T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

INTELLIGENT SUBSTATION AUTOMATION SYSTEMS FOR ROBUST OPERATION AND MANAGEMENT OF DISTRIBUTION NETWORKS

MASTER'S THESIS

Hasan Almuthana Jaber JASIM

Engineering Management Department

Engineering Management Master in English Program

AUGUST 2022

T.C.
ISTANBUL GEDİK UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

INTELLIGENT SUBSTATION AUTOMATION SYSTEMS FOR ROBUST OPERATION AND MANAGEMENT OF DISTRIBUTION NETWORKS

MASTER'S THESIS

Hasan Almuthana Jaber JASIM
(201281004)

Engineering Management Department

Engineering Management Master in English Program

Thesis Advisor: Prof. Dr. GÖZDE ULUTAGAY

AUGUST 2022

T.C.
İSTANBUL GEDİK ÜNİVERSİTESİ
LİSANSÜSTÜ EĞİTİM ENSTİTÜSÜ MÜDÜRLÜĞÜ

Yüksek Lisans Tez Onay Belgesi

Enstitümüz, Engineering Management Department İngilizce Tezli Yüksek Lisans Programı 201281004 numaralı öğrencisi Hasan Almuthana Jaber JASIM'in "Intelligent Substation Automation Systems for Robust Operation and Management of Distribution Networks" adlı tez çalışması Enstitümüz Yönetim Kurulunun 10/08/2022 tarihinde oluşturulan jüri tarafından *Oy Birliği* ile Yüksek Lisans tezi olarak *Kabul* edilmiştir.

Öğretim Üyesi Adı Soyadı

Tez SavunmaTarihi: 10/08/2022

1) Tez Danışmanı: Prof. Dr. Gözde ULUTAGAY

2) Jüri Üyesi: Dr. Öğr. Üyesi Tuğbay Burçin GÜMÜŞ

3) Jüri Üyesi: Prof. Dr. Selma GÜLER

DECLARATION

I, Hasan Almuthana Jaber JASIM, do hereby declare that this thesis titled as “Intelligent Substation Automation Systems for Robust Operation and Management of Distribution Networks” was an original academic work done by me for the award of the master’s degree in the Engineering Management faculty. I also declare that this thesis or any part of it has not been submitted or presented for any other degree or research paper in any other university or institution. (10.08.2022)

Hasan Almuthana Jaber JASIM

DEDICATION

I would like to present this dissertation and my humble efforts for accomplishing this work to my kindly family, classmate and all my sincere friends for the great support, advising and encouragement along the period of my trip for education, search and life. Special dedication goes to my supervisor Prof. Dr. GÖZDE ULUTAGAY my father, my mother and my family for their support and prayers during my research work, and thanks so much to my university "Istanbul Gedik University".

PREFACE

I would really be presenting my appreciation to every one supported me all through study and searching period of this voyage. I might to present my thank to my advisor, Prof. Dr. GÖZDE ULUTAGAY, for being my guide whenever I thought I was lost myself during research work and being in extraordinary role to haulage the culmination in this significant result. Addition to that, l would like to thank my supervisor for all the supportive and perfect advices that greatly enhanced my steps in the optimization of this work. Finally, I might to thank my university and especially the institution for hosting me during these wonderful years. I am very thankful to my mother, my father, my brothers and all my friends, whose instructions motivated me to keep on my aim. To my family, to everyone and to my country great the appreciation and love.

August 2022 Hasan Almuthana Jaber JASIM

TABLE OF CONTENT

Page

ABBREVATIONS

ADA : Advanced Distribution Automation
AMR : Automatic Meter Reading
ANN : Artificial Neural Network
ATS : Automated Transformer Substation
CA : Customer (premises) Automation
CBs : Circuit Breakers
CSS : Compact Secondary Substation
DAS : Distribution Automation System
DG : Distributed Generation
DR : Demand Response
DSE : Distribution State Estimation
DSM : Demand Side Management
ESS : Energy Storage Systems
EV : Electric Vehicle
FA : Feeder Automation
FACTS : Flexible AC Transmission Systems
FLISR : Isolation and Service Restoration
HMI : Human Machine Interface
HV : HIGH-Voltage
ICT : Information And Communication Technology
IDA : Intelligent Distribution Automation
IEA : International Energy Agency
IED’s : Intelligent Electronic Devices
IP : Internet Protocol
LTC : Load-Tap-Changer
LV : Low-Voltage
MM : Microgrid Management
MV : Medium-Voltage
NCCs : Numerous Control Centers
OMS : Outage Management Systems
PLCC : Power Line Carrier Communication
PMUs : Phasor Measurement Units
RES : Renewable Energy Sources
RTUs : Remote Terminal Units
SA : Substation Automation
SAS : Substation Automation System
SCADA : Supervision Control And Data Acquisition
SD : Switch-Disconnectors
SG : THE SMART GRID
SHG : Self-Healing Grid
SNs : Smart Nodes
SS : Secondary Substation
STS : Smart Transformer Substation

TS	: Transformer Substation
UHF	: Ultra High Frequency
VHF	: Very High Frequency
VVO	: Voltage/VAr Optimization
ZC	: Zone Concept

LIST OF TABLES

LIST OF FIGURS

Pages

INTELLIGENT SUBSTATION AUTOMATION SYSTEMS FOR ROBUST OPERATION AND MANAGEMENT OF DISTRIBUTION NETWORKS

ABSTRACT

This work is a process of selecting an automation system for secondary stations in the electricity distribution network in Iraq, which facilitates energy management and reduces losses and risks that accompany the energy distribution process. It is also the first step towards managing smart grids in the electrical system. The process of selecting, the appropriate system will be based on the data of the stretches that will be classified through the complete survey of the electrical network. The timetable for completing the study stages was prepared according to the estimated time for each stage. A neural network-based estimation system is proposed and simulated. The simulation results show a high performance for data loose overcoming.

Keywords: *Automation systems, Energy management, Distribution Networks and Robust Operation of Distribution Networks, Neural Networks*

DAĞITIM AĞLARININ GÜÇLÜ ÇALIŞMASI VE YÖNETIMI IÇIN AKILLI TRAFO OTOMASYON SISTEMLERI

ÖZET

Bu çalışma, Irak'taki elektrik dağıtım şebekesindeki ikincil istasyonlar için enerji yönetimini kolaylaştıran ve enerji dağıtım sürecine eşlik eden kayıp ve riskleri azaltan bir otomasyon sistemi seçme sürecidir. Aynı zamanda elektrik güç sistemindeki akıllı şebekeleri yönetmeye yönelik ilk adımdır. Uygun sistemi seçme süreci, elektrik şebekesinin tam incelemesi yoluyla sınıflandırılacak olan uzantıların verilerine dayanacaktır. Çalışma aşamalarını tamamlama takvimi, her aşama için tahmini süreye göre hazırlanmıştır. Sinir ağı tabanlı bir tahmin sistemi önerilmiş ve simüle edilmiştir. Simülasyon sonuçları, veri gevşekliğinin üstesinden gelmek için yüksek bir performans gösterir.

Anahtar Kelimeler: *Otomasyon sistemleri, Enerji yönetimi, Dağıtım Ağları ve Dağıtım Ağlarının Güçlü Çalışması, Sinir Ağları*

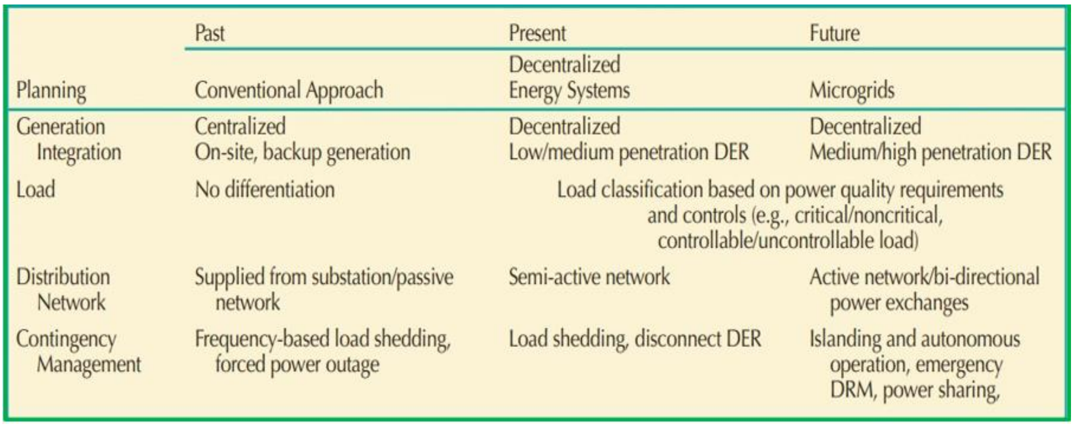
1. INTRODUCTION

1.1 Background

The last various experiences showed, clearly, sensitivity and weak of the interconnected electric energy systems according to grid defeat which is happened by natural threats or sudden phenomena. In other side, changes in users' different requirements, increasing in economical stresses because of liberalized markets of electric, and the significant degree of dependency of modern societies on upgraded services, especially the technological services, also intensify the load on conventional electrical systems and need to power delivery infrastructure with higher reliable and greater resilient. A restructured electric distribution networks can progress the service under high reliability for systems and can supply nice service variations.

Table 1.1 explains the main differences between traditional ways of various distribution power systems planning and the present planning programs that depending on the both, decentralized energy generation and microgrid programs.

Table 1.1: Main Variations between Traditional Ways of Distribution Systems Design and the Emerging Design Methods



	Past	Present	Future
Planning	Conventional Approach	Decentralized Energy Systems	Microgrids
Generation Integration	Centralized On-site, backup generation	Decentralized Low/medium penetration DER	Decentralized Medium/high penetration DER
Load	No differentiation	Load classification based on power quality requirements and controls (e.g., critical/noncritical, controllable/uncontrollable load)	
Distribution Network	Supplied from substation/passive network	Semi-active network	Active network/bi-directional power exchanges
Contingency Management	Frequency-based load shedding, forced power outage	Load shedding, disconnect DER	Islanding and autonomous operation, emergency DRM, power sharing,

Practically, the traditional planning approaches was planned depending on electric generation in known central electric generation stations, while the power delivery to the customer by final passive distribution networks. Actually, in explained construction, all users, those are provide with power coming from the substations of distribution, are essentially exposed for, approximately, the known quality scale of this supplied power (Driesen and Katiraei, 2008).

The term of distributed Intelligence can involve systems of structures that work together to causes, trace, solution of troubles, think abstractly, understanding the ideas and languages, and learning, or it can be defining as an entity of all shapes of intelligent operation or a specific system containing humans, various robots, intelligent sensors, and so on. In distributed Intelligence systems, various structures usually specialize in specific fields of the mission at hand.

The Intelligence Distributed in known computer science (and various related fields) is for generating the desired systems of intelligent sensors, the agents of various software, various employed robots, desired computer systems, and all peoples or animals (for instance, dogs of the search and salvage) that can operate jointly at the same scale of capacity or expertise as known human groups. Such as these systems can solve several important issues, involving not only civil search and salvage, but military operations that depending on the networks, technologies and simulation of the different gaming, modern methods of computer security, and so froths.

Absolutely, some implementations can be resolved utilizing a distributed solution method, essentially, these missions that are normally published during a place, time, or employment. In addition, if a specific system is fixing different subproblems, it will provide the ability of decreasing the total time of mission implementation.

Any system containing of multiple or, occasionally, excessive, entities, provides abilities of raising the strong and precision of the solution, because of the capability of one structure for taking over from another unsuccessful structure. Finally, according to several applications, constructing of a linked and connected structure that can process each side of an issue can be costly and complicated so much; instead, constructing various or more expert enti-ties that can engage the load of work provides the ability of decreasing the complications of the single structures. Therefore, as a study topic, the searches in distributed intelligence have owned great popularity present time.

The term of distributed energy and distributed intelligence are practically connected, significantly. The grid should supply best abilities of computing, communication, monitoring, and optimization because it treats with unwanted fast-rising mix of desired distributed renewable resources. The intelligent grids have been considered as a digital conversion center with good response, near-autonomous and enables the reciprocate of energy for a huge amounts of assets, frictionless, for instance, Electric Vehicle (EV) charging stations, various storage systems, and intermittent or distributed generating sources, took great and wide sectors in this modern transformation (Monadi, 2016).

A modern distributed energy systems have been presented as an effective, reliable, and environmentally friendly substitutional of the conventional power systems. Conventionally, power stations have been big and localize plants. There is a modern approach is upgrade across distributed energy generation, that means the power conversion stations will be placed in near to energy users, and undesired large stations will be alternative stations to these smaller ones. (Alanne and Saari, 2006).

As utilities, practically, accept fast-expanding group from the distributed renewable resources at a boundary of the specific distribution grid's, they should collect and upgrade those resources over a various flexible resolutions involving -for instance-storage capability and demand restrain treatment too. This development will give the distributed sources the ability to operate as same as the types of power they are assumed to substitute, essentially, fossil fuel manufacturing or another central generating sources with always-on baseload generation. This sample of these distributed generation have to be resembled with a desired and modern distributed intelligence sample that gives the ability to computation in order to be distributed on the boundary of a specific grid for connecting and developing the trucked and non-continuous loads through intelligent substation implementations, which have the ability to communicate during the desired real-time over certain systems and specific protocols for supervision and data acquisition (SCADA) of the grid.

In all various industry association and agency, also the International Energy Agency (IEA), network updating is seen as the essential and main method for responding of undesired global climate variation demands. Updating the network starts with updating the certain substation. The specific substation is the fateful facilitator of each component within the intelligent grid – involving raised utilize of intermittent renewables, electricity charging and short- term storage.

Finally, the intelligent grid notion cannot be achieved without the Modernizing of substations. (Kezunovic *et al.*, 2010).

1.2 The Substation Automation System (SAS)

The substation automation system (SAS), depending on the studies, can be specified through its functions which, as its name implies, replace the efforts of the operators with automated action. Thus, automated tasks are required to keep the electric power transmission and distribution secure and reliable. This would involve monitoring, data collecting, protection, control, and remote access communication. Remote terminal units (RTUs) were formerly only available as interfaces among the electrical power switchgear at the substation level and the system of the network management of the utilities for remote monitoring tasks. These modules have numerous entrances and outputs as interfaces of the communication to far control centers (NCCs). The terms SCADA stands for Supervisory Control and Data Acquisition System. figure 1.1 was constructed by RTUs and NCC in this structure.

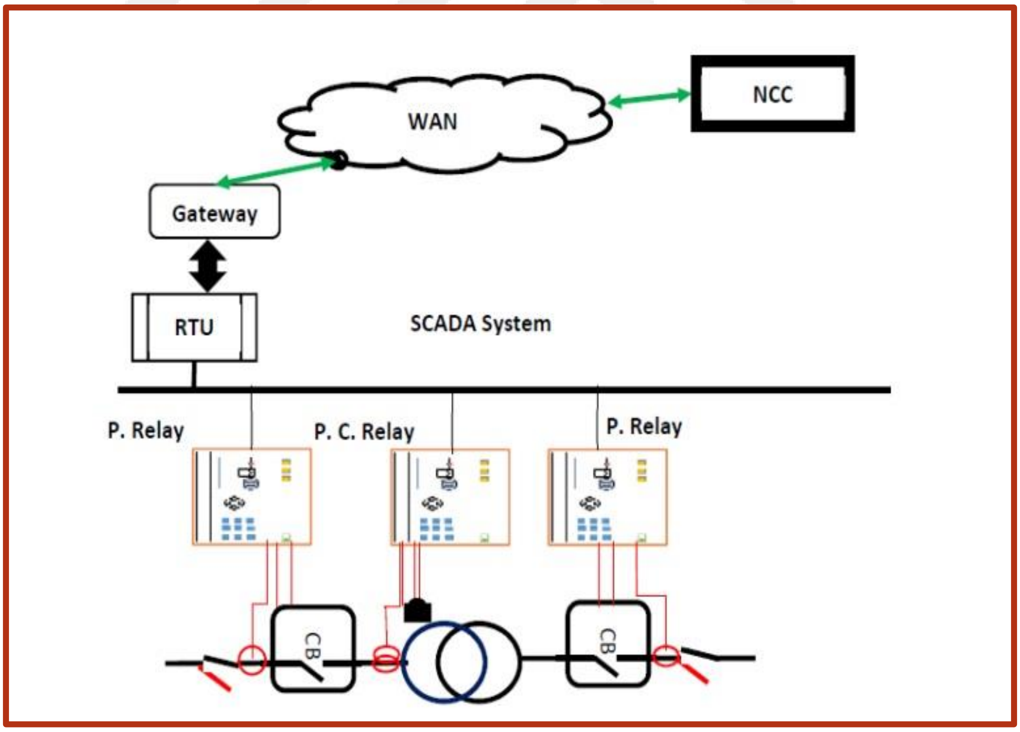


Figure 1.1: SAS, A Known Architecture of Essential SCADA

For instance, Arizona State University's Power Systems Engineering Research Center states the following functions of the substation automation system (Kezunovic *et al.*, 2010):

a. Voltage transformation control (Load Tape Changer Control).
b. Buses, lines, feeders, transformers, generators, and other equipment are all protected.
c. Interlocks and switchgear switching mechanisms should be automated.
d. Data transmission to the control center
e. Resolving local or remote power system failures
f. Inter-substation (intra) and regional control center communications.

The substation automation system obviously gives vital information to the central system at the utility level (enterprise). The SAS, on the other hand, receives updated control data from control centers in order to keep the power system operational. Various functions in SAS are coordinated for self-healing in the event of equipment failure or short circuit problems, for example. Various devices and their jobs on either the main device or subordinate machines spread their functions. If maintenance, repair, extension, or modification operations are performed between these devices and this equipment, it will take a significant amount of time and effort (Grigsby, 2006). Master slave design in a star topology was common in early Substation Automation Systems (SAS). Vendor proprietary protocols were utilized by the Sub-Station and its Network Control Center (NCC)/SCADA System. Because of the lack of communication and data modeling compatibility, substation integration was extremely difficult and hazardous. A vendor was regularly associated with the user (Choi *et al.*, 2011). The usage of protocol converters was frequently required. Of course, engineering data interoperability was not a topic of discussion at the time.

Power management has become one of the most pressing concerns around the world as the supply and demand mismatch widens. The world's energy usage is rapidly increasing.

Power automation supplying electric supply locations frequently necessitates extra safeguards against fault-induced impacts. When a fault condition develops, protection relays must activate quickly. As a result, Intelligent Electronic Equipment (IEDs) are introduced for the safe operation of switchyard devices, which can assist prevent energy supply disasters and improve human safety. Utility communication will be used for substation automation and protection within a substation and between substations with the advent of IEC 61850. The Substation Automation System (SAS) allows you to control and monitor all substation's equipment both locally and remotely. A Human Machine Interface (HMI) is provided by a Supervisory Operate and Data Acquisition (SCADA) system, which can be used to control, monitor, and safeguard devices. This helps us save money and time. Substations are critical components of power grid, allowing for efficient electricity transmission and distribution. Substation automation systems provide for real-time control and monitoring, boosting availability, efficiency, reliability, safety, and data integration (Arun, Lathesh and Suhas, 2016).

The pressure on utilities to make money as a result of market liberalization and other factors is forcing a rethinking of entire secondary technology in the substation. It is necessary to evaluate possible synergies among the safeguard, control and the monitoring

At the same time, assets must be used more efficiently and profitably, and energy delivery security must be improved. This is due to increased costs associated with non-delivery of electrical energy, in addition to the negative consequences of blackouts, customer demands, and public opinion.

Because of the rebuilding of the electrical power market, the business climate for utilities has altered dramatically. The resulting business pressure forces a rethinking of the secondary technology generally, specifically, the employing of potential synergies among safeguard, control, and monitoring. Several aspects must be addressed in order to achieve cost optimization:

a. The secondary technology itself, with a focus on the integration and standardization impacts

b. Maintenance issues, with a focus on the various impacts and the IEC 61850 standard.

c. System behavior (failure or blackouts), with a focus on the effect of desired protection, control, and monitoring over a large area.

The sector of protection and substation automation technical has changed dramatically and continues to do so. The use of numerical technology allows multifunctional devices to communicate serially and exchange data across all applications, whereas electromechanical or stationary technical was depended on a "one device - one function" program, resulting in a tough separation of applications of the safeguard, control and monitoring. The employing of this technology in control and protection required a rethinking of substation secondary technology principles. Based on their experiences with sequential communication utilizing regalical protocols for the communication of installed IEDs in addition to the control of it, users have requested an open protocol for each activity such as protection, control, with monitoring, within the sub-station (Intelligent Electronic Devices). Open means that changes can be made without relying on a manufacturer formerly providing sections of the substation equipment. It also implies that third-party equipment should be simple to integrate into the systems of any manufacturer. Numerical technology makes it easier to build new solutions and achieve higher levels of integration. This, combined with developments in information technology, adds to enhanced network management efficiency, leading in fewer outages, better substation asset utilization, better fault investigation, and higher quality monitoring features, all of which contribute to cost savings.

a. As a result, four significant challenges must be addressed: The degree of integration.
b. The aspects of standardization.
c. Information technology.
d. The system of wide-area monitoring, control, and protection (De Mesmaeker, Rytoft and Reinhardt, 2007).

Finally, a substation is a power distribution facility where power is mixed, separated, or converted. A substation automation system (SA) is responsible for monitoring and protecting the substation's major equipment and feeders. The SA system also has administrative tasks such as configuration, communication management and software management.

1.3 The Work and Outlines

Substation automation (SA) is the process of remotely monitoring, managing, and coordinating the distribution components installed in a substation using instrumentation and control devices (Arun, Lathesh and Suhas, 2016). This project involves choosing an automation system for secondary stations in Iraq's electricity distribution network, which will help with energy management and reduce losses and risks associated with energy distribution. It's also the initial step toward intelligent grid management in the electrical system. The data of stretches that will be identified by a full survey of the electrical network will be used to determine the right system.

It will be explained how to choose an automation system for substations that suits the nature of the electrical network and secondary stations in Iraq, where it must be compatible with the nature of the communication technologies used in electrical system transference and distribution networks. A study of the different types of substations utilized in the network will be carried out and classified based on the nature of the connection and the type and amount of data processed.

A sophisticated automation system that can handle all or most of the substations in Iraq's electrical distribution network will also be investigated. The ability to use more than one automation system to construct these stations is made possible by the classification of sub-stations based on the type of communication and the nature of the data being handled.

2. DISTRIBUTION NETWORKS

This chapter reviews relevant literature and develops a problem-solving strategy related to the problems increased in the theory. The chapter pursues the introduction and explains the idea behind it.

2.1 The SMART GRID (SG)

Power systems must be able to operate the power grid additional efficiently and effectively for improving the reliability, suitable efficiency, desired power quality, and using of distribution assets. In addition to that, information must be made available so that customers can doing known decisions regarding their power use styles or/and action. SG is an electricity supply system that uses the latest technological advances to achieve these two main goals (Uluski, 2010). The European Commission has identified SG as a main investment sector in the future, and automation settlements are in line with this topic, helping to improve the responsiveness of the power grid. Since significant changes are expected for the power grid in the near future, the following topics are discussed:

2.1.1 Smart grid's conception

With advances in information and communication technology (ICT) and upgrading of cutting-edge sensor technology, sector of automation has arrived modern heights, resulting in new products and solutions in the energy supply industry, commonly referred to as SG technology. The term SG has become increasingly important in recent years as technological means are available to achieve it, with automation technologies supporting its implementation (Rodriguez-Calvo *et al.,* 2012). SG refers to a power system that employs advanced information exchange, automatic control, and telecommunications to provide enhanced operational supervision, regulate, smartness, and communication (Mohagheghi et al., 2011). As a result, the notion of automation is expanded to all system level, involving protection, control, metering, monitoring, and resulting in a smart distribution system. In terms of generation, SG ranking, regional, and Distributed Generation (DG) such as air flow, photovoltaic, and other renewables, transforming the customer into a micro producer dubbed the "Prosumer." This is significant because the shift to greater of Renewable Energy Sources (RES) utilizing, that have an unpredictable generation pattern, is unavoidable. From the standpoint of consumption, SG enables demand flexibility, thereby assisting the Demand Response (DR) feature of Demand Side Management (DSM). These increases demand flexibility with generation, and customers can benefit financially as a result, all while contributing to better and more effectively utilize of result resources and lower rate volatility. Electric vehicles (EVs), whether plug-in or hybrid, are receiving much concern in the SG idea because they can be employed as regulated energy reserves when demand, eliminating the deman for energy storage systems (ESS) on a grid (Arun, Lathesh, and Suhas, 2016). From the grid perspective, SG is simply a notion for a completely automated power network (grid) that allows utilities to monitor and control their assets and services in real time through a bidirectional flow of information between grid nodes (Thomas, Arora, and Chandna, 2011). It is also known as the ability to remotely monitor and control critical network components through sensors and remotely control switches and breakers over communication functions. These suitable methods have been used over much time, usually in the HV level transmission grids and power sits, but the medium voltage level distribution networks (MV), that is the most, commonly, used, have been neglected. Through the introduction of various smart metering systems, this functionality has recently been brought into the Low-Voltage (LV) level distribution network This essence is summarized by the Finnish energy industry, which describes (SG) as a "tuned" power grid. Though the definition of (SG) is broad and varies from country to country and industry to industry, the essence remains the same: the evolution of current electrical systems. The introduction of smart meters in the Finland and the introduction of photovoltaics in the Germany are two instances showing that several changes can happen more quickly. Over time, knowledge of this concept and shared visions will evolve, and a combined context will emerge. The shift to SG is the development rather than the revolution (Arun, Lathesh and Suhas, 2016).

2.1.2 The perspective of technology

IEEE describes SG as a next-generation electric energy system characterized by raised utilizing of ICT at each level of electric power consumption, delivery, and generation (Sen and Sen, 2015). From a technology perspective, Mohagheghi et al. describe SG as an electric energy system that integrates state-of-the-art ICT for achieving the increased operational observation, control, cleverness, and connection (Mohagheghi et al., 2009). These are relatively broad determinations of (SG), which focuing on the use of ICT throughout the electric power operation. However, there is one aspect of SG that few have mentioned: the human element. People are the ones who build the framework that executes these operations, and the design of these systems is the much important and difficult component. The complexity is due in part to the lack of technology for all activities and in part to the presence of an existing system that is extremely old and whose full upgrade is not feasible. Therefore, SG encompasses a wide range of instruments, processes, and technologies that enable utilities to assess power flows and regulate all points of the both, the transmission in addition to distribution grid more accurately utilizing two-way digital technical (Singh, 2015). In addition to technology, these tools and processes also meet the additional requirements of SG.

2.1.3 Characteristics smart grid

The smart grid concept has several main aspects, including (Uluski, 2010):

i- Intelligent generation: new tools for the most efficient and cost-effective use of centralized generation assets and the incorporation of up-coming DG and DERs.

ii- Intelligent Transmission: Phasor Measurement Units (PMUs) and Flexible AC Transmission Systems (FACTS)s for more effective and accurate control over operation of the specific power grid.

iii- Intelligent Distribution Feeds: Innovative sensors that highly get better visibility of circumstances outside substations on electrical establishment feeders and monitoring of distribution assets.

iv- Intelligent primary with secondary sub-stations: these are characterized by the increased use of intelligent electronic devices (IEDs) for better monitoring and management of primary with secondary assets within a sub-station.

v- Intelligent metering: Improved the infrastructure of metering that provides customers with power consumption data and price indicatives, supports need response methods, and abilities additional efficient management of electrical devices as portion of LV or house automation.

There is also a notion of Smart Market, which is one of the most recent subjects under research, in addition to these five characteristics. All these separate smart elements must be connected using the tools and procedures described above.

2.1.4 Capabilities of smart grid

The characteristics discussed in the previous chapter represent only one view of SG, which varies from person to person. Although there has been much discussion on the topic in the field and among scholars, there is still no consensus on what SG is, what its capabilities are, and what its domains are. Therefore, based on the term SG, the focus could be shifted to the use of smart grids (Arun, Lathesh, and Suhas, 2016). However, the impact of SG on the power grid is widely recognized, and the functions it can bring to the power grid include the following:

i. Advanced monitoring systems for fast and accurate data analysis.
ii. Communications and measurement infrastructure to provide real-time information on network equipment and resources
iii. Provision of an interoperable infrastructure that allows equipment from different manufacturers to work together.
iv. Self-healing techniques for effective grid disturbance response.
v. Provision for the inclusion of additional DG on a regular basis.
vi. DR initiatives that are effective for active customers.
vii. Future-proof design provides adaptation and flexibility to accommodate the newest emerging technologies

2.1.5 Distribution network smart grid

Since the topic of this thesis is related to the distribution network, the perspective of SG is relevant from this point of view. Garcia et al. believe that SG will automate the essential components of the distribution networks, enabling the detection of network conditions and the rapid integration of new DERs, as well as improved quality of service (Garcia, Navarro, and Alonso, 2013). This component of automation is true and the most important. Mamo et al. agree, noting that with the SG development plan, there is a growing expectation for distribution grid automation to provide operators with unique capabilities for improved grid management (Mamo et al., 2009). With stricter environmental regulations on power plants and the availability of tiny renewable generation plants, DER is becoming more common in the distribution grid, making it more difficult to handle faults and deal with the intermittent nature of RES. The goal of SG can be achieved by integrating smart microgrids, which are tiny inter-connected networks of (DER) systems (resources or loads) that can work inside or outside the network (Thomas, Arora, and Chandna, 2011). This leads to islanding of the distribution grid, that is an important part of an idea of (SG), but is currently rather difficult to implement. Another advantage of SG as portion of the distribution grid is its ability to "self-heal," i.e., it can detect a fault, diagnose and locate the problem, take corrective action, and restore power to the non-faulty segment with little or no human intervention (Fu et al., 2014). This results fully automatic process of the distribution grid, that is another important but difficult feature of the idea of SG. These features are part of the distribution network automation concept of SG, which is briefly explained in the next section.

2.1.6 The secondary substation of the smart grid and automation

An essential part of the idea of SG is the secondary substation (SS). The primary terminology is SS, although other publications use SSS, Transformer Substation (TS), Smart Transformer Substation (STS), or Automated Transformer Substation (ATS). Besides the primary goal of voltage transformation, the word SSS refers to SS, which provides many functions such as monitoring, protection, autonomous decision making, remote control, and others. In Finland, mainly poles are used, and Compact Secondary Substation (CSS) is the latest trend, which is available as a prefabricated component. The idea of (SG) is depending on the widespread data collection through devices placed throughout the power grid and the use of communication solutions for achieving the operational requirements to monitor and control operations (de Melo Leite, de Errico, and do Couto Boaventura, 2013). Through using of novel smart devices, the SS serves as an intelligent instrumentation node to collect and distribute measurement information from sector appliances (SEMs, ESSs, DERs, and others). It also performs local automation tasks and interfaces with the NCC for network management and remote control. Therefore, in the context of the distribution network SG, SS is a critical component of the distribution SG and requires a creative and advanced role (Cangemi et al., 2014). This advancement consists in its method as an integration node, where additional data accumulating field appliances can be accommodated and several local automation methods can be executed, with the capability for interfacing with the network (NCC) for distant control when needed. This requires the upgrading of specialized solutions depending on modern standardized equipment and resulted modules that can be used in conjunction with the existent primary and secondary substation infrastructure (Cangemi et al., 2014). As a result, SS for SG has the potential to obtain and share, through its services, large amounts of pertinent data about the operational status of the distribution grid, allowing better network control in terms of faster fault location, isolation and restoration of service (FLISR), easier integration of (DER)s and (EV)s inside the networks, etc. Understanding the basics of distribution network configuration is critical to understanding distribution network automation and how to perform it for integration into the SG.

2.1.7 Configuring the distribution network

A feeder is a three-phase circuit originating from a substation, and these feeders can be structured in a number of ways in a distribution network. Typically, both primary (MV) addition to secondary (LV) distribution networks are designed as radial networks because they show numerous properties, including (Short, 2018):

- Fault current safeguard under more easy condition.
- Fault currents are lower throughout the specific circuit
- Voltage regulation under more easy condition.
- Power flows can be predicted and controlled more easily.
- Lower cost.

2.2 Automatic Distribution

The increasing demand for electrical energy and the accompanying increase in grid complexity require a higher level of automation and communication for remote control and management of the power grid (Bakhtiari Nejad and Frarahani Najafabadi, 2012), which requires the modernization of the existing grid infrastructure, which involves numerous complicated changes. In the context of the need to improve the operational performance of the distribution network and uplifting the use of (ICT), the notion of distribution network automation in the field SG has received many names, all of which are comparable. Distribution Automation (DA) is the most common term, but some authors refer to it as Advanced Distribution Automation (ADA). In the 1970s, DA became a household name. As a key component of SG, DA enables the use of advanced computing and communications technologies and infrastructures to transform the administration and process of distribution networks from a semi-automated to a completely automated state (Mohagheghi et al., 2011). The major impetus of DA was initially efficiency, but has since evolved into upgraded reliability and goodness of energy distribution (Pahwa, 2005). Since then, DA has grown and matured into a well-known idea. With the advent of low-cost ICT and an industry-wide push toward SG, DA is receiving more and more attention to build more reliable and efficient distribution networks. As a result, the notion of DA is depending on the use of evolving computing with communication technologies to improve the operational performance of distribution systems (Pahwa, 2005) and is thus the integration of power, information, and communication technologies (Thomas, Arora, and Chandna, 2011). Although the definition of DA varies, it generally refers to the use of ICT-based automation technical for real-time safeguard, control, monitoring, and work of specific and desired distribution systems from far places utilizing improved two-way communications, like what is done at level of the transmission Consequently, the term DA refers to the use of a variety of techniques and methods for distant work of distribution systems (Rudd et al., 2011). Various researchers and editors have given DA a variety of names, and some refer to the associated systems as Distribution Automation System (DAS).

In the Staszesky’s study, he calls it Intelligent Distribution Automation (IDA), and has introduced it as DA, that takes properties of evolutions in computer technology in addition to communications for bringing cleverness closer to the issues for being solve (Staszesky, 2006), using IEDs. DAS as well as, can be determined as a system that takes the abilities of an electric utility for remotely monitoring, coordinate, and operating the distribution components through the specific real time (Bakhtiari Nejad and Frarahani Najafabadi, 2012). DAS refers to any device that consists of a set of components and contributes in some way to the automation and distant work of the distribution grid (de Groot, Morren, and Slootweg, 2012). The ADA system also includes a variety of integrated applications, such as distributed computing and smart devices. The complexity arises from the fact that multidisciplinary systems involve various technical specializations, inclusive but not limited to communications, networking, software engineering, and electrical/electronic engineering (Hughes, 2008), in addition to the requirement that all products used be compatible with each other. It should be remembered that DA is not the same as SA. Control and monitoring of circuit breakers at the HV and MV levels falls under SA, but control and monitoring of switchgear at the MV level of SS falls under DA (Javaheri and Afshar, 2013). The following subsections provide a brief discussion of. DA.

2.2.1 The latest version of automatic distribution is required

The distribution network's structure will become increasingly vast and complex as small-scale power plants, such as DG/DERs, become more prevalent in the future (Arun, Lathesh and Suhas, 2016). The reason is that while DG helps to power local parts of the grid, it could also destabilize the grid. To avoid a negative impact, DA needs to closely control DER as part of DG, and the latest version of DA can also enable utilities to do so. Utilities have extensive automation and control capabilities for their transmission networks, and with the latest DA they can achieve the same level of capability for their distribution networks. In addition, as DG grows, so does the number of network nodes, requiring a higher level of automation. As a result, DA is required at these nodes; many of them currently placed at SS will be largely in the future. The extent of implementation of DA depends on the need, which can range from a simple upgrade of a manual switching system to a fully automated system with IEDs. DA is demanded, and its final version regarding to modern automation principles with technologies is also required because it will help in automatic monitoring, protection, and management of switching works by IEDs for restoring the power supply operation through a fault caused by successive events (Chen and Sabir, 2001). Consequently, DA will help maintain improved operating conditions and restore power system operation in the event of a fault. The final version of DA simplifies connection to the distribution network from a specific central position, reducing dependence on on-site operations and network workers (Asgeirsson, 2010). This requires the use of a DMS to analyze the data collected by each sensor (protective relays, fault locators, smart meters, and others) for improving the administration of network of the distribution through information administration for preventing the outages and make timely decisions (locally or remotely) in the event of an outage (Simard, Lavoie, and Chartrand, 2006). Hydro Québec envisions that DA will move beyond distant control (remote operation of key equipment such as circuit breakers, load breakers, and capacitors in the distribution system) as the distribution system communication infrastructure evolves. This could be expressed as enabling DA to enable self-healing of the distribution grid, and thus higher efficiency, while at the same time enabling the introduction of DERs (Uluski, 2010). Another important requirement for the latest edition of DA is to make the best use of existing infrastructure. New ideas for grid operations will lead to more efficient use of the power grid as part of DA. This can be in terms of increased operational efficiency, which can be achieved, for example, by managing peak loads using new ideas such as DR, new technologies, and communication capabilities for devices such as novel IEDs and unique FLISR techniques. Thus, the latest version of DA can lead to the construction of the distribution grid of the future, where DA and its final notion will take ability of optimal execution of the grid even under fluctuating power generation situations, while reducing undesired working costs. One of the goals of DA is to provide real-time load control (one method is DR) and generation control (one method is energy storage), all without (or with minimal) human interaction. The next subsection discusses DA, an important part of SG.

2.2.2 The role of distribution automation in the smart grid

Electricity systems are adapting to the future by adopting a smart distribution grid, with the digital grid serving as the only path to smart grids (Xu et al., 2010). The term "digital" refers to the use of advanced electronics, communications, and networking technologies, while "smart grid" is a synonym for "smart grid." The technology SG could be called the "Internet for electricity" (Singh, 2015), as it has the potential to change the way electricity is generated, distributed, and consumed. DA is based on this technology SG. When human interaction is neither possible nor practical, DA creates additional criteria for remote control of power systems. As a result, the "self-healing" functionality of SG (Rudd et al., 2011) can be implemented by automating the control of grid equipment (switches, transformers, capacitor banks, and others). Automation could be based on recommendations of distribution optimization algorithms that the DMS could provide as portion of the modern automated DA function for smart grid. With the increasing use of distributed generation, power systems are becoming more susceptible to cascading failures that can lead to power outages, requiring remote management of breakers (relays, disconnects, and reclosers) via a telecommunication link with the NCC (Li and Zheng, 2012). In addition, as mentioned earlier, portion of the self-healing function of SG, namely the ability to reorganize networks, reroute power flows, isolate faults, and prohibit overloading of network equipment, is a requirement for optimal performance that can be met by DA (de Groot, Morren, and Slootweg, 2012). By considering technologies such as DA, the development plan for power distribution expansion can be aligned with the planned goal of Smart Grid (Heidari, Fotuhi-Firuzabad, and Kazemi, 2014). DA Contributes to the concept of SG by using the latest advances in sensor and control technology for the DN. These can also improve power goodness and reliability by decreasing outages and using state-of-the-art distribution equipment (FACTS, solid state transformers and others). The concept of DR is one of the most recent and most discussed DA approaches for SG. This could be used for industrial, commercial, or residential loads, and DR could be used to manage these loads (to varying degrees depending on demand and contracts). Customers can receive real-time price signals for optimizing their power exhaustion behavior and reduce costs in a dynamic way. DA plays a larger role in enabling Demand Side Management (DSM) by providing mechanisms for data exchange. DSM measures, such as automatic meter reading (AMR) and load administration, now fall under the new responsibility of DA (LM). AMR has already been performed in Finland, while DSM and LM are currently available (to some extent) only for industrial customers, while residential customers are expected to be included soon.

2.2.3 Distribution automation types

Due to its wide range of abilities and applications, DA can be deployed at various network scales [36], and automation functions can be classified in different ways, e.g., monitoring, control, measurement, and protection. DA tasks can be categorized to three classes in terms of location (Chen and Sabir, 2001):

a) Secondary sub-station automation: the DA functions at the SS involve:
  i. Sub-station equipment control with the process of monitoring (domestic and distant).
  ii. Transformer safeguard and load tap alternator (LTC) control.
  iii. Incorporation of DG.
  iv. Ground fault reparations.
  v. Coordination of safeguard.
  vi. Communications (downstream with upstream).

b) Feeder automation (FA): The functionalities of DA on the feeder involve:
  i. Feeder disconnection/automatic switching and dynamic reconfiguration.
  ii. Feeder voltage (through VAR control via capacitor banks and voltage regulator control).
  i. FLISR.
  ii. Network reconfiguration at its best (Uluski, 2010)..
  iii. Determination of the optimal switching sequence.
  iv. Determination of the load on the redistributed feeder lines (Ren et al., 2008).
  v. Intentional (planned) islanding (Uluski, 2010) for islanding a portion of the grid, i.e., microgrid management (MM)..

c) Automation at the customer (on-site) (CA): The functionalities of DA at the customer level are quite extensive and include:
  i. Load regulator.
  ii. Real-time cost signaling.
  iii. Remote measure reading and billing.
  iv. DR and LM as segment of DSM.

Apart from the above mentioned functions, DA also provides several other functions, such as the outage management system (OMS), Distribution State Estimation (DSE), Voltage/VAr Optimization (VVO), EV integration, load forecasting and modeling, and others, all of which are typically placed in the.

2.2.4 Distribution automation's benefits

The benefits of DA can be classified in a similar way to those discussed above and include financial benefits, operation and repair advantages, buyer benefits, as well as others. There's far too many advantages for DA that mention them all, but enhancing reliability as part of the operational advantages is at the top of the list, as reliability is now related with financial benefits for network operators.

2.2.5 Communication for distribution automation

Distributed data acquisition, monitoring, and control system operations are all possible with a communication system (Lahiri *et al.*, 2009). Because the communication system is a key aspect of DA (Chen and Sabir, 2001), it must meet current needs while also allowing for future functionality (Kim, Metzner and Lee, 2009). The MV distribution network must be constructed with reliable data connection in order to make high working reliability and goodness of service while lowering maintenance expenses. As a result, an effective, dependable, and secure communication infrastructure is critical for successful enforcement of DA (Kim, Metzner and Lee, 2009). As a result, DA has specific communication channel needs, which include (Zheng *et al.*, 2013):

a. Reliability.
b. Security.
c. Establishment and maintenance costs.
d. Communication path privatization.

The main objective of using communication infrastructures and software development for DA is to remotely access observation and management power station, especially switchgear. Prior to the invention of DA, field personnel had to manually perform switching operations within the network, which necessitated physically walk-throughs and confirmation of each modulation process, also at remote locations. However, with advancement of wireless data transfer for DA, utilities now have new options for extend its system to far and remote places. The following are examples of communications media used to reach DA:

i. Radio Ultra Higher Frequencies (UHF).
ii. Power Line Carrier Communication (PLCC).
iii. Optic Fiber cables.
iv. Public switched telephone network and paging services for automatic dial-up.
v. One-path Very High Frequency (VHF) radio for load regulator.
vi. Internet Protocol (IP) built communications (wired or wireless).

Automation systems have different network requirements depending on the functions required, and most automation systems have used dedicated communications networks independently, resulting in duplication of effort, and some are still using them. To Long time, SA reliance on private communications resulted in a haphazard assortment of communication networks that were specialized to certain uses but incompatible with one another. Microwaves, telecommunication lines, and multiple addressing (MAS) radios were one of the most popular techniques, and as the applications increased, incompatible communication technologies appeared, posing new obstacles. SA can teach DA how to avoid making the same error. IP-based communications systems, on the other hand, are not monopolistic and may simultaneously support multiple applications on the same network. In additional to IT, various applications in the power industry, such as SA, DA, and others, require a dependable and quick communication network (Belagur and Schmidt, 2008), and IP technology offers a cost-effective way to meet these needs. For the installation of distribution network communications, routers in the field and in the NCC (distribution SCADA) are necessary so that all network devices may be monitored and managed from a single location, thereby accelerating two-path communications in the distribution network.

2.2.6 Distribution automation fault management

The main purpose of the DA system is to quickly and accurately detect and correct faults, limit fault coverage, and reduce downtime, while improving the quality and reliability of the power supply to customers (Meng and Wang, 2014). This is accomplished by giving details concerning problems, such as their identification, notification, localization, isolation, and restoration of supply via topology control or remote controllability. If a fault occurs in a distribution system, the substation's feeder protection trips and interrupts power to the entire feeder. All customers on that branch are then affected by an interruption in supply of this.

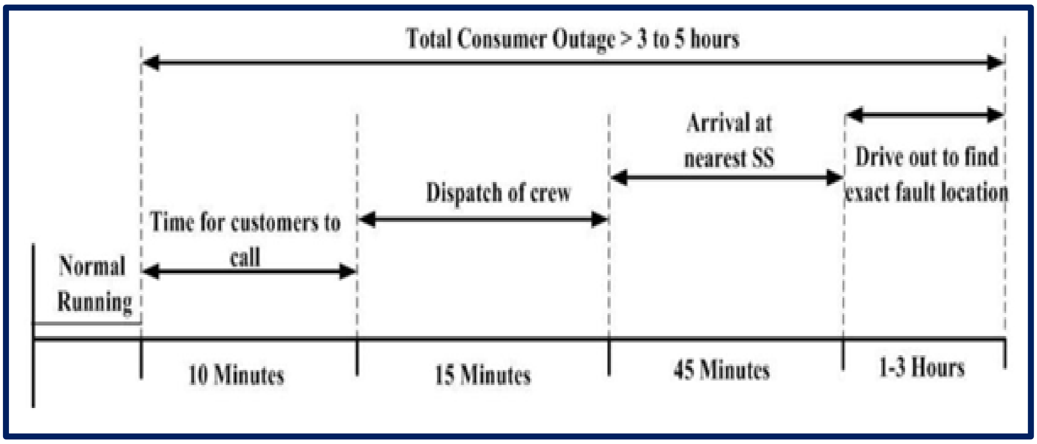


Figure 2.1: Timeline for Fault Management (Without FLISR)

Figure 2.1 illustrates a common fault situation and interruption time compare without FLISR deployment.

As depicted in the diagram, each outage requires around three to four hours of fault management. When a faulty feeder is failed, the faulted section of the tripped feeder must be determined. This is the piece of the feeder between two switches (SDs or CBs) situated on the poles or in SSs. Since the feeder is not automated, it cannot be connected to the NCC, rendering online fault visibility and management impossible. Along with a result, long supply interruptions occur, affecting supply security and reliability. Once the fault is located, both parties must manually isolate the fault with switches. Eventually, the problem is fixed and power is restored. If a backup connection is available for that section of the grid, supply can be restored more quickly. As demonstrated in Figure 2.2, if this operation, also known as the FLISR process, is automated, the overall outage duration can be reduced to one hour or less every outage.

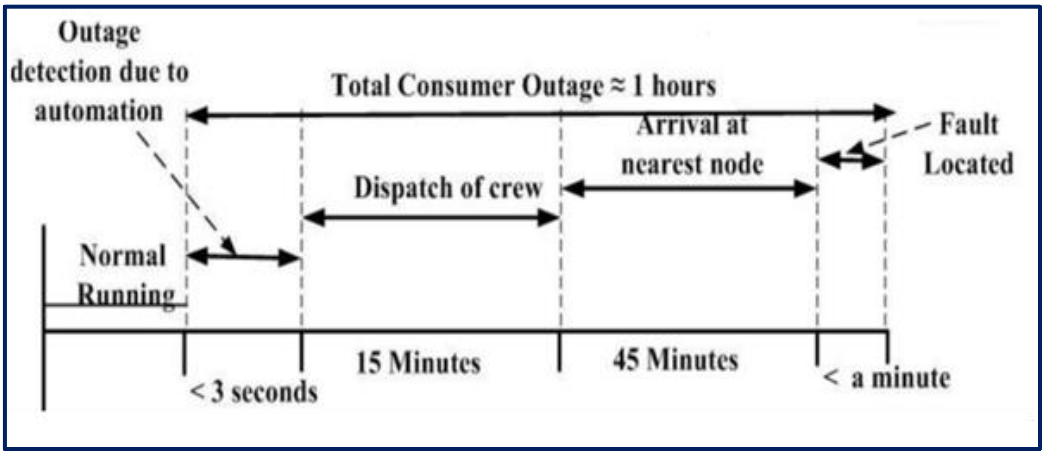


Figure 2.2: Timeline for Fault Management (With FLISR)

The duration of the outage is also determined by a number of other factors, including the number of remotely managed switches, backup connections, backup connection capacity, and others. In this circumstance, the problem management technique is comparable to the previous one, but the majority of manual operations are conducted remotely using monitoring, protection, control, and communication technology. The number of controlled breakers (CBs or SDs) is determined by the DSO based on the amount of faults and other criteria. The FLISR operation can be centralized, with the majority of decision-making authority residing in the NCC, or decentralized or distributed, with the majority of automation decision-making authority residing in SS and limited control available in the NCC. FLISR increases the distribution network's reliability by restoring power to as many consumers as feasible in the lowest period of time (Parikh, Voloh, and Mahony, 2013).

2.2.7 Distribution automation SCADA

ADA is comprised of two fundamental elements: a communication framework and a system of suitable (interoperable) power systems. Nonetheless, they must be integrated in order to give the necessary functionality. Due to a lack of penetration in the distribution grid, the SCADA system cannot deliver the same capability to DG and DER in additional to diversity, resulting in decreased efficiency, sustainability, and dependability (Gezer and Uludag, 2013). The IEDs (with sensors and transducers) that collect information throughout the distribution network form the infrastructure of the integrated monitoring system DA (Zavoda, 2008), and the ability to monitor, coordinate, and operate them in real time from the NCC leads to the creation of DAS (Gezer and Uludag, 2013), which necessitates the development of SCADA systems from generation and transmission (PS) to distribution (DAS) (Gezer and Uludag, 2013). (SS). SCADA for distribution is the basis of DA and a requirement for the implementation of DAS (Wu, Yang, and Qi, 2009). In addition, DA contains modern detectors, control systems, and SCADA in a unified system to provide the distribution network's required performance and dependability (Mohagheghi et al., 2011). This results in the development of SCADA at the distribution level, in accordance with the concept SG to accept and integrate ICT improvements in the network (Gezer and Uludag, 2013), hence expanding the notion of the "Internet of Things" for use in electrical engineering. In furthermore, by integrating with the distribution system SCADA, sophisticated IEDs enable real-time supervision of the grid situation, automatic realignment of the grid to improve the quality of the power supply, and decrease of the effect and duration of outages (Zavoda, 2008), thereby increasing the distribution grid's overall reliability.

2.3 Secondary Automation Substation Distribution

The SS is an important component of the distribution network, and utilities have many of them. It has long response times for resolving outages and low operational visibility due to its geographic distribution. This requires more SS monitoring and management to achieve optimal MV network operation during both normal and fault conditions. Supervision of field devices (recloses and disconnects) are now restricted to the PS level. In the event of a fault, switching (on or off) must be performed either autonomously or remotely from the NCC, since it is currently performed manually or left to chance. Due to its multiple functions and applications, DA can be used at different network levels (Heidari, Fotuhi-Firuzabad, and Kazemi, 2014), with SS being one of the most important. Since SS hosts the majority of distribution devices, it has access to the infrastructure required to provide additional functions, making it the most important node to study. In addition, In additional to voltage conversion, the automated SS can perform a plethora of other operations that are vital to the transition of the distribution network to SG.

2.3.1 Smart node in a secondary substation

SSs serve as smart nodes (SNs) in the context of SG since they are dispersed all through the distribution network and then have the capability to apply DA effectively. SS can deploy the monitoring, measuring, communications, and control capabilities of SG as SN. Consequently, SN is anticipated to act as an aggregation point for real-time distribution network management and as a distributed network for MV and LV networks to make autonomous and remote decisions (Alberto et al., 2012). Therefore, SN becomes an integral part of the DA system. In addition, SS is handled as SN because that is where all the equipment (switchgear, transformers, etc.) is situated, or at least nearby, and it makes sense to have local automation there with remote management communications capabilities. This is supported by the capacity to communicate with local devices, sensors, and other equipment (Alberto et al., 2012). Due to its information aggregation, control, and communication capabilities, SN can utilize the modularity and extension concepts to construct distributed intelligence as part of DA. Consequently, SN will play a crucial role in the evolution of distribution towards SG (Rodriguez-Calvo et al., 2012) by enhancing continuity of treatment. Conventional SS may be fixed on a pole or located in a building, such as a cabin or indoor substation. The transformer substation (TS) comprises of an MV/LV distribution transformer installed on a utility pole (DT). CSS, which stands for indoor substation, is comprised of three primary components: a medium-voltage switchboard, one or more DTs, and a low-voltage switchboard. When a TS lacks a transformer but contains a switching mechanism, it is referred to as a Feeder Terminal Unit (FTU), which comes under the word FA in the DA. Even if it is not an SS, it is nonetheless an SN because it possesses all SN features. In urban locations, SSs are typically outfitted as RMUs, are unmanned, and are within driving distance of utility service employees. The RMU functions as an open loop distribution network with variable interruption times based on distance traveled and traffic volume. This is mostly because the FLISR procedure needs the synchronization of numerous switches with the core substation (PS). The outbound MV feeders on PS are fully automated, including relays, switches, and SCADA remote control, whereas the inbound MV feeders on SS are not entirely automated, with the exception of some feeders' automatic reclosers. Since DA is affiliated with automation of the secondary distribution network, which is mainly located out beyond PS, including automation of feeders coming from and covering DTs, Ring Main Units (RMUs), disconnectors, and reclosers (Terese et al., 2007), some modifications are necessary to convert DA for SS into SN. Each feeder in the RMU must be fitted with meters to send current and voltage signals to the RMU controller, which can then communicate with a SCADA system and other systems through an RTU in order to share data with the NCC. Any switch (breaker or breaker) in the RMU can be monitored and relayed to the SCADA system for reconfiguration of the network via the controller. Traditional RMUs with some automation continue to function without communication, detecting faults and restoring loads by sensing the voltage at each breaker (at two radial feeders separated by a normally open breaker). This loop technique has the drawback that control decisions are based exclusively on local measurements, and small field devices have extremely limited knowledge of the condition of the entire distribution system (Greer et al., 2011). This can be easily improved by employing a communicating device, such as an RTU, between the local device and the central network, and this is also the focus of this effort. The expanded capabilities give SS with improved system vision, allowing it to complete the FLISR process autonomously while coordinating with the NCC, hence enabling the self-healing component of the SG concept. The current DA offers two control techniques for SS (Xu and Xu, 2008):

i. Central control type: uses a communication system to integrate field data into NCC and performs operations centralized analysis, regulator, and optimization.

ii. Local control type: must function without an NCC or communication system automatically completes the FLISR through deterministic coordinating between switches.

There are several methods to use functions DA, for example, Antila et al investigated DA for MV networks and came up with three options (Antila, Heine and Lehtonen, 2003):

i. Model of centralized automation.
ii. Overall automation modeling (combination of centralized and local automatic).
iii. Safety modeling (exclusively for circle networks).

It has proposed a comparable technique that can be implemented in a variety of ways for such Self-Healing Grid (SHG) (Coster, Kerstens and Schroedel, 2014):

i- Central solution.
ii- Decentral solution.
iii- Distribute solution.

These are shown in Figure 2.3.

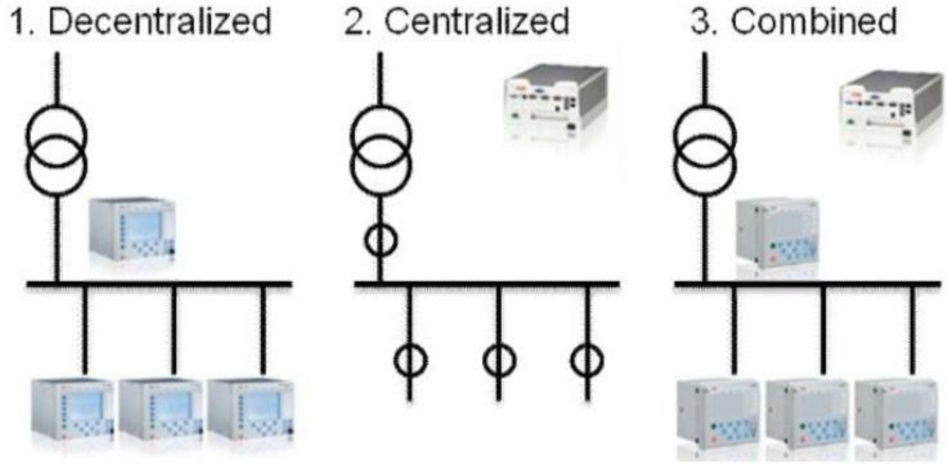


Figure 2.3: Secondary Substation Architecture Options

As mentioned previously, the SG concept utilizes SCADA to combine the two kinds of methods for topology control without human interference, providing in self-healing capabilities. The level of automation at the SS level influences the ability of SS to manage fault situations; hence, SS must have communication capabilities to transmit status indicators, measurements, control orders, and other data as required by the application. Depending on the extent, this may result in a small number of affected customers and a swift power restoration with fewer employees. This scope is determined by the sensitivity to disruption and the singularity of the load inside site SS, which are the primary factors for identifying marginal sites for protection.

2.3.2 Zone concept in automatic distribution for secondary substation

The zone concept (ZC) in DA describes the partitioning of a network into smaller zones. Based on loads, load criticality, and fault susceptibility, the ZC separates the distribution network into controlled portions [60]. As indicated previously, the required level of automation in a zone is defined by the difference in fault vulnerability between a zone and other zones, as well as the load priority. Consequently, the ZC is founded on the concept of limiting the effects of a network malfunction or supply interruption to the smallest area possible. As indicated in Figure, the ZC has two primary functions: protection and control (7). These would be applied to the outward MV feeders to create either a protection zone or a control zone, based on the capacity of the zone divider and the necessity to ensure supply to places with substantial and/or essential demand. Each protective zone has a number of lateral outlets that can be utilized to create its own protection and control zones

(Singh, 2015). When an issue arises in the distribution network, the entire feeder and all related loads are affected. ZC accomplishes this by combining the tasks of protection and reclosure. By directing reclosure functions and interruptions to the specific network parts or zones where a problem occurs, the approach prevents distribution interruptions on other network sections. Critical components for ZC include circuit breakers (CBs) and loading break switches (SD) as zone isolators for protection and interruption/closure or disconnection only. Line reclosers (CBs with an automatic closing mechanism), automatic disconnectors, and remote disconnectors are advanced components. As required, they may additionally feature remote compensation devices. In order to further automate ZC, communication facilities must also connect with higher-level systems (Wikund et al., 2011). This enables the remote interchange of application-required condition indicators, measurements, control commands, and other data. Several methods exist for implementing ZC utilizing the components. This is typically accomplished by increasing the density of HV/MV substations or by separating the network into sections supplied by numerous substations (Singh, 2015). Moreover, voltage fluctuations or dips are confined to a small portion of the network.

2.4 Intelligent Grid Management System

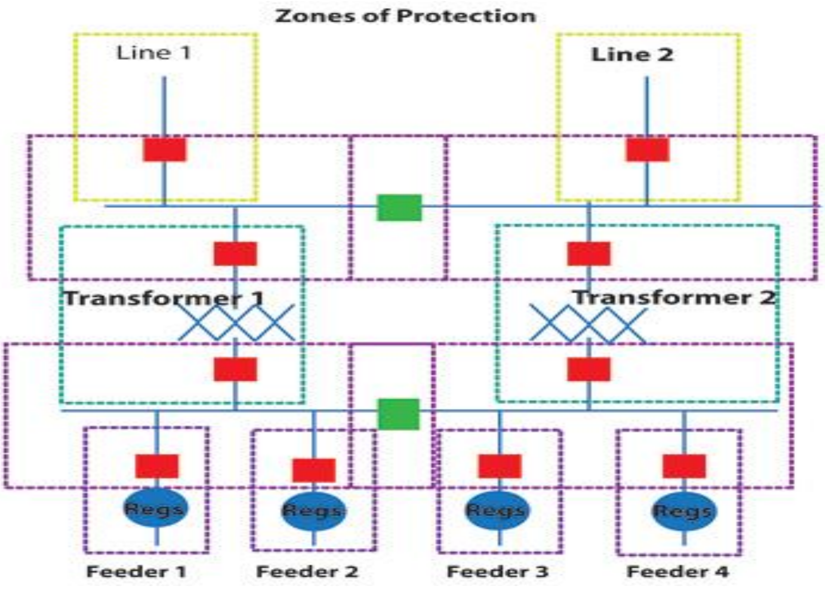


Figure 2.4: Zone Protection

Electricity transmission and distribution networks consist of many old devices that can lead to lower reliability due to wear and tear. The authors suggest a "intelligent network management system" (IGMS) to keep T and D systems efficient and of good quality. Consequently, the IGMS blends the concepts of asset management and smart grid. Additionally, the IGMS optimizes power flow routes and maintenance schedules based on outage risk, T&D loss, overload operation, power user life estimation, customer outage, and other variables. Individual equipment failure can affect the entire operation of the T&D system and lead to power outages and secondary problems. The age of the equipment has a considerable effect on the whole system's dependability. The IGMS computes the costs associated with all T & D system occurrences. In addition, the risks are computed depending on the failure rate's impact., which is calculated from the diagnostic results of the condition monitoring of the power supply equipment. The reliability and maintenance costs of the system are determined by the isolation system (Hanai, 2011). The protection plan's overall concept is based on segmenting the distribution system into different zones (figure 2.4_. When zoning, network loads and DG placement and generation capacity are taken into account. Following network zoning and the establishment of zone boundaries, switches that can operate repeatedly and quickly and can also receive distant signals are positioned between each pair of system zones. Check-synchronization relays are a requirement for these switches as well. A computer-based relay with powerful processing capabilities and plenty of storage space must be installed in the distribution network's supplying substation (also known as a sub-transmission substation) in order to operate the protection plan. The computer-based relay installed in the subtransmission substation is in charge of maintaining constant monitoring of the currents passing through some particular network locations.

2.4.1 Concept of IGMS

When a balance is found between the cost and quality of the power supply, the total cost of T and D decreases to a minimum, and the T and D option is chosen. As a result, the cost and reliability of the entire T and D system, rather than individual devices, must be evaluated. The IGMS concept is illustrated in Figure 2.5. Diagnostic and information systems record current performance and history of equipment operation and maintenance. All data is collected in the control center. A complete evaluation of the T and D system is made in terms of T and D losses, reliability of the T and D system, overload operation, total cost, and other characteristics. The result of the evaluation is that the T and D system is operating optimally. In addition, the maintenance technique and schedule of the equipment are evaluated, and the best maintenance approach is suggested. As shown in Figure 2.6, an IGMS is a combination of an asset management system and an intelligent network. The horizontal axis represents a period of time, while the vertical axis represents the complexity of maintaining the equipment.

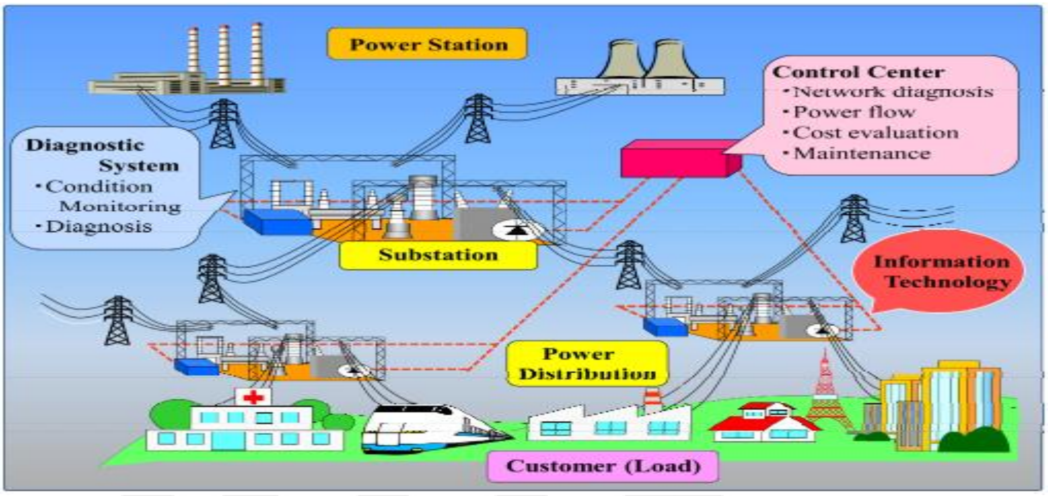


Figure 2.5: The Idea Intelligent Grid Management System (IGMS)

Over time, the asset management system applies TMB (time-based maintenance) and CBM (condition-based maintenance). Although asset management only considers equipment degradation, it does not implement power flow control. On the other hand, unlike asset management, power flow control does not consider equipment degradation. By using power flow control and device maintenance, IGMS can reduce the impact of individual device reliability on the entire isolation system. An important aspect to note is that this assessment changes all status in costs, which is concept that is fundamentally different from that of other systems (Hanai et al., 2013).

2.5 Assessment of Reliability in IGMS

Gathering outage data and analyzing system designs are two aspects of transmission and distribution reliability. The T & D system's reliability is decreasing as the apparatus deteriorates owing to their age. The transmission and distribution system's dependability is linked to the particular apparatus's reliability. The T&D system's reliability is improved by doing several types of maintenance. As a result, some authors proposed an Intelligent Grid Management System that would provide an appropriate maintenance plan as well as optimal power control. The word "system reliability" can be divided into two parts: System sufficiency and security. The system concept adequacy is defined as the presence of adequate facilities inside the system to meet customer load demand and operational restrictions. These facilities include the ones required to generate enough energy, as well as the transmission and distribution systems that transfer the energy to the actual consumer load sites. As a result, adequacy relates to static conditions that are free of system disruptions. Security, on the other hand, is thought to be concerned with the system's ability to respond to internal disruptions. As a result, security is linked to the power system's reaction to any disruption they are exposed to. These include local and long-range repercussions, as well as the loss of key generation and transmission facilities. The security notion is concerned with systems' transitory actions as they move from one location to another (Parmar, Karena and Parekh, no date).

2.6 Artificial Neural Network

Smart Neural Network is a mathematic algorithm that is biologically inspired and used to model data for machine learning techniques by using graphs of Artificial Neurons, which is a mathematical model that can approximate the work of human brain neurons, and it can be defined as a mathematical system compose of various a number of simple, so much connected to each other processing components, have the ability to process different data by their dynamic stamina (Mukhometzianov, Rinat., 2017).

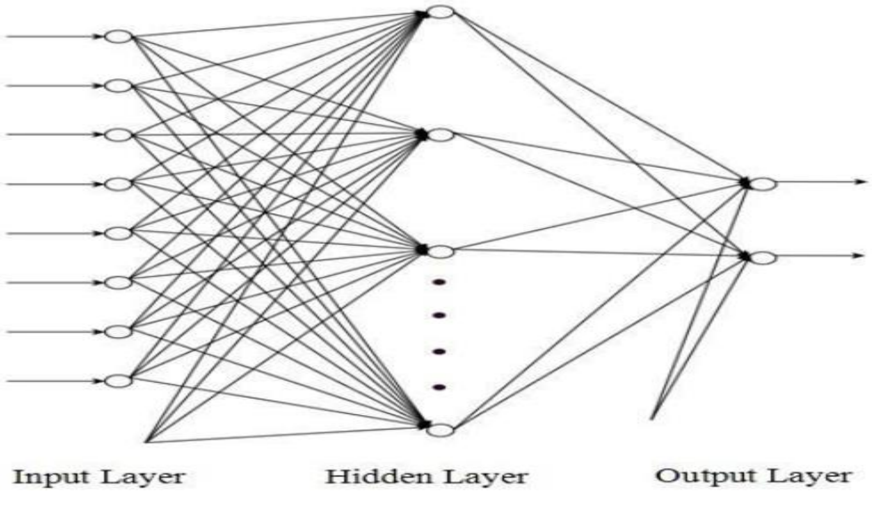


Figure 2.6: The Neural Network General Topology Where Hidden Layers Maybe One or More

In figure 2.6 , the model of neural network with the layers of cells called neurons and weight training, and the general topology of neural network can be shown in figure 2.7 (Siswantoro *et al.*, 2016) .

The learning algorithm, transfer function, and topology of a neural network determine its performance. Consequently, if a neural network classifier uses an inappropriate structure, it appears to be weaker. The structure of a neural network is determined by the difficulty of the relation transferred from input to output, and no exact rules can be established to determine the structure of the neural network. Consequently, studies must focus on improving the categorization of neural network performance by changing the topology of the neural network to make the problem easier to solve. According to the results of several studies, a linear model based on the Kalman filter can improve the performance of the original neural network. The linear function, step function and sigmoid function are the transfer functions used in neural networks, as shown in equations (2.1) and (2.2):

$$S = \sum_{i=1}^{n} w_i p_i + b \tag{2.1}$$

$$a = (S) \tag{2.2}$$

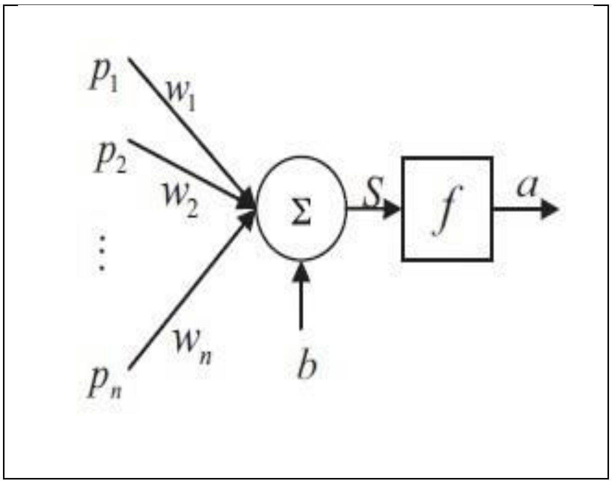


Figure 2.7: Model of A Neuron

Where:

w_i = the weights of inputs.

p_i = the inputs

b = the bias.

S = the output.

$f(S)$= the transfer functions (Siswantoro, J., Prabuwono, A. S., Abdullah, A., & Idrus, 2016).

Weights and bias must be changed based on training data and learning process until the error between the desired and predicted outputs (mean square error – MSR) reaches a minimum value. The value of mean square error MSR can be calculated by the equation (2.3):

$$\text{MSR}=\frac{1}{K*M}\sum_{i=1}^{k} \parallel \hat{z}_i - z_i \parallel^{2} \quad \textbf{(2.3)}$$

Where:

K= the sample number.

M= neural network output numbers. z= portend output.

ẑ= desired output (Siswantoro, J., Prabuwono, A. S., Abdullah, A., & Idrus, 2016).

2.6.1 ANN modeling challenges

Because the ANNs full applications have the ability to respect the factors of data analysis, such as fault tolerance, accuracy, processing speed, latency, volume, scalability, performance, or convergence, they have become a competitor to statistical models and conventional regression. But there are some challenges with ANN modeling which can be abbreviated as bellow:

i. Model transparency is extremely important, as input data has a significant impact on intended results; therefore, improving model transparency must be approached with caution.

ii. The ANN does not have the predictive ability to cope with a wide range of data, such as utilizing ANN to improve financial market modeling forecast based on textual and data information. As a result, substantial time and effort must be expended in order to enhance the architecture of these models under a variety of scenarios and achieve the required correlation and robustness.

iii. It's difficult to assess the quality of ANN forecasts, which can restrict their usefulness when uncertainty in the predictions isn't taken into consideration, which isn't always the case; consequently, it's critical to work on novel methods to uncertainty (Abiodun *et al.*, 2018).

2.6.2 Categories of ANN

i. A feedforward neural network (FFNN): It is a machine learning classification technique built from collective layers, in which all the other units in the layers are connected, and each connection has a different power or weight. The NN units are referred to as nodes in the topology of a neural network. Dynamical systems control and space control are two of FFNN's applications

ii. The feed-backward neural network (FBNN): The connections between nodes in feedback NNs or backpropagation are quite sequential. The construction of this type of neural network can aid it in processing sequences of data inputs by allowing it to use its internal state (stored information). Un-segmentation and pattern recognition are examples of jobs where feed-backward NN can be used (Abiodun *et al.*, 2018).

The two models of ANN and inter classifications in figure 2.8.

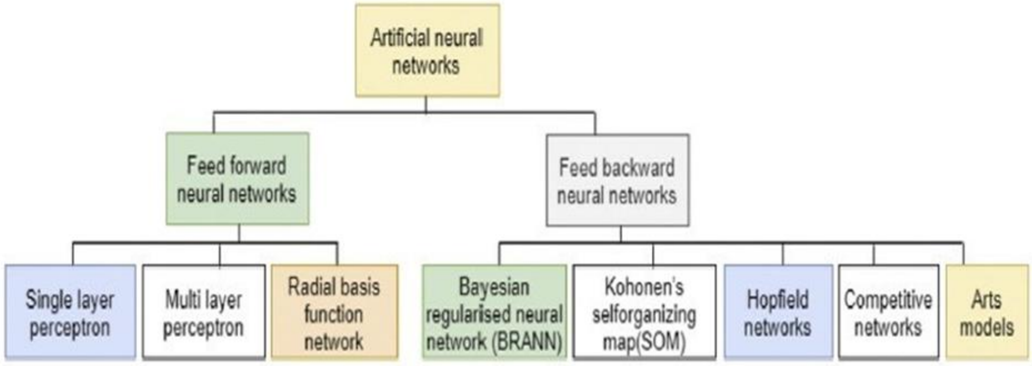


Figure 2.8: The two Models of ANN and Their Classifications

2.6.3 Applications of ANN

ANN techniques have been adopted in many academia and industries fields in order to The use of neural networks in various power system operation and control tactics has yielded satisfactory results. These include:

i- In load forecasting: load forecasting of power systems is a widespread and popular topic that plays an essential role in economic and financial development, expansion and planning. Most publications and projects on this topic fall into three categories:

1) Unit determination, economic dispatch, power transmission planning, and real-time control all require short-term load forecasts at time intervals ranging from

one hour to one week. Much research has been conducted on the use of short-term load forecasting using a variety of approaches. Short-term load forecasting over a range of time intervals (Hippert, Pedreira, and Souza, 2001).

Some of these techniques can be categorized as follows: Regression models include expert systems, fuzzy inference, neural fuzzy models, and stochastic time series analysis. Some of these methods have significant drawbacks, such as the inability to adapt to rapid nonlinear system load changes, difficulty to establish a functional relationship between all attribute variables and immediate load demand, the inability to expand the set of rules governing the expert systems, and the inability to ignore some forecast attribute conditions. These difficulties can be solved with NNs. Most NN-based projects have successfully incorporated a variety of elements such as weather, holidays, weekends, and days of major sporting events into their forecast models. This is due to the ability of NNs to learn from multiple input sources.

2) After calculating energy prices spanning one month to five years, medium-term load projections are utilized to purchase sufficient fuel for power stations.

3) Long-term load forecasting (LTLF) is a technique used by planners and economists to predict the type and size of generating facilities that minimize both fixed and variable costs over a period of 5 to 20 years or more.

2.6.4 Fault Diagnosis\Fault Location

The quantity of data available in real - time monitoring (SCADA) systems has grown as a result of developments in communications and modern devices (Hippert, Pedreira, and Souza, 2001). Although information is valuable, when events produce outages, the administrator may be overwhelmed by the enormous number of concurrently active messages, lengthening the time required to identify the reason of the outage and commence recovery. In addition, factors such as stress and inexperience might impact the performance of the operator; consequently, it is advantageous to have a tool that facilitates real-time decision making. Protection devices are responsible for detecting problems and, if necessary, transmitting event signals to circuit breakers in order to isolate the faulty portion of the system. When switches or circuit breakers fail, however, bigger portions of the network may be shut down. It is crucial to restore the system as soon as possible after such occurrences to prevent damage to utilities and consumers. Before restoration can begin, however, it is required to establish the cause of the warnings, such as a failure of the protective system, problems in the communication route, or improper data collecting. The key advantage of a neural network is its adaptability in the presence of noisy inputs, whereas the main disadvantage is the length of time required to train a feed-forward network using the backpropagation technique, particularly when the power system's dimensions are vast. Recursive Neural Network (GRNN) in Feed-Forward Topologies, Probabilistic Neural Network (PNN), Adaptive Neurofuzzy Methods, and Selective Backpropagation Algorithm Have Been Proposed as Alternative Training Time Reducing Methods.

2.6.5 Economic Dispatch

The primary objective of economic dispatch (ED) is to lower operating costs based on demand and subject to certain constraints, such as how to allocate required load demand between existing generating units (Kumarappan, Mohan, and Murugappan, 2002). Due to physical and functional constraints, the unit's complete operational range may not always be accessible for load sharing.

The Lagrangian relaxation method, linear programming techniques, especially dynamic programming (DP), Beale's quadratic programming, the Newton economic Raphson method, the Lagrangian augmented function, and, more recently, genetic algorithms and neural networks have been used to solve economic dispatch problems. Because the economic load dispatch problem has become a nonconvex optimization problem, the Lagrange multiplier method, which is frequently utilized at ED, cannot be applied directly. The method of dynamic programming is one of the most popular approaches, however for practical-sized systems, the tiny step size and huge number of units frequently result in the "curse of dimensionality." The key downsides of genetic algorithms and tabu search for ED include the complexity in specifying the fitness function, the discovery of several poor solutions with no assurance that this solution is not locally optimal, and the longer search time. It has been thoroughly established that neural networks, specifically the Hopfield model, can solve coupled optimization issues. This approach has been utilized to tackle traditional ED problems for units with continuous or piecewise quadratic fuel cost functions. Due to the fact that this network can account for all constraints, such as line losses and transmission capacity constraints, it is optimal.

2.6.6 Security Assessment

The main objective of a power system is to supply consumers with the energy they need while maintaining the permissible voltages and frequencies limits. This is task must be accomplished in real time while being safe, reliable, and cost-effective. Figure 2.9 shows the basic data flow in a power system with real-time measurements stored in a database. Then, the state estimator compensates for erroneous and missing data. The existing mathematical model of the power system is based on the estimated values. The system's safety level is determined based on a simulation of a hypothetical equipment failure. If the system is considered dangerous due to one or more potential failures, control measures must be taken (Chan *et al.*, 2000)

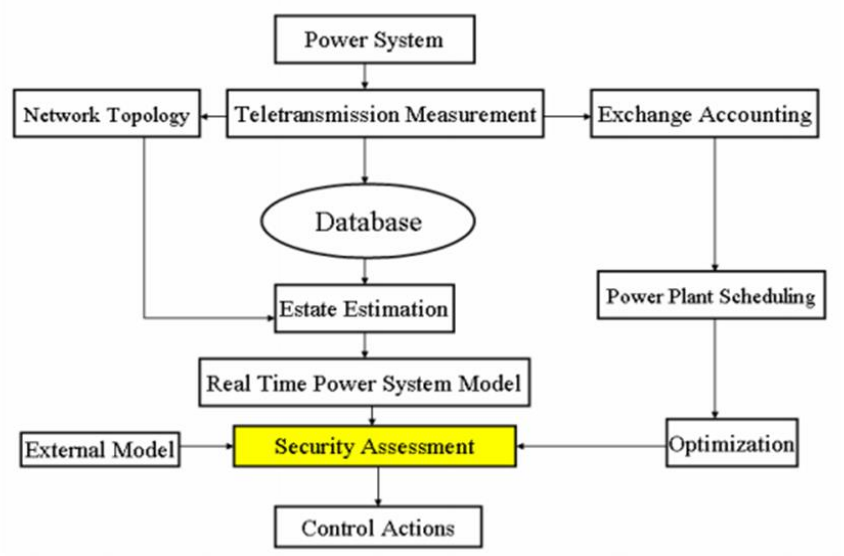


Figure 2.9: Data Flow in Power System Operation

3. METHODOLOGY

Following a detailed investigation of the requirements for achieving the practical features of SG for DA in the parts that follow, a thorough knowledge of the fundamental ideas and studies for the distribution network and the electrical networks in general can be attained. This section also discusses grid requirements, goods, and solutions, the many levels of intelligence that can be attained, the various methods of communication with NCC, and the essential parts and specifications for future smart SS.

3.1 General Issue Understanding

As previously said, majority of generation facilities and transmission grids are already largely automated, which is consistent with SG's objective of promoting an extended and enhanced electric grid. However, whereas most industrial and commercial facilities are increasingly automated, the distribution grid lags behind. Historically, the availability and cost-effectiveness of the underlying technology have been the most significant obstacles. This has altered, however, with the creation of modern IEDs as a result of ICT breakthroughs that permit control and monitoring of current equipment, among other tasks. This is accomplished by the implementation of automation technologies for the protection, control, monitoring, and operation of distribution systems (Mohagheghi et al., 2009) in accordance with the idea DA. As a component of DA, intelligent distribution enables continuous real-time monitoring of substations and feeders to enhance efficiency, performance, and dependability. As DA is an unavoidable prerequisite for the modernisation of the electric power system, the movement is often toward adding new active elements to the grid or transforming old passive elements into active ones (Wu, Yang, and Qi, 2009).

The impact of the DA concept on grid dependability, which is progressively developed and enlarged inside the DAS model, is a crucial concept function. From the perspective of grid interruptions, this is especially true. The primary reason is that system dependability has a cost, and regulators reward or penalize those that enhance system reliability. From this perspective, pole-mounted switch automation in sparsely populated areas can be regarded a top priority (Dondi, Peeters, and Singh, 2001). However, as the subterranean network becomes more popular at the MV level because to its many advantages, pole-mounted CSSs are being replaced by buried CSSs. One of the aims of this study is to find the best level of automation for the SS to maintain dependable supply continuity within the Finnish MV network, which will be discussed in the next section.

It is essential to minimize the impact of unavoidable failures by minimizing downtime and consumer impact. There are numerous significant development directions for addressing this issue, but only two are pertinent: improving the intelligence of the system and its components and moving to underground networks that are less susceptible to natural disasters (Kumpulainen et al., 2007).

3.2 Iraq Network Nature

In Iraq, 95 percent of MV 's lines are overhead, making them extremely vulnerable to external disturbances, which are the most common cause of temporary outages and lead to lower reliability. It is critical to reduce the impact of unavoidable faults by keeping downtime as short as possible and the number of customers affected as small as possible. There are several key evolutionary trends toward this solution, two of which are significant: enhancing the system's and its components' intelligence and shifting to underground networks that are less susceptible to natural disasters.

AR is typically deployed as an outage protection strategy for overhead networks MV, resulting in small interruptions. Depending on the application, this can take the shap of High-Speed Automatic Reclosing (HSAR) or Delayed Automatic Reclosing (DAR). Nikander et al, studied the usage of a Shunt Circuit Breaker (SCB) for phase grounding was investigated. Although it produces effects similar to ARs [69] for transient ground faults without interruptions, it ceases to function in the presence of a two-phase ground problem in the network when SCB tripping must be safely avoided. Since the CB is shunted and did not connect in series, it cannot be used for grid switching or other reasons, which puts its cost effectiveness to the test. Since the networks of the future will be mainly underground and there will be persistent faults, this feature is no longer practical and, on the contrary, may destroy the cable.

Short circuits and ground faults are the most common network failures caused by storms, lightning, malfunction or equipment failure, or human error. Passage of electricity through an unplanned path without a low-resistance path is called a short circuit. This can occur between two or three phases due to the low-resistance route, and the resulting current is frequently at least an order of magnitude more than the regular load current. In contrast, a ground fault happens when one or more of those phase conductors make contact with ground, causing current to flow through a low-impedance channel. As a result of these problems, disturbances can occur in the power distribution system, causing all or part of the power supply to fail. Using a balanced neutral instead of an isolated neutral helps reduce the frequency of interruptions due to ground faults. These fault scenarios pose a threat to the safety of the network, so it is critical to quickly isolate the faulted section from the rest of the network. Therefore, power distribution planning must anticipate problems in order to minimize interruptions without jeopardizing individual safety. As a result, fault reduction is a crucial issue, and the necessity for automated systems and solutions to do this duty is described in the next section.

3.3 Smart Distribution Network Requirements

A large investment is necessary to deploy technology to move the distribution network towards SG, which involves determining the right level of automation. This ideal level cannot be defined by a single element, but must take into account requirements of network, technologies and equipment available to achieve it. For future-proof it, currently literature may be used to incorporate new thoughts and elements that will be published in the coming years. For pragmatic purposes, case studies of efforts that have already partially implemented similar concepts were utilized. All this information contributes to a thorough understanding of the problem and enables its solution. All of this is discussed in more detail in the following sections.

3.3.1 Grid requirements

The most important prerequisite for finding a solution is to understand the network's requirements. This was accomplished by examining the Distribution Systems Operator's point of view (DSO).

i. The biggest issue is pinpointing the exact site of the defect, which might take many hours in severe circumstances (For example, one 20kilometres long feeder through the desert).
ii. Expanded tunnel network is being laid because it is less susceptible to transitional faults.
iii. Circuit breakers may be utilized if they add functionality at a low cost.
iv. CSS will be utilized more in the future since it is more accessible, albeit it is also more expensive.
v. The numbers of outgoing feeders out of a single SS should be minimized, and small CSS should be employed in huge numbers instead (increasing the controllable nodes number).
vi. More compatibility is required for new products, as present CSSs come from a variety of manufacturers, resulting in diverse layouts and equipment.
vii. Remote operation is required, but it also necessitates great operational reliability. It should operate when needed, including during power outages, and should not fail for any reason.

3.4 Analyze Requirements

Any system's design is governed by a formal specification of technical needs known as a Functional Requirements Specification [98]. These specifications outline the services, tasks, and functions that must be provided by the system. These are grouped into the following two categories:

3.4.1 Non functional prerequisites

The non functional prerequisites specify how the system should function, i.e. the principles that describe how the system should work. Here's a rundown of what they're all about:

i. Low-cost options for increasing reliability.
ii. Modular design for functionality selection and future expansion based on necessity.
iii. Energy storage for operation in the event of a loss of mains (LOM).

iv. Easy to use and maintain for huge deployment.
v. All system components operate in a robust and scalable manner.
vi. Retrofitting to update existing pieces rather than replacing them entirely - Compatibility with older goods for effective deployment
vii. Communication capability for sharing information among parts of the system and the associated security and stability
viii. Reliability.

3.4.2 Functional Requirements

Based on the non-functional requirements, the functional needs specify what is expected from system, i.e., each specific system functionality.

i. Remote monitoring and control solutions that are intelligent.
ii. Fault safety feature (bay-level or central).
iii. Exact position of the fault (lead up to detection).
iv. Expanding the below the surface system - Increasing the use of CSS while decreasing the amount of outgoing transmission lines was increased from one to two SS.
v. Support for CBs inbound and outbound - Support for remote or local motorized process (24V DC) of SDs and CBs with DC supply and auxiliary battery packs.
vi. MV short circuit and ground faults are displayed.
vii. Creation of a communication connection between the SS unit and the NCC's SCADA/DMS systems.
viii. PLUG and PLAY approach for IED element installation, incorporating power, control, data acquisition, communications, and other modules.
ix. In MV networks, several protection zones are used to reduce the impact of single faults.
x. For local operation, there is a local display and control.
xi. Antenna detachable for improved signal receptions.

Smart computing and flexible technologies need to be researched and developed to meet the above requirements. These have been analyzed from the point of view of the proposed system to acknowledge the system functions, and their task is described by simulation.

3.5 Architecture of the Proposed System

Based on the results of the analysis phase carried out in the earlier section, this can be concluded that the system will contain all or part of following functions:

1. Observing
2. Measurements.
3. Information sharing
4. Security
5. Regulate

The basic task is important for monitoring status the network components various including such switchgears, transformers and other components. The interaction function is essential to exchange monitoring data with other equipment and directly with NCC. The safety function is required to protect the system through event of a fault. This function requires accurate measurements of current, voltage and other characteristics. The process is required to use the breakers as soon as they are needed, which can be either manual or automated. This can also be automated remotely or by connecting to the NCC, but in the case of a LOM, energy storage systems to operate the equipment.

The following elements/devices are required to perform the above functions and are not extended to:

i. Sensors or instrument transformers: current or voltage transformers (CTs or VTs).
ii. IEDs that collect signals from CTs, VTs, as well as other devices and act on them, for example, the IEDs might be a switch with minor improvements.
iii. Through internet connections, routers or transmitters directly coupled to the NCC or through SCADA, a wired (RJ45,fiber or other) or wireless (LTE, GSM, 4G,5G, radio,...) communications.
iv. For regional or distant operation, a motorized configuration (SDs, CBs, and others) is used.

The solution employed in this study is described in the next part, along with a summary of the characteristics needed and utilized.

3.6 Proposed System Simulation

A network example of this type has been included in the PowerWorld software for emulation purposes, but because it loses programmed instructional capability, It could focus only on solving network parameters such as voltage, current, and many others, as well as detecting the effects of switching operations in real-time, but these switching operations cannot be completed by next predefined functions in the software. Figure 3.1 shows a single line diagram (SLD) of an example system in RMU architecture.

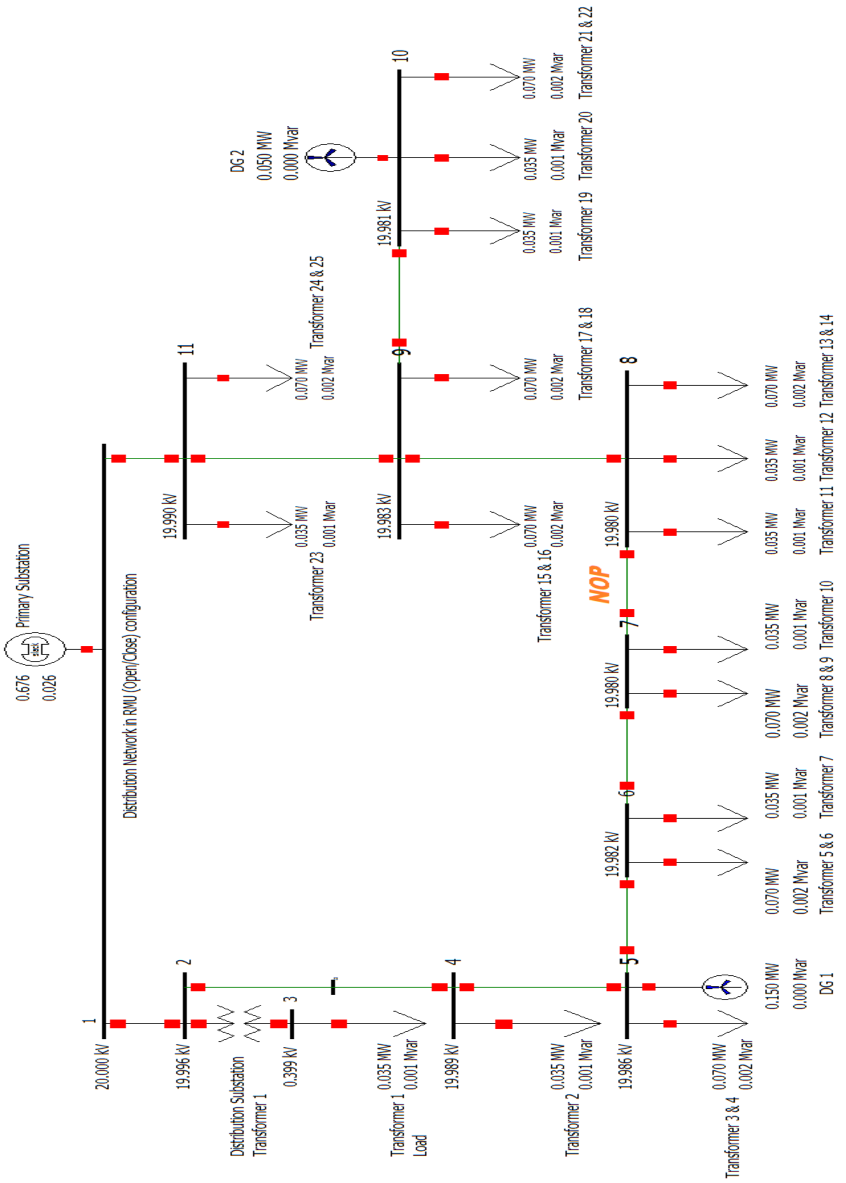


Figure 3.1: Power World Model for RMU

3.6.1 Design the secondary substation

According to the information received from the makers, the SS is available in a variety of variations. They can be air-insulated or SF6-insulated, and their configuration, size, and performance are determined by the network company for which they are being developed. These layouts differ across Iraq, but the most common design is shown in figure 3.2.

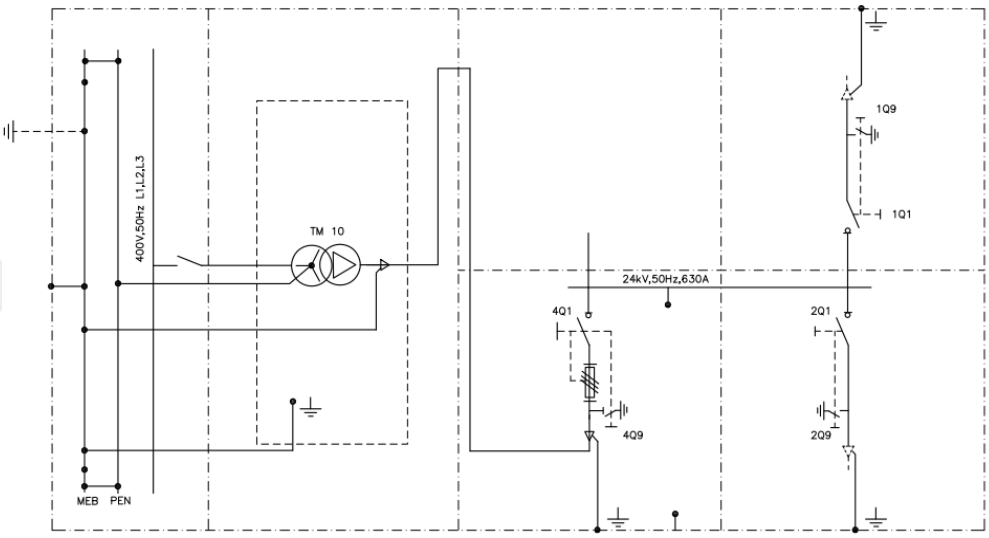


Figure 3.2: Substation Configuration

3.6.2 Remote terminal unit (RTU)

In a digital substation based on IEC 61850, SAS and communication architectures play an important role in the entire scheme. Regulator, status, recording, communication and protection tasks are three basic roles of substation automation. The RTU may monitor the Bay Control Unit's open/closed equipment status (BCU). For status and commands, the BCU can employ an input, output module, as well as current and voltage coils for measurements. The BCU and the RTU SCADA master are connected by a fiber optic line. The RTU panels, as well as the components with the power supply card, memory communication card, and processor, are powered by 220 AC voltage and run on 48V DC.

Because it's impossible to achieve with the SAS when communication fails, the communication system needs to be changed. In power applications, the Remote Terminal Unit (RTU) is an important component of the SCADA system that executes directives from the SCADA system [21]. The RTU acts as a link between the IEDs and the SCADA master, assisting supervisors with accurate and timely real-time control and monitoring of analog and digital data. In addition, the RTU relies on the analog input (AI), digital input (DI), communications interface (CI), and digital output (DO) to function (DO). The electronic cards used to monitor the measurement elements in the substation are the analog input and the digital input. The CI module includes a serial receiver, a decoder, an internal timer, a data and time logger (DTL), and encoding and transmitting components that receive instructions from the control station and decode them before sending the converted data back to the control station. SAS IEC 61850 RTU communication system is shown as figure (3.3).

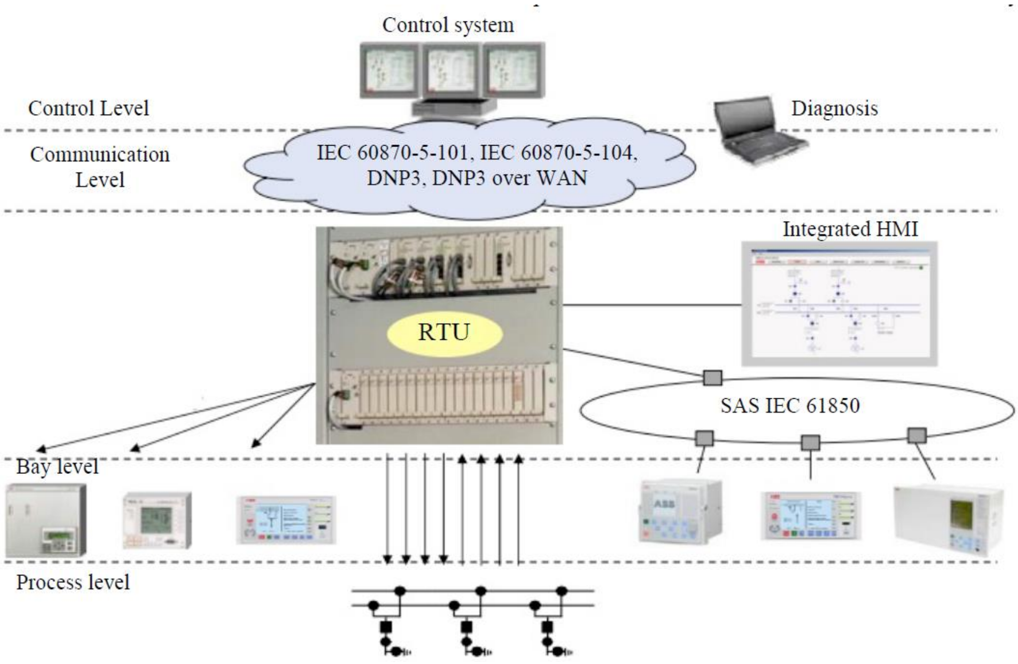


Figure 3.3: SAS IEC 61850 RTU Communication System

Figure 3.3 shows an RMU-shaped MV distribution network designed by Power World. The thick lines are bus-bars, while the sharp lines are 20kV MV distribution lines/feeds (exposed or underground). The red squares represent the breakers, while the lower squares indicate the loads on each bus-bar. At Bus-1, there is a primary generator feeding the entire grid via PS and two wind generators representing DG. The SSs are represented by bus-bar numbers 2 through 11 and are labelled SS -2 through SS -11. Each SS consists of at least one feeder, one or even more distribution transformers (MV/LV), and one or more feeders. The transformer is only installed on bus-2, but is present on each vehicle as a load. Although the suggested MV network has a circular structural topology, the procedure is radial and generates a NOP. In order to simplify the automation as much as feasible, the switches linking bus-7 and bus-8 (the switch at the output of SS -7 and the switch at the inputs of SS -8) have been designated as NOP. This is especially crucial in a network with a meshed structure, as there may be several methods of extracting the network after a breakdown. The NOP is essential to the FLISR process's recovery procedure; hence, its automation is required.

4. DESIGN RESULTS AND DISCUSSION

The proposed automation systems need to satisfy a very accurate estimation for the distribution grid parameters to overcome and sensor or communication error, so that it is important to use suitable estimation software to do that. Neural network is the suitable technique for this task. A deep neural network with 10 hidden layers was trained with a data for 33 bus distribution system. The training process was performed in two scenarios, where in the first scenario the whole system data was used for training the neural network and in the second scenario a part of the system data was used for training the neural network.

4.1 33 Bus System Data

The studied distribution system load data is in table 4.1 and the system bus line data in table 4.2 which contains 33bus system.

Table 4.1: System Load Data

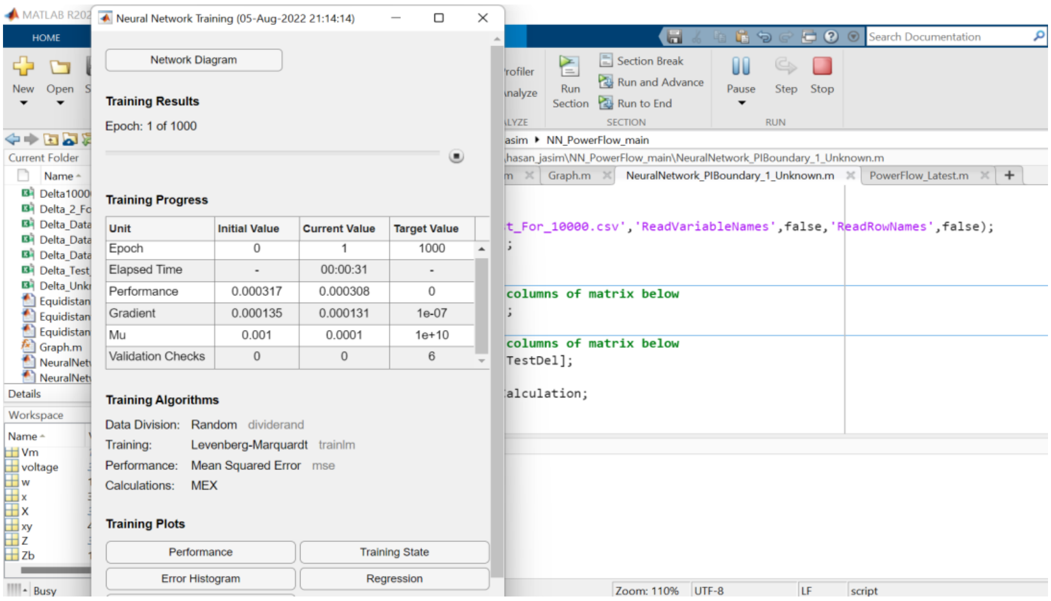
Bus No.	**KW**	**KVAr**	**Q**	**Bus No.**	**KW**	**KVAr**	**Q**
1	0	0	0	17	60	20	0
2	100	60	0	18	90	40	0
3	90	40	0	19	90	40	0
4	120	80	0	20	90	40	0
5	60	30	0	21	90	40	0
6	60	20	0	22	90	40	0
7	200	100	0	23	90	50	0
8	200	100	0	24	420	200	0
9	60	20	0	25	420	200	0
10	60	20	0	26	60	25	0
11	45	30	0	27	60	25	0
12	60	35	0	28	60	20	0
13	60	35	0	29	120	70	0
14	120	80	0	30	200	600	0
15	60	10	0	31	150	70	0
16	60	20	0	32	210	100	0
				33	60	40	0

Table 4.2: Data for the 33 Bus System's Lines

Line No.	From	To	R(Ω)	X(Ω)
1	1	2	0.0922	0.047
2	2	3	0.493	0.2511
3	3	4	0.366	0.1864
4	4	5	0.3811	0.1941
4	5	6	0.819	0.707
6	6	7	0.1872	0.6188
7	7	8	0.7114	0.2351
8	8	9	1.03	0.74
9	9	10	1.044	0.74
10	10	11	0.1966	0.065
11	11	12	0.3744	0.1238
12	12	13	1.468	1.155
13	13	14	0.5416	0.7129
14	14	15	0.591	0.526
15	15	16	0.7463	0.545
16	16	17	1.289	1.721
17	17	18	0.732	0.574
18	2	19	0.164	0.1565
19	19	20	1.5042	1.3554
20	20	21	0.4095	0.4784
21	21	22	0.7089	0.9373
22	3	23	0.4512	0.3083
23	23	24	0.898	0.7091
24	24	25	0.896	0.7011
25	6	26	0.203	0.1034
26	26	27	0.2842	0.1447
27	27	28	1.059	0.9337
28	28	29	0.8042	0.7006
29	29	30	0.5075	0.2585
30	30	31	0.9744	0.963
31	31	32	0.3105	0.3619
32	32	33	0.341	0.5302

4.2 Neural Network

The neural network used to estimate the system parameters is a deep neural network with 10 hidden layers. The proposed system during training is shown in Figure 4.1. Neural network training behavior is shown in figure 4.2 while the error histogram for the training process is shown in Figure 4.3, and training status is shown in figure 4.4.



Neural Network Training (05-Aug-2022 21:14:14)

Training Results

Epoch: 1 of 1000

Training Progress

Unit	Initial Value	Current Value	Target Value
Epoch	0	1	1000
Elapsed Time	-	00:00:31	-
Performance	0.000317	0.000308	0
Gradient	0.000135	0.000131	1e-07
Mu	0.001	0.0001	1e+10
Validation Checks	0	0	6

Training Algorithms

Data Division: Random dividerand
Training: Levenberg-Marquardt trainlm
Performance: Mean Squared Error mse
Calculations: MEX

Training Plots

```
t_For_10000.csv','ReadVariableNames',false,'ReadRowNames',false);
;

columns of matrix below
;

columns of matrix below
TestDel];

alculation;
```

Figure 4.1: Proposed System During Training

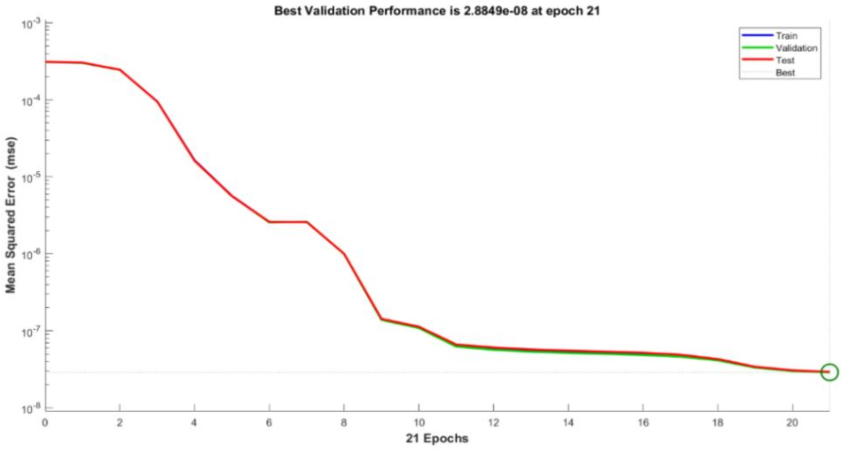


Figure 4.2: Neural Network Training Behavior

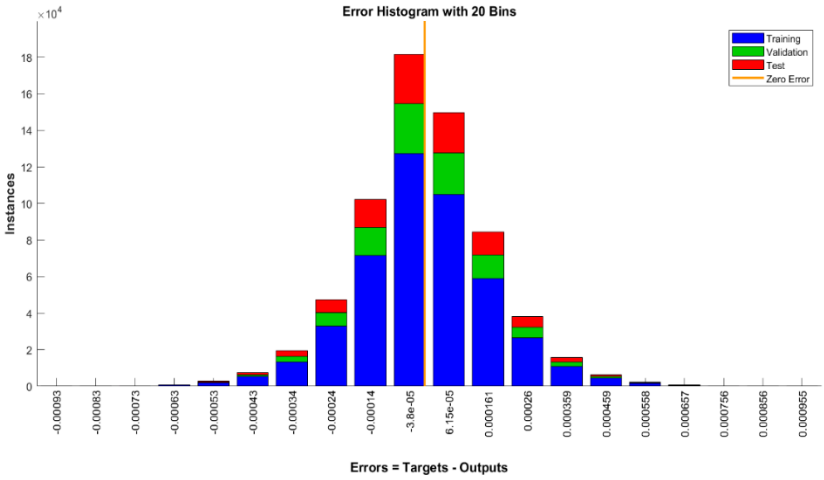


Figure 4.3: Neural Network Training Error Histogram

To verify the training results, it important to use a verification process, here the linear regression is used to check the accuracy of the neural network training process results, the linear regression result is shown in figure 4.3. It is clear that the training accuracy is very good, therefor the trained neural network can be used in the proposed system. The training status is shown in figure 4.4.

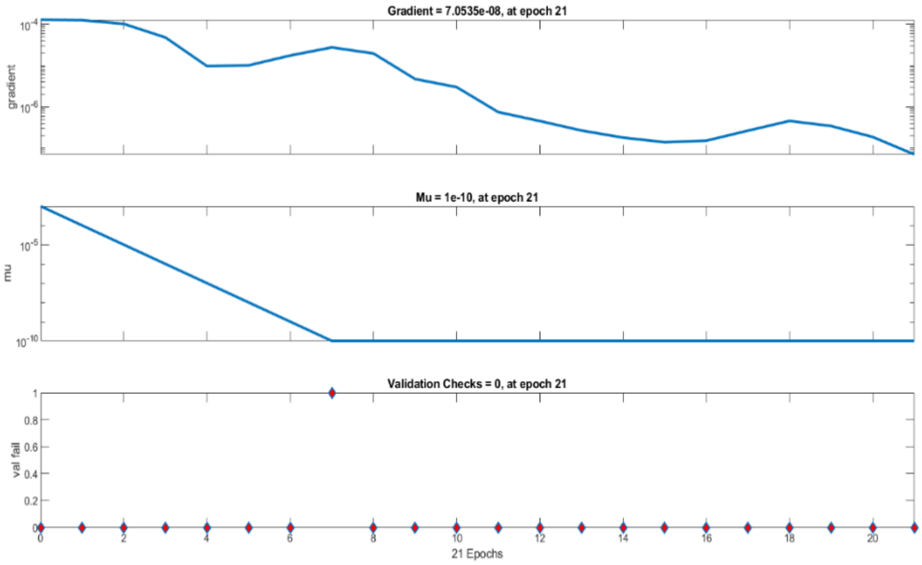


Figure 4.4: Training Status for the Neural Network

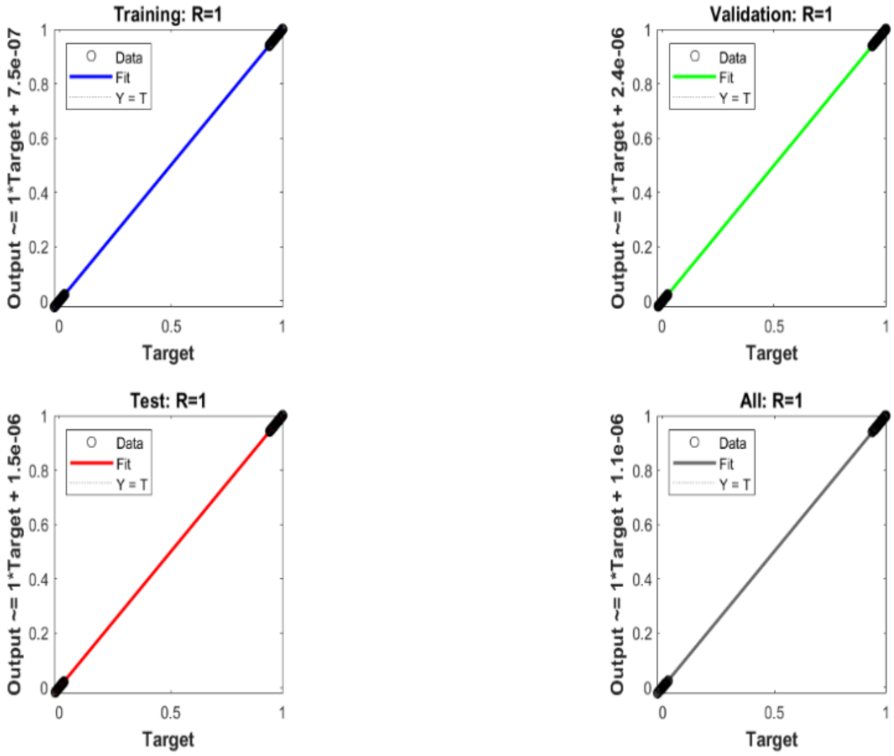


Figure 4.5: Linear Regression for Neural Network Training Results

4.3 First Scenario: Total System Data Using

In this scenario, the whole system data is used to train the neural network, and the actual system data is compared for both voltages and angles for each bus; Figure 4.6 shows the actual and estimated bus voltages.

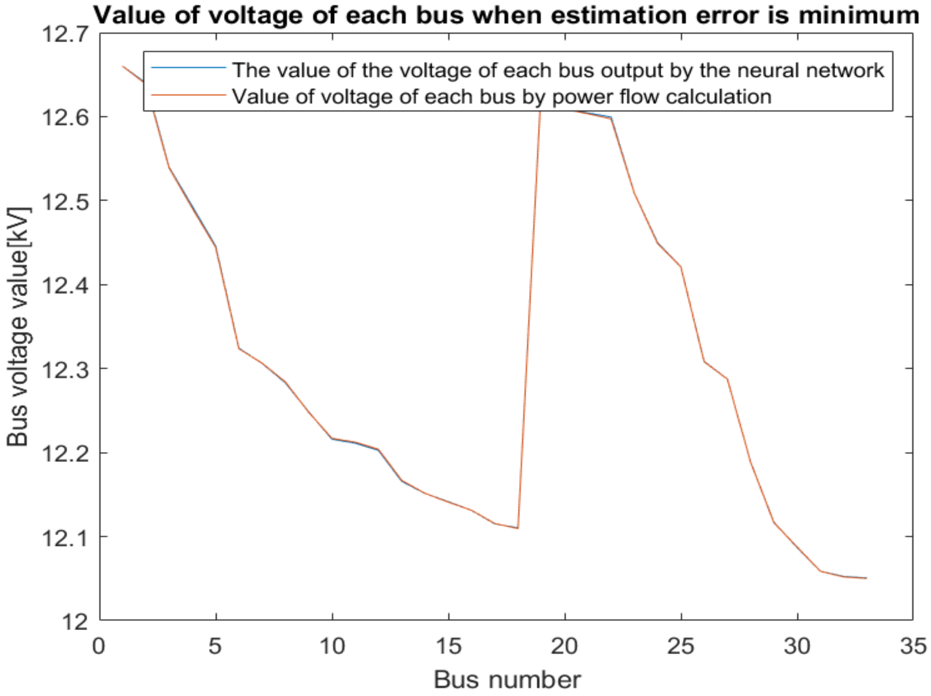


Figure 4.6: Bus Voltages for Automated System and Load Flow Analysis

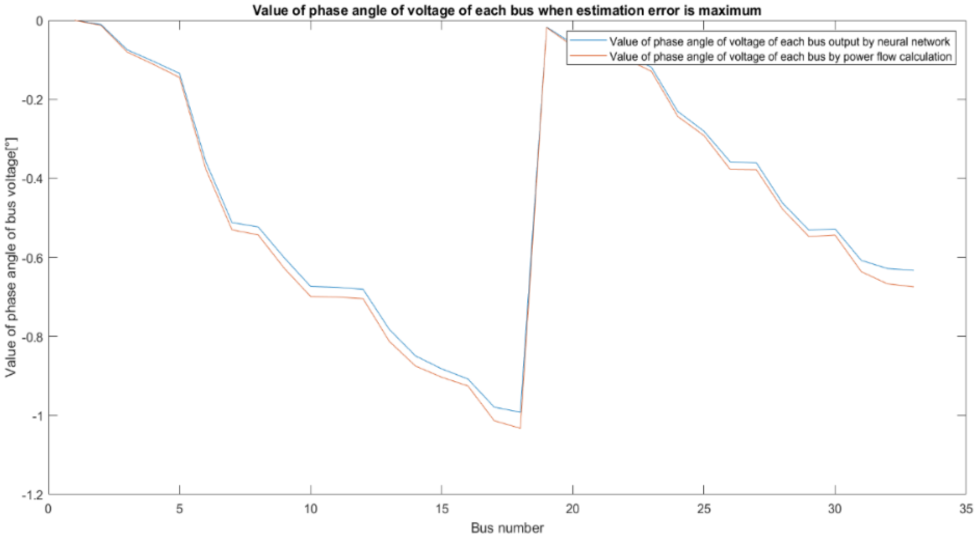


Figure 4.7: Bus Voltages for both Automated and Actual System In Case Of Maximum Error

Figure 4.7 shows the voltages for each bus when the error in maximum value, both neural network based data and actual system data are shown in the figure.

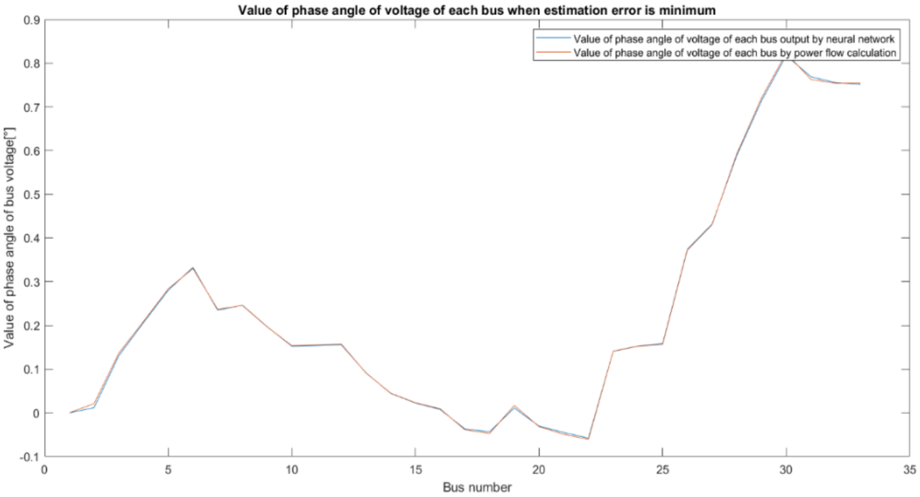


Figure 4.8: System Phase Angle in Minimum Error Case

The phase angle for the system in both methods when the error in minimum value is shown as Figure (4.8).

While the system phase angles in case of maximum error is shown in Figure 4.9, its clear that the error is within accepted range.

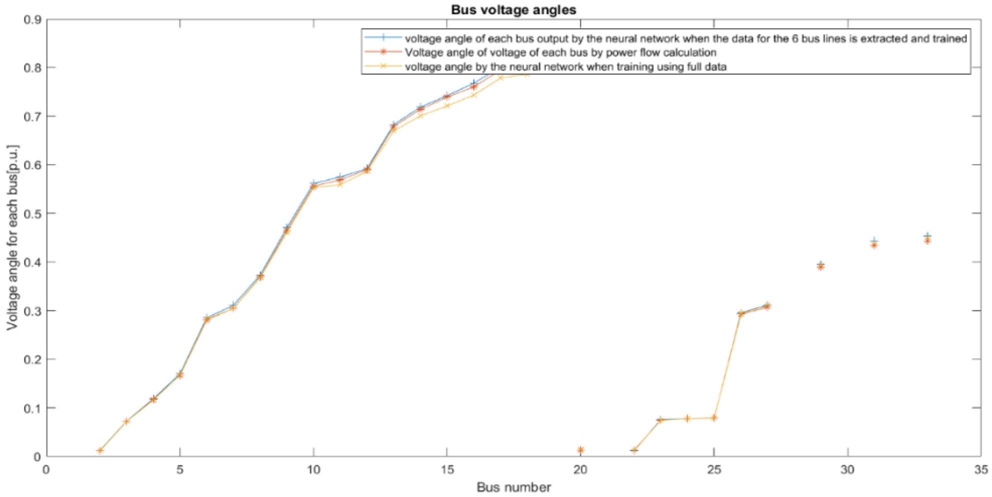


Figure 4.9: Bus Voltage Angles in Case 6 Bus Data Training

4.4 Second Scenario

In this scenario, reduced data is used to train the neural network. The reduced data is used to simulate missing data in the automated system due to communication errors, sensor failures, or other reasons for missing data. Figure 4.10 shows the bus voltage in case of using only 6 bus data for training compared to the training results with complete data and the calculated load flow.

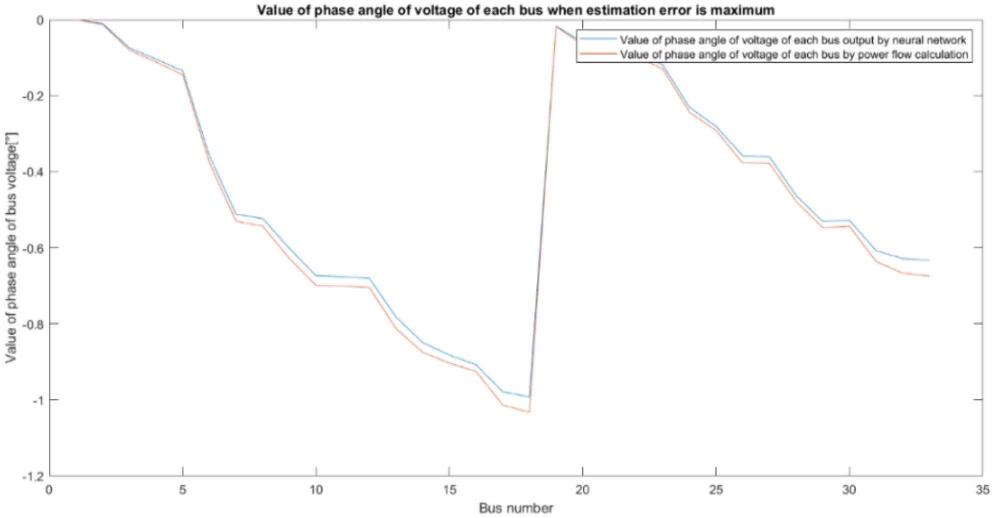


Figure 4.10: System Phase Angles in Case of Maximum Error

The voltage angle for the overall system in case of using only 6 buses data for training compared with complete data training and load flow calculation are shown in Figure 4.11.

Another case for reduced data for training, namely for 7-bus data, the bus voltage in this case is shown in Figure 4.12 and the voltage angles are shown in Figure 4.13.

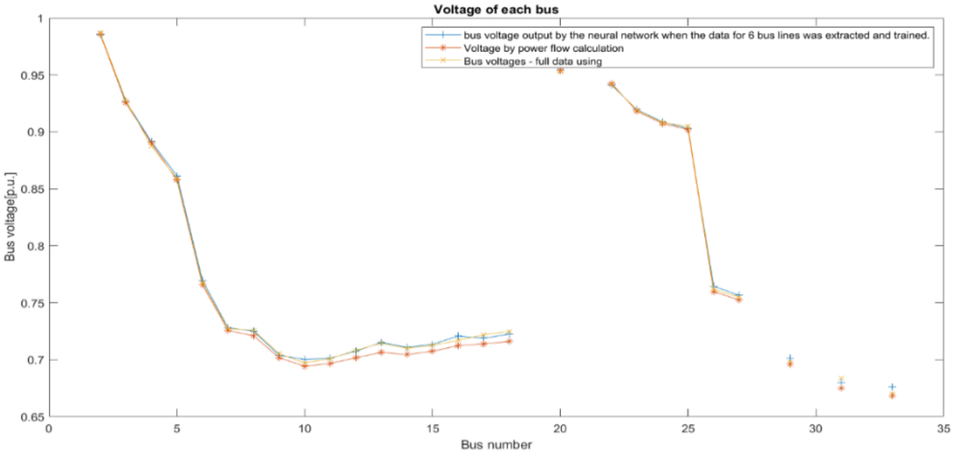


Figure 4.11: Bus Voltage in Case of Using Only 6 Buses for Training

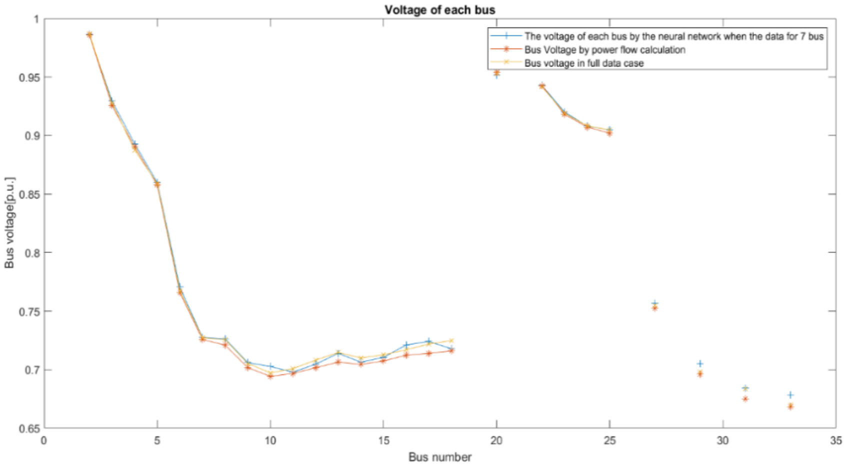


Figure 4.12: Bus Voltage in Case of 7 Bus Data Training

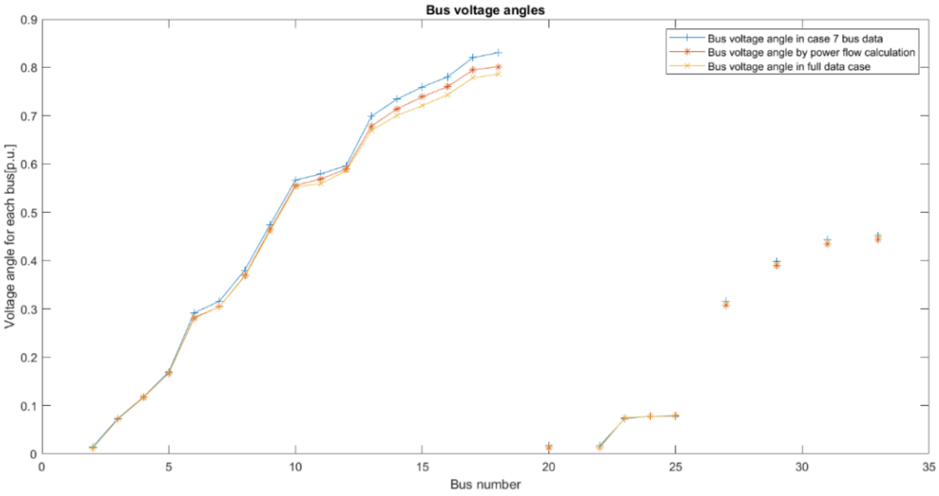


Figure 4.13: Voltage Angles in Case of 7 Bus Data Training

5. SUMMARY RESULTS AND FUTURE WORK

5.1 Summary Results

Smart grids contain a lot of automated equipment such as smart meters and substations that are the subject of research in this work. The transition to the automated system requires the use of many sensors, which are usually remotely managed. Automated system requires high reliability and the possibility of avoiding errors.

To design a complete automated distribution network, it is very important to overcome and expected communication or sensor failed error. In this work a neural network estimation system is proposed to be used as a part of a complete automation system that can be used in Iraq power distribution network in medium voltage range. The proposed method contains two estimation scenarios on in normal operating case (no error in both communication or sensors) and the other in fault case (communication error or sensors error). The results for both scenarios are compared with standard power flow analyses. For compete data training (normal operating case) the estimation of system parameters error range within a limit of 10^{-6} in both voltage or voltage angle, while in reduced training data the error was in range about 10-3 in both voltage and voltage angles, this error seems to be high compared with complete training data (normal operation) but it assumed to be normal or accepted value when we know the used number of used data foe training (only 6 buses or 7 buses). The proposed method simulation results show that this method may be suitable for unstable distribution networks even in hard faults such as many buses data loose.

5.2 Future Work

The proposed method can be integrated with suitable communication system that can connect the substations from each brand into one smart automated distribution grid.

The studied method can be implemented in experimental model to realize the estimation results.

A survey study on the substations in Iraq distribution network can give a suitable data for the proposed system design and implementation.

Utilizing internet of things application can be the fist step to perform automated substations, and also can be used in smart grids and distributed generators. It is possible to connect the smart meters of the microgrid with the automated secondary switching stations for each microgrid to facilitate monitoring of loads and prediction of errors that may occur and to avoid them if they occur while maintaining the electrical power supply.

REFERENCES

Abiodun, O. I. *et al.* (2018) 'State-of-the-art in artificial neural network applications: A survey', *Heliyon*, 4(11), p. e00938.

Alanne, K. and Saari, A. (2006) 'Distributed energy generation and sustainable development', *Renewable and sustainable energy reviews*, 10(6), pp. 539–558.

Alberto, M. *et al.* (2012) 'OpenNode: A smart secondary substation node and its integration in a distribution grid of the future', in *2012 Federated Conference on Computer Science and Information Systems (FedCSIS)*. IEEE, pp. 1277–1284.

Antila, E., Heine, P. and Lehtonen, M. (2003) 'Economic analysis of implementing novel power distribution automation', in *CIGRE/IEEE PES International Symposium Quality and Security of Electric Power Delivery Systems, 2003. CIGRE/PES 2003.* IEEE, pp. 121–126.

Arun, T. V, Lathesh, L. and Suhas, A. R. (2016) 'Substation automation system', *International Journal of Scientific & Engineering Research*, 7(5), pp. 215–218.

Asgeirsson, H. (2010) 'Distribution automation—The foundation for the smart grid at DTE energy', in *IEEE PES General Meeting*. IEEE, pp. 1–3.

Bakhtiari Nejad, S. and Frarahani Najafabadi, K. (2012) 'Improvement of distribution automation by implementing MasterRTU', in *Proceedings of the 2012 7th IEEE Conference on Industrial Electronics and Applications, ICIEA 2012*. IEEE, pp. 834–837. doi: 10.1109/ICIEA.2012.6360840.

Belagur, J. and Schmidt, R. (2008) 'IP communication for substation automation, distribution automation, and other utility applications-A business case', in *2008 IEEE/PES Transmission and Distribution Conference and Exposition*. IEEE, pp. 1–9.

Cangemi, G. *et al.* (2014) 'Critical issues and future prospects of the secondary substation in smart grid context', in *2014 AEIT Annual Conference-From Research to Industry: The Need for a More Effective Technology Transfer (AEIT)*. IEEE, pp. 1–6.

Chan, K. W. *et al.* (2000) 'On-line dynamic security contingency screening using artificial neural networks', *IEE Proceedings-Generation, Transmission and Distribution*, 147(6), pp. 367–372.

Chen, R.-L. and Sabir, S. (2001) 'The benefits of implementing distribution automation and system monitoring in the open electricity market', in *Canadian Conference on Electrical and Computer Engineering 2001. Conference Proceedings (Cat. No. 01TH8555)*. IEEE, pp. 825–830.

Choi, W.-S. *et al.* (2011) ‘The study of substation automation systems based on IEC 61850’, in *2011 International Conference on Electrical Machines and Systems*. IEEE, pp. 1–4.

Coster, E. J., Kerstens, W. C. M. and Schroedel, O. (2014) ‘Implementation of an automatic FLIR-scheme in a 20 kV distribution grid’.

Dondi, P., Peeters, Y. and Singh, N. (2001) ‘Achieving real benefits by distribution automation solutions’, in *16th International Conference and Exhibition on Electricity Distribution, 2001. Part 1: Contributions. CIRED.(IEE Conf. Publ No. 482)*. IET, pp. 5-pp.

Driesen, J. and Katiraei, F. (2008) ‘Design for distributed energy resources’, *IEEE power and energy magazine*, 6(3), pp. 30–40.

Fu, Y. *et al.* (2014) ‘Research and application of distribution grid self-healing based on distribution automation’, in *2014 China International Conference on Electricity Distribution (CICED)*. IEEE, pp. 1211–1214.

Garcia, J. G., Navarro, M. G. and Alonso, J. C. (2013) ‘Smart secondary substation management device’.

Gezer, D. and Uludag, S. (2013) ‘An MV distribution automation system and its assessment in light of the smart grid vision’, in *4th International Conference on Power Engineering, Energy and Electrical Drives*. IEEE, pp. 1116–1122.

Greer, R. *et al.* (2011) ‘Distribution automation systems with advanced features’, in *2011 Rural Electric Power Conference*. IEEE, pp. C4-1.

Grigsby, L. L. (2006) *Electric power engineering handbook*. CRC Press LLC, London.

de Groot, R. J. W., Morren, J. and Slootweg, J. G. (2012) ‘Smart integration of distribution automation applications’, in *2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)*. IEEE, pp. 1–7.

Hanai, M. (2011) ‘Maintenance optimization of power apparatus by intelligent grid management system (IGMS) and upgrading by component diagnosis’, in *CIGRE SC A2 & D1 Joint Colloquium 2011*.

Hanai, M. *et al.* (2013) ‘Integration of asset management and smart grid with intelligent grid management system’, *IEEE Transactions on Dielectrics and Electrical Insulation*, 20(6), pp. 2195–2202.

Heidari, S., Fotuhi-Firuzabad, M. and Kazemi, S. (2014) ‘Power distribution network expansion planning considering distribution automation’, *IEEE Transactions on Power Systems*, 30(3), pp. 1261–1269.

Hippert, H. S., Pedreira, C. E. and Souza, R. C. (2001) ‘Neural networks for short-term load forecasting: A review and evaluation’, *IEEE Transactions on power systems*, 16(1), pp. 44–55.

Hughes, J. W. (2008) ‘Challenges of developing the next generation distribution automation system’, in *2008 IEEE/PES Transmission and Distribution Conference and Exposition*. IEEE, pp. 1–4.

Javaheri, E. and Afshar, R. (2013) ‘Design of an economical and technical distribution automation system’.

Kezunovic, M. *et al.* (2010) ‘The 21st century substation design: Vision of the future’, in *2010 IREP Symposium Bulk Power System Dynamics and Control-VIII (IREP)*. IEEE, pp. 1–8.

Kim, M., Metzner, J. J. and Lee, K. Y. (2009) ‘Design and implementation of a last-mile optical network for distribution automation’, *IEEE transactions on power delivery*, 24(3), pp. 1198–1205.

Kumarappan, N., Mohan, M. R. and Murugappan, S. (2002) ‘ANN approach applied to combined economic and emission dispatch for large-scale system’, in *Proceedings of the 2002 International Joint Conference on Neural Networks. IJCNN’02 (Cat. No. 02CH37290)*. IEEE, pp. 323–327.

Kumpulainen, L. *et al.* (2007) ‘Vision of the future power system-Distribution Network 2030’, in *International Conference on Electricity Distribution*.

Lahiri, R. N. *et al.* (2009) ‘Importance of distribution automation system for Indian power utility’, in *2009 IEEE Power & Energy Society General Meeting*. IEEE, pp. 1–7.

Li, G. and Zheng, G. (2012) ‘Self-reconfiguration architecture for distribution automation system based on cyber-physical’, in *2012 Asia-Pacific Power and Energy Engineering Conference*. IEEE, pp. 1–4.

Mamo, X. *et al.* (2009) ‘Distribution automation: The cornerstone for smart grid development strategy’, in *2009 IEEE Power & Energy Society General Meeting*. IEEE, pp. 1–6.

de Melo Leite, L. H., de Errico, L. and do Couto Boaventura, W. (2013) ‘Criteria for the selection of communication infrastructure applied to power distribution automation’, in *2013 IEEE PES Conference on Innovative Smart Grid Technologies (ISGT Latin America)*. IEEE, pp. 1–8.

Meng, Q. and Wang, T. (2014) ‘Effects of distribution automation on distribution system reliability’, in *2014 IEEE Conference and Expo Transportation Electrification Asia-Pacific (ITEC Asia-Pacific)*. IEEE, pp. 1–4.

De Mesmaeker, I., Rytoft, C. and Reinhardt, P. (2007) ‘Protection and substation automation: Standardisation integration and IT’, *ABB Power Technologies, Energize*, pp. 30–35.

Mohagheghi, S. *et al.* (2009) ‘Modeling distribution automation system components using IEC 61850’, in *2009 IEEE Power & Energy Society General Meeting*. IEEE, pp. 1–6.

Mohagheghi, S. *et al.* (2011) ‘Applications of IEC 61850 in distribution automation’, in *2011 IEEE/PES Power Systems Conference and Exposition, PSCE 2011*. IEEE, pp. 1–9. doi: 10.1109/PSCE.2011.5772491.

Monadi, M. (2016) ‘Protection and fault management in active distribution systems’.

Mukhometzianov, Rinat., Y. W. (2017) ‘Review . Machine Learning Techniques For Traffic Sign Detection’, *arXiv preprint arXiv:1712.04391*.

Pahwa, A. (2005) ‘Planning and analysis tools to evaluate distribution automation implementation and benefits’, in *IEEE Power Engineering Society*

General Meeting, 2005. IEEE, pp. 2622–2623.

Parikh, P., Voloh, I. and Mahony, M. (2013) ‘Fault location, isolation, and service restoration (FLISR) technique using IEC 61850 GOOSE’, in *2013 IEEE Power & Energy Society General Meeting*. IEEE, pp. 1–6.

Parker, L. E. (2007) ‘Distributed Intelligence: Overview of the Field and its Application in Multi-Robot Systems.’, in *AAAI fall symposium: regarding the intelligence in distributed intelligent systems*, pp. 1–6.

Parmar, K., Karena, M. and Parekh, J. (no date) ‘Reliability assessment in IGMS using NEPLAN software’.

Ren, R. *et al.* (2008) ‘The realization of the feeder automation function in distribution automation systems’, in *2008 China International Conference on Electricity Distribution*. IEEE, pp. 1–4.

Rodriguez-Calvo, A. *et al.* (2012) ‘Optimal degree of smart transformer substations in distribution networks for reliability improvement’, in *2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)*. IEEE, pp. 1–7.

Rudd, S. E. *et al.* (2011) ‘Intelligent monitoring of the health and performance of distribution automation’, in *2011 16th International Conference on Intelligent System Applications to Power Systems*. IEEE, pp. 1–6.

Sen, K. K. and Sen, M. L. (2015) ‘SMART Power Flow Controller for smarter grid applications’, in *2015 IEEE Power & Energy Society General Meeting*. IEEE, pp. 1–5.

Short, T. A. (2018) *Electric power distribution equipment and systems*. CRC press.

Simard, G., Lavoie, V. and Chartrand, D. (2006) ‘Hydro-Quebec’s vision of the Distribution Automation’, in *2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition*.

Singh, G. (2015) ‘Design and engineering for smart secondary substation automation panel’.

Siswantoro, J., Prabuwono, A. S., Abdullah, A., & Idrus, B. (2016) ‘A linear model based on Kalman filter for improving neural network classification performance’, (Expert Systems with Applications, 49), pp. 112–122.

Siswantoro, J. *et al.* (2016) ‘A linear model based on Kalman filter for improving neural network classification performance’, *Expert Systems with Applications*, 49, pp. 112–122.

Skeie, T., Johannessen, S. and Brunner, C. (2002) ‘Ethernet in substation automation’, *IEEE control systems magazine*, 22(3), pp. 43–51.

Staszesky, D. M. (2006) ‘Use of virtual agents to effect intelligent distribution automation’, in *2006 IEEE Power Engineering Society General Meeting*. IEEE, pp. 6-pp.

Terese, J. R. *et al.* (2007) ‘City distribution automation projects-Economic justification aspects’, in *2007 IEEE Power Engineering Society General Meeting*. IEEE, pp. 1–6.

Thomas, M. S., Arora, S. and Chandna, V. K. (2011) ‘Distribution automation leading to a smarter grid', in *ISGT2011-India*. IEEE, pp. 211–216.

Uluski, R. W. (2010) 'The role of advanced distribution automation in the smart grid', in *IEEE PES General Meeting*. IEEE, pp. 1–5.

Wikund, G. *et al.* (2011) '„Towards self-healing power sistribution by means of the zone concept.“', in *Proceedings of the 21nd International Conference on Electricity Distribution (CIRED 2011), Frankfurt a. M.*

Wu, X., Yang, L. and Qi, Y. (2009) 'Simple analysis of the application of distribution automation system in power supply enterprises', in *2009 International Conference on Intelligent Human-Machine Systems and Cybernetics, IHMSC 2009*. IEEE, pp. 368–371. doi: 10.1109/IHMSC.2009.215.

Xu, W. *et al.* (2010) 'Discussion on Digital Distribution Automation System based on IEC 61850', in *CICED 2010 Proceedings*. IEEE, pp. 1–7.

Xu, Y. and Xu, X. (2008) 'Typical scheme designs of distribution network automation for northeast rural areas of China', in *2008 Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*. IEEE, pp. 2028–2031.

Zavoda, F. (2008) 'The key role of intelligent electronic devices (IED) in advanced Distribution Automation (ADA)', in *2008 China International Conference on Electricity Distribution*. IEEE, pp. 1–7.

Zheng, Y. *et al.* (2013) 'Study of the techniques and development strategy for a concentrated type distribution automation', in *2013 IEEE PES Innovative Smart Grid Technologies Conference (ISGT)*. IEEE, pp. 1–4.

RESUME

Hasan Almuthana Jaber JASIM

University: University of Technology, Department of Electromechanical Engineering

Review : On 3/8/2006 I was appointed to the Iraqi Ministry of Electricity / General Company for North Electricity Distribution / Salah El-Din Electricity Distribution Branch / Balad Electricity Distribution Department / I worked in the Technical Division in planning in the delivery of electric current to residential neighborhoods, villages and rural areas and maintenance of the electrical network of high voltage and voltage Low level, installation and maintenance of transformers of all sizes and capacities, maintenance of secondary stations 33/11 kv, maintenance of midwives, and on March 8, 2008 I became director of the Balad Electricity Distribution Department to supervise the technical and administrative work of the aforementioned judiciary until now.