

Méthodes analytiques d'étude pour la diminution des pertes de puissance dans les réseaux électriques maillés en utilisant des techniques d'optimisation pour le dimensionnement et l'emplacement des générateurs décentralisés

Ahmed Al Ameri

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THESE

Pour obtenir le diplôme de doctorat

Spécialité Génie Electrique

Préparée au sein de l'Université du Havre

Méthodes analytiques d'étude pour la diminution des pertes de puissance dans les réseaux électriques maillés en utilisant des techniques d'optimisation pour le dimensionnement et l'emplacement des générateurs décentralisés

Analytical study methods for reducing power losses in meshed electrical networks using optimization techniques for the sizing and location of decentralized generators

Présentée et soutenue par Ahmed AL AMERI

Thèse soutenue publiquement le 04 Avril 2017 devant le jury composé de		
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Abstract

The capability of the classical network to support the level penetration of Distribution Generation (DG) and wind energy system has been presented to analysis how to achieve a better integration of flexible demand of Electrical Networks. Real time monitor of grids required less computation time in calculation of power system analysis. Based on this analysis, different simulation algorithms have been proposed to reduce CPU time and memory, can help the grid operator and planner to assess power situation and increase penetration level of DG.

Firstly, we deal with algorithms developed for load flow studies in electrical power systems using Schur complement method and Run Length Encoding (RLE). Then, linear model (simple, efficient, and flexible) has been developed to calculate the real power loss of the system.

Secondly, distributed Generation (DG) network is modelled with the aim of estimating optimal size of DG using Kalman filter and graph theory. In the first stage, the graph flow method is used to generate the incident matrix to build the linear model and in the second stage, a Kalman filter algorithm is applied to obtain the optimal size of the DG at each bus system. A second stage method is proposed to estimate the best size of DGs.

Challenges of using multi Distributed Generation (DG) units have been addressed to minimize the objective function (real power loss) taking into account DG capacity, transmission line capacity and voltage profile constraints. Genetic Algorithm (GA) and interior point optimization techniques are proposed to find global and local, respectively, optimal sizing and location of multi distributed generations in electrical networks.

Finally, the real power load model is designed to study different load types (residential, commercial and industrial) connected to load buses. Also, we present Simulink simulations of a wind farm integration into the grid and we develop analytical study to select its size and placement taking into account the reduction of total active power loss. Furthermore, we revealed that the annual variation of wind speed could have a strong effect on real power loss calculations. In addition, in order to improve utilities efficiency, we developed specific designs to speeding up integration of wind farm into power grids.

Publications Arising

Articles dans des revues internationales avec comité de lecture

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- ACL2. Ahmed Al Ameri and Cristian Nichita, "Linear Model for Optimal Distributed Generation Size Predication", Advances in Electrical and Electronic Engineering, accepted (unpublished) 2017.
- ACL3. T. Riouch, R. EL-Bachtiri, Université de Fez LESSI, A. Al Ameri, C. Nichita, Université du Havre – GREAH, « Renewable Energy and Power Quality Journal (RE&PQJ) Control of Battery Energy Storage System for Wind Turbine based on DFIG during Symmetrical Grid Fault », Renewable Energy & Power Quality Journal, No.13, March 2015.
- ACL4. Ahmed Al Ameri, Cristian Nichita and Brayima Dakyo, «An Efficient Algorithm for Power Load Flow Solutions by Schur Complement and Threshold Technique", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Volume 3, Issue 8, August 2014.

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- RI2. Ahmed Al Ameri and Cristian Nichita, "Contribution to the Reduction of Power Loss in Electrical Network Using Optimal Placement and Size of Multi DG Units", ELECTRIMACS 2017.

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List of Abbreviations and Acronyms

ABC	Artificial Bee Colony
AI	Improved Analytical
ANN	Artificial Neural Network
ATS	Automatic Transfer Switch
CPU	Central Processing Unit
DFIG	Doubly Fed Induction Generator
DG	Distribution Generations
DNO	Distribution Network Operator
ELF	Exhaustive Load Flow
ERDF	Electricité Réseau Distribution France
ESS	Energy Storage System
EU	European Union
FACTS	Flexible AC Transmission System
FCM	Fuzzy C-Means
FD	Fast Decoupled
GA	Genetic Algorithm
GW	Gigawatt
HEQ	High Environmental Quality
HV	High Voltage
Hz	Hertz
ICA	Imperialist Competitve Algorithm
IP	Interior Point
KW	Kilowatt
LM	Linear Method
LV	Low Voltage
MLD	Maximum Load Deviation
MPPT	Maximum Power Point Tracking
MRA	Multi-Resolution Analysis

MSFLA	Modified Shuffled Frog Leaping Algorithm
MV	Medium Voltage
MW	Megawatt
NA	Analytical Approach
NR	Newton Raphson
OLI	Optimal Locator Index
OPF	Optimal Power Flow
OPF	Optimal Power Flow
PSO	Particle Swarm Optimization
PV	Photovoltaic
QCQP	Quadratic Constrained Quadratic Program
R	Resistance
RLE	Run Length Encoding
RPF	Real Power Flow
RPL	Real Power Losses
RTTR	Real Time Thermal Rating
SA	Simulated Annealing
SC	Schur Complement
SFLA	Shuffled Frog Leaping Algorithm
SO	System Operator
T&D	Transmission and Distribution
TS	Tabu Search
TSO	Transmission System Operators
TW	Terawatt
TWh	Terawatt hour
Х	Reactance

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General introduction

General introduction

In the past decade, distributed generation (DG) has become one of the fastest growing technology and it expected that development to continue. Interconnecting DG to an existing distribution system is increase to fulfil the yearly electrical energy grows in demand. DG provides various benefits such as power quality enhancement, loss reduction, voltage profile improvement etc. However, the planning and operation of distribution networks are facing different challenges when more DG is connected. The network planner should consider the positive and negative effects of DG when an efficient network is designed with high penetration levels of DG. The optima location, sizing and type of DG can give guidance to designer on how we could achieve a set of objectives and maximize the benefits of DG. Placement and type of renewable DGs is significantly influenced by the natural environment (climatic conditions), site and availability of primary fuel. Anyway, DG placements and sizes problem is still play a vital role in **reducing network losses**. Therefore, the big questions, when placing a DG or DG units in the existing system, what will be the size, where these units will be connected.

Finding the **optimal size and location of DGs** correspond to optimizing the operation and planning of electrical distribution network taking into account capacity of DG units as constraints. Accurate solution for optimization problem is more important to the operation planning than time of calculation. Issues of operation planning go on the timescale (seconds to days) and could be concentrate on how to add DG units on the system, rather than the existing resources, to meet objectives. On the contrary, a near-optimal speed up **time calculation** to solve the problem for an instantaneous operation can be more useful for Distribution System Operators (DSO) at real-time operation. Load flow problem is the heart of power system analysis and speed up its calculation is required for real time monitor and operation. Real-time processing of generation, DG and load data will enable DSO to control and optimize the integration of DG into the distribution network. The DG placement problem has no influence or control on DSO real time decision to reduce network losses but it is very necessary to determine the DG units' size when the DG placement is fixed.

In addition to planning for size and placement of DG required, the type of DG resources matters. Wind energy differs from conventional renewable resources in its output generation

characteristics due to the limited predictability and **variability of wind speed**. Unlike conventional generators, the uncontrolled power output of wind turbines cannot be used in maintaining the balance of power between production and demand. Most of wind energy sources can either be small onshore wind turbines or large scale onshore/offshore wind farms. Both small wind turbines and large-scale wind farms are typically connected to a mesh network structure. Nevertheless, problems arise when the wind energy is integrated with the distribution network, as the classical distribution power systems have been designed to operate without future consideration for this new generation.

The improper placement of wind farm could increase the real power losses in the distribution system. Moreover, most challenging for utilities is determined by the wind turbine farm capacity that will be connected into the electrical network. The hardest part for most of DSOs is to determine the optimal capacity of wind energy at time varying behavior of the demand (load). Most analysis of power system using distribution network models typically evaluates peak load profile. However, losses are happen in the transmission/distribution lines throughout the year while majority of losses arrive off-peak. Planning and operation improvement of modern distribution systems require more attention to grid power losses under different load conditions with connected wind energy.

The main goal of this thesis is to quantify the impact of DG and wind energy on losses of distribution networks (mesh structure) considering several aspects. In order to achieve this objective, a number of steps have been determined and each of these steps has its own sub objectives related to the overall research objective.

The **first sub objective** of this thesis is to explore the application of a number of approaches in the area of power system analysis. The approaches adopted attempt to speed up the calculations and reduce computer memory for nonlinear load flow methods to be considered for real time monitoring or operation. Furthermore, the big data of large-scale power system must be processed with less memory and CPU times.

The **second sub objective** of this thesis is to develop linear models suitable for the prediction of optimal DG's size. Since the active power has strong coupling with the voltage angle in the power system, fast-predicted linear model should be used to estimate the real power losses. Moreover, faster and acceptable accuracy calculation must be efficient tools for grid operator to assess the power system with the large-scale DG connected.

The **third sub objective** is to investigate the impact of DG size on real power losses into grid. Since fast-predicted linear model (developed under second sub-objective) cause error in estimating optimal DG's size and minimum power loss, develop a methodology should achieve time saving advantage at only a small estimation error. Extending the methodologies previously presented to analyze multi DG units based on wind energy resources as well as finding the optimal placement of each DGs are part of the next research sub-objective.

The **fourth sub objective** of this thesis is to explore solution facilitating the electrical power system integration of DG units. The requirement for integration solutions can be assessed by using the insights got above into the relevant power system parameters. Thus, optimal solutions (global and local) for power system integration of large-scale DG can then be determined and the last parts of the research objective is accomplished.

The **fifth sub objective** is to develop a methodology for the demonstration of distribution network performance based on load profile modeling as methods improve Distribution Network Operators (DNOs) choice in power systems. The methodology should allow for efficient selecting of generation resources under variable load profile. Also, methodology should be adequate to identify the power flow and real power losses into the distribution system.

The sixth, and **final sub objective** is to achieve better understanding of wind variation impact on distribution network losses. The real power loss calculations should be considered when place and size of wind farm are fixed taking into account the annual variation of wind speed. This must be applied to acquire insight into changes in real power losses as result of wind power.

The present thesis has been constructed into six chapters:

- Chapter 1: Challenges of integration of DG and Wind Power on Power System.
- Chapter 2: Improvement of power system analysis and linearization of power losses.
- > Chapter 3: Fast selection of DG' size and optimization techniques for loss reduction.
- Chapter 4: Time varying load model and impact of wind variation on power losses.
- Chapter 5: Simulation results of proposed algorithms, discussion.
- Chapter 6: Conclusions and Future Research.

The first chapter provides the information needed to understand the context and motivations of this research. The main structure of electrical power system is described in broad outline, with particular attention to distribution network configuration and the ability to provide additional generation in existing networks. This first part highlights the advantages and disadvantages of main configuration of distribution network (radial and mesh) in the presence of DG. Furthermore, a grid-connected wind turbine explained the use of IEEE benchmark test systems with mesh structure.

In a second step, different DG technologies are categorized as their size and a state of the art is established on the main problems encountered in the integration of DG into grid. The state of the art identifies the possible difficulties to be overcome to encourage their implementation in the distribution networks.

The scope of this research has explored the subject areas and identified any possible restrictions on results due to limitations of this research. The approaches, used to study the impacts of DG and wind energy into grid, are compared in order to identify their calculation assumptions and their major limitations. Chapter 1 concludes with a positioning of the present works in relation to the existing studies.

The second chapter focuses on the methods developed to efficiently improve the power system analysis with less computer memory and calculation time reduction. The solution of the power flow is the most accurate approach for modeling the balanced electric power system and studying the steady state behavior of transmission network. From the power flow solution, each bus in the system contains the voltage magnitude and phase angles, all values can be calculated, such as power flow (real and reactive) in all the lines in the system. That for why, in the introduction of this chapter 2, a complex bibliographic search is first conducted on load flows techniques, including nonlinear and approximation methods.

Most classical methods commonly used to solve load flow problem mostly need sequential calculations of the nonlinear equations that take more computation time and storage memory. Some other methods can be faster in order to online monitor and operations but with less accuracy and probably be weak convergence.

This is why a new method, which is faster and has little impact on the accuracy of the results, has been investigated: the construction of an approximated calculating model of the nonlinear power analysis using Schur complement method and Run Length Encoding method. Then, DC load flow model, which is simplified method considering number of approximations, is proposed and developed to build direct relation between injected generation and power losses. This relation has been formulated with help of graph theory and analytical approach in order to use as simplified power losses model. A bibliographic search is first conducted on load flows techniques, including nonlinear and approximation methods, in the introduction of this chapter 2.

Chapter 3 provides an initial contribution to the optimization of planning and operation strategies. After presenting possible mathematical formulations of the optimization problem, a state of the art of optimization algorithms in the presence of DG is drawn up with the aim of choosing an algorithm adapted to the particularities of the problem.

Firstly, fast selection of DG size is implemented to reduce the real power losses in the grid by using Kalman technique. The powerful state estimation algorithm is applied by determining the noise models, process model and measurements. In this method, the optimal size of DG is find by applying the linear state model based on the analytical approach.

The distribution system operator need fast tools to estimate the minimum real power losses according to the selection of DG size into grid. Then, optimization for size and location of multi DG unit is carried out, where the optimization objective function is oriented to achieve the minimum real power loss in network. Two optimization techniques (Genetic Algorithm and Interior Point Method) have been developed to determine this objective function under different conditions. As a result, the optimal size and location of DG units is obtained together with the less consumption of time calculation. Finally, the comparison of the global and local optimization technique is carried out.

In the **fourth chapter**, an analysis of the state of the art to demonstrate the impact of load profile and wind speed variation on real power losses, will be done. From the aforementioned existing review, the fact that the real power loss is significantly changed with the variation of load as well as wind speed variation, when wind power generation connected to the grid.

Therefore, in this chapter a Simulink simulation is suggested and applied to study the performance of IEEE benchmark test system when different load profile connected. In additional, the wind farm is modelled, with its internal architecture and control modes. Moreover, the modeling of wind power output is described according to Weibull statistic: the total real power losses are developed as a function of rated wind power output.

Chapter 5, several IEEE bus systems are tested to explain the ability of proposed efficient methods. Schur complement method and Run Length Encoding algorithm are applied to classical newton Raphson method in order to reduce computer memory and time computation required.

Graphical representations of the IEEE bus Test Systems to generate the incident matrix also are given in this Chapter. The simplified power losses method has been implemented to facilitate the decision making process and the modeling of optimization problem.

The estimate error of this simplified method has been reduced by using Kalman filter to select the optimal size of DG unit. Kalman filter has been designed to estimate accurate and fast predictions that help the distribution system operator to monitor the system in real time. Moreover, the contribution of the proposed optimization techniques has been discussed and compared in this work. The optimal size and location of DG units in different conditions, quality and inequality constraints were achieved by taking into account the main objective function (minimization of real power losses) of the problem.

The IEEE 5 bus system are simulated in the presence of different load profiles. The simulation tool is detailed and implemented block by block before it grouped. The block of time varying load has been particularly designed to satisfy all types of load profiles. Then, wind turbines are modeled and controlled to form wind farm that connected to IEEE 5 bus system. The real power losses are simulated by transforming the values of wind speed via the output power of the wind turbine at the site. Finally, the comparison between real power losses calculation considering the Weibull distribution and mathematical results with non-variable load grid has been discussed.

Lastly, the **sixth chapter** describes the contributions and conclusions of the present PhD work, possible propositions about the developed topics and offering some future lines. A diagram to present the chapters and their organization is presented in Table 1 bellow.

	State of art	Methods developed	Main goals
Chapter 1	Main structure of power		
	system, Impact of DG into		
	the electrical network,		
	Wind energy development		
	Nonlinear methods,	Methods to reduce the	Improvement of load
	approximation	computer memory and	flow and develop method
Chapter 2	approaches, time reduction	Iteration number, simple	to calculate real losses
	of load flow calculations	model for power loss	
		calculations.	
	Optimization algorithms	Fast and optimization	Comparison of several
	for optimal size and	methods of multi DG to	optimization techniques.
Chapter 3	placement of DG.	minimize the real power	Test method on several
		loss.	IEEE benchmark test
			systems.
	different load profiles,	Load model and	Real power loss
Chapter 4	penetration of wind energy	simulation adapted to	comparison of electrical
	and speed variation	wind power into	network including effect
		electrical network	of load profiles and wind
			power.
Chapter 5	Results, comparison and discussion		
Chapter 6	Conclusion and future work		

Table 1 Chapters organization

Chapter 1

Challenges of integration of DG and Wind Power on Power System

Challenges of integration of DG and Wind Power on Power System

The distribution network was designed to operate without any generation on it. The introduction of DG in systems can significantly affect the power flow and voltage conditions at both, customers and utility equipment. These impacts can be manifested as having positive or negative influence, depending on the DG features, characteristics of distribution system operation and its structure. Integration of DG units into the distribution network has triggered many technical challenges that have not yet been fully solved.

One renewable technology way to generate electricity is to use wind energy to convert the kinetic energy delivered by blades into mechanical power, which can convert into electricity. Wind generation system is one of the common distributed generation in electrical networks. Wind energy generation is the current subject of much academic research and commercial interests. Recent work indicates that wind energy in longer term may become commercially so attractive that there will be wide range implementation in many countries of the developed world. The wind systems have the following general advantages over other power plants: no fuel cost, no greenhouse gas emission, low cost of installation, low effective cost, long life span of the system's components, and possible export of reactive power to the electrical network.

The purpose of Chapter 1 is to explain the problem of operating and planning power network in the presence of DG and wind energy - which is the reason for the present research. After a brief description of the electrical power system, we will present the impact of Distribution Generation (DG) on different structures of distribution systems (Mesh and Radial systems) by determining the definition of DG. A state of the art is then drawn on the main problems (power losses and voltage profile) encountered in the integration of DG into the electrical network. We will focus on wind turbine as DG unit, while taking care to explain the growth of its size and grid connection. Particular attention will be paid to the main scope of this research by studying the aspects of power system planning and operation that are relevant for this thesis. This research scoping is followed by an exploration of different approaches of this research taken into account the research objectives proposed in the general introduction section.

Chapter 1 concludes with the positioning of this work in relation to existing approaches and gives its main contributions and limitations.

1.1 Electrical Power Systems

The supply of electrical power is fundamental for advancement and progress in industrialized countries as well as in developing countries. It is impossible to turn out certain necessary products without electricity. It is difficult for people to do things without electricity, which is an essential part of life these days. The countries everywhere throughout the world are utilizing a variety of different energy sources e.g. hydropower, nuclear, coal or gas-fired plants etc.

As the season and the time of day varies, the utilization of electric power and electric energy also varies. These variations depend on the different activities of residential commercial and industrial customers. The use of electricity is also dependent on the climatic situation.

The electrical power system consists of three major components: generation system, transmission line system, and distribution system as shown in Figure 1. The high voltage (HV) transmission system links the generation units to substations, which supply electrical power to the end user through the distribution system. Any interruptions in these connecting links can disrupt the flow of power in this system.



Figure 1 Traditional power system structure [1]

Load growths until a predetermined amount require to add new capacity to the network like new substations or to expand existing capacities of substations and their associated new feeders or both. That means extra expense to building up the traditional transmission and distribution (T&D) grid that delivers bulk power to load centers, and from there, to consumers.

Chapter 1. Challenges of integration of DG and Wind Power on Power System

Many renewable resources are installing in all over the world to exceed these extra expense of continuous developing T&D facilities and tariffs, as is shown in Figure 2.



Figure 2 Generator connect to T&D system

The electrical power flows from generation center into transmission networks and then into medium or/and low-voltage distribution networks, hence only in one direction. Some of advantages of interconnected power system are plant capacity savings, emergency power interchange, increased reliability, and interchange due to diversity and aggregation of load variations. Presently, it has seen an increase for generation being connected to the distribution network. Trend progressively drives to bi-directional power flows in the distribution system [2].

In observing the traditional structure of power systems, it is critical to note that significant amounts of electrical power energy cannot be stored. Thus, the consumption of electrical power energy is expected to occur at the same moment of generation. Power system reliability fundamentally concerns a precise balance between total system load (including transmission and distribution losses) and generation. It is difficult to control the load; only adjusting the generation units can maintain the power balance and follow the demand at all times. The operation of power systems is consequently fundamentally reliant on the abilities of generators for balancing the load.

1.1.1 Power Generation

Electrical power generation is the process of generating electric power from other sources of primary energy, which burns fossil fuel such as petroleum, natural gas or coal to produce electricity. The primary energy sources is converted into electrical energy by produce the highpressure steam, which rotate a mechanical part to produce the electricity. Same principle can be used for nuclear generation units but the heat released by nuclear fission. For hydroelectric power, kinetic energy of water is initial source of energy and it changed to mechanical energy when flow to turns blades of a turbine that drives the generator rotor to produce electricity. Increasing or reducing the amounts of fossil fuels (or water) are used to control the primary energy sources in traditional power systems: Hence, a relatively small number of generation units be enough to control the power balance in the entire large-scale power system. The benefits of controllable primary energy sources have made it possible to follow widely and freely load vary during the day and during the year. As long as sufficient generation units is installed to match the varying of load at all times, reliable operation of the system can be able to ensure. In order to guarantee a reliable power supply, significant amounts of renewables can be used as conventional generation to improve the operation of power systems. In other hand, the integration of large amounts of renewables may need the system load to be more adequate to power generation availability.

1.1.2 Transmission system

Transmission network can be define as the bulk movement of electrical energy from central generation units to an electrical substation (load center). Electricity is transmitted at high voltages by power transformer to reduce the power loss, which occurs in long distance transmission lines. In other hand, another power transformer is used to transform electrical power to lower voltage levels near the load centers [3]. In the past, transmission network capacity was designed to transport the generation production as efficiently as feasible, while taking into account network safety, economic factors and redundancy. Transmission planning and operation is ensured by transmission system operators (TSOs) who have to be sure of system reliability when lot of investments are done by generation utilities. In order to serve the system, it is the task of the TSO to maintain a continuous balance between energy supply from power generation units and load consumed by consumers (Figure 3).

Chapter 1. Challenges of integration of DG and Wind Power on Power System



Figure 3 Traditional Transmission line [4]

1.1.3 Distribution system

Electric power distribution is the section of the power system infrastructure that takes the electricity from the high-voltage transmission lines and delivers it to customers. At a distribution substation, a high voltage substation transformer takes the incoming transmission line voltage (35 to 230 kV) and steps it down to several secondary distribution systems connect to the end user ((commonly 120/240 V). Primary distribution lines are mainly divided into two voltage levels (medium-voltage and low-voltage).

Medium voltage distribution substations are connected to the transmission system; its transformers steps down the transmission high-voltage to medium voltage ranging between 2 kV and 35 kV. This medium voltage electricity carrying by primary distribution lines to distribution transformers located near the end customer. Closer to the customer, distribution transformers step down distribution voltages to the utilization voltage of appliances. Residential, Commercial and industrial customers are connected to the distribution lines through service drops (overhead electrical line).

Distribution network configurations

There are two main topologies for defining the configuration of a distribution network, the radial and the mesh network topology.

The radial system is a tree shape topology where exist only open loops. This means that power start on one bus and deliver to the next without the possibility of re-flow to the original bus,

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except if power is turned backward by distributed generation. This type of topology is the simplest and cheapest for an electrical network but, with this topology, it is not reliable because if a primary line is disconnected for some reason, all other secondary lines downstream also lose power.

In the mesh topology, it is impossible to find open loops where the power is delivered through multiples lines, connected to each other, configuring a mesh figure. This kind of topology have less loss (more reliable) but it means bigger investments.

Market and electricity companies are interested to reduce costs by increasing penetration level of Distribution Generations (DG's) in utility systems with best integration and developing measurements. Mesh and Radial distribution systems have different structures that change the capability of the network to support the penetration level of Distribution Generation (DG).

The conventional classical radial system (Figure 4) receives power from transmission system at a single substation (utility supply voltage) and steps the voltage down to the utilization level. For single line diagram, a representative schematic of a classical radial distribution system can be shown clearly in Figure 5.

Typically, high-voltage breakers are used in electrical power transmission networks (voltages in excess of 72 kV); some specialized HV breakers are rated to 1000 kV or above and controlled by heavy-duty solenoids.

Different methods used to extinguish arcs. Older devices was used oil, although this practice is in decline due to spills and other hazards. The new technology use air, vacuum, and SF6 methods. Both medium-voltage breakers and high-voltage switches are used to control, monitor, and protect transmission networks as an integral part of switchgear panels.

An electrical switch that connect a load between two different sources is called transfer switch. There are two type of transfer switches, manual and automatic. Manual transfer switches are effects the transfer by an operator who throwing a switch, while automatic transfer switches are switching when detect the sources has lost or gained power. An Automatic Transfer Switch (ATS) is often located near to backup generator, so that if the utility source fails, the generator will temporary provide electrical power.



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Figure 4 Classical Radial Network [5]

The radial distribution system is utilized only when power is generated at low voltage (LV) and the substation is situated close to the load center. Radial systems are utilized for two main reasons; they are less expensive than ring or meshed operation and they are less complex to operate, design, plan and maintenance. However, they generally have lower reliability, immoderate voltage drop and more line power losses than the alternatives. The larger part of distribution systems across the world are worked radially with the point of preference being that in case of a fault they do not affect the wider power system.





Figure 5 Simplified diagram of Radial Network

Mesh (ring or loop) system (Figure 6) consists of one or more feeders with two or more distribution transformers forming a ring or loop. The ring, or loop, starts at the system of distribution substation and is encircles or connected to an area serving one or more load centers or distribution transformers as shown in Figure 7. The line of the distribution system returns to the same substation. Each primary loop is worked such that one of the loop sectionalizing switches is kept open to avoid parallel operation of the sources [6]. Typically, the availability of two services from the utility will help the system to be more effective.

Mesh structure is used usually with high or medium voltage and in higher density population areas while radial is used with low level voltage and in urban areas or less density population areas [7]. Mesh structure is more expensive to build than the radial type, but it is more reliable and presents less voltage fluctuations at end user's terminal. So that, it can be justified in an area where uninterrupted service is of considerable importance (medical centers). Table 2 summaries main difference between radial and mesh distribution system.

Topology	Advantages	Disadvantages
Radial	• Simplicity	• Quality of service
	• Operation	• Less reliable
	Installation costs	• Maintenance require feeder
		interrupting
Mesh	• Simplicity	Installation costs
	• Quality of service	
	• More reliable	
	• Maintenance don't require feeder interrupti	ing

 Table 2 Comparison between radial and mesh network

In general, most substations are connected to a mesh network of the medium voltage distribution system. With this arrangement, each substation is supplied at least by two independent sources or more giving a full redundancy. This type of distribution system designed to feed power from a large generation stations to very large number of end-users and is not designed to accept power generated at medium voltage (MV) or low voltage (LV) levels. Recently, request of associating DG (as renewable resources) to LV or MV distribution network significantly increased. Most of wind power (as distributed generator) feeds into MV distribution grid while mostly for PV power is connect to LV grid.



Figure 6 Classical Mesh Network [8]




Figure 7 Simplified diagram of Mesh Network

1.2 Distributed Generation (DG)

The structure, operation and planning of electric power networks undergo considerable and rapid changes, due to increased global energy consumption. Therefore, electric utility companies make great efforts to install the renewable distributed generation (DG) as energy resources, to meet growing customer load demand. The renewable energy sources used by the distributed generation can take the form of fuel cell, photovoltaic, wind power etc. In recent years, the installation of renewable distributed generation (DG) on the electrical network has provided numerous benefits: preclusion of required system upgrades (no need for upgrade distribution or transmission systems), improved power quality, reduction of energy losses, improved reliability, and increased efficiency. Figure 8 shows different DG technology integrated into electrical power system network.



Figure 8 Power System Network with DG units [9]

Distributed generation is considered as an electrical source connected to the power system, in a point very close to/or at consumer's site, which is small enough compared with the centralized power plants. These new technologies allow the electricity to be generated in small sized plants. Moreover, the increasing use of renewable sources in order to reduce the environmental impact of power generation leads to the development and application of new electrical energy supply schemes.

Market and electricity companies are interested to reduce costs by increasing penetration level of DG's in utility systems with best integration and developing measurements. The distribution systems have different structures which change the capability of the network to support the level penetration of Distribution Generation (DG). The capability of the classical network to support the level penetration of Distribution Generation (DG) could be changed according different structures of distribution systems (Mesh and Radial systems), as mentioned in pervious section.

By the addition of Distribution Generation (DG) to distribution networks, voltage profile is improved, loss reduction and energy demand from the utility network is decreased. Also enhancing DG is an attractive distribution planning option because it avoids degradation of power quality, improving reliability and control of the utility systems [10].

1.2.1 DG Definition

There are number of different definitions of DG over the world that introduced a lot of definitions used to classify DG in various countries [11]. Generally, DG can be defined as electric power source with small-scale connected directly to the distribution power network.

There is a vast range of terminologies used for "distributed generation," such as "embedded generation," "dispersed generation," as well as "decentralized generation" [11]. Considering these definitions of distributed resources and the energy demand side management, the storage could also be considered as a distributed resource. The first term "distributed generation" will be used for the purposes of this thesis. In general, DGs have different types depending on the source of energy producing electric power. The DG technologies (Figure 9) include fuel cells, storage devices, and a number of renewable energy-based technologies; for example wind, photovoltaic, thermal, biomass, ocean, etc. [12].



Figure 9 Different DG technologies

The most commonly used of different DG technologies and their size can be summaries as follows Table 3:

DG Technology	Size	
Wind turbine	(200 watt – 10 MW)	
Photovoltaic Array	(20 Watt – 600 W)	
Stirling Engine	(2kW - 100kw)	
Gas turbine combined-cycle	(35MW – 460MW)	
Fuel Cell	(1kW – 5MW)	
Micro Turbine	(30kW – 1MW)	

Table 3 Categories of DG technologies according their sizes

According to summaries above, some categories that define the size of the generation unit are presented in follows [13]:

- Micro distributed generation 1Watt < 5kW
- Small distributed generation 5kW < 5 MW
- Medium distributed generation 5 MW < 50MW
- Large distributed generation 50MW < 300MW

1.2.2 Integration of DG into the Electrical Network

The role of electrical network has changed after increasing penetration of DG. While the delivery of electricity to the consumer was originally made by passive networks, now networks are being utilized with several distributed energy resources. The technical characteristics of the network has changed due to increased expansion of these distributed generators as well as the bidirectional active and reactive power flows with more variables. These changes of technical characteristics of the networks will push them to operate closer to their reliable and limited operation.

DG systems can reduce peak system losses by lowering the power delivery needed by the classical distribution system during peak time. In radial structure, location of DG's reduce losses with percentage around 35% losses while at mesh structure, size of DG can be got more discount around 42% which mean less cost.

One of the major impacts of Distributed Generation is on the losses in the feeders or lines. Location and size of the DG units are an important criterion that has to be analyzed to achieve a better reliability of the system with reduced losses.

An overview of impact of DG on these different structures with different voltage levels is presented thereafter with respect to different issues like power losses, voltage profile, protection, reconfiguration, load balance, reliability, planning and cost. In that sense, a general view of the main problems encountered in the integration of DG into the electrical network is also presented.

A. Incidence of DG on Reliability, Planning and Cost

Reliability of supply is defined as "the ability to supply adequate electric service on a nearly continuous basis with few interruptions over an extended period of time" [14]. It is worth noting that very high standards of reliability are obtained considering the requirement of continuity of power supply. The increasing of use the DG's (like renewable energy and fossil fuel resources) are leading to significant changes in the planning and operation of electric power systems.

The unpredictability on the amount of DG interconnection requests in the future, regarding their location and their type (wind energy, solar energy, etc.) to integrate them in traditional planning studies without taking a risk choosing a strategy that turns out to be inappropriate in the future [15]. It has been considered in this reference the new architectures (mutation from a radial

to a meshed structure) for Enedis and proposed a Monte Carlo algorithm as an efficient tool for analyzing and assessing the relationship between distribution network architecture and DG penetration rate.

Increasing the DG penetration rate can provide opportunities for reducing the overall cost generation. Some of these opportunities can be by adding overall system generation capacity, reducing loaded on generation, transmission, and distribution systems, and finally by supporting maintenance and restoration of power system operations by providing potential generation of temporary backup power [16].

B. Effect of DG on Reconfiguration and Load Balance

Reconfiguration for distribution system mostly used for load balance and loss reduction in radial structure, it will be more complex with DG's, because it means to find optimum solutions under many and new constraints. Many of probabilities with many variables will increase computation times and storage memory that impose algorithms which has high performance to find optimum solution. Many of recently researches are focused in our work issues.

In any electrical system, the generation and load have to be balanced at any time. DG units can provide assistance in active balancing as well as the reactive balancing with power electronic frequency converters to support the voltage in a distribution system as described in [17]. These active and reactive power control services have the potential to assist the electric power system in different time scales (disturbances and during normal conditions) while also potentially providing economic value to end users and variable renewable generation proprietors.

C. Impact of DG on Protection

The majority of protection systems for distribution network operate based on unidirectional power flows from the transmission network down through the lower voltage networks. As mentioned previously, DG is changing the flows on the network. This can lead to problems with the operation of the protection system.

One of the principal features of distribution systems is that the power flows radially, from the main generating station down to the feeders to support all loads. In this design, protection devices are placed on feeders and laterals of the distribution network, in order to maintain continuous

supply for all loads and to protect equipment and different appliances of the system from power outages.

The distribution network become more similar to transmission line network after connected several or many of DG to medium voltage network. This new structure will mix the generation and load nodes making protection system design more complex. The straightforward concept of protection based on the assumption that fault current have only one direction to applying overcurrent protection, is not always true when there are DG units.

D. Impact of DG on power losses and voltage profile

The electrical power loss occurs in the distribution line when current flows through it. This line loss depends on the amount of current that flows in the distribution network and the length of the line. The active power loss can cause a critical impact on the optimal economic dispatch based on the distribution network configuration. These losses can be reduced by decreasing the current amount flow in the distribution line.

If DG units are integrated into the distribution system, the amount of currents, which are flowing in the lines or parts of the network, will be reduced to a certain percentage. This will significantly contribute to reduce the power loss and delay of network upgrading. The main impact of DG on power losses depends on the size and location of the DG units. However, improper sizing or location of DG units can cause excessive power losses and overload.

Integration of DG units in a power system has a substantial impact on the distribution voltage profile also. It can enhance the voltage profile and ensure that voltage received at the end users' load sides is within acceptable and the designed limits. The voltage profile of the system will improve because DG units will supply a percentage of active and reactive power at the load sides. This will reduce the current flow along the section of the distribution lines and boost the voltage supply at the load sides.

Typically, the ratio X / R in the distribution systems is lower than the transmission systems. The bus voltage always decreases due to the active power consumption in the distribution lines, which can be compensated by transformer tap switches or by line drop compensation. In addition, the injection of DG units as active power will increase the voltage in the low and medium voltage networks. In general, some of researchers use standard data like IEEE benchmark test systems to compare their results with another methods that could be implemented. While others prefer to use their local data buses to verify real results which can be more interested for their local electricity companies.

Medium Voltage (MV) distribution network has been modified by connecting two sets of DG units to reduce loss energy into a feeder including both, radial and meshed topologies [18]. The technical operating restrictions of the network are taken into account the location of these two sets of DG units, when algorithms that sequentially optimize are implemented.

Generally, the power losses changes due to DGs contributions are considered according to voltage and load variations in [19]. The losses in the mesh distribution network, in the absence of distributed generation and when located, have been treated. The method is based on tracing the real and imaginary parts of the currents.

Another optimization method based on a Hybrid Genetic Algorithm and Particle Swarm Optimization (HGAPSO) has been proposed for optimal DG allocation in radial distribution network [20]. Better quality and less number of iterations compared with simple generated algorithms methods have resulted.

The multi-objective optimal placement of distributed generation (DG) was solved by simulated annealing with less computing time compare with other optimization methods like genetic algorithm (GA) and "tabu search" (TS) [21]. The result on the IEEE 30 bus test system shows that the multi-objective problems are capable of obtaining higher quality solution efficiently comparing with single objective.

Combination of heuristic search and Particle Swarm Optimization (PSO) methods has compared with Modified Shuffled Frog Leaping Algorithm (MSFLA) for optimal location and sizing of distributed generation (DG) in a radial distribution network. Shuffled Frog Leaping Algorithm (SFLA) is a heuristic search algorithm used to achieve a method to solve complicated optimization problems without any use of traditional mathematical optimization tools. Test results on the 33-bus radial distribution systems show that MSFLA method can achieve better results than PSO and simple heuristic search method [22].

The connection of DG may result in changes in voltage profile along a feeder by changing the direction and magnitude of real and reactive power flows as shown in Figure 10. Nevertheless, DG

impact on voltage regulation can be positive or negative depending on distribution system and distributed generator characteristics as well as size and location of DG.



Figure 10 Voltage profile for system with and without DG

Another method based on the use of Genetic Algorithms is proposed [23]. Power losses are minimized and voltage profile is kept acceptable, to find the optimal size and location of distributed generation units in a distribution grid. In order to implement the search of the optimal solution, different solutions are presented for each season, with more generators placed in the more scenarios.

The allocation and sizing of DG resources into existing distribution networks is formulated as a multi objective function to permits the planner to decide the best compromise between cost of network upgrading, cost of power losses, cost of energy not supplied, and cost of energy required by the served customers. The implemented technique is based on a genetic algorithm and a constrained method that allows obtaining a set of non-inferior solutions (an improvement in one objective requires a degradation of another) [24].

Optimizing DG model in terms of size, location and operating mode was presented in [25] by using forward backward sweep method to minimize network losses in a distribution feeder. The forward backward sweep method is designed to solve the differential algebraic system generated by the Maximum Principle that characterizes the solution, so that, this method do not need Jacobian matrix unlike Newton Raphson method. However, conventional backward forward sweep method

is not useful for modern active distribution networks. Practical distribution network of multi-node pure chain style have been tested and results have proven that up to 76% of power loss can be reduced.

The problem of multiple distributed generators (DG units) placement has been investigated to achieve a high loss reduction in large-scale primary distribution networks. The optimal size of four different DG types and a methodology to identify the best location for DG allocation is based on improved analytical method. Three distribution test systems with varying sizes and complexity has tested and validated [26]. It proposed a parallel algorithm for DG placement design based on 'critical bus tracking' method. It presented the optimal location of DG to reduce the power loss and increase the stability with less computation time.

A simple method based on voltage sensitivity index analysis has presented for real power loss reduction, voltage profile improvement and substation capacity release in [27]. The forward-backward sweep method was used to analysis power flow for IEEE-33 bus test system and to study validates the suitability of this proposed method.

Imperialist Competitive Algorithm (ICA) to determine optimal distributed generation location and size are proposed in a distribution network. The IEEE 33-bus system is tested by this method to minimize power losses and improved the voltage profile. Results shows the efficient of ICA with compare to Heuristic Search and PSO optimization methods [28].

Some approaches to compute annual energy losses variations are actually studied for distribution network when connected to DGs with different penetration and concentration levels. Different DG technologies, such as combined heat and power, wind power, photovoltaic, and fuel cells, are used to analyze the impact on losses of them [29].

1.3 Wind energy as DG unit

The European White Paper on Renewable Energy includes a 2020 targets entail (33% of gross electricity generation). Wind energy system has various benefits that set it apart from different renewables. As a matter of first importance, its essential energy source, the wind, is globally available in wealth both at sea (offshore) and on land (onshore). In addition, the investment cost of wind power is relatively low compared to other renewable resources, for example solar systems. Besides, the wind turbines have High Environmental Quality (HEQ). Within around six months, wind power generates enough electricity to compensate for all power used during material extraction, recycling, demolition, operation, installation and turbine construction, with life designed for more than twenty years [30].

A wind system could produce optimal cost electricity if it installed on a site that has best natural wind resources. If wind systems sited well then wind turbines have small impacts on nature and wildlife beside its effect on the landscape will not appreciated by everyone. This means the planners of power system must carry out environmental impact assessment and feasibility studies to find out optimal locations for the wind system. The height of the wind system above the ground and the wind speed capacity are the main factors for the output power of the wind system. The wind speed capacity is depend on the kinetic energy amount that is available to operate the wind system. This can be successfully reached with a proper wind resource assessment.

The rapid development of a wind system as a way to reduce the power shortage problem and the greenhouse effect is a demonstration of the best wind system characteristic. This feature has doubled the capacity of world wind energy for the past five years.

The development of wind energy has been consistently impressive around the world in last years. At the end of 2000, electricity-generating over 50 countries were operating almost 17 500 MW of wind turbines. Of these, the European Union (EU) were installed over 70%. At 2000 itself, over 3500 MW of new units was installed in the European Union.

Governmental support mechanisms a considerable growth of wind energy especially for renewable wind parked since wind power is a sustainable generation technology, increasingly cost effective energy and globally applicable technology. In Figure 11, the globally wind power cumulative capacity installed from 1996 up to present is shown. Before 1996, main location of

wind power capacity was in the US. In the nineties, Europe started a large growth in wind power, especially in Denmark, Spain and Germany. In the last years, also Asia countries such as China increased the amounts of wind power.





At the end of 2015, the global total for wind power system was 432.9 GW, representing more than 17% growth of cumulative market. This growth was supported by an astounding new installations in China (figure of 30,753 MW); the global industry of wind power installed 63,467 MW, representing growth of 22% in annual market [31]. By the end of 2015, there was 26 country with more than 1 GW installed capacity: including 17 country in Europe; 1 in Africa (South Africa) and in Latin America (Brazil); 3 in North America (US, Canada, Mexico), and 1 and 4 in Asia-Pacific (China, Japan, Australia & India). Beside eight countries had more than 10 GW of installed capacity including France (10,358 MW), Canada (11,205 MW), UK (13,603 MW), Spain (23,025 MW), India (25,088 MW), Germany (44,947 MW), US (74,471 MW), and China (145,362 MW) as demonstrated in Figure 12.



Figure 12 Installed and cumulative capacity of wind power 2015

1.3.1 Growth of Wind Turbine Size

At the start of the millennium, a significant renewable energy source as wind power has continues to grow rapidly. In fact mathematically exponential, not only has the installed capacity of wind power grown with time, also an ever-increasing growth in the size of individual wind turbines has increased by manufacturers.

The growth of wind turbine size is driven by a number of factors, including cost reduction (especially for offshore), availability of onshore sites, and location considerations. The wind park size is a second trend in wind power development, which partially increase the size of turbine. Recently, hundreds of wind turbines grouped to form wind power farms instead of using individual wind turbine. The increasing of wind turbine size enabled to develop the wind parks offshore and wind farms. This developments brings a various opportunities on one hand and lot of challenges (variation and fluctuation wind speed) of on the other. The output power of wind turbine depending

on wind speed characteristics, which fluctuate from seconds to seasons. The wind speed is varying on timescales depends on many meteorological factors that can be forecast up to limited time. The mean, wind power output cannot be accurately assess for long time cause prediction of wind speed variation can only be accurate for short-range weather forecasts.

The early small sizes (micro turbines), around 20-60 kW, were developed in Denmark but were not optimum for system economics. Micro wind turbines remain much more expensive than large one in view of kW installation because towers need to be higher in proportion to diameter, controls, electrical connection to grid and maintenance are a much higher proportion of the capital value of the system. The current dominant facts tells that bigger is better as a competitive element in global manufacturers' marketing, and public research funding programs focus on developing size of larger wind turbines contributed to the growth through the 1990s. At 1995, wind turbine with 80m diameter rotor and 2 MW was built to generate four times more electricity than 40 m diameter rotor and 500 kW.

At beginning of 21st century, wind turbine manufactures were documented an increasing growth in size of turbine with tower height 112m. Note also that, multidisciplinary science and engineering challenges are still available in recent years even though the fast growth of the wind turbine installed capacity. Moreover, wind turbine installations must guarantee both economic advantages and power capture, thus motivating the dramatic growth of wind turbine as shown in Figure 13.



Figure 13 Development of size and rating or wind turbines [32]

Land-based wind, is also referred to as onshore wind, is the energy generated by wind turbines deployed far from the shore (mainly inland). It proven as mature technology with an extensive chain of global supply. Over the last five years, the onshore technology has evolved to increase electricity produced per megawatt (MW) capacity installed. Currently wind turbine manufacturers offer utility-scale turbines with larger rotor diameters ranging from 50 m to 125 m, taller hub heights (90 m to 150 m), and generators from 1.5 MW to 3.5 MW. In addition, some manufacturers have offered 4-5 MW platforms over the last two years. Meanwhile, the capacity of largest single generator installed onshore wind turbine reached 7.5 MW and hub height to 150m.

Offshore wind is the wind farms that can capture wind resources off the coasts and convert that wind to electricity. Offshore turbines achieve full-load hours more than onshore turbines cause it takes advantage of better wind resources when it deploying several tens of kilometers in the sea. Offshore wind farms can be installed near large centers of coastal demand, therefore, it can be particularly attractive for countries with coastal demand and land-based resources sited far mainland, such as several European countries, China, and the US. As a result, Large-scale offshore wind farms has started, more slowly than initially hoped (1.5 GW in 2008), mostly in Europe.

By the end of 2012, offshore with 5.4 GW had been installed, mainly in Denmark (1 GW) and United Kingdom (3 GW), with large offshore wind power plants installed in Belgium, Germany, Netherlands, Sweden, Norway, China, Japan, Portugal and Korea, while new projects are planned in the United States and France. The global offshore wind generated 25 TWh in 2014, 20% higher than in 2013. Then, global capacity of installed offshore wind exceeded 8.8 GW, with around 1.7 GW of new additions versus 2012 [33].

1.3.2 Wind Turbine Grid Connection

Wind turbine produce electrical energy from wind energy, then it fed into electrical network. Wind power technology (onshore and offshore) challenge the planning and operation of transmission and distribution grids. Grid connection challenges are technical, economical issues, spatial planning aspects, the capacity factor of transmission and distribution system, and legal issues. Wind power technology comes in a vast range of sizes suitable for a wide range of applications.

Small wind turbines (up to 10 kW) are used to power individual homes, and are typically grid connected or off-grid applications such as water pumping, battery charging stations, or telecom sites. Medium sized turbines (10 kW-500 kW) used to provide low voltage distribution system (power small villages) that is connected to the grid, often in conjunction with hybrid systems relying on solar or diesel generators in remote areas. Large wind turbines (500 kW – 7.5 MW) are used in offshore wind farms and provide power to grid by connected to medium voltage distribution or transmission system.

The Wind turbine are connected to the grid in different voltage levels, low, medium, high as well as extra high voltage system. While large offshore wind farms connected to the high and extra high voltage system, nowadays most of the turbines are connected to the medium voltage level of the grid [34]. That mean, planner and operator of power system have to consider that most of wind turbine connecting to the mesh topologies on medium and high voltage system.

1.4 Research Scope and Approach

It has become clear from the integration perspectives discussed above, that DG and specifically wind power present a broad range of challenges for power system planning and operation. To figure a clear research objective, it is important to describe the aspect of power system planning and operation, most relevant to this research. The main scope of this research can then be defined by using the descriptions and definitions given bellow.

1.4.1 Research Scope

A. Power system analysis

Electrical power system represents a large system consisting of generation, transmission, distribution and load complex components. Large power plants are usually located close to the primary energy and far away from electricity consumers. Electricity is delivered to the customers using transmission and distribution infrastructure, which involves HV, MV and LV networks. The power flows only from upper voltage levels down-to customers in one direction to pass these three stages (generation, transmission and distribution) before supply the final user.

In the first stage, the large generation plants is located in non-populated areas away from loads to generated electricity with the economics of size and environmental issues. Next, power flows into grid with the support of transformers, overhead transmission lines and underground cables in second stage. The last stage is the link between the utility system and the end customers through the distribution system. The electricity demand is increasing continuously. Consequently, electricity generation must increase in order to meet the demand requirements. Traditional power systems face this growth; installing new support systems in level 1 (see Figure 14). Whilst, addition in the transmission and distribution levels are less frequent.





Figure 14 Traditional electrical energy supply

B. Power flow calculation

The operation of generation units is mainly depended on the balance between generation and load sides as well as the economic dispatching. The transmission system operator (TSO) has the responsibility to transmit electrical power from generation units over the electrical grid to distribution system which is controlled by local distribution operators. During real-time operation, TSO must maintain continuous balance (second-by-second) at power system by determining the optimal power flow, and ensure the provision of reserves that will take into account sudden contingencies.

In addition to its roles of real-time dispatch of generation and managing security, the System Operator (SO) also carries out investigations, planning to ensure that supply can meet demand, and system security that can be maintained during future trading periods. Planning work examples may add up coordinating generator and outages of transmission, facilitating commissioning of new power plant and ancillary services procurement plan to support power system operation.

C. Real Power losses

During the transmission and distribution of electrical power, some real power (usually in the form of heat) is lost (5-7%) from these systems. For SO, losses can be define as the main difference between the amount of power generation providing to the system and the electrical power consuming in the demand side. The quantity of electrical power dissipated via losses can be

determined by power flow calculations during real time operation. Less computation time with acceptable accuracy for power loss calculations can play significant role to increase stability of the system.

Different kind of methods can be used to reduce power losses inside the grid:

- 1- Optimization methods of electrical losses in transmission and distribution networks involving tools of power system modeling and planning.
- 2- Modification of the electrical network structure. Optimal network reconfiguration in distribution system can play main role in power loss reduction as well as in load balancing.
- 3- Electrical power losses can be reduced by determining the optimal size and location of DG units as renewable resources.

D. Distributed generation and wind energy

At the present time, the new technologies, environmental policies, and the expansion of the finance and electrical markets, are allowing the electricity to be generated in small sized power plants. In order to reduce the environmental impact of power generation, the use of renewable sources increasing which leads to the development and application of new electrical power supply schemes.

In the availability of distributed generation, the generation is unlimited to specific level (Level1). Hence, part of the energy-demand is supplied by distributed generation while the great part is produced by the centralized generation. That mean, the electricity is flowing from new directions closer to the customers (final users) as show in Figure 15.



Figure 15 Energy flow with availability of DG

The penetration of distributed generation in the power network changes the characteristics of network from passive to active network. Furthermore, it will have an impact on various technical parameters based on its location and size of DG units in the network.

A major potential advantage offered by DG units is the reduction in electrical power losses, which can be significant under heavy load conditions. With the inclusion of DG, the active power loss in the distribution system can be modified. The active power losses change along the network, depending on how much power is produced by DG units, its locations, production levels and load.

DG units include wide range of technologies (gas turbine, wind turbine, photovoltaic etc.). In this context, medium power generators (wind turbines or park) typically located at MV distribution or transmission grids. Large-scale wind power (onshore and offshore parks) challenge the planning and operation of the grid. Grid connection has many challenges as technical, economical issues, planning aspects, and operation aspects. The impacts of wind power on power system cost mainly depend on annual variability of wind, penetration level, location and size of wind turbines.

1.4.2 Approaches of our research

The approach of this research taken into account the research objectives those analyzed in pervious section. Firstly, Schur complement method is applied to power system analysis to reduce memory and CPU times. We used it by dividing a Jacobian matrix at load flow into two separated matrices, so that; we could avoided divergence of the solution and reduce memory required with reasonable computation time.

A next step that was applied is based on data compression technique in order to improve the simulated algorithms for load flow calculation in electrical power systems. We proposed an algorithm based on Run Length Encoding (RLE) method where only non-zero data are stored as a single data values into Jacobian matrix elements.

Then, a predictive linear model for optimal size of Distributed Generation (DG), that addresses the minimum power loss, is presented. Simple, efficient, and flexible linear model has been developed to calculate the real power loss of the system. This method is based fundamentally on strong coupling between active power and voltage angle as well as between reactive power and voltage magnitudes.

We proposed also a simplified method to calculate the total power losses in electrical grid for different distributed generation (DG) sizes and locations. The 2-stage method is suggested to estimate the best size of DGs in a distributed power grid. In the first main step, incident matrix to build the linear model is generated by using the graph flow method while in the second step, a Kalman filter algorithm is then applied to obtain the optimal DG size at each bus system.

Genetic Algorithm (GA) optimization technique proposed to find global optimal size and location of multi distributed generations in electrical networks. The objective function based on a model to calculate the real power losses as a function of power generators. In order to demonstrate the effectiveness of the proposed method, it is applied on (14, 30 and 57) IEEE benchmark test systems by set maximum and minimum capacity of multi DG units based on the type of renewable energy resources.

Then, main local optimization tool used is the interior point, which is the faster and able to solve large-scale nonlinear problems. The proposed algorithm applied to obtain the local optimal location and size of the Distributed Generation (DG) units at each bus system with a substantial

reduction in the computation speed. The limitation of DG size has the flexibility to be changed with fixed or variable renewable generators types and sizes.

Finally, variable load network modeling is designed and presented. The main purpose of this design is to demonstrate the performance of power network based on load profile modeling as a means for enhance Distribution Network Operators (DNOs) decision in power systems. The IEEE five bus system is used as a test bed and simulated under Simulink. This simulation has been developed by simulate the wind farm integration into grid. The size and location of wind farm has been optimized by using the analytical approach.

1.5 Conclusion

Electrical Power system is divided into the generation system that supply the electrical power, the transmission system that carries this electrical power to the load centers and the distribution system that feed electrical currents to customers. The planning and operation of an electric network refers to all the means used to anticipate the evolutions of the network necessary for the delivery of electricity.

In traditional planning and operation methods, the distribution network is structured to work without DG units. In the presence of DG units, number of significant impacts on distribution planning and operations are apparent. The capability of the classical network to support the penetration level of Distribution Generation (DG) could be changed according different structures of distribution systems (Mesh and Radial systems). Based on this analysis, we emphasized that distribution topologies have different impact depending on size and type of DG as well as penetration level of it.

Radial usually used with low level voltage and in urban areas or less density population areas while mesh structure used with high or medium voltage and in higher density population areas. Recently, demand of connecting renewable energy to LV or MV distribution system significantly increased. Most of distributed generators (as renewable resources) feed either into MV distribution grid, which is mostly for wind power, or into LV grid, which is mostly for PV. So that, proposed algorithm in this thesis will focus on IEEE benchmark test systems that has mesh structure network.

The growth of wind turbine size brings a various challenges such as variation and fluctuation wind speed. The Wind turbine are connected to the grid in different voltage levels. Small wind turbines are typically grid connected or off-grid applications, medium sized turbines used to provide low voltage distribution system while large wind turbines are connected to medium voltage distribution or transmission system. Nowadays, planner and operator of power system has to consider that most of wind turbine connecting to the mesh network structure (medium and high voltage system).

The aspect of power system planning and operation (most relevant to this thesis) was specified the end goal to figure a clear research objective. The approach of this research is taken to achieve the research objectives those discussions are made in general introduction section. It is clear from the selection of publications mentioned in this chapter that an impressive assortment of work has been done into the integration of DG units and wind energy.

The main focus of this research explicitly on the real power losses and concern the consequences for load flows in the grid in term of time calculation and memory level. As mentioned in section 1.2.2, DG has a big impact on the electrical power losses and power flow calculation. Chapter 2 will highlight these topics.



Improvement of power system analysis and modelling of power losses calculation

Improvement of power system analysis and modelling of power losses calculation

The objective of this second chapter is to present the theoretical methods of power system analysis in order to build useful tools that can help the analysis of DG and wind energy integration into electric network in the next chapters. We develop approaches and methods that are used to reduce memory required and time consumption in power system analysis and real power losses calculation (Chapter 1).

These methods that will present below, allow us to study the impacts of a DG and wind energy on the real power losses of a distribution network in response to different scenarios with variable and fixed load demands. These methods have been implemented in a Simulink environment in order to facilitate their implementation on case studies.

Firstly in this chapter, we will detail the methods (Schur and Run Length Encoding) necessary for the improvement of power system analysis, that is, when computer memory and execution time considered as important factor for strategy of DG size and placement.

Secondly, specific method based on analytical approach taking into account size and location of wind farm integration into grid will be presented this chapter; an illustration of its implementation will be shown in Chapter 4. Finally, chapter 2 presents the graph theory used to generate the incident matrix to build the linear model that we will use in the next chapter, to consider a Kalman filter algorithm. DC power flow model will be demonstrated to derivative direct relation between voltage angels and real power loss. This relation will be used as principle to construct simple method for power loss calculation at the end of this chapter.

2.1 Introduction

Power flow analysis is necessary for planning, operation, economic scheduling and exchange of power between utilities. Power flow analysis is required for many other analyses such as transient stability, optimal power flow and for a future event or circumstance that is possible but cannot be predicted with certainty, which called contingency studies. The principal information of power flow analysis is to find the magnitude and phase angle of voltage at each bus and the real and reactive power flowing in each transmission lines. Power flow problem could be viewed as a multi-input multi-output system. Each input could have effect on each of the outputs, more or less. Thus, it makes it more difficult to appreciate the correlation between these variables.

In view of the topological transmission and distribution networks, many researchers have proposed several special load flow techniques [27-30]. However, an acceptable load flow method should meet the requirements such as high speed and low storage requirements, highly reliable, and accepted versatility and simplicity. The starting of studies for the load flow calculations was begin with the Ward & Hale [35], while the Newton-Raphson (N-R) method [36], [37] are being widely used. The problem of the computation iteration time has been solved by the developments of the Fast Decoupled Load Flow [38], then Fast Load Flow Method Retaining Nonlinearity [39], and so on. A large variety of proposed solution for power flow problem are addressed with different targets like reduce computation time [40] [41] [42], ill-conditioned cases and robustness [43] [44] [45], and optimal power flow (OPF) problems [46] [47] [48] [49].

Transmission loss allocation is not a simple task even in a simple two-node system with a single load supplying by one generator. In a real system, matters get more complicated because of two facts. The first is that the determination of the line power flows caused by each load through each transmission line has a good degree of arbitrariness. The second is that the loss of transmission line is a nonlinear function of the line flow. Some researchers [50, 51] are developed simple method independent of network topology and reliant on injection power at buses. The method has been implemented on system has only two loads, one located close to generator and other far away from generator. However, method has never taken into account the topology of the network.

2.2 Load flow concepts

A load flow approach can be very useful to merge uncertainties directly into the solution processes. The analysis results give multi solutions over the range of the uncertainties, i.e., instead of single values, solutions are sets of values. Network buses are of three different types and can be classified as:

- PQ bus the real power |P| and reactive power |Q| are specified. It is also known as Load Bus.
- PV bus the real power |P| and the voltage magnitude |V| are specified. It is also known as Generator Bus.
- Slack bus to balance the active and reactive power in the system. It is also known as the Reference Bus or the Swing Bus.

The use of a slack bus has an inherent disadvantage when dealing with uncertain input variables: the slack bus must absorb all uncertainties arising from the system and thus must have the widest possible nodal power distributions. Even moderate amounts of uncertainty in a large system may allow the resulting distributions to contain values beyond the slack bus's margins.

The slack bus provides or absorbs active and reactive power to and from the transmission line to provide for losses, since these variables are unknown until the final solution is established. The slack bus is the only bus for which the phase angle of system reference is defined. From this, the various angular differences can be calculated in the power flow equations. If a slack bus is not specified, then a generator bus with maximum real power |P| acts as the slack bus. A given scheme can involve more than one slack bus.

The most common formulation of the load flow problem specifies all input variables (PQ at loads, PV at generators) as deterministic values. Each set of specified values corresponds to one system state, which depends on a set of system conditions. When those conditions are uncertain, numerous scenarios must be analyzed.

A classic load flow analysis consists of calculating voltage magnitude and phase angle at the buses, as well as the active and reactive line flows for the specified terminal (or bus conditions). Four variables are associated with each bus:

Chapter 2. Improvement of power system analysis and modelling of power losses calculation

- 1. Voltage magnitude |V|
- 2. Voltage angle $|\delta|$
- 3. active or real power |P|
- 4. reactive power |Q|

Real and reactive powers (i.e. complex power) cannot be fixed. The net complex power flow into the network is not known in advance, and the system power losses are unknown until the study is complete. It is necessary to have one bus (i.e. the slack bus) at which complex power is unspecified so that it supplies the difference in the total system load plus losses and the sum of the complex powers specified at the remaining buses. The slack bus must also be a generator bus. The complex power allocated to this bus is computed as part of the solution. In order for the variations in real and reactive powers of the slack bus to be a small percentage of its generating capacity during the solution process, the bus connected to the largest generating station is normally selected as the slack bus.

The solution requires mathematical formulation and numerical solution. Since load flow problems generate non-linear equations that computers cannot solve quickly, numerical methods are required. The following methods are commonly used algorithms such as Gauss Iterative Method, Fast Decoupled Load Flow Method, Gauss-Seidel Method and Newton-Raphson Method.

2.3 Non Linear Load Flow

Newton Raphson method requires foremost the construction of admittance $(n \ge n)$ matrix, where *n* is number of bus system. The diagonal elements of the admittance matrix represent the self-admittance of the bus and the off diagonal represent the mutual admittance between buses.

$$Y = \begin{bmatrix} Y_{11} & \dots & Y_{jk} \\ \vdots & \ddots & \vdots \\ Y_{kj} & \dots & Y_{kk} \end{bmatrix}$$
(1)

where Y_{jk} is admittance between bus *j* and bus *k*.

For each Load Bus, equations included are the power balance equations (real and reactive). For each Generator Bus only the real power balance equation is included because the net reactive power injected is assumed to be unknown and therefore including the reactive power balance equation would result in an additional unknown variable. For similar reasons, there are no equations written for the Slack Bus.

In many transmission systems, the voltage angles are usually relatively small. There is thus a strong coupling between real power and voltage angle, and between reactive power and voltage magnitude, while the coupling between real power and voltage magnitude, as well as reactive power and voltage angle, is weak. As a result, real power is usually transmitted from the bus with higher voltage angle to the bus with lower voltage angle, and reactive power is usually transmitted from the bus with higher voltage magnitude to the bus with lower voltage magnitude. However, this approximation does not hold when the voltage angle is very large.

The real and reactive power are calculated at specific bus using initial guess (normally initial voltages assumed to be 1 p.u. and zero for voltage angles) and specified voltage magnitude and angle (for slack bus). The iteration methods were used to solve these nonlinear equations like (Gauss Sidle and Newton Raphson). Newton Raphson was more efficient and robust, and basically, it calculated powers as follows [52]:

$$P_k^{calc(x)} = \sum_{j=1}^n |V_k| |V_j| |Y_{kj}| \cos(\Theta_{kj} - \delta_k + \delta_j)$$
⁽²⁾

$$Q_k^{calc(x)} = -\sum_{j=1}^n |V_k| |V_j| |Y_{kj}| sin(\Theta_{kj} - \delta_k + \delta_j)$$
(3)

Where

 P_k is active or real power at bus k.

 Q_k is reactive power at bus k.

 Θ_{kj} is phase angle between bus k and j

Final iteration will depend on tolerance of the power mismatch which be calculated by difference between specified P_k^{sch} and calculated $P_k^{calc(x)}$ value as formulas:

$$\Delta P_k^{(x)} = P_k^{sch} - P_k^{calc(x)} \tag{4}$$

$$\Delta Q_k^{(x)} = Q_k^{sch} - Q_k^{calc(x)}$$
(5)

The Jacobian matrix of this method can be represented by:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta |V| \end{bmatrix}$$
(6)

The elements of the Jacobian matrix are partial derivative values of either P or Q with respect to either |V| or δ .

$$J = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix}$$
(7)

Typically, the Jacobian matrix is inversed and added to the left side of the equation, the final form looks like the following:

$$\begin{bmatrix} \Delta \ \delta \\ \Delta \ |V| \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}^{-1} \begin{bmatrix} \Delta \ P \\ \Delta \ Q \end{bmatrix}$$
(8)

All unknown voltage magnitudes and angles would initially require a guess would be 1p.u. and 0, respectively, because voltage magnitude must not exceed 3% of voltage reference and voltage angles must be close to angle of voltage reference. As far as concern, buses and parameters classified as shown in Table 4.

Bus	Known Parameter	Unknown
		Parameter
Slack or Swing Bus	$ V $ and δ	P and Q
Generator or PV or Regulated bus	P and V	Q and δ
Load or PQ Bus	P and Q	$ V $ and δ

Table 4 Classification of Buses in Electrical Network

If iteration continue then the new voltage magnitude and angle can be updated with the following equations:

Voltage angle mismatch $\delta_k^{(x+1)} = \delta_k^{(x)} + \Delta \delta_k^{(x)}$ (9)

Voltage magnitude mismatch

 $\left|V_{k}^{(x+1)}\right| = \left|V_{k}^{(x)}\right| + \Delta \left|V_{k}^{(x)}\right| \tag{10}$

The general form of the Newton Raphson (N-R) method will be:

$$\begin{bmatrix} \Delta P_{2} \\ \vdots \\ \Delta P_{n-1} \\ \Delta Q_{2} \\ \vdots \\ \Delta Q_{n-ng-1} \end{bmatrix} \begin{bmatrix} \frac{\partial P_{2}}{\partial \delta_{2}} & \frac{\partial P_{2}}{\partial |V_{2}|} & & \\ & \ddots & & \ddots & \\ & \frac{\partial P_{n-1}}{\partial \delta_{n-1}} & \frac{\partial P_{n-1}}{\partial |V_{n-ng-1}|} \\ \frac{\partial Q_{2}}{\partial \delta_{2}} & \frac{\partial Q_{2}}{\partial |V_{2}|} & & \\ & \ddots & & \ddots & \\ & \frac{\partial Q_{n-ng-1}}{\partial \delta_{n-1}} & \frac{\partial Q_{n-ng-1}}{\partial |V_{n-ng-1}|} \end{bmatrix} \begin{bmatrix} \Delta \delta_{2} \\ \vdots \\ \Delta \delta_{n-1} \\ \Delta |V_{2}| \\ \vdots \\ \Delta |V_{n-ng-1}| \end{bmatrix}$$
(11)

The matrix size is calculated by 2 * nbus - ng - 2 * ns, where *nbus* is the total number of bus of network, *ng* is the total number of generator bus in network and *ns* is the number of slack bus.

J1 diagonal element

$$\frac{\partial P_k}{\partial \delta_k}^{(x)} = \sum_{j \neq k} |V_k| |V_j| |Y_{kj}| \sin(\Theta_{kj} - \delta_k + \delta_j)$$
(12)

J1 off diagonal element

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$$\frac{\partial P_k^{(x)}}{\partial \delta_j} = -|V_k| |V_j| |Y_{kj}| \sin(\Theta_{kj} - \delta_k + \delta_j)$$
(13)

J2 diagonal element

$$\frac{\partial P_k}{\partial |V_k|}^{(x)} = 2|V_k||Y_{kk}|\cos\theta_{kk} + \sum_{j\neq k} |V_j||Y_{kj}|\cos(\theta_{kj} - \delta_k + \delta_j)$$
(14)

J2 off diagonal element

$$\frac{\partial P_k}{\partial |V_j|}^{(x)} = |V_k| |Y_{kj}| \cos(\Theta_{kj} - \delta_k + \delta_j)$$
(15)

J3 diagonal element

$$\frac{\partial Q_k}{\partial \delta_k}^{(x)} = \sum_{j \neq k} |V_k| |V_j| |Y_{kj}| \cos(\Theta_{kj} - \delta_k + \delta_j)$$
(16)

J3 off diagonal element

$$\frac{\partial Q_k}{\partial \delta_j}^{(x)} = -|V_k| |V_j| |Y_{kj}| \cos(\Theta_{kj} - \delta_k + \delta_j)$$
(17)

J4 diagonal element

$$\frac{\partial Q_k}{\partial |V_k|}^{(x)} = -2|V_k||Y_{kk}|\sin\theta_{kk} - \sum_{j\neq k} |V_j||Y_{kj}|\sin(\theta_{kj} - \delta_k + \delta_j)$$
(18)

J4 off diagonal element

$$\frac{\partial Q_k}{\partial |V_j|}^{(x)} = -|V_k||Y_{kj}|\sin(\Theta_{kj} - \delta_k + \delta_j)$$
(19)

2.3.1 The Schur complement method

In the theory of matrices and linear algebra, the sub-domain problems usually involve interior, local interface and external interface variables. The Schur complement technique is a procedure to eliminate the interior variables in each sub-domain and derive a global, reduced in size, linear system involving only the interface variables [53]. Suppose that the square matrix (M) is partitioned into four sub matrix blocks as A, B, C and D:

$$M = \begin{bmatrix} A & B \\ C & D \end{bmatrix}$$
(20)

Let suppose that A, B, C and D are respectively dimensioned $m \times m, m \times n$, $n \times m$ and $n \times n$ matrices, and D is invertible. So that M is a $(m+n) \times (m+n)$ matrix.

That mean, A and D are square matrices, while B and C are not square unless m = n. so that inverse of M is a $(m+n) \times (m+n)$ matrix:

$$\begin{pmatrix} A_{m*m} & B_{m*n} \\ C_{n*m} & D_{n*n} \end{pmatrix}^{-1} = \begin{pmatrix} (A - BD^{-1}C)^{-1} & -(A - BD^{-1}C)^{-1}BD^{-1} \\ -(D - CA^{-1}B)^{-1}CA^{-1} & (D - CA^{-1}B)^{-1} \end{pmatrix}$$
(21)

Then the Schur complement of the block D or A of the matrix M is the $m \times n$ matrix:

$$A-BD^{1} C \text{ or } D-CA^{1}B$$
(22)

Each iteration of load flow solution requires basic matrix operations (multiplication and inversion) to be performed. For large-scale power system, improve computation times and memory storage required for calculation can be done by using efficient numerical techniques. In most practical electrical network, Jacobian matrix is sparse matrix because it include lot of elements equal to zero, For example, nonzero elements (nz) in Jacobian matrices of 118 and 300 IEEE bus systems can be plotted by Matlab as in Figure 16, where nz are 1051 and 3726 of 118 bus (13924 elements) and 300 bus(90000 elements), respectively.

Because the Jacobian matrix is not regular as in Figure 16, Schur method can be used to decouple the unknown variables of matrix in sub-matrices, sub-domain internal unknown variables and interface unknown variables [54]. In same figure, two perpendicular red lines can divide Jacobian matrix of 300 bus to construct four diagonal sub-matrices. That mean, no need for large memory when inverse matrix which will be more powerful in iteration methods by separate their

variables. In practice, one needs D to be well conditioned in order for this algorithm to be numerically accurate.



Figure 16 Jacobian Matrix for different systems

2.3.2 RLE (Run Length Encoding)

RLE is a very simple algorithm of lossless data compression in which runs of data that contains many consecutive data elements. This is most useful on data to store, rather than as the original run, as a single data value and count, for example, images of simple graphic such as line drawings, animations, and icons. This section discusses intuitive Data compression method that is achieved by reducing redundancy.

The main idea behind RLE approach to data compression is: if (*a*) is data has item (d) occurs (*n*) consecutive times in the input stream, replace (*n*) occurrences with the single pair (*nd*). The (*n*) consecutive occurrence of (*a*) data item are called (*a*) run length of (*n*), and this approach to data compression is called run length encoding (RLE) [55].

For example, consider a screen containing plain black text on a solid white background. There will be many long runs of white pixels in the blank space, and many short runs of black pixels within the text. A hypothetical scan line, with B representing a black pixel and W representing white, might read as follows:

Chapter 2. Improvement of power system analysis and modelling of power losses calculation

With a run-length encoding (RLE) data compression algorithm applied to the above hypothetical scan line; it can be rendered as follows:

12W1B12W3B24W1B14W

This can be interpreted as a sequence of twelve Ws, one B, twelve Ws, three Bs, etc. The runlength code represents the original 67 characters in only 18. The RLE method has been applied to text compression and image compression as explained in next sections.

A. In text compression:

RLE represented as simple compression algorithm used to compress containing subsequent repetitions of the same character. Run Length Coding is used to compress ASCII character set by a pair of RUNS and LEVELS, where RUNS shows the number of consecutive LEVELS, the ASCII character in the ASCII character set [56]. Code can be obtained by compressing a particular sequence, as *aaaaa* can be coded as #a5 (where # represents the repetition mark) while 5 is a counter for number of repetition.

The data compression ratio is a term used to quantify the reduction in data-representation size produced by a data compression algorithm. This ratio produced by RLE for text compression can be calculated by:

$$\frac{N}{N-M(L-3)}$$
(23)

Where N is string of characters contains M repetitions of average length L each. Example: N=1000, M=10, L=3 yield a compression ratio of 1000/[1000-10(4-3)]=1.01, A better result is obtained in the case N=1000, M=50, L=10, where the ratio is 1.538.

Figure 17 is the graphical representation of the RLE algorithm [57] applying on temperature readings.


Figure 17 Flow chart for text compression

B. Image compression

A digital image consists of small dots (Pixels). Each pixel can be either one bit (white or black) or several bits (one of several colors or shades of grey). Compression an image using RLE is based on assumption that if random pixel is selected, there is a good chance that its neighbors will have

the same color. The size of the compressed stream depends on the complexity of the image (Figure 18).

The compression ratio of a uniform area equal:

Half the length of the perimeter total number of pixels in the area



Figure 18 Uniform area and scan lines

Best compression can be obtained when the number of scan lines traversing a better direction depends on uniform area. It can be show different direction as Figure 19 bellow:



Figure 19 RLE Scanning

This algorithm is easy to implement and does not require much CPU power. RLE compression is efficient with data that contain many repetitive. These can be text if they contain large spaces for indenting but line-art images that contain large white or black areas are far more suitable.

The algorithm of the RLE creates a dictionary of the phrases that occur in the input data. When they encounter a phrase already present in the dictionary, they just output the index number of the phrase in the dictionary. The diagram in Figure 20 shown that first two input colors are represented in the dictionary by number 1 and same procedure applied to number 4 as output data.



Figure 20 Dictionary Algorithm

2.4 Linear Load Flow

2.4.1 P δ – QV Decoupling

The AC power flow problem has been formulated at Newton-Raphson method by the following power flow equations:

$$f(x) = \begin{pmatrix} \Delta P(x) \\ \Delta Q(x) \end{pmatrix} = 0$$
(24)

The functions $\Delta P(x)$ is active mismatches and $\Delta Q(x)$ is reactive power mismatches. The solutions are determined approximately by considering the first term of the Taylor series:

$$J(x)\begin{pmatrix}\Delta\delta\\\Delta V\end{pmatrix} + \begin{pmatrix}\Delta P(x)\\\Delta Q(x)\end{pmatrix} = 0$$
(25)

The partial derivative values of the Jacobian matrix, which are either P or Q with respect to either |V| or δ :

$$J(x) = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix}$$
(26)

The matrices $\frac{\partial P}{\partial \delta}$, $\frac{\partial Q}{\partial |V|}$ and J in eq. (26) are always quadratic. The four matrix variables associated with each power network node k:

- P_k , the net active power (generation load) at node k
- Q_k , the net reactive power (generation load) at node k
- V_k , the voltage magnitude at node k
- δ_k , the voltage angle at node k

For transmission line systems, it can be normally observed the strong coupling between P and δ , as well as between Q and V. This property will be used in this section to accelerate and simplify the computations. Then, it will derive a linear approximation called linearization of power flow in the next section. This model will has linear relation between the bus active power P and voltage angle δ .

Let consider a simple model of a transmission line system (k to m) as in Figure 21, the active and reactive power flows can be expressed mathematically as follows:

$$P_{km} = V_k^2 G_{km} - V_k V_m G_{km} Cos \delta_{km} - V_k V_m B_{km} Sin \delta_{km}$$
(27)

$$Q_{km} = -V_k^2(B_{km}) + V_k V_m B_{km} Cos\delta_{km} - V_k V_m G_{km} Sin\delta_{km}$$
(28)

where

 G_{km} , the transmission line conductance $(1/R_{km})$. B_{km} , the transmission line susceptance $(1/X_{km})$. X_{km} is the series reactance of the line. R_{km} is the series resistance of the line



Figure 21 Power flow in transmission line

If the series resistance and the shunt admittance both are neglected and assumed to were zero, then above expressions can be simplified as:

$$P_{km} = \frac{V_k V_m Sin\delta_{km}}{x_{km}}$$
(29)

$$Q_{km} = \frac{V_k^2 - V_k V_m Cos \delta_{km}}{x_{km}}$$
(30)

The elements of matrix in Eq. (26) can find the partial derivative approximately between the function (power flows P_{km} and Q_{km}) and the state variables (V and δ) as:

$$\frac{\partial P_{km}}{\partial \delta_k} = \frac{V_k V_m Cos \delta_{km}}{x_{km}}$$
(31)

$$\frac{\partial P_{km}}{\partial V_k} = \frac{V_m \sin \delta_{km}}{x_{km}} \tag{32}$$

$$\frac{\partial Q_{km}}{\partial \delta_k} = \frac{V_k V_m \sin \delta_{km}}{x_{km}} \tag{33}$$

$$\frac{\partial Q_{km}}{\partial V_k} = \frac{2V_k - V_m \cos \delta_{km}}{x_{km}} \tag{34}$$

In case of perfect decoupling conditions, it is observed that $\delta_{km} = 0$:

$$\frac{\partial P_{km}}{\partial \delta_k} = \frac{V_k V_m}{x_{km}} \tag{35}$$

$$\frac{\partial P_{km}}{\partial V_k} = 0 \tag{36}$$

$$\frac{\partial Q_{km}}{\partial \delta_k} = 0 \tag{37}$$

$$\frac{\partial Q_{km}}{\partial V_k} = \frac{2V_k - V_m}{x_{km}} \tag{38}$$

As shown in Figure 22, the voltage angles are relatively small in the usual range of operations, a strong coupling between active power and voltage angle as well as between reactive power and voltage magnitudes exists. Whereas much weaker coupling between active power and voltage magnitude, and between reactive power and voltage angle exists. When δ_{km} near to 90°, strong coupling between *P* and *V* as well as between *Q* and δ observed clearly [58].

With this assumption, the elements of Jacobian Matrix can be considered as:

$$J = \begin{bmatrix} \frac{\partial P}{\partial \delta} & 0\\ 0 & \frac{\partial Q}{\partial |V|} \end{bmatrix}$$
(39)





Figure 22 P $-\delta$ and Q $-\delta$ relation for a transimssion line

Thus, the updates of voltage magnitudes and angles has no coupling between them, and eq.(26) can be divided into two uncoupled equations:

$$\frac{\partial P}{\partial \delta}(\Delta \delta) + \Delta P(\delta, V) = 0$$
(40)

$$\frac{\partial Q}{\partial V}(\Delta V) + \Delta Q \ (\delta, V) = 0 \tag{41}$$

The solution can be even faster (but then only an approximate solution) if approximations concerning the active and reactive power mismatches are used.

2.4.2 DC Power Flow Model

In this section, it will be driven linearization equations of power flow. Again, considering transmission line in last section with expressions for the active power flows (P_{km} and P_{mk}) can represent by [59]:

$$P_{km} = V_k^2 G_{km} - V_k V_m G_{km} Cos \delta_{km} - V_k V_m B_{km} Sin \delta_{km}$$
(42)

$$P_{mk} = V_{mk}^2 G_{km} - V_k V_m G_{km} Cos\delta_{km} + V_k V_m B_{km} Sin\delta_{km}$$
(43)

The active power losses can be determined by using the transmission line equations (42 and 43) to get:

$$P_{km} + P_{mk} = G_{km} (V_k^2 + V_m^2 - 2V_k V_m Cos \delta_{km})$$
(44)

If the terms corresponding to the active power losses in eqs. (42) and (43), are ignored, the result is:

$$P_{km} = -P_{mk} = -V_k V_m B_{km} Sin\delta_{km} \tag{45}$$

During light load conditions, the following additional approximations are particularly valid:

$$V_k \approx V_m \approx 1 \ p.u. \tag{46}$$

$$\sin \delta_{km} \approx \delta_{km} \tag{47}$$

and since

$$B_{km} = -1/x_{km} \tag{48}$$

The expression of active power flow P_{km} can simplify to

$$P_{km} = \frac{\delta_{km}}{x_{km}} = \frac{\delta_k - \delta_m}{x_{km}} \tag{49}$$

$$P_{km} = x_{km}^{-1} \delta_{km} \tag{50}$$

where

- • P_{km} is the power flow in transmission line (k to m).
- • δ_k and δ_m are the voltages angles at terminals of line.

• x_{km} is the reactance of transmission line (k to m).

Thus, for k = 1, 2, ..., N, where N is the number of buses in the electrical network. The active power injection at bus k is calculated by

$$P_k = \sum_{m \in N} x_{km}^{-1} \delta_{km} = \left(\sum_{m \in N} x_{km}^{-1} \right) \delta_k + \sum_{m \in N} (-x_{km}^{-1} \delta_m)$$
(51)

58

This can be write into matrix form as follows:

$$P = B' \Delta \delta \tag{52}$$

where

•*P* is the vector of the net power injections at node k.

 $\cdot B'$ is the nodal admittance transpose matrix with the following elements:

$$B_{km} = x_{km}^{-1}, \ B_{kk} = \sum_{m \in \mathbb{N}} x_{km}^{-1}$$
(53)

The determinant of matrix *B* in eq. (52) is equal to zero, singular matrix. Where slack node has zero angle reference, i.e. $\delta_{ref} = 0$, that mean one of the equations in the system is removed. Of course, the angle reference is still needed but the bus associated with that row and column will be disposed. This means that the equations in eq. (52) has no unique solution and that the rows of matrix *B* are linearly dependent.

2.5 Graph Theory and Incidence Matrix

The power system, is converted to a graph G(V, E), where V represents the set of vertices or nodes (buses in the network) and E represents arcs (interconnection lines among buses in the network) [60]. Figure 23 and Figure 24 show an example of a IEEE 5 bus system (adopted in this work) and its direct graph representation.

The incidence matrix (A) of a graph G is a (M^*N -I) matrix that shows the relationship between nodes and arcs, where M and N-I are the numbers of lines and buses respectively. This matrix contains a number of rows equal to the number of arcs and a number of columns equal to the number of nodes. Note that it has only N-I columns because the angle of reference bus is being set equal zero.



Figure 23 Single line diagram of IEEE 5 bus network



Figure 24 Representative direct graph of IEEE 5 bus network

The incidence matrix (*A*) can be expressed mathematically as follows:

$$A_{ij} = \begin{cases} 1 \text{ if arc } j \text{ starts at node } i \\ -1 \text{ if arc } j \text{ ends at node } i \\ 0 \text{ otherwise} \end{cases}$$
(54)

For 5 bus system above, the incidence matrix will be:

$$At = \begin{bmatrix} -1 & 0 & 0 & 0\\ 0 & -1 & 0 & 0\\ 1 & -1 & 0 & 0\\ 1 & 0 & -1 & 0\\ 1 & 0 & 0 & -1\\ 0 & 1 & -1 & 0\\ 0 & 0 & 1 & -1 \end{bmatrix}$$
(55)

2.6 Analytical Approach

Let us consider a π -model of a transmission line (*k* to *m*). In per unit system, the voltage magnitude throughout any power network is relatively close to unity during light load conditions:

$$V_k \approx V_m \approx 1 \ p.u. \tag{56}$$

where

 V_k : is voltage magnitude at bus k.

 V_m : is voltage magnitude at bus *m*.

For most typical operating conditions, the difference in angles of the voltages at two buses k and m connected by a circuit, which is $\delta_k - \delta_m$ for buses k and m, is less than 10-15 degrees. It is extremely rare to see such angular separation exceed 30 degrees. Thus, it can considered that:

$$\sin \delta_{km} \approx \delta_{km} \tag{57}$$

In the usual range of operations, a strong coupling between active power and voltage angle as well as between reactive power and voltage magnitudes exists, while a much weaker coupling between reactive power and voltage angle, and between voltage magnitude and active power exists as in Figure 22.

Based on the above, the AC power flow in lines can be approximated and linearized by neglecting the imaginary part of system (reactive power) where R << X, voltage magnitude of buses are set to 1.0 per unit and voltage angle is assumed be small. The active power (*P*) injections in buses can be derived and calculated by multiplying the nodal admittance matrix (*B*) by the angles (δ) of the buses as follows:

$$P = B.\delta \quad or \quad \delta = B^{-1} * P \tag{58}$$

While the active power flow through transmission line can be calculated by multiplying nondiagonal elements of negative susceptance by difference between voltage angles of two line terminals as [61]:

$$P_{pf} = D.\Delta\delta = D * (At * \delta)$$
⁽⁵⁹⁾

where

- P_{pf} is the vector of power flow which has dimension (M^*1).
- D is the vector (M^*I) or diagonal matrix (M^*M) elements which is formed by placing the negative susceptance (-x).
- δ is the vector of voltage angles of buses (*N*-1*1).
- At is the incidence matrix (*M***N*-1) between node (voltage angle) and arc (voltage angles differences).

2.7 Simplified Power Losses method

Losses are distributed across all buses, according to their level of generation or consumption only. The slack bus is just a phase reference bus and like other generators, bus is not in charge for compensating the total loss of system but also divide the losses between generators and loads. Therefore, power system analysis will be performed to calculate exact total losses.

The method to calculate active power losses presents simple equations. At any line, losses onto the series impedance of a transmission line are I^2 . *R* and I^2 . *X*:

$$I = \left(\frac{P - JQ}{V^*}\right) \tag{60}$$

$$I^* = \left(\frac{P + JQ}{V}\right) \tag{61}$$

$$I^{2} = I.I^{*}\left(\frac{(P - JQ)(P + JQ)}{V.V^{*}}\right) = \frac{(P^{2} + Q^{2})}{V^{2}}$$
(62)

$$P_{losses} = I^2 \cdot R = \left(\frac{P^2 + Q^2}{V^2}\right) \cdot R$$
 (63)

$$Q_{losses} = I^2 \cdot X = \left(\frac{P^2 + Q^2}{V^2}\right) \cdot X$$
 (64)

That mean, transmission loss is dividing into two components. The first is due to active power loss and second is reactive power loss. In this work, It will interested on active or real power losses which more effected by DG. Most of DG represented by active power generation which are located near loads to reduce total losses due to reduce current flow from generators to loads and losses due to difference between generators voltage. So that, reactive power flow will be same for both nonlinear and linear model and can be neglected.

The DG also improve voltage profile in system but power flows will slightly different. In additional, voltage values at each bus is around 1 p.u. which can simplified the equation of active power flow as follows:

$$P_{losses} = P^2 * R \tag{65}$$

So that, direct relation between injected power and power losses can be done by:

$$P_{losses} = (D * At * P/B)^2 * R$$
(66)

2.8 Conclusion

The development of computer systems meant power flow studies could be execute more efficiently allowing for much better operating and planning of power systems. Supercomputers and high performance parallel computer systems are significantly expensive and required more costly power and cooling system. Many efforts have been made to reduce computation time and amount of computer memory required for power system analysis. An overview of these researches has been demonstrated and discussed in the first part of this chapter.

In this second chapter the principle of classical load flow studies have been presented based on techniques of complex analysis. Determine the most suitable method for a power system analysis is main problem faced the power industrial. A high degree accuracy for non-linear load flow required more calculation time and computer memory. The Schur complement method has been presented to develop the Newton Raphson method by separating the Jacobian matrix. The separation of matrix can improve the amount of computer memory and speed up the processing if it execute tasks in parallel on a multi core CPU.

Related to the time consumption based on the number of iterations, it has been demonstrated that the data compression method (RLE) is the best strategy to speed up the time required for Newton Raphson method. With RLE method, skip useless values in Jacobian matrix can reduce the iteration numbers as well as the iteration step. The proposed method applied to the nonlinear load flow and good results will be shown in chapter five, which can actually generate time and processing economy. Both (Schur complement and RLE methods) will be used to improve the nonlinear load flow (NR) which will be used in chapter 3.

In other hand, less accurate load flow method has been illustrated to explain the need of faster method in other cases. DC power flow model mostly used instead of Newton Raphson method to analysis large network and online monitor to help DSO. This linear method has been developed with help of graph theory and neglecting reactive power to find direct relation between power flow in lines and voltage angles. Analytical method is developed simple method for power loss calculation will be help to find optimal solutions in chapter three and four. Direct relation between power injected and power losses has been introduced to reduce the demand for much consumption time.

Chapter 3

Fast selection of DG' size and

optimization techniques for loss reduction

Fast selection of DG' size and optimization techniques for loss reduction

This third chapter explains the optimization process carried out in the present PhD in order to optimize both DG size and placement. These optimal strategies are applied to develop the DG units integration (as wind energy in the fourth chapter) into electrical power grid, which we consider one of the main contribution of this PhD work.

In the first subsection, the state of art of recent optimization technique that concerned on size and location of DG for different objectives is presented. After that, we introduce the basic principle of Kalman filter and how it can be used to select the optimal DG size based on analytical method in last chapter. Then, the sequence to obtain the global optimal size and location for multi DG units are summarized.

In addition, the interior point method sequence to obtain the local optimal strategy is developed. The results of these optimization techniques are presented based on several IEEE benchmark test systems. Finally, the comparison between local and global optimal results based on power loss modeled in chapter 2 is carried out, showing the optimality of the presented proposition.

3.1 Introduction

Location of distributed generation (DG) may be either positive or negative impact on power system network [62]. Although the distributed generators are small size generators, it is expected to play an increasing role in power systems and predicted to be a significant percentage of all new generation going online. Many different kinds of resources can be used in DG, such as photovoltaic, wind, fuel cells, biomass, etc. [11].

Determining the geographic siting of the DG into an electrical network is the most challenging part, for most utilities. A poor choice of location of the DG would increase the losses in the system more so, than when there is no renewable distributed generation at all. Therefore, many researchers have considered and proposed different approaches for optimal placement in electrical networks.

The impact of Distributed Generation has been discussed with reference to, system voltage, system protection, loss of the power grid, system restoration and related network issues in [63]. A case study assessed the impact of the connection of significant amounts of DG on energy losses and voltage drop in the distribution system [64]. To solve the problem of optimal location of DGs, researchers have employed conventional analytical approaches using sensitivity factors obtained from quantities such as, system bus impedance and admittance matrices, and the special power loss formula [65, 66, 67].

The annual investment and operation costs as an objective function have been minimized by using a mixed integer, linear programming approach, considering different load levels and the associated capability of different types of DGs [68]. In addition, a mixed integer, non-linear Programming and heuristic approach, has been developed, to minimize the real and reactive losses by finding the ideal location of DG's [69].

Different optimization techniques have been used to find the optimal location of single or multiple DG's. Some studies have been implemented based on artificial intelligence. The Genetic Algorithm (GA) with consideration to the voltage stability as an objective function is presented in [70]. The artificial neural network (ANN) is implemented to reduce line losses and beneficially increase the voltage profile. Further to this, it improves power quality by deducing the optimal generation dispatch [71].

Chapter 3. Fast selection of DG' size and optimization techniques for loss reduction

The optimal DG placement problem is a complex problem with nonlinear objective function and nonlinear constraints. Many of techniques have been proposed to define the optimal locations and capacities of DGs [72, 73].

The analytical approach (noted as NA) has been demonstrated in [67] to find the optimal size and location of DG to minimize the real power losses and enhancement in voltage profile. In [74] has proposed analytical expressions for finding optimal size and power factor of different types of distributed generators for minimizing losses in primary distribution systems. Heuristic methods have been used instead of analytical approach (NA) because this problem is hard and may not be able to get a global acceptance solution.

The simulated annealing (SA) is applied to solve the multi- objective optimal placement of distributed generation (DG) [21]. An artificial bee colony (ABC) algorithm has been employed to determine the optimal DG-unit's size, power factor, and location in order to minimize the total system real power loss [75]. The load models can significantly affect the optimal location and sizing of DG resources in distribution systems, which presented as a multi-objective index based approach for optimally determining the size and location of multi-distributed generation (multi-DG) units [76].

Some studies have been implemented based on Genetic Algorithm (GA).In [70], optimization problem is solved by GA where voltage stability is considered as objective function. A combination of Particle Swarm Optimization (PSO) and GA is used in the radial distribution systems to minimize the power loss and improve voltage regulation [73]. A combination of simulated annealing and GA meta-heuristic method is used to solve optimal DG power output [77]. Another research succeeded in merging both genetic algorithm (GA) and optimal power flow (OPF) calculations in one optimization problem. The main objective function included in the optimization problem was investment costs of active and reactive power [78].

The fuzzy EP is used to find the optimal size of the two types of DG in an effort to minimize the total prospective payments levied during compensation issues attributable to system losses and offset of the DG's capital costs [79]. An artificial bee colony (ABC) algorithm has been employed to determine the optimal DG's size, power factor, and location, in order to minimize the total system real power loss [75].

Chapter 3. Fast selection of DG' size and optimization techniques for loss reduction

In [80], analytical approach has been developed to find optimum size of DG units in order to minimize the power loss. It considered mutual coupling factor to reduce the computation time required and compared results with Exhaustive Load Flow (ELF) and Improved Analytical (AI) methods.

High levels of variable electricity generation produced by renewable resources need for flexibility of calculation with less time to improve the stability, reliability and economy. The computer execution time was important factor for many of researchers in the DG placement strategy [81].

Kalman filtering algorithm has also been of interest in selection of optimal sizes of multiple DGs [82, 83]. It has been proposed in the context of generalized generation distribution factors to select the optimal location of the DGs. The work reported in [82] was then extended in [83] to consider the power loss sensitivity and Kalman filter algorithm in obtaining the optimal location of the DG. The optimal locations is determined by considering new factor called optimal locator index (OLI) which developed by the power loss sensitivities. In other hand, optimal sizes has been determined by applying Kalman filter algorithm.

3.2 Kalman Filter

Kalman Filter is a powerful state estimation algorithm that assumes that the state of a system at time t depends on the previous state at time t-1. Noise models, process model and measurements are therefore can be used to obtain an accurate estimate of the states of the process [84].

The linearized state equation of the network can be formulated as follows:

$$X_t = F_t X_{t-1} + B_t u_t + w_t \tag{67}$$

Where F_t and B_t are the matrices of state transition and control input, respectively. X_t and u_t are respectively representing the state and control input vectors, and w_t is the vector containing the process noise terms for each parameter in the state vector. In this study, the state model applied to find the optimal size of DG is given as

$$[\delta] = [I][\delta] + [D * A]^{-1}[P_{DG}] + w_t$$
(68)

Where δ and $P_{DG} (\in R_{n-1} * 1)$ are as given in (59), *I* is the identity vector with same dimension of , $D(\in R_{n-1} * n - 1)$ is the negative susceptance, and w_t is the input noise (assumed to be equal to 0.0001). Analysis of the network is performed using the linearized model given in (67). The vector components (Z_t) are obtained from:

$$Z_t = y_t + v_t \tag{69}$$

where, y_t is the estimated output and v_t is the measurement noise terms for each observation. The estimated output (y_t) can therefore be obtained from:

$$y_t = a.x + b \tag{70}$$

Where a and b are coefficients of the linear network model. These coefficients are calculated based on two samples taken from Newton Raphson method.

The implementation of Kalman filter algorithms proceeds according to the following sequential steps:

1) Compute the Innovation, using following:

$$Inn = y_t - c * (At * \delta) \tag{71}$$

2) Compute covariance of the Innovation, using following:

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$$S = c' * P_{t-1} * c + S_z \tag{72}$$

where S_z is a measurement of error covariance and c is the inverse of inductance for each line.

3) Calculate the Kalman Gain matrix, using following:

$$K_{t} = I * P_{t-1} * c * inv(S)$$
(73)

4) Update the state estimate, using following:

$$\delta_t = \delta_{t-1} + Bt * (K_t * Inn) \tag{74}$$

5) Compute the covariance of the estimation error.

$$P_t = P_{t-1} - K_t * S + S_w \tag{75}$$

where S_w is the process noise covariance and P_t is the initial estimation covariance.

3.3 Genetic Algorithm Technique

According to the artificial intelligence definition, the genetic algorithm is a search heuristic that simulates the mechanism of natural selection. As such they represent an intelligent running of a random search used to solve optimization problems. It simulates survival of the fittest among individuals over consecutive generation in a competitive environment for solving a problem. Each individual is codified into a chromosome consisting of genes which representing his characteristic. Each individual represents a point in a search space while each generation consists of a population of strings (chromosomes), which encode candidate solutions (individuals) to an optimization problem and evolves toward better solutions [85].

Traditionally, a chromosome is structured by a string of values in binary form (0 and 1) but a real encoding GA can be used. Since, the parameters in siting and size of DG's are real numbers, the chromosome is defined as an array of real numbers with the mutation and crossover operators. The individual variables are analogous to chromosomes and genes respectively. Thus, a solution (chromosome) is composed of several variables (genes). The fitness value is used to summarize how close a given solution is to achieving the set aims. The procedure of generic selection can be implemented as follows:

- 1. The fitness function is evaluated for each individual by providing fitness values then dividing the fitness value of each individual by the sum of all fitness values.
- 2. The population sorted descending order by fitness value.
- 3. Accumulated normalized fitness values are computed and accumulated fitness value of the last individual should be 1.
- 4. The random number should be between 0 and 1.
- 5. The selected individual is the first one whose accumulated normalized value is greater than the random number.

To start the search procedure, a population of randomly generated individuals and its size should be fixed and determined. In each generation, the fitness function is evaluated for giving population; multiple individuals are selected from the current population and modified to form a new population. The optimal solution obtained when either a satisfactory fitness level has reached

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for the population, or maximum number of generations has produced. There are three operators to evaluate the population of design vectors.

Firstly, the reproduction operator which used to determine the strings with the above-average fitness value from population and insert their multiple copies based on the probabilistic procedure. Then, crossover operator which normally is implemented after the reproduction, aims create new strings in the population by exchanging the information.

After the crossover operation, the mutation operator should be applied to the new strings. This operator changes the specific bits of the strings 0 to 1 or vice versa.

3.3.1 Problem Formulation

The main goal of the proposed algorithm is to minimize the power losses by finding the optimal allocation and the size of the DG units in a given electrical network. The combination between simple nonlinear model and GA optimization method are used to help the planner to manage the electrical network (in smart grid) with the availability of multi-distributed generations.

A. Objective function

The objective function of real power losses can be expressed as follows:

$$Min P_{losses} = f(X) \tag{76}$$

Where P_{losses} denotes total power losses of the system. If P_{DGi} denote the active power of the ith DG, n is the number of candidate load buses and then the variables of X can be expressed as:

$$Min P_{losses} = f(X) \tag{77}$$

$$X = [P_{DG1}, P_{DG2}, \dots, P_{DGi}] \quad for \ i = 1, 2, \dots, n$$
(78)

In equation (66), the real power losses of the network are selected as objective function to minimize as follows:

$$Min P_{losses}(P_{DG}) = R * (D * A * P/B)^2$$
⁽⁷⁹⁾

B. Constraints

The main constraints in the proposed optimization problem are:

- 1. Voltages angle constraints.
- 2. Voltages magnitude constraints
- 3. DG's size constraints
- 4. Transmission line constraints

These constraints can be represented as follows equality and inequality constraints:

$$P - B' \,\delta = 0$$

$$V_{min}^{m} \leq V^{m} \leq V_{max}^{m}$$

$$P_{Line}^{m} \leq P_{Line} (max)^{m}$$

$$P_{DG} (min)^{m} \leq P_{DG}^{m} \leq P_{DG} (max)^{m}$$
(80)

71

Where *P* is injected power at bus (plus the power of DG) and *m* is the set of load buses. Note that δ is calculated from Newton Raphson (NR) load flow method firstly without DG then it will be changed according to size of additional DG as in equation (52).

The size of DG is considered not more than load required after subtracting generation at (PV) control buses.

3.4 Interior Point Optimization Method

In recent years, application of interior point methods to solve optimization problems of power system has been paid great attention [86]. This is due to the fact that IP methods are mathematical method with the ability of fast convergence, robustness and not sensitive to initial value, well suited to solve large-scale nonlinear optimization problems. The main goal of the proposed algorithm is to minimize the power losses in a given electrical network considering the possibility of an optimal allocation and size of the DG units. The features of simple non-linear model and IP optimization method are introduced to allow the planner to manage the electrical network (in smart grid) with availability of multi-distributed generations with less time.

The nonlinear programming problem under consideration is selected the real power losses in (59) as objective function to minimize as:

$$Min f(x) = Min P_{losses}(P_{DG}) = R * (D * At * P/B)^2$$
(81)

Subject to the following equality and inequality constraints:

$$g(x) = 0 \rightarrow P - B' \delta = 0$$

$$x_{l} \leq x(x) \leq x_{u} \rightarrow P_{DG}(min)^{m} \leq P_{DG}^{m} \leq P_{DG}(max)^{m}$$

$$h_{l} \leq h(x) \leq h_{u} \rightarrow V_{min}^{m} \leq V^{m} \leq V_{max}^{m}$$
(82)

Where $f: R_n \to R$, $g: R_n \to R_m$, and $h: R_n \to R_t$ are smooth functions. *P* is injected power at bus plus power of DG and m is the set of load buses. Note that δ is calculated by Newton Raphson (NR) load flow method firstly without DG then losses will be changed according to size of additional DG as in inverse of (52) and (59).

The first problem to solved is to transform the inequalities constrained problem to an equality constrained by introducing slack variables,

$$Min f(x) \tag{83}$$

Subject to

$$g(x) = 0$$

$$h(x) + s_h = h_u,$$

$$s_h + s_{sh} = h_u - h_l,$$

$$x + s_x = x_u,$$

(84)

$$x - x_l \ge 0$$
, $s_h, s_{sh}, s_x \ge 0$

_	-
_ /	-
1	-

Chapter 3. Fast selection of DG' size and optimization techniques for loss reduction

The next step is to treat non-negativity conditions in (83) by appending the logarithmic barrier functions to the objective function, and the resulting primal barrier problem is defined as follows,

 $Minf_{u} = f(x) - \mu \sum_{i=1}^{n} In(x - x_{i})_{i} - \mu \sum_{j=1}^{n} In(s_{x})_{i} - \mu \sum_{j=1}^{m} In(s_{h})_{j} - \mu \sum_{j=1}^{m} In(s_{sh})_{j}$ (85)

Subject to

$$g(x) = 0$$

$$h(x) + s_h = h_u,$$

$$s_h + s_{sh} = h_u - h_l,$$

$$x + s_x = x_u$$
(86)

Where the barrier parameter u is a positive number. After define the Lagrange function by using y, y_h , y_{sh} as lagrangian multipliers, the first order optimality conductions can be considered as nonlinear equations. These nonlinear equations are then to be solved by some iterative method (predictor-corrector or Newton's) to obtain a search direction.

Along the search direction, a step size α is chosen to preserve the non-negativity conditions. The new primal and dual variables are computed from,

$$\begin{aligned} x^{k} &= \bar{x} + \overline{\alpha}_{p} \Delta_{x}, \quad y^{k} = \bar{y} + \overline{\alpha}_{D} \Delta_{y} \\ s^{k}_{x} &= \bar{s}_{x} + \overline{\alpha}_{p} \Delta_{sx}, \quad y^{k}_{x} = \bar{y}_{x} + \overline{\alpha}_{D} \Delta_{yx} \\ s^{k}_{h} &= \bar{s}_{h} + \overline{\alpha}_{p} \Delta_{sh}, \quad y^{k}_{h} = \bar{y}_{h} + \overline{\alpha}_{D} \Delta_{yh} \\ s^{k}_{sh} &= \bar{s}_{sh} + \overline{\alpha}_{p} \Delta_{ssh}, \quad y^{k}_{sh} = \bar{y}_{sh} + \overline{\alpha}_{D} \Delta_{ysh} \end{aligned}$$
(87)

The new value of the vector of variables PDG is determined according to the following equation:

$$P_{DG}^{k+1} = P_{DG}^k + \alpha_p^k \Delta P_{DG}^k \tag{88}$$

where:

k – number of iterations, α_p^k – step in the direction of vector ΔP_{DG}^k .

The iteration procedures are ended as the relative complementary gap and the mismatches of first order optimality conditions are sufficiently small. The outline of the method is as the following [87]:

Chapter 3. Fast selection of DG' size and optimization techniques for loss reduction

Initialization. Choose a proper initial point such that the non-negativity conditions are fulfilled.

- 1. Compute the barrier parameter *u*.
- 2. Solve the first order system of nonlinear equations of optimality conductions.
- 3. Determine the step size α and update the solution.
- 4. If the solution meets the convergence criterion (convergence test), optimal solution is found, otherwise go back to step 2.

3.5 Conclusion

Review of recent researches on optimization techniques have been present to analysis how to achieve a better integration of flexible demand with Distributed Generation. This would lead to an increase of the use of Distributed Generation and a decrease of problems caused by intermittent distributed generation in electricity systems and at the electricity market. This objective can be instantiated with several algorithms and conducts stage-appropriate implementation such that, algorithms bringing the most improvement to the DG (wind energy) integration, will be favored.

The third chapter contains one of the main contributions of the present PhD work: the optimal size and location of DG unit/units are the third and fourth objectives that have been introduced in the general introduction section, and they have been illustrated and developed in this chapter.

Firstly, the principle and procedure of the Kalman filter algorithm has been explained and developed in detail. This procedure includes the noise model, process model and measurement for carrying out the optimal sizing of the selected DG. The objective function has been formulated based on simple power loss calculation presented in chapter 2.

The main contribution of the proposed algorithm is to produce best estimate for real power losses calculation, with the possibility to execute fast and acceptable accuracy calculation to assess the power system with the large-scale DG connected.

For multi DG units, the sizing and locating optimization problem has been presented. Considering the main two stages (planning and operating) required for power system, determining the placement and size of DG units is significantly needed at planning stage; and at operation stage where location and maximum size already fixed, the optimal size (generation) of DG units for each location must be calculated in order to minimize the real power losses. Global and local optimization techniques has been used to solve the problem after the process of identification for objective function, constrains (equalities and inequalities), and lower and upper bound. As Kalman filter model, the simple power loss calculation has been considered to define the objective function for both techniques. Genetic algorithm as global optimization technique has been used to generate high-quality solutions to the search problem by setting up the mutation, crossover and selection. Results show that GA combined with the simple loss calculation model is efficient in reducing real power losses up to 86 percentage for some test cases.

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In real-time management of power grids, the time of calculation is crucial factor in large-scale power system. For time saving, the Interior Point (IP) optimization method is used to minimizing the power loss with expense a small difference in calculating for the DG size. The results shows the efficiency of PI to reduce the real power losses about 80% of original total losses without DG's with less computing time. This optimal location and size achieved at the expense of only a small difference in exact calculating by nonlinear (Newton Raphson) method. The Interior Point (IP) has less time computation compared with global optimization method (GA) for same size and location DG units. The simulation is flexible, can easily change the limitation of DG capacity according to wind renewable resources, and can be used as online tools to help DSO and TSO whose work on smart grid to select the optimal DG's size and location.



Impact of Time varying load and wind variation on power losses

Impact of Time varying load and wind variation on power losses

Deregulation of the electric energy systems and a progressive increase of the load play a key role in improving reliability and continuity of the electrical utility services they provide. Due to the complexity of load profile, many challenges facing electrical power system analysis, like, state estimation, load flow calculation, and network planning and operation. Distribution network operators (DNOs) report the performance of their network based on inadequate modelling approaches because large power systems are simply represented by a bulk load.

This work attempts to simulate the electrical network with different load profile (residential, commercial and industrial), which can help DNOs to avert the underestimation of network's performance at bulk generation points for more actual estimation of customer interruptions. Load demand has been developed to determine the overall power flow and identify generation sources required to meet its increasing as well as exceeded rating elements in the network.

The growth of the electrical demand increases the need of wind generation as renewable energy sources to handle it. Electrical power losses are important factor when wind farm location and size are selected. The capitalized cost of constantly power losses during life of wind farm is keep going to higher levels. During the operation period, method to determine if the losses meet the requirements of design is significantly needed. This chapter presents a Simulink simulation of wind farm integration into the grid; the aim is to achieve better understanding of wind variation impact on grid losses. Location and size of wind farm power has been optimized based on proposed methods in chapter 3.

4.1 Introduction

The hardest part for most DNOs is to determine the errors between estimated and actual load profile. There is some of early-published state estimation studies describing the role of load profiling on the classical electrical power networks. Author in [88], presents a statistic analysis of different load curves to obtain the representative curves of the most important customers. The measurements were performed for residential, commercial and industrial to determine customers' daily load profile. The fuzzy c-means (FCM) method is used for load profiling in [89]. The load profile assignment performed by using customers' monthly energy usage data in two steps. After load profiling, the author used recognition technique to assign 500 customers. In [90], it was interesting to used load profile for energy diagnosis system. Different load profile data according to customer type (residential, commercial and industrial) obtained from metering devices. Consumption separation method was used to classify duration of load devices to a certain time interval (1 hour, 1 day, 1 week and 1 month).

On other hand, other authors have modelled the optimal power flow control for dynamic grid where the load changes according to a profile. [91] Presents an algorithm to calculate a sequence of Primal-Dual Interior Point optimization solutions under variable load conditions. This methodology to find optimal power flow is based on two main steps: predictor step, which estimate a new operating point for an increment in the load by linear approximation; and corrector step, which uses non-linear method to find the optimal solution to the new load level.

A three-load profile are used to find the optimal reactive power control. The daily load curves divided into several sequential levels to reduce operations of control devices switching. Voltage quality and power loss for different loads were consider as objective function for optimization techniques. Typical clustering method and heuristic iteration technique used the maximum load deviation (MLD) to decompose the load curve [92].

Other opportunities to improve planning and operation of modern network with/without distributed generation and storage under different load conditions are considered in a large number of articles recently [93-100]. This fact shows that this subject continues an interesting topic of research. In relation to modern network, a real-time classification and encoding of load profiles has been proposed in [93]. The author presents software framework to manage the load profile at

Chapter 4. Impact of Time varying load and wind variation on power losses

power system operation. The framework is based on artificial neural network as encoding engine and local hashing algorithm as classifier engine. A dynamic load profile was cluster and classify by multi-resolution analysis (MRA) method [94]. The ability of traditional methods in profiling load developed by MRA method for three key (large, volatility and uncertain smart metering data). A more flexible load profiling with less computation presented in this method by three main steps (decomposition, clustering and reconstruction).

Moreover, there has been an increasing amount of literature on the planning of modern power system's reliability. In active distribution systems, [95] proposed methodology based on empirical load profile and time-varying fault probabilities for reliability planning and risk estimation. The approach is developed to avoid the underestimation of network's performance at bulk supply points for more realistic estimation of customer interruptions. In [96], real time load shedding optimization has been used to solve mixed integer linear problem taken into account the critical operating time and building appliances powers. The objective of this research is the power balance by load shedding and restoration.

Research has shown that installation of distributed generation and storage energy take more attention. Radial distribution networks with photovoltaic (PV) generation was tested to optimize the real power consumption of loads in [97]. The power management scheme developed to determine the optimal demand response schedule that accounts for variable real power injection by PV units. So that, the programmable loads provide opportunity to reduce the peak load in periods of inappropriate generation.

In distribution feeders, load profile data and realistic photovoltaic (PV) generation are utilized to optimize its operation. The active and reactive power set points for PV were determined according to voltage regulation and a variety of objective functions [98]. The proposed method leverage a linearized version to formulate a quadratic constrained quadratic program (QCQP) as direct applications to distribution networks with PV systems. The cost efficiency of the residential electricity consumption improved by load scheduling [99]. The load-scheduling framework based on fractional programing approach to develop a cost efficient for the demand side's day-ahead process and real-time pricing mechanism. The proposed algorithm considered the distributed energy resources and service free in their framework.

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In an attempt to improve the power system operation more effectively, energy storage systems (ESS) installed with/without distributed generation to the modern grid. Real load connecting to distribution networks has tested to schedule the ESS by Monte Carlo simulation [100]. The optimization technique used for solving an ESS scheduling problem considering real load, variable wind energy sources and transmission line real time thermal rating (RTTR). The load shifting by optimize placement, sizing and control of energy storage system is presented in [101]. The network topologies with regardless/regard of the load demand, generation capacities and line flow limitations effected the costs. A charging/discharging policy for the installed storage units formulated as slower time-scales. However, investigating and modelling varying energy demands in various sectors (residential, commercial and industrial) will cause significant changes in planning, operation and control of power system. Most studies in load modelling and profiling into electrical power network have been carried out in a small number of area.

The impact of renewable resources (as Distributed Generation DG) on distribution network with several numbers of important issues (system voltage, protection loss of the power grid, system restoration and network) has been discussed in [102]. The effectiveness of the capacity and placement of different types of DG has been discussed in [103]. This paper explained if DG sources exceed a certain amount, real power losses will always arise and leads to rise voltage in the low voltage layer.

Some efforts has been done to reduce computation time required when a planning strategy is applied to distribution network integration of renewable energy with multi-year scenarios. The proposed approach has been implemented in a tool that simulates the annual evolution of the network to guarantee an error of less than 1% and better accuracy [104]. A strategy for simulation large-scale distribution systems has been implemented to improve the power flow analysis. The proposed method attempted to design and develop the future grid to facing the challenges such as the connection of DGs considering multithread processing [105].

Determining the capacity of the wind farm into electrical network is the most challenging part for most utilities. The improper allocation wind farm would increase the losses in the system more than when there is no renewable distributed generation. Therefore, many researchers have proposed different approaches to evaluate the proper placement and sizing of wind turbines in electrical networks [106]. However, this optimization technique based only on environment and
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economic power dispatch as objective function. Since wind turbine units have a small capacity compared to central power plants, its impact is minor if the penetration level is low (1%-5%). However, the penetration level of wind farm increases to the anticipated level of 20%-30%, which has high impact on active power loss of grid [107].

A case study assessed the impact of the connection of significant amounts of DG on energy losses and voltage drop in the distribution system [108]. To solve the problem of optimal size and allocation of DGs, researchers have employed conventional analytical approaches using sensitivity factors obtained from quantities, such as the system bus impedance and admittance matrices, and the exact loss formula [109] [110] [111]. The impact of wind energy integration on voltage stability by using Flexible AC Transmission System (FACTS) has been presented in [112] and [113]. The injection of reactive power into grid (controlled by the thyristor firing angle) is considered as state variable in power flow calculation. The FACTS are used to provide the reactive power to control the voltage and optimized it is profile.

Increase the penetration level of wind power was interesting for different researchers. The wind power development and the financial risk for its investors in Denmark, Germany, Spain and Ireland has been discussed [114]. The fault ride-through and voltage maintenance of grid has been considered for the integration of wind turbines into the Germany transmission system [115]. In [116], the Spanish transmission system with wind farms behavior has been discussed to confirm the verification, validation and certification procedure. However, the research goals must take into account the impact of wind speed on power loss calculations.

4.2 Load Profile

In power system, a load profile is a graph illustrating the variation in the demand/electrical load versus time. A load profile will vary according to temperature, holiday seasons and customer type (typical examples include residential, commercial and industrial). DNOs use this information to plan how much electricity they will need to generate at any given period. These load curves are useful in the selection of generator units for providing electricity.

Direct metering devices such as smart grid meters, data logging sub-meters, utility meter load profilers and portable data loggers can determine load profiles. Real demand can be collected at strategic locations to analysis load performance, which is beneficial to both distribution and end-user customers looking for peak consumption. For most customers, based on meter reading schedules, consumption is measured on a monthly. Load profiles are used to convert the monthly consumption data into estimates of hourly or sub hourly consumption in order to determine the electrical utilities obligation. For each hour, these estimates are aggregated for all customers of an energy provider, and the aggregate amount is used as the total demand that must be covered by the utilities.

In this section, the detailed simulation of the load profile would be described. For brevity purpose, detailed simulation of the load profile for residential, commercial and industrial would be shown, covering the lower and higher side of the residential units. Simulation of three-bus load are described concisely.

A. Residential Consumers

More than half of all electrical power is consumed by residences type, which vary in their daily activity patterns and the types of appliance they own. Load varies by time of day and year where its curve shape be function of consumer demand. Figure 25 illustrates how electrical demand characteristics vary over a day, or when house owners are using electrical power.





Figure 25 Example of residential consumption

Due to the differences in electric appliances, the definition of the representative curves of a range is not an easy task to be done and the people habits rising to curves of shapes in the peak. In some countries, the residential energy consumption value is mainly due to refrigerator or freezer, whilst the water heating gives the curve peak where heater resistance take 8 min. Therefore, it is very hard to characterize the peak demand because load pattern not fixed for all residential usage and depends on many factories such as weather, type of human work etc.

B. Commercial and Industrial Consumers

In commercial businesses load, small and large consumers having similar end uses to residential (cooling, heating etc.) in addition to many need to commercial devices (office machinery, cash register, escalators etc.). Figure 26 represents the electrical use of a commercial facility during 24 hours. The commercial load (office building, restaurants stores etc.) shows a strong upward curve during summer (or winter) session because it depend heavily on cooling (or heating) systems [117].





Figure 26 Example of commercial consumption

Finally, industrial facilities and plants use electricity to variety of manufacturing applications such as compressor motors, heating systems etc. The industrial load profile does not vary as much through the day where it depend on work, weekends and break times. The peak demand of summer day for industrial consumption from utility system shown in Figure 27.



Figure 27 Example of industrial consumption

4.3 Wind Farm Model

The actual mechanical power output (P_m) extracted from wind is given by [118]

$$P_m = \frac{1}{2} \rho \pi R^2 v_w^3 C_p(\lambda, \beta)$$
(89)

Where, ρ is the air density (kg/m3), R is the blade radius of the wind turbine (m), v_w is the wind speed (m/sec), and C_p is the power coefficient. The power coefficient varies with the speed of wind, the rotation speed of turbine and turbine blade parameters. Therefore, C_p is a function of tip speed ratio λ and blade pitch angle β . C_p has been approximated using the following function:

$$C_p(\lambda,\beta) = 0.22 \left(\frac{116}{\lambda_i} - 0.4 \cdot \beta - 5 \right) \cdot exp(-\frac{12.5}{\lambda_i})$$
(90)

where:

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 - 1}$$
(91)

Figure 28 shows calculated relationship between the power coefficient and tip-speed ratio for pitch angle $\beta = 0$.



Figure 28 Cp-λ Characteristic

The tip speed ratio expressed as:

$$\lambda = \frac{R \,\Omega_t}{V_w} \tag{92}$$

Where, Ω_t is the wind turbine speed. The turbine torque is the ratio of the output power to the shaft speed:

$$T_t = \frac{P_t}{\Omega_t} \tag{93}$$

The turbine is normally coupled to the generator shaft through a gearbox whose gear ratio G is chosen in order to set the generator shaft speed within a desired speed range. Neglecting the transmission losses, the torque and shaft speed of the wind turbine, referred to the turbine side of the gearbox are given by:

$$T_g = \frac{T_t}{G}$$
 and $\Omega_t = \frac{\Omega_g}{G}$ (94)

Where T_t and T_g are respectively the turbine and generator torques.

The optimal mechanical power, which can be generated using the Maximum Power Point Tracking (MPPT), can be expressed from (89), (92) and (94) as:

$$P_{mec-opt} = -\frac{C_{p-max}}{\lambda_{opt}^2} \frac{\rho \pi R^5}{2} \frac{\Omega_{mec}^3}{G^3}$$
(95)

Wind turbine model with control speed is shows in Figure 29.



Figure 29 Wind turbine model with control speed

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Wind farm has been represented as active generator in power flow studies. This active power generator will be added at load bus only into grid. The output electrical power generation is given by

$$P_{W} = \begin{cases} 0 & v_{w} < v_{cin} \\ P_{rated} & \frac{v_{w}^{2} - v_{cin}^{2}}{v_{N}^{2} - v_{cin}^{2}}, v_{cin} \le v_{w} \le v_{N} \\ P_{rated} & v_{N} \le v_{w} \le v_{cout} \\ 0 & v_{w} > v_{cout} \end{cases}$$
(96)

where v_{cin} , v_{cout} and v_N are cut-in speed, cut-out speed and nominal speed of wind turbine respectively. P_{rated} is the rated output power of the turbine and v_w is the average wind speed.

Wind farm consists of multi wind turbines connected to the power grid through transformer. In this study, doubly fed induction generator (DFIG) has been selected as the wind turbine system, as shown in Figure 30. This (DFIG) configuration is attractive from an economical point of view because it uses a smaller frequency converter, which compensated the reactive power consumed by the DFIG and power electronics equipment.



Figure 30 Single line diagram of wind farm

4.4 5 Node Network Modelling

Throughout the electrical power network, there are common buses that look like important branch points within the power grid. These buses operate at a defined voltage level and phase angle to forming the complex bus voltage. In general, three types of busses is consider in a power network, namely the slack bus (bus 1), the generator bus (bus 2) and the load bus (3, 4, and 5).



Figure 31 Single line diagram of 5 bus network

Figure 31 shows a single line diagram of a 5 bus (1,2,3,4,5) system with two generating units *G1* and *G2*, seven lines (Line 1-2, Line 1-3, Line 2-3, Line 2-4, Line 3-4, Line 4-5, Line 5-2) and load demands (L-3, L-4, L-5). Per unit system based on 100 MVA was considered for all parts of network. Four basic parts of the system are modelled: slack generator, PV control generator, transmission lines and load profiles. Figure 32 presents the simulation of the 5 bus network using Simulink.

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Figure 32 5 bus network simulation

All generation units, load demand and power loss calculated is shown in Table 5.

Unit	Total (MW)
Total Generation (Slack Power Generation PG1)	unlimited
Total Generation (PV Power Generation PG2)	90
Max. Demand(Power Demand PD3) residential	45
Max. Demand(Power Demand PD4) Commercial	40
Max. Demand(Power Demand PD5) Industrial	60

Table 5 Generation and load demand for IEEE 5bus

A. Slack generator

In a simulated power system, some quantities allowed to vary or swing to solve particular steady-state problem successfully. For that, there is only one slack generator has known voltage magnitude |P| and voltage phase (set to $1.0 \ge 0.0^{\circ}$ (per-unit)). In Figure 33, P_{sg} and Q_{sg} are the swing variables and obtained through the load flow solution as follows:

$$S_{sg} = P_{sg} + j Q_{sg} \tag{97}$$



Figure 33 Slack Power Generation (PG1) simulation

B. Voltage Control Generator

Generator buses or voltage-controlled buses have inputs of the voltage magnitude corresponding to the generator voltage and real power P_g corresponds to its rating (Figure 34). Generally, voltage controlled busses are connected to equipment used for voltage correction, such as static VAR correction systems, generators and shunt capacitors (Figure 35). The reactive power generation Q_g and phase angle of the bus voltage are calculated by load flow solution. In general, generator is modelled as a complex power injection at a specific bus (i):

$$S_g^i = P_g^i + j Q_g^i \tag{98}$$



Figure 34 Voltage Control Power Generator (PG2) simulation



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Figure 35 Voltage Regulator (VR) simulation

C. Transmission Line

The analysis of power system is mainly dependent on the performance of the transmission line in the power grid. This section deals with the modelling of transmission line elements encountered in the electrical power network. Transmission line transmits bulk power from sending to receiving end and represented by standard (π model) consisting of four main elements (resistance, inductance, capacitance and conductance). The analysis of power system is mainly dependent on the performance of the transmission line in the power grid. All transmission lines, transformers, and phase shifters are modeled with a common branch model as shown in Figure 36. The threephase series RLC branch block (Figure 37) used to simulate performance of transmission line by setting its parameter corresponding data of network [119].





Figure 36 Representation of $\ll \pi$ model »



Figure 37 Transmission line simulation

D. Load bus

At this bus, the real (P_d) and reactive power load (Q_d) are specified and no generator is connected to it. It is required to find out the voltage magnitude and phase angle through load flow calculations.

The total demand of the system is represented by the distributed loads over the whole network. Power Systems on whether they represent an industrial, commercial or residential load, they can vary greatly in electrical characteristics as well as quantity. In most power simulation, it sees the load as a simplest PQ load characteristic with constant demand of real and reactive power that does not change with any external influences. Various load models have been introduced, taking into account day, month and year cycles as well as it can be consider the voltage and frequency dependencies in the future work. Normally constant power loads are modeled as real and reactive power consumed at a bus (i) as follows:



$$S_d^i = P_d^i + jQ_d^i \tag{99}$$

Figure 38 Variable load simulation

The loads can be modeled using Simulink block (three-phase series RLC load) but it will be represented as fixed (static) load. A constant MVA load model have no ability to vary with time. Therefore, that, simulation for variable real power load construct with fixed bus voltage reference and variable real power as shown in Figure 38. Fault or any external changes of network state will not effect on load parameters. This load models can be described by the following equation:

$$P_d = P_o\left(\frac{v}{v_o}\right) \tag{100}$$

$$Q_d = Q_o \left(\frac{V}{V_o}\right) \tag{101}$$

Where Q_o stand for reactive powers consumed at reference voltage V_o and represented by three phase series RLC load while P_o is vary according to load profile curve connected to this model. The external control structure block connected to this model can be variable load curve (continues or discrete). This model will enhance the ability of the system to be studied at different loading conditions.

4.5 Power loss of wind farm integration grid

From eqs. 58 and 59, the power flow is a function of power injections as follows:

$$P_{nf} = D * A * B^{-1} * P \tag{102}$$

While the power injections can be expressed as:

$$P = f(P_{Gi}, P_W) = \sum_{i=1}^{M} P_{Gi} + P_W$$
(103)

Where P_{Gi} and P_W are the active power output of the m generators (reference generator is not included) and active power output of wind farm (vector (m*1) of zero except wind bus) respectively.

Note that the total number of generators is N. So that, the power output of the generators can be considered as:

$$P_{Gi} = [P_{G1}, P_{G2}, \dots, P_{Gm}]^T$$
(104)

The total annual energy produced by wind farm is a function of wind speed which mostly represented by Weibull probability distribution. This distribution is used to estimate the total yearly average power output by combining the power produced with hours at any wind speed. Figure 39 illustrates example of relation between wind speed and its hours per year, [120].



Figure 39 Weibull probability distribution (Yearly wind speed variation)

According to this statistic, time of wind speed can be divided into three categories duration:

$$t = \begin{cases} t_0, & v_w > v_{cin} \\ t_V, & v_{cin} \le v_w \le v_N \\ t_r, & v_N \le v_w \le v_{cout} \\ t_{out} & v_w > v_{cout} \end{cases}$$
(105)

For Figure 40, t_0 is duration when wind speed is less than the cut-in speed (between 2.5 to 3 m/s), t_V is duration when wind speed between cut-in and rated speed (10m/s to 16m/s), t_r is duration when wind speed between rated speed and cut-out speed (20 to 25m/s) and t_{out} when wind speed exceed cut-out. That mean, total annual duration is:



$$\Delta t = t_0 + t_v + t_r \tag{106}$$



Aggregating the wind power output and duration of annual wind speed from (67) and (78) respectively, the annual output energy of wind farm will be calculated as:

Annual Energy= Power output
$$(P_W)$$
 x annual duration (Δt)
 $P_W * \Delta t = P_0 t_0 + P_v t_v + P_r t_r + P_{out} t_{out}$ (107)

$$P_W = (P_0 t_0 + P_v t_v + P_r t_r + P_{out} t_{out}) / \Delta t)$$
(108)

where

 P_0 and P_{out} is zero power output when wind speed less than cut-in speed or more than cutout speed, respectively.

 P_{ν} is power output less than rated power and its value changes when the wind speed changes.

 P_r is the rated power of wind farm when wind speed more than rated wind speed and less than cutout speed.

This section will concern itself with active or real power losses which more affected by wind farm. The total real power losses can be expressed as a function of wind farm output and it will have three values, two of them remain constant while third one will increase or decrease corresponding to a wind speed pattern.

At any line, losses across the series impedance of a transmission line are:

$$P_{loss} = I^2. R = \left(\frac{P_{pf}^2 + Q_{pf}^2}{V^2}\right). R$$
(109)

Most of wind turbine is represented by the active power generation. So that, reactive power flow can be neglected. In additional, voltage values at each bus is around 1 p.u. which can simplify the equation of real power loss as follows:

$$P_{losses} = P_{pf}^2 * R \tag{110}$$

and with wind farm output, it will be

$$P_{loss} = P_{loss}(P_0) + P_{loss}(P_v) + P_{loss}(P_r)$$
(111)

Referring to eq. (66), power loss for P_0 and P_{out_r} equal zero because wind turbine has no output power at cut-in and cut-out duration, respectively:

$$P_{losses}(P_0) = P_{losses}(P_{out}) = P_{pf}^2(P_0) * R = D * A * B^{-1} * P_{Gi} = 0$$
(112)

while power loss for P_r is constant value as follows

$$P_{losses}(P_r) = P_{pf}^2(P_r) * R = D * A * B^{-1} * (P_{Gi} + P_r)$$
(113)

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Chapter 4. Impact of Time varying load and wind variation on power losses

Variable power loss between cut-in and rated wind speed can be written as

$$P_{loss}(P_{\nu}) = P_{pf}^{2}(P_{\nu}) * R = D * A * B^{-1} * (P_{Gi} + P_{\nu})$$
(114)

The total real power losses as a function of rated wind power output as

$$P_{loss}(total) = f(P_{\nu}) \tag{115}$$

4.6 Conclusion

Power system is an electrical network that supplies industrial, commercial and resident regions with power. Load profiles of industrial and commercial customers vary in their daily/monthly patterns less than residential. A progressive increase of the load will add more complexity to determine adequate solutions for power system analysis. In particular, it is more important to have methodologies that be able to analyze the behavior of power systems with varying time load. In the introduction of this chapter, the scientific literature shows that there the research not take into their account the impact of wind speed on power loss calculations. Moreover, some attempts has been made by researchers to study the effect of varying time load on real loss calculation but there is no relevant simulation model with different type of loads in all cases.

This chapter has presented Simulink network modelling with variable varying time load profile. This simulation is adapted to IEEE five bus system accommodating different types of generation resources and load profiles. The models demonstrate that varying demand can change the dynamic performance of the system and could be adequate to identify the real power losses into network. The network has been analysis based on the improvement nonlinear method (Schur and RLE) that demonstrated in chapter 2.

Next, the Simulink simulation focused on integrating wind farm, which can be helpful at the margin in providing clean power. The size and location of wind farm is selected depending on the analytical model explained in chapter 2 and optimization technique illustrated in chapter 3. The model explains the calculation real power losses is totally different than when we have considered Weibull statistic as will prove in chapter 5. According to this statistic, wind speed time duration has divided into three duration and total real power losses was expressed as a function of wind farm output for these durations. In 5 bus model, the calculations of total real power losses will be changed by the fluctuation of wind farm output due to the wind speed variation. As more intermittent wind power sources come online, the impact of wind farm on real power losses can lead to control and assess of the large-scale power grid.

Chapter 5

Simulation results using proposed algorithms

Simulation results using proposed algorithms

In this chapter, we implement different algorithms described in chapters (2-4) and we present results that could be used by operator or planner as analysis tool to assess grid situation with availability of DG and wind energy resources.

Load flow problem is heart of power system analysis and it required calculate active and reactive power flow in lines connected between buses in networks. Many topology and structures for transmission and distribution systems has been proposed to reduce CPU times and memory.

Firstly, two methods (proposed in chapter two) are used to reduce the large memory required for Newton Raphson method and the number of iterations for load flow calculation.

Schur complement method divided Jacobian matrix into two separated matrices to reduce computer memory and avoid divergence of the solution with reasonable computation time. A next step that was proposed is data compression technique (RLE) to improve the load flow calculation algorithm where only single data (non-zero) are stored as a values into Jacobian matrix elements.

Then, a linear relation between voltage angles and real power losses has been used to find minimum power loss in electrical grid by predicted optimal size of Distributed Generation (DG). Fast predictive model to select optimal size of DG can be useful tool for DSOs in real time operation. Although, this method is an effective method for reducing the CPU time (computing time), but it has acceptable error estimates in calculated results. Therefore, two methods based on graph theory and Kalman filter algorithm has been proposed in chapter 3 to reduce the error estimates in linear model. Thus, linear model was built by generated incident matrix using the graph flow method while Kalman filter algorithm is applied to obtain the optimal size of DG at each bus system.

Based on the algorithms discussed in the third chapter, global and local optimization techniques proposed to find optimal sizing and location of multi DG in electrical distribution networks. Firstly, Genetic Algorithm (GA) method modelled the real power losses as a function of DG output to obtain the global objective function. Then, faster local optimization method (interior point) was applied to solve large-scale nonlinear problems with a substantial reduction in the computation speed. To demonstrate the feasibility of our approaches, we have made a

comparison between both optimization proposed methods, (14, 30 and 57) IEEE benchmark test systems have been tested to optimize placement and size of the Distributed Generation (DG) units at each bus system.

Finally, Simulink simulation has been developed in chapter four is implemented to demonstrate the performance of power network based on load profile modeling. The main purpose of this design is to enhance Distribution Network Operators (DNOs) decision in power systems.

Several load profiles (residential, commercial and industrial) has been used to test IEEE five bus system used as a test bed under Simulink. Then, this simulation has been expended to investigate whether the annual wind variation can be changed planning strategy of wind farm size and location according to network real power losses. The structure, operation and planning of electric power network has a number of challenges in wind farm installation, including its size and placement into grid. In additional to wind capacity and reliability, the grid connections options can change the decision of planner. Furthermore, power system operator has to find optimal wind farm integration into grid is made taking into account wind variation. The location and size of wind farm have been determined and optimized by using the optimization techniques from previous algorithms.

5.1 Schur results for time and memory reduction

After study and analysis Newton Raphson method to understand the behavior of Jacobian Matrix during iterations for several systems (5, 14 and 30 bus), it was noted that values of few elements will slightly change at the beginning of every iteration while mostly of them remain constants during all iterations. Figure 41, Figure 42 and Figure 43 bellow explain this fact.



Figure 41 Jacobin Matrix at beginning and end of iterations for 5 Bus systems



Figure 42 Jacobian Matrix at beginning and end of iterations for 14 Bus systems



That mean convergence and divergence will followed the main element values of Jacobian (derivative values) and it is not changed at each iterations. Problems concerning the convergence or divergence tend to be difficult because there are many of roots for each case. Most of ill conditional cases appear to surf ace when system has low R and X line values which effect on solution and it will be fluctuated (Up – Down) near point of root as in Figure 44. These factors will constrain convergence and delivering divergence.



Figure 44 Newton Raphson convergence for 5, 14 and 30 Bus

The Schur complement (SC) method can eliminate or reduce the off-diagonals effects, when Jacobian matrix (Eq. 6) has high values of which make it close to be singular. This matrix will divided to 4 sub-matrices. That mean, it will have separated equations for voltage and voltage angle as follows:

$$\Delta \delta = X_1 (\Delta P - Y_1 \Delta Q) \tag{116}$$

$$\Delta \boldsymbol{V} = \boldsymbol{X}_2 (\Delta \boldsymbol{Q} - \boldsymbol{Y}_2 \Delta \boldsymbol{P}) \tag{117}$$

where

$$X_{1} = A - BD^{-1}C$$

$$X_{2} = D - CA^{-1}B$$

$$Y_{1} = BD^{-1}$$

$$Y_{2} = CA^{-1}$$
(118)

The off-diagonal matrices like B and C will melt inside inverse of matrix B as term $(BD^{-1}C)$, while second term $(CA^{-1}B)$ will has same values of term above if we eliminated rows and columns for (PV Buses) in matrix A which are already disappeared in matrix D. It can be considered that X1 equal X2 for same dimensions.

All matrices X1, X2, Y1 and Y2 will slightly change after each iteration which can considered as constant matrix. In same time, X1 and X2 will tend to be as symmetric matrices and more linearity in their element values. Threshold technique can be used with Y1 and Y2, which has more differences between element values. According to above procedures, the load flow algorithm can be presented as follows:



Figure 45 Schur algorithm for load flow

This algorithm has been applied successfully to reduce computation time of load flow iterations, memory required and convergence strategy. Different number of buses has been tested (5, 14,30 and 118) and results has been compared with Newton Raphson (NR) method and Fast Decoupled (FD) method, which shows the efficiency of Schur complement to got good accuracy with less memory and time.

Threshold process has applied successfully to Y1 and Y2 through their values, which has high differences to reduce fluctuation in calculations, memory required and computation time. With reference to threshold value which chosen, the value of element should be zero if it below threshold value and no change if it over threshold value. In most of cases, 70% of elements will has zero value if it applied threshold factors for each row. Threshold values for each row can be considered up to 30% of maximum value of elements in the row, which will not effect at the accuracy of results. Following table shows results of program for different cases [121]:

No. Of Bus		5	14	30	118
SC	Accuracy	3.751e-5	0.000106	0.000448	0.000862
	Time(s)	0.2496	0.2808	0.3276	0.3588
NR	Accuracy	1.01*e-10	0.00072	3.535e-8	4.2797e-5
	Time(s)	0.312	0.2808	0.3564	0.4524
FD	Accuracy	5.185e-5	0.000749	0.000841	Diverge
	Time(s)	0.1560	0.2028	0.2340	2.246

Table 6 Comparison results

The ability of dividing Jacobian matrix by two sub-matrices allowed to reduce effect of fluctuation up and down near the solution. At same time, it can be observed that performance of algorithm more flexible to find solution with reasonable accuracy and less time (Figure 46). The two separated matrices can be controlled easily, especially when study the stability of system is required.

All these features are recommended using this algorithm to find load flow solution in real applications and in real time calculation for large systems.



Figure 46 Compression type of calculations

5.2 Comparison results of iterations between normal and RLE method

The effectiveness of RLE algorithm has been demonstrated by testing three different numbers of buses (Standard IEEE 5, 14 and 30 buses). Differences in iteration numbers between proposed method and normal method (such as NR) depended mainly on number of lines, number of buses and accuracy required. It is noted that differences increased exponentially when number of buses increased. That means, high reduction in calculating time will be less iteration number of calculated active and reactive power flow.

We simulated a system having 5 buses and 7 lines as follows in Table 7:

Sending Bus	Receiving Bus	R	X	No. of Bus	Type of Bus
1	2	0.02000	0.06000	1	Slack
1	3	0.08000	0.24000	2	PV Bus
2	3	0.06000	0.18000	3	PQ Bus
2	4	0.06000	0.18000	4	PQ Bus
2	5	0.04000	0.12000	5	PQ Bus
3	4	0.01000	0.03000		
4	5	0.08000	0.24000		

Table 7 IEEE Standard 5 Bus

The system can be represented by two-dimension matrix with 5*5 contains 1 for connection and 0 for no connection as follows [122]:

$$\begin{pmatrix} 1 & 1 & 1 & 0 & 0 \\ 1 & 1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 & 1 \end{pmatrix}$$
(119)

The total number of iterations can be determined by matrix dimensions or multiply number of bus by number of lines. For IEEE 5 bus system, the number of iterations are (5*5=25) by matrix dimensions or (5*7=35) for 5 bus and 7 lines. The nonzero off diagonal elements (16) at Jacobian Matrix are represented the number of iterations at the executed calculation and has been tested in Matlab program. By RLE algorithm, number of iteration will be 16 as required and will represented as follows:



The first column represents number of bus, the second column represents the number of lines connected to bus at first column, and the rest of elements at each row represent numbers of each bus connected to bus at the first column. The above RLE representation is then reconstructed as a vector instead of matrix including all data after compression, which mean convert it from 2 dimensions to 1 dimension to reduce memory and iteration required, as follows:



Figure 47 shows a functional flowchart for the process of generating the network incidence matrix using the binary tree graph and the RLE method.





Figure 47 A functional flowchart for generating the incidence matrix using the binary tree graph and RLE method

Total iteration needed equal summation of tree paths for each node (except slack bus) plus number of load buses, which mean in this case (4+3+4+2+3=16). From this example, it was proved that the less number of iteration has validated by RLE algorithm while other results for rest of systems show bellow:

NO. of Buses	No. of iter	No. of iteration for accuracy				
	1	2	5	10		
5(Normal)	40	80	200	400		
5 (RLE)	16	32	80	160		
14 (Normal)	280	560	1400	2800		
14 (RLE)	40	80	200	400		
30 (Normal)	1230	2460	6150	12300		
30 (RLE)	82	164	410	820		

Table 8 Comparison results of iterations for calculation between normal and RLE method

The column diagram for iterations for accuracy and iterations for calculations show bellow:



Figure 48 Result comparison by RLE and normal method

While the differences between normal method and RLE method in iterations of calculations with exponential change can be explained by linear curve bellow:



No. of iterations for accuracy Figure 49 Differences of iterations comparison by RLE with normal method

5.3 Results of simplified power loss calculation with DG

The prediction for the optimal sizes of DG at each load bus in several IEEE benchmark test systems has been formulated with a linear state equation. A linearized state space model for a 5-bus power network has been presented in chapter 2 using the minimum real power loss as a reference. However, value for the DGs size calculated by linear model are not optimal because the reactive power flow in lines connecting two buses was ignored, all voltage values assumed to be 1 p.u. and approximation method to calculate active power flows. The procedure of simplified power loss calculation has smooth properties which lead solution close to optimal values with less iterations, memories and computation times. In addition, the error from linearization method can be reduced during the estimation process.

Firstly, the systems with (5, 14, 30) buses has been tested with Newton Raphson load flow method to calculate power flows at each bus then find exact total power losses without DG. These calculations has been repeated by considering different locations of DG at load buses of these systems. At each location, the size of DOG has initiated with 1 MW at beginning then it increased by 1 MW until it reach maximum load demand required for whole system. This is illustrated in Figure 50, three curves indicting each total power loss (for each system) are varied according to the size of DG for different locations.





Figure 51 14 Buses losses with different DG locations



Figure 52 30 Buses losses with different DG locations

The figures (Figure 50, Figure 51 and Figure 52) show that at each bus, losses has similar behavior which can be divided into two parts. In first part, the losses curves are beginning to be close as linear part, where it decreased when MW of DG is increased until it reach the minimum point. Then, it goes to be nonlinear in the second part, where continue increase generation of DG will increase losses into grid.

In linear part, order of losses curves will continue in same sequences from lower to upper one but sometimes it changed at non-linear part. Most of researchers has been considered the lower losses curve as optimal location. In fact, that there is an optimal size of DG at each location for the total losses but it is not necessary to be at the lower one. The principle of using linear model to find the estimated optimal size of DG based on the linear part of these curves. In addition, the linear relation between the changing of voltage magnitude and angles, and increasing of power generation of DG show in Figure 53.

The procedure begins to compute total active power losses in lines before DG, which will be located later in different load buses. DG at each load bus has initialized with small amount (1 MW), the power flow computation based on the linear method proposed and initial power loss is obtained by simplified active power losses calculation. Then, the information on the individual power loss corresponding to DG increased by 1MW are stored in Plosses,n and DGi,n in respectively. When size of DG reached maximum total demand of the system, the minimum value of these losses will be selected by comparing the values of DG's (stored in memory).





Figure 53 Voltage magnitude and angle changing different DG sizes (1-40)MW
Actual values for DG and total power loss at each location are required to verify whether the optimal sizes of DG estimated by the linear model proposed are acceptable. The following steps summarize these values of power losses:

- 1. Find initial voltage angles and active power losses by Newton Raphson method.
- 2. Build impedance matrix (X) for system.
- 3. Choose location of DG at one of load buses.
- 4. Increase DG power 1 MW at each step.
- 5. Calculate active power flow from equation (27).
- 6. Find summation of power losses in system by equation (36).
- 7. Compare losses for last two cases and save minimum results.
- 8. Repeat steps from 4 until generation of DG reach total demand.
- 9. Determine minimum losses and size of DG.
- 10. Repeat steps from 3 for all load system buses.

Lately, the accumulated data of the minimum power loss, location and size of DG are obtained. The results of proposed linear method (LM) has been validated with exact solution by using Newton Raphson method (NR) for (14 and 30) bus as shown in Figure 54 and Figure 55.



Figure 54 Newton Raphson and linear method Comparison for 14 Bus





Figure 55 Newton Raphson and linear method Comparison for 30 Bus

It is observed that each state converges sufficiently for different systems and it can predicted optimal size of DG for minimum losses. Table 9 shows the significant execution times saving by proposed method (LM) compared to that required by NR. Time complexity analysis of LM and NR are performed on a computer with 2.7GHz CPU, core i7-4800MQ, RAM of 16GB and Windows 7 operation system running in real-time mode. The results show that the proposed method is capable of predicting approximate optimal size of DG after compared with precision calculations. The method that linearizes a complex model showed a good result, which can actually generate time and processing economy. The reducing of time and memory consumption required by proposed linear model will help control center of utilities by providing real-time data. In additional to helping utilities improve efficiency, no propriety designed to speed up integration of DG into grids.

System	Time Consumptions (s)		
	NR Method	LM Method	
Bus 5	0.2888	0.007588	
Bus 14	4.17	0.049	
Bus 30	28.95	0.154	

Table 9 Comparison of LM and NR time consumptions

5.4 Total power loss comparisons between Kalman Filter and Newton Raphson

Exact total power losses for the network are calculated using Newton Raphson method. At each load bus, DG has initialized with 1 MW and increased in a step of 1 MW until the maximum load demand is reached. Figure 56 shows the obtained power loss results for different DG places. The obtained minimum power loss point at each DG placement represents the optimal DG size. These points are then used as a reference to validate the proposed DG size estimation method using Kalman filter.





The network state variables of the network under study are voltage angle (δ) for the network buses (2, 3, 4 and 5). The voltage angle of bus 1 (slack bus) is constant and thus it equals to zero. The power of each DG is added as a control input to the system. Figure 57 shows an example for the behavior of the state variables as the DG size increases. It can be noticed that the system behavior follows the system input, i.e. the DG size. The power flow in the transmission lines is considered as the estimated output. Figure 58 illustrates the linear behavior of the power flow as the DG size increases. The non-linear behavior of the power flow (shown in Figure 58) is due to the initialization error of Kalman filter algorithm.





Figure 57 Behavior of system state variables versus DG size (Bus 3)



Figure 58 Power flow in network transmission lines versus DG size

Figure 59 shows total power loss comparisons between Kalman Filter and Newton Raphson methods, taking the DG at bus 5 as an example. As expected, it can be noticed that the Kalman filter estimation tracks closely the load flow curve which represents the exact solution. The deviation demonstrated at DG size < 20 can be neglected as it has no effect on obtaining the minimum power loss point. Other tests at different DG locations have shown similar patterns with the exception that the corresponding minimum points occur at different sizes [123].





Figure 59 Total power loss comparisons between Kalman Filter and Newton Raphson methods (DG at bus 5)

In this test, capacity of the DG has increased at each load bus at 1 MW steps until the total demand required each system to find the optimal size of DG with minimum total power losses. The 1 MW steps can be adjusted and reduced to the required resolution. Table 10 summaries performance of the proposed Kalman filter method as compared to the Newton Raphson method.

	Minimum loss (MW)		DG size (MW)	
	Kalman F.	NR.	Kalman F.	NR.
DG on bus 3	1.3918	1.3887	87	87
DG on bus 4	1.2991	1.2865	86	87
DG on bus 5	1.4012	1.3914	71	73

Table 10 Performance Comparision Betwee Kalman Filter and Newton Raphson Methods

Time complexity analysis of the proposed algorithm are performed on a computer with core i7-4800MQ CPU, 2.7GHz, 16GB RAM and Microsoft Windows 7 operating system running in real-time mode. Measurements of the execution time for both the proposed method and load flow methods are performed in a similar manner to that reported in [124]. Performance of the proposed algorithm showed a significant execution time saving when compared to that required by the Newton Raphson method, as shown clearly in Figure 60.



Figure 60 Computation time comparisons between Kalman Filter and Newton Raphson methods

5.5 Results of optimal size and location of multi DG by Genetic Algorithm

This simulation based on two techniques, simple real power loss equations and Genetic Algorithm. These techniques are used to obtain optimal size and allocation of multi DG units with less calculation time required. Accuracy and efficiency of calculation was proved by testing several IEEE benchmark systems. The simulation procedures are constructed as follows:

- 1) Standardized data for several IEEE benchmark test systems considered without adding DG.
- 2) Implement Newton Raphson (NR) method to find all parameters of systems.
- 3) Calculate the real power losses by using equation (22) and make it as a reference to compare with losses after adding DG units.
- 4) Set the maximum and minimum size of DG, voltages of (PQ) load buses and line capacity.
- 5) Set initial value of DG and step size according to equation (24) with the boundary of the maximum and minimum values.
- 6) Generate the initial population (location of DG units) and determine its size during GA.
- 7) Evaluate the fitness function (real power loss) for a given population.
- 8) Produce a new population to find the optimal location and size of DG units.

The proposed method is applied on (14, 30 and 57) IEEE benchmark test systems. In these tests, the maximum and minimum capacity of DG units chosen between zero and 200MW. The (14, 30 & 57) bus systems has (20, 41 & 80) sections and (259, 283.4 & 1250.8 MW) total load, respectively, where the base of MVA is 100. For GA, the size of the population was 100 while the maximum number of iterations was 1000 [125].

A. Fitness Function

The fitness function is computed when real power DG units are added at each PQ load bus. The evaluation of fitness function is each generation of the three systems are shown in Figure 61Figure 62 andFigure 63). It easily noted that fitness function has different behavior between these Bus systems. The convergence and accuracy were obtained after 88, 619 and 983 iteration for 14, 30 and 57 Bus, respectively. After satisfying all constraints, the least cost was 0.0262, 0.0229 and 0.0590 for same the sequence of Bus systems and GA terminated at condition of maximum iteration number. These figures show best and mean fitness values for each Bus system.



Figure 61 Fitness function evaluation for 14 Bus





Figure 63 Fitness function evaluation for 57 Bus

B. Optimal location and size of DG units

Results showed that the optimal allocations and DGs size in PQ load buses are shown in Figure 64Figure 65Figure 66). The maximum size of DG, required for 14 Bus system located in bus 4, was (1.03 p.u.). In the 30 Bus system, maximum capacity of DG was located at bus number 7 and it is value was (73.5 p.u.). Finally, the maximum value of DG was registered at 57 Bus system with (061 p.u.) and sit at bus 16.



Figure 64 Optimal size and allocation of DG units for 14 Bus



Figure 65 Optimal size and allocation of DG units for 30 Bus



Figure 66 Optimal size and allocation of DG units for 57 Bus

C. Line Losses

The maximum real power line loss for 14 bus before using DG units was located between bus 1 and bus 2 with (4.276 MW). After insert DG units, the maximum power loss reduced to 1.71MW at the line between bus 3 and bus4 as shown in Figure 67.



Figure 67 Line losses with and without DG units for 14 Bus



Figure 68 Line losses with and without DG units for 30 Bus

In Figure 68, for 41 sections and 283.4MW total load, the maximum power loss reduced from 5.36MW (between bus1 and bus2) to 1.54MW in line between bus 5 and bus 7. In system with 57 bus, DG units were used to minimize maximum real power loss from 3.68MW to 2.84MW. This loss was relocated from the line (bus1 to bus15) to line (bus8 to bus9) with the availability of DG units as shown in Figure 69.



Figure 69 Line losses with and without DG units for 57 Bus

Results show the efficiency of the GA to find the optimal size and allocation of DG units in several IEEE benchmark test systems. The DG units were reduced power losses up to 79 percentage in 14 Bus system where total real power losses were 12.771MW before applying GA. In the 30 Bus system, the total real power loss has been reduced to 2.3MW (86.13%) while its original loss was 16.59MW. The insertion of DG units into 57 Bus system presented a reduction of total power loss from 23.48MW to 5.53MW as shown in Table 11.

System	Total	Total Real Losses Total	
	With DG	Without DG	
14 Bus	2.6MW	12.77MW	197MW
30 Bus	2.3MW	16.59MW	227MW
57 Bus	5.53MW	23.48MW	399MW

Table 11 power losses with and without DG units

5.6 Results of Interior Point Optimization for loss reduction

This simulation merges two techniques namely, simple real power losses equations and interior Point optimization method. Both techniques are used to obtain the best calculation times for optimal size and allocation of multi DG units. Several IEEE benchmark test systems has been tested by simulation to prove it is preset calculation accuracy and efficiency. The simulation procedures are built as follows:

- 1) Standard data for several IEEE benchmark test systems considered without adding DG.
- 2) Implement Newton Raphson (NR) technique to find all parameters of systems.
- 3) Calculate the real power losses by using equation (20) and make it as references to compare with losses after adding DG units.
- 4) Set the minimum and maximum size of DG and voltages of load buses.
- 5) Set initial value of DG and step size according to (26) with boundary of minimum and maximum values.
- 6) Start IP optimization method for multi DG unites in load buses to find optimal size and locations of DG's.

In order to demonstrate the effectiveness of the proposed method, systems by set minimum and maximum capacity of multi DG units based on the type of renewable energy resources applied on (14, 30 and 57) IEEE benchmark test. . In these testes, the minimum and maximum capacity of DG units chosen between zero and 200MW. The (14, 30 & 57) systems has (20, 41 & 80) lines and (259, 283.4 & 1250.8 MW) total load, respectively. All the calculations have been carried out in per unit three-phase system with a base of MVA is 100. This simulation have been developed in MATLAB environment to run real power losses algorithm and optimization technique to obtain optimal size and placement of DG.

A. Test 14 Bus System

The 14-bus system has total real power losses of 12.771MW (4.93%). The results of using IP optimization method to find optimal allocation and size of DG's in load buses are shown in Figure 70. The total minimum real power loss is (2.6MW) while maximum size of DG required in bus 4 (1.03 p.u.) and maximum power loss (1.71MW) occurs in line between bus3 to bus4 as in Figure 71. The proposed method can reduce loss by 79.63% of its original loss.



Figure 70 Optimal size and allocation of DG for 14 Bus



Figure 71 power losses at each line for 14 Bus

B. Test 30 Bus System

Results shows that losses has been reduced to 2.3MW (86.13%) while its original losses was 16.59MW. The optimal allocations and DGs size results in load buses are shown in Figure 72. The maximum size of DG required in bus 7 (73.5 p.u.) and maximum power loss (1.54MW) occurs in line between bus5 to bus7 as in Figure 73.



Figure 72 Optimal size and allocation of DG for 30 Bus



Figure 73 power losses at each line for 30 Bus

C. Test 57 Bus System

For 80 sections and 1250.8MW total load, the total minimum power losses reduced to 5.53MW (76.44% of its original loss) after applied IP method. Determining the optimal place and size of DG units in load buses systems are shown in Figure 74 while Figure 75 shows that maximum power loss (2.84MW) occurs in line between bus8 to bus9. In additional, the maximum size of DG required in bus 16 (0.61 p.u.).



Figure 74 Optimal size and allocation of DG for 57 Bus



Figure 75 power losses at each line for 57 Bus

Observe that when DG with a large size is located at any placements near high load bus, the total real power losses are high. Conversely, just a small size of DG is added at the other locations, a lower loss reduction can be achieved. These finding enhance our understanding of the best location at which the total loss is minimum.

The efficient of using IP method to reduce power losses by finding optimal size and allocation of DG units in several IEEE benchmark test systems shows in Figure 76. It demonstrated the performance of the systems with and without DGs. The results show that the proposed method is capable of reducing real power losses with average 80% of its original losses with less computation time compared with global optimization Genetic Algorithm (GA).



Figure 76 power losses with and without DG units

To validate the results of proposed method, Newton Raphson (NR) method used to find the exact values of real power flow, then calculate the real power loss taking into account the reactive power flow. Table 12 shows total real power losses of different systems calculated by Newton Raphson (NR), Interior Point (IP) and Genetic Algorithm (GA). It is apparent from this table that only a small difference in exact calculation in return for less computation time required to estimate the optimal size and location of DG unites. Performance of the proposed algorithm (as local optimization method) showed a significant execution time saving when compared to that required by the Genetic Algorithm (GA) method (global), as shown clearly in Figure 77. Time complexity

analysis of the proposed algorithm are executed on a computer with CPU 2.7GHz, core i7-4800MQ, 16GB RAM and Microsoft Windows 7 operating system running in real-time mode.

	Losses Comparison (MW)					
	NR lossIP lossGA loss					
Bus14	2.776	2.623	2.6			
Bus30	3.048	2.297	2.3			
Bus57	8.68	5.527	5.53			

Table 12 Comparison of IP loss calculation with and IP time with GA



Figure 77 Computation time comparisons between IP and GA methods

The voltage profiles for three systems improved significantly with DG units. Table 13 shows the minimum voltages at various buses before and after DG by non-linear calculations. What is interesting in this results are that in all the cases the voltage profile improves significantly after optimal placement of each size of DGs.

systems	Min Voltage at Bus without DG	Voltage at Bus with DG
14 Bus	0.92879623 at bus 3	0.95929623 at bus 3
30 Bus	0.84499623 at bus 30	0.97839623 at bus 30
57 Bus	0.83549623 at bus 31	0.98339623 at bus 2

5.7 Grid performance with variable load

Today's system operators face the big challenge of constructing simulation of systems that make efficient select of generation resources under variable load profiles. This section describes IEEE five bus system model using Simulink. The real power load model designed to allow different load profile types (residential, commercial and industrial) connecting to load buses. Before modelling the IEEE 5 bus, Newton Raphson method has been implemented to calculate all the parameters of the system. All generation units, load demand and power loss calculated is shown in Table 14.

Unit	Total (MW)
Total Generation (P _{G1} ,P _{G2})	148.05
Total Demand (PD3, PD4, PD5)	145
Total real power loss	3.05

Table 14 Generation, load demand and losses for IEEE 5bus

The 5 bus IEEE modelling has been developed with Simulink in order to study its behavior under different load conditions. Slack generator simulated to has unlimited real and reactive power generation while its voltage and voltage angel set to $1.06 \angle 0.0^{\circ}$ per unit. Parameters of generation, load, voltage and voltage angel for other buses have set according to data of IEEE five bus shown in Table 15.

Table 15 IEEE 5 Bus Dat	a
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Bus	Type	Gen	eration	L	oad	Voltag	e
No.	Type	Real	React.	Real	React.	Magnitude	angle
1	1	0	0	0	0	1.06	0
2	2	90	0	0	0	1	0
3	0	0	0	45	15	1	0
4	0	0	0	40	5	1	0
5	0	0	0	60	10	1	0

At the beginning, load is considered as constant and simulation implemented for 10 seconds to compare with Newton Raphson (NR) method results. Figure 78 and Figure 79 shows measurements of real power flow (RPF) and losses (RPL), respectively, in all the transmission lines [126].



Figure 78 Active power flow on the lines with constant load



Figure 79 Active power losses on the lines with constant load

These measurements have been compared with accurate calculated by Newton Raphson method to valid Simulink model as in Table 16Erreur ! Référence non valide pour un signet..

	Transmission Lines						
	1-2	1-3	2-3	2-4	2-5	3-4	5-4
RPF (MW)	15.09	27.05	30.50	32.60	56.06	11.76	3.97
RPL (MW)	0.069	0.55	0.525	0.594	0.429	0.013	0.013

Table 16 Real power lines flow and losses by NR

In order to validate the proposed variable load simulation, random load profile used as input signal to instead of constant one. In Figure 80, input and output signals are identical except very small transient when signal switch from value to another.



Figure 80 Load model testing

Three different daily load profile (residential, commercial and industrial) are connected to load buses as follows: residential load curve (Figure 81) connect to bus 3, commercial load curve (Figure 82) connect to bus 4 and industrial load curve (Figure 83) connect to bus 5.







Figure 82 Commercial daily load curve connect to bus 4





Figure 83 Industrial daily load curve connect to bus 5

The results show that real power flow and losses in transmission lines will be effected by variable load profiles as shown in Figure 84 and Figure 85.



Figure 84 Lines Power flow with variable loads





Figure 85 Lines losses with variable loads

The 5 bus Simulink simulation under different load conditions is performed on a computer with core i7-4800MQ CPU, 2.7GHz, 16GB RAM and Microsoft Windows 7 operating system running in real-time mode. The results are shown with constant and variable load model. The results indicate the effectiveness of this flexible load profile model applied to the five bus system.

5.8 Size and placement selection of wind farm

Firstly, the 5 bus IEEE standard systems has been tested with linear load flow method to calculate total real power losses without wind farm. These calculations corresponding to the power losses at duration t_0 (where wind farm has zero output). Then, it has been repeated by adding wind farm inside this system in different locations at load buses. At each location, the capacity of wind farm has initiated with 1 MW power at beginning, then it increases by 1 MW step till it reach total demand required for whole system. Figure 86 shows power loss variation with total wind farm power for three different locations of the farm. However, the wind farm capacity is approximately optimal values because the reactive power flow in lines was ignored, all voltage values assumed to be 1 p.u. and an approximation method to calculate real power flows was used. The procedure presented in this work has smooth properties, which lead to solution close to optimal values with less iterations, memories and computation times. In addition, the error from linearization method can be reduced during the estimation process.



Figure 86 Buses losses with different Wind Farm locations

The figure shows that for each location (bus), curves will have similar behavior which can be divided into two parts. In the first part, the curves are close to be linear and the losses will be decreased at each MW step of wind farm until it reach the minimum value. Then, curves behavior be nonlinear in the second part where the losses will increase when the wind farm output continues increasing. Mostly, these curves will continue in parallel at linear part from lower to upper one but sometimes it intersected at non-linear part.

The procedure begins to compute total real power losses in lines before adding wind turbines, which will be located in different load buses. After adding the small amount of power (1 MW at first load bus), the power flow computation based on the proposed linear method and obtained initial power loss by simplified the real power loss calculation. Then, the information of the individual power loss corresponding to wind farm capacity (increased by 1MW step) are stored in Plosses,n and in, respectively. The capacity and location of wind turbines will selected by comparing the minimum value of these losses in stored memory taking into account size not exceed 30% of total generation.

Finally, the accumulated data of the minimum power loss, location and size of wind turbines are obtained. It is observed that each state converges sufficiently for different systems and it can predict optimal size and location of wind farm for minimum losses. The time reduction and memory consumption required by proposed linear model will help control center of utilities by providing real-time data.

5.9 Analytical model results

Before wind farm integrated into IEEE 5 bus, linear method has been implemented to calculate the total real power loss for the system. All generation units, load demand and power loss calculated is shown in Table 17.

Unit	Total (MW)
Total Generation (P_{G1}, P_{G2})	148.05
Total Demand (P _{D3} , P _{D4} , P _{D5)}	145
Total real power loss	3.05

Table 17 Generation, load demand and losses for IEEE 5bus

From Figure 86, it is observed that bus 5 has minimum real power losses and it can be selected as optimal placement of wind farm. In addition, it is noted that increasing MW continue to decrease real power losses more than 50MW. So that, the capacity of wind farm will be selected based on condition (30% of total generation required), which is 45MW. So that, wind farm will consist of 30 individual wind turbines with rated output power 1.5MW and each of them will subject to same distributed wind field.

The wind farm output power has two constant values, zero (MW) when wind speed less than cut-in speed (3m/s) and rated power output (1.5MW) when wind speed between rated (11m/s) and cut-out (25m/s). In additional, the variable values when wind speed is varying between cut-in and rated, which can be found by subtracting the losses from the mechanical power by (1) according to the speed variation in Figure 39.

The real power loss for 5 IEEE bus with wind farm penetration has been calculated for four durations (t_0 , t_v , t_r , t_{out}) to find the average value taking into account the variation of annual wind speed. Table 18 Shows the real power output of wind farm and total real losses for three constant values durations (t_0 , t_r , t_{out}) in additional to the variation in the value when wind speed between cut-in and rated speed. It is noted that the percentage differences between the averages yearly of real power losses and losses calculated for wind farm rated is 37% for 5 bus IEEE. The time consumption with proposed method is less than (5ms) which is performed on a computer with core i7-4800MQ CPU, 2.7GHz, 16GB RAM and Microsoft Windows 7 operating system running in real-time mode.

Wind Speed (m/s)	Hours per year	Power output of wind farm (MW)	Total Real losses (MW)
< 3 or >25	827	0	3.05
3	729	0.9117	3.049
4	869	2.161	3.00
5	941	4.220	2.89
6	946	7.293	2.77
7	896	11.582	2.58
8	805	17.288	2.37
9	690	24.616	2.12
10	565	33.767	1.87
>=11	1489	44.944	1.66
Annu	2.53		

Table 18 Total real power losses for 5 bus with wind farm

5.10 Wind grid integration results

In order to validate the proposed analytical model, the 5 bus IEEE modelling has been developed with Simulink. The wind farm (45MW) has been presented by 5 groups; each one has 6 wind turbines with rated output power 1.5MW. The output power provided by the wind farm will vary due to the wind speed variations as shown in Figure 39. Firstly, the real power flow at each line (7 lines) in the system has been measured before integration of wind farm. This measurement has been compared with more accurate calculated by Newton Raphson method to valid Simulink model as in Figure 87. Then, the real power losses have been measured at each line to calculate the total losses in the system (3.07MW) as shown in Figure 88. This calculation has been considered at steady state of the system and at constant loads.



Figure 87 Active power flow on the lines before integration of the wind farm





Figure 88 Active power losses in the lines before integration of the wind farm

After connecting the wind farm into the 5 bus IEEE system, the power flow as well as the power losses into lines will varies due to the output variation of wind power as shown in Figure 89 and Figure 90. The power output of wind farm follows the same wind speed variation (Figure 39) applied in the analytical model.



Figure 89 Active power flow on the lines with wind farm connected at bus5





Figure 90 Active power losses in the lines with wind farm connected at bus5

The location of wind farm inside grid has been changed to evaluate the real power losses in each case. It is proved that the power injection of wind farm output into bus 5 will minimize the total power losses more than other locations. The variation of real power losses was between 1.1 to 2.1 MW while the average of it will be approximately 1.25 MW as shown in Figure 91.



Figure 91 Active power losses in the network before and after integration of the wind farm





Figure 92 Comparison of Annual average real power losses by analytical method and Simulink

The annual average real power losses for 5 bus system has been shown in Figure 92. PLay represents the average power losses per year calculated by analytical method while PLoss-5 represents the total power losses into grid taking into account changeable wind speeds during special period by Simulink.

The results show that the proposed method is capable of predicting optimal size and location of wind turbines compared with Simulink simulation. The acceptable accuracy with less time and memory required can help the grid operator to assess wind farm power situation and power flow in large-scale system.

5.11 Conclusion

In this fifth chapter, the validation of the proposed algorithms to improve the DG and wind energy integration into grid has been presented. The main objective of this validation is to prove that the goals of this research is achieved under different conditions used for this study. It has been demonstrate the possibility of improve the impact of DG and wind energy on the power loss calculation in different stages (planning and operations).

Two different strategies have been adopted to manage the planning and operation process. The first one concerned on the time consumptions and computer memory required to speed up the power system analysis, which can be helpful DSO in real time monitor and assessment. In second strategy, the important effect of varying load profiles and wind speed variation on power loss calculation for long service life.

Several algorithms, as described in chapters 2&3, has been validated in this chapter to explain the implementation of first strategy. In order to avoid useless iterations (computations with zero vectors values), validation of decompressing data method known (RLE) has been presented. This algorithm has been combined the advantage of accuracy solutions by NR with the advantages of the RLE technique to reduce calculation time required.

Moreover, Schur complement method has been compared with classical load flow methods as NR and FD to demonstrate its ability to reduce the computer memory required and speed up the load flow calculations. It has been stated that the calculation of load flow is suited to parallel computation when dividing the Jacobian matrix by Schur algorithm.

In additional to that, the simple power loss calculation test the IEEE bus systems to improve that the estimation of DG size is faster than classic methods. In spite of conventional DG placement, fast selection of DG size with appropriate accuracy has been implemented by using Kalman filter and graph theory. Both methods have been performed to illustrate the possibility as online tools to help DSO utility who work on smart grid to select the optimal DG's size. Then, the challenges of integration multi DG units into grid have been implemented by global and local optimization techniques.

Genetic algorithm as global technique has been applied to determine the optimal size and location of these DG units based on description in chapter five. The obtained results was the same

when interior point method performed but less computation time was needed. Comparison of these two methods has been done to explain the ability of local optimization technique to achieve highly optimized results with avoid much execution time.

Simulink often provides more set of block libraries and offers integration with the MATLAB scripts. These features make it widely used in automatic control and models in real-time on the physical system. The IEEE benchmark test of 5 bus systems has been simulated with different load profiles to study its main effect on the real power loss calculation. It reveals significant difference in calculation of real power losses for same network between fixed and varying loads.

The steady state behavior of electrical power systems under several load profiles can be better operated and analyzed. Moreover, Weibull distribution has been applied to the wind farm simulation in order to analyse the real power losses as a function of the wind speed. The output power of wind farm has been categorized according to the time duration of wind speed variation. Besides, it would possible to estimate variations of the electrical power losses in this model by considering, in the same time, the varying time load and wind power variation.

More conclusions and feature work will be detailed and presented in next chapter.
Chapter 6

Conclusions and Future Research

6.1 Conclusions

The impact of Distribution Generation and wind energy into grid has been the object of this thesis. A list of conclusions for different algorithms developed to improve the time calculation and memories will be present in this section.

6.1.1 Impact Analysis of Distributed Generation on Mesh and Radial distribution network

Distribution networks have usually a radial or loop design, while transmission networks has only mesh design. Therefore, the power flow in distribution networks usually is one-directional and no or little redundancy exists. The interconnection is further impacted through aspects of the network topology.

Many of research papers on distributed generation from different countries have been collected and categorized. The main topics discussed are DG and it is impact on mesh and radial electricity supply, flexibility in electricity demand, and integration opportunities on utility system.

Most of researches are still in tables; only few were actual business cases or in field-test level. Although many of optimization algorithms to find best location and size of DG has been proposed but are not public available yet. According to market rules, the integration of different generation units differ between countries but we conclude three main points:

- The simplest network structures to protect are radial systems while meshed distribution networks have a higher short circuit power.
- The advantage of meshed networks is relatively balanced voltage profile and high reliability through redundancy.
- Most of distributed generators (as wind energy) feed either into mesh structure, usually used with high or medium voltage, while radial used with low level voltage, which is mostly for PV.

6. Conclusions and Future Research

The motivation adducted to increase the penetration of DG and wind energy and market development are:

- Reducing of cost of production when demand increased which make business area more interested to apply these researches and developing tools can be used for this field.
- The successful integration for DG's inside different type of distribution system from the technical and economic views will change rules of markets.
- Select optimum location and size according different structure of distribution system will change amount of cost.

6.1.2 Schur and RLE approaches to improve power system analysis

In this simulation, Schur complement has been used to develop the load flow program, which solve the nonlinear power flow questions, by separate the Jacobian matrix into two matrices. The first matrix represents the relationship between voltage angles and apparent powers while second matrix represents relationship between voltage magnitudes and apparent powers. These two matrices are combined to form a direct approach with better convergence, especially when Jacobian matrix is singular. This algorithm testes several IEEE benchmark test systems and compare it results with Newton Raphson and Fast decoupled methods. Reasonable computation time with less memory and smooth convergence resulted by utilizing this algorithm.

The proposed algorithm used Data compression technique tested different systems and results shows it is efficiency. More accuracy for large systems will need more iterations calculation which mean increasing time consumption, while Run Length Encoding (RLE) algorithm is fitness to optimized calculation numbers to exact number because data matrix has no zero values included. Network structure was represented as one dimension vector instead of 2D Matrix and it is effectiveness results was valid, by avoid exponential growth, when RLE algorithm utilized. Matlab results obtained by applied RLE algorithm match theoretical results. These algorithms have been implemented and tested on several IEEE standard systems as (5, 14 and 30 Buses). Results have been compared with Newton Raphson and Fast Decoupled methods in term of influence of convergence properties and algorithm efficiency. Reasonable computation time with less memory and smooth convergence resulted by utilizing Schur complement algorithm. Results show the efficiency of the RLE algorithm to reduce iteration numbers to calculate active and reactive power flow in these systems to the minimum number without losses of the time. It noted that time required to implement these calculation increased exponentially with increase of the number of buses and more accuracy required. Algorithm optimized CPU execution time and number of calculation iterations with less memory.

6.1.3 Fast Estimation Methods for Selection of Optimal Distributed Generation Size

Linear equations modelling has been used to develop simplified power losses calculations. These calculations accelerated the process to predicate approximate optimal DG size. Each location of DG at load buses has optimal size of DG for minimum power losses. The proposed method has acceptable accuracy with less time and memory consumption where it is crucial factor in real-time management of power grids. The loss reduction by properly placed and appropriately sizes of DG's is one of the more significant finding to emerge from this study. It also noted that optimal size for optimal location is not necessary to be same as optimal location for optimal size. With these benefits, control and assess of large scales power grid will become easy predictable as more intermittent power sources, such as wind and solar, come online. Several IEEE benchmark test systems has been tested and results are validated with exact calculations.

A fast DG size estimation method based on graph theory and Kalman filter is then suggested and successfully implemented. The proposed method has been implemented and tested on standard IEEE 5-bus test system. Simulation results showed that the proposed method could saving a significant time when compared to an existing method based on load flow. The obtained simulation results showed that the developed estimation method could save more than 60% of the required execution time when compared to an existing method based on Newton Raphson method. This time saving advantage is achieved at the expense of only a small error in estimating both the minimum power loss and the DG size. This estimation error is caused by the adopted model linearization, which excludes the effect of the reactive power loss. In practice, the method can be considered an important tool at the planning and decision-making phase of building an electric power generation network.

6.1.4 Optimization Techniques for Network Loss Reduction integrating Multiple Distributed Generations

Two-optimization techniques (local and global) based on linearized calculation for real power loss model has been presented. Firstly, the Genetic Algorithm (GA) successfully implemented to find the final chromosome that represents the optimal location and size of DG units in the grid. A fitness function expresses the main aim of the model, which is to minimize the total real power losses subject to inequality (voltage, transmission line capacity and power generation limitations) and equality constraints. The Genetic Algorithm optimization method was very effective in the area of DG allocation and capacity when it applied on the standard IEEE bus electrical networks. The total real power loss has reduced up to 86 percentage for some test cases. The simulation is extremely flexible and can easily change the limitation of DG capacity according to any renewable resources. Results show that the linear model combined with GA is efficient in reducing real power losses by finding the global optimal location and size of DG units.

Secondly, the Interior Point (IP) optimization method is used to solve the optimization problem and minimizing the objective function for multi distributed generation (DG) units. The proposed simulation is applied on standard IEEE bus electrical networks, in order to evaluate the efficiency of this method. The results shows the efficiency of PI to find the optimal location and size with less computing time. With the optimal placement of DG units, the real power losses has been reduced in average about 80% of original total losses without DG's. This time saving advantage achieved at the expense of only a small difference in exact calculating the minimum power loss by nonlinear (Newton Raphson) method. The limitation of DG size is used between (0-200) MW (with 1MW step) and it is flexible to change according to any renewable energies. The proposed method has less time computation compared with global optimization method (GA) for linear method in additional nonlinear.

One of the more significant findings to emerge from this study is that properly placed and appropriately, sized DG's can reduce losses significantly. In large-scale power system, the time of calculation is crucial factor in real-time management of power grids. This time saving advantage is accomplished at the expense of only a small difference in calculating both the minimum power loss and the DG size. This method can be used in additional to design and re-design of electrical network by optimization DG's location, as online tools to help utility operators whose work on smart grid to select the optimal DG's size.

6.1.5 The Impact of Wind Farm on Electrical Power Network with Variable Load Simulation

This work has presented network modelling with variable load profile using Simulink. System of IEEE five bus is used as a test bed. This simulation can be easily adapted to accommodate different types of generation resources by considering time-varying load profile. The simulation introduce four main blocks represent slack generator, control generator, transmission line and variable load. Three different types of load profile (residential, commercial and industrial) tested the five-bus network simulation. The results demonstrate that the simulation can be adequate to identify the real power flow and losses into transmission lines. Simulation results indicate that varying demand can change the dynamic performance of the system and will help DNOs understand what they need to do to provide solutions for network stability.

The growth of the electrical demand increases the need of renewable energy sources such as wind generation to handle it. The wind farm can be helpful at the margin in providing clean power. The problem for selection the size and location of wind farm at each load bus in 5 bus IEEE standard systems has been formulated with linear state equations. The analytical model and Simulink simulation focused on integrating wind farm into grid to minimize the power loss. However, this is not optimal solution cause the reactive power flow was ignored, all voltage values assumed to be 1 p.u. and an approximation method to calculate real power flows. In contrary, the analytical method gives results that are more accurate because it takes into account annual variation of wind speed.

In case of 5 bus system, the fluctuation of wind power output due to the wind speed variation has changed the calculations of total real power losses within 37%. To validate analytical results, the 5 bus system modelling with Simulink has been developed and tested with/without wind farm. The impact of wind farm on real power losses are presented and results from simulated reveal that losses can be strongly affected by changes in wind speed. The computation times required for analytical method was less than Simulink. The proposed algorithm describes a simple, easy and predictable technique, which can lead to control and assess of the large-scale power grid as more intermittent wind power sources come online.

6.2. Recommandation for Future Research

- 1- This work can be extended to analyze high penetration of renewable distributed generation integration in the larger-scale network based on other renewable energy resources such as PV plant. Results of analysis related most important parameters such as costs, size and location of PV plant, and prediction of PV output and size of storage energy. Complex network analysis with a variety of distributed generation resources are significant challenges that utilities faced today.
- 2- Research of monitoring online and operation of grid is still in a topic. Implementing fast and optimal methods as Matlab file structure into Simulink infrastructure can be a real future challenge for future researches. The development of software can avoid needing of measurement devices and equipment of electrical grid that mean less support and maintenance cost. Converting the complex data of power system into information can help managers and DSO take faster correct decision online.
- 3- The objective function for optimization methods can be expanded to include reactive power flow with more constraints such as voltage stability and system reliability. Optimal size and location of wind energy determination can be based on reactive power compensation required. The choice of compensation system as reactive power can be an economic decision if it considering life cycle cost and initial investment, where the boundary condition set by the DSO act as an important requirements.
- 4- Real power losses may be considered in the calculation of annual income during the operation period. The output power of wind farms is set as a function of the wind speed variation. Moreover, variable load and variable power output of wind farms together can play main role in the analysis and calculation of real power losses. A tool for studying the effect of wind resource and load variation at the same time on the power system analysis is significantly important.

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Schur Complements

Let M be an matrix written as

$$M = \begin{pmatrix} A & B \\ C & D \end{pmatrix}$$

Where M is a N*N matrix, A is a m*m and D is a n*n, with N=m+n (that mean, B is a m*n matrix and C is a n*m matrix). It can solve the linear system

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} \begin{pmatrix} x \\ y \end{pmatrix} = \begin{pmatrix} c \\ d \end{pmatrix}$$

That is

$$Ax + By = c$$
$$Cx + Dy = d$$

By assuming that D is invertible matrix and using Gaussian elimination method, y getting:

$$y = D^{-1}(d - Cx)$$

After substituting this expression for y in the first equation, it get

$$Ax + B\left(D^{-1}(d - Cx)\right) = c$$

That is,

$$(A - BD^{-1}C) = c - BD^{-1}d$$

If the matrix $A - BD^{-1}C$ is invertible, then it obtain the solution to system

$$x = (A - BD^{-1}C)^{-1}(c - BD^{-1}d)$$
$$y = D^{-1}(d - (A - BD^{-1}C)^{-1}(c - BD^{-1}d))$$

The matrix, $A - BD^{-1}C$, is called Schur complement of *D* in *M*. If *A* is invertible, then by eliminating *x* first using the first equation it find that the schur complement of *A* in *M* is (this corresponds to the Schur complement defined when $C = B^T$).

The above equations are written as

$$x = (A - BD^{-1}C)^{-1}c - (A - BD^{-1}C)^{-1}BD^{-1}d$$
$$y = -D^{-1}C(A - BD^{-1}C)^{-1}c + (D^{-1} + D^{-1}C(A - BD^{-1}C)^{-1}BD^{-1})d$$

Yield a formula for the inverse of *M* in terms of the Schur complement of *D* in M, namely

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}^{-1} = \begin{pmatrix} (A - BD^{-1}C)^{-1} & (A - BD^{-1}C)^{-1}BD^{-1} \\ -D^{-1}C(A - BD^{-1}C)^{-1} & (D^{-1} + D^{-1}C(A - BD^{-1}C)^{-1}BD^{-1}) \end{pmatrix}$$

A moment of reflexing reveals that

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}^{-1} = \begin{pmatrix} (A - BD^{-1}C)^{-1} & 0 \\ -D^{-1}C(A - BD^{-1}C)^{-1} & D^{-1} \end{pmatrix} \begin{pmatrix} I & -BD^{-1} \\ 0 & I \end{pmatrix}$$

It follows immediately that

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}^{-1} = \begin{pmatrix} I & -BD^{-1} \\ 0 & I \end{pmatrix} \begin{pmatrix} A - BD^{-1}C & 0 \\ 0 & D \end{pmatrix} \begin{pmatrix} I & 0 \\ D^{-1}C & I \end{pmatrix}$$

The above expression can be checked directly and has the advantage of only requiring the inevitability of D.

Remark: If A is invertible, then it can use the Schur complement, $D - CA^{-1}B$, of A to obtain the following factorization of M:

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix} = \begin{pmatrix} I & 0 \\ CA^{-1} & I \end{pmatrix} \begin{pmatrix} A & 0 \\ 0 & D - CA^{-1}B \end{pmatrix} \begin{pmatrix} I & A^{-1}B \\ 0 & I \end{pmatrix}$$

If $D - CA^{-1}B$ is invertible, it can invert all three matrices above and it get another formula for the inverse of *M* in terms of $(D - CA^{-1}B)$, namely,

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}^{-1} = \begin{pmatrix} (A - BD^{-1}C)^{-1} & (A - BD^{-1}C)^{-1}BD^{-1} \\ -D^{-1}C(A - BD^{-1}C)^{-1} & (D^{-1} + D^{-1}C(A - BD^{-1}C)^{-1}BD^{-1}) \end{pmatrix}$$

If A, D and both Schur complements $A - BD^{-1}C$ and $D - CA^{-1}B$ are all invertible, by comparing the two expressions for M^{-1} , it get the (non-obvious) formula

$$(A - BD^{-1}C)^{-1} = A^{-1} + A^{-1}B(D - CA^{-1}B)^{-1}CA^{-1}$$

Using this formula, it obtain another expression for the inverse of M involving the Schur complements of A and D

$$\begin{pmatrix} A & B \\ C & D \end{pmatrix}^{-1} = \begin{pmatrix} (A - BD^{-1}C)^{-1} & -A^{-1}B(D - CA^{-1}B)^{-1} \\ -(D - CA^{-1}B)^{-1}CA^{-1} & (D - CA^{-1}B)^{-1} \end{pmatrix}$$

IEEE 5-BUS SYSTEM DATA

Bus **Bus Voltage** Generation Load Phase Angle Magnitude Reactive Real Reactive No. Real Per Unit Degrees MW **MVAR** MW **MVAR** 1.06 0.0 1 0 0 0 0 0.0 2 1.0 40 30 20 10 3 1.0 0.0 15 0 0 45 4 1.0 0.0 0 0 40 5 5 1.0 0.0 0 0 60 10

Table A2.1 Bus Data

Table A2.2 Line Data

Bus Line	Line impedance Z _{km}		Susceptance per unit
k-m	R per unit	X per unit	$\sqrt{Y_{pq}}/2$
1-2	0.02	0.06	0.0 + j0.030
1-3	0.08	0.24	0.0 + j0.025
2-3	0.06	0.25	0.0 + 0.020
2-4	0.06	0.18	0.0 + j0.020
2-5	0.04	0.12	0.0 + j0.015
3-4	0.01	0.03	0.0 + j0.010
4-5	0.08	0.24	0.0 + j0.025

Table A2.3 MW Limits for Branches

Line (k-m)	MW Limit (p.u)
1-2	0.8
1-3	0.3
2-3	0.2
2-4	0.2
2-5	0.6
3-4	0.1
4-5	0.1

IEEE 14-BUS SYSTEM DATA

Table A3.1 Bus Data

Bus	Bus Voltage		Generation		Load	
No.	Magnitude	Phase Angle	Real	Reactive	Real	Reactive
	Per Unit	Degrees	MW	MVAR	MW	MVAR
1	1.06	0.0	232.4	-16.9	0.0	0.0
2	1.045	-4.98	40.0	42.4	21.7	12.7
3	1.010	-12.72	0.0	23.4	94.2	19.0
4	1.019	-10.33	0.0	0.0	47.8	3.9
5	1.020	-8.78	0.0	0.0	7.6	1.6
6	1.070	-14.22	0.0	12.2	11.2	7.5
7	1.062	-13.37	0.0	0.0	0.0	0.0
8	1.090	-13.36	0.0	17.4	0.0	0.0
9	1.056	-14.94	0.0	0.0	29.5	16.6
10	1.051	-15.10	0.0	0.0	9.0	5.8
11	1.057	-14.79	0.0	0.0	3.5	1.8
12	1.055	-18.07	0.0	0.0	6.1	1.6
13	1.050	-15.16	0.0	0.0	13.5	5.8
14	1.036	-16.04	0.0	0.0	14.9	5.0

Bus Line	Line impe	dance Z _{km}	Susceptance per unit
k-m	R per unit	X per unit	$\sqrt{Y_{pq}}/2$
1-2	0.01938	0.05917	0.02640
2-3	0.04699	0.19797	0.02190
2-4	0.05811	0.19797	0.01870
1-5	0.05403	0.22304	0.02460
2-5	0.05695	0.17388	0.01700
3-4	0.06701	0.17103	0.01730
4-5	0.01335	0.04211	0.0064
5-6	0.0	0.25202	0.0
4-7	0.0	0.20912	0.0
7-8	0.0	0.17615	0.0
4-9	0.0	0.55618	0.0
7-9	0.0	0.11001	0.0
9-10	0.03181	0.08450	0.0
6-11	0.09498	0.19890	0.0
6-12	0.12291	0.25581	0.0
6-13	0.06615	0.13027	0.0
9-14	0.12711	0.27038	0.0
10-11	0.8205	0.19207	0.0
12-13	0.22092	0.19988	0.0
13-14	0.17093	0.34802	0.0

Table A3.2 Line Data

Line (k-m)	MW Limit (p.u.)
1-2	0.6
2-3	0.7
2-4	0.8
1-5	0.5
2-5	0.4
3-4	0.3
4-5	0.2
5-6	0.5
4-7	0.4
7-8	0.2
4-9	0.2
7-9	0.2
9-10	0.2
6-11	0.3
6-12	0.2
6-13	0.2
9-14	0.2
10-11	0.2
12-13	0.2
13-14	0.2

Table A3.3 MW Limits for Branches

IEEE 30 BUS SYSTEM DATA

Table A4.1 Bus Data

Bus	Bus Voltage		Generation		Load	
No.	Magnitude	Phase Angle	Real	Reactive	Real	Reactive
	Per Unit	Degrees	MW	MVAR	MW	MVAR
1	1.0500	0.0	138.48	-2.79	0.0	0.0
2	1.0338	-2.7339	57.56	2.47	21.7	12.7
3	1.0313	-4.6815	0.0	0.0	2.4	1.2
4	1.0263	-5.6077	0.0	0.0	7.6	1.6
5	1.0058	-8.9930	24.56	22.57	94.2	19.0
6	1.0208	-6.4547	0.0	0.0	0.0	0.0
7	1.0069	-8.0244	0.0	0.0	22.8	10.9
8	1.0230	-6.4733	35.0	34.84	30.0	30.0
9	1.0332	-8.0300	0.0	0.0	0.0	0.0
10	1.0183	-9.9268	0.0	0.0	5.8	2.0
11	1.0913	-6.1345	17.93	30.78	0.0	0.0
12	1.0399	-9.4036	0.0	0.0	11.2	7.5
13	1.0883	-8.2049	16.91	37.83	0.0	0.0
14	1.0236	-10.3086	0.0	0.0	6.2	1.6
15	1.0179	-10.3600	0.0	0.0	8.2	2.5
16	1.0235	-9.90280	0.0	0.0	3.5	1.8
17	1.0144	-10.1356	0.0	0.0	9.0	5.8
18	1.0057	-10.9253	0.0	0.0	3.2	0.9
19	1.0017	-11.0615	0.0	0.0	9.5	3.4
20	1.0051	-10.8310	0.0	0.0	2.2	0.7
21	1.0061	-10.4047	0.0	0.0	17.5	11.2
22	1.0069	-10.3936	0.0	0.0	0.0	0.0
23	1.0053	-10.7221	0.0	0.0	3.2	1.6
24	0.9971	-10.8465	0.0	0.0	8.7	6.7
25	1.0086	-10.9074	0.0	0.0	0.0	0.0
26	0.9908	-11.3345	0.0	0.0	3.5	2.3
27	1.0245	-10.6624	0.0	0.0	0.0	0.0
28	1.0156	-6.86710	0.0	0.0	0.0	0.0
29	1.0047	-11.8893	0.0	0.0	2.4	0.9
30	0.9932	-12.7699	0.0	0.0	10.6	1.9

Bus Line	Line impedance Z _{km}		Susceptance per unit	
k-m	R per unit	X per unit	$\sqrt{Y_{pq}}/2$	
1-2	0.0192	0.0575	0.0528	
1-3	0.0452	0.1652	0.0408	
2-4	0.0570	0.1737	0.0368	
3-4	0.0132	0.0379	0.0084	
2-5	0.0472	0.1983	0.0418	
2-6	0.0581	0.1763	0.0374	
4-6	0.0119	0.0414	0.0090	
5-7	0.0460	0.1160	0.0204	
6-7	0.0267	0.0820	0.0170	
6-8	0.120	0.0420	0.0090	
6-9	0.0	0.2080	0.0	
6-10	0.0	0.5560	0.0	
9-10	0.0	0.1100	0.0	
4-12	0.0	0.2560	0.0	
12-14	0.1231	0.2559	0.0	
12-15	0.0662	0.1304	0.0	
12-16	0.0945	0.1987	0.0	
14-15	0.2210	0.1997	0.0	
16-17	0.0524	0.1923	0.0	
15-18	0.1073	0.2185	0.0	
18-19	0.0639	0.1292	0.0	
19-20	0.0340	0.0680	0.0	
10-20	0.0936	0.2090	0.0	
10-17	0.0324	0.0845	0.0	
10-21	0.0348	0.0749	0.0	
10-22	0.0727	0.1499	0.0	
21-22	0.0116	0.0236	0.0	
15-23	0.1000	0.2020	0.0	
22-24	0.1150	0.1790	0.0	
23-24	0.1320	0.2700	0.0	
24-25	0.1885	0.3292	0.0	
25-27	0.1093	0.2087	0.0	
27-28	0.0	0.3960	0.0	
27-29	0.2198	0.4153	0.0	
27-30	0.3202	0.6027	0.0	
29-30	0.2399	0.4533	0.0	
8-28	0.0636	0.2000	0.4028	
6-28	0.0169	0.0599	0.0130	
9-11	0.0	0.2080	0.0	
12-13	0.0	0.1400	0.0	
25-26	0.2544	0.3800	0.0	

Table A4.2 Line Data

Line (k-m)	MW Limit (p.u.)
1-2	1.0400
1-3	1.0400
2-4	0.5200
3-4	1.0400
2-5	1.0400
2-6	0.5200
4-6	0.7200
5-7	0.5600
6-7	1.0400
6-8	0.2560
6-9	0.5200
6-10	0.2560
9-10	0.5200
4-12	0.5200
12-14	0.2560
12-15	0.2560
12-16	0.2560
14-15	0.1280
16-17	0.1280
15-18	0.1280
18-19	0.1280
19-20	0.2560
10-20	0.2560
10-17	0.2560
10-21	0.2560
10-22	0.2560
21-22	0.2560
15-23	0.1280
22-24	0.1280
23-24	0.1280
24-25	0.4800
25-27	0.1280
27-28	0.5200
27-29	0.1280
27-30	0.1280
29-30	0.1280
8-28	0.2560
6-28	0.2560
9-11	0.5200
12-13	0.5200
25-26	0.1280

Table A4.3 MW Limits for Branches