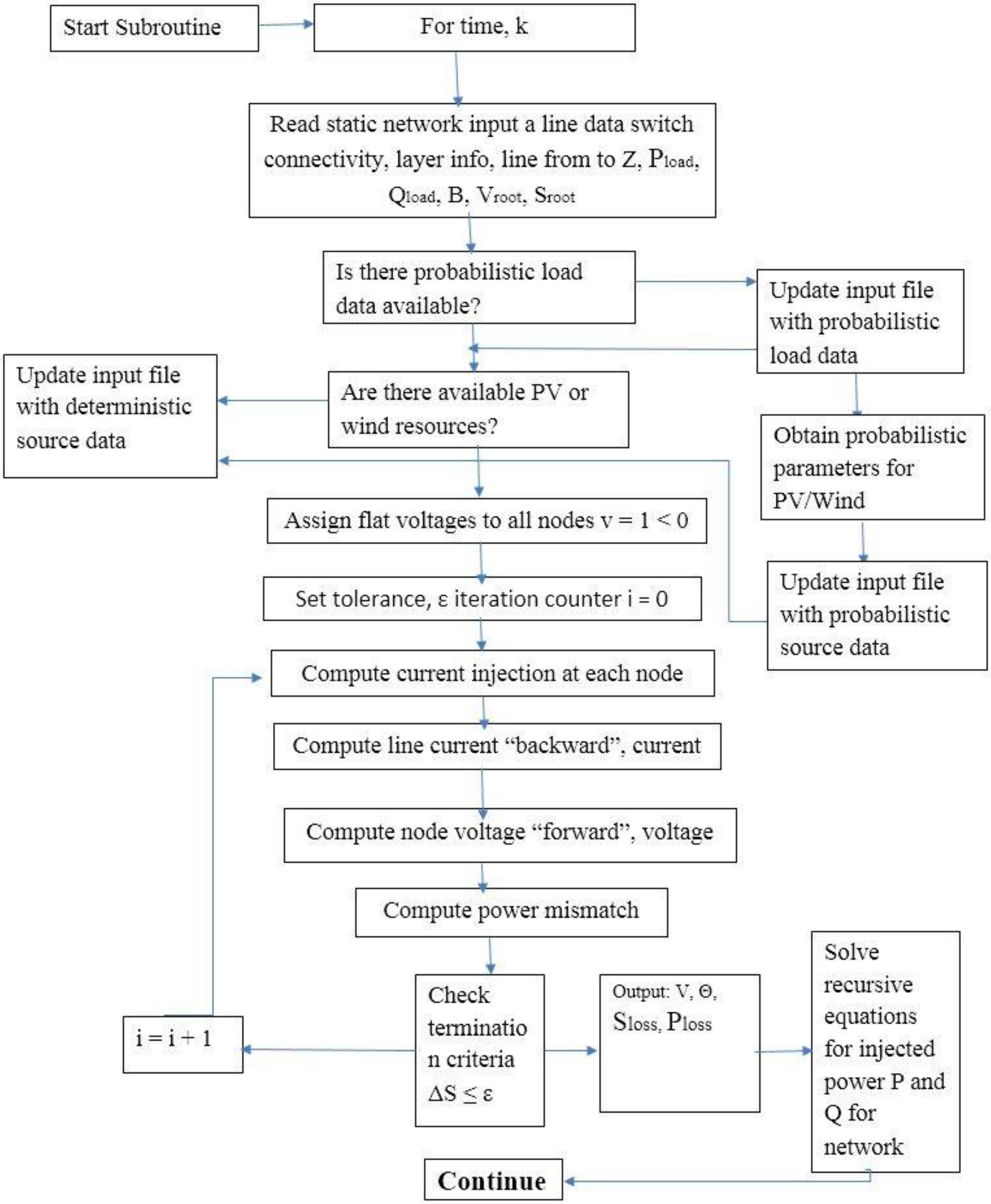
ATC is the maximum amount of additional MW transfer possible between two parts of a power system. Additional means that existing transfers are considered part of the “base case” and are not included in the ATC number. Typically these two parts are control areas or it can be any group of power injections. The term “maximum” refers to cases of either no overloads occurring in the system as the transfer is increased or no overloads occurring in the system during contingencies as the transfer is increased in online real time.

ATC = TTC−∑ (CBM, TRM and existing TC)
where the components are Total Transfer Capability (TTC), Capacity Benefit Margin (CBM), Transmission Reliability Margin (TRM), and “ existing Transmission Commitments ”.ATC is particularly important because it signals the point where power system reliability meets electricity market efficiency. It can have a huge impact on market outcomes and system reliability.

The load flow is solved using the iterate solution on:

$$\begin{bmatrix} \Delta\delta \\ \Delta V \end{bmatrix} = \left[J \right]^{-1} \begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix}$$

The load flow is also used in distributed networks:



(Fig. 3.2)

3.3 Cases of the Development of Stochastic Dynamic Optimal Power Flow (DSOPF):

DSOPF is being developed by the author. The DSOPF computational algorithm has the following built - in performance measures that are also defined for other general Purpose tools:

Controllability and interoperability: This is important for enabling different devices, systems, and subsystems to provide greater observe ability when different devices interact as agents for cooperation and benefits.

Reliability: quality measure of electricity delivered to achieve adequacy and performance using intelligence tools, support devices, and software; ability to achieve power quality and improve voltage profile is one of the attributes of the smart grid.

Adaptability and sustainability: ability of the grid to adapt to changes; meeting energy needs in a way that can sustain life and civilization.

Anticipatory behavior and affirmation of security: ability of the grid to anticipate different scenarios and prepare to handle the dynamic changes while guaranteeing system security.

3.3.1 DSOPF APPLICATION TO THE SMART GRID:

Adaptive Dynamic Programming (ADP) is a computational intelligence technique that incorporates time Framework for Implementation of DSOPF.

There is a need for a generalized framework for solving the many classes of power system problems where programmers, domain experts, and so on, can submit their challenge problem. The collective knowledge will published and posted on the Web for dissemination.

Figure 3.3 shows the general framework for the application of ADP to develop a new class of OPF problems called DSOPF; it is divided into three modules.

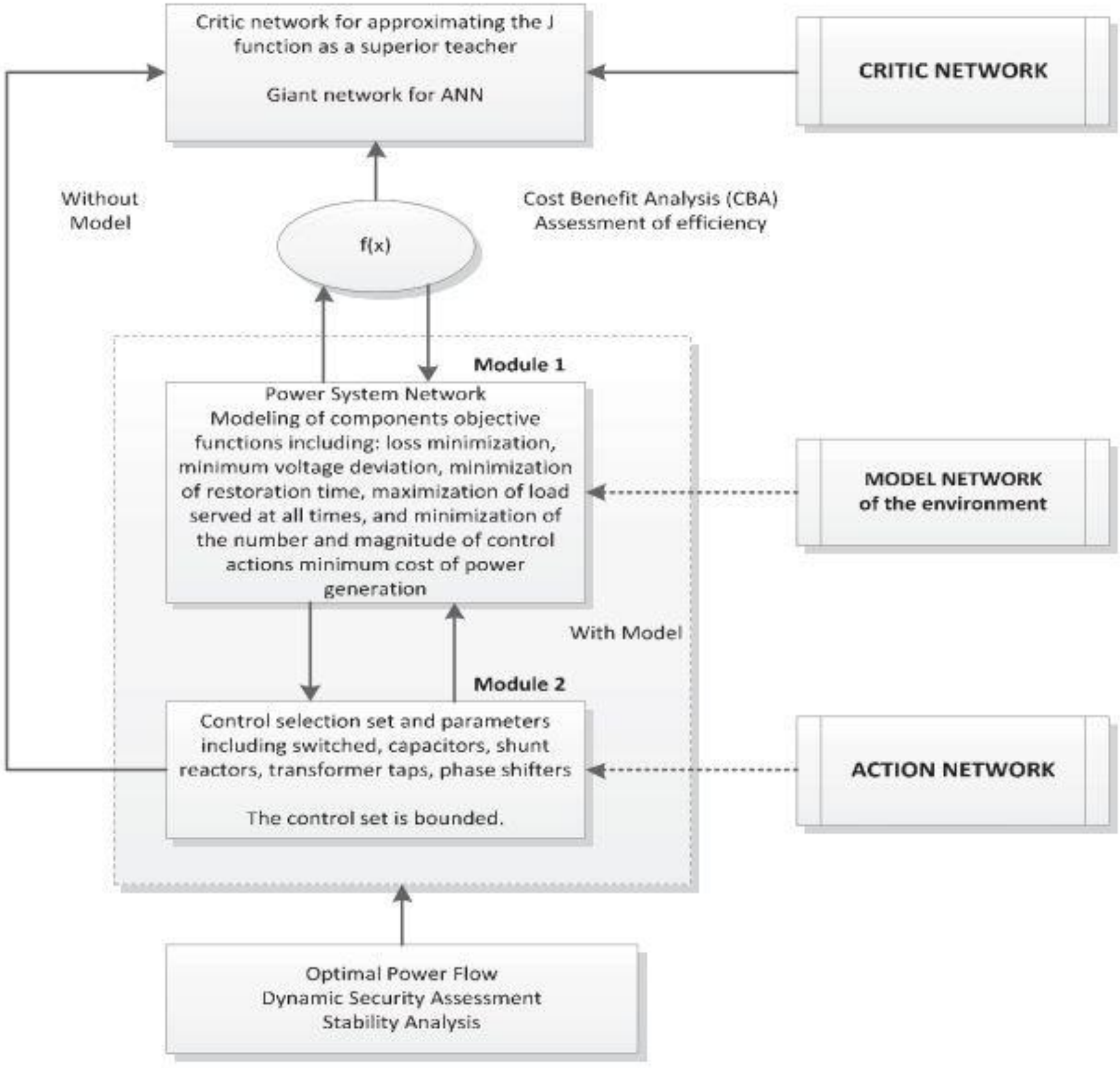


Figure 3.3: Framework of ADP applications to power systems

Module 1: Read power system parameters and obtain distribution function for state estimation of measurement errors inherent in data; ascertain and improve accuracy of data. Infer relationships between the past data and future of unknown period using time series and dynamical systems; in all cases determine the time - dependent model approximation behavior of the generation data. Define the model with the uncertainties, including defining the problem objective and constraint functions for each problem.

Module 2: Determine the feasibility region of operation of the power system and the emergency state with corresponding violations under different contingencies. Enumerate and schedule different control options over time for the different contingency scenarios. Coordinate the controls and perform post optimizations of additional changes. Evaluate results and perform sensitivity analysis studies.

Module 3: Address the post optimization process through cost benefit analysis to evaluate the various controls (cost effectiveness and efficiency). In the power system parlance, a big network, which will perform this evaluation, is essential and indispensable. The critic network from ADP techniques will help realize the dual goals of cost effectiveness and efficiency of the solution via the optimization process.

3.4 Software based load Simulation for Smart Grid:

As the number of renewable integration is increased in smart grid more sophisticated grid connection is needed which are complex enough to solve for power flow analysis. The possible solution may be the use of software based simulation to analyze the behavior of any interconnected large grid.

There are many software’s offering solution for hardware connected equipment to analyze the power flow, short circuit analysis, reliability analysis and many more.

Etap, Cyme, Wasp lV and many other software vendors are coming forward with their sophisticated algorithm to solve large interconnected grid with more renewable integration and this software’s can also be used for substation automation.

3.5 Summary:

This chapter has discussed several needed tools for analysis of smart grid design, operation, and performance. Such tools include load flow, optimal power flow, and contingencies. Reviews of classical methods were presented along with details about each solution tool’s incorporation into the smart grid.

CHAPTER

4

MEASUREMENT, CONTROL AND COMMUNICATION TECHNOLOGIES FOR SMART GRID.

4. Smart Metering and Demand-Side Integration:

Smart metering refers to systems that measure, collect, analyze, and manage energy use using advanced ICT (Information and Communication Technology). The concept includes two-way communication networks between smart meters and various actors in the energy supply system.

Load control or load management has been widespread in power system operation for a long time with a variety of terminology used to describe it. The name Demand-Side Management (DSM) has been used since the 1970s for a systematic way of managing loads. Later on, Demand Response (DR), Demand-Side Response (DSR), Demand-Side Bidding (DSB) and Demand Bidding (DB) were used to describe a range of different demand side initiatives. To avoid the confusion caused by such overlapping concepts and terminologies, Demand-Side Integration (DSI) is used in this chapter to refer to all aspects of the relationships between the electric power system, the energy supply and the end-user load.

4.1 Smart Metering:

The Smart Grid vision represents a logical extension of these capabilities to encompass two-way broadband communications supporting a wide range of Smart Grid applications including distribution automation and control as well as power quality monitoring.

The most common type of meter is an accumulation meter, which records energy consumption over time. Accumulation meters in consumer premises are read manually to assess how much energy has been used within a billing period. Smart meters are even more sophisticated as they have two-way communications and provide a real-time display of energy use and pricing information, dynamic tariffs and facilitate the automatic control of electrical appliances.

4.1.1 Conventional and Smart Metering Comparison:

The differences between conventional metering and smart metering are shown schematically in Figure 4.1. Smart meters have two-way communications to a Gateway and/or a Home Area Network (HAN) controller. The Gateway allows the transfer of smart meter data to energy suppliers, Distribution Network Operators (DNOs) and other emerging energy service companies.

They may receive meter data through a data management company or from smart meters directly.

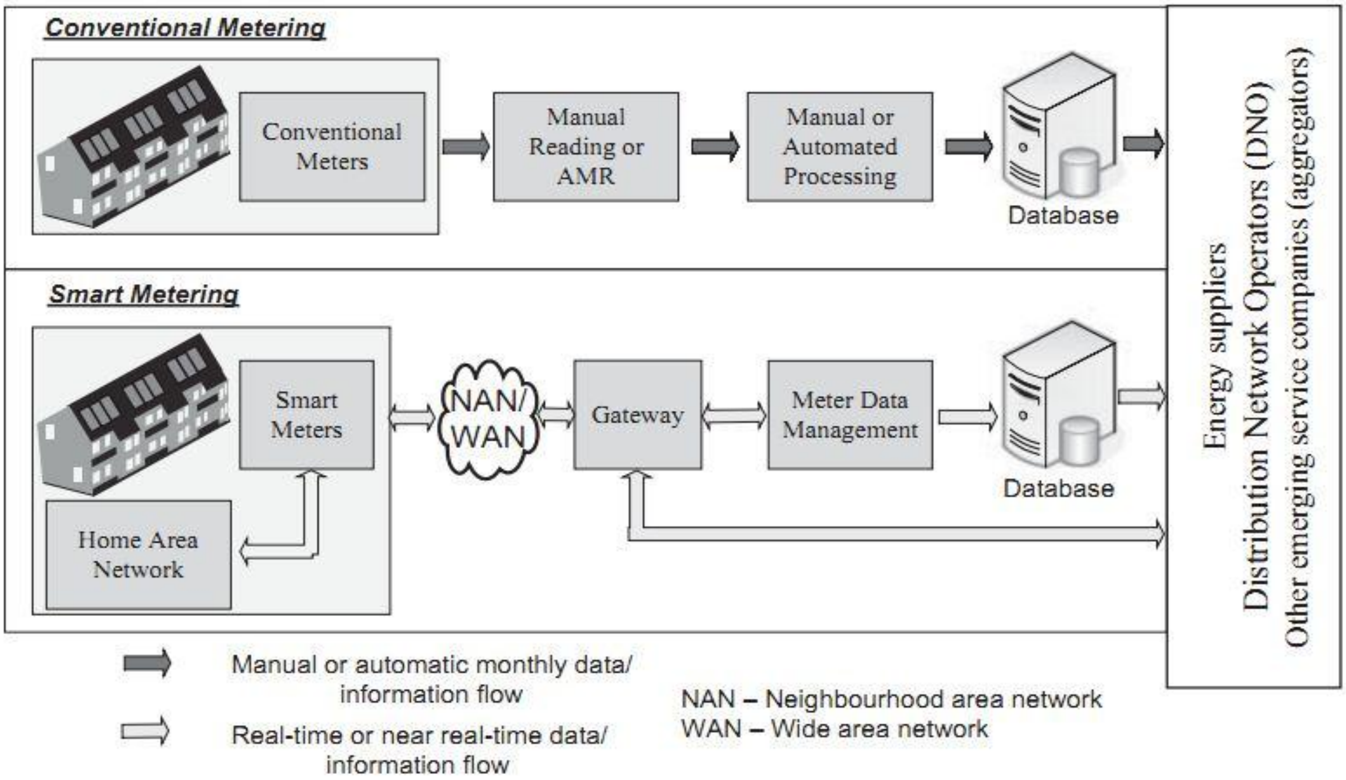


Fig 4.1: Conventional and Smart Metering Comparison.

4.1.2 Key components of smart metering:

Smart metering consists of four main components: smart meters, a two-way communication network, a Meter Data Management system (MDM), and HAN. In order to integrate smart metering into the operation and management of the power system, interfaces to a number of existing systems are required, for example, the interface to the load forecasting system, the Outage Management System (OMS), and a Customer Information System (CIS) etc.

4.2 Smart meters: An overview of the hardware used:

Early electronic meters had a display to show energy consumption but were read manually for billing purposes. More recently electronic meters with two-way communications have been introduced. Figure 4.2 provides a general functional block diagram of a smart meter. In Figure 4.2, the smart meter architecture has been split into five sections: signal acquisition, signal conditioning, Analogue to Digital Conversion (ADC), computation and communication.

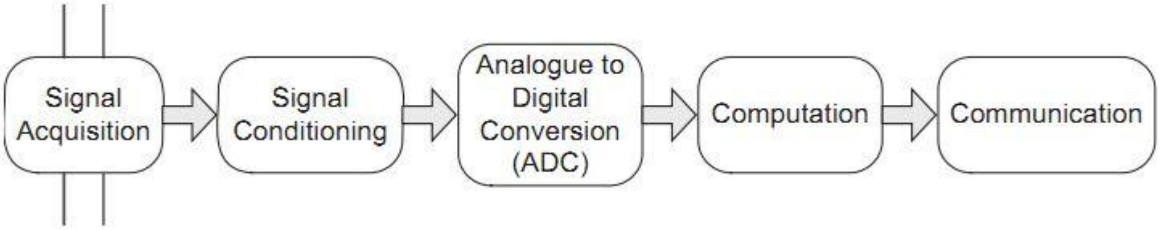


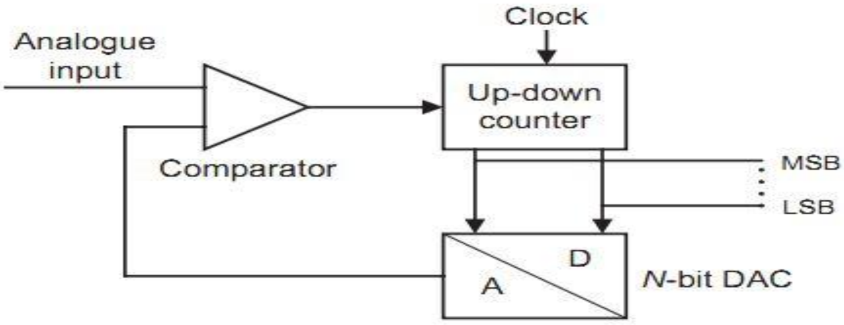
Fig 4.2: Functional Block Diagram of a Smart Meter.

4.2.1 Signal Acquisition

Current and voltage sensors measure the current into the premises (load) and the voltage at the point of supply. In low-cost meters the measuring circuits are connected directly to the power lines, typically using a current-sensing shunt resistor on the current input channel and a resistive voltage divider on the voltage input channel.

4.2.2 Analogue to Digital Conversion

Current and voltage signals obtained from the sensors are first sampled and then digitized to be processed by the metering software. Since there are two signals (current and voltage) in a single phase meter, if a single ADC is used, multiplexer is required to send the signals in turn to the ADC. The ADC converts analogue signals coming from the sensors into a digital form. As the number of levels available for analogue to digital conversion limited, the ADC conversion always appears in discrete form.



4.2.3 Computation

The computation requirements are split into arithmetic operations on input signals, time-stamping of data, preparation of data for communication or output peripherals, handling of routines associated with irregular input (such as payment, tamper detection), storage of data, system updates and coordinating different functions. The block diagram shown in Figure 4.3 shows different functional blocks associated with the computation functions of a smart meter.

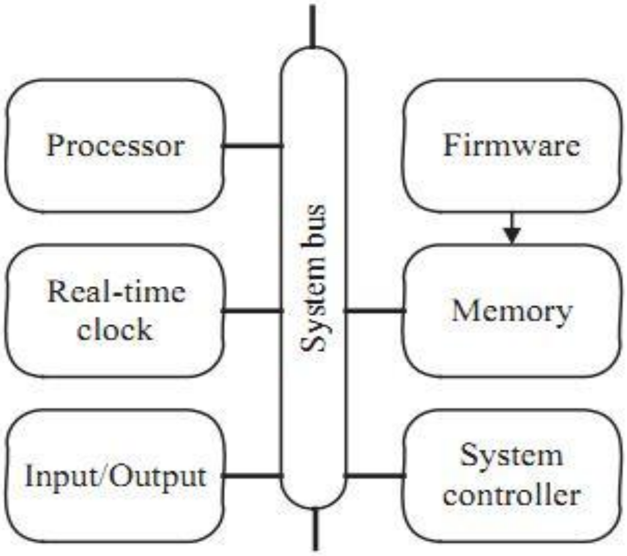


Fig 4.3: Computation overview Block Diagram.

4.2.4 Input/ Output

Fig 4.4: Smart Meter

As mart meter has a display that presents information in the form of text and graphs for the human user. Liquid Crystal Displays (LCD) and the Light Emitting Diodes (LED) are preferred for their low cost and low power consumption requirements. Both display types are available in seven-segment, alphanumeric and matrix format. LEDs are relatively efficient light sources, as they produce a significant amount of light when directly polarized (at relatively low voltages: 1.2–1.6 V), and a current of a few milliamps is applied.

4.3 Communications Infrastructure for Smart Metering:

A typical communications architecture for smart metering is shown in Figure 4.5 It has three communications interfaces: Wide Area Network (WAN), Neighborhood Area Network (NAN) and Home Area Network (HAN).

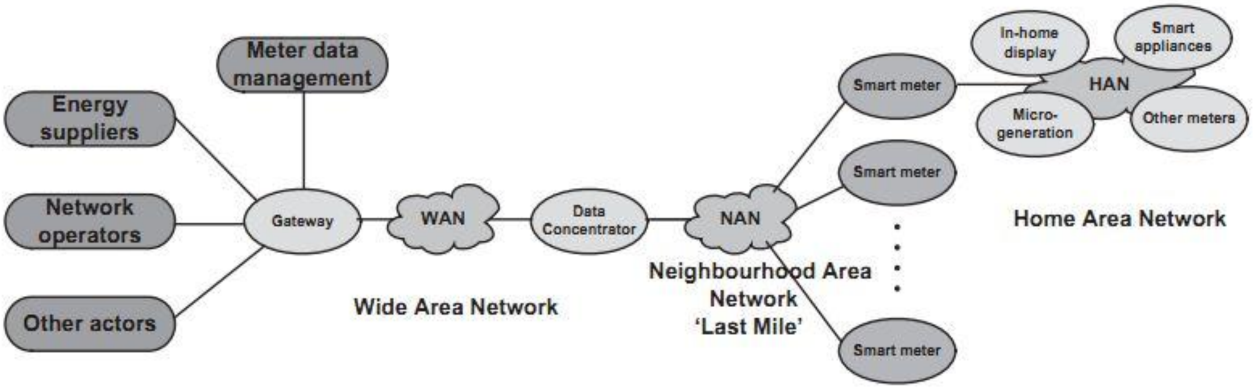


Figure 4.5: Smart metering communications

4.3.1 Home-Area Network (HAN):

A Home-Area Network (HAN) is an integrated system of smart meter, in-home display, micro-generation, smart appliances, smart sockets, HVAC (Heating, Ventilation, Air Conditioning) facilities and plug-in hybrid/electric vehicles. A HAN uses wired or wireless communications and networking protocols to ensure the interoperability of networked appliances and the interface to a smart meter. It also includes security mechanisms to protect consumer data and the metering system.

A HAN enables centralized energy management and services as well as providing different facilities for the convenience and comfort of the household. Energy management functions provided by HAN include energy monitoring and display, controlling the HVAC system and controlling smart appliances and smart plugs. The services provided by HAN for the convenience of the household can include scheduling and remote operation of household appliances as well as household security systems.

4.3.2 Neighborhood-Area Network (NAN)

The primary function of the Neighborhood Area Network (NAN) is to transfer consumption readings from smart meters. The NAN should also facilitate diagnostic messages, firmware upgrades and real-time or near real-time messages for the power system support. It is anticipated that the data volume transferred from a household for simple metering is less than 100 kB per day and firmware upgrades may require 400 kB of data to be transferred.

The communication technology used for the NAN is based on the volume of data transfer. For example, if ZigBee technology which has a data transfer rate of 250 kb/s is used, then each household would use the communication link only a fraction of a second per day to transfer energy consumption data to the data concentrator.

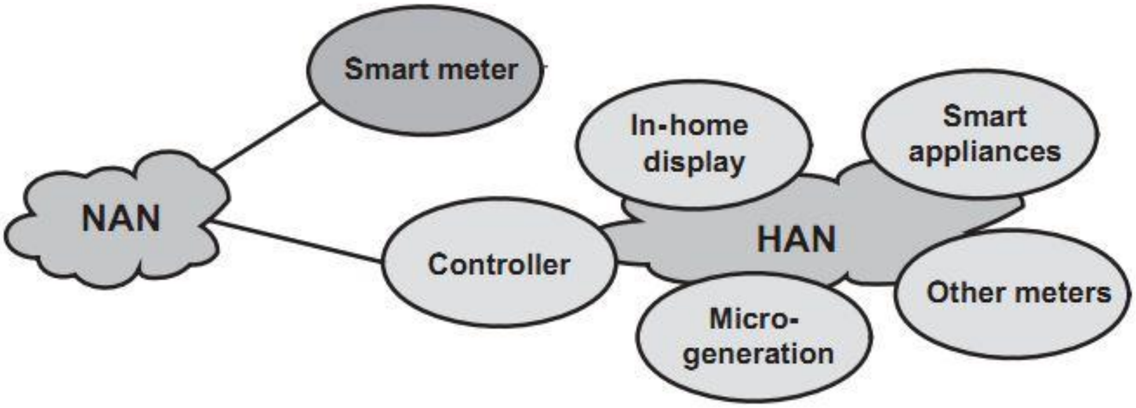


Figure 4.5: Interface between the HAN and NAN

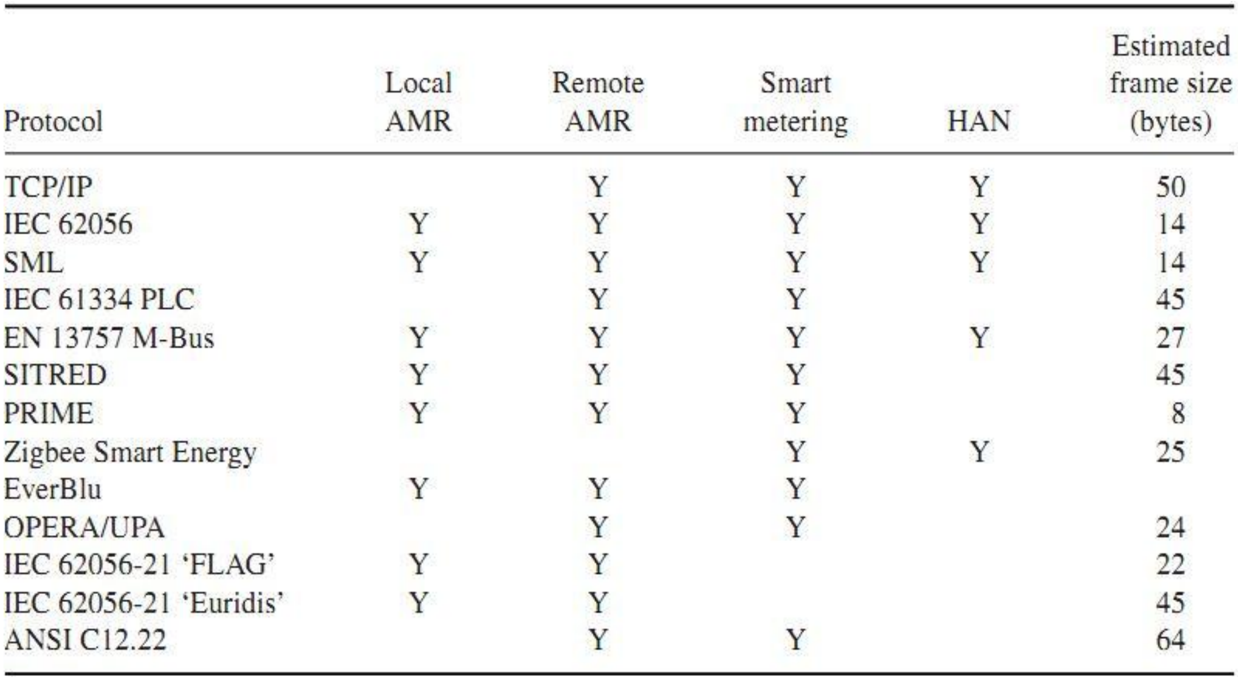
4.3.3 Meter Data Management System

The core of a meter data management system is a database. It typically provides services such as data acquisition, validation, adjustment, storage and calculation (for example, data aggregation), in order to provide refined information for customer service and system operation purposes such as billing, demand forecasting and demand response.

A major issue in the design and implementation of a meter data management system is how to make i t open and flexible enough to integrate to existing business/enterprise applications and deliver better services and more value to customers while ensuring data security. Besides the common database functionalities, a meter data management system for smart metering also provides functions such as remote meter connection/disconnection, power status verification, supply restoration verification and on-demand reading of remote smart meters.

4.3.4 Protocols for Communications

Currently various kinds of communication and protocol types are used for smart metering. For example, a combination of Power Line Carrier (PLC) and GPRS communication is used in Denmark, Finland and Italy. In these European examples, PLC is used between the meter and data concentrator as the last mile technology and GPRS is used between the concentrator and gateway to the data management system.



Protocol	Local AMR	Remote AMR	Smart metering	HAN	Estimated frame size (bytes)
TCP/IP		Y	Y	Y	50
IEC 62056	Y	Y	Y	Y	14
SML	Y	Y	Y	Y	14
IEC 61334 PLC		Y	Y		45
EN 13757 M-Bus	Y	Y	Y	Y	27
SITRED	Y	Y	Y		45
PRIME	Y	Y	Y		8
Zigbee Smart Energy			Y	Y	25
EverBlu	Y	Y	Y		
OPERA/UPA		Y	Y		24
IEC 62056-21 ‘FLAG’	Y	Y			22
IEC 62056-21 ‘Euridis’	Y	Y			45
ANSI C12.22		Y	Y		64

Fig 4.6: Main Smart Metering Protocols.

4.4 Demand-Side Integration (DSI):

Demand-Side Integration (DSI) is a set of measures to use loads and local generation to support network operation/management and improve the quality of power supply. DSI can help defer investment in new infrastructure by reducing system peak demand. In practice, the potential of DSI depends on: availability and timing of information provided to consumers, the duration and timing of their demand response, performance of the ICT infrastructure, metering, automation of end-use equipment and pricing/contracts.

4.4.1 Services provided by DSI

Demand-side resources such as flexible loads, distributed generation and storage can provide various services to the power system by modifying the load consumption patterns. Such services can include load shifting, valley filling, peak clipping, dynamic energy management, energy efficiency improvement and strategic load growth. Simple daily domestic load profiles are used to illustrate the function of each service:

Load shifting is the movement of load between times of day (from on-peak to off-peak) or seasons. In a load such as a wet appliance (washing machine) that consumes1 kW for 2 hours is shifted to off-peak time.

Valley filling, which is to increase off-peak demand through storing energy, f or example, in a battery of a plug-in electric vehicle or thermal storage in an electric storage heater. The main difference between valley filling and load shifting is that valley filling introduces new loads to off-peak time periods, but load shifting only shifts loads so the total energy consumption is unchanged.

Peak clipping reduces the peak load demand, especially when demand approaches the thermal limits of feeders/transformers, or the supply limits of the whole system.

Energy efficiency programs are intended to reduce the overall use of energy. Approaches include offering incentives to adopt energy-efficient appliances, lighting, and other end-uses; or strategies that encourage more efficient electricity use.

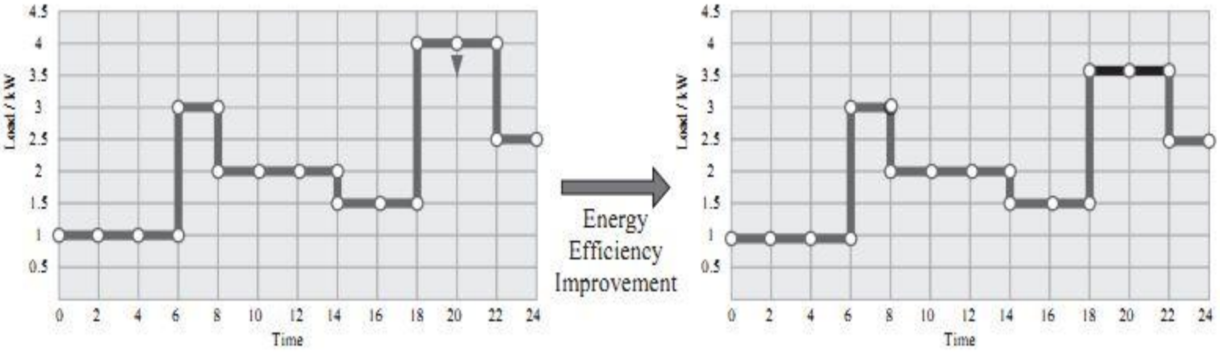


Figure 4.7 Energy efficiency improvement.

4.4.2 Price-Based DSI Implementations

Tariffs and pricing can be effective mechanisms to influence customer behavior, especially in unbundled electricity markets. Price schemes employed include time of use rates, real-time pricing and critical peak pricing:

Time of use (ToU): ToU rates use different unit prices for different time blocks, usually pre-defined for a 24-hour day. ToU rates reflect the cost of generating and delivering power during different time periods.

Real-time pricing (RTP): the electricity price provided by RTP rates typically fluctuates hourly, reflecting changes in the wholesale electricity price. Customers are normally notified of RTP prices on a day-ahead or hour-ahead basis.

Critical peak pricing (CPP): CPP rates are a hybrid design of the ToU and RTP. The basic rate structure is ToU. However, the normal peak price is replaced by a much higher CPP event price under predefined trigger conditions (for example, when system is suffering from some operational problem or the supply price is very high).

4.4.3 Hardware Support to DSI implementations

The essential ICT infrastructure required for DSI can be provided by smart metering. In addition, load control switches, controllable thermostats, lighting controls and adjustable speed drives are required. Such equipment receives signals such as alarms or price signals and controls loads accordingly.

4.4.4 System Support from DSI

Emergency load shedding has been used in many power systems to maintain the integrity of the power system in the event of a major disturbance. It is triggered by under-frequency relays when the frequency drops under a certain threshold, for example, 48.8 Hz in England and Wales, and consists of the tripping of entire distribution feeders. Load shedding is planned by the TSO but is implemented by the DNOs who arrange the tripping of distribution feeders and choose which feeders are tripped.

DSI programs can significantly reduce the requirement for primary and secondary responses from partially loaded generators by shedding load in a controlled manner. Large loads that are contracted to provide frequency response are typically steelworks or aluminum smelters though hospitals and banks that have their own generators can also take part in this market. Using load in this way r educes the system operating cost and, depending on the alternative generation being used, CO_2 emissions.

4.5 **Summary**:

This chapter is aimed to get the idea of flexibility in the demand side & smart metering system in smart grid with the dual aims of reducing CO2 emissions and improving energy security. However, connection of a large amount of intermittent renewable generation alters the pattern of the output of central generation and the power flows in both transmission and distribution circuits. One solution to this increase in variability is to add large-scale energy storage devices to the power system. This is often not practical at present due to technical limitations and cost. Therefore, flexibility in the demand side is seen as another way to enable the integration of a large amount of renewable energy with smart metering system.

CHAPTER

5

A SMART SUBSTATION FOR SMART GRID

5. Typical Substation Elements:

Over the past decade, automation of the distribution system has increased in order to improve the quality of supply and allow the connection of more distributed generation. The connection and management of distributed generation are accelerating the shift from passive to active management of the distribution network. Network voltage changes and fault levels are increasing due to the connection of distributed generation. Without active management of the network, the costs of connection of distributed generation will rise and the connection of additional distributed generation may be limited

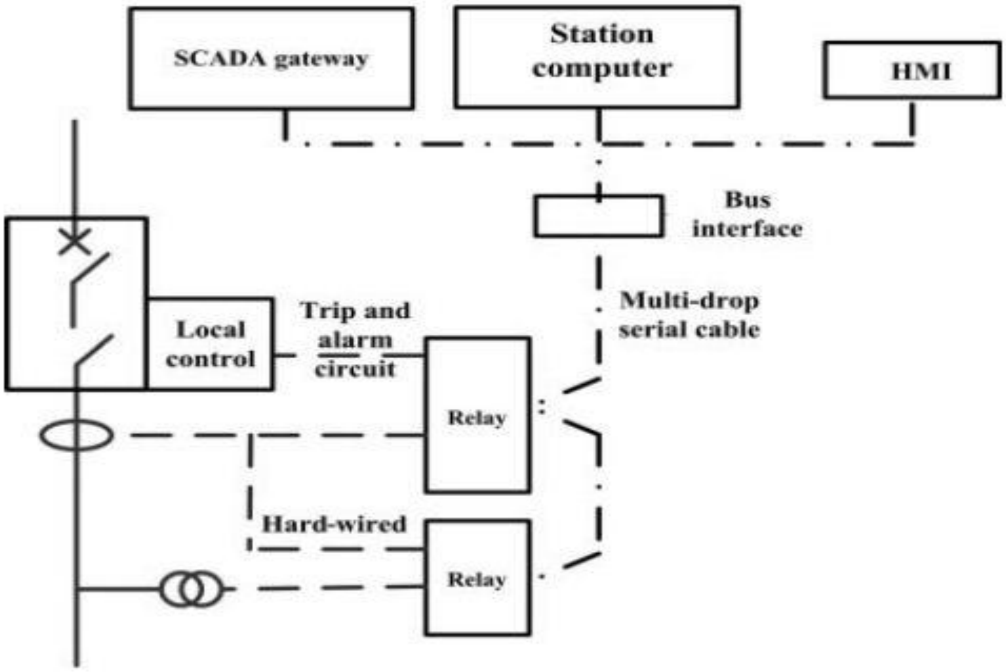


Fig 5.1: Typical Substation Elements.

Operation of the generation and transmission systems is monitored and controlled by *Supervisory Control and Data Acquisition (SCADA)* systems. These link the various elements through communication networks (for example, microwave and fiber optic circuits) and connect the transmission substations and generators to a manned control center that maintains system security and facilitates integrated operation.

5.1 Smart Substation Elements:

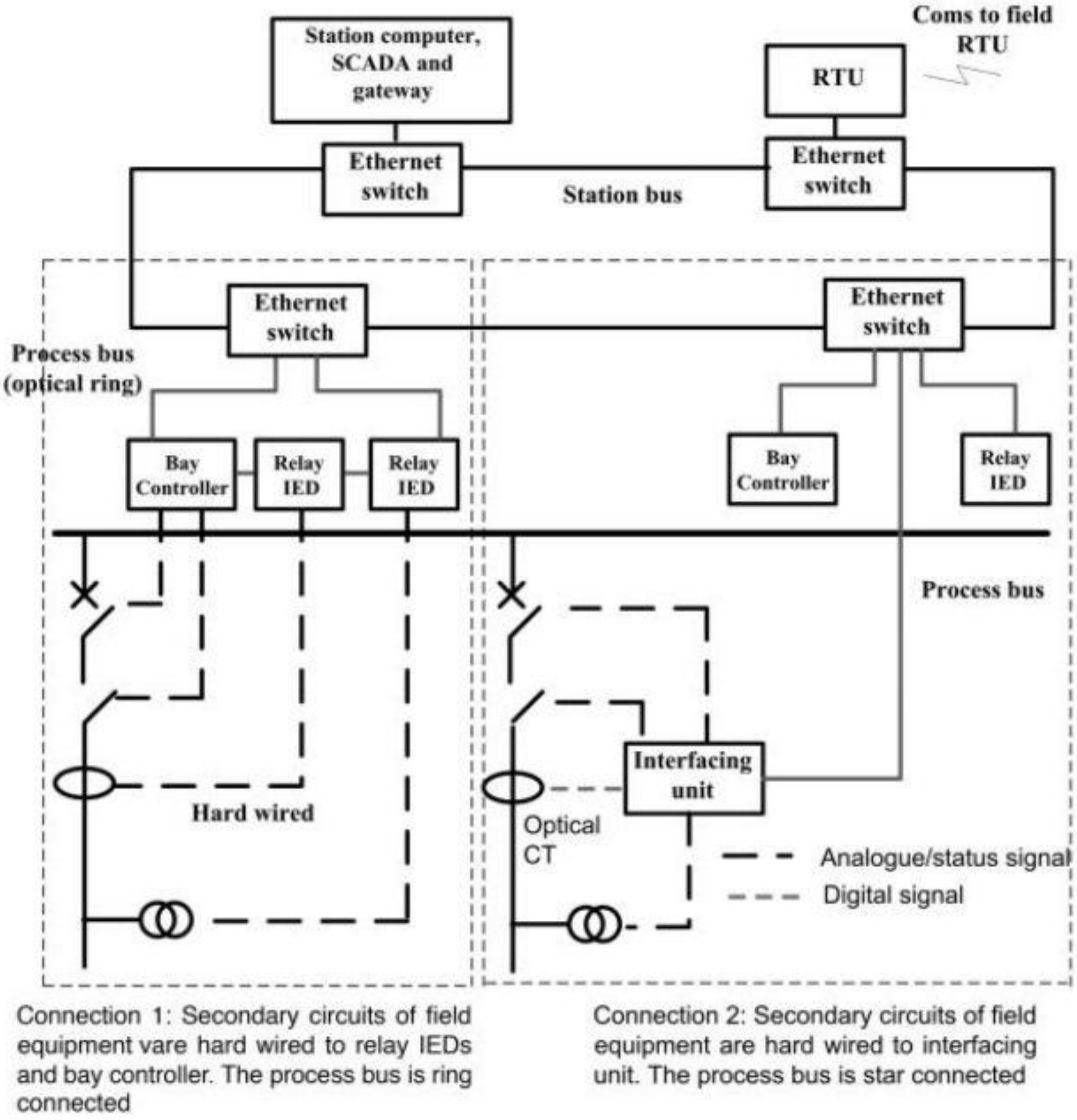


Fig 5.2: Smart Substation Elements

The configuration of a modern substation automation system is illustrated in Figure 5.2.Two possible connections (marked by boxes) of the substation equipment are shown in Figure 5.2. Although it may vary from design to design, generally it comprises three levels:

- ***The station level*** includes the substation computer, the substation human machine interface (which displays the station layout and the status of station equipment) and the gateway to the control center.
- ***The bay level*** includes all the controllers and intelligent electronic devices (which provide protection of various network components and a real-time assessment of the distribution network).
- ***The process level*** consists of switchgear control and monitoring, current transformers (CTs), voltage transformers (VTs) and other sensors.

The station bus operates in a peer-to-peer mode. This bus is a LAN formed by connecting various Ethernet switches through a fiber-optic circuit. The data collected from the IEDs is processed for control and maintenance by SCADA software that resides in the station computer.

5.1.1 Current Transformers:

The normal load current of transmission and distribution circuits varies up to hundreds or even thousands of amperes. When a short circuit fault occurs, the current may increase to more than 20 times the normal load current. Current transformers (CTs) are used to transform the primary current to a lower value (typically 1 or 5 A maximum) suitable for use by the IEDs or interfacing units.

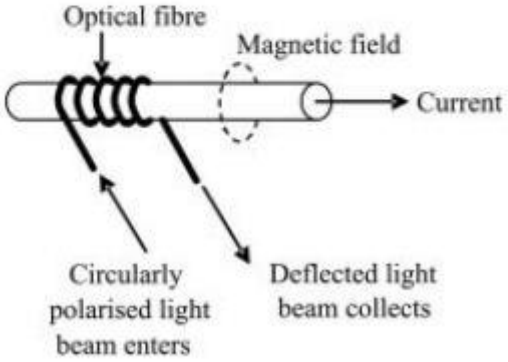


Fig 5.3: A Simple Optical CT

Optical CTs use the Faraday Effect, whereby the plane of polarization of a light beam when subjected to a magnetic field, is rotated through an angle. This angle of rotations proportional to the magnetic field thus to the primary current. Figure 5.3 shows this type of CT in its simplest form.

5.1.2 Voltage Transformers:

It is necessary to transform the power system primary voltage down to a lower voltage to be transferred through process bus to IEDs, bay controller and station computer. The secondary voltage used is usually 110 V. At primary voltages up to 66 kV, electromagnetic voltage transformers (similar to a power transformer with much lower output rating) are used but at 132 kV and above, i t i s common to use a capacitor voltage transformers (CVT).

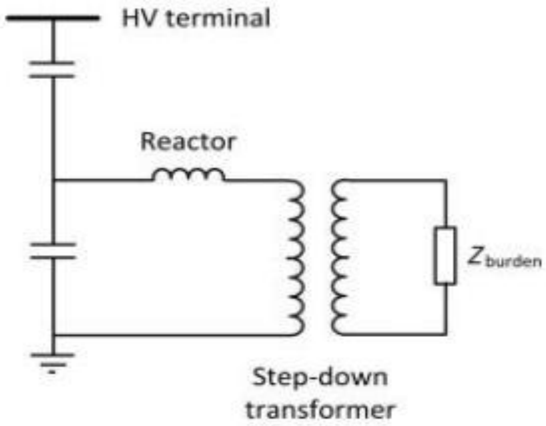


Fig 5.4: A high voltage CVT.

The basic arrangement of a high voltage CVT is a capacitor divider, a series reactor (to compensate for the phase shift introduced by the capacitor divider) and a step-down transformer (for reducing the voltage to 110 V). The voltage is first stepped down to a high value by a capacitor divider and further reduced by the transformer, as shown in Figure 5.4.

5.1.3 Intelligent Electronic Devices (IED):

The name Intelligent Electronic Device (IED) describes a range of devices that perform one or more of functions of protection, measurement, fault recording and control. An IED consists of a signal processing unit a microprocessor with input and output devices, and a communication interface. Communication interfaces such as EIA 232/EIA 483, Ethernet, Modbus and DNP3 are available in many IEDs.

5.1.3.1 <u>Relay IED:</u>

Modern relay IEDs combine a number of different protection functions with measurement, recording and monitoring. For example, the relay IED shown in Figure 5.5 has the following protection functions:

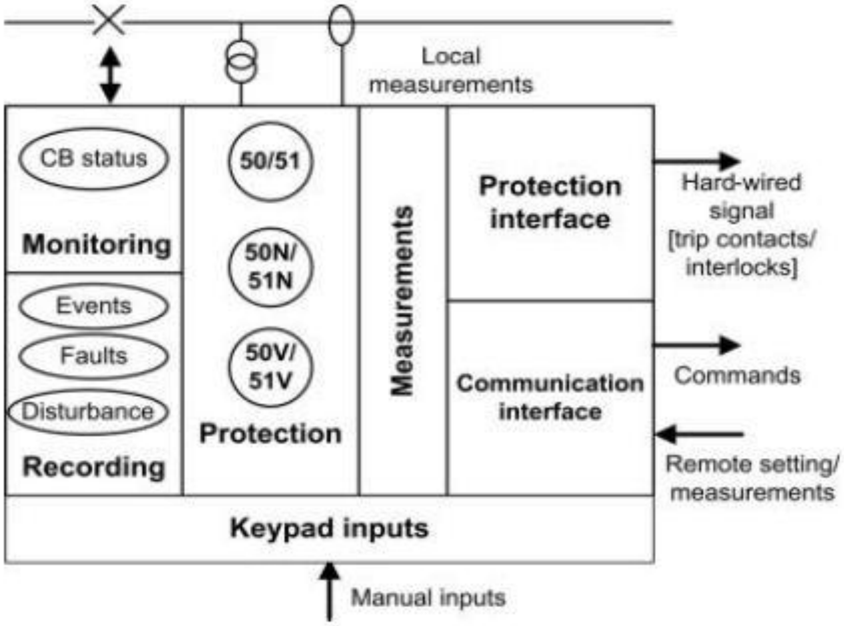


Fig 5.5: Typical configuration of a relay IED.

- Three-phase instantaneous over-current: Type50(IEEE/ANSI designation);
- Three-phase time-delayed over- current (IDMT): Type 51;
- Three-phase voltage controlled or voltage restrained instantaneous or time-delayed over-current: Types 50V and 51V;
- Earth fault instantaneous or time-delayed over- current: Types 50N and 51N.

Various algorithms for different protection functions are stored in a ROM. For example, the algorithm corresponding to Type 50 continuously checks the local current measurements against a set value (which can be set by the user or can be set remotely) to determine whether there is an over- current on the feeder to which the circuit breaker is connected. If the current is greater than the setting, a trip command is generated and communicated to the Circuit Breaker (CB).

5.1.3.2 Meter IED:

A meter IED provides a comprehensive range of functions and features for measuring three-phase and single-phase parameters. A typical meter IED measures voltage, current, power, power factor, energy over a period, maximum demand, maximum and minimum values, total harmonic distortion and harmonic components.

5.1.3.3 Recording IED:

Even though meter and protection IEDs provide different parameters (some also have a data storage capability), separate recording IEDs are used to monitor and record status changes in the substation and outgoing feeders. Continuous event recording up to a resolution of 1 ms is available in some IEDs. These records are sometimes interrogated by an expert to analyze a past event. This fault recorder records the pre-fault and fault values for currents and voltages. The disturbance records are used to understand the system behavior and performance of related primary and secondary equipment during and after a disturbance.

5.1.4 Bay Controller:

Bay controllers (Figure 5.6) are employed for control and monitoring of switchgear, trans-formers and other bay equipment. The bay controller facilitates the remote control actions (from the control center or from an on-site substation control point) and local control actions (at a point closer to the plant).

The functionalities available in a bay controller can vary, but typically include:

- CB control
- Switchgear interlock check
- Transformer tap change control
- Programmable automatic sequence control.

Fig 5.6: Bay controller. Source: Courtesy of Toshiba.

5.1.5 Remote Terminal Units (RTU):

The distribution SCADA system acquires data (measurements and states) of the distribution network from Remote Terminal Units (RTU). This data is received by an RTU situated in the substation (referred to here as the station RTU), from the remote terminal units situated in other parts of the distribution network (referred to here as the field RTU).

The field RTUs act as the interface between the sensors in the field and the station RTU. The main functions of the field RTU are to:

- Monitor both the analogue and digital sensor signals (measurements) and actuator signals (status).
- Converting the analogue signals coming from the sensors and actuators into digital form.

Modern RTUs, which are microprocessor-based, are capable of performing control functions in addition to data processing and communication. The software stored in the microprocessor sets the monitoring parameters and sample time; executes control laws; sends the control actions to final circuits; sets off calling alarms and assists communications functions.

5.2 Faults in the Distribution System:

When a fault occurs in the transmission or distribution system, the power system voltage is depressed over a wide area of the network and only recovers when the fault is cleared. Transmission systems use fast-acting protection and circuit breakers to clear faults within around 100ms. In contrast, the time-graded over- current protection of distribution circuits and their slower CBs only clear faults more slowly, typically taking up to 500ms.

Fast clearance of faults is important for industrial, commercial and increasingly for domestic premises. Many industrial processes rely on motor drives and other power electronic equipment which is controlled by microprocessors. Commercial and domestic premises use ever more Information Technology Equipment (ITE). This equipment is becoming increasingly sensitive to voltage dips.

During a fault on the AC network, depending on the location of the fault, the voltage will drop. The subsequent operation of the ITE depends on the fault clearance time and the voltage dip. Short-circuit faults are inevitable in any distribution system and so interruption in function of sensitive load equipment can only be avoided by doing the following:

- ensuring the load equipment is robust against these transient voltage changes;
- using very high speed protection and circuit breakers;
- adding equipment to mitigate the voltage depressions for example, a Dynamic Voltage Restorer (DVR) or STATCOM.

5.2.1 Components for Fault Isolation and Restoration:

Whenever there is a fault on a part of the distribution network, the fault current should be interrupted rapidly, the faulted section isolated from the healthy network and, then once the fault has been removed, supplies to customers should be restored. This is achieved through arrange of equipment generally known as switchgear. The term switchgear includes:

- ***Circuit breaker*** which is capable of making and breaking fault currents,

- ***Recloser*** which is essentially a CB with a limited fault-breaking capacity and variable pattern of automatic tripping and closing.
- ***Switch disconnector*** which has a limited fault-making capability (and which is capable of making and breaking normal load current)
- ***Sectionalizer*** which is capable of making and breaking normal load current but not the fault current.

In modern switchgear, instead of a motor wound spring, compressed gas or magnetic actuators are increasingly used. Most overhead line faults are transient and self-clearing once the circuit is de-energized. Hence either auto-reclose of the substations CBs or a s elf-controlled recloser, which can per-form a variable pattern of tripping and reclosing, is used on many overhead distribution circuits. These will prevent unnecessary sustained outages for temporary faults.

A distribution feeder which employs a pole-mounted recloser is shown in Figure 5.7.The recloser characteristic is selected so as to make sure that its fast operating time is much faster than the operating time of the downstream fuses and its slow operating time is slower than the operating time of the fuses.

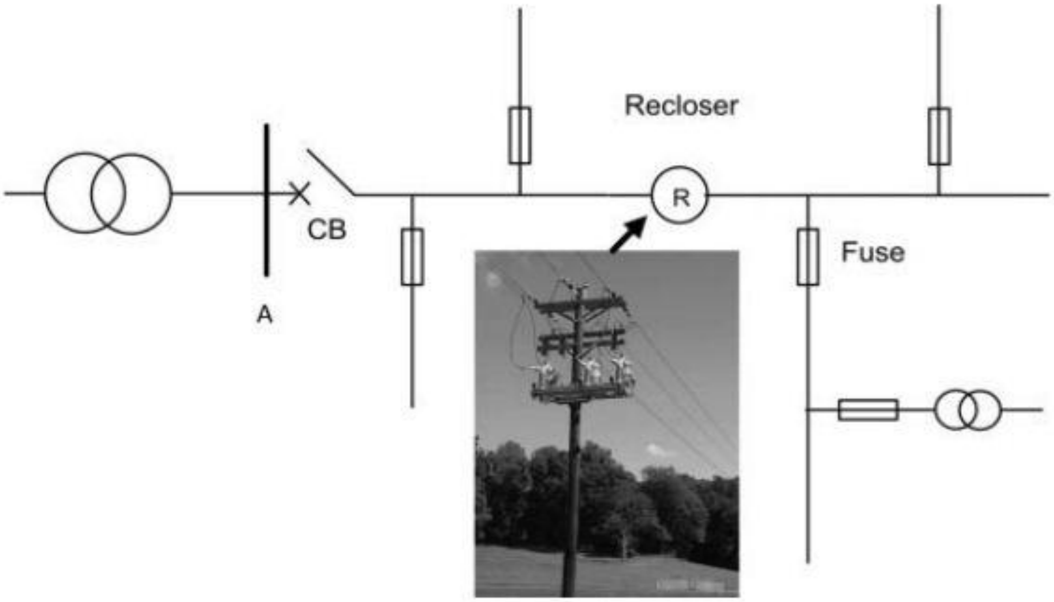


Fig 5.7: A Typical Distribution Feeder with Recloser & Fuses.

Source: Courtesy of S & C Electric Europe Ltd.

5.2.2 Fault Location, Isolation and Restoration:

Figure 5.8 shows a typical 11 kV distribution network. When there is a fault on the network at the location shown, the over- current protection element in IED1 detects the fault and opens CB1. This will result in an outage at loads L1 to L5. Since there are no automated components in the network, supply restoration for a part of the network requires the intervention of a restoration crew and in some areas may take up to ***80 minutes***.

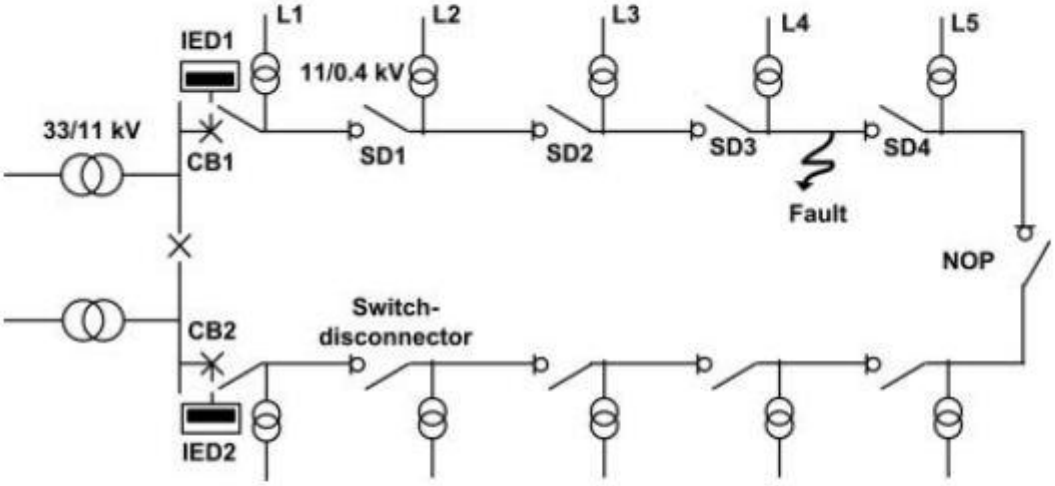


Fig 5.8: A Typical Distribution Network Section.

Supply restoration is normally initiated by phone calls from one or more customers (in the area where outage occurred) reporting ***a loss of supply to the electricity*** supplier. Upon receiving these calls a restoration crew is dispatched to the area. It will take some time for the team to locate the fault and manually isolate it by opening SD3 and SD4. Then CB1 is closed to restore the supply to L1, L2 and L3. The normally open point (NOP) is closed to restore the supply to L5. Load L4 will be without supply until the fault is repaired.

A simple method to reduce the restoration time of loads L1, L2, L3 and L4 is using a pole-mounted recloser and sectionaliser as shown in Figure 5.9.

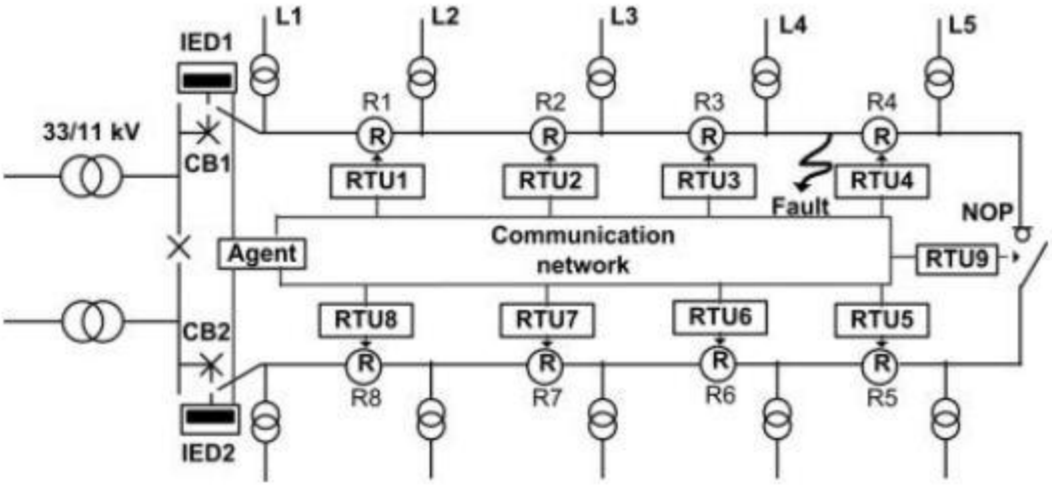


Figure 5.9: Fully Automated Distribution Network.

i. Send a command to IED1 to close CB1.
ii. Send a command to RTU1 to reclose R1. If the fault current prevails, initiate a trip but as there is no fault current, R1 remains closed. Similarly send commands to RTU2, 3 and 4 to reclose R2, R3 and R4. When R3 is closed, fault current flows, thus causing R3 to trip and lock-out.
iii. Then send a command to RTU9 to close the normally open point.
iv. Finally, send a command to RTU4 to close R4. As the fault current flows, a trip command is initiated for R4. R3 and R4 thus isolate the fault and supply is restored to loads L1, L2, L3 and L5.

5.3 Summary:

This chapter is aimed to get familiarized with the typical substation elements and the smart substation equipment and their performance comparison. Faults in distribution system and their components for fault isolation and restoration techniques is also discussed in brief to get a basic idea for smart grid system.

CHAPTER

6

SUBSTATION SURVEYS

&

SIMULATION RESULTS

6. Load Flow Study for Our Visited Substation:

Existing load flow performance tools capable of determining voltage, angle, flows, MW/Mvar, and scheduling dispatch are mostly offline although a few can give real - time results. Most of the existing substations don't have the performance analysis tool for the real time data collection. However, for data collection and analysis we used the following two types of tools:

6.1 Data Collection Using Clamp Tester:

Clamp Tester is normally used for taking data from bus connection. When it is connected to any bus bar it can show the current values, temperature and resistance also. We used Clam Tester for collecting the current values different bus in IUT substation.

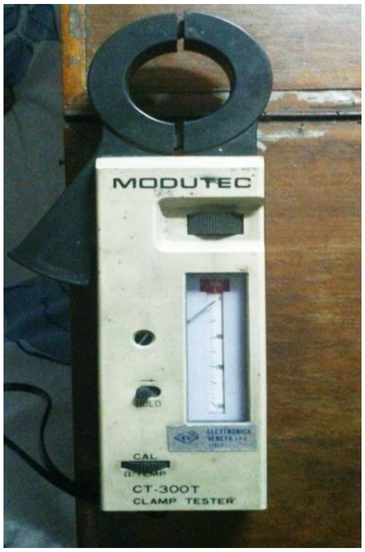


Fig 6.1: Clam Tester

etap®
Thinking Power

Fig 6.2: Etap Software Logo

6.1.1 Load Flow Simulation Using Etap Software:

ETAP offers a suite of fully integrated Electrical Engineering software solutions including arc flash, load flow, short circuit, transient stability, relay coordination, optimal power flow and more. ETAP Load Flow software performs power flow analysis and voltage drop calculations with accurate and reliable results. Its calculation program calculates bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with unlimited power grids and generator connections. For details: http://etap.com/index.htm.

6.1.2 **Load Flow Simulation for Board Bazar Substation**:

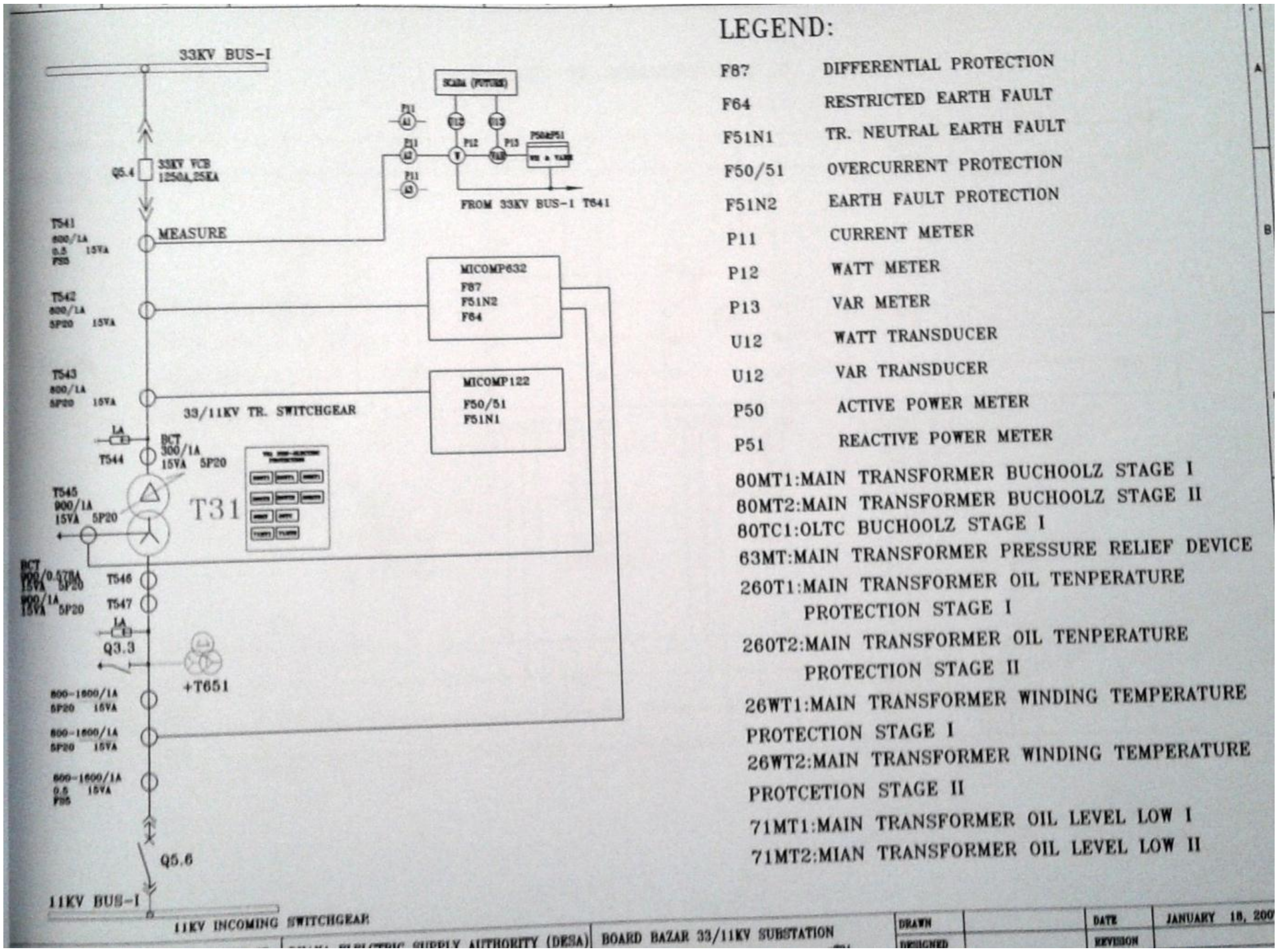
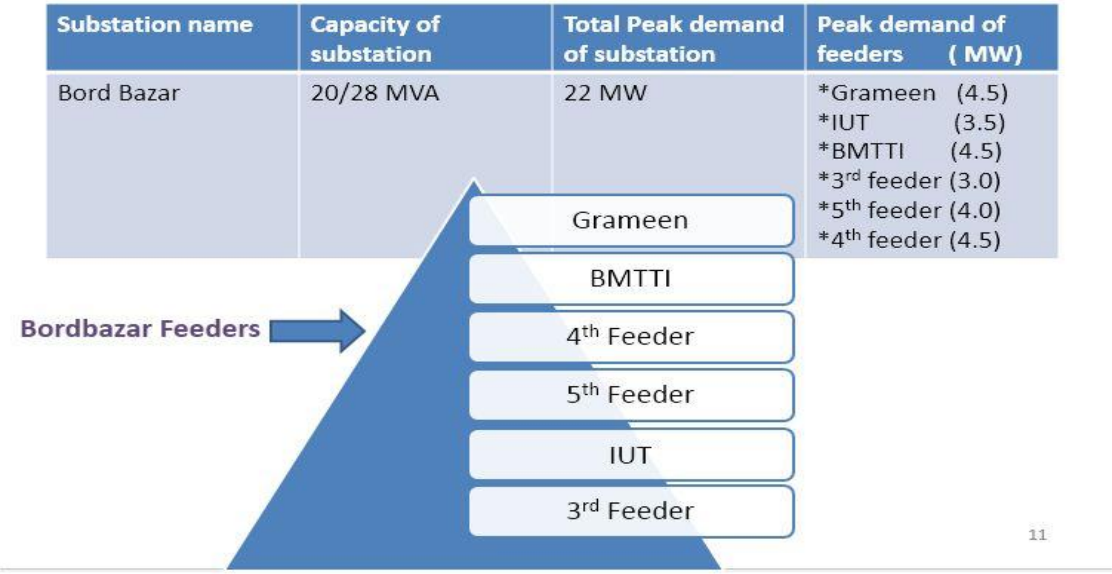


Fig 6.3: One Line Diagram of Board Bazar Substation

- Board Bazar substation can be considered as distribution substation.
- Board Bazar substation receives the power at 33 KV (Tongi substation) and converts the receiving power to 11 KV using transformer.
- Total capacity of Board Bazar substation is 20-28 MVA.
- Board Bazar substation is buildup of Chinese equipment.
- Board Bazar substation feeds six (11 KV) feeders and IUT is one of them.

Transformer Rating:

- Incoming: 33 KV Frequency: 50 HZ
- Outgoing: 11 KV
- Rate capacity: 10/14 MVA Rated voltage: 33 KV



Substation name	Capacity of substation	Total Peak demand of substation	Peak demand of feeders (MW)
Bord Bazar	20/28 MVA	22 MW	*Grameen (4.5) *IUT (3.5) *BMTTI (4.5) *3rd feeder (3.0) *5th feeder (4.0) *4th feeder (4.5)

Bordbazar Feeders

Grameen

BMTTI

4th Feeder

5th Feeder

IUT

3rd Feeder

Fig 6.4: Six (11 KV) feeders of Board Bazar Substation

- The above one line diagram along with all data is simulated in *Etap Software* for Load flow calculation at the peak demand.

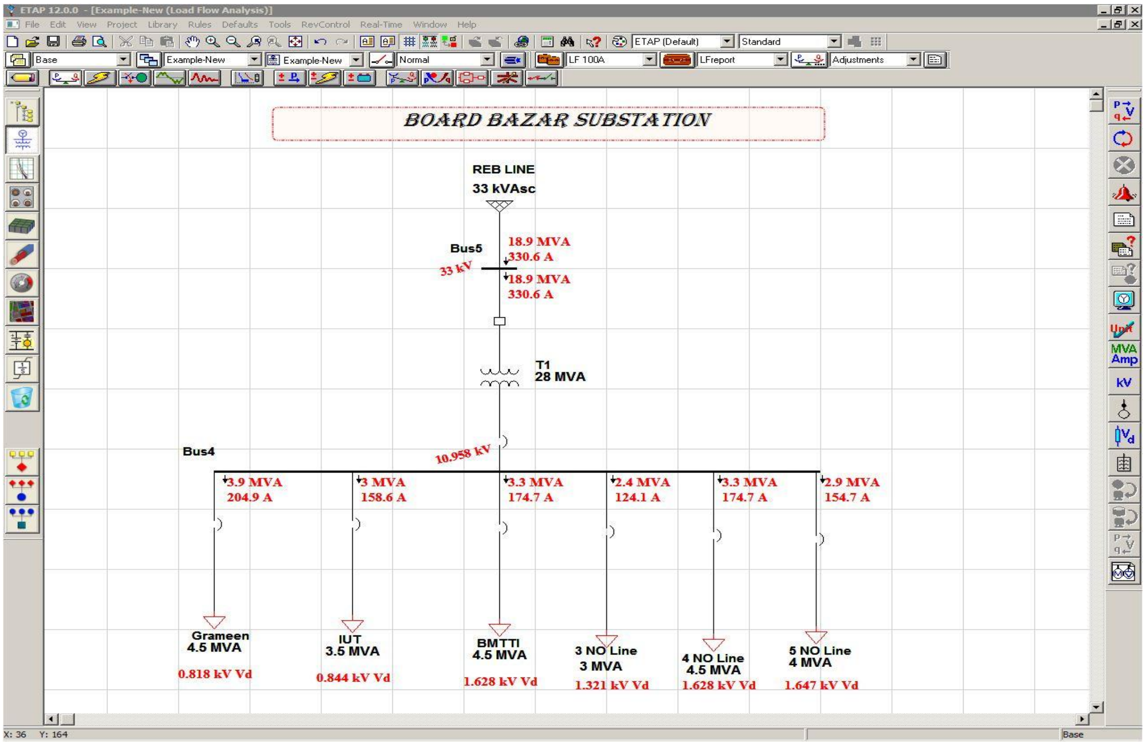


Fig 6.5: Load Flow Calculation for Board Bazar Substation.

6.1.3 Load Flow Simulation for IUT Substation:

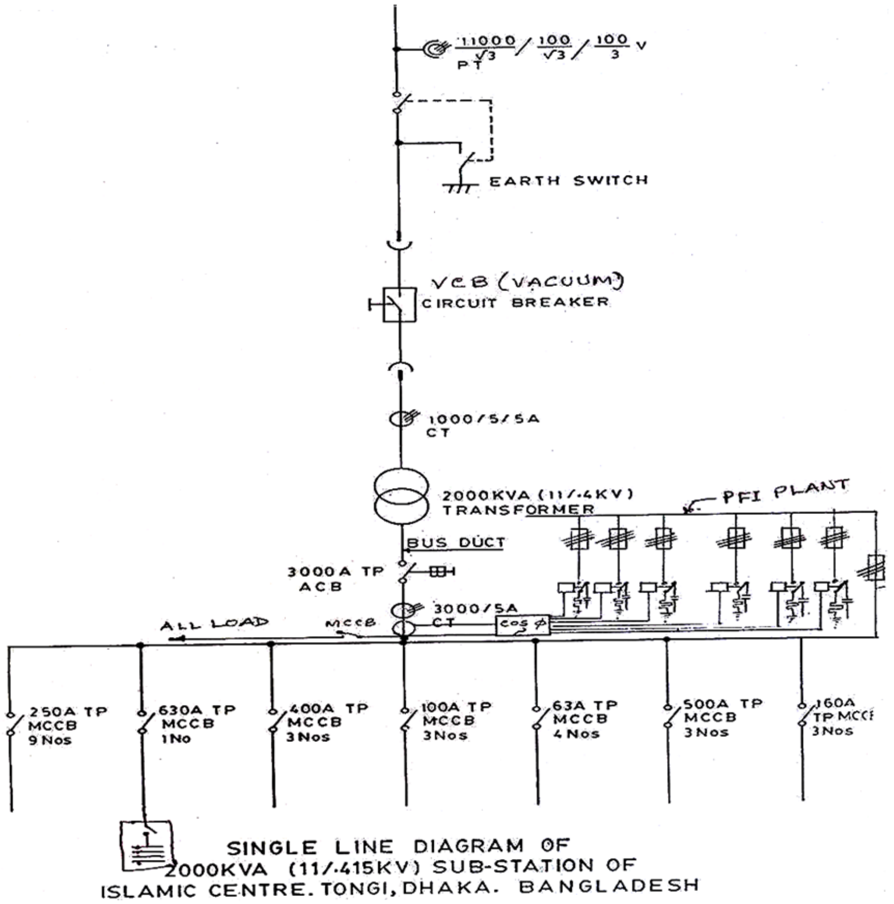


Fig 6.6: One Line Diagram IUT Substation.

- IUT substation receives the power at 11 KV (Board bazar) and convert the receiving power to 0.4 KV using transformer.

Transformer Rating:

Incoming: 11 KV	Rated Voltage: 11 KV
Outgoing: 0.4 KV	Rated Current: 2782 A
Frequency: 50 HZ	Rated Capacity: 2000 KVA
For H.T: 105 A	For L.T: 3000 A

- There are **two generators** in IUT substation.

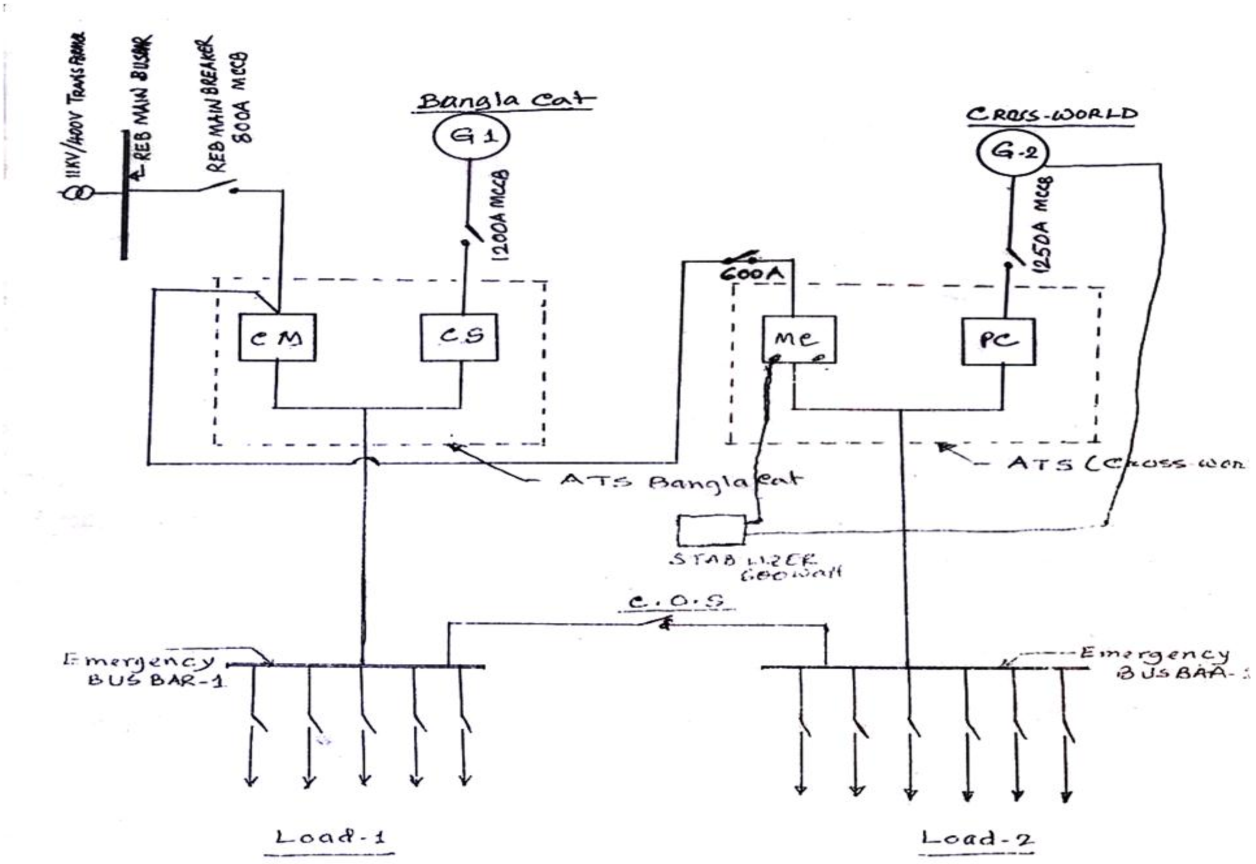
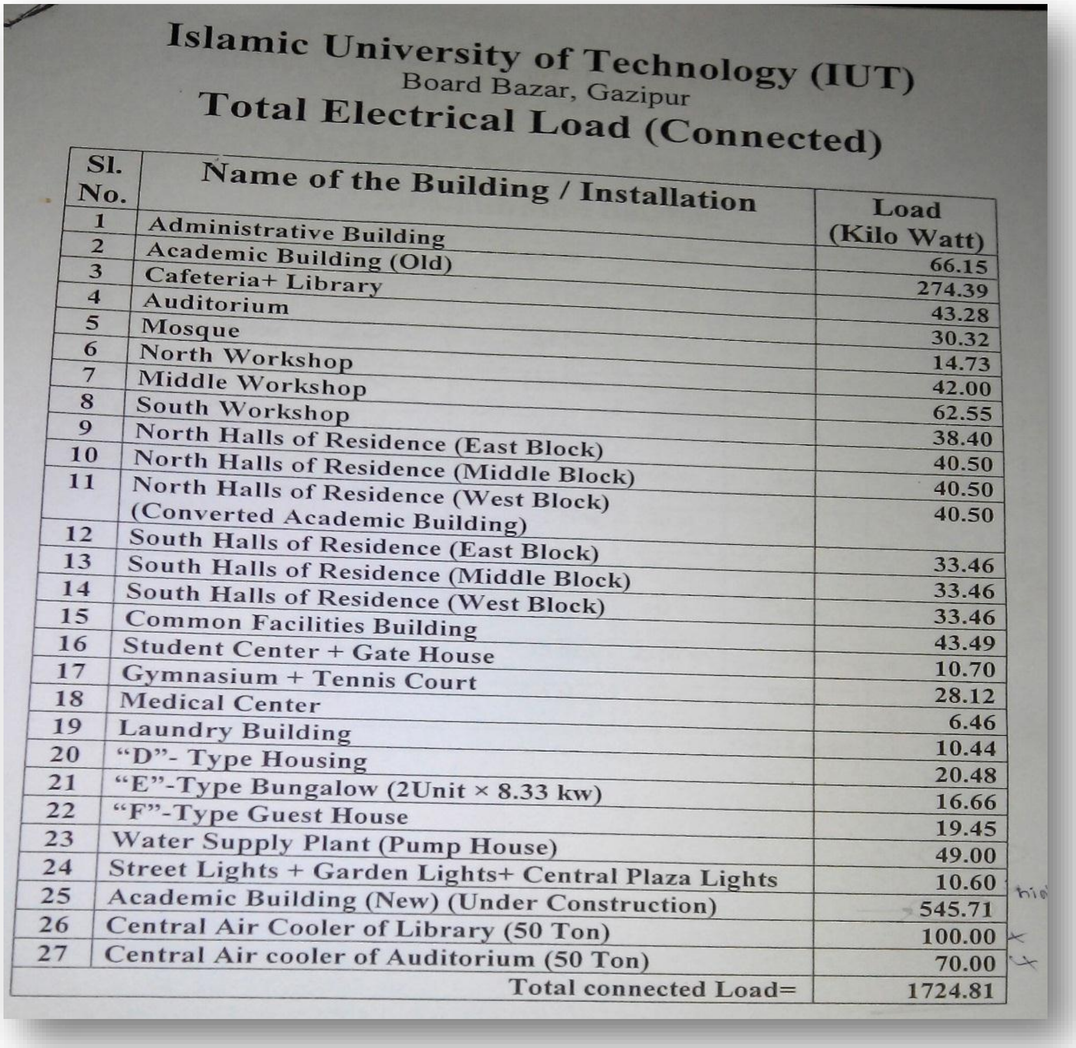


Fig 6.7: One Line Diagram of Generator Connection in IUT Substation.

- From the **Fig 6.7** Load 1 & Load 2 are actually the line connection for different buildings inside IUT which are receiving power from IUT substation.

- During load shedding this two generators supply the required power for all buildings. Both of them are Diesel Generators.

- Name of these buildings along with their demands in Kilo Watt (KW) is given below :



Islamic University of Technology (IUT)
Board Bazar, Gazipur
Total Electrical Load (Connected)

Sl. No.	Name of the Building / Installation	Load (Kilo Watt)
1	Administrative Building	66.15
2	Academic Building (Old)	274.39
3	Cafeteria+ Library	43.28
4	Auditorium	30.32
5	Mosque	14.73
6	North Workshop	42.00
7	Middle Workshop	62.55
8	South Workshop	38.40
9	North Halls of Residence (East Block)	40.50
10	North Halls of Residence (Middle Block)	40.50
11	North Halls of Residence (West Block) (Converted Academic Building)	40.50
12	South Halls of Residence (East Block)	33.46
13	South Halls of Residence (Middle Block)	33.46
14	South Halls of Residence (West Block)	33.46
15	Common Facilities Building	43.49
16	Student Center + Gate House	10.70
17	Gymnasium + Tennis Court	28.12
18	Medical Center	6.46
19	Laundry Building	10.44
20	"D"- Type Housing	20.48
21	"E"-Type Bungalow (2Unit × 8.33 kw)	16.66
22	"F"-Type Guest House	19.45
23	Water Supply Plant (Pump House)	49.00
24	Street Lights + Garden Lights+ Central Plaza Lights	10.60
25	Academic Building (New) (Under Construction)	545.71
26	Central Air Cooler of Library (50 Ton)	100.00
27	Central Air cooler of Auditorium (50 Ton)	70.00
	Total connected Load=	1724.81

Fig 6.8: Name of the Buildings with Their Demands in Kilo Watt (KW).

- At this stage we took practical data for different buildings from their bus bar connection using *Clamp Tester* and then finally we simulated the one line diagram in *Etap Software* for further analysis.

- As the current consumption rate changes in every second the following data are collected using *Clamp Tester* may also vary from the real time calculation.

Feeders name	First Reading (2:35) PM 17/6/2013 REB Line ON Voltage = 395 V Total Load=700A	Second Reading (12:30) PM 18/6/2013 GEN. 1 ON Voltage = 392 V Total Load=600A	Third Reading (12:00) PM 20/6/2013 REB Line ON Voltage = 392 V Total Load=650A
Administrative Building	70A	80 A	60 A
Auditorium	2A	10 A	10 A
‘D’ Type Building	10 A	22 A	12 A
Guest House	10 A	0 A	5 A
Academic Building	72 A	100 A	80 A
Dormitories / Pump House/ Student Center/ Common Facilities Building/ Level-5(A.B)	250 A	200 A	300 A
New Academic Building	412 A	350A	150A
Cafeteria/ Library	40 A	52 A	42 A
Mosque	6 A	10 A	5 A
North Work-shop	20 A	5 A	0 A
Middle Work-shop	15 A	0 A	5 A
Welding Work-shop	0 A	0 A	20 A
South Work-shop	25 A	20 A	5 A
Street Light	0 A	0 A	0 A

Table 6.1: Name of the Feeders & Current Consumption in Ampere (A).

- The above one line diagram along with all data is simulated in *Etap Software* for Load flow calculation at the peak demand:

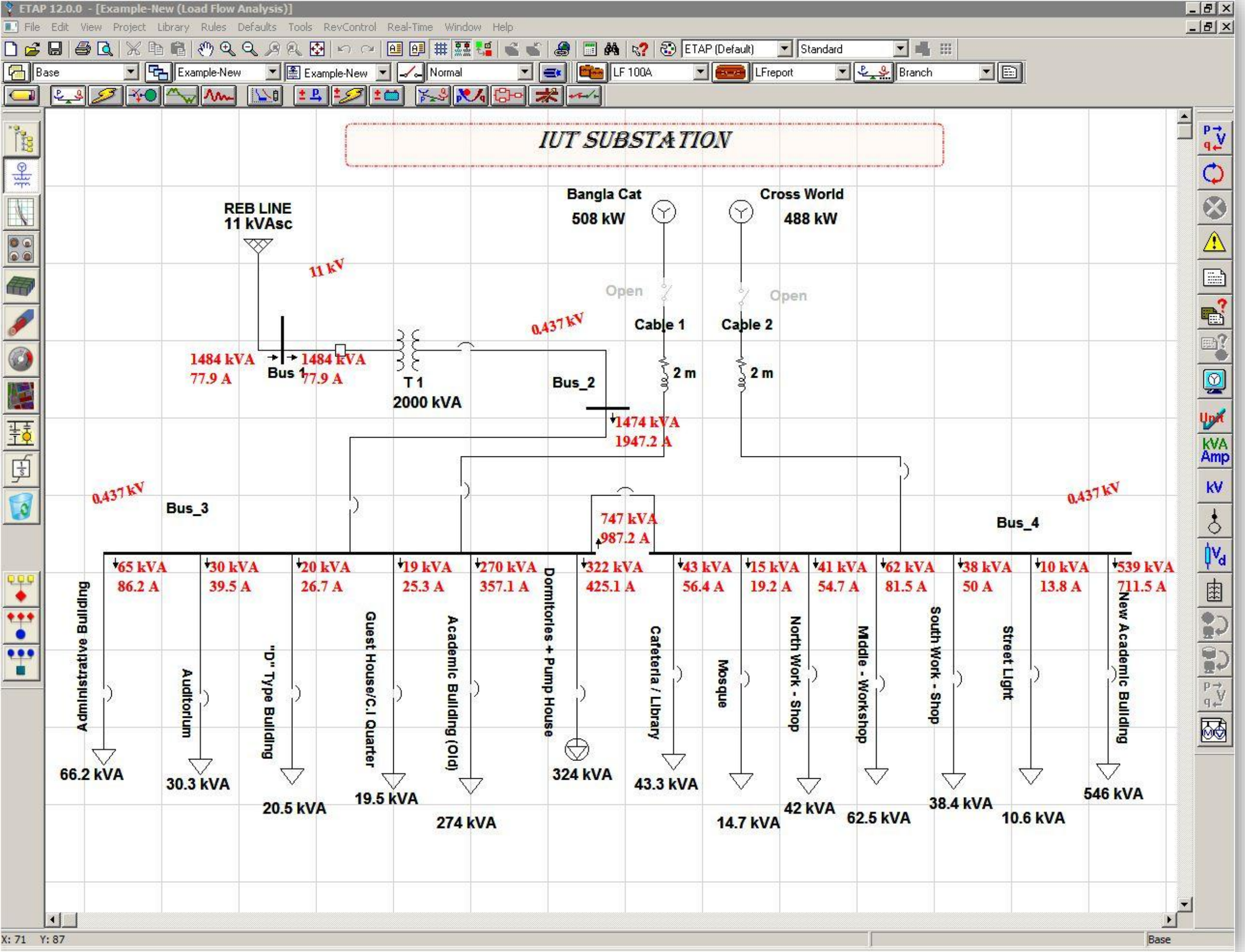


Fig 6.9: Load Flow Calculation for IUT Substation.

- The above load flow calculation is done for ‘REB Line ON’ condition which means that IUT substation is receiving power from Board Bazar substation and there is no load shedding going on.

6.1.4 Comparison of Data Analysis :

- We can compare our practical data collected from *Clamp Tester* and the data we obtained from the *Etap Software* simulation as given below:

Load Type	**Data in (Amp) from *Clamp Tester***	**Data in (Amp) from *Etap Software***
Dormitories + Pump House + Student Centre	300	425
Administrative Building	80	86
Staff Home	22	26
Cafe + Library	52	56
Mosque	10	19
Auditorium	10	39

Table 6.2: Comparison of Data Analysis in Load Flow Study

- As the current consumption rate changes in every second it is not really acceptable to have the same data in both case.
- Though we got some similar type of data in both case which implies that the one line diagram that we have designed in *Etap Software* is accurate enough for further analysis.

6.1.5 Load Flow for Combined Network (Board Bazar + IUT):

- ➢ The load flow analysis for combined one line diagram of Board Bazar & IUT substation is given below:

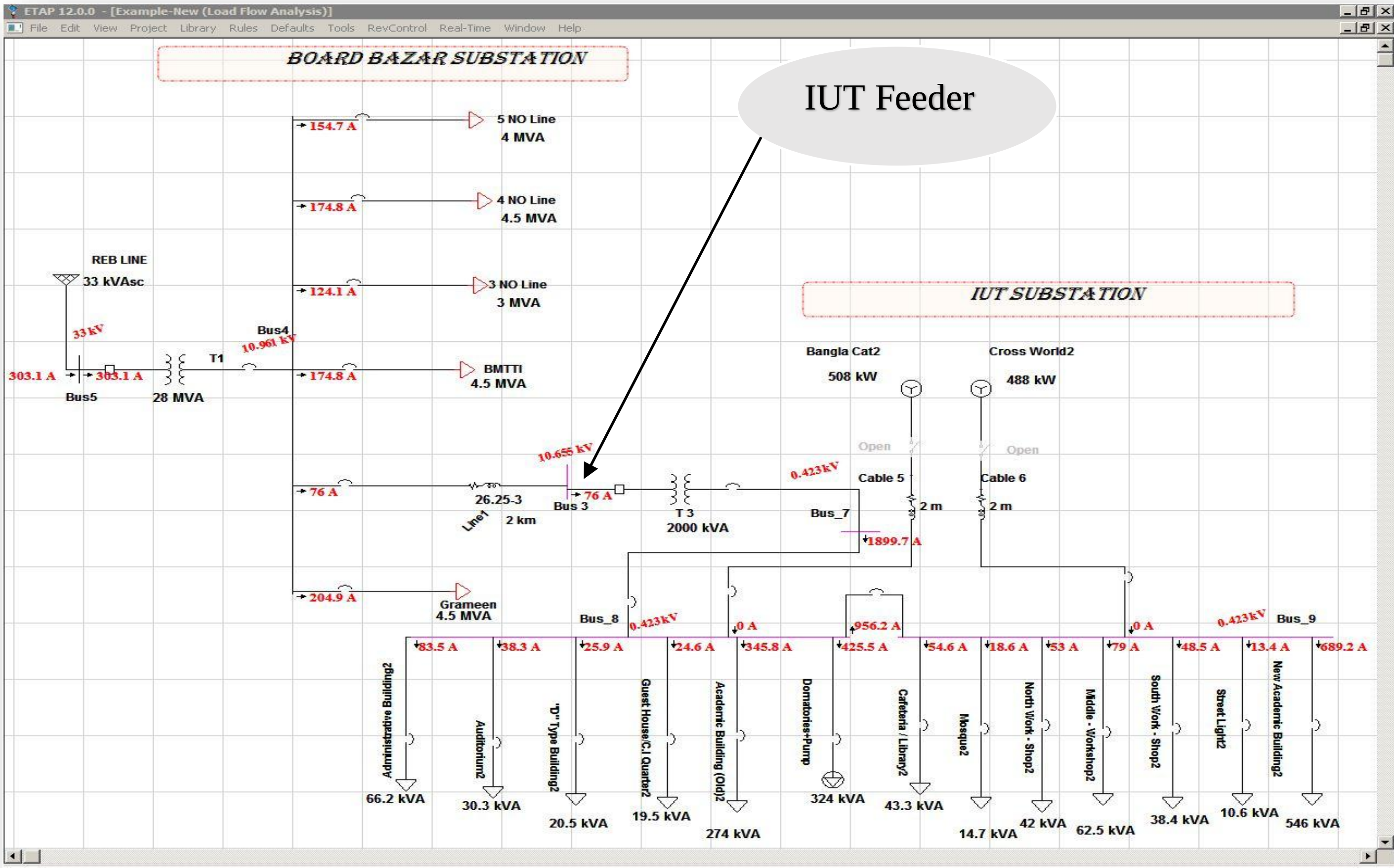


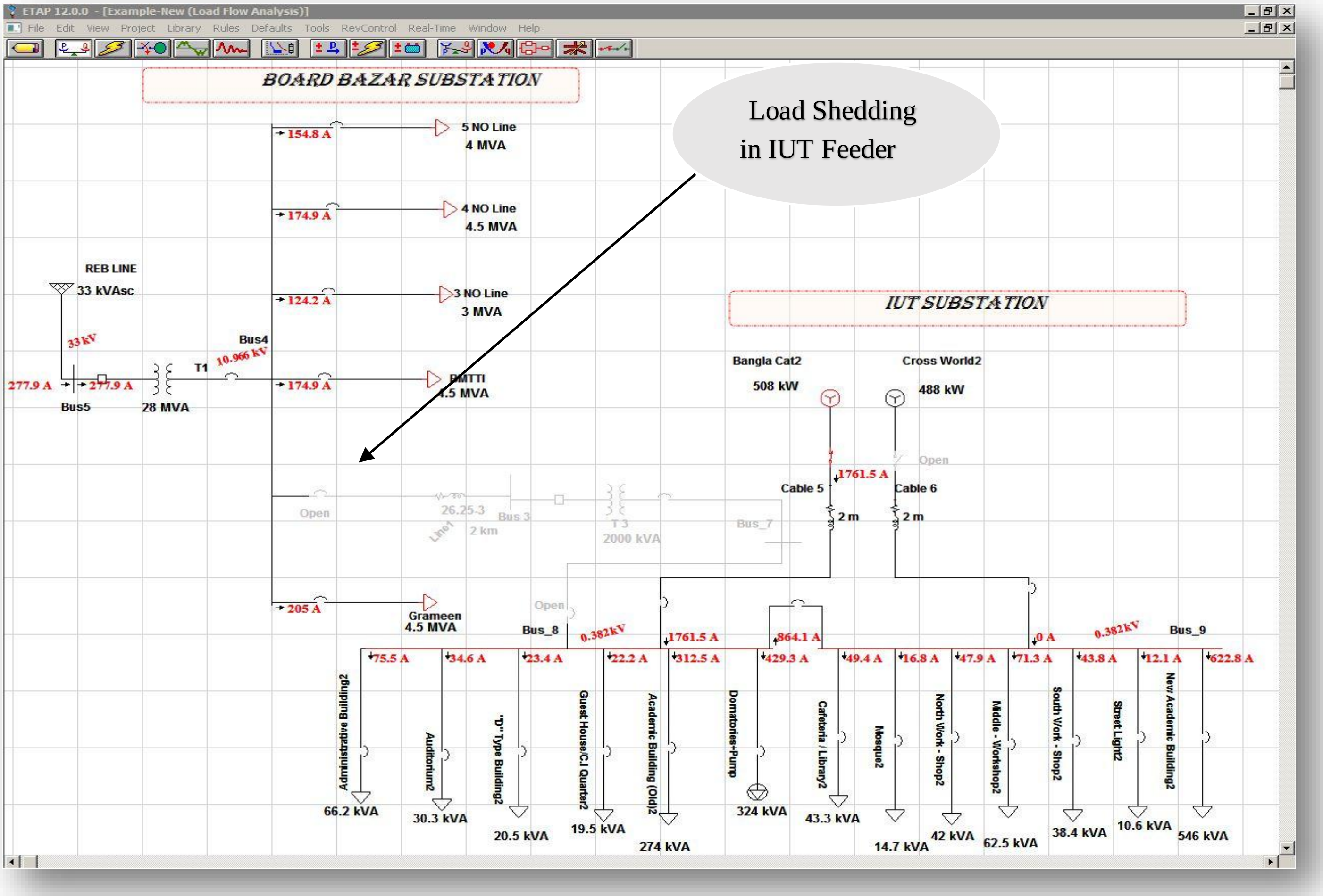
Fig 6.10: Load Flow Calculation for Combined Network.

- ➢ The above load flow calculation is done for ‘REB Line ON’ condition which means that IUT substation is receiving power from Board Bazar substation and there is no load shedding going on.

- ➢ In reality during peak time when the demand is high it often causes outage problem as a result power failure occurs frequently.

- ➢ As uninterrupted power supply is the prerequisite for smart grid implementation, therefore outage problem should be minimized as much as possible.

- The load flow analysis for combined one line diagram of Board Bazar & IUT substation during **load shedding** is given below:



Load Shedding in IUT Feeder

Fig 6.11: Load Flow Calculation during Power Outage.

- The above figure shows the outage problem in IUT feeder whereas, same scenario may happen in other feeders also.
- Though because of generator we are getting power, more robust & reliable system is required for uninterrupted power supply with extensive monitoring.

6.2 Reliability Analysis:

- The reliability associated with an electric utility system is a measure of the ability of the system to provide an adequate supply of electrical energy consistently.

- Reliability of a power system is generally addressed by considering two basic aspects of the utility power system: ***Adequacy*** and ***Security***.
- **Adequacy** relates to the existence of sufficient generation, transmission and distribution facilities to supply the total electric power and energy requirements of the customers at all times, taking into consideration planned and random outages of system components.
- **Security**, on the other hand, relates to the ability of the electric utility power system to withstand both local and widespread disturbances and unanticipated loss of generation and transmission equipment.

The basic reliability indices normally used to predict or assess the reliability of a distribution system consist of two reliability indices:

- Load point average failure rate (l) in fault per year (f/yr)
- Average outage duration (r) in hours per year (hr/yr)

The following reliability studies is based on this two indices.

6.2.1 Reliability Analysis for IUT Substation:

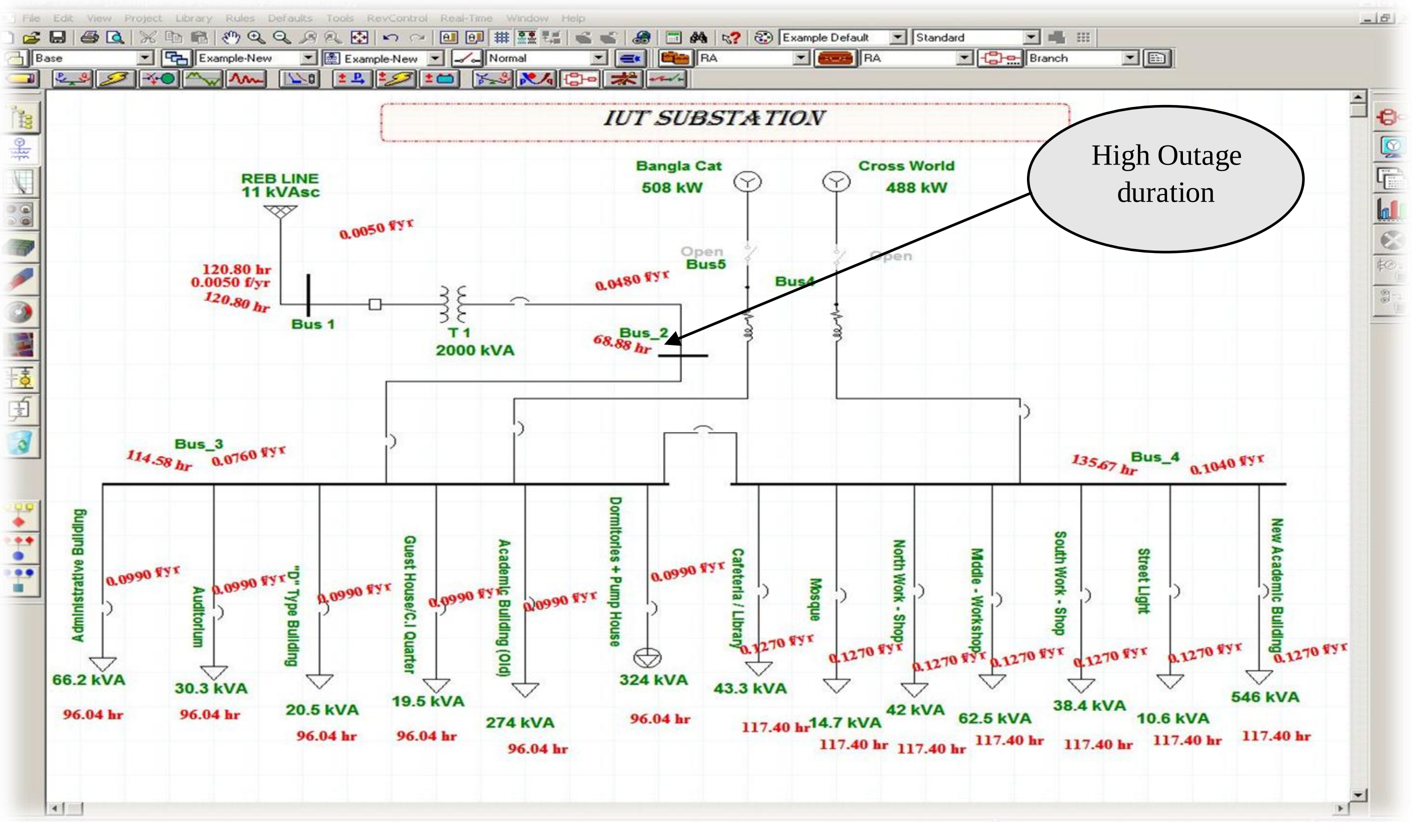


Fig 6.12: Reliability Analysis for IUT Substation.

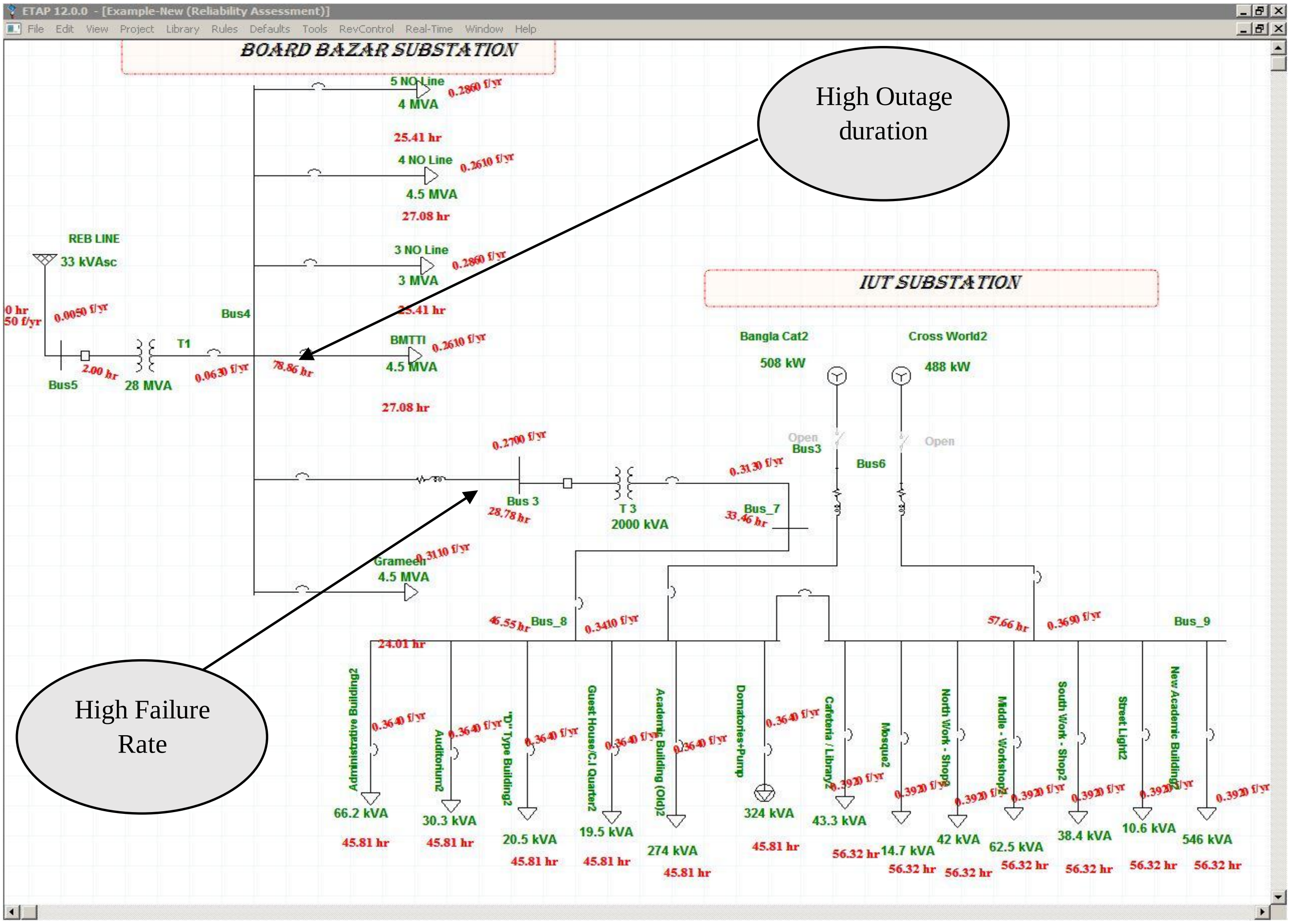
- From the above reliability analysis for IUT substation we obtained

  High load point average failure rate (l) = 0.140 times fault per year* &

  High average outage duration (r) = 68.88 hours*
- Further analysis of combined network will give us appropriate results to propose our model to mitigate this problems.

*This results are software simulated based on random probabilistic function which may vary with real time operation.

6.2.2 Reliability Analysis for Combined Network (Board Bazar + IUT):



High Outage duration

High Failure Rate

Fig 6.13: Reliability Analysis for Combined Network.

- From the above reliability analysis for Combined Network we obtained

  High average outage duration (r) = 78.86 hours at 11 KV feeder line as well as high load point average failure rate (l) at different load points.

- So from the above load flow & reliability analysis we acknowledged that the present grid system has so many problems that are summarized in next topic.

6.3 Problems with the Existing Grid System:

The following problems are listed below from the above analysis of present grid system:

- ***Lack of two way Power flow system***
- ***Integration of renewable energy is absent***
- ***No system for storage facility***
- ***High outage rate***
- ***High average failure rate***

- Actually the above problems are the main reason of implementing ***Smart Grid*** technology to ensure a healthy and self-healing power system.

- So, we will try to mitigate this problems by adopting some basic characteristic technology of ***Smart Grid*** in our proposed model in following chapter.

6.4 Summary:

This chapter is aimed to find out the problem with the present grid system through some software simulated analysis of IUT and Board Bazar substation using Etap 12.0 demo version. All the data we got may vary with the real time system. However, we will step forward to mitigate these problem by designing an interconnected self-healing system in next chapter.

CHAPTER
7
OUR PROPOSALS

7.1 Finding Solution through Smart Grid Technology:

- The problems that we faced in case of present grid can be mitigated by adopting some key technologies which are actually define the Smart Grid.

- For this we have to keep in mind the above problems and to ensure the healthy and uninterrupted power system which is the prime concern of ***Standard Grid Substation***, the following steps should be noted while designing an interconnected grid system:

  - ***Ensuring two way Power flow***
  - ***Integration of renewable energy in grid***
  - ***System for storage facility***
  - ***Reducing the outage rate***
  - ***Reducing the average failure rate***

- In this chapter we will design an interconnected system for Board Bazar & IUT substation using Etap software and also analysis the load flow and reliability for our designed grid system to ensure the above criteria.

- First we will represent our proposed model in a block diagram to make it easier to understand and then we will go for the load flow & reliability analysis to compare our results with the present system.

7.2 Block Diagram Representation of Our Proposed Model:

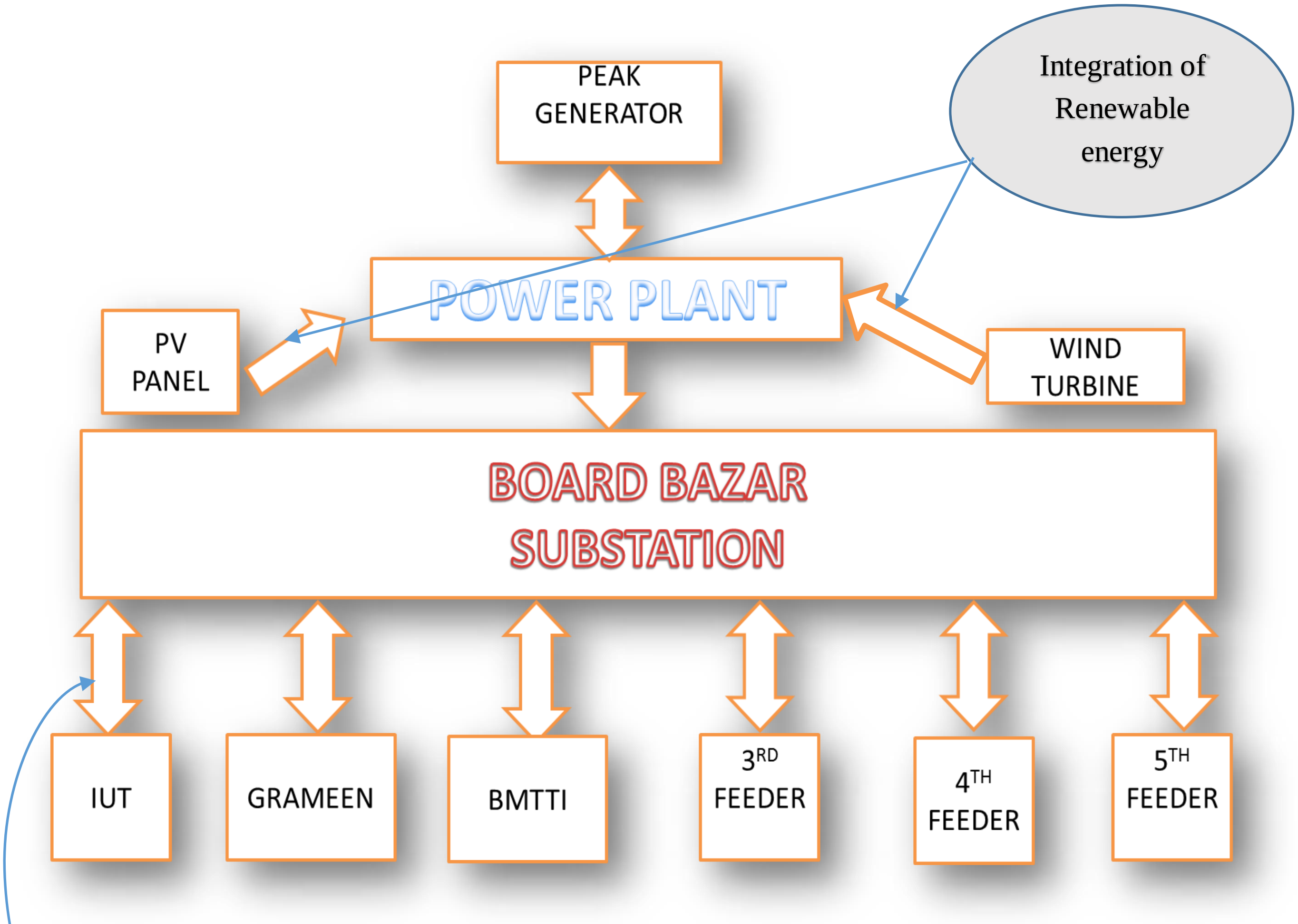


Fig 7.1: Block Diagram of Interconnected Grid System.

The above figure is shown for Board Bazar substation & its six feeders where:

- Two way of power flow is considered &
- Integration renewable energy is also ensured.

Two way power flow is required during peak time to feedback the power from consumer to utility and integration of renewable sources ensure the pollution free electricity production which is the major concern in case of reducing greenhouse gases (CO_2).

- The following figure is shown for only the IUT substation and its interconnected system:

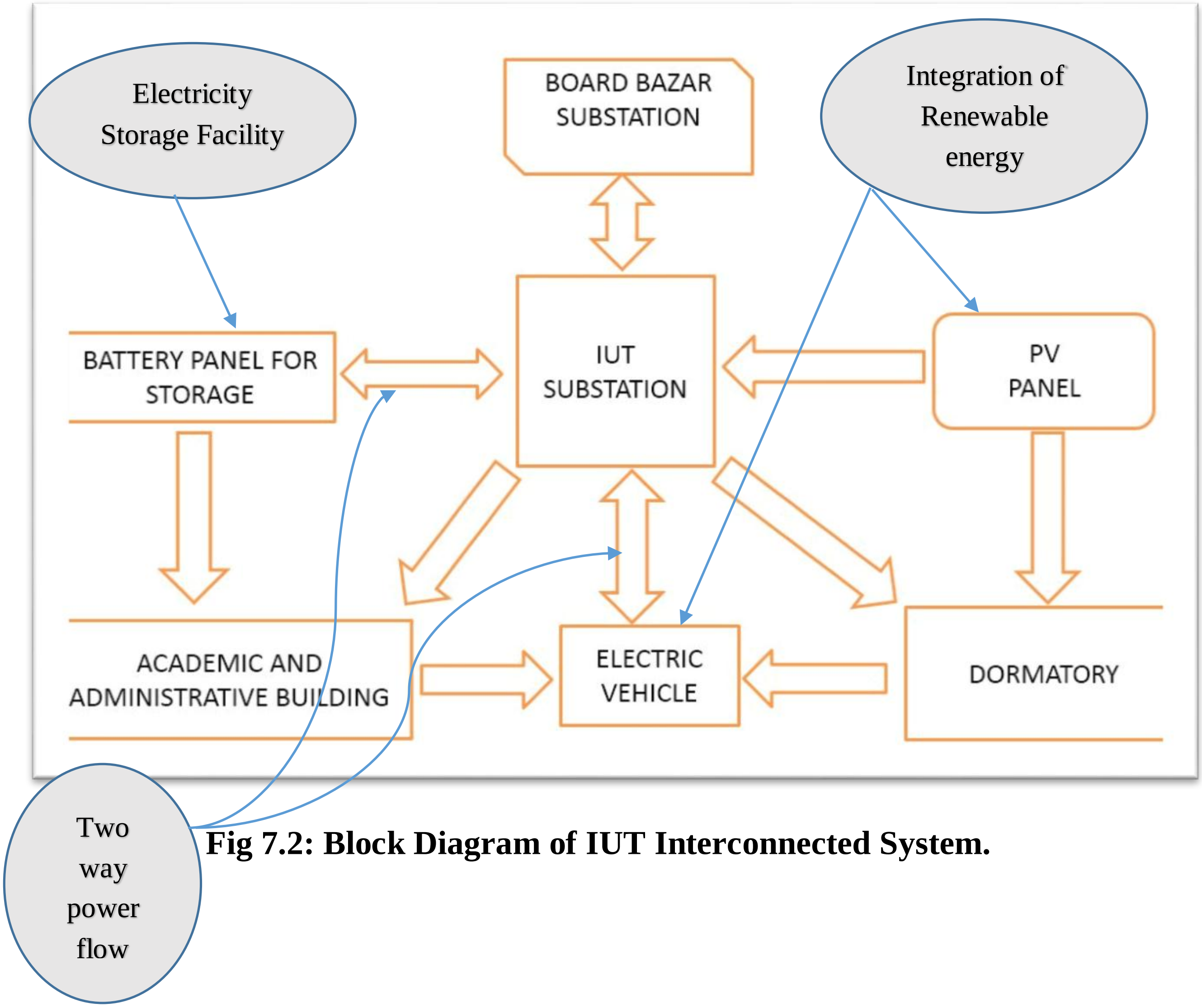


Fig 7.2: Block Diagram of IUT Interconnected System.

- From the above figure it is acceptable to have the two way power flow, integration of renewable energy and electricity storage system for IUT substation which will be self-healing as well as capable of feeding back power to Board Bazar substation during peak demand via two way power flow system keeping the record that amount of power in smart meter for billing purpose.

7.3 One Line Diagram of Our Proposed Model:

- Here we will step forward to design the one line diagram of IUT & Board Bazar interconnected grid system in Etap software keeping those criteria in mind for further analysis:

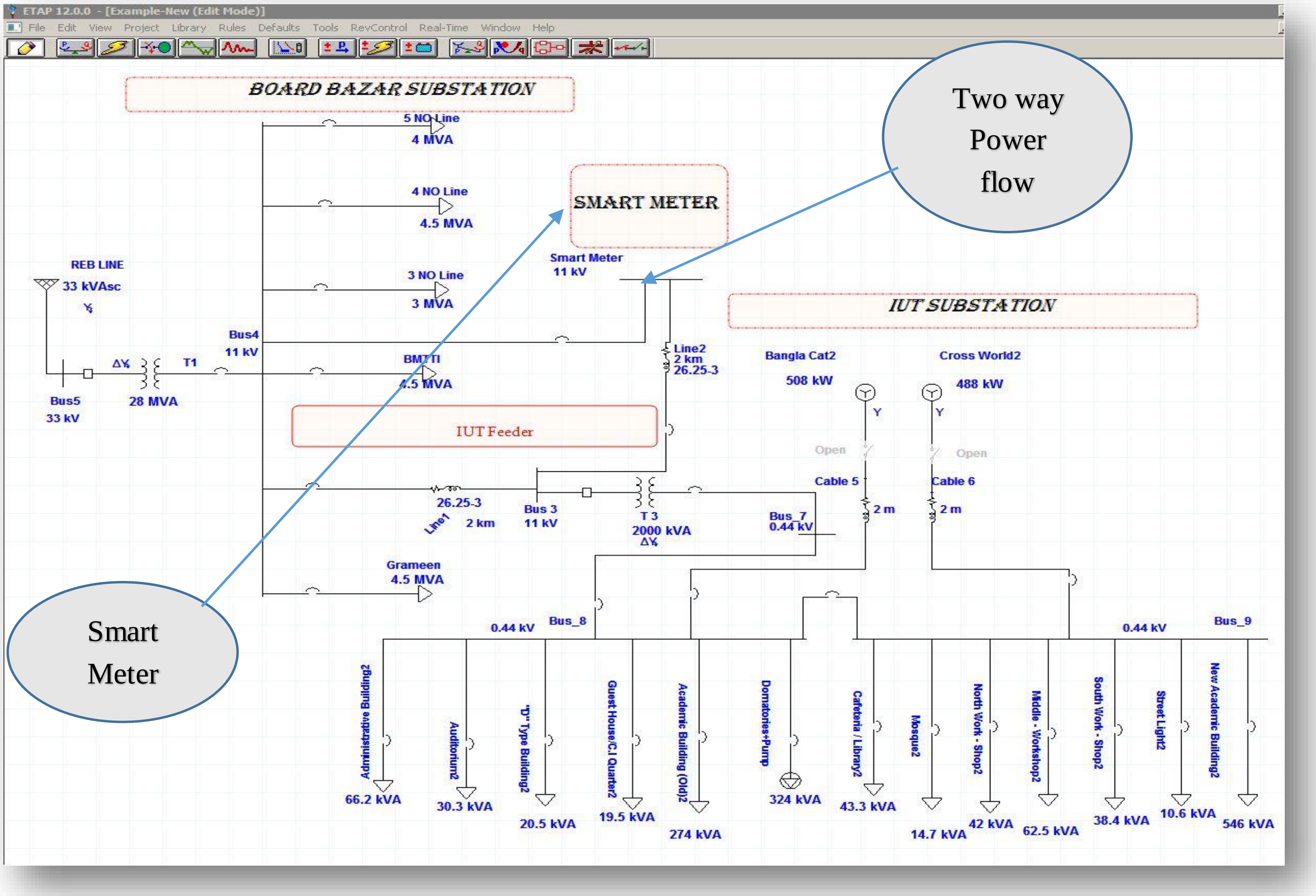


Fig 7.3: One Line Diagram of Interconnected Grid System.

- The two way power flow path via smart meter is shown in the above figure from IUT to Board Bazar substation which ensures the power feeding back system in peak demand when IUT substation will have adequate power generation.

- The load flow simulation for this one line diagrams given below:

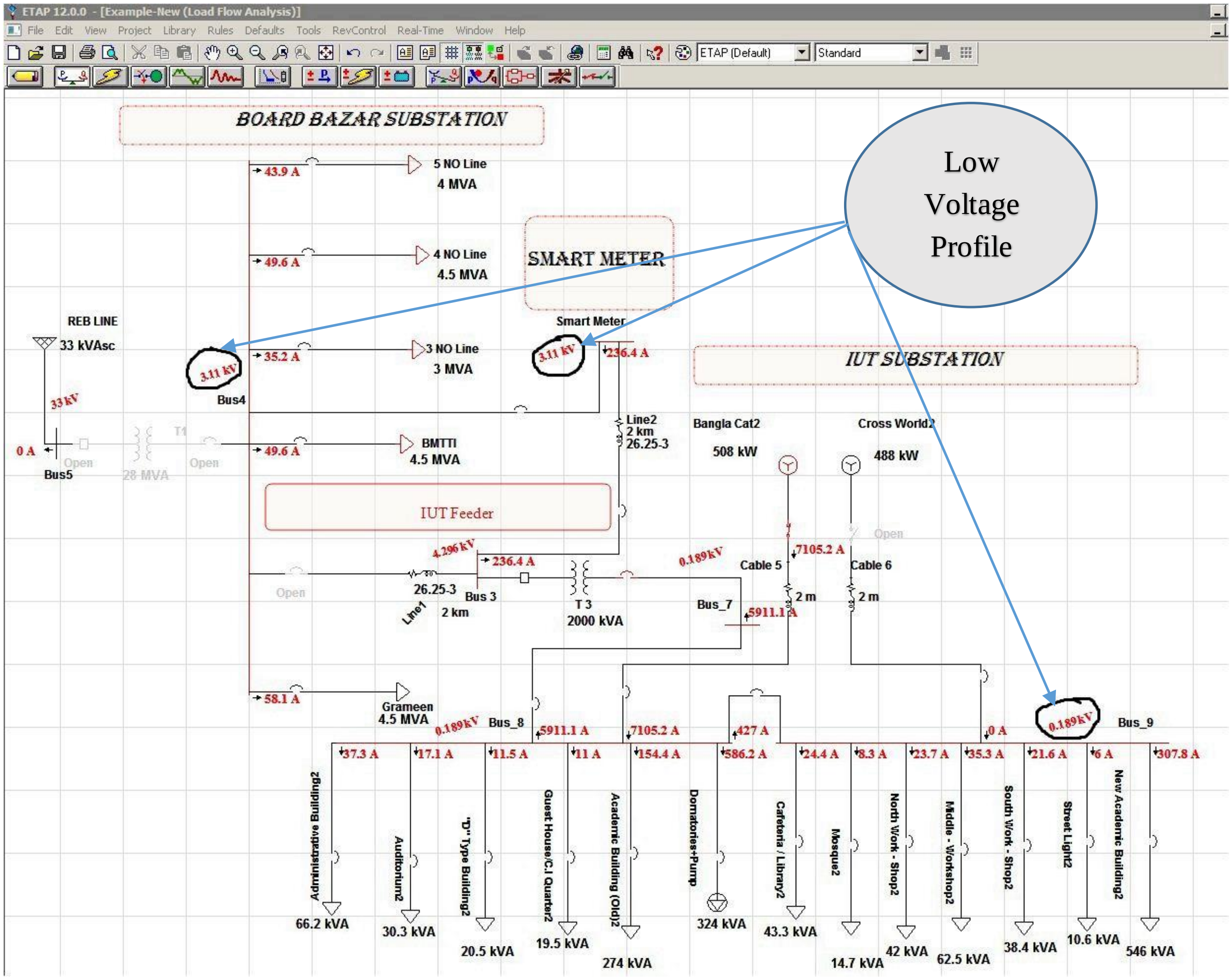


Fig 7.4: Load flow of One Line Diagram of Interconnected Grid System.

- The above load flow is done when the IUT substation is getting power from its generator and the REB line is off.
- As the load shedding is going on the other feeders of Board Bazar substation will not get power but here because of two way power flow system they are also getting power from IUT substation.
- Here the smart meter is keeping the record of how much power is going back from IUT substation. Thus one criterion is fulfilled for adopting smart grid technology.
- It is not really practical to feed all the feeders with only one generator of IUT substation and that's why *the low voltage profile* is shown here.

- ➢ This low voltage profile reminds us that we have lack of renewable sources integration in our model and there is no storage system which is also another reason of this problem as well as another prerequisite for smart grid.
- ➢ So we need to modify our system with adding renewable source for electricity production and with storage facility to meet the peak demand.

- ➢ The following figure is shown for the modified model to reduce the above problems:

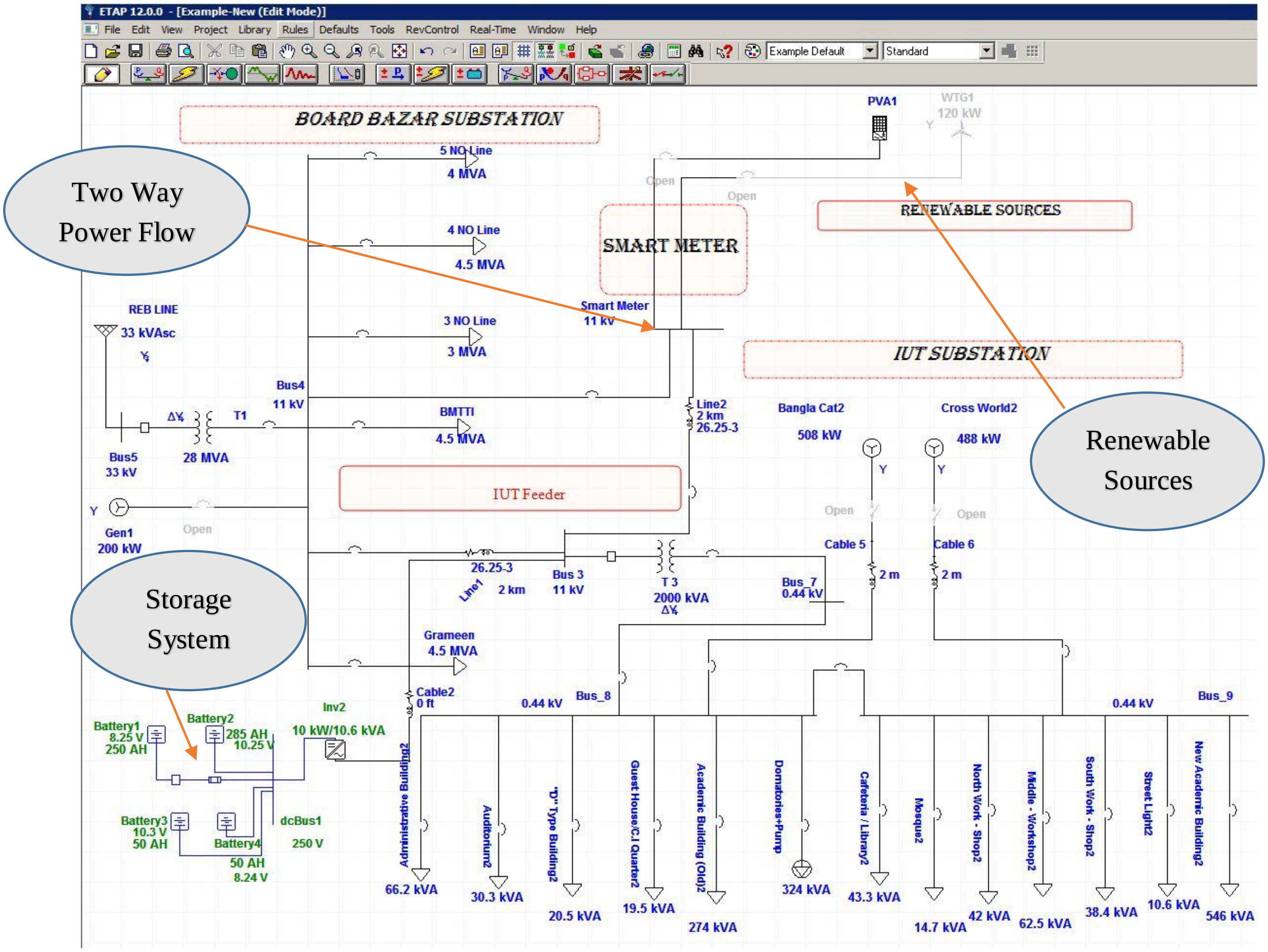


Fig 7.5: One Line Diagram of Our Proposed Interconnected Grid System.

- ➢ In the above figure all the basic criteria of smart grid is ensured by adding two way power flow, renewable sources(Wind turbine, PV array) and storage system(adequate battery panel).

- Now, the load flow analysis & reliability analysis of the above model can give us better solution by mitigating the above problems.

7.4 Reliability Analysis of Our Proposed Model:

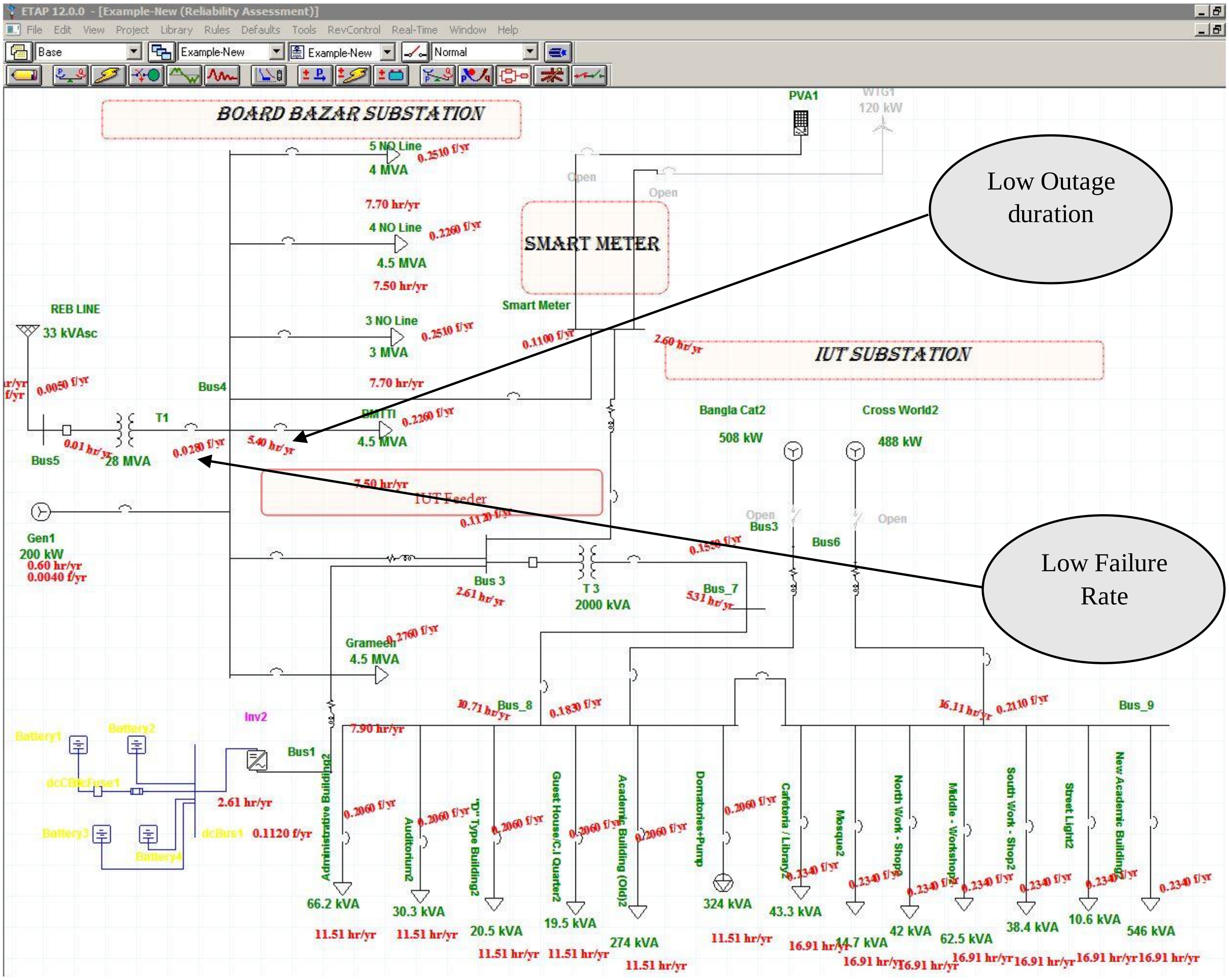


Fig 7.6: Reliability Analysis of Our Proposed Interconnected Grid System.

- Reliability analysis of our proposed model shows better results compared to the present grid reliability analysis.

7.5 Comparison of Data Analysis:

- The comparison of data analysis between our proposed model and the present grid system is given below:

Types of Faults	Current Grid System	Proposed “Smart Grid” System
Average Failure Rate	**0.0630**	**0.028**
So, Average Failure Rate is improved by 55%		
Average load Shedding	**78.86**	**5.40**
So, Average Load Shedding Rate is decreased by 93 %		

Table 7.1: Comparison of Data Analysis.

- The above data is taken from the 11 KV feeder of Board Bazar substation from the proposed model.

- Due to the integration of renewable sources, capacity of storage facility and two way of power flow system in the grid, the average outage rate and failure rate is improved dramatically which is the prime concern of smart grid technology.

- So the modified model consisting all basic criteria of smart grid technology shows better result with less failure rate and decreased load shedding rate.

7.6 Overall Pictorial View of Our Proposed Model:

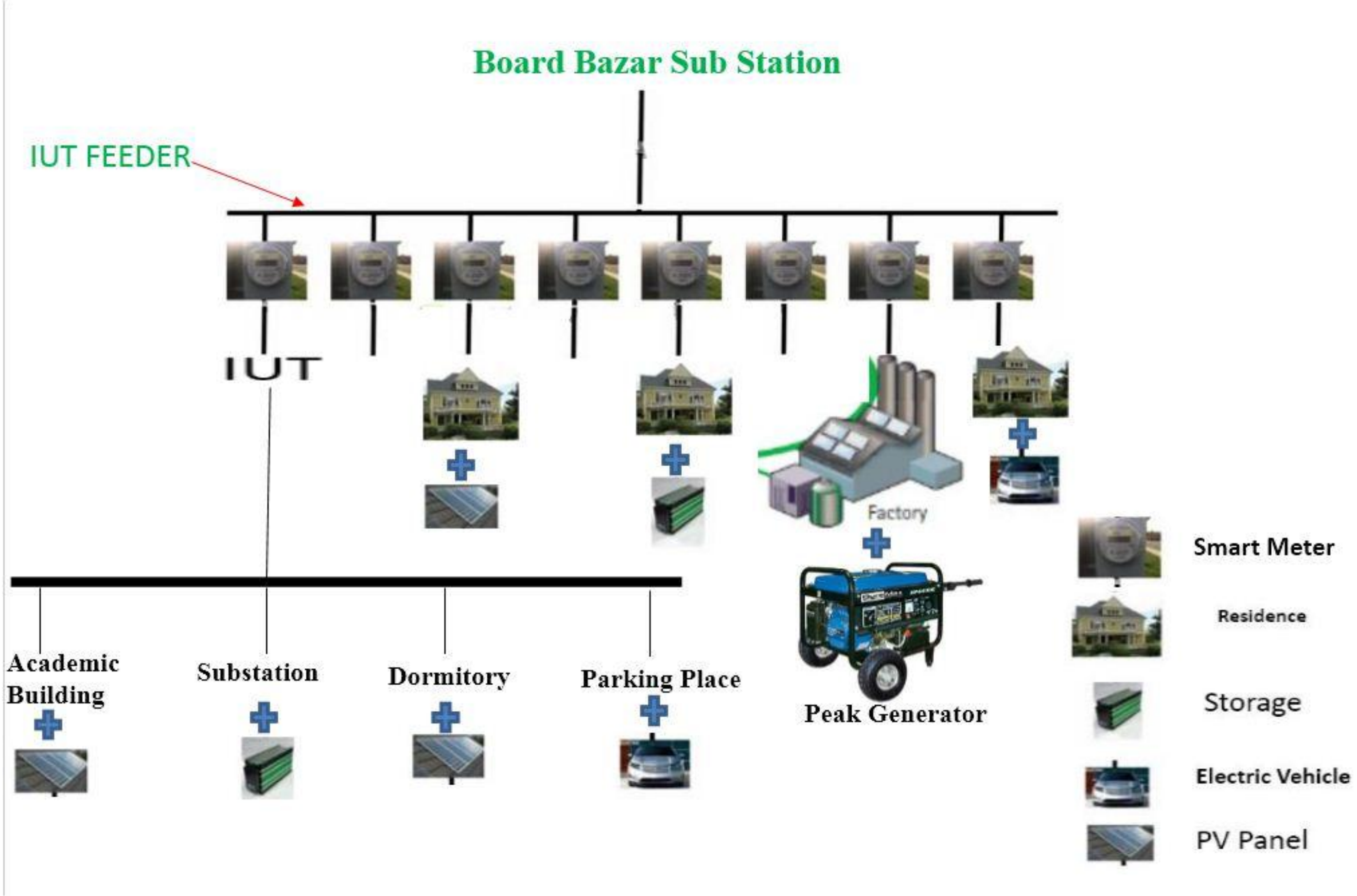


Fig 7.7: Overall Pictorial View of Our Proposed Model Grid System.

The overall pictorial view of our proposed model states the following facts:

- *For areas outside IUT under IUT feeder*

  Every 11 KV feeders connected to the Board Bazar substation is receiving power and during peak demand they can also feedback the power via smart meter where the meter will keep the record of that power.

  Every feeders should have enough renewable integration within their interconnected system so that they can meet their peak demand.

  For the large factory situated within the IUT feeder with their own peak generator can also feedback the power via smart meter to the substation.

Residential area under IUT feeder with their solar PV and electric vehicle can also contribute to the power sharing. Enough storage facility for proper application should also be considered for peak demand.

- *For inside IUT:*

  - Every building inside IUT should have the solar PV module integration with the substation to increase the electricity production.
  - Storage facility with battery panel integrated with the substation can be built for charging during vacation time when the load of dormitory and academic building is reduced and thus the power can be used again.
  - As new academic building is taking more power compared to the other building, the load minimizing scheme should be taken for this building to maintain the optimal power flow.
  - More digital equipment should be introduced in IUT substation to make it a smart substation as stated in previous discussion of *Smart Substation* equipment chapter.
  - The communication system between different buildings about load status should be introduced with a center control system through wired or wireless technology.
  - Sufficient system should be built to charge up the electric vehicle in parking place and to take power from them during peak time via smart meter and many more initiative can be taken to transform the present electric system for IUT substation into a smart grid system.

7.7 Summary:

This chapter is aimed to find out the solution of the problems of present electrical grid system with adopting some smart grid features implemented in our visited substation where we can observe the improvement of power flow analysis and reliability analysis. For this purpose we used all practical data needed to simulate the diagrams in Etap software and in some cases we used typical data ready from the software database.

Conclusion

The traditional “work harder” approach would imply meeting the growth in variability with an increase in spinning reserves. This is not only costly but can partly negate the environmental advantage of renewable generation.

The “work smarter” approach takes a more comprehensive view of the transmission system. Whereas the control system of a traditional grid assumes the demand side to be a “given,” smart grids will increasingly incentivize consumers to modify their consumption patterns to suit availability.

The smart grid will require engineers and professionals with greater expertise and training than the skilled workforce of today. In addition to the technological aspects of development, engineers will need to study manufacturing, data management, asset optimization, and policy and protocol development. The smart grid will also depend upon expanding current research efforts in the areas of cyber security, controls, communication, computational intelligence techniques, and decision support tools.

Operation and management of electricity generation, transmission, and distribution are changing due to technological and power marketing developments. Technological changes are being driven by the introduction of emerging technologies such as power electronics, DG, RER, micro grids, digital protection coordination, supervisory control, and energy management. The market - driven power business environment has created a need for nonelectrical engineering topics such as operations research and economics.

This thesis expatiated the influence of smart grid on power system throughput performance. Some works have been done with incorporating the previous researches and analysis.

Then a comparison has been made between present grid and future smart grid through analysis. From this comparison an optimum grid system can be selected for a particular areas with more extensive monitoring.

It is expected that this thesis work can be a useful tool for real time implementation of standard grid with the addition of other modern technologies.

References

[1] James Momoh *"SMART GRID Fundamentals of Design and Analysis"* IEEE Press by the Institute of Electrical and Electronics Engineers. Published by John Wiley & Sons, Inc., Hoboken, New Jersey, 2012.

[2] Janaka Ekanayake, Kithsiri Liyanage, Jianzhong Wu, Akihiko Yokoyama, Nick Je nkins *"SMART GRID TECHNOLOGY AND APPLICATIONS"* Published by John Wiley & Sons, Ltd, 2012

[3] Erinmez, I.A., Bickers, D.O., Wood, G.F. and Hung, W. W. (1999) NGC *Experience with frequency control in England and Wales: provision of frequency response by generator*, IEEE PES Winter Meeting, 31 January–4 February 1999, New York, USA.

[4] Sun, Q., Wu, J., Zhang, Y. et al. (2010) *Comparison of the development of Smart Grids in China and the United Kingdom*. I EEE PES Conference on Innovative Smart Grid Technologies Europe, 11–13 October 2010, Gothenburg, Sweden.

[5] De Craemer, K, and Deconinck, G. (2010) *Analysis of State-of-the-Art Smart Metering Communication Standards, SmartMeteringCommStandards*.pdf https://lirias.kuleuven.be/bitstream/123456789/265822/1

[6] Department of Energy and Climate Change, UK, *Smart Metering Implementation Programme: Prospectus*, March 2011, http://www.decc.gov.uk/en/content/cms/consultations/smart_mtr_imp/smart_mtr_imp.aspx.

[7] Vilathgamuwa, D.M., Wijekoon, H.M. and Choi, S.S. (2006) *A novel technique to compensate voltage sags in multiline distribution system: the interline dynamic voltage restorer*. IEEE Transactions on Industrial Electronics, 53(5), 1603–1611.

[8] Staszesky, D.M., Craig, D. and Befus, C. (2005) *Advanced feeder automation is here*. IEEE Power Engineering Magazine,3(5), 56–63.

[9] Publication "*Smart grids: best practice fundamentals for a modern energy system*" by World Energy Council, 2012.

[10] The corporate technical journal **"***ABB Review*" published by ABB Group R&D and Technology.