ARAB ACADEMY FOR SCIENCE, TECHNOLOGY AND MARITIME TRANSPORT

College of Engineering and Technology
Electrical and Control Engineering Department

SMART GRID OPTIMAL POWER FLOW CONTROL UTILIZING A NEW DEVELOPED ARTIFICIAL INTELLIGENCE TECHNIQUE

By:

MOHAMED FATHY ABDELHAMID ELFAKHARANY
Senior Electrical Engineer

This Thesis is submitted for the partial fulfillment of the requirement for the
MASTER OF SCIENCE
In
ELECTRICAL ENGINEERING

Supervised By:

Prof. Dr. Yasser G. Mostafa
Electrical and Control Engineering
Arab Academy for Science and Technology

Dr. Noha H. El-Amary
Electrical and Control Engineering
Arab Academy for Science and Technology

Egypt
2015

ACKNOWLEDGMENT

My deep gratitude and thanks is dedicated to Prof. Dr. Yasser Galal for his great support and continuous guidance in achieving this work. No words can describe his great and important supervision and care.

Words can not express my deepest appreciation to Dr. Noha El-Amary, my direct supervisor, for her continuous support, help and care. I am so grateful to her for everything, for her valuable time and the great effort she did to help me in achieving this work.

ABSTRACT

Smart electrical power flow control in distribution and transmission systems is targeted in this research. Optimal electrical power continuity through energy management, self healing, high reliability and real-time pricing is one of the main aims of the researches. In this research, a smart electrical power grid is represented to save the power flow continuity with minimum power losses in case of any abnormal condition.

The optimum power continuity is achieved utilizing a developed Particle Swarm Optimization (PSO) technique. This technique is programmed to fulfill two main tasks. The first task is finding all the possible alternative paths for supplying the loads, in case of fault occur or abnormal condition. The second task is modifying the angles of the buses' voltages of the electrical power system to determine the optimal path with minimum power loss. The optimal determined path could have less power losses than that of the path already obtained by the initial power flow analysis. The buses' voltages angles can be modified using static VAR compensators, capacitor banks, or Flexible AC Transmission System devices (FACTs) technology. The work is done through three main stages. First stage, is the system simulation using ETAP program. Second stage, is the determination of all the possible alternative paths for load supplying. Third stage, is the selection of the optimal path according to its modified and optimized buses' voltages angles.

The performance of the developed technique is tested on a standard IEEE 14-bus system, a standard IEEE 57-bus system and a practical electrical distribution power system for an offshore platform. The results obtained for the three tested systems are satisfactory.

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LIST OF SYMBOLS AND ABBREVIATIONS

CHAPTER ONE: INTRODUCTION

AI	:	Artificial Intelligence.
CI	:	Computational Intelligence.
DER	:	Distributed Energy Resources.
DOPF	:	Distribution Optimal Power Flow.
EA	:	Evolutionary Algorithms.
ETAP		Electrical Transient Analysis Program.
FACTS	:	Flexible Alternating Current Transmission System.
GPS	:	Global Positioning Satellites (System).
HAN	:	Home Automation Network.
IEEE	:	Institute of Electrical and Electronics Engineers.
LDC		Local Distribution Company.
NIST	:	National Institute of Standards and Technology.
PMU	:	Phasor Measurement Unit.
PQ	:	Power Quality.
PSO	:	Particle Swarm Optimization.
SCADA	:	Supervisory Control and Data Acquisition.
SG	:	Smart Grid.
SCG		Smart City Grid.
WAMS	:	Wide Area Monitoring System.

CHAPTER TWO: POWER FLOW MODELING AND ANALYSIS

DSM	:	Demand Side Management.
EMI	:	Electromagnetic Interference.

ETAP	:	Electrical Transient and Analysis Program.
IEC	:	International Electrotechnical Commission
P_i, Q_i	:	The real and reactive power injected to bus i.
P_{ij}, Q_{ij}	:	The real and reactive power flow from bus i to bus j.
θ_{ij}		The admittance angle of the line connected bus i and bus j.

CHAPTER THREE: PARTICLE SWARM OPTIMIZATION FOR OPTIMIZING POWER FLOW

EA	:	Evolutionary Algorithms.
EC	:	Evolutionary Computation.
EP	:	Evolutionary Programming.
ES	:	Evolution Strategies.
FPAA	:	Field Programmable Analog Arrays.
FPGA	:	Field Programmable Gate Arrays.
GA	:	Genetic Algorithms.
GP	:	Genetic Programming.
TSM	:	Tree Search Method
c_1 , c_2	:	The cognition and social factors, that are usually set to 2.0.
CF	:	The cost function.
G_{best}	:	The location of the best fitness returned for the entire swarm “global best position”.
n	:	The number of the particles (size) of the swarm.
P_{best}	:	The location of the best fitness returned for a specific agent “personal best position”.
UPFC	:	Unified Power Flow.

rand()	:	A random number between 0 and 1.
SA	:	Simulated Annealing.
V_i^k	:	The i^{th} velocity component at iteration k.
w	:	The inertia weight.
X_i^k	:	The current position in the i^{th} dimension at iteration k.
Δt	:	The time step.

CHAPTER FOUR: SIMULATION AND RESULTS

C	:	Compensator.
G	:	Generator.
N	:	The total number of the network buses.
Plossmin		Minimum Power Loss.
Plt	:	Total Power Loss.

CHAPTER ONE

INTRODUCTION

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INTRODUCTION

1.1 OVERVIEW

This chapter is an introductory chapter. It introduces the meaning of smart grid, the difference between the smart grid and the conventional utility grid. The need for smart grids implementation and a historical background of smart grids are also cited. Thesis objectives and outlines are stated at the end of this chapter.

1.2 INTRODUCTION

There are many recent researches on what modern electrical systems can do and how they should look like in the future. From the operational perspective, a smart grid should provide many new and advanced abilities such as high reliability, self-healing, energy management, monitoring, self-control and real-time pricing. From the design perspective, a smart grid will likely incorporate new technologies such as advanced metering, automation, communication, distributed generation and distributed storage.

To define smart grid we have to answer three basic questions:

i- What is a “Smart Grid”?

ii- How does a Smart Grid differ from the existing utility Grid?

iii- Why do we need it?

1.3 SMART GRID DEFINITION

Smart Grid (SG) can be defined in many ways, however, there is no agreement on a universal definition for it because of the diverse range of factors, and numerous competing taxonomies.

SG refers to a modernization of the electricity delivery system so it monitors, protects and automatically optimizes the operation of its interconnected elements (from the central and distributed generator through the high-voltage network and distribution system, to industrial users and building automation systems, energy storage installations, end-use consumers, their thermostats, electric vehicles, appliances and other household devices)

SG delivers electrical power from suppliers to consumers using digital technology to save energy, reduce cost and increase reliability and transparency [1]-[3].

In brief, smart grid is the use of sensors, communications, computational ability and control in some form to enhance the overall functionality and reliability, and improve the efficiency and quality of the electric power system [1]-[3].

1.4 DIFFERENCES BETWEEN SG & CONVENTIONAL UTILITY GRID

1.4.1 The Conventional Utility Grid

A- Centralized Generation

The conventional utility grid is a centralized system where power flows in one direction, from generation resources through the transmission-distribution system to the customer. Generation may not be located in the same geographic area as the load being served, which can often require transmission from distant locations [7].

B- Utility to customer power flow

Existing utility grids may not include Supervisory Control and Data Acquisition (SCADA) sensors, computing, and communications to monitor grid performance. So they may depend instead on separate reporting systems, periodic studies, and standalone outage management applications [8].

C- Periodic Billing

Information to the customer is generally limited to a periodic bill for services which is consumed in a prior time period or billing cycle. Utility web sites may not provide customers with access to their usage data. Energy usage is usually presented as an aggregate kWh value for a specific billing cycle, which may not align with monthly calendar boundaries [8].

1.4.2 Smart Grid

I- Power Generation

A- Generation Alternatives

The first step to transform the existing grid into a SG requires the addition of generation options throughout the grid at bulk power transfer points, substations, other distribution locations and on the customer side [8].

B- Bi-directional Power flows between the utility and the customer

Adding generation nodes throughout the grid allows power sources to be located closer to their point of use, reducing investment in transmission and distribution, and in many cases reducing energy losses. Implementation of widespread, smaller generation resources diversifies supply, reduces risks of major outages, and improves overall reliability [8].

C- Sensors and switches in transmission and distribution system

Sensors, remote monitoring, automated switches, reclosers, upgraded capacitor banks, and other equipment may be integrated into the grid to provide end-to-end monitoring and control of the transmission and distribution network [8].

D- Smart appliances

On the customer side, equivalent automated control systems and smart appliances with embedded price, event-sensing and energy management capability. Sensors provide the information to better grid operation, while control devices provide options to better system operation [8].

E- Power Quality

Not all commercial enterprises, and certainly not all residential customers, need the same quality of power. SG supplies varying grades of power and supports variable pricing accordingly. The cost of premium power-quality (PQ) features can be included in the electrical service contract. Advanced control methods monitor essential components; enabling rapid diagnosis and precise solutions to PQ events, which arise from lightning, switching surges, line faults and harmonic sources. A smart grid also helps in buffering the electrical system from irregularities caused by consumer electronic loads [8], [9].

II- Communications and Information

The last necessary stage for creating a SG is the addition of communication systems to support information transmission that fully link both the utility and customer sides of the grid [8], [9].

The National Institute of Standards and Technology (NIST) Smart Grid Conceptual Model is shown in Fig.1.1. It provides a high-level framework for the smart grid that defines seven important domains: Bulk Generation, Transmission, Distribution, Customers, Operations, Markets and Service Providers. It shows all the communications and energy/electricity flows connecting each domain and how they are interrelated. Each individual domain is itself comprised of important smart grid elements that are connected to each other through two-way communications and energy/electricity paths. These connections are the basis of the future, intelligent and dynamic power electricity grid [7].

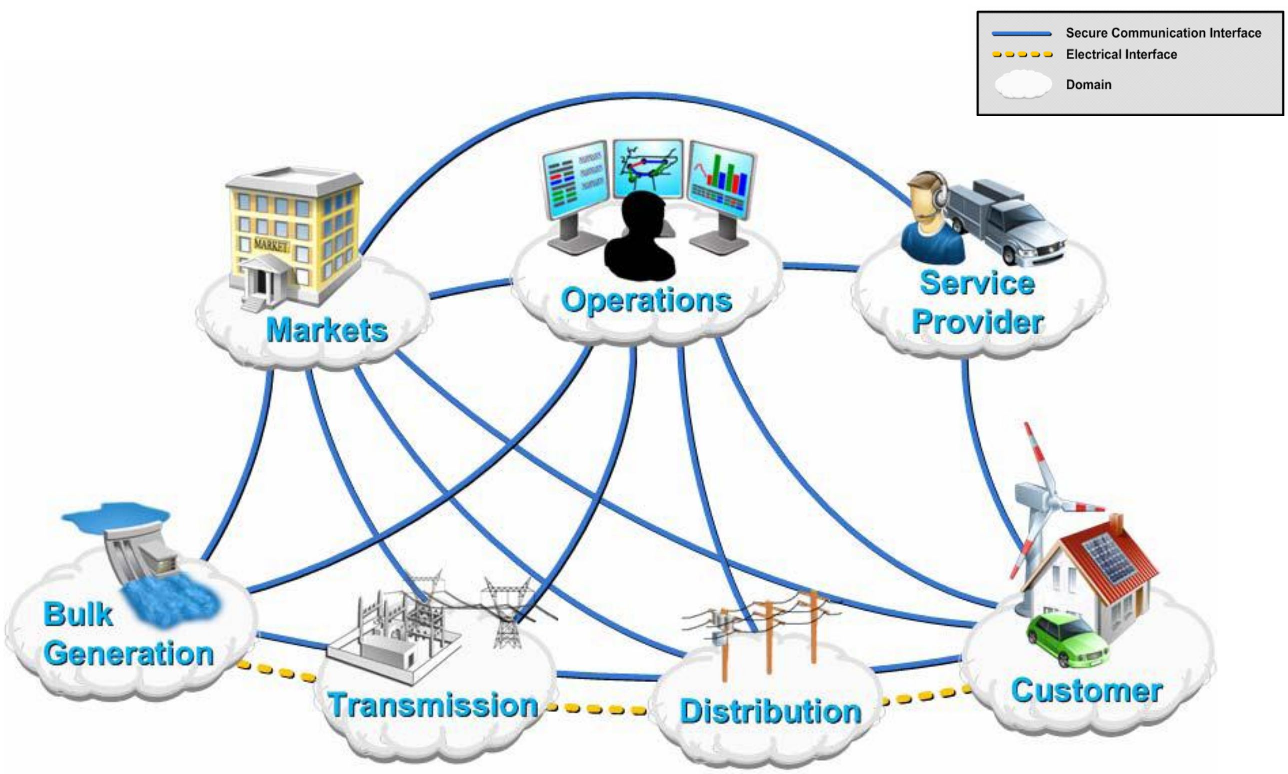

Fig.1.1 Smart Grid Conceptual Model (NIST)

The NIST Smart Grid Conceptual Model helps stakeholders understand the building blocks of an end-to-end smart grid system, from Generation to (and from) Customers. It explores the interrelation between these smart grid segments. IEEE deals with the smart grid as a large "System of Systems," where each NIST smart grid domain is expanded into three smart grid foundational layers: (i) the Power and Energy Layer, (ii) the Communication Layer and (iii) the IT/Computer Layer. The communication and IT/ Computer Layers are enabling infrastructure platforms of the Power and Energy Layer that makes the grid smarter [7].

On the utility side of the grid, sensors will be integrated with high speed switches and expert systems to automatically balance power flows, isolate and re-route power around disturbances , report outages, and continuously update system operators with weather, demand, and performance data from throughout the system [8].
On the customer side of the grid, near real-time meter data will be available. So customers can better understand how individual appliances and behavior impact their energy usage and costs. Broadcast price, reliability and event signals may be monitored directly by smart appliances or through home automation gateways, responding automatically to customer preferences to defer or reduce usage during high-priced or constrained reliability periods [8].

1.5 IMPORTANCE OF THE SMART GRID

1.5.1 Economic Competitiveness

Smart Grid provides higher quality power that will save money, which is wasted from outages and enabling electricity markets to flourish.

Correctly-designed and operated markets efficiently reveal cost-benefit tradeoffs to consumers by creating an opportunity for competing services to bid. A smart grid accounts for all the fundamental of dynamics of the value/cost relationship. Some of the independent grid variables that must be explicitly managed are energy, capacity, location, time, rate of change, and quality. Markets can play a major role in the management of these variables. Regulators, owners/operators, and consumers need the flexibility to modify the rules of business to suit operating and market conditions [8].

1.5.2 Energy Independence

A smart grid accommodates not only large, centralized power plants, but also the growing array of Distributed Energy Resources (DER). DER integration will increase rapidly all along the value chain, from supplier, marketers to customers. Those distributed resources will be diverse and widespread, including renewable, distributed generation and energy storage [8].

1.5.3 Empowerment of the Consumer

With Smart Grids consumers are motivated to actively participate in operations of the grid and have more control over the source of their power and the price they pay for it.

Consumers become an integral part of the electric power system. They help balance supply and demand, and ensure reliability by modifying the way they use and purchase electricity. These modifications come as a result of consumers having choices that motivate different purchasing patterns and behavior. These choices involve new technologies, new information about their electricity use, and new form of electricity pricing and incentives [8].

1.5.4 Environmental Sustainability

Smart Grid offers a genuine path toward significant environmental improvement and reduction of greenhouse gas emissions. Energy is shifted to off-peak periods, therefore fewer power plants will need to be built, and electricity needs will be met by cleaner and more efficient sources.

Resiliency refers to the ability of a system to react to events such that problematic elements are isolated while the rest of the system is restored to normal operation. These self-healing actions result in reducing interruption of service to consumers and help service providers in better management of the delivery infrastructure. A smart grid responds resiliently to attacks, whether organized by others or the result of natural disasters. These threats include physical attacks and cyber attacks. A smart grid addresses security from the outset, as a requirement for all the elements and ensures an integrated and balanced approach across the system [8].

1.5.5 Efficiency

Utilities can run more efficiently and route power more efficiently without overloading the grid. It compromises its reliability by analyzing real-time information about where power is needed and what energy sources are available.

A smart grid applies the latest technologies to optimize the use of its assets. For example, optimized capacity can be attainable with dynamic ratings, which allow assets to be used at greater loads by continuously sensing and rating their capacities. Maintenance efficiency involves attaining a reliable state of equipment or “optimized condition”. This state is attainable with condition-based maintenance, which signals the need for equipment maintenance at precisely the right time. System-control devices can be adjusted to reduce losses and eliminate congestion. Operating efficiency increases when selecting the least-cost-energy-delivery system which is available through these adjustments of system-control devices [8], [9].

1.6 LITERATURE REVIEW

1.6.1 First Cities with SG

A century ago, most industrialized countries built the electric power grid which has been growing ever since in its capacity and size. In the last few decades, the grid has been technologically upgraded with automation and monitoring schemes. New techniques have been implemented to modernize the grid. In the last two decades there was a high concentration on the integration of renewable energy sources into the grid in order to minimize environmental concerns [4]. The earliest, and still largest, example of a smart grid is the Italian system which is installed by EnelS.p.A. of Italy. In 2005, the Telegestore project was highly unusual in the utility world because the company designed and manufactured their own meters. They had their own system integration, and developed their own software. The Telegestore project is widely regarded as the first commercial scale use of smart grid technology to the home. It delivers annual savings of 500 million euros at a project cost of 2.1 billion euros [15]-[20].

In the US, Texas has been working on building its smart grid since 2003, when its utility first replaced 1/3 of its manual meters with smart meters that communicate via a wireless mesh network. It has managed 1700,000 real-time devices (smart meters, smart thermostats, and sensors across its service area) till 2009, servicing 1 million consumers and 43,000 businesses. Boulder, Colorado has completed the first phase of its smart grid project in August 2008. Both systems use the smart meter as a gateway to the Home Automation Network (HAN) that controls smart sockets and devices. Some HAN designers prefer decoupling control functions from the meter, out of concern of future mismatches with new standards and technologies available from the fast moving business segment of home electronic devices [15]-[20].

Hydro One, in Ontario, Canada is in the midst of a large-scale Smart Grid initiative, deploying a standards-compliant communications infrastructure from Trilliant. By the end of 2010, the system has served 1.3 million customers in the province of Ontario. The initiative won the "Best AMR Initiative in North America" award from the Utility Planning Network [15]-[20].

1.6.2 The Evolution of SG with Phasor Measurement Units

The evolution of SG is traced to several innovations such as the installation of power system stabilizers, phase shifting transformers, FACT's and Phasor Measurement Units (PMU's) with the aim of achieving better control of the grid and minimizing power losses [6]. In the middle of the 1980's, many electrical engineering researchers have paid a great attention to the application of PMU's in power system monitoring and control.

PMU's are high speed units distributed throughout a transmission network, which can obtain phasor measurements by synchronizing with each other through the Global Positioning Satellites (GPS). This network of PMU's forms a Wide Area Monitoring System (WAMS) that can provide real-time monitoring on a regional and national scale [5], [6].

1.6.3 The Advancement of Smart Grid

The United States Department of Energy proposes that five types of technology will drive the advancement of smart grids which are:

1- Integrated communications, connecting components to open architecture for real-time information and control, allowing every part of the grid to both ‘talk’ and ‘listen’.
2- Sensing and measurement technologies, to support faster and more accurate response such as remote monitoring, time-of-use pricing and demand-side management.
3- Advanced components, to apply the latest research in superconductivity, storage, power electronics and diagnostics.
4- Advanced control methods, to monitor essential components, enabling rapid diagnosis and precise solutions appropriate to any event.
5- Improved interfaces and decision support, to amplify human decision-making, transforming grid operators and managers quite literally into visionaries when it comes to seeing into their systems [9], [15].

1.6.4 Governmental Policies for SG Implementation and Development

Many countries realized the importance and benefits of the development and implementation of SG, so they put new policies for this purpose.

A- Canada

In 2006 the government of Ontario, Canada, through the Energy Conservation Responsibility Act, has mandated the installation of Smart Meters in all Ontario businesses and households by 2010 [15].

B- China

China builds a WAMS and by 2012 plans, PMU sensors should be installed at all generators of 300 megawatts substations of 500 kilovolts and above. All generation and transmission is tightly controlled by the state, so standards and compliance processes are rapid. Requirements to use the same PMUs from the same Chinese manufacturer and stabilizers conforming to the same state specified are strictly adhered to. All communications are via broadband using a private network, so data flows to control centers without significant time delays [15].

C- European Union

Development of smart grid technologies is part of the European Technology Platform (ETP) initiative and is called the Smart Grids Technology platform. The Smart Grids European Technology Platform for electricity networks of the future began its work in 2005. Its aim is to formulate and promote a vision for the development of European electricity networks looking towards 2020 and beyond [15].

D- United States

Support for smart grids became federal policy with passage of the Energy Independence and Security Act of 2007. The law, Title13, sets out $100 million in funding per fiscal year from 2008–2012. It establishes a matching program to states, utilities and consumers to build smart grid capabilities, and create a Grid Modernization Commission to assess the benefits of Demand response and to recommend needed protocol standards. The Energy Independence and Security Act of 2007 directs the National Institute of Standards and Technology to coordinate the development of smart grid standards, which FERC would then promulgate through official rulemakings. Smart grids received further support with the passage of the American Recovery and Reinvestment Act of 2009, which set aside $11 billion for the creation of a smart grid. In 2009, President Barack Obama asked the United States Congress "to act without delay" to pass legislation that included doubling alternative energy production in the next three years and building a new "smart grid". On April 13th, 2009, George W. Arnold was named the first National Coordinator for Smart Grid Interoperability [15].

1.6.5 Smart Grid Previous Studies

Together with the advantages of intelligent technologies, SG has become a topical research area in recent years. Considering the abundant and complex technologies it contains, the development of SG should be divided into several stages, and a well designed development strategy is required to improve the transition from current power grid to newly SG step by step. Facing outstanding challenges and problems, city power grid resorts to intelligent technologies and management much more eagerly, a concept of Smart City Grid (SCG) was proposed in [10], stating its advantages and the significant relationships between SG and SCG.

Because a modern power grid needs to become smarter in order to provide an affordable, reliable, and sustainable supply of electricity, considerable activity has been carried out in the United States and Europe to formulate and promote a vision for the development of future smart power grids. However, the majority of these activities emphasized only the distribution grid and demand side leaving the big picture of the transmission grid in the context of smart grids unclear. A vision for the future of smart transmission grids was presented in [11], in which their major features were identified. In this vision, each smart transmission grid was regarded as an integrated system that functionally consists of three interactive, smart components, which have smart control centers, smart transmission networks, and smart substations. The features and functions of each of the three functional components were described, as well as the enabling technologies to achieve these features and functions [11].

An investigation was carried out in [12] on how the electric power system generation expansion plans change based on (i) the availability of Smart Grid technologies improving the performance of the distribution system,or (ii) the availability of the technologies shifting the demand from peak hours to off-peak hours. Multi-objective multi-period generation expansion planning problems were solved to determine the electricity generation technology options to be added, It also determine the location at which the technology should be constructed to simultaneously minimize multiple objectives such as cost, and air emissions, e.g., CO_2. Unmet demand was also considered in the objective function so that the proposed approach considers the reliability of the system. The approach used explicitly considers availability of the system components and operational dispatching decisions. Monte Carlo simulation was used to generate component availability scenarios. Then, the mixed-integer optimization problem was solved to find optimum expansion solutions considering these scenarios [12].

SGs provide opportunities to improve the reliability, efficiency, and sustainability of the existing electric power infrastructure. The development of such a smart power grid requires multidisciplinary research and engineering efforts. More importantly, it needs intelligence and innovations in virtually every aspect of electrical power engineering.

Computational Intelligence (CI) is an adaptive and flexible method which has been applied to solve many challenging real-world problems. A comprehensive overview on various CI applications in the context of SGs was provided in [13]. The CI paradigm provided promising candidate solutions to deliver intelligence to a power grid.

A generic and comprehensive Distribution Optimal Power Flow (DOPF) model was presented in [19] that can be used by Local Distribution Companies (LDCs) to integrate their distribution system feeders into a Smart Grid. The three-phase DOPF framework incorporates detailed modeling of distribution system components and considers various operating objectives. Phase specific and voltage dependent modeling of customer loads in the three-phase DOPF model allows LDC operators to determine realistic operating strategies that can improve the overall feeder efficiency. The proposed distribution system operation objective was based on the minimization of the energy drawn from the substation while seeking to minimize the number of switching operations of load tap changers and capacitors. A method for solving the three-phase DOPF model by transforming the mixed-integer non-linear programming problem to a non-linear programming problem was proposed which reduces the computational burden and facilitates its practical implementation and application.
Two practical case studies were presented in this research, including a real distribution feeder test case, to demonstrate the features of the proposed methodology. The results illustrated the benefits of the proposed DOPF in terms of reducing energy losses while limiting the number of switching operations [14].

1.6.6 History and Background of Power Systems Analysis

A- Application of Computers

The planning, design, and operation of a power system require continual and comprehensive analyses to evaluate current system performance and to establish the effectiveness of alternative plans for system expansion.

The computational work to determine power flows and voltage levels resulting from a single operating condition for even a small network is all but insurmountable if performed by manual methods. The need for computational aids led to the design of a special purpose analog computer (ac network analyzer) as early as 1929. It provided the ability to determine flows and voltages during normal and emergency conditions and to study the transient behavior of the system resulting from fault conditions and switching operations.

The earliest application of digital computers to power system problems dates back to the late 1940s. Most of the early applications were limited in scope because of the small capacity of the punched card calculators in use during that period. Large-scale digital computers became available in the mid-1950s. The initial success of load flow programs led to the development of programs for short-circuit and stability calculations.

Nowadays, the digital computer is an indispensable tool in power system planning, in which it is necessary to predict future growth and simulate day-to-day operations over periods of twenty years or more [21].

As computer technology has advanced, so has the complexity of industrial and commercial power systems. These power systems have grown in recent decades with capacities far exceeding that of a small electric utility system.

Today's intensely competitive business environment forces plant or building management personnel to be very aware of the total owning cost of the power distribution system. Therefore, they demand assurances of maximum return on all capital investments in the power system. The use of digital computers makes it possible to study the performance of proposed and actual systems under many operating conditions. Answers to many questions regarding impact of expansion on the system, short-circuit capacity, stability, load distribution, etc., can be intelligently and economically obtained [21].

B- Load Flow Calculations

One of the most common computational procedures used in power system analysis is the load flow calculation. The planning, design, and operation of power systems require such calculations to analyze the steady-state (quiescent) performance of the power system under various operating conditions and to study the effects of changes in equipment configuration.

These load flow solutions are performed using computer programs designed specifically for this purpose. The basic load flow target is to calculate the load power consumption at all buses of a known electric power system configuration and the power production at each generator, find the power flow in each line and transformer of the interconnecting network and the voltage magnitude and phase angle at each bus.

Analyzing the solution of this problem for numerous conditions helps ensure that the power system is designed to satisfy its performance criteria while incurring the most favorable investment and operation costs [21].

Some of the uses of load flow studies are to determine component or circuit loadings, steady-state bus voltages, reactive power flows, transformer tap settings, system losses, generator exciter/regulator voltage set points and performance under emergency conditions.

Modern systems are complex and have many paths or branches over which power can flow. Such systems form networks of series and parallel paths. Electric power flow in these networks divides among the branches until a balance is reached in accordance with Kirchhoff's laws [21].

Computer programs to solve load flows are divided into two types, static (offline) and dynamic (real time). Most load flow studies for system analysis are based on static network models. Real time load flows (online) that incorporate data input from the actual networks are typically used by utilities in SCADA systems. Such systems are used primarily as operating tools for optimization of generation, var control, dispatch, losses, and tie line control [21].

Because the load flow problem pertains to balanced, steady-state operation of power systems, a single-phase, positive sequence model of the power system is used. Three-phase load flow analysis software is available; but it is not normally needed for routine industrial power system studies.

A load flow calculation determines the state of the power system for a given load and generation distribution. It represents a steady-state condition as if that condition had been held fixed for some time. In actuality, line flows and bus voltages fluctuate constantly by small amounts because loads change constantly as lights, motors, and other loads are turned on and off. However, these small fluctuations can be ignored in calculating the steady-state effects on system equipment [21].

As the load distribution, and possibly the network, will vary considerably during different time periods, it may be necessary to obtain load flow solutions representing different system conditions such as peak load, average load, or light load. These solutions will be used to determine either optimum operating modes for normal conditions, such as the proper setting of voltage control devices, or how the system will respond to abnormal conditions, such as outages of lines or transformers. Load flows form the basis for determining both when new equipment additions are needed and the effectiveness of new alternatives to solve present deficiencies and meet future system requirements [21].

The load flow model is also the basis for several other types of studies such as short-circuit, stability, motor starting, and harmonic studies. The load flow model supplies the network data and an initial steady-state condition for these studies [21]. Load flow calculations carried out in this research is described in Chapter (2).

1.6.7 Particle Swarm Optimization (PSO)

Particle Swarm Optimization (PSO) is an advanced Artificial Intelligence (AI) technique that can be considered as a member of the wide category of swarm intelligence [34]. It was used to solve a wide variety of optimization problems such as artificial neural networks training [41], [42], and function minimization [43], [44]. PSO was recently adopted by a lot of researchers due to its superiority to other Evolutionary Algorithms (EA) regarding its memory, and computational time requirements. It relies mainly on very simple mathematical operations, and requires very few lines of computer code to implement [45].

The PSO technique is discussed later in details in Chapter (3).

1.7 THESIS OBJECTIVES

The main objectives of this work are as follows:

- Targeting a smart electrical power flow control through both transmission and distribution systems especially at fault occurrence.
- Determining the alternative power paths that can feed a critical load during fault occurrence.
- Developing a Particle Swarm Optimization (PSO) technique for optimizing the angle of the bus voltage at constant voltage magnitude to optimize power flow in the electrical power system and hence achieve better energy management in the smart grid.
- Testing the performance of the proposed technique on the IEEE14-bus system, IEEE 57-bus system and an Offshore Platform electrical system.

1.8 THESIS OUTLINES

The thesis is composed of five chapters organized in the following form:

Chapter (1) is an introductory chapter introducing the meaning of a smart grid, how the smart grid differs from the existing utility grid, the need for implementation of smart grids and a historical background of smart grids.

Chapter (2) discusses the power flow concept on a simplified two-bus network which is the basis for load flow calculations for other systems. Power losses in electrical systems are also discussed, including losses in both transmission and distribution systems and how to minimize these losses. Electrical Transient and Analysis Program (ETAP) is introduced and how it is implemented in electrical systems studies in general and in our research in particular.

Chapter (3) introduces an application for a Particle Swarm Optimization (PSO) technique. It is used to optimize the power flow of a critical load through an alternative power path in case of fault occurrence. It works to achieve maximum power continuity. The chapter starts with an introduction and literature survey about Artificial Intelligence (AI) especially PSO. A Matlab program for the proposed technique is developed and tested on the power continuity problem of IEEE 14-bus standard system, IEEE 57-bus standard system and Offshore Platform electrical system.

Chapter (4) presents an illustration for the whole developed work. It is tested on three studied systems, which are the IEEE 14-bus standard system, the IEEE 57-bus standard system and the offshore platform electrical system. The results and analysis are also discussed in this chapter.

Chapter (5) presents a summary of the conclusions and achievements of this work.

In addition to the mentioned chapters, the list of references and an appendix are included in the thesis.

The **Appendix** includes the used data of the IEEE test systems and the Offshore Platform electrical system.

CHAPTER TWO

POWER FLOW MODELING AND ANALYSIS

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POWER FLOW MODELING AND ANALYSIS

2.1 GENERAL

In this chapter, the power flow concept is discussed on a simplified two-bus network which is the basis for load flow calculations for other systems. Power losses in electrical systems are also discussed, including losses in both transmission and distribution systems and how to minimize these losses.

At the end of this chapter, Electrical Transient and Analysis Program (ETAP) is introduced and how it is implemented in electrical system studies in general and in our research in particular.

2.2 ELECTRICAL POWER SYSTEM ANALYSIS

The bus-total power calculations and the transmitted power equations are explained on two-bus system and then generalized for the studied systems (IEEE 14-bus standard system, the IEEE 57-bus standard system and the Offshore Platform electrical system).

Figure 2.1 represents two buses with voltage phasors $V_i \angle \delta_i$ and $V_j \angle \delta_j$. The two buses are connected through a transmission line with impedance Z = R + jX. The current phasor $I \angle \beta$ flows through the line from bus-i to bus-j. The phasor diagram of the two-bus system voltages and currents is presented in Fig. 2.2, in which

$$V_j \angle \delta_j = V_i \angle \delta_i - \Delta V \tag{2.1}$$

$$\Delta V = I \angle \beta \, (R + jX) \qquad \text{(Assume no charging current)} \tag{2.2}$$

In power system analysis, the real and reactive power injected to each bus (P_i, Q_i), the real and reactive power flow from bus i to bus j (P_{ij}, Q_{ij}) can be calculated, affecting the bus voltages magnitudes and angles.

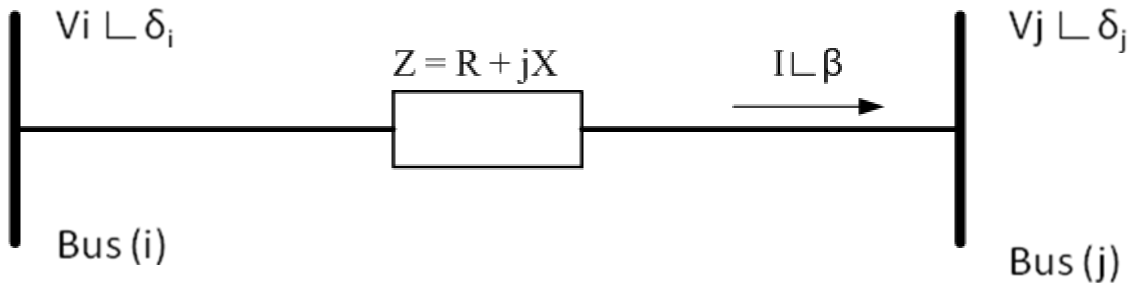

Fig. 2.1 Simplified two-bus network

The calculated functions for these power quantities are given by

$P_i = \Sigma\,(V_i\,V_j\,Y_{ij}\cos(\delta_i-\delta_j+\theta_{ij}))$, for j = 1, 2, …., N (2.3)

$Q_i = \Sigma\,(V_i\,V_j\,Y_{ij}\sin(\delta_i-\delta_j+\theta_{ij}))$, for j = 1, 2, …., N (2.4)

$P_{ij} = V_i\,V_j\,Y_{ij}\cos(\delta_i-\delta_j+\theta_{ij}) - V_i^2\,Y_{ij}\cos(\theta_{ij})$ (2.5)

$Q_{ij} = V_i\,V_j\,Y_{ij}\sin(\delta_i-\delta_j+\theta_{ij}) - V_i^2\,(Y_{ij}\sin(\theta_{ij}) + B_{capij})$ (2.6)

where;

Y_{ij} : is the admittance magnitude of the line connected bus i and bus j.

θ_{ij} : is the admittance angle of the line connected bus i and bus j.

δ_i : is the angle of the bus i voltage.

B_{capij} : is the total line charging susceptance.

N : is the total number of the network buses.

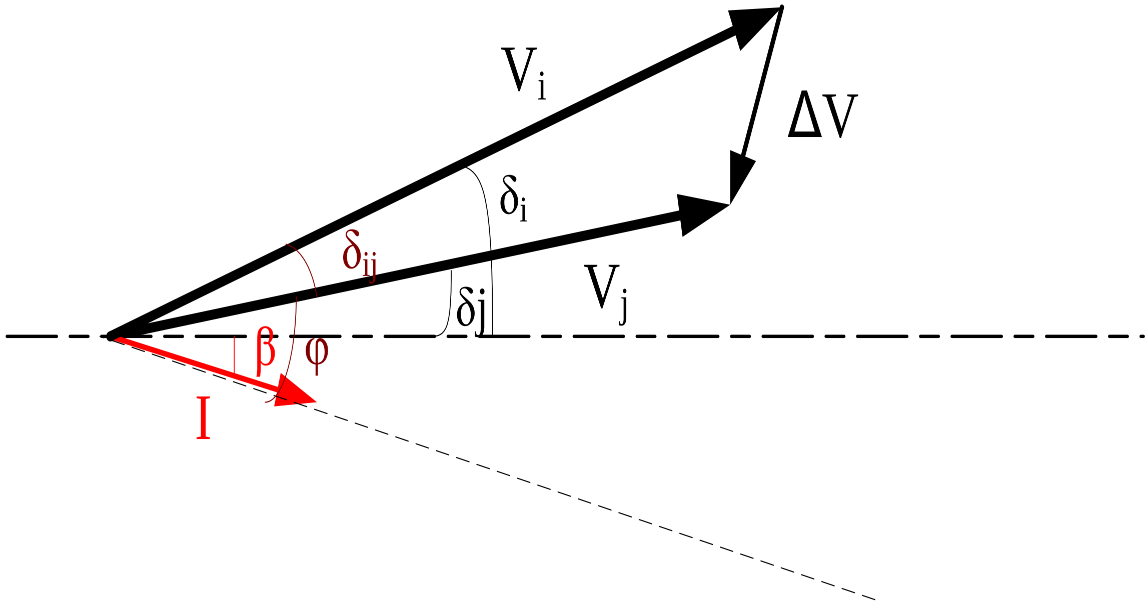

Fig. 2.2 Phasor diagram of the simplified two-bus network

2.3 POWER LOSS CALCULATIONS

In electrical power systems there are always electrical power losses. These power losses are not desirable to be large in the system, as this will affect the overall quality of the power delivered by the network and the reliability of the electrical system. So the power loss optimization and control are considered from the major topics in power system research. It leads the researchers to continuously search for new methods to reduce the power losses in the electrical network [9].

One of the main targets from the developed smart grid, in this research, is minimization the grid power losses and maximization the delivered power to customers.

2.3.1 Losses in Transmission Lines

The power system network that weaves about the United States is by far the largest interconnection of a dynamic system in existence to date. Like all other systems, no matter how carefully the system is designed, losses are present and must be modeled before an accurate representation of the system response can be calculated. Due to the size of the area that the power system serves, the majority of the system components are dedicated to power transmission [22].

The basic rule of calculating power loss in the network transmission lines is

$$P_{loss} = I^2R \tag{2.7}$$

Where:

P_{loss}: is the transmission line power loss

I: is the current flowing in the transmission line

R: is the resistance of the transmission line.

And it can be converted to the following form:

$$P_{loss}= (\Delta|V|/Z)^2 R \tag{2.8}$$

Where:

ΔV: is the voltage difference between any two consecutive connected buses.

$$\Delta V= ((V_i \cos(\theta_i) - V_j \cos(\theta_j))^2 + (V_i \sin(\theta_i) - V_j \sin(\theta_j))^2)^{1/2} \tag{2.9}$$

I- System Parameters

When current flows in a transmission line, the characteristics exhibited are explained in terms of magnetic and electric field interaction. The phenomena that results from field interactions is represented by circuit elements or parameters. A transmission line consists of four parameters which directly affect its ability to transfer power efficiently [25]. These elements are combined to form an equivalent circuit representation of the transmission line which can be used to determine some of the transmission losses.

The parameter associated with the dielectric losses that occur is represented as a shunt conductance [24]. Conductance from line to line or a line to ground accounts for losses which occur due to the leakage current at the cable insulation and the insulators between overhead lines. The conductance of the line is affected by many unpredictable factors, such as atmospheric pressure, and is not uniformly distributed along the line [26]. The influence of these factors does not allow for accurate measurements of conductance values. Fortunately, the leakage in the overhead lines is negligible, even in detailed transient analysis. This fact allows this parameter to be completely neglected.

The primary source of losses, incurred in a transmission system, is in the resistance of the conductors. For a certain section of a line, the power dissipated in the form of useless heat as the current attempts to overcome the ohmic resistance of the line, and is directly proportional to the square of the rms current traveling through the line. It directly follows that the losses due to the line resistance can be substantially lowered by raising the transmission voltage level, but there is a limit at which the cost of the transformers and insulators will exceed the savings [27].

The efficiency of a transmission line is defined as

$$\eta = P_R / P_S = P_R / (P_{R+} P_{Loss}) \qquad (2.10)$$

where P_R is the load received power and P_{loss} is the net sum of the power lost in the transmission system [23].

II- Line Models

Due to the required distances between conductors, the loops formed between outgoing and return conductors are of considerable area. The changing flux in these loops will generate opposing voltages in the conductors which may be of considerable importance; particularly in regard to the voltage regulation of the line [24]. It is often more convenient to model the polyphase transmission system by a single phase representation and to calculate parameters as per mile quantities [25]. With the exception of detailed transient analysis and some calculations for long transmission lines, the models are based on a lumped parameter representation of the system.

A. Short Lines

A transmission line with length less than 50 miles is classified as being a short transmission line. When power is transmitted along a short transmission line the difference in conditions at the sending and receiving ends is due to the series impedance of the line. The impedance is that of a series connection between a resistive and an inductive element shown in Fig. 2.3, V_S and V_R are the sending and receiving line to neutral voltages and I_S and I_R are the sending and receiving currents, respectively. Since there are no shunt components

$$I_R = I_S \tag{2.13}$$

$$V_R = V_S - I_R\,(R+j\omega L) \tag{2.14}$$

The induced voltage in the line is directly proportional to the current and will depend on the physical dimensions of the conductor. The value of this induced voltage, per mile, for a single conductor is given by

$$E_i = 0.00466 \text{ x } f \text{ x } I \text{ x } \log_{10}(1.285.\ d/r) \tag{2.15}$$

where d is the distance between conductors, r is the radius of the conductor, I is the rms amplitude of the current, and f is the frequency of the current in Hertz [24].

The effect of the line impedance and the variation of the load power factor can best be seen in the load regulation of the line.

Percent Regulation = $(|V_{R,NL}| - |V_{R,FL}|) / V_{R,FL} \times 100\%$ (2.16)

where $|V_{R,NL}|$ is the magnitude of the receiving end voltage at no load and $|V_{R,FL}|$ is the magnitude of the receiving end voltage at full load [34].

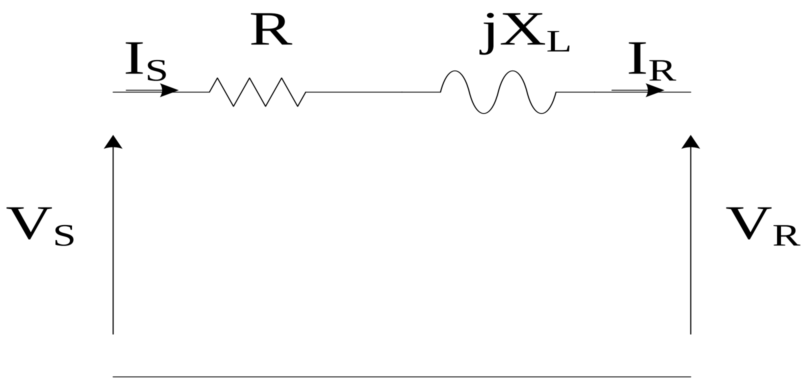

Fig. 2.3 Short transmission line model

B. Medium Lines

Lines of length between 50 and 150 miles are classified as medium length transmission lines. A shunt capacitance is added to the short line model to create the model for medium length lines. This extra element is needed because the increase in line length increases the capacitance, and its effects on the system become significant. The line capacitance between two parallel cylindrical conductors given in micro Farads, per mile, is

$C= 0.0194 / \log_{10} (a + a^2 -1)^{1/2}$ (2.17)

where a is the distance between the conductors divided by the diameter of the conductor[18]. Typically, the shunt admittance is divided equally and placed at either end of the line. This representation, shown in Fig. 2.4 is known as the nominal π equivalent circuit. By modeling the line in this manner, the receiving end voltages and currents can be obtained using ABCD two port network model parameters which is shown in Fig. 2.5.

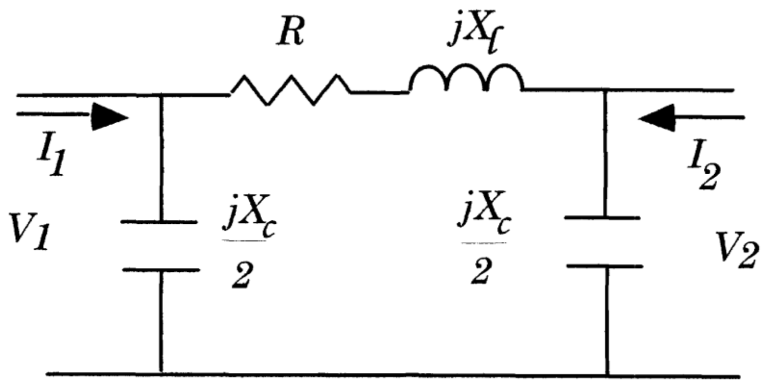

Fig. 2.4 Medium length transmission line model

Where;

$A = D = (ZY/2) + 1$ (2.18)

$B = Z$ (2.19)

$C = Y\,(1 + ZY/4)$ (2.20)

$Y = 1 / 2\, j\omega C$ (2.21)

$Z = R + j\omega L$ (2.22)

$V_1 = (ZY/2 + 1).V_2 + ZI_2$ (2.23)

$I_1 = V_2Y(1 + ZY/4) + (ZY/2 + 1)\, I_2$ (2.24)

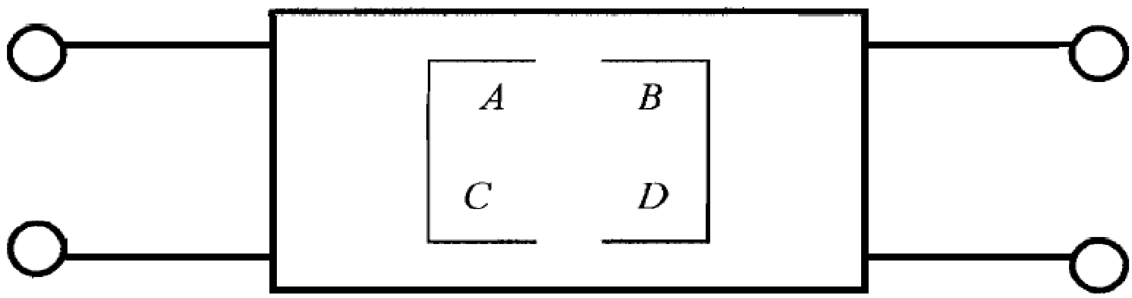

Fig. 2.5 Two port network and ABCD parameters

$V_1 = AV_2 + B\, I_2$ (2.25)

$I_1 = CV_2 + D\, I_2$ (2.26)

C. Long Lines

As transmission lines grow in length, the effect of the capacitance becomes more predominant. There is a sizable component of the total current which leads the voltage by 90 degrees. The voltages induced by this current lags the phase current by 90 degrees and produces the charging current [24]. This reduces the necessary size of the sending voltage. The effect is most noticeable when the lines are subjected to very light loads. The long line model is similar to that of the medium line, The difference is that the long line is represented by distributed parameters instead of lumped parameters [26].

2.3.2 Losses in Power Distribution Systems

After electric power generation, the power is sent through the transmission lines to the many distribution centers. The purpose of the distribution system is to take that power from the transmission system and deliver it to the consumers to serve their needs. However, a significant portion of the power that a utility generates, is lost in the distribution process. These losses occur in numerous small components in the distribution system, such as transformers and distribution lines. Due to the lower power level of these components, the losses inherent in each component are lower than those in comparable components of the transmission system. While each of these components may have relatively small losses, the large number of components involved makes it important to examine the losses in the distribution system. These losses typically account for approximately four percent of the total system load [29].
One of the major sources of losses in the distribution system is the power lines which connect the substation to the loads. Virtually all real power that is lost in the distribution system is due to copper losses. Since these losses are a function of the square of the current flow through the line, it should be obvious that the losses in distribution lines are larger at high power levels than they are at lower levels.
Since power loss in the distribution lines can be considered to be entirely due to copper losses, it can be calculated using Equ. (2.7).
It is clear that anything which changes either current or line resistance will affect the amount of power lost in the line.

The primary determining factor for the magnitude of line current is the amount of real and reactive power loading at the end of the line. As the power that is transmitted along the line increases, the current flow through the line becomes larger. Another factor which affects the level of current flow is the operating voltage of the line. For a given real and reactive power load level, (S_L), a high voltage line will have a lower current than a low voltage one.

2.3.3 Methods of Lowering Distribution System Losses

Since distribution losses cost the utilities a sizable amount of penalty, it is necessary to examine the various methods of reducing these losses. Although many ways of lowering losses can be used on existing systems, other methods are easiest to be used during the initial design and installation of a new distribution system. An example of these methods is to carefully select the location of the substation so as to minimize the needed length of distribution lines. Another way is to use as high voltage as for the lines to limit the transmitted current in the lines and transformer windings. Also, the higher resistivity of aluminum means it will have larger losses than an equivalent copper distribution line. Therefore, copper should be used on lines where losses are abnormally high. Other methods, such as high efficiency transformers and shunt capacitor banks, may be easier to install during initial construction than they would be on an existing system.

High efficiency transformers, which use new core types, are beginning to see widespread use in the United States. One example of a more efficient core is that uses amorphous metal. Amorphous metal is formed by rapidly cooling liquid metal. Approximately 60,000 to 70,000 amorphous metal transformers are currently in use, mostly in the United States. Amorphous metal transformers cost 25 to 50% more than silicon iron transformers. They also claim 60 to 70% less losses. Therefore, utilities with high energy costs or those facing new plant constructions would do well to consider them [31]. Perhaps the most common method of reducing system losses is the use of shunt capacitor banks. Capacitors are used to compensate reactive loads in order to provide a highly resistive equivalent load and a near to unity power factor. Hence there is less current flow in the line and lower losses. The capacitors are strategically placed to provide the best voltage support and current reduction. In one case, the use of shunt capacitors reduced distribution system losses by approximately 20 %. However, care must be used when choosing the placement of the capacitor banks. In the above example, the loss reduction was calculated to be less than 5% when the capacitors were equally distributed throughout the system [29], [32].

Another method of minimizing system losses is by reducing the amount of harmonics presented in the system. This can be accomplished by placing filters at each load that produces major non sinusoidal signals. However, these filters cost money and have inherent losses due to the imperfect nature of the components which limit the loss reduction that is achieved.
Utilities may also reduce losses that occur in the distribution system by ensuring that the load is well balanced on all three phases. This will keep the copper losses in the lines and transformers to a minimum.

A final method of reducing distribution system losses is Demand-Side Management (DSM). With DSM, a utility reduces the system loading, especially at peak periods, by turning off certain loads or providing incentives for efficiency. Overall load is reduced by encouraging improved efficiency by consumers with such things as rebates for high efficiency motors, refrigerators, and lighting. Peak load can be reduced by direct load control of such items as air conditioners, hot water heaters, and some industrial loads. DSM has an added benefit in loss reduction because the primary load reduction occurs at peak loading when system copper losses are greatest.

2.4 ELECTRICAL TRANSIENT AND ANALYSIS PROGRAM (ETAP)

2.4.1 General

Electrical Transient and Analysis Program (ETAP) offers a suite of fully integrated electrical engineering software solutions including arc flash, load flow, short circuit, transient stability, relay coordination, cable ampacity, optimal power flow, and more. Its modular functionality can be customized to fit the needs of any project, from small to large power systems. ETAP is the most comprehensive enterprise solution for design, simulation, operation, control, optimization, and automation of generation, transmission, distribution, and industrial power systems [9].

ETAP Smart Grid offers comprehensive applications enabling electrical utilities to plan, coordinate, and safely operate their grid. This real-time system has the ability to manage, control, visualize, optimize, and automate power transmission and distribution [33].

ETAP’s Load Flow module calculates:

- Bus Voltages, Currents & power factors.
- Voltage Drops
- Power Flows throughout the electrical system.

Figure 2.6 represents an example for ETAP simulation. Different elements of an electrical system (such as Generators, busbars, transformers, motors and circuit breakers …etc), are simulated and connected together forming an electrical network that is desired to be studied.

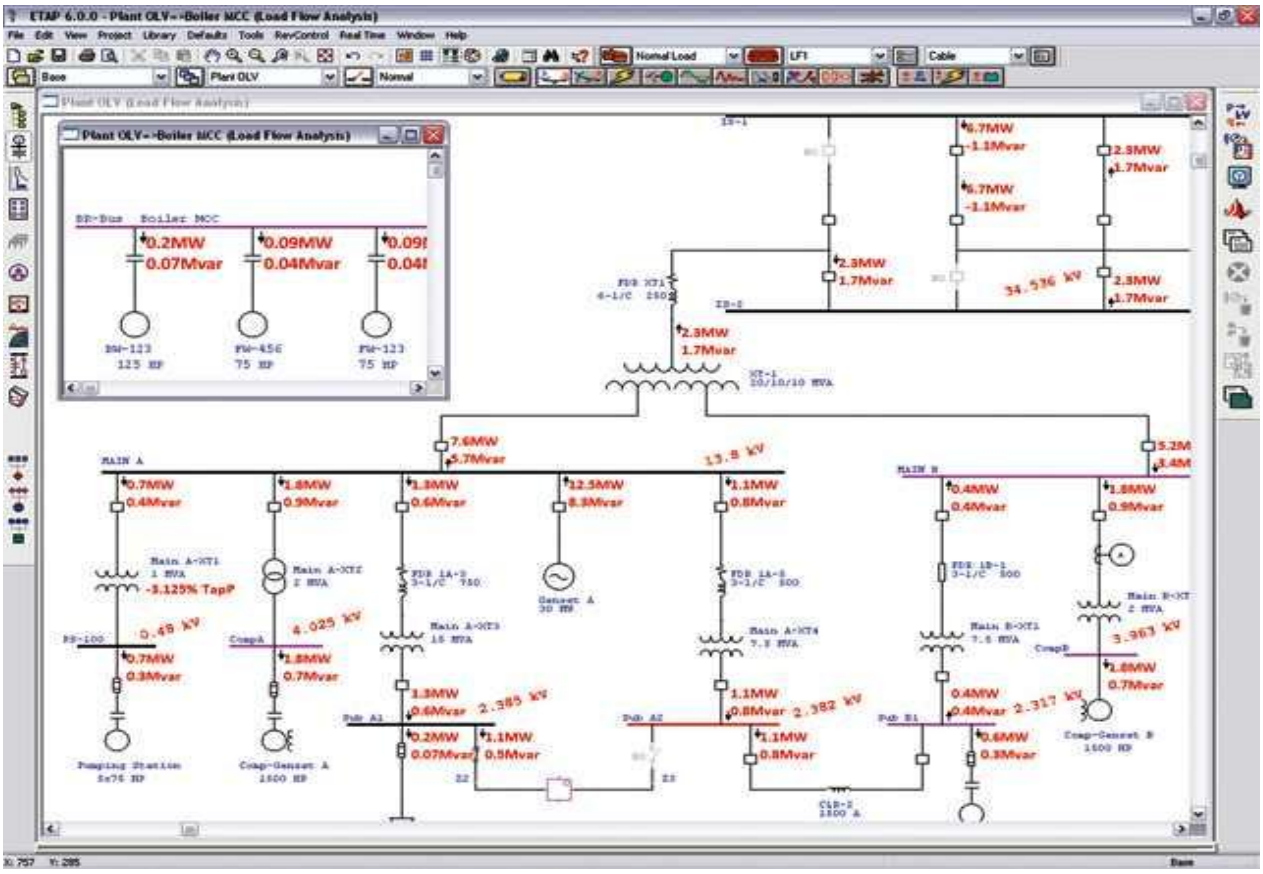

Fig. 2.6 Example for ETAP Simulation Program

2.4.2 Newton Raphson Method

Mainly there are three methods for load flow, which are Gauss Seidel, Newton Raphson and Fast Decoupled. In this research Newton Raphson method is used for load flow analysis [9].

The most widely used power flow solution employs Newton Raphson technique, Newton's method is mathematically superior to the Gauss-Seidel method and is less prone to divergence with ill-conditioned problems due to its quadratic convergence. For large power systems, the Newton Raphson method is found to be more efficient and practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required for each iteration [9].

2.5 THE STUDIED CASES

In our research ETAP is used to simulate two studied IEEE standard systems (14-bus and 57-bus) and the Offshore Platform electrical system. Load flow module of ETAP is used to determine the buses' voltage angles after faulted conditions [described later in Chapter (4)]. ETAP feeds the PSO program with the obtained buses' voltage angles in order to optimize these angles to obtain an optimum path of minimum power loss for the same buses voltages' magnitude and load real power.

The three studied systems are three phase AC power systems, where active and reactive power flows from the generating station to the load through different network buses and branches. The flow of active and reactive power provides a systematic mathematical approach for determination of various bus voltages angles.

Load flow studies have been performed on ETAP based on the International Electrotechnical Commission (IEC) standard. The load flow studies have been performed for a number of cases to cover normal case and abnormal case. Reports are generated from ETAP and the results of the various load flow cases are discussed in details in Chapter 4. Low voltage (LV) connected loads have been grouped as a single lumped load per LV switchboard (per bus-section). One generator is selected as a swing bus in each system. Maximum number of iterations is specified as 100 iterations. Input data was checked and verified to carry the load they are feeding like sizes of generators, transformers and utilities. Also, lengths and impedances of the branches are checked to avoid divergence in the load flow calculation.

The ETAP models of the 3 studied cases are shown below.

2.5.1 ETAP Model of the IEEE 14-Bus System

Figure 2.7 represents the ETAP model for the IEEE 14-Bus system.

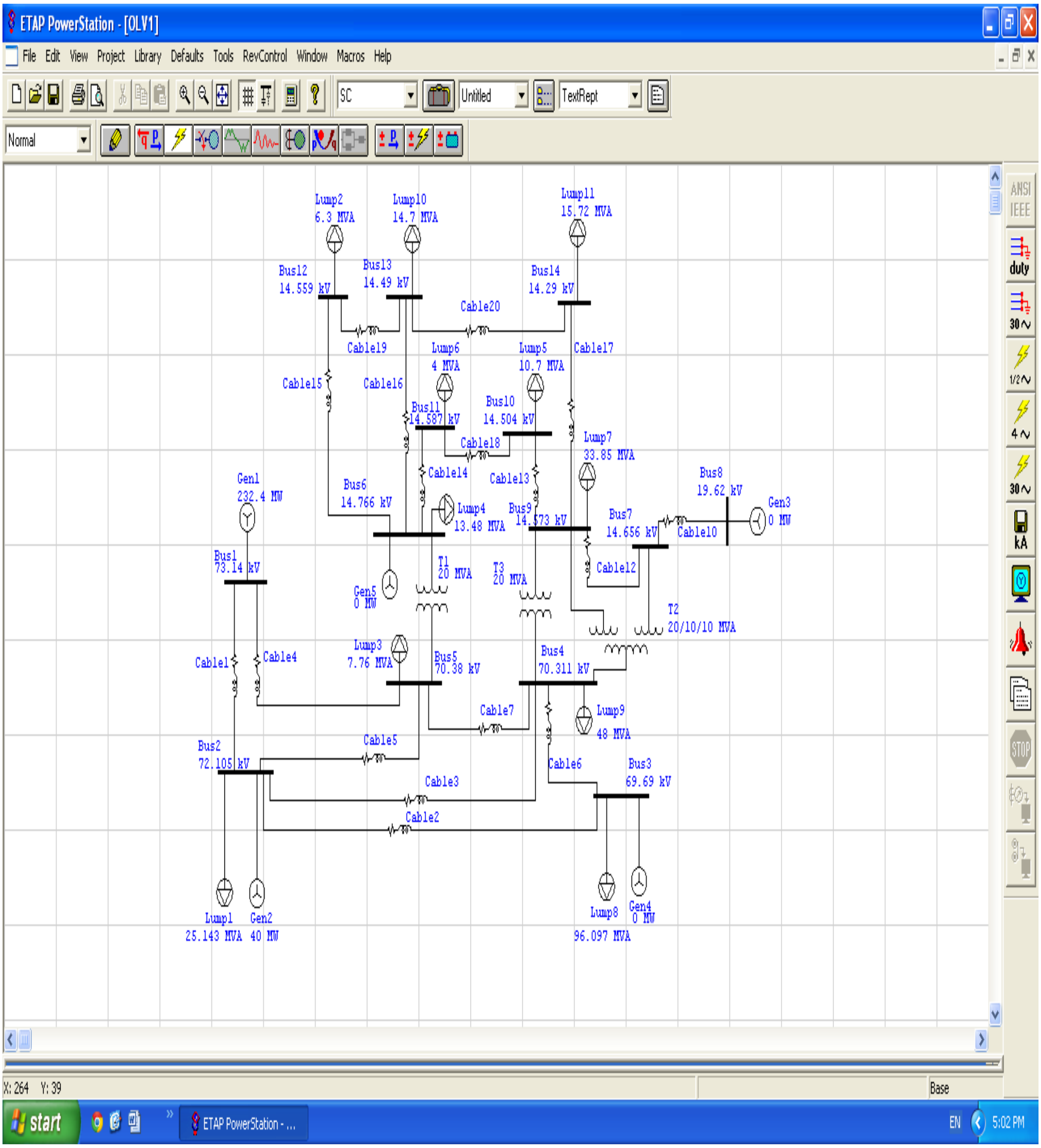

Fig. 2.7 ETAP Simulation of the IEEE 14-bus system

2.5.2 ETAP Model of the IEEE 57-Bus System

Figure 2.8 represents the ETAP model for the IEEE 57-Bus system.

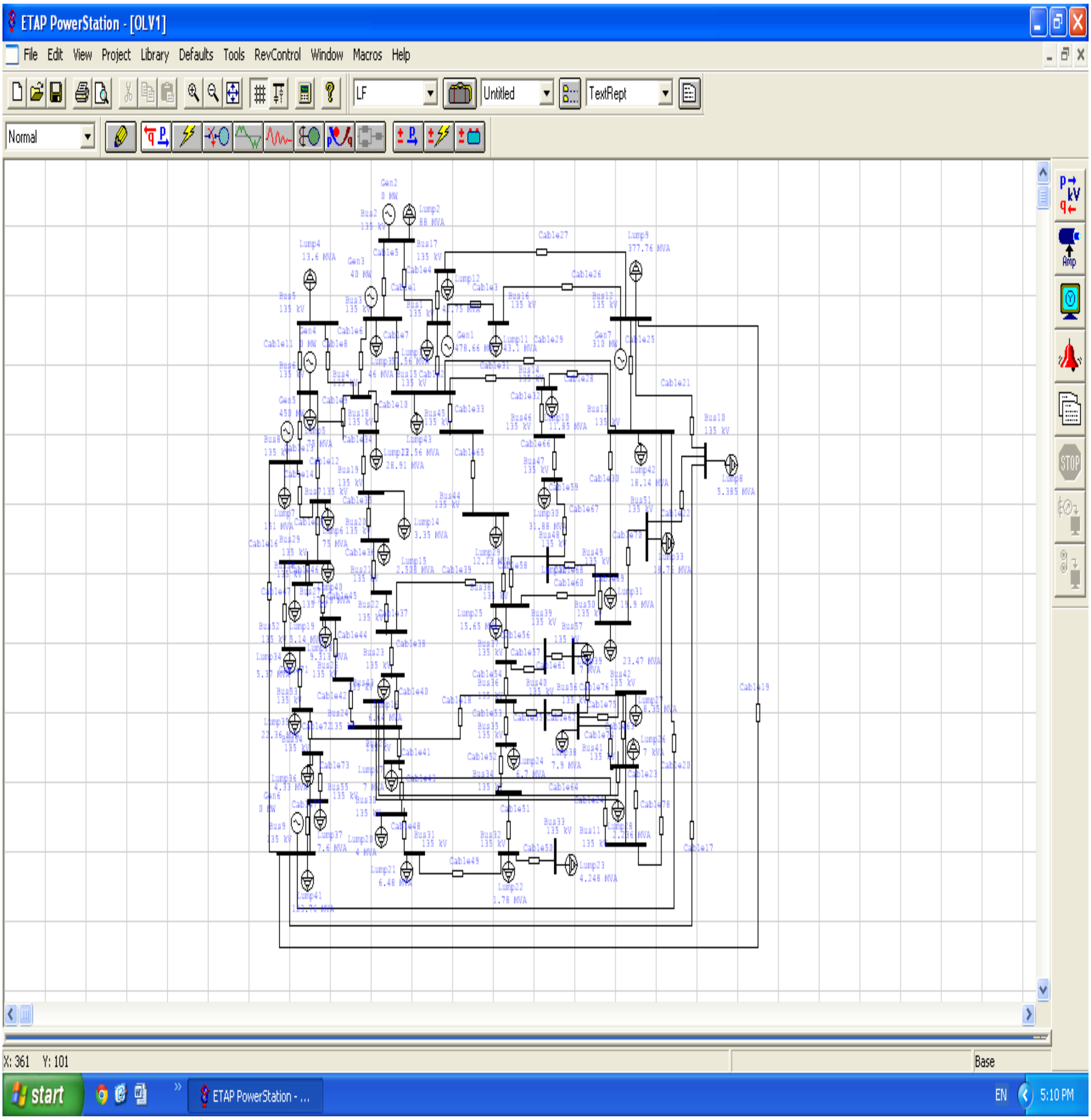

Fig. 2.8 ETAP Simulation of the IEEE 57-bus system

2.5.3 ETAP Model of the Offshore Platform Electrical System

Figure 2.9 represents the ETAP model for the Offshore Platform electrical system.

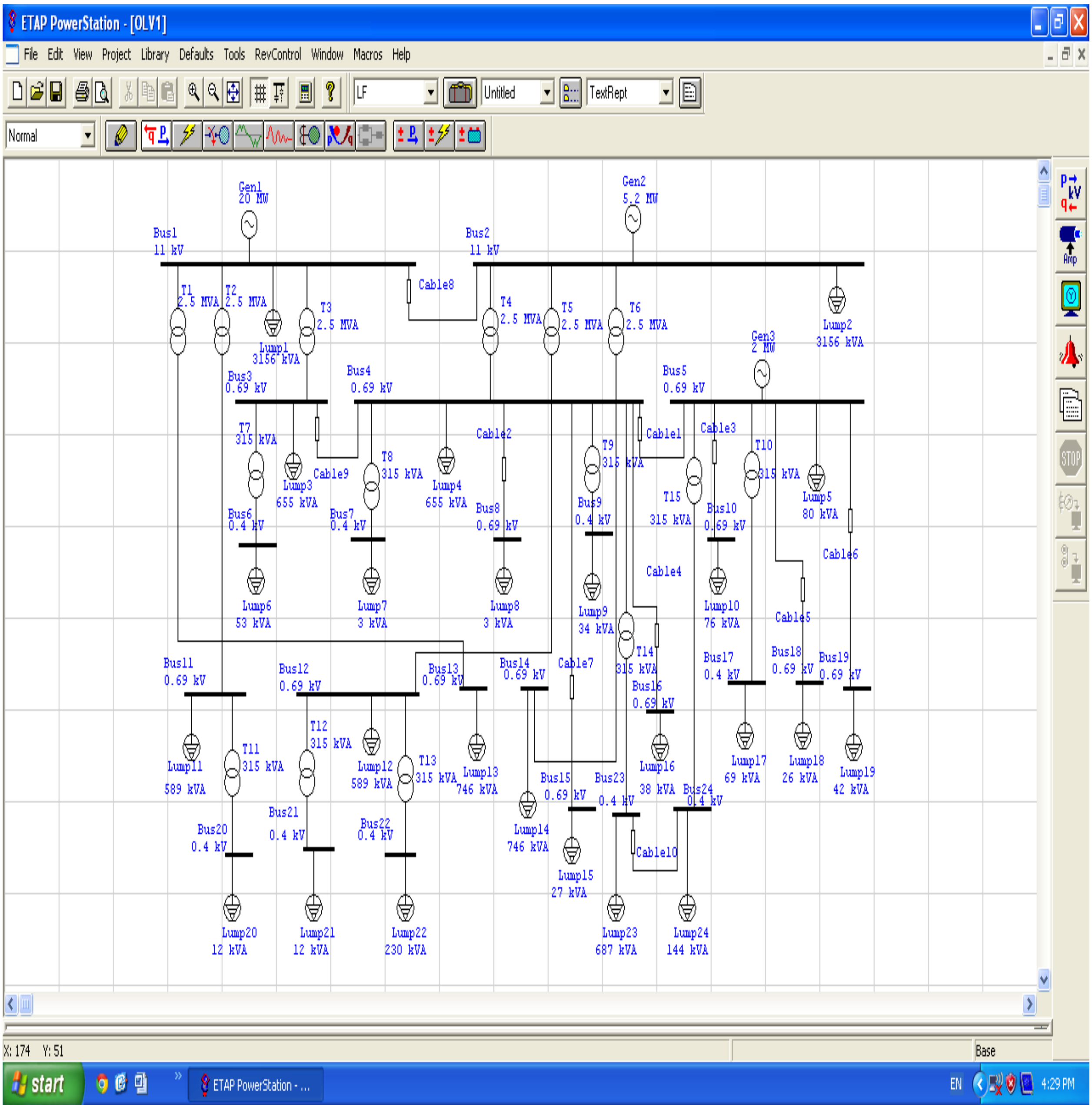

Fig. 2.9 ETAP Simulation of the Offshore Platform electrical system

CHAPTER THREE

PARTICLE SWARM OPTIMIZATION FOR OPTIMIZING POWER FLOW

PARTICLE SWARM OPTIMIZATION FOR OPTIMIZING POWER FLOW

3.1 OVERVIEW

This chapter introduces an application for a Particle Swarm Optimization (PSO) technique. It is used to optimize the power flow of a critical load through an alternative power path in case of fault occurrence. It works to achieve maximum power continuity. The chapter starts with an introduction and literature survey about Artificial Intelligence (AI) especially PSO. A Matlab program for the proposed technique is developed and tested on the power continuity problem of IEEE 14-bus standard system, IEEE 57-bus standard system and Offshore Platform electrical system.

3.2 INTRODUCTION

Over the last few decades, several heuristic techniques have been developed, which are built upon observations of processes in the physical and biological sciences [28]. For example, Genetic Algorithms (GA) which use biological methods such as reproduction, crossover, and mutation to quickly search for solutions to complex problems. Also Simulated Annealing (SA) is an analogy with thermodynamics, specifically with the physical annealing of solids.

More recently, scientists have been turning to insects for ideas that can be used for heuristics. Many aspects of the collective activities of social insects, such as ants, are self-organizing. It means that complex group behaviors are emerged from the interactions of individuals who exhibit simple behaviors by themselves. Examples of these collective activities among ants are finding food and building a nest. The results of self-organization are global in nature, but come about from interactions based entirely on local information. To achieve this, self-organization relies on several components, i.e. positive feedback, negative feedback, amplification of fluctuations, and multiple interactions [34].

Positive feedback comes from basic behavioral rules, such as the recruitment of other insects to forage a food source, which create the necessary structure for collective behavior. Negative feedback is provided by limitations on behavior caused by events such as the depletion of a food source. Amplification of fluctuations refers to the necessity of random events, such as an ant getting lost but finding a new source of food to exploit. Self-organization also requires the multiple interactions of individuals. These interactions can be direct, (for example, physical, visual, or chemical contact) or indirect. Indirect contact can take the form of stigmergy, where one individual performs an action based on what was performed earlier by a different individual. An example of this can be seen from the construction of wasp nests, where certain configurations of existing cells trigger the creation of a new cell.

The expression, swarm intelligence was originally used in the context of cellular robotic systems to describe the self-organization of simple mechanical agents through nearest-neighbor interaction. Recently, it was extended to include any attempt to design algorithms or distributed problem-solving devices inspired by the collective behavior of social insect colonies and other animal societies. This includes the behaviors of certain ants, honeybees, wasps, cockroaches, beetles, and termites. Solutions of many different problems have already been found using heuristics based on the behavior of ants searching for food [34].

According to [35], the principles of swarm intelligence are:

1. **Proximity** : the swarm must be able to perform simple space and time computations.
2. **Quality** : the swarm should be able to respond to quality factors in the environment.
3. **Diverse response** : the swarm should not commit its activities along excessively narrow channels.
4. **Stability** : the swarm should not change its behavior every time the environment alters.
5. **Adaptability** : the swarm must be able to change its behavior, when the computational cost is not prohibitive.

One of these developed algorithms is the Particle Swarm Optimization (PSO) that refers to a relatively new family of algorithms that may be used to find optimal or near-optimal solutions to numerical and qualitative problems. It is believed that to fully understand the PSO algorithm, a return back to the roots of PSO is required. The roots of PSO go back to its older variants of Evolutionary Computation (EC) techniques.

3.2.1 Soft Computing

Soft computing is the name that is being put forth as an alternative to artificial intelligence for the plethora of advanced in information processing technologies that have been emerged in the past decade. This field is characterized by a certain tolerance for imprecision and ambiguity. Expert systems, neural networks, evolutionary computation, fuzzy logic, cellular automata, chaotic systems, wavelets, complexity theory, and anticipatory systems are some of the constituent of soft computing [36]. Soft computing refers to computational tools whose distinguishing characteristic is that they provide approximate solutions to approximately formulated problems.

Whereas, the traditional hard computing considers any impression and uncertainty undesirable. In soft computing, some tolerance for impression and uncertainty is exploited in order to develop more tractable and robust models of systems, at a lower cost and greater economy of communication and computation.

3.2.2 Evolutionary Computation

Evolutionary Computation (EC) defines a number of methods designed to simulate evolution. These methods are all population-based, and rely on a combination of random variation and selection to solve problems [37]. Several approaches exist within the field, including Evolution Strategies (ES), Evolutionary Programming (EP), Genetic Algorithms (GA) and Genetic Programming (GP). Usually the collection of the above algorithms is referred to as Evolutionary Algorithms (EA).

The fundamental principle underlying evolution is one of the optimization concepts, where the goal is survival of the species. This does not mean, however, that EC methods can only be applied to optimization problems. The EC paradigms named above helped in solving problems that were previously considered computationally intractable. Several categories have been identified to which EC has successfully been applied, for example, planning, design, simulation and identification, control, and classification.

One of the newest areas of EC involves the use of evolvable hardware [38]. Evolvable hardware includes devices such as Field Programmable Gate Arrays (FPGA) and Field Programmable Analog Arrays (FPAA). The idea of evolvable hardware is to embody each individual of the evolving population into hardware and thereby exploit the massive parallelism of the hardware to perform evolution in silicon. These devices are reconfigurable with very short configuration times and download times. The use of FPGA to evolve a frequency discriminator circuit and a robot controller using the recently developed Xilinix XC6216 chip was achieved in the year 1996 [38].

3.2.3 Evolutionary Process

The processes responsible for driving the evolutionary process include reproduction, mutation, competition and selection. Reproduction is affected through the transfer of an individual’s genetic program to its progeny. This way, genetic traits that resulted in a successful organism are preserved. The transfer of the genetic program is, however, subject to error. These errors, called mutations, may either improve or impede the resulting organism. Competition results when the resources in the environment are limited and the population of organisms cannot expand without bound. Thus an organism must strive to be better than its competitors in order to survive. In the presence of competition, the replication process leads to selection. So that the more successful individuals survive and produce offspring while the less successful ones face extinction.

3.2.4 Evolutionary Algorithms

Evolutionary Algorithms (EA) are a class of general stochastic search algorithms applicable to problems of which a little knowledge is available, as they make few assumptions about the problem to be solved [39]. This make them successfully applied to a wide range of problems in learning and optimization. EA have been applied to numerous problems in combinatorial optimization, function optimization, artificial neural network learning, fuzzy logic system learning, etc. EA have two prominent features that distinguish them from other search algorithms. First, they are all population based. Second, there are communications and information exchange among individuals in a population. Such communications and information exchange result from selection, competition, and recombination. Different representation or encoding schemes, selection scheme, and search operators can lead to different EA. For example, GA normally use crossover and mutation as search operators, while EP only uses mutation. GA often emphasizes genetic evolution, while EP and ES put more emphasis on the evolution of behaviors. The general EA framework can be summarized as follows [39]:

1. Generate a random population P(0), and set i = 0.
2. Repeat until the population converges or time is up:
   a. Evaluate the fitness of each individual in P(i).
   b. Select parents form P(i) based on their fitness in P(i).
   c. Apply search operators to parents and produce offspring. The next generation P(i+1) is obtained from the offspring and possibly parents.

Although EA are often introduced from the point of view of survival of the fittest and from the analogy to natural evolution, they can also be understood through the framework of generate-and-test search. The advantage of introducing EA as a type of population-based generate-and-test search algorithms is that the relationships between EA and other search algorithms, such as Simulated Annealing (SA), Tabu Search (TS), hill-climbing, etc., can be made clearer and thus easier to explore. It is clear that the difference between the algorithms is due to the difference in their strategies for perturbation, i.e. methods of generating the next solution. A general generate-and-test algorithm is as follows [39]:

1. Generate the initial solution at random and denote it as the current solution.
2. Generate the next solution from the current one by perturbation.

3. Test whether the newly generated solution is acceptable:
   a. Accept it as the current solution if yes.
   b. Keep the current solution unchanged otherwise.
4. Go to step 2, if the current solution is not satisfactory.

A common feature of all EA that they are very good at global search, but rather poor at local search, especially GA [39]. One way to improve the EA's performance is to combine it with another algorithm that has better local search ability. SA has been used as such a local search for GA. This genetic annealing algorithm compared favorably to GA or SA alone. The idea is simply inserting an SA procedure before each individual evaluates its fitness function, so that each individual can perform a local search in addition to its participation in the population-based global search.

EA can be regarded as a population-based version of generate-and-test search. They make use of search operators like crossover and mutation to generate new solutions (offspring), and use selection to test whether a solution is good or not through the evaluation of a certain function, known as the fitness function.

3.3 PARTICLE SWARM OPTIMIZATION

In 1995, a new evolutionary computation technique was proposed by Kennedy, a social-psychologist, and Eberhart, an electrical engineer, which they called Particle Swarm Optimizer (PSO). It was reported as an optimization technique as claimed by its co-founder [40].

3.3.1 Biological and Social Behaviors

PSO is a population-based optimization technique that was originally inspired by the sociological behavior associated with bird flocking and fish schooling [35], [37]. One of the main advantages of PSO is that it needs no gradient information derived from the objective function. The aforementioned feature is a common property of all EA (including PSO) allowing them to be used on functions where the gradient is either unavailable (due to the discontinuity of most of real functions), or computationally expensive to obtain.

To understand the search mechanism of PSO, an analogy similar to the one that led to its inspiration adopted form is given to clarify the idea [46]. Imagine a swarm of bees in a field. Their goal is to find in the field the location with the highest density of flowers. Without any prior knowledge of the field, the bees begin in random locations with random velocities looking for flowers. Each bee can remember the locations that it found the most flowers, and somehow knows the locations where the other bees found an abundance of flowers. Torn between returning to the location where it had personally found the most flowers, or exploring the location reported by others to have the most flowers. The ambivalent bee accelerates in both directions altering its trajectory to fly somewhere between the two points depending on whether nostalgia or social influence dominates its decision. The above situation is clearly seen in Fig. 3.1(a). Along the way, a bee might find a place with a higher concentration of flowers than it had found previously. It would then be drawn to this new location as well as the location of the most flowers found by the whole swarm. Occasionally, one bee may flyover a place with more flowers than had been encountered by any bee in the swarm. The whole swarm would then be drawn toward that location in additional to their own personal discovery. In this way, the bees explore the field for a bee over-flying the locations of greatest concentration, then, it is pulled back toward them by the influence of other bees. Constantly, they are checking the territory they fly over against previously encountered locations of highest concentration, hoping to find the absolute highest concentration of flowers. Eventually, the bees' flight leads them to the one place in the field with the highest concentration of flowers. Soon, all the bees swarm (cluster) around this point. Unable to find any points of higher flower concentration, they are continually drawn back to the highest flower concentration. This can be seen in Fig. 3.1(b).

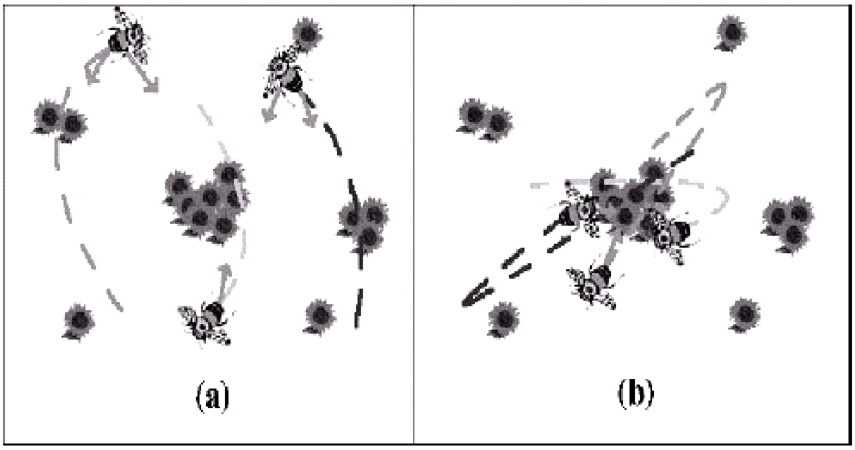

Fig. 3.1 Natural analogy of the PSO search mechanism
(a) Bees searching a field for the location of the most flowers
(b) All the bees swarm around the best location over-flying it only to be pulled back in after failing to find a higher concentration of flowers elsewhere [46]

3.3.2 PSO Language and Terminology

PSO has a kind of specific language and terminologies that are derived from the analogy of particles in a swarm. Table 3.1 summarizes these terminologies. A detailed discussion for these keywords is given below [46]:

- **Particle** : Each individual in the swarm (bees in the analogy above) or **Agent** is referred to as a particle or agent. All the particles in the swarm act individually under the same governing principle, i.e. accelerate toward the best personal and best overall location while constantly checking the value of its current location.

- **Location** or **Position** : In the analogy above, position referred to a bee's place in the field. This is represented by coordinates on the x-y plane. In general, however, this idea can be extended to any N-dimensional space according to the problem at hand. This N-dimensional space is the solution space for the problem being optimized, where any set of coordinates represents a solution to the problem. Reducing the optimization problem to a set of values that could represent a position in solution space is an essential step in utilizing the PSO.
- **Fitness** : As in all EC techniques there must be some function or method to evaluate the quality (goodness) of a position. The fitness function must take the position in the solution space and return a single number representing the value of that position. In the analogy above the fitness function would simply be the density of flowers, i.e. the higher the density, the better the location. The fitness function provides the interface between the physical problem and the optimization algorithm.
- **P_{best}** : In the analogy above, each bee remembers the location where it personally encountered the most flowers. This location with the highest fitness value personally

discovered by a bee is known as the personal best or P_{best}. Each bee has its own P_{best} determined by the path that it has flown. At each point along its path the bee compares the fitness value of its current location to that of P_{best}. If the current location has a higher fitness value, P_{best} is replaced with its current location.

- **G_{best}** : Each bee also has some way of knowing the highest concentration of flowers discovered by the entire swarm. This location of highest fitness encountered is known as the global best or G_{best}. For the entire swarm there is one G_{best} to which each bee is attracted. At each point along their path every bee compares the fitness of their current location to that of G_{best}. If any bee is at a location of higher fitness, G_{best} is replaced by that bee's current position.

TABLE 3.1

SOME KEYWORDS USED TO DESCRIBE THE PSO ALGORITHM

PSO Keywords		
Particle or Agent	:	One single individual in the swarm.
Location or Position	:	Agent's N-dimensional coordinates that represents a solution to the optimization problem.
Swarm	:	The entire collection of agents.
Fitness	:	A single number representing the quality of a given solution.
P_{best}	:	The location of the best fitness returned for a specific agent.

G_{best}	:	The location of the best fitness returned for the entire swarm.
Maximum velocity	:	The maximum allowed velocity in a given direction.

3.3.3 The Standard PSO Algorithm

The main idea of the PSO algorithm is to maintain a population of particles (agents), referred to as “swarm”, where each particle represents a potential solution to the objective function under consideration. Each particle in the swarm can memorize its current position that is determined by evaluation of the objective function, velocity, and the best position visited during its flying tour in the problem search space referred to as “personal best position” (P_{best}). Here it is meant by the personal best position, the one that yields the highest fitness value for that particle. For a minimization task, the position having a smaller function value is regarded to as having a higher fitness. Also the best position visited by all particles is memorized, i.e. the best position among all P_{best} positions referred to as “global best position” (G_{best}). The particles of the swarm are assumed to travel the problem search space in a discrete rather than continuous time steps. At each time step (iteration) the velocity of each particle is modified using its current velocity and its distance from P_{best} and G_{best} according to:

$$V_i^{k+1} = V_i^k + c_1 \text{ rand() } (P_{besti} - X_i^k)/\Delta t + c_2 \text{ rand() } (G_{best}^k - X_i^k)/\Delta t \qquad (3.1)$$

where;

V_i^k	:	is the $i^{\underline{th}}$ velocity component at iteration k.
rand()	:	is random number between 0 and 1.
X_i^k	:	is the current position in the $i^{\underline{th}}$ dimension at iteration k.

c_1 , c_2 : are the cognition and social factors, that are usually set to 2.0.

P_{besti} : is the personal best position in the i$\underline{\text{th}}$ dimension.

G_{best}^{k} : is the global best position in the i$\underline{\text{th}}$ dimension.

Δt : is the time step.

Usually the value of the velocity is clamped to the range $[-V_{max}, V_{max}]$ to reduce the possibility that the particle might fly out of the search space. If the space is defined by the bounds $[-X_{max}, X_{max}]$, then the value of V_{max} is typically set so that $V_{max} = kX_{max}$, where $0.1 \leq k \leq 1$ [37]. After that, each particle is allowed to update its position using its current velocity to explore the problem search space for a better solution as follows:

$$X_i^{k+1} = X_i^{k} + V_i^{k+1} \; \Delta t \tag{3.2}$$

It is a common practice in PSO literature to choose a unity time step (Δt), accordingly (Δt) is set to one second through out this work. The personal best position is updated after the k$\underline{\text{th}}$ iteration according to:

$$P_{besti}^{k+1} = \begin{cases} P_{besti}^{k} & \text{iff } CF(X_i^{k+1}) \geq CF(P_{besti}^{k}) \\ X_i^{k+1} & \text{iff } CF(X_i^{k+1}) < CF(P_{besti}^{k}) \end{cases} \tag{3.3}$$

where;

iff : means if and only if.

CF : is the cost function. It is a minimum solution objective function

Referring to Equ. (3.1), the velocity update equation has three terms; the first term represents the particle's inertia (change in position) in the different dimensions of the search space, the second term is associated with "cognition" since it only takes into account the particle's own experience, while the third one represents the “social interaction” between the particles. These three components are shown in Fig. 3.2 [47]. Each agent updates each location according to the interaction of the above three components, as can be seen in Fig. 3.3 [48]. In brief, the PSO algorithm for unconstraint optimization can be summarized as follows [49]:

1- Create an initial swarm, with a random distribution and random initial velocities.
2- Calculate a velocity vector for each particle, using the particle's memory and the knowledge gained by the swarm.
3- Update the position of each particle, using its velocity vector and previous position.
4- Update the personal best position of each particle, and the global best position of all particles.
5- Go to step 2 and repeat until convergence, or the termination criteria is met.

It is important to realize that the velocity term models the rate of change in the position of the particle. Therefore, the changes induced by the velocity update equation represent acceleration, which explains the name of cognition and social factors for the constants c_1 and c_2 respectively. The acceleration coefficients can be thought of as a balance between exploration (searching for a good solution) and exploitation (taking advantage of someone else's success). Too little exploration and the particles will all converge on the first good solution encountered, while too little exploitation and the particles will never converge, i.e. they will just keep searching. There is another way of looking at this rather than behaviors (exploration and exploitation). What must be properly balanced is individuality and sociality, i.e. traits that influence behavior. Ideally, individuals prefer being individualistic yet they still like to know what others have achieved so that they can learn from.

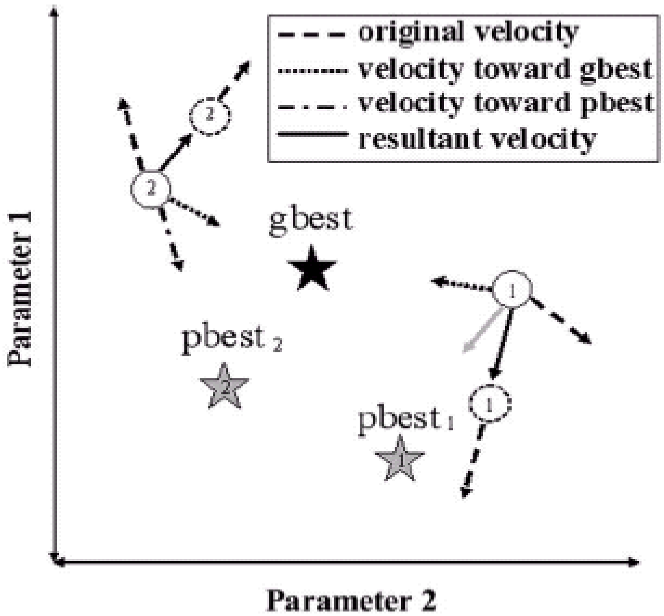

Fig. 3.2 The three components of the velocity update equation in a 2-D space

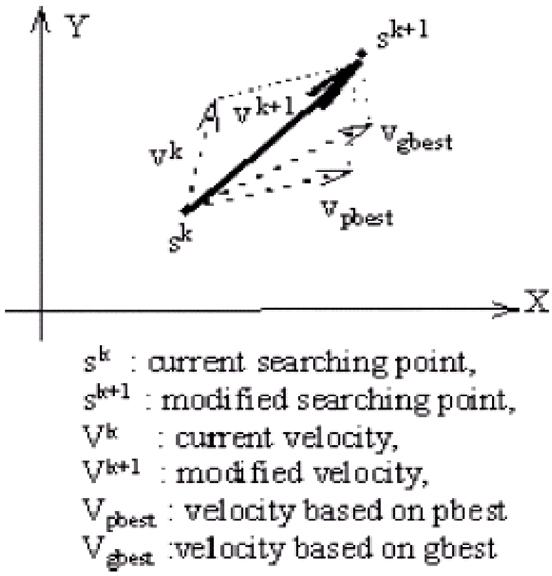

Fig. 3.3 The position update of agents in a 2-D space [36]

3.3.4 The Relation between PSO and EA

The PSO is clearly related to some extent to the EA. First, the PSO maintains a population of individuals representing potential solutions, a property that is common to all EA. If the personal best positions (P_{best}) are treated as part of the population, then there is clearly a weak form of selection [37]. In EA, the offspring compete with the parents, replacing them if they are more fitting. The update Equ. (3.3) resembles this mechanism, with the difference that each personal best position (parent) can only be replaced by its own current position (offspring), if the current position is more fit than the old personal best position. In summary, reference [37] concludes that there appears to be some weak form of selection presented in the PSO.

The velocity update equation resembles the arithmetic crossover operator found in real-valued GA. Normally; the arithmetic crossover produces two offspring that are linear blends of the two parents involved. The PSO velocity update equation, without the first term of Equ. (3.1), can be interpreted as a form of arithmetic crossover involving two parents, returning a single offspring. Alternatively, the velocity update equation, without the first term, can be seen as a mutation operator, with the strength of the mutation, governed by the distance that the particle is from its two parents.

A better way to model this term is to think of each iteration not as a process of replacing the previous population with a new one (death and birth), but rather as a process of adaptation [37]. In other words, PSO employs a cooperative search strategy, unlike most EA that employ a competitive strategy. In this way, the current position of each particle is not replaced, but rather adopted using its velocity. This makes the difference between PSO and other EA clearer. PSO maintains information regarding position and velocity (changes in position). In contrast, traditional EA only keep track of position. Therefore it appears that there is some degree of overlap between the PSO and most other EA, but the PSO has some characteristics that are currently not presented in other EA. Especially, the fact that the PSO models the velocity of the particles as well as the position.

3.4 APPLICATIONS OF PSO

The PSO algorithm has been applied to a lot of engineering problems with very promising results. Among the published literature, PSO has been used in electrical power engineering for:

- Training neural networks for power transformer protection [42].
- Controlling voltage and reactive power in electric power systems [50].
- Estimating states in a practical distribution system [48].
- Solving the economic dispatch problem [51], [52].
- Designing an optimum PID controller in AVR system [53].
- Designing a multi-machine power system stabilizer [54].
- Identifying dynamic security border [55].

In addition, PSO has been used in other engineering fields, for instance:

- Optimizing a profiled corrugated horn antenna [46], [47].
- Optimizing recurrent neural networks design [56].
- Synthesizing a far-field radiation pattern [57].
- Detecting the pareto-optimal front [58].

3.5 PSO RECENT STUDIES

3.5.1 Utility of PSO for Loss Minimization and Enhancement of Voltage Profile using Unified Power Flow Controller (UPFC)

In 2011, a method to provide simultaneous or individual controls of basic system parameters like transmission voltage, impedance and phase angle, which are controlled by using Unified Power Flow Controller (UPFC) is presented. PSO method is used to compute the power flow in optimum value. The performance of this technique is tested using IEEE-14 bus system through the MatLab/Simulink simulation software package. The simulation results of test power system show that the location of the UPFC has been able to enhance the voltage level of the test power system and also minimize the transmission line losses [60].

3.5.2 Economic Load Dispatch of Generating Units with Multiple Fuel Options Using PSO

In 2012, a method to solve the optimal generation and dispatch of electrical power with multiple fuel options at different power levels is presented. This method is applicable to the generating units that can use multiple fuels through valve at different generation levels as well as other problems which result in multiple intersecting continuous and discontinuous cost curves for any unit. This method is applicable to both continuous and discontinuous cost curves of systems. Also it does not require selection of unit and type of fuel to be used after computation for a number of combinations which is a cumbersome task. The simulation is carried out using MATLAB software. It can be used for real time implementation and operation [61].

3.5.3 PSO-Based Approaches in Image Segmentation

At the end of 2012, Amanpreet Kaur and M.D. Singh have showed how PSO can be successfully combined with various other methodologies such as neural networks, rough sets, clustering, thresholding, genetic algorithm, wavelets and fuzzy systems in image segmentation [62].

Image segmentation is a low level vision task which is applicable in various applications such as object recognition, medical imaging and document analysis. Image segmentation has received a lot of attention by the research people. It subdivides an image into its constituents regions which are more meaningful and easier to analyze. The level of details to which subdivision is carried depends on the problem being solved [62].

3.5.4 Particle Swarm Optimization and its Hybrids

In 2013, some of the commonly used hybrid PSO algorithms are illustrated. Their performance is studied through typical nonlinear optimization problems. The performance of the PSO algorithm can be further improved by hybrid techniques. The research shows that the PSO-GA outperformed other hybrid algorithms [63].

3.6 ADVANTAGES OF PSO

Artificial Intelligence techniques play great role in dealing with the power system problems. The PSO technique is one of the advanced and, nowadays, widely used optimization techniques that can be applied to many of power systems optimization problems.

PSO technique has many advantages such as [59]:

1) It has fewer parameters to adjust and so it is easier to be implemented.

2) It has a more effective memory capability since every particle remembers its own previous best value as well as the neighborhood best.

3) It is more efficient in maintaining the diversity of the swarm, since all the particles use the information related to the most successful particle in order to improve themselves.

4) It is not largely affected by the size and nonlinearity of the problem and can converge to the optimal solution where most analytical methods fail to converge.

3.7 THE DEVELOPED WORK ALGORITHM

The algorithm procedures and the flowchart of the PSO program are based on the assumption that bus voltages magnitudes and the real power are constants. The used technique changes only the values of the angles of the buses aiming to find the optimal alternative path that could deliver power with the lowest power loss value. The algorithm procedures can be summarized in the following steps;

I- Network Analysis and Data Entering:

First step is entering the network parameters, initial values and results after running the load flow program (ETAP program) and after clearing the fault (considering the faulty bus out of service).

II- Alternative Paths Determination:

In this step, the available alternative paths and the number of variables and varying angles are determined (using m-files) by applying the Tree Search Method (TSM) algorithm starting from arranging the branches and sub-branches of the system equivalent tree, and ending with determining the alternative available paths [64]. The algorithm procedures of TSM program can be summarized in the following steps;

1- Determination of the branching points, and the number of branches from each point.

2- Arrangement of the paths, branches, and sub-branches.

3- Finding the possible alternative paths.

III- PSO Technique for Path Optimization;

1- Initialization of particles positions and velocities.

2- Constraints check:

i- Checking the angle condition.

ii- Checking the power condition.

3- Calculating Voltage Differences (ΔV) and Power Loss (P_{loss}).

A- Calculating Voltage Differences (ΔV)

The difference in voltages between each two successive buses in the path of electrical power flow is calculated. It is illustrated in the formula in Equ. (2.9)

$$\Delta V= ((V_i \cos(\theta_i) - V_j \cos(\theta_j))^2 + (V_i \sin(\theta_i) - V_j \sin(\theta_j))^2)^{1/2} \qquad (2.9)$$

B- Calculating Power losses (P_{loss})

The power loss of the available paths after the fault is calculated using Equ. (2.8).

$$P_{loss}= (\Delta V/Z)^2 R \qquad (2.8)$$

4- Cost Function :

Calculating the Cost Function (CF) and initializing θ_{gbest}. The cost function is the objective function of the studied case.

5- Applying PSO technique concept using (3.1) and (3.2).

6- Checking the constraint ($\Delta\theta$).

$\Delta\theta = | \theta_{n+1} - \theta_n |$

$0 < \Delta\theta < 90°$

If the constraint is not satisfied, a small shift is made using Equ.(3.4) to search for another suitable angle.

$$\theta_{n+1} = \theta_n - 0.15 - P*0.02 \qquad (3.4)$$

7- CF minimization using (2.8) and (2.9).

8- Determining θ_{pbest} and θ_{gbest}.

9- Checking the END conditions (No. of iteration or $P_{lossmin}$)

A Matlab program is developed to solve the power loss calculation problem using the PSO technique. Figure 3.4 shows the flowchart which summarizes the previous steps of the developed PSO technique program. One of the program initial angles vector is the angles vectors obtained from ETAP load flow results after fault conditions.

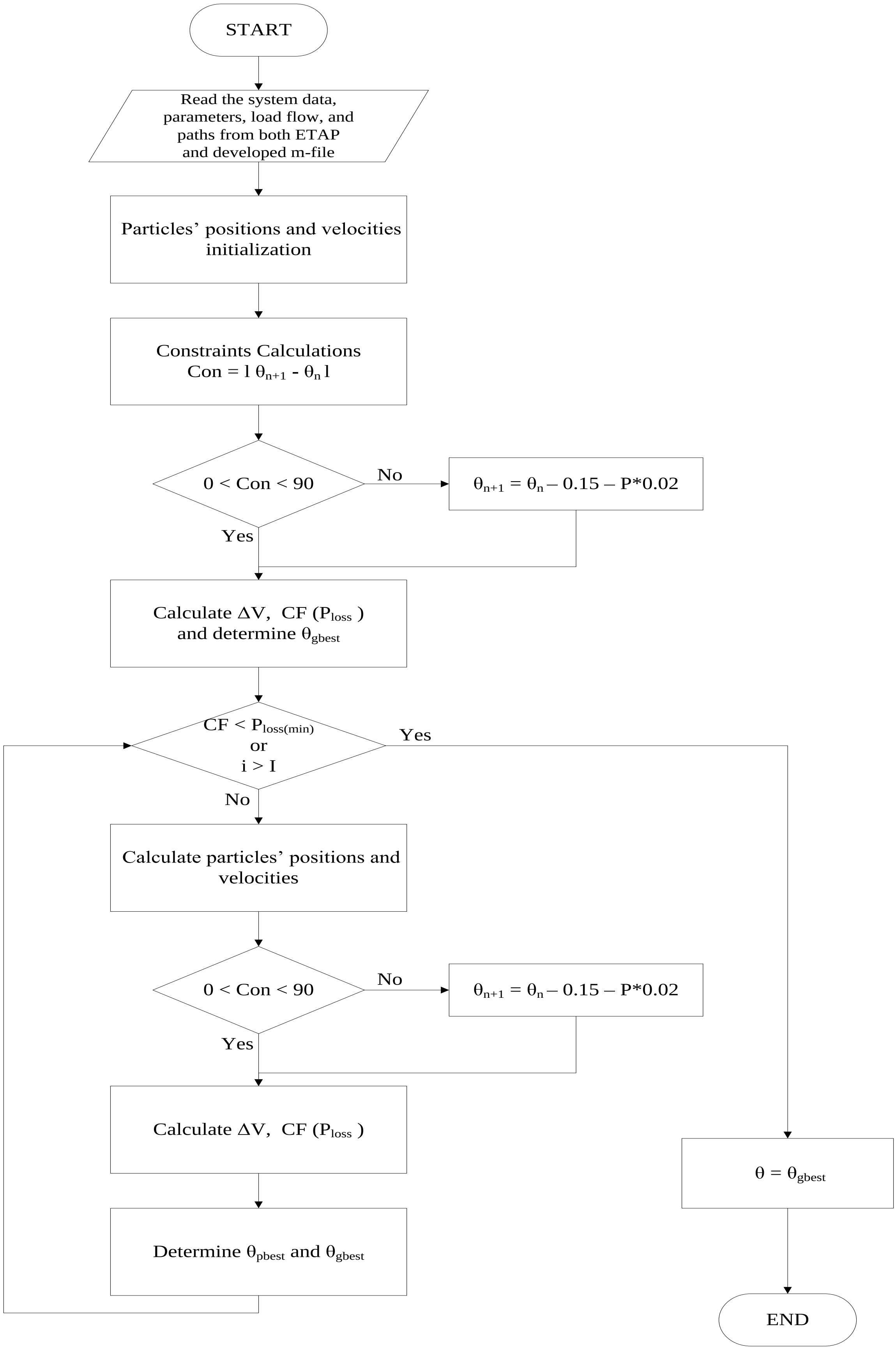

Fig. 3.4 PSO Technique Flowchart

CHAPTER FOUR

SIMULATION AND RESULTS

CHAPTER FOUR
SIMULATION AND RESULTS

4.1 OVERVIEW

This chapter presents an illustration for the whole developed work. It is tested on three studied systems, which are the 14-bus IEEE standard system, the 57-bus IEEE standard system and the offshore platform electrical system. The results and analysis are also discussed in this chapter.

4.2 GENERAL

This work aims two main targets, which are; 1- searching all the alternative possible paths to feed critical loads in case of faulted network, 2- finding the optimal path and adjusting the value of its buses' voltage angles for optimizing the power flow to be with minimum power losses.

This work is developed through three stages, which are;

1- Simulating the power network on ETAP to evaluate the power flow in normal healthy case and in faulted (unhealthy) case.

2- Developing a Matlab/m-file program, to find all the possible alternative paths for the power, to feed the critical disconnected load due to the fault.

3- Developing a PSO technique program to find the optimal path. The PSO program finds the optimum values of the buses' voltage angles of the optimal path, for optimizing the power flow through minimizing its power loss. The voltage magnitude and load active power remain constants. The PSO program is fed from the ETAP output and the developed Matlab/m-file programs to determine the available alternative paths.

The previous stages are illustrated in Fig. 4.1.

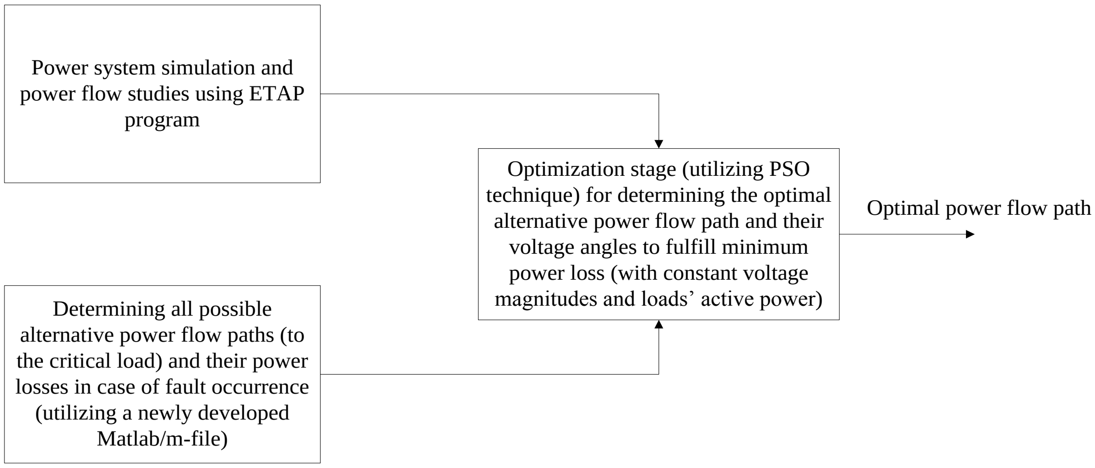

Fig. 4.1 The three main stages of the developed work

4.2.1 Initial Power Loss Calculation

The procedures of determining the alternative paths and calculating the initial power loss calculation, after a fault occurrence, can be summarized in the flowchart shown in Fig. 4.2.

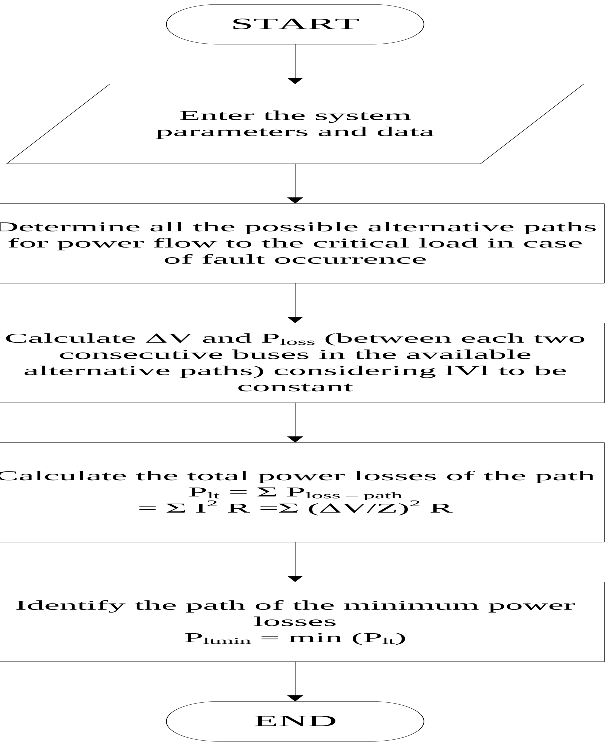

Fig. 4.2 Initial Power Loss Calculation Flowchart

4.2.2 Calculations using the PSO Technique

The algorithm procedures of the PSO technique is described in details in Chapter (3) section (3.7).

4.3 STUDIED SYSTEMS AND RESULTS

Three different power systems are studied in this chapter. The developed technique is tested on the IEEE 14-bus standard system, the IEEE 57-Bus standard system and a practical system for an offshore platform.

4.3.1 The IEEE 14-Bus Standard System

The first studied system is the IEEE 14-bus system shown in Fig 4.3. The system data and parameters are clarified in Appendix. A scenario is proposed that there is a critical load at bus-13 which shall be fed continuously without interruption, although any fault occurred in the system. In case (1), it is assumed that the fault occurred at one of the system's buses which is bus-6. In case (2), the fault is assumed to be at one of the system's branches which is the branch connecting bus-6 and bus-13. The total number of the available alternative paths from the generation sources to the critical load is calculated after the occurrence of the fault in each case using a developed Matlab/m-file program.

The total number of paths that can feed the critical load at bus-13 from the different generation sources of the IEEE 14-Bus system are 63 paths without the occurrence of any fault in the system.

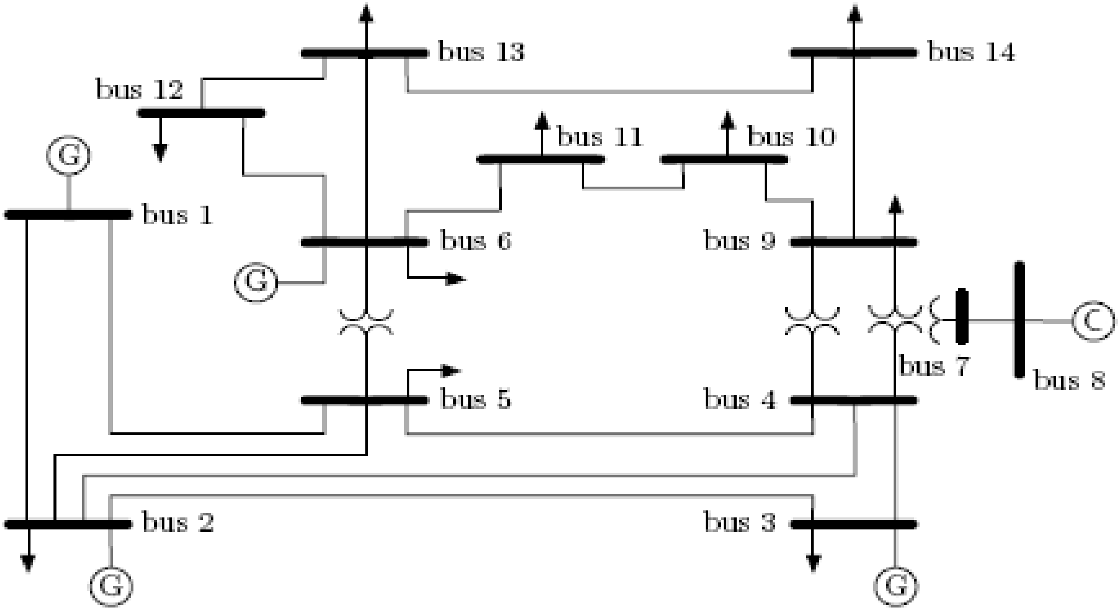

Fig. 4.3 IEEE 14-Bus System

The IEEE 14-bus system comprises 4 generators and 1 synchronous compensator connected to the buses of the system. The 4 generators supply power to all loads. However, load dispatching is not considered in this study. So the contribution of each generator is not studied or the amount of power dedicated to each load from each generator.

I- *Load Flow for the IEEE 14-Bus system*

Load flow for the IEEE 14-bus system has been carried out using ETAP program for both healthy and unhealthy conditions (before and after the fault occurrence, respectively).

Load flow results are obtained after the occurrence of the fault. The voltages' magnitudes and angles are entered as initial inputs into the PSO program.

Table 4.1 represents the IEEE 14-bus system buses' voltages magnitudes and angles for healthy case, and Table 4.2 represents the same for the faulted (unhealthy) case. These results are extracted from ETAP load flow report.

Table 4.1
IEEE 14-bus system buses' voltages magnitudes and angles extracted from load flow report. (before fault)

Bus	Voltage % Magnitude	Voltage Angle (degrees)
1	96.340	0.0
2	96.407	-0.3
3	100.115	-0.5
4	99.134	-0.4
5	98.990	-0.4
6	98.124	-2.5
7	97.234	-0.5
8	97.633	-0.5
9	96.840	-0.9
10	96.516	-1.4
11	96.982	-2.0
12	96.045	-2.9
13	95.751	-2.9
14	95.580	-2.2

Table 4.2
IEEE 14-bus system buses' voltages magnitudes and angles extracted from load flow report. (after fault at bus-6)

Bus	Voltage % Magnitude	Voltage Angle (degrees)
1	96.340	0.0
2	96.414	-0.3
3	100.126	-0.5
4	99.147	-0.4
5	99.010	-0.4
6	removed after fault	
7	97.177	-0.4
8	97.591	-0.4
9	96.720	-0.8
10	96.669	-1.0
11	96.788	-1.2
12	96.558	-4.0
13	95.928	-3.9
14	95.798	-2.5

II- AI Technique for Determination of Paths after a Fault

Case (1) - Fault at a Bus

Figure 4.4 illustrates the circuit diagram of the standard IEEE 14-bus system with fault occurrence at bus-6. The faulted bus is circled by a dotted oval shape.

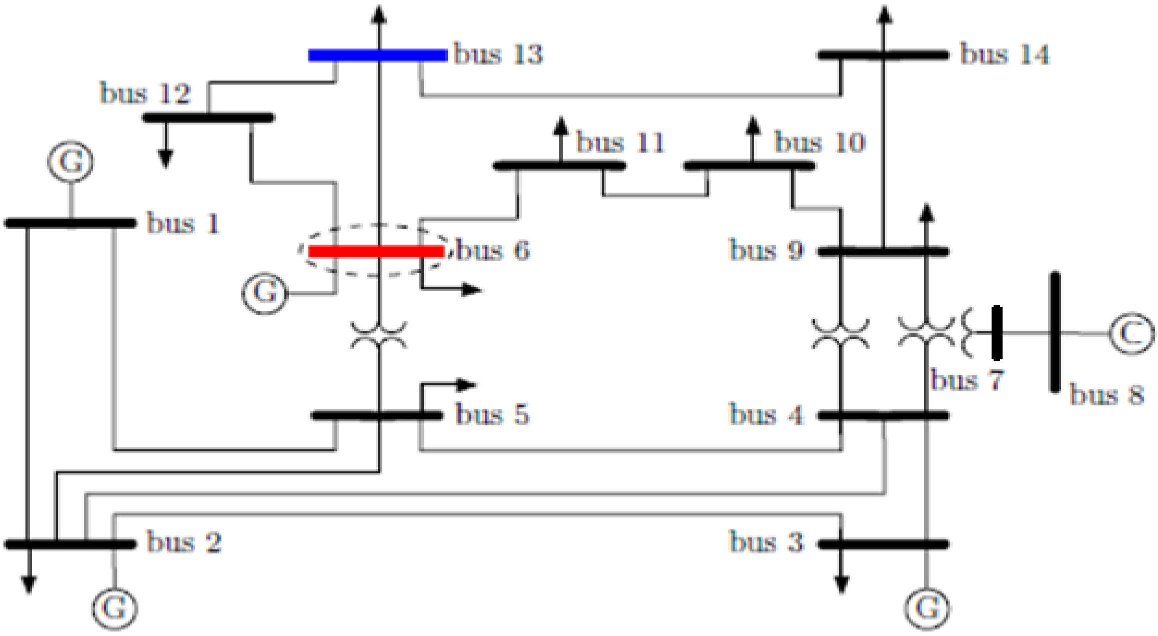

Fig. 4.4 IEEE 14-Bus System - Fault at bus-6

After the occurrence of a fault at bus-6, there are only 18 paths which are available to feed the critical load at bus 13 as shown in Table 4.3. The available paths consist of up to 8 buses at maximum which have voltage magnitudes and angles that will be entered as inputs to the PSO program.

Table 4.3: Available paths after fault occurrence at bus-6

G	Bus	Path No.	Paths										
1	1	1	1	2	3	4	9	14	13	-	-	-	-
		2	1	2	3	4	7	9	14	13	-	-	-
		3	1	2	4	9	14	13	-	-	-	-	-
		4	1	2	4	7	9	14	13	-	-	-	-
		5	1	2	5	4	9	14	13	-	-	-	-
		6	1	2	5	4	7	9	14	13	-	-	-
		7	1	5	4	9	14	13	-	-	-	-	-
		8	1	5	4	7	9	14	13	-	-	-	-

G	Bus	Path No.	Paths										
2	2	9	2	3	4	9	14	13	-	-	-	-	-
		10	2	3	4	7	9	14	13	-	-	-	-
		11	2	4	9	14	13	-	-	-	-	-	-
		12	2	4	7	9	14	13	-	-	-	-	-
		13	2	5	4	9	14	13	-	-	-	-	-
		14	2	5	4	7	9	14	13	-	-	-	-
4	3	15	3	2	5	4	9	14	13	-	-	-	-
		16	3	2	5	4	7	9	14	13	-	-	-
		17	3	4	9	14	13	-	-	-	-	-	-
		18	3	4	7	9	14	13	-	-	-	-	-

Case (2) - Fault at a Branch

Figure 4.5 illustrates the circuit diagram of the standard IEEE 14-Bus system with fault occurrence at the branch between bus-6 and bus-13. The faulted branch is circled by a dotted oval shape.

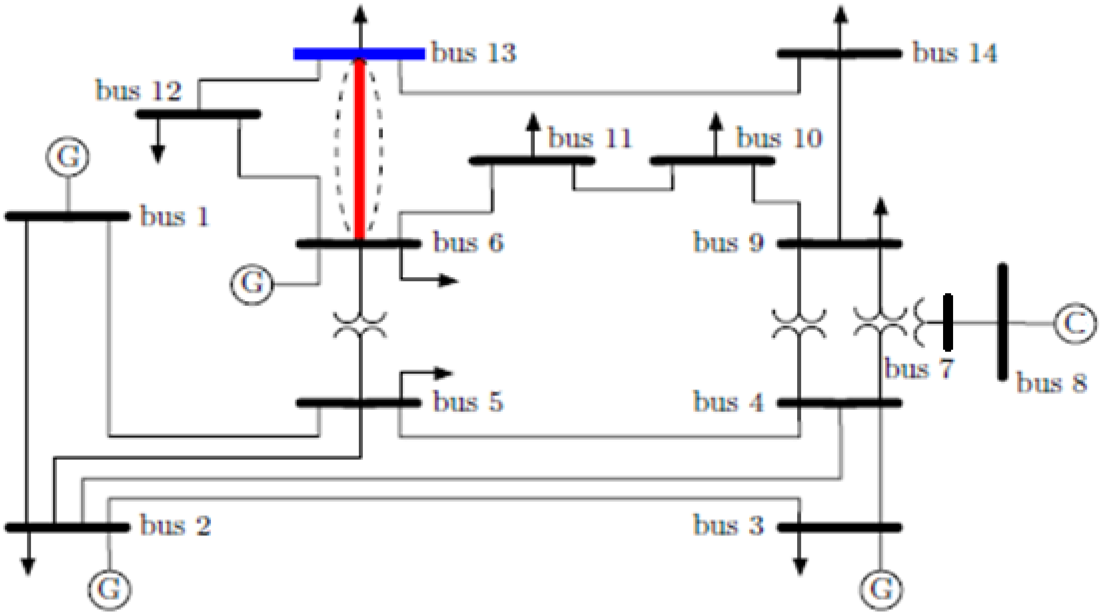

Fig. 4.5 IEEE 14-Bus System - Fault at Branch between bus-6 and bus-13

An assumed fault occurs at the branch connecting bus-6 and bus-13. There are 42 alternative paths available to feed the critical load at bus-13 as shown in Table 4.4.

Table 4.4 Available paths after fault occurrence at the branch between bus-6 and bus-13 for IEEE 14-bus system

G	**Bus**	**Path No.**	**Path**										
1	1	1	1	2	3	4	9	10	11	6	12	13	-
		2	1	2	3	4	9	14	13	-	-	-	-
		3	1	2	3	4	7	9	10	11	16	12	13
		4	1	2	3	4	7	9	14	13	-	-	-
		5	1	2	4	9	10	11	6	12	13	-	-
		6	1	2	4	9	14	13	-	-	-	-	-
		7	1	2	4	7	9	10	11	6	12	13	-
		8	1	2	4	7	9	14	13	-	-	-	-
		9	1	2	5	4	9	10	11	6	12	13	-
		10	1	2	5	4	9	14	13	-	-	-	-
		11	1	2	5	4	7	9	10	11	6	12	13
		12	1	2	5	4	7	9	14	13	-	-	-
		13	1	5	4	9	10	11	6	12	13	-	-
		14	1	5	4	9	14	13	-	-	-	-	-
		15	1	5	4	7	9	10	11	6	12	13	-
		16	1	5	4	7	9	14	13	-	-	-	-
		17	1	5	6	12	13	-	-	-	-	-	-
		18	1	5	6	11	10	9	14	13	-	-	-
2	2	19	2	3	4	9	10	11	6	12	13	-	-
		20	2	3	4	9	14	13	-	-	-	-	-
		21	2	3	4	7	9	10	11	6	12	13	
		22	2	3	4	7	9	14	13	-	-	-	-
		23	2	4	9	10	11	6	12	13	-	-	-
		24	2	4	9	14	13	-	-	-	-	-	-
		25	2	4	7	9	10	11	6	12	13		
		26	2	4	7	9	14	13	-	-	-	-	-
		27	2	5	4	9	10	11	6	12	13	-	-
		28	2	5	4	9	14	13	-	-	-	-	-
		29	2	5	4	7	9	10	11	6	12	13	-
		30	2	5	4	7	9	14	13	-	-	-	-
4	3	31	3	2	5	4	9	10	11	6	12	13	-
		32	3	2	5	4	9	14	13	-	-	-	-
		33	3	2	5	4	7	9	10	11	6	12	13
		34	3	2	5	4	7	9	14	13	-	-	-
		35	3	4	9	10	11	6	12	13	-	-	-
		36	3	4	9	14	13	-	-	-	-	-	-
		37	3	4	7	9	10	11	6	12	13	-	-
		38	3	4	7	9	14	13	-	-	-	-	-
		39	3	4	5	6	11	10	9	14	13	-	-
		40	3	4	5	6	12	13	-	-	-	-	-
5	6	41	6	11	10	9	14	13	-	-	-	-	-
		42	6	12	13	-	-	-	-	-	-	-	-

III- Initial Power Loss Results

The total power loss for each path is calculated for case (1) (IEEE 14-Bus system with a fault at bus-6). The power losses calculation results are shown in Table 4.5.

Table 4.5 Initial total power loss results for IEEE 14-Bus system

Path	Total Power Loss (Plt) in [MW]
1	0.0058
2	0.0058
3	0.0053
4	0.0053
5	0.0053
6	0.0053
7	0.0046
8	0.0046
9	0.0045
10	0.0045
11	0.0040
12	0.0040
13	0.0040
14	0.0040
15	0.0052
16	0.0054
17	**0.0031**
18	0.0036

The calculation shows that the minimum power loss (Pltmin) is equal to 0.0031. It occurs in the 17^{th} path which passes through buses 3-4-9-14-13.

IV- PSO Technique Results

In studying case (1), where the fault is at Bus-6, the 18 available alternative paths which can feed the critical load at Bus-13 are considered. Each path consists of 8 buses at maximum, which leads to have swarm particle with [8x18] variables at maximum. The developed PSO technique is composed of 10 particles.

The particle swarm personal best "θ_{pbest}" for the 10 particles are calculated, from which the global best "θ_{gbest}" is obtained, as shown in Table 4.6.

Table 4.6 Results of θpbest and θgbest for IEEE 14-bus system

θpbest (-)								
Path 1	0	0.0030	0.0060	0.0090	0.0120	0.0150	0.0180	0.0210
Path 2	0	0.0020	0.0040	0.0060	0.0080	0.0100	0.0120	0.0140
Path 3	0	0.0024	0.0048	0.0072	0.0096	0.0120	_	_
Path 4	0	0.0016	0.0032	0.2446	0.2462	0.2478	0.2494	_
Path 5	0	0.0016	0.0032	0.0048	0.1204	0.1220	0.1236	_
Path 6	0	0.0030	0.0060	0.0090	0.0120	0.0150	0.0180	0.0210
Path 7	0	0.0030	0.0060	0.0090	0.0120	0.0150	0.0180	0.0210
Path 8	0	0.0016	0.0032	0.0048	0.0064	0.0080	0.0096	_
Path 9	0.0052	0.0066	0.0080	0.0094	0.0108	0.0122	_	_
Path 10	0.0052	0.0066	0.0080	0.1528	0.1542	0.1556	0.1570	_
Path 11	0.0052	0.0066	0.1570	0.1584	0.1598	_	_	_
Path 12	0.0052	0.0076	0.0100	0.0124	0.0148	0.0172	_	_
Path 13	0.0052	0.0078	0.0104	0.0130	0.0156	0.0182	_	_
Path 14	0.0052	0.0066	0.0080	0.2809	0.2823	0.2837	0.2851	_
Path 15	0.0087	0.0117	0.0147	0.0177	0.0207	0.0237	0.0267	0.0297
Path 16	0.0087	0.0117	0.0147	0.0177	0.0207	0.0237	0.0267	0.0297
Path 17	0.0087	0.0117	0.0147	0.0177	0.0207	0.0237	0.0267	0.0297
Path 18	0.0087	0.0111	0.5954	0.6696	0.6720	0.6744	_	_

θgbest (-)							
0.0087	0.0111	0.5954	0.6696	0.6720	0.6744	_	_

The initial values of the angles of the 18th path are changed as shown in Table 4.7 to give θ_{gbest} which give minimum power loss.

Table 4.7 The selected path θgbest and θi (initial values) for IEEE 14-bus system

Path	3	4	7	9	14	13
θ_i	-0.5	-0.4	-0.4	-0.8	-2.5	-3.9
θ_{gbest}	-0.0087	-0.0111	-0.5954	-0.6696	-0.6720	-0.6744

V- Power Losses Results

Each Particle carries the 18 paths. The minimum power loss that can be obtained in each particle for the 18th path is shown in Table 4.8.

Table 4.8 Final total power loss results of the 18th alternative path for IEEE 14-bus system

Particle	Total Power Loss [MW]
1	**0.0010**
2	0.0011
3	0.0012
4	0.0013
5	0.0015
6	0.0018
7	0.0010
8	0.0024
9	0.0010
10	0.0010

The lowest Power Loss ($P_{lossmin}$) occurs on particles 1, 7, 9 and 10 with a value equals to 0.0010 MW.

The new calculated voltage angles leads to reduce the power losses of the system from **0.0031 MW** to **0.0010 MW** as clarified in Table 4.9. They lead to have another alternative path of a lower power loss which is the path passing through the buses **3-4-7-9-14-13**.

Table 4.9 Power loss comparison between the initial and developed technique results for IEEE 14-bus system

Power Loss	P [MW]	Path No.
Initial Case (IEEE 14 Bus System)	0.0031	17
Using PSO technique (IEEE 14 Bus System)	0.0010	18

Figure 4.6 shows the initial path of minimum power loss with the dotted arrows. The alternative path of lower power loss than the initial path is shown in Fig. 4.7 with the solid arrows.

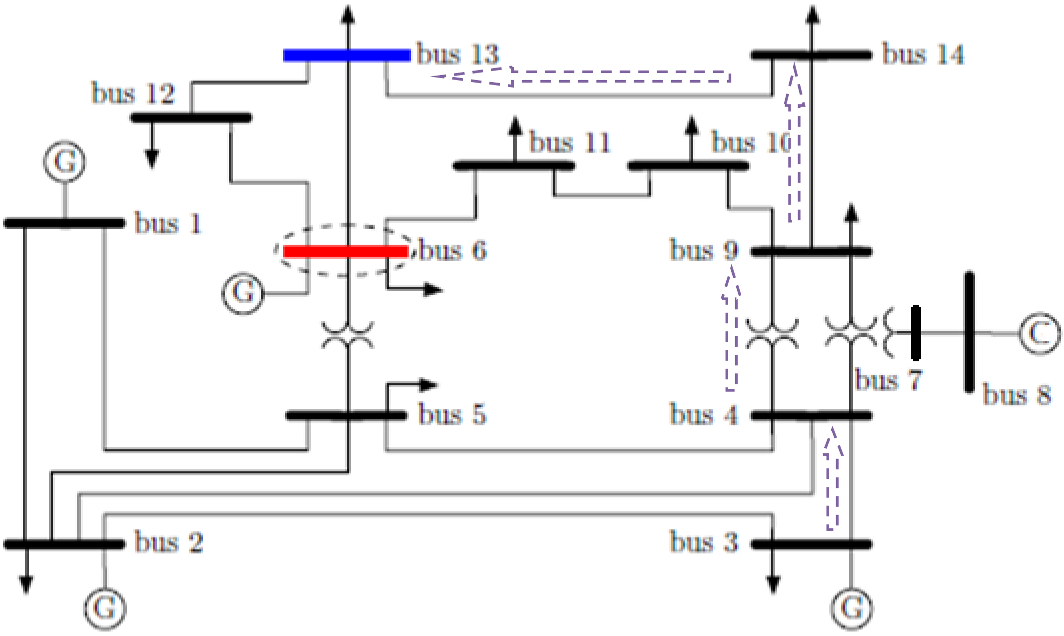

Fig. 4.6 Initial path for the IEEE 14-bus system

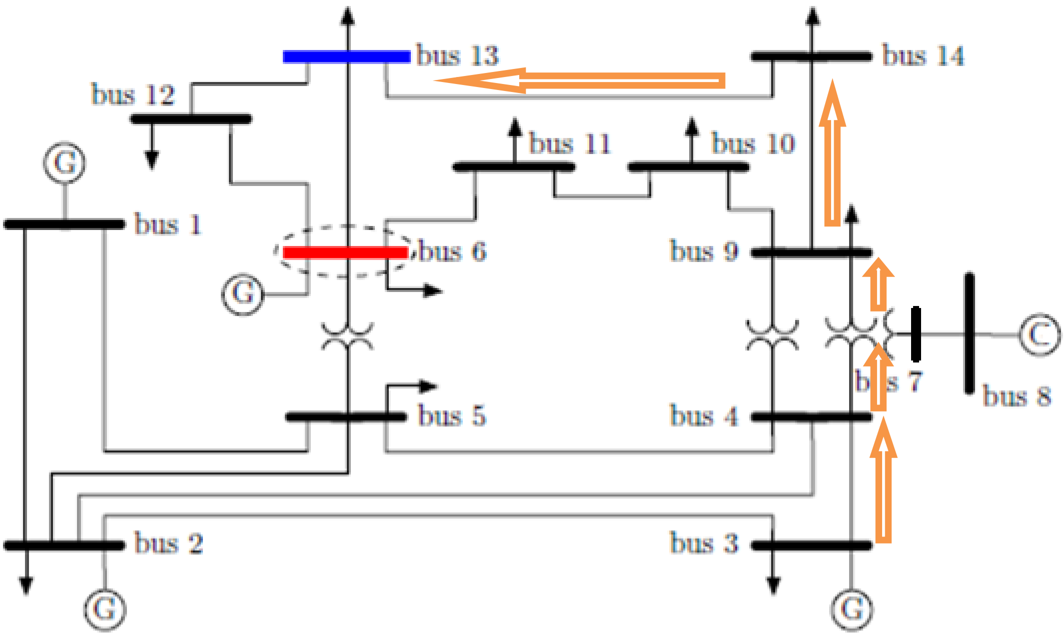

Fig. 4.7 Alternative path for the IEEE 14-bus system

4.3.2 The IEEE 57-Bus system

The second system studied is the IEEE 57-bus system. The system power generation units are at buses 1, 3, 8 and 12, while other machines at buses 2, 6 and 9 act as synchronous compensators.

It has been assumed that faults occurred at buses 1 and 15. Electrical power should be supplied to a critical load in the network which is connected to bus 38.

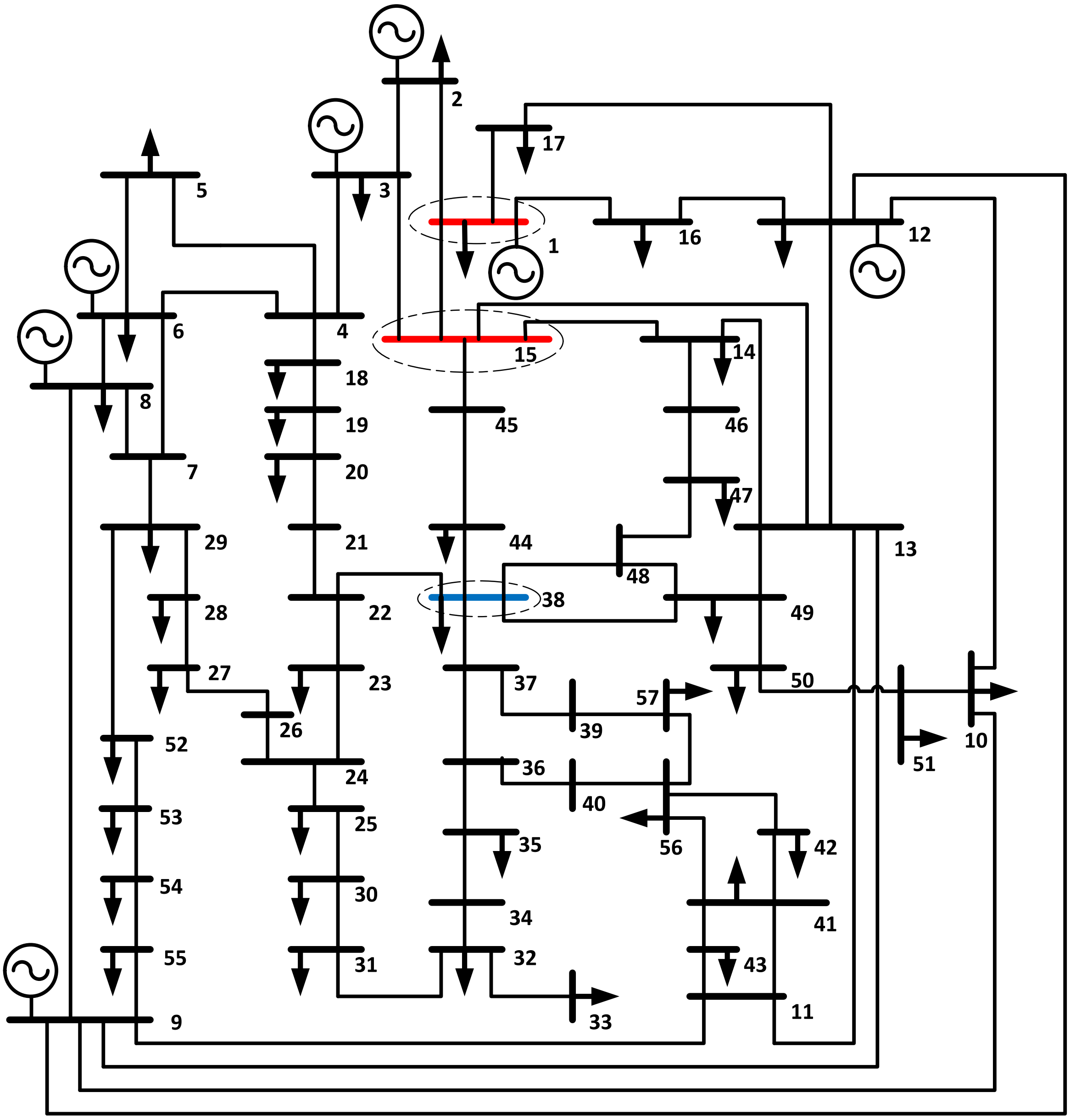

Fig. 4.8 IEEE 57-bus system

Table 4.10 represents the IEEE 57-bus system buses' voltages magnitudes and angles for healthy case as extracted from ETAP load flow report.

Table 4.10
IEEE 57-bus system buses' voltages magnitudes and angles extracted from load flow report. (before fault)

Bus	Voltage % Magnitude	Voltage Angle (degrees)
1	100.548	-0.10
2	100.412	-0.12
3	100	0
4	100.183	0.16
5	100.451	-0.18
6	100.581	-0.19
7	101.029	-0.22
8	101.324	-0.24
9	101.476	-0.32
10	102.061	-0.36
11	101.223	-0.38
12	101.200	-0.40
13	101.017	-0.42
14	100.838	-0.43
15	100.574	-0.15
16	101.016	-0.28
17	100.794	-0.20
18	100.338	0.10
19	100.540	-0.18
20	100.668	-0.19
21	100.889	-0.24
22	100.924	-0.47
23	100.926	-0.44
24	100.967	-0.42
25	100.958	-0.43
26	100.975	-0.38
27	101.018	-0.35
28	101.034	-0.32
29	101.044	-0.29
30	100.957	-0.42
31	100.954	-0.44

Bus	Voltage % Magnitude	Voltage Angle (degrees)
32	100.950	-0.46
33	100.950	-0.48
34	100.946	-0.56
35	100.946	-0.54
36	100.946	-0.52
37	100.943	-0.50
38	100.928	-0.51
39	100.946	-0.55
40	100.950	-0.57
41	101.112	-0.36
42	101.088	-0.38
43	101.219	-0.40
44	100.855	-0.20
45	100.699	-0.22
46	100.883	-0.44
47	100.929	-0.46
48	100.946	-0.48
49	101.087	-0.50
50	101.388	-0.52
51	101.909	-0.54
52	101.139	-0.30
53	101.189	-0.32
54	101.309	-0.34
55	101.426	-0.36
56	101.065	-0.38
57	101.047	-0.42

Table 4.11 represents the IEEE 57-bus system buses' voltages magnitudes and angles for the faulted (unhealthy) case as extracted from ETAP load flow report.

Table 4.11
IEEE 57-bus system buses' voltages magnitudes and angles extracted from load flow report. (after fault at bus-1&bus-15)

Bus	Voltage % Magnitude	Voltage Angle (degrees)
1	removed after fault	
2	99.999	-0.10

Bus	Voltage % Magnitude	Voltage Angle (degrees)
3	100	0
4	99.997	0.15
5	99,992	-0.17
6	99.990	-0.10
7	99.987	-0.24
8	99.986	-0.21
9	99.985	-0.30
10	99.983	-0.35
11	99.984	-0.32
12	99.981	-0.34
13	99.983	-0.37
14	99.983	-0.40
15	removed after fault	
16	99.981	-0.38
17	99.981	-0.39
18	99.985	0.17
19	99.987	-0.19
20	99.983	-0.21
21	99.983	-0.23
22	99.982	-0.46
23	99.982	-0.43
24	99.983	-0.40
25	99.981	-0.42
26	99.983	-0.37
27	99.985	-0.34
28	99.986	-0.30
29	99.987	-0.27
30	99.980	-0.44
31	99.980	-0.46
32	99.980	-0.48
33	99.980	-0.50
34	99.981	-0.58
35	99.981	-0.56
36	99.981	-0.54
37	99.982	-0.52
38	99.982	-0.49
39	99.982	-0.54
40	99.981	-0.56
41	99.983	-0.34
42	99.982	-0.36
43	99.984	-0.38
44	99.982	-0.19
45	99.982	-0.17
46	99.982	-0.43
47	99.982	-0.45
48	99.982	-0.47
49	99.982	-0.49
50	99.982	-0.51
51	99.983	-0.53
52	99.985	-0.29
53	99.984	-0.31
54	99.984	-0.33
55	99.984	-0.35
56	99.981	-0.38
57	99.981	-0.40

I- Determination of Paths after faults at Buses 1 and 15

After the occurrence of faults at bus-1 and bus-15, there are 43 paths available to feed the critical load at bus-38 as shown in Table 4.12.

Table 4.12 Available paths to feed bus-38 after fault occurrence at bus-1 and bus-15 for IEEE 57-bus system

G	Bus	Path No.	Paths																						
3	3	1	3	4	18	19	20	21	22	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		2	3	4	18	19	20	21	22	23	24	25	30	31	32	34	35	36	37	38	_	_	_	_	_	_
		3	3	4	18	19	20	21	22	23	24	25	30	31	32	34	35	36	40	56	57	39	37	38	_	_
		4	3	4	6	7	29	28	27	26	24	23	22	38	_	_	_	_	_	_	_	_	_	_	_	_
		5	3	4	6	7	29	28	27	26	24	25	30	31	32	34	35	36	37	38	_	_	_	_	_	_
		6	3	4	6	7	29	28	27	26	24	25	30	31	32	34	35	36	40	56	57	39	37	38	_	_
		7	3	4	5	6	7	29	28	27	26	24	23	22	38	_	_	_	_	_	_	_	_	_	_	_
		8	3	4	5	6	7	29	28	27	26	24	25	30	31	32	34	35	36	37	38	_	_	_	_	_
		9	3	4	5	6	7	29	28	27	26	24	25	30	31	32	34	35	36	40	56	57	39	37	38	_
		10	3	4	6	8	9	11	41	42	56	57	39	37	38	_	_	_	_	_	_	_	_	_	_	_
		11	3	4	6	8	9	11	41	42	56	40	36	37	38	_	_	_	_	_	_	_	_	_	_	_
		12	3	4	6	8	9	11	43	41	56	57	39	37	38	_	_	_	_	_	_	_	_	_	_	_
		13	3	4	6	8	9	11	43	41	56	40	36	37	38	_	_	_	_	_	_	_	_	_	_	_
		14	3	4	5	6	8	9	11	41	42	56	57	39	37	38	_	_	_	_	_	_	_	_	_	_
		15	3	4	5	6	8	9	11	41	42	56	40	36	37	38	_	_	_	_	_	_	_	_	_	_
		16	3	4	5	6	8	9	11	43	41	56	57	39	37	38	_	_	_	_	_	_	_	_	_	_
		17	3	4	5	6	8	9	11	43	41	56	40	36	37	38	_	_	_	_	_	_	_	_	_	_
		18	3	4	6	7	52	53	54	55	9	11	41	42	56	40	36	37	38	_	_	_	_	_	_	_
		19	3	4	6	7	52	53	54	55	9	11	41	42	56	57	39	37	38	_	_	_	_	_	_	_
		20	3	4	6	7	52	53	54	55	9	11	41	56	40	36	37	38	_	_	_	_	_	_	_	_
		21	3	4	6	7	52	53	54	55	9	11	41	56	57	39	37	38	_	_	_	_	_	_	_	_
		22	3	4	5	6	7	52	53	54	55	9	11	41	42	56	40	36	37	38	_	_	_	_	_	_
		23	3	4	5	6	7	52	53	54	55	9	11	41	42	56	57	39	37	38	_	_	_	_	_	_
		24	3	4	5	6	7	52	53	54	55	9	11	41	56	40	36	37	38	_	_	_	_	_	_	_
		25	3	4	5	6	7	52	53	54	55	9	11	41	56	57	39	37	38	_	_	_	_	_	_	_
5	8	26	8	9	11	41	42	56	57	39	37	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		27	8	9	11	41	42	56	40	36	37	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		28	8	9	11	43	41	56	57	39	37	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		29	8	9	11	43	41	56	40	36	37	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		30	8	6	7	29	28	27	26	24	23	22	38	_	_	_	_	_	_	_	_	_	_	_	_	_
		31	8	6	7	29	28	27	26	24	25	30	31	32	34	35	36	37	38	_	_	_	_	_	_	_
		32	8	6	7	29	28	27	26	24	25	30	31	32	34	35	36	40	56	57	39	37	38	_	_	_
		33	8	7	29	28	27	26	24	23	22	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		34	8	7	29	28	27	26	24	25	30	31	32	34	35	36	37	38	_	_	_	_	_	_	_	_
		35	8	7	29	28	27	26	24	25	30	31	32	34	35	36	40	56	57	39	37	38	_	_	_	_
		36	8	6	5	4	18	19	20	21	22	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		37	8	6	5	4	18	19	20	21	22	23	24	25	30	31	32	34	35	36	37	38	_	_	_	_
		38	8	6	5	4	18	19	20	21	22	23	24	25	30	31	32	34	35	36	40	56	57	39	37	38
		39	8	6	4	18	19	20	21	22	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		40	8	6	4	18	19	20	21	22	23	24	25	30	31	32	34	35	36	37	38	_	_	_	_	_
		41	8	6	4	18	19	20	21	22	23	24	25	30	31	32	34	35	36	40	56	57	39	37	38	
7	12	42	12	10	51	50	49	48	38	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_
		43	12	10	51	50	49	38		_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_

II- Initial Power Loss Results

The initial power loss calculations shows that the minimum power loss occurs in path no. 33 passing through buses 8-7-29-28-27-26-24-23-22-38

III- PSO technique Results

Implementing the PSO technique it was found that the minimum power loss occurred also in path no. 33 passing through buses 8-7-29-28-27-26-24-23-22-38, after checking the condition of minimum power loss, reaching the maximum number of iterations and repeating the minimum value of power loss for three times.

The values of the angles of the selected buses of minimum power loss have changed as shown in Table 4.13 leading to the same path no.33 obtained from the initial calculations.

Table 4.13 The selected path θ_{gbest} and θ_i (initial values) for IEEE 57-bus system

Path	8	7	29	28	27	26	24	23	22	38
θ_i	-0.21	-0.24	-0.27	-0.3	-0.34	-0.37	-0.4	-0.43	-0.46	-0.49
θ_{gbest}	-0.0035	-0.0049	-٠.٠٠٦٣	-0.0077	- ٠.٠١٨٢	-٠.٠١٩٦	-0.0210	-0.0224	-0.0238	-0.0252

IV- Power Losses Results

The lowest Power Loss ($P_{lossmin}$) occurred on particles 1, 6 and 8 with a value equals to 0.02 as shown in Table 4.14.

Initially, the path number 33 is the path with the minimum power loss.

After PSO technique execution, path no. 33 is still the one with the minimum power loss. It means that the PSO technique did not find a better path with lower power losses. So the 33rd path is the optimum path of minimal power loss as shown in Table 4.15.

Table 4.14 Final total power loss results of the 33rd path for IEEE 57 bus system

Particle	Total Power Loss [MW]
1	0.02
2	0.08
3	0.15
4	0.24
5	0.36
6	0.02
7	0.66
8	0.02
9	1.05
10	1.29

Table 4.15 Power loss comparison between the initial and developed technique results for IEEE 57-bus system

Power Loss	P [MW]	Path No.
Initial Case (IEEE 57 bus System)	0.0294	33
Using PSO technique (IEEE 57 bus System)	0.0294	33

Figure 4.9 shows the path of the minimum power loss which is obtained from the initial power loss calculation as well as the PSO technique implementation for IEEE 57-bus system. The targeted path is illustrated using arrows.

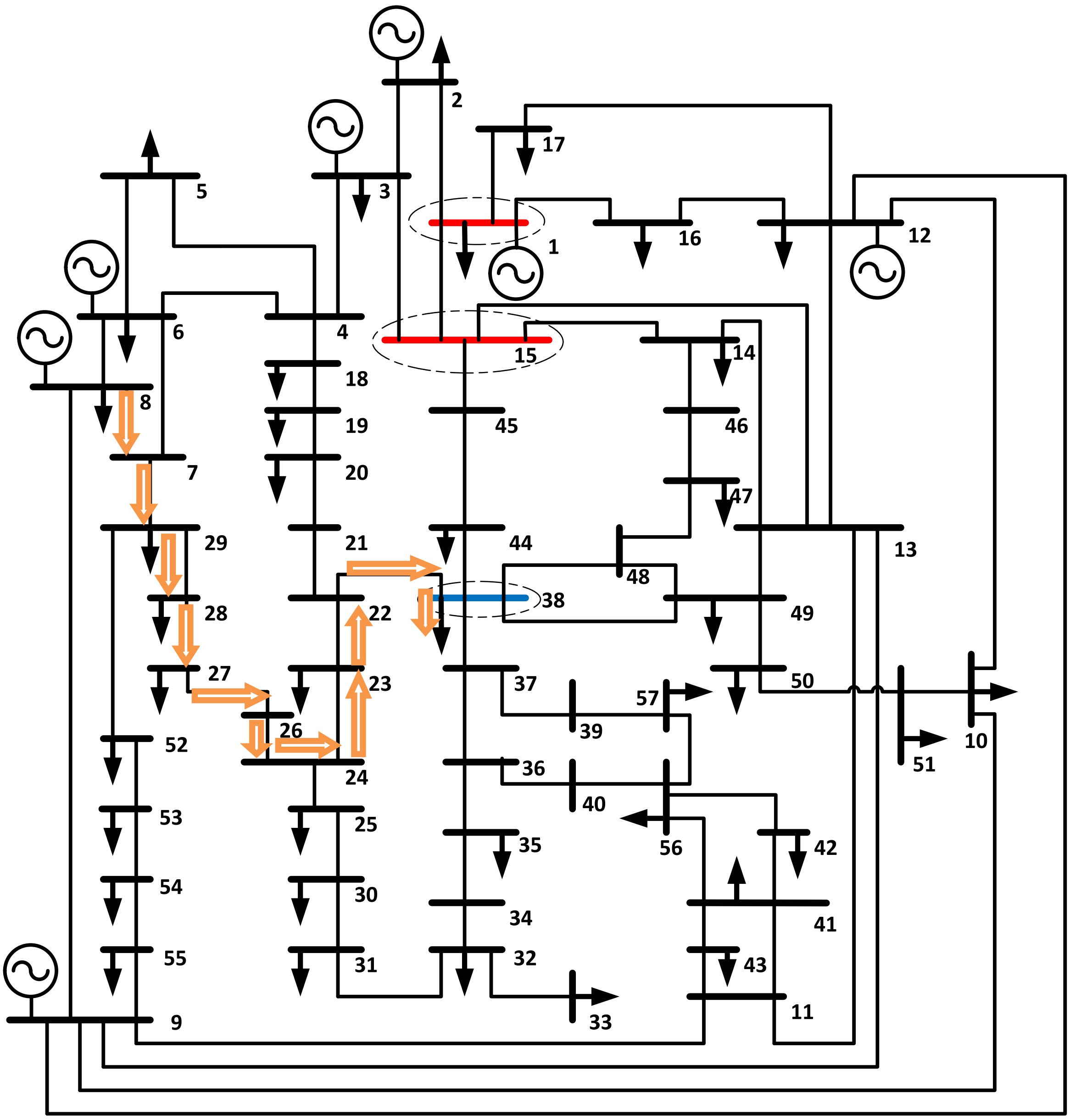

Fig. 4.9 Minimum power loss path for the IEEE 57-bus system

4.3.3 The Offshore Platform Electrical Power system

The Offshore Platform electrical system comprises 3 generators with total generation capacity of 27 MW. The network loads are considered to be lumped loads (hybrid combination between static and dynamic loads) as shown in Fig. 4.10.

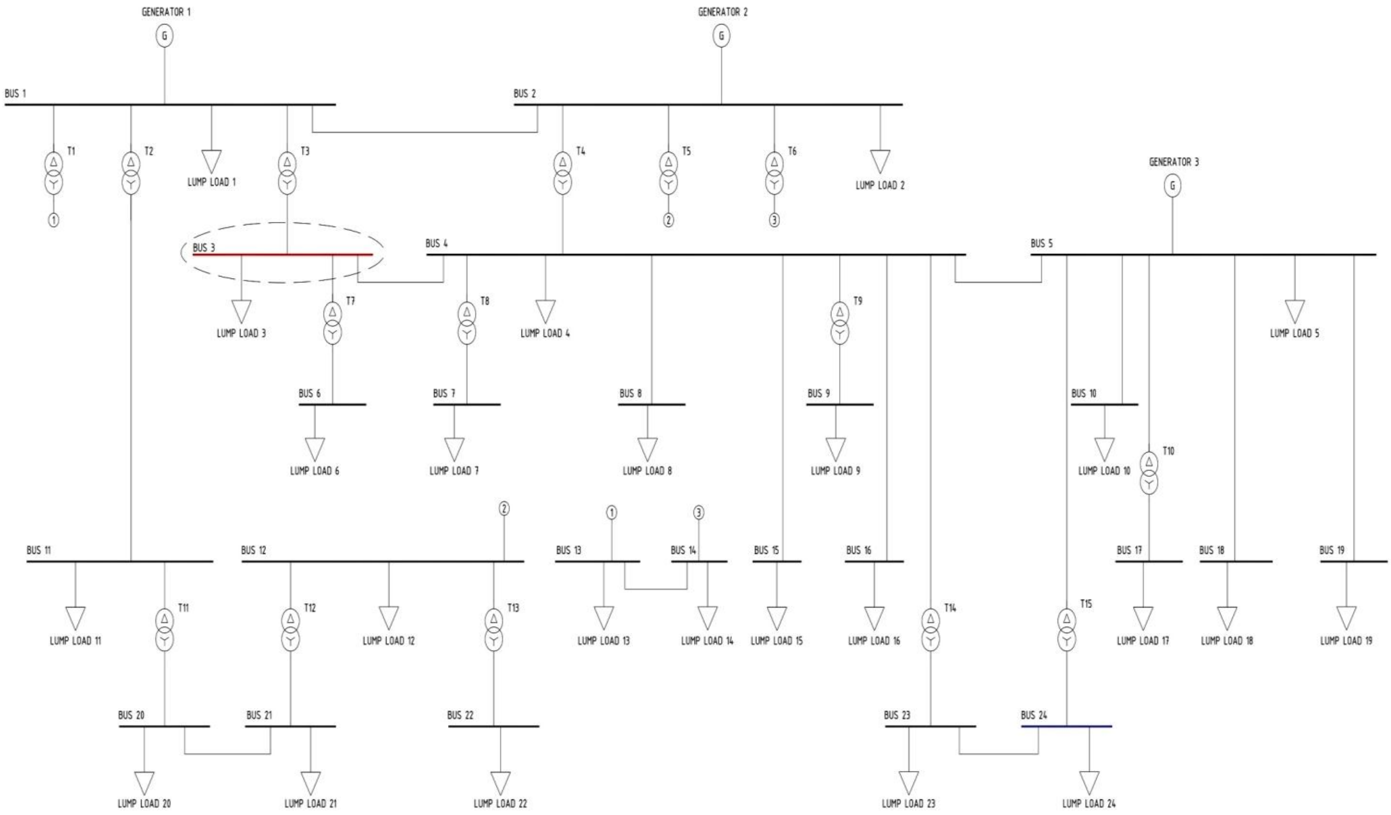

Fig. 4.10 The Offshore Platform electrical power system

I- Load Flow for the Offshore Platform electrical power system

The load flow of the Offshore Platform electrical system has been carried out using ETAP program for faulted and unfaulted (healthy) conditions. The fault occurs at bus-3.

The load flow results are obtained before the occurrence of the fault. The voltages' magnitudes and angles are shown in Table 4.16.

Table 4.16 Buses’ voltages magnitudes and angles extracted from the load flow report for the Offshore platform system (before fault)

Bus	Voltage % Magnitude	Voltage Angle (degrees)
1	100	0
2	99.958	0
3	98.446	-1.3
4	97.628	-1.4
5	96.867	-1.5
6	97.878	-1.7
7	97.596	-1.4
8	97.624	-1.4
9	97.263	-1.7
10	96.788	-1.5
11	99.155	-0.6
12	98.767	-0.9
13	98.948	-0.8
14	98.906	-0.8
15	97.619	-1.4
16	97.566	-1.4
17	96.118	-1.9
18	96.858	-1.5
19	96.798	-1.4
20	99.028	-0.7
21	98.640	-1.0
22	96.250	-2.4
23	95.519	-6.2
24	95.289	-2.4

Table 4.17 represents the offshore platform system buses’ voltages magnitudes and angles for the faulted (unhealthy) case as extracted from ETAP load flow report.

Table 4.17 Buses' voltages magnitudes and angles extracted from the load flow report for the Offshore platform system (after fault at bus-3)

Bus	Voltage % Magnitude	Voltage Angle (degrees)
1	100	0
2	99.955	0
3	removed after fault	
4	97.050	-2.0
5	96.286	-2.0
6	removed after fault	
7	97.018	-2.0
8	97.046	-2.0
9	96.683	-2.2
10	96.207	-2.0
11	99.155	-0.6
12	98.764	-0.9
13	98.948	-0.8
14	98.903	-0.8
15	97.041	-2.0
16	96.988	-2.0
17	95.534	-2.5
18	96.277	-2.0
19	96..217	-2.0
20	99.028	-0.7
21	98.636	-1.0
22	96.247	-2.4
23	95.515	-6.8
24	95.285	-3.0

II- Determination of Paths after fault at Bus-3

It is assumed that a fault occurs at bus-3. A critical load should be fed at bus-24. The available alternative paths which can feed the critical load is determined using the Matlab/m-file. The alternative paths are clarified in Table 4.18

Table 4.18 The available load feeding paths after fault occurrence at bus-3 in the Offshore Platform system

G	Bus	Path No.	Paths				
1	1	1	1	2	4	23	24
		2	1	2	4	5	24
2	2	3	2	4	23	24	-
		4	2	4	5	24	-
3	5	5	5	24	-	-	-
		6	5	4	23	24	-

III- Initial Power Loss Results

The initial power loss calculations show that path no. **3** has the minimum power loss of a value equal to 2.5543MW as presented in Table 4.19.

Table 4.19 Initial total power loss results for the Offshore platform system

Path	Total Power Loss (Plt) in [MW]
1	2.5820
2	15.7882
3	**2.5543**
4	١٥.٧٥٤٤
5	٣.٤٩٦٧
6	١٨.٣٠٨٧

IV- PSO technique Results

The PSO technique is applied to the Offshore Platform electrical power system to determine the optimal path of minimum power loss system, which can supply the critical load during the fault case. The PSO technique results in finding the fifth path as an alternative path with lower power loss than the third path (initially obtained).

The values of the particle swarm personal best of buses' angles "θpbest" is calculated from which the global best angles "θgbest" are obtained, as shown in Table 4.20.

Table 4.20 Results of θpbest and θgbest for the Offshore Platform system

θpbest (-)					
Path1	0	0.0018	0.0036	0.5556	0.5574
Path 2	0	0.0030	0.0060	0.0090	0.0120
Path 3	0	0.0244	0.0750	0.0750	_
Path 4	0	0.0667	0.0679	0.0691	_
Path 5	0.0262	0.0278	_	_	_
Path 6	0.0262	0.0276	0.5412	0.5426	_

⇨

θgbest (-)				
0.0262	0.0278	_	_	_

The initial values of the buses' voltages angles of path no. 5 are changed into θgbest as illustrated in Table 4.21.

Table 4.21 The selected path θgbest and θi (initial values) for the Offshore platform system

Path	5	24
θi	**-2.0**	**-3.0**
θgbest	**-0.0262**	**-0.0278**

V- Power Losses Results

The minimum power loss is obtained with each particle is shown in Table 4.22.The minimum Power Loss (Plossmin) occurs on particle (3) with value equals to 1.4580MW.

Table 4.22 Final total power loss results of the 5th alternative path for the Offshore Platform system

Particle	Total Power Loss [MW]
1	1.4635
2	1.4772
3	**1.4580**
4	1.5250
5	1.4592
6	1.6002
7	1.6481
8	1.4616
9	1.7643
10	1.4635

The new voltage angles of the alternative path buses' voltages lead to reduce the power losses of the system from 2.5543MW to 1.4580MW as clarified in Table 4.23. It leads to have another alternative path of a lower power loss which is the path going through the buses 5-24.

Table 4.23: Power loss comparison between the initial and developed technique results for the Offshore system

Power Loss	**P [MW]**	**Path No.**
Initial Case (Practical System)	2.5543	3
Using PSO technique (Practical System)	1.4580	5

In Figure 4.1, the dotted arrows show the initial path with minimum power loss (path no. **3**), while the solid arrows show the optimal alternative path (path no. **5**) after enhance the buses' voltages angles utilizing PSO technique.

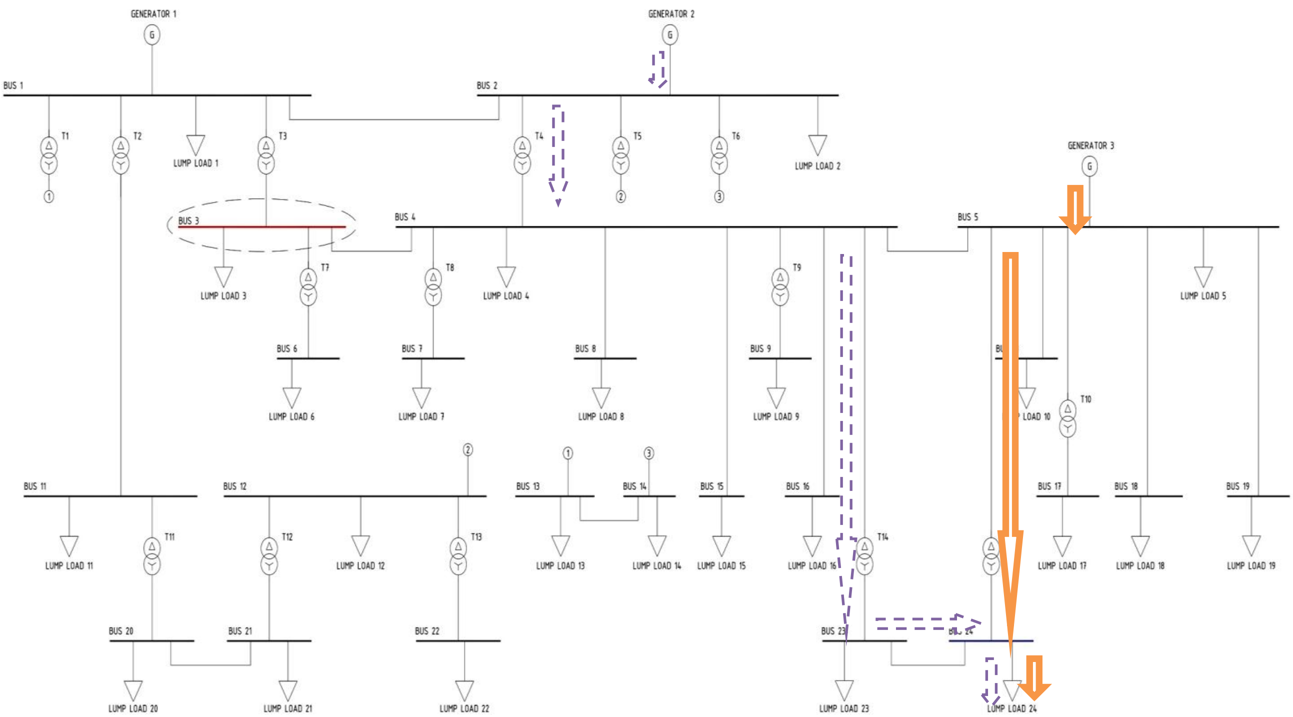

Fig. 4.11 Minimum power loss path for the Offshore Platform system

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK

CHAPTER FIVE

CONCLUSIONS AND FUTURE WORK

5.1 CONCLUSIONS

This research presents an intelligent smart grid which can achieve optimum power continuity and smart power flow control through transmission and distribution systems during any abnormal conditions.

The research targets to find all the alternative possible paths to feed a critical load in case of faulted network, then adjust the values of the paths buses voltages angles for optimizing the power flow of the optimal selected alternative path to be with minimum power losses. The buses voltages' magnitudes and loads active powers almost remain constant.

This work is developed through three stages, which are;

1- Simulating the power network on the ETAP simulation program to evaluate the power flow in normal healthy case and in abnormal conditions (faulted unhealthy cases).

2- Developing a Matlab/m-file program, to find all the possible alternative paths, for the power, to feed the system disconnected parts during the fault.

3- Developing a PSO technique program to find the optimal path. The PSO program finds the optimum values of the buses' voltage angles of the optimal path with fixed voltage magnitudes, for optimizing the power flow through minimizing its power loss. The PSO program is fed from the ETAP and the developed Matlab/m-file programs to determine the available alternative paths. The optimal determined path may have less power losses than that of the path already obtained by the initial power flow analysis.

The developed PSO technique succeeds in finding an available alternative power flow path and adjusting its buses voltages angles to be with minimum power loss in case of fault occurrence.

The technique is applied to a standard IEEE 14-Bus system, IEEE 57-Bus system and the Offshore Platform electrical distribution power system. The results illustrate that this technique can be used to achieve the optimal power flow continuity.

The conventional power loss calculation method is used to determine the initial power loss values. PSO technique is applied aiming to find a more optimal solution. After applying both the conventional power loss calculation method and PSO technique on all the studied cases, it is concluded that;

5.1.1 For IEEE standard systems:

PSO technique gives either the same results or better results than the initial conventional power loss calculation.

5.1.2 For the Offshore Platform electrical power system:

PSO technique gives better results than the initial power loss calculation.

5.2 FUTURE WORK

As a continuation of research in this thesis area, couple of suggestions are presented in the following points;

- Applying the thesis practically by calculating the equivalent required capacitor banks, which should be connected to the selected buses.
- Studying the subject of the thesis utilizing other different AI techniques.

REFERENCES

[1] Clark W. Gellings, "The Smart Grid: Enabling Energy Efficiency And Demand Response", The Fairmont Press, April 20, 2011.

[2] Andres Carvallo, and John Cooper, "The Advanced Smart Grid Edge Power Driving And Sustainability", Artech House, 2011.

[3] Rohjans, S., Uslar M. and Bleiker R., "Survey of Smart Grid Standardization Studies and Recommendations", Smart Grid Communications, 2010 First IEEE International Conference, October 2010.

[4] M. Godoy Simões, R. Roche, E. Kyriakides, A. Miraoui, B. Blunier, K. McBee, S. Suryanarayanan, P Nguyen and P. Ribeiro "Smart-Grid Technologies and Progress in Europe and the USA", IEEE Energy Conversion Congress and Exposition (ECCE), September 17, 2011.

[5] S. M. Amin, "For the good of the grid", IEEE Power and Energy Magazine, Vol. 6, No. 6, pp. 48-59, Oct. 2008.

[6] S. Chakrabarti, E. Kyriakides, and D. G. Eliades, "Placement of synchronized measurements for power system observability", IEEE Transactions on Power Delivery, Vol. 24, No. 1, pp. 12-19, Jan. 2009.

[7] IEEE Smart Grid, IEEE: The Expertise To Make Smart Grid A Reality, Smart Grid Conceptual Model
[Online]: http://smartgrid.ieee.org/ieee-smart-grid/smart-grid-conceptual-model

[8] Chuck Goldman and Roger Levy "An Introduction- Smart Grid 101" Lawerence Berkely National Laborator, Smart Grid Technical Advisory Project, February 2010.

[9] Yiman Wang, Yemula P. and Bose A., "Decentralized Communication and Control Systems for Power System Operation", Smart Grid, IEEE Transactions, Volume 6, Issue 2, October 2014.

[10] Qiqi Zhang, Shentu Gang and Puming Li, "Smart City Grid: The Start to Develop Smart Grid ", E-Product E-Service and E-Entertainment (ICEEE),

2010 International Conference, 7-9 November 2010.

[11] Fangxing Li, Wei Qiao, Hongbin Sun, Jianhui Wang, Yan Xia, Zhao Xu, and Pei Zhang, "Smart Transmission Grid: Vision and Framework", IEEE Transactions on Smart Grid, Vol. 1, No. 2, September 2010.

[12] Hatice Tekiner, David W. Coit, Frank A. Felder, "Effects Of Smart Grid Technologies on Generation Expansion Plans", IEEE Transactions on Power Delivery, Vol. 17, No. 1, pp. 33-46, January 2002.

[13] Ronald G. Harley and Jiaqi Liang, "Computational Intelligence in Smart Grids", National Science Foundation, Series on Computational Intelligence (SSCI), 2011.

[14] Sumit Paudyal, Claudio A. Ca˜nizares, and Kankar Bhattacharya, "Optimal Operation Of Distribution Feeders in Smart Grids", IEEE Transactions On Industrial Electronics, January 2011.

[15] China Smart Grid Strategy, July 2009.
[Online]: http://www.ceptchina.com/UserFiles/File/1247447637955.pdf

[16] A.Einfalt, F.Kupzog, H.Brunner and A. Lugmaier, "Control Strategies for Smart Low Voltage Grids – the Project DG DemoNet-Smart LV Grid" CIRED 2012 Workshop: Integration of Renewables into the Distribution Grid, May 2012.

[17] J. A. Pecas Lopes, F. J. Soares and P. M. Almeida, "Smart Charging Strategies for Electric Vehicles: Enhancing Grid Performance and Maximizing the Use of Variable Renewable Energy Resources", EVS24 International Battery, Hybrid and Fuel Cell Electric Vehicle Symposium, Stavanger, Norway, May 2009.

[18] Sarvapali D. Ramchurn, Perukrishnen Vytelingum and Alex Rogers"Putting The 'Smarts' Into The Smart Grid: A Grand Challenge For Artificial Intelligence", Communications of the ACM, Volume 55, Issue 4, April 2012

[19] Ye Yan, Yi Qian, Sharif H. and Tipper D., "A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges", Communications Surveys and Tutorials, IEEE, Vol. 15, Issue: 1, February 2013.

[20] Stefanovic C., Loncar Turukalo and Japundzic Zigon, “An Evolutionary Path To Smart Grid Communications Over Converged Telecom and Energy Provider Networks”, Wireless Communications, Vehicular Technology, Information Theory and Aerospace & Electronic Systems (VITAE), 2014 4th International Conference, May 2014

[21] L. Guy Jackson, M. Shan Griffith, Stephen S. Miller, Glenn E. Word, Chet E. Davis, "IEEE Recommended Practice for Industrial & Commercial Power System Analysis ", IEEE Std 399-1997, September 1997.

[22] E. Benedict, T. Collins, D. Gotham, S. Hoffman, D. Karipides, S. Pekarek, and R. Ramabhadran, "Losses In Electric Power Systems", ECE Technical Reports. Paper 266, December 1992.

[23] Alfred Still, "Electric Power Transmission”, Third Edition, New York, 1927.

[24] Zaborszky & Rittenhouse, "Electric Power Transmission", New York, 1969.

[25] C.M.Ong, "EE 432 Class Notes", Purdue University, Fall 1992.

[26] W.D. Stevenson Jr., "Elements of Power System Analysis, Fourth Edition", New York, 1982.

[27] Westinghouse Electric Corp., "Transmission and Distribution Reference Fourth Edition", Penn., 1950.

[28] Fitzgerald & Kingsley, "Electric Machinery”, Fourth Edition, New York, 1990.

[29] D. I. H. Sun, S. Abe, R. R. Shoults, M. S. Chen, P. Eichenberger, D. Farris, "Calculation of Energy Losses in a Distribution System," IEEE Transactions on Power Apparatus and Systems, v. PAS-99, No. 4, Jul. 1980.

[30] John J. Grainger and William D. Stevenson, “Power System Analysis,” McGraw-Hill, International Editions 1994.

[31] H. W. Ng, R. Hasegawa, A. C. Lee, L. A. Lowdermilk, "Amorphous

Alloy Core Distribution Transformers," IEEE Proceedings,V. 79, No. 11, Nov. 1991.

[32] T. Gonen, "Electric Power Distribution System Engineering", 1986.

[33] ETAP Power System Software.
[Online]:http://etap.com/index.htm

[34] P. Tarasewich, and P. R. McMullen, "Swarm Intelligence: Power in Numbers", Appears in Communications of the ACM, pp. 62-67, August 2002.
[Online]: http:// www.ccs.neu.edu/home/tarase/TaraseMcMullSwarm.pdf

[35] K. E. Parsopoulos, and M. N. Vrahatis, "Recent Approaches to Global Optimization Problems through Particle Swarm Optimization", 2002. [Online]: http://www.math. upatras.gr/~kostasp/papers/NatComp.pdf

[36] L. H. Tsoukalas, and R. E. Uhrig, "Fuzzy and Neural Networks Approaches in Engineering", John Wiley & Sons, Inc., 1997.

[37] F. Van Den Bergh, "An Analysis of Particle Swarm Optimizer", Ph.D. Dissertation, Faculty of Natural and Agricultural Science, Univ. Pretoria, South Africa, 2001.
[Online]: http://www.cs.up.ac.za/cs/fvdbergh/ publications.php

[38] J. R. Koza, "Genetic Programming", Encyclopedia of Computer Science and Technology, 1998.
[Online]: http://citeseer.ist.psu.edu/212034.html

[39] X. Yao, "Global Optimization by Evolutionary Algorithms", Parallel Algorithms/Architecture Synthesis Symposium, pp. 282-291, 1997.

[40] J. Kennedy, and R. Eberhart, "Particle Swarm Optimization", IEEE Neural Networks Conf., IEEE Service center, Piscataway, NJ, pp. 1942-1948, 1995.

[41] R. Eberhart, and X. Hu, "Human Tremor Analysis Using Particle Swarm Optimization", 1999.
[Online]: http://web.ics.purdue.edu/~hux/papers/ CEC1999Human.pdf

[42] A. I. El-Gallad, M. E. El-Hawary, A. A. Sallam, and A. Kalas, "Swarm

Intelligent Trained Neural Network for Power Transformer Protection", Canadian Electrical and Computer Engineering Conf., Vol. 2, pp. 265-269, 2001.

[43] A. I. El-Gallad, M. E. El-Hawary and A. A. Sallam, "Swarming of Intelligent Particles for Solving the Nonlinear Constrained Optimization Problem", Engineering Intelligent Systems, Vol. 9, No. 3, pp. 155-163, September 2001.

[44] A. I. El-Gallad, M. E. El-Hawary, A. A. Sallam, and A. Kalas, "Swarm Intelligent for Hybrid Cost Dispatch Problem", Canadian Electrical and Computer Engineering Conf., Vol. 2, pp. 753-757, 2001.

[45] J. Kennedy, and R. Eberhart, "A New Optimizer Using Particle Swarm Theory", Symposium on Micro Machine and Human Science (Nagoya, Japan), IEEE Service center, Piscataway, NJ, pp. 39-43, 1995.

[46] J. Robinson, and Y. Rahmat-Samii, "Particle Swarm Optimization in Electromagnetics", IEEE Transactions on Antennas and Propagation, Vol. 52, No. 2, pp.397-407, February 2004.

[47] J. Robinson, S. Sinton, and Y. Rahmat-Samii, "Particle Swarm, Genetic Algorithm, and Their Hybrids: Optimization of a Profiled Corrugated Horn Antenna", IEEE Symposium on Antennas Propagation, Vol. 1, pp. 314-317, 2002.

[48] S. Naka, T. Genji, T. Yura, and Y. Fukuyama, "A Hybrid Particle Swarm Optimization for Distribution State Estimation", IEEE Transactions on Power Systems, Vol. 18, No. 1, pp. 60-68, February 2003.

[49] G. Venter, and J. S. Sobieski, "Multidisciplinary Optimization of a Transport Aircraft Wing Using Particle Swarm Optimization", Published by the American Institute of Aeronautics and Astronautics, 2002.
[Online]: http://www.vrand.com/pub/vs_mdo_ 2002. pdf

[50] Y. Fukuyama, and H. Yoshida, "A Particle Swarm Optimization for Reactive Power and Voltage Control in Electric Power Systems", Evolutionary Computation Congress, Vol. 1, pp. 87-93, 2001.

[51] Z. L. Gaing, "Particle Swarm Optimization to Solving the Economic Dispatch Considering the Generator Constraints", IEEE Transactions on

Power Systems, Vol. 18, No. 3, pp. 1187-1195, August 2003.

[52] J. B. Park, K. S. Lee, J. R. Shin, and K. Y. Lee, "A Particle Swarm Optimization for Economic Dispatch with Nonsmooth Cost Functions", IEEE Transactions on Power Systems, Vol. 20, No. 1, pp. 34-42, February 2005.

[53] Z. L. Gaing, "A Particle Swarm Optimization Approach for Optimum Design of PID Controller in AVR System", IEEE Transactions on Energy Conversion, Vol. 19, No. 2, pp. 384-391, June 2004.

[54] M. A. Abido, "Particle Swarm Optimization for Multimachine Power System Stabilizer Design", Power Engineering Society Summer Meeting, Vol. 3, pp. 1346–1351, 2001.

[55] I. N. Kassabalidis, M. A. El-Sharkawi, R. J. Marks, L. S. Moulin, and A. P. Alves da Silva, "Dynamic Security Border Identification Using Enhanced Particle Swarm Optimization", IEEE Transactions on Power Systems, Vol. 17, No. 3, pp.723-729, August 2002.

[56] C. F. Juang, "A Hybrid of Genetic Algorithm and Particle Swarm Optimization for Recurrent Network Design", IEEE Transactions on Systems, Man, and Cybernetics, Vol. 34, No. 2, pp. 997-1006, April 2004.

[57] D. W. Boeringer, and D. H. Werner, "Particle Swarm Optimization Versus Genetic Algorithms for Phased Array Synthesis", IEEE Transactions on Antennas and Propagation, Vol. 52, No. 3, pp.771- 779, March 2004.

[58] U. Baumgartner, Ch. Magele, and W. Renhart, "Pareto Optimality and Particle Swarm Optimization", IEEE Transactions on Magnetics, Vol. 40, No. 2, pp. 1172-1175, March 2004.

[59] Yamille del Valle, Ganesh Kumar Venayagamoorthy, Salman Mohagheghi, Jean-Carlos Hernandez, Ronald G. Harley, "Particle Swarm Optimization: Basic Concepts, Variants and Applications in Power Systems", IEEE Transactions on Evolutionary Computation, Vol. 12, No. 2, April 2008.

[60] A. S Kannan, and R. Kayalvizhi, "Utility of PSO for Loss Minimization and Enhancement of Voltage Profile Using UPFC", International Journal of Scientific and Engineering Research, Vol. 2, No. 2, February 2011.

[61] S. Agrawal, T. Bakshi and D. Majumdar, “Economic Load Dispatch of Generating Units with Multiple Fuel Options Using PSO”, International Journal of Control and Automation, Vol. 5, No. 4, December 2012.

[62] Amanpreet Kaur and M.D. Singh, “An Overview of PSO-Based Approaches in Image Segmentation”, International Journal of Engineering and Technology, Vol. 2, No. 8, August 2012.

[63] M. Fikret Ercan and Xiang Li, “Particle Swarm Optimization and Its Hybrids”, International Journal of Computer and Communication Engineering, Vol. 2, No. 1, January 2013.

[64] Noha H. El-Amary, Mohammed A. Badr, Mohammed M. Mansour, Yasser G. Mostafa and Said F. Mekhamer, “State Estimation And Observability Of Large Power System Using Phasor Measurement Units”, Ain Shams University, Faculty Of Engineering, Electrical Power And Machines Department, 2009.

APPENDIX

A.1 THE 14-BUS IEEE STANDARD SYSTEM [64]

I. Bus Data

Bus No.	Bus Type	P_d (MW)	Q_d (MVAR)	G_s (MW)	B_s (MVAR)	V_m (p.u.)	V_a (degrees)
1	3	0	0	0	0	1.06	0
2	2	21.7	12.7	0	0	1.045	-4.98
3	2	94.2	19	0	0	1.01	-12.72
4	1	47.8	-3.9	0	0	1.019	-10.33
5	1	7.6	1.6	0	0	1.02	-8.78
6	2	11.2	7.5	0	0	1.07	-14.22
7	1	0	0	0	0	1.062	-13.37
8	2	0	0	0	0	1.09	-13.36
9	1	29.5	16.6	0	19	1.056	-14.94
10	1	9	5.8	0	0	1.051	-15.1
11	1	3.5	1.8	0	0	1.057	-14.79
12	1	6.1	1.6	0	0	1.055	-15.07
13	1	13.5	5.8	0	0	1.05	-15.16
14	1	14.9	5	0	0	1.036	-16.04

Where, Bus Type (1) is PQ bus.

Bus Type (2) is PV bus.

Bus Type (3) is Swing bus.

II. Branch Data

FBus	TBus	R (p.u.)	X (p.u.)	B (p.u.)	Trans. Ratio
1	**2**	0.01938	0.05917	0.0528	0
1	**5**	0.05403	0.22304	0.0492	0
2	**3**	0.04699	0.19797	0.0438	0
2	**4**	0.05811	0.17632	0.034	0
2	**5**	0.05695	0.17388	0.0346	0
3	**4**	0.06701	0.17103	0.0128	0
4	**5**	0.01335	0.04211	0	0
4	**7**	0	0.20912	0	0.978
4	**9**	0	0.55618	0	0.969
5	**6**	0	0.25202	0	0.932
6	**11**	0.09498	0.1989	0	0
6	**12**	0.12291	0.25581	0	0
6	**13**	0.06615	0.13027	0	0
7	**8**	0	0.17615	0	0
7	**9**	0	0.11001	0	0
9	**10**	0.03181	0.0845	0	0
9	**14**	0.12711	0.27038	0	0
10	**11**	0.08205	0.19207	0	0
12	**13**	0.22092	0.19988	0	0
13	**14**	0.17093	0.34802	0	0

A.2 THE 57-BUS IEEE STANDARD SYSTEM [64]

I. Bus Data

Bus No.	Bus Type	P_d (MW)	Q_d (MVAR)	G_s (MW)	B_s (MVAR)	V_m (p.u.)	V_a (degrees)
1	3	55	17	0	0	1.04	0
2	2	3	88	0	0	1.01	-1.18
3	2	41	21	0	0	0.985	-5.97
4	1	0	0	0	0	0.981	-7.32
5	1	13	4	0	0	0.976	-8.52
6	2	75	2	0	0	0.98	-8.65
7	1	0	0	0	0	0.984	-7.58
8	2	150	22	0	0	1.005	-4.45
9	2	121	26	0	0	0.98	-9.56
10	1	5	2	0	0	0.986	-11.43
11	1	0	0	0	0	0.974	-10.17
12	2	377	24	0	0	1.015	-10.46
13	1	18	2.3	0	0	0.979	-9.79
14	1	10.5	5.3	0	0	0.97	-9.33
15	1	22	5	0	0	0.988	-7.18
16	1	43	3	0	0	1.013	-8.85
17	1	42	8	0	0	1.017	-5.39
18	1	27.2	9.8	0	10	1.001	-11.71
19	1	3.3	0.6	0	0	0.97	-13.2
20	1	2.3	1	0	0	0.964	-13.41

21	1	0	0	0	0	1.008	-12.89
22	1	0	0	0	0	1.01	-12.84
23	1	6.3	2.1	0	0	1.008	-12.91
24	1	0	0	0	0	0.999	-13.25
25	1	6.3	3.2	0	5.9	0.982	-18.13
26	1	0	0	0	0	0.959	-12.95
27	1	9.3	0.5	0	0	0.982	-11.48
28	1	4.6	2.3	0	0	0.997	-10.45
29	1	17	2.6	0	0	1.01	-9.75
30	1	3.6	1.8	0	0	0.962	-18.68
31	1	5.8	2.9	0	0	0.936	-19.34
32	1	1.6	0.8	0	0	0.949	-18.46
33	1	3.8	1.9	0	0	0.947	-18.5
34	1	0	0	0	0	0.959	-14.1
35	1	6	3	0	0	0.966	-13.86
36	1	0	0	0	0	0.976	-13.59
37	1	0	0	0	0	0.985	-13.41
38	1	14	7	0	0	1.013	-12.71
39	1	0	0	0	0	0.983	-13.46
40	1	0	0	0	0	0.973	-13.62
41	1	6.3	3	0	0	0.996	-14.05
42	1	7.1	4.4	0	0	0.966	-15.5
43	1	2	1	0	0	1.01	-11.33
44	1	12	1.8	0	0	1.017	-11.86

45	1	0	0	0	0	1.036	-9.25
46	1	0	0	0	0	1.05	-11.89
47	1	29.7	11.6	0	0	1.033	-12.49
48	1	0	0	0	0	1.027	-12.59
49	1	18	8.5	0	0	1.036	-12.92
50	1	21	10.5	0	0	1.023	-13.39
51	1	18	5.3	0	0	1.052	-12.52
52	1	4.9	2.2	0	0	0.98	-11.47
53	1	20	10	0	6.3	0.971	-12.23
54	1	4.1	1.4	0	0	0.996	-11.69
55	1	6.8	3.4	0	0	1.031	-10.78
56	1	7.6	2.2	0	0	0.968	-16.04
57	1	6.7	2	0	0	0.965	-16.56

II. Branch Data

FBus	TBus	R (p.u.)	X (p.u.)	B (p.u.)	Trans. Ratio
1	**2**	0.0083	0.028	0.129	0
1	**15**	0.0178	0.091	0.0988	0
1	**16**	0.0454	0.206	0.0546	0
1	**17**	0.0238	0.108	0.0286	0
2	**3**	0.0298	0.085	0.0818	0
3	**4**	0.0112	0.0366	0.038	0
3	**15**	0.0162	0.053	0.0544	0
4	**5**	0.0625	0.132	0.0258	0

4	**6**	0.043	0.148	0.0348	0
4	**18**	0	0.555	0	0.97
4	**18**	0	0.43	0	0.978
5	**6**	0.0302	0.0641	0.0124	0
6	**7**	0.02	0.102	0.0276	0
6	**8**	0.0339	0.173	0.047	0
7	**8**	0.0139	0.0712	0.0194	0
7	**29**	0	0.0648	0	0.967
8	**9**	0.0099	0.0505	0.0548	0
9	**10**	0.0369	0.1679	0.044	0
9	**11**	0.0258	0.0848	0.0218	0
9	**12**	0.0648	0.295	0.0772	0
9	**13**	0.0481	0.158	0.0406	0
9	**55**	0	0.1205	0	0.94
10	**12**	0.0277	0.1262	0.0328	0
10	**51**	0	0.0712	0	0.93
11	**13**	0.0223	0.0732	0.0188	0
11	**41**	0	0.749	0	0.955
11	**43**	0	0.153	0	0.958
12	**13**	0.0178	0.058	0.0604	0
12	**16**	0.018	0.0813	0.0216	0
12	**17**	0.0397	0.179	0.0476	0
13	**14**	0.0132	0.0434	0.011	0
13	**15**	0.0269	0.0869	0.023	0

13	**49**	0	0.191	0	0.895
14	**15**	0.0171	0.0547	0.0148	0
14	**46**	0	0.0735	0	0.9
15	**45**	0	0.1042	0	0.955
18	**19**	0.461	0.685	0	0
19	**20**	0.283	0.434	0	0
21	**20**	0	0.7767	0	1.043
21	**22**	0.0736	0.117	0	0
22	**23**	0.0099	0.0152	0	0
22	**38**	0.0192	0.0295	0	0
23	**24**	0.166	0.256	0.0084	0
24	**25**	0	1.182	0	1
24	**25**	0	1.23	0	1
24	**26**	0	0.0473	0	1.043
25	**30**	0.135	0.202	0	0
26	**27**	0.165	0.254	0	0
27	**28**	0.0618	0.0954	0	0
28	**29**	0.0418	0.0587	0	0
29	**52**	0.1442	0.187	0	0
30	**31**	0.326	0.497	0	0
31	**32**	0.507	0.755	0	0
32	**33**	0.0392	0.036	0	0
34	**32**	0	0.953	0	0.975
34	**35**	0.052	0.078	0.0032	0

35	**36**	0.043	0.0537	0.0016	0
36	**37**	0.029	0.0366	0	0
36	**40**	0.03	0.0466	0	0
37	**38**	0.0651	0.1009	0.002	0
37	**39**	0.0239	0.0379	0	0
38	**44**	0.0289	0.0585	0.002	0
38	**48**	0.0312	0.0482	0	0
38	**49**	0.115	0.177	0.003	0
39	**57**	0	1.355	0	0.98
40	**56**	0	1.195	0	0.958
41	**42**	0.207	0.352	0	0
41	**43**	0	0.412	0	0
44	**45**	0.0624	0.1242	0.004	0
46	**47**	0.023	0.068	0.0032	0
47	**48**	0.0182	0.0233	0	0
48	**49**	0.0834	0.129	0.0048	0
49	**50**	0.0801	0.128	0	0
50	**51**	0.1386	0.22	0	0
52	**53**	0.0762	0.0984	0	0
53	**54**	0.1878	0.232	0	0
54	**55**	0.1732	0.2265	0	0
56	**41**	0.553	0.549	0	0
56	**42**	0.2125	0.354	0	0
57	**56**	0.174	0.26	0	0

A.3 THE OFFSHORE PLATFORM ELECTRICAL POWER SYSTEM

I. Bus Data

Bus No.	Bus Type	P_d (MW)	Q_d (MVAR)	G_s (MW)	B_s (MVAR)	V_m (p.u.)	V_a (degrees)
1	3	2.683	1.663	0	0	1.04	0
2	1	2.683	1.663	0	0	1.01	-1.18
3	1	0.557	0.345	0	0	0.985	-5.97
4	1	0.557	0.345	0	0	0.981	-7.32
5	1	0.068	0.042	0	0	0.976	-8.52
6	1	0.045	0.028	0	0	0.98	-8.65
7	1	0.003	0.002	0	0	0.984	-7.58
8	1	0.003	0.002	0	0	1.005	-4.45
9	1	0.029	0.018	0	0	0.98	-9.56
10	1	0.065	0.040	0	0	0.986	-11.43
11	1	0.501	0.310	0	0	0.974	-10.17
12	1	0.501	0.310	0	0	1.015	-10.46
13	1	0.634	0.393	0	0	0.979	-9.79
14	1	0.634	0.393	0	0	0.97	-9.33
15	1	0.023	0.014	0	0	0.988	-7.18
16	1	0.032	0.020	0	0	1.013	-8.85
17	1	0.059	0.036	0	0	1.017	-5.39
18	1	0.022	0.014	0	0	1.001	-11.71
19	1	0.036	0.022	0	0	0.97	-13.2

20	1	0.010	0.006	0	0	0.964	-13.41
21	1	0.010	0.006	0	0	1.008	-12.89
22	1	0.196	0.121	0	0	1.01	-12.84
23	1	0.584	0.362	0	0	1.008	-12.91
24	1	0.122	0.076	0	0	0.999	-13.25

II. Branch Data

FBus	TBus	R (p.u.)	X (p.u.)	B (p.u.)	Trans. Ratio
1	**2**	0.1322	0.0940	0	0
3	**4**	0.1322	0.0940	0	0
4	**5**	0.1322	0.0940	0	0
4	**8**	0.1062	0.0860	0	0
4	**15**	0.1024	0.0345	0	0
5	**10**	0.0408	0.0420	0	0
5	**18**	0.1024	0.0345	0	0
5	**19**	0.5553	0.0740	0	0
23	**24**	0.1249	0.0940	0	0

ملخص بحث رسالة ماجستير بعنوان

التحكم المثالى فى تدفق القوى الكهربية بالشبكة الذكية

باستخدام تقنية ذكاء اصطناعى حديثة متقدمة

اسم الباحث : محمد فتحى عبد الحميد الفخرانى

اسم الدرجة : ماجستير في الهندسة الكهربية

ملخص الرسالة

يستهدف هذا البحث التحكم الذكي في تدفق الطاقة الكهربية بنظم التوزيع والنقل. حيث تمثل الاستمرارية المثلى للطاقة الكهربية من خلال إدارة الطاقة والاصلاح الذاتي، والاعتمادية العالية والتسعير في الوقت الحقيقي ابرز الأهداف الرئيسية في مجال ابحاث الطاقة الكهربية. فقد تم تمثيل شبكة قوى كهربية ذكية، في هذا البحث، لتوفير استمرارية تدفق الطاقة الكهربية بأقل فاقد ممكن في حال وجود أي عطل بالشبكة.

ويتم تحقيق استمرارية الطاقة المثلى باستخدام التقنية الحديثة لخوارزمات إيجاد الحل الأمثل بطريقة حشد الجزيئات (PSO). حيث تمت برمجة هذه التقنية لإنجاز مهمتين رئيسيتين، وهما: المهمة الأولى: وتتمثل في ايجاد جميع المسارات البديلة الممكنة لامداد الأحمال الكهربية في حالة حدوث أعطال أو حالات تشغيل غير منطقية. اما المهمة الثانية: فتكون بتعديل زوايا جهد القضبان المشاركة في المسارات البديلة بنظام الطاقة الكهربية لتحديد المسار الأمثل مع الحد الأدنى من فقدان الطاقة. حيث وجد انه من الممكن أن يكون المسار الأمثل المحدد ذو فاقد طاقة أقل من المسارالذى تم تحديده عن طريق التحليل الاولي لتدفق الطاقة. فمن الممكن تعديل زوايا الجهد باستخدام المعوضات الثابتة للقوى التخيلية (VAR) وبنوك المكثفات، أوتكنولوجيا أجهزة نظام ناقل الطاقة المرنة (FACTS). و يقوم هذا البحث من خلال ثلاث مراحل رئيسية، وهم: المرحلة الأولى، وبها يتم محاكاة النظام باستخدام برنامج (ETAP). اما المرحلة الثانية، وبها يتم تحديد جميع المسارات البديلة الممكنة لتغذية الحمل المتأثر بالعطل. والمرحلة الثالثة، وهي لأختيار المسار الأمثل وفقا لزوايا الجهد الكهربي المعدلة المثالية.

وتم اختبار أداء هذه التقنية المتقدمة على كلا نظامي القوى IEEE القياسيين ذوي ١٤ و ٥٧ من قضبان التوصيل، كما تم اختبارها على نظام عملي لتوزيع الطاقة الكهربية لمنصة بحرية. حيث وجد أن نتائج الأختبارات للأنظمة الثلاثة التي تم الحصول عليها نتائج مقبولة.

وتحتوي هذه الرسالة علي خمسة فصول، تم تناولها على النحو الآتي:

الفصل الأول:

ويشمل المقدمة، ويمثل فصل تمهيدي للرسالة. حيث يقدم ما هو المقصود من الشبكة الذكية، وكيفية اختلافها عن شبكة القوى الكهربية التقليدية القائمة، ومدى الاحتياج إلى تنفيذ الشبكات الذكية، والخلفية التاريخية لتلك الشبكات. وقد اختتم الفصل بالأهداف والخطة المقترحة في هذا البحث مع عرض ملخص بسيط لكل فصل.

الفصل الثاني:

ويناقش الفصل الثانى المفاهيم الرئيسية لتدفق القوى والطاقة المفقودة في نظم القوى الكهربية. ويشرح الفصل الأهداف الرئيسية من الشبكة الذكية المقدمة في هذا البحث، وهى التقليل من فقدان الشبكة الكهربية للطاقة وتعظيم القوى التى تصل للمستخدمين والتي تؤدي الى اعتبارالتحكم فى فقدان القوى أحد الموضوعات الرئيسية في مجال بحوث نظم الطاقة الكهربية.

الفصل الثالث:

ويقدم تقنية إيجاد الحل الأمثل بطريقة حشد الجزيئات (PSO). والتي تعمل على تحديد المسار البديل، ذو الحد الأدنى من الطاقة المفقودة، لتوصيل الطاقة الكهربية للاحمال الحرجة ذات الاولوية القصوى في استمرار العمل، وذلك في حالة حدوث عطل في مسار التغذية الكهربية الرئيسي الخاص بهذا الحمل. كما تعمل تقنية ال (PSO) على حساب زواية الجهد الخاصة بقضبان التوصيل بالنظام الكهربي، وذلك في الحدود التقنية المسموح بها لتوجيه الطاقة الي هذا المسار وتقليل الطاقة المفقودة الي اقصى حد. وتم تصميم برنامج باستخدام ال Matlab لهذه التقنية واختبارها على كلا نظامي ال IEEE القياسيين ذوي ١٤ و ٥٧ من قضبان التوصيل. كما تم تطبيق التقنية أيضا على نظام عملي للقوى الكهربية. ويتم توضيح خوارزمات وخريطة برمجة البرنامج المصمم لتطبيق تلك التقنية.

الفصل الرابع

ويوضح الفصل الرابع المراحل الثلاث الرئيسية لهذا العمل، وهم: أولا، محاكاة شبكات الطاقة الخاصة بالانظمة المدروسة على برنامج ال (ETAP)، وحساب وتحليل تدفق الطاقة بالانظمة المدروسة في حالة التشغيل الطبيعية، وفي الحالات المعيبة. ثانيا، استخدام برنامج ال Matlab/m-file لتحديد كافة المسارات البديلة الممكنة للطاقة لتغذية الاحمال الحرجة وأجزاء النظام المنفصلة بعد حدوث العطل. ثالثا، تطبيق تقنية إيجاد الحل الأمثل بطريقة حشد الجزيئات (PSO) للعثور على مسار التوصيل البديل والأمثل ذي الحد الأدنى من الطاقة المفقودة. كما تم اختبار البحث على كلا نظامي ال IEEE القياسيين ذوي ١٤ و ٥٧ من قضبان التوصيل ونظام عملي للقوى الكهربية لمنصة بحرية. حيث أظهرت نتائج الأنظمة المدروسة نتائج مقبولة وذلك بعد اجراء مقارنة بين نتائج الحسابات الاولية لتحديد للمسارات البديلة والطاقة المفقودة بها قبل تطبيق التقنية الحديثة وبعدها، ومناقشتها في هذا الفصل.

الفصل الخامس

ويشمل خلاصة البحث والتوصيات المقترحة.

وأخيراً يضم البحث ملحق إضافي يعرض البيانات الخاصة بكلا نظامي ال IEEE القياسيين ذوي ١٤ و ٥٧ من قضبان التوصيل و النظام الكهربي العملي لمنصة بحرية.

الاكاديمية العربية للعلوم والتكنولوجيا والنقل البحرى

كلية الهندسة و التكنولوجيا
قسم هندسة الكهرباء والتحكم

التحكم المثالى فى تدفق القوى الكهربية بالشبكة الذكية باستخدام تقنية ذكاء اصطناعى حديثة متقدمة

مقدمة من

المهندس/ محمد فتحى عبد الحميد الفخرانى

الرسالة مقدمة كجزء من المتطلبات للحصول على
درجة الماجستير
فى
الهندسة الكهربية

هيئة الإشراف:

أ.د. ياسر جلال مصطفى
هندسة الكهرباء والتحكم
الاكاديمية العربية للعلوم والتكنولوجيا

د. نهى هانى العمارى
هندسة الكهرباء والتحكم
الاكاديمية العربية للعلوم والتكنولوجيا

مصر
2015