IMPROVING POWER LOSSES USING DISTIBUTED GENERATION

QUSAY A. SALIH

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Faculty of Electrical and Electronic Engineering
University Tun Hussein Onn Malaysia

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ABSTRACT

The electrical energy generation companies try always to improve the system performance through reducing the active power losses and that lead the fuel cost is reduced also. One of the way is by incorporate is Distributed Generation (DGs). DGs are becoming more prominent in transmission systems due to increased demand for the electrical energy. The location of DGs sources will have an impact on system losses of distribution network. In this Project, Sensitivity Analysis will be used to solving the problem of optimal location of DGs. The objective is to minimize network power loss in the transmission lines. This case will be applied for two types of load demands i.e. minimum and maximum. The present study will be carried out by using 30 Bus IEEE test system. For reducing the power losses, the simulation results have showing that the bus 13 which has the most negative of partial derivative $\frac{\partial P_{Loss}}{\partial P_N}$ giving the most efficient of the network.

ABSTRAK

Syarikat-syarikat penjanaan tenaga elektrik sentiasa berusaha meningkatkan keupayaan system dengan mengurangkan kehilangan kuasa aktif dimana ianya boleh mengurangkan kos bahan api. Salah satu cara adalah dengan menggabungan sistem yang ada dengan pengagih penjana.Pengagih penjana menjadi lebih menonjol berbanding dengan sistem penghantaran disebabkan peningkatan permintaan tenaga elektrik. Kedudukan atau lokasi pengagih penjana akan memberi kesan terhadap kehilangan/kerugian di sistem pengagihan. Di dalam projek ini, sensitif analisis digunakan untuk menyelesaikan masalah lokasi optimum bagi sesebuah pengagih penjana. Objektif utama adalah untuk meminimumkan kehilangan kuasa rangkaian elektrik di sistem penghantaran. Untuk kes ini, dua jenis beban digunakan iaitu beban minimum dan beban maksimum. Kajian ini dijalankan dengan sistem ujiam IEEE 30 Bus. Bagi mengurangkan kehilangan sistem, hasil simulasi dapat menunjukkan bahawa sistem mempunyai terbitan separa $\frac{\partial P_{Loss}}{\partial P_N}$ yang lebih negative di bus ke 13 dimana ianya memberikan keputusan paling efisian kepada rangkain elektrik.

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CHAPTER 1

INTRODUCTION

1.1 Introduction

The importance of electric power in today's world cannot be overemphasized, for it is the key energy source for industrial, commercial and domestic activities. Its availability in the right quantity is essential to advancement of civilization. Electrical energy produced at through the use of transmission lines run from one place to another. As a result of the physical properties of the transmission medium, some of the transmitted powers are lost to the surroundings. The overall effect of power losses on the system is a reduction in the quantity of power available to the consumers. As such, adequate measures must be put in place to reduce power losses to the minimum [1].

Ideally, losses in an electric system should be around 3 to 6%. In developed countries, it is not greater than 10%, however, in developing countries, the percentage of active power losses is around 20%, therefore, utilities in the electric sector are currently interested in reducing it in order to be more competitive, since the electricity prices in deregulated markets are related to the system losses.

In India, collective of all states, in 2008 The technical and non-technical losses are accounted as 23% of the total input energy [2].

Active power losses in the transmission are about 4–8% of the total active power generated as example for that in Brazil the cost of the loss is half a billion U.S. dollars a year [3].

Recently, Distributed Generations (DGs) have received great attention in power systems as a solution to environmental and economical challenges caused by

conventional power plants. DGs are defined as electric power generations directly connected to near the loads or in the distribution networks, also the DGs range from a few kWs to a few MWs and DGs have many types like (wind turbines, photovoltaic, full-cells, biomass, micro turbines, etc.) [4].

According to CIGRE report, the contribution of DGs in Denmark and the Netherlands has reached 37% and 40%, respectively, as a result of liberalization of power market in Europe [5].

In general because of the fundamental importance of these sources (renewable energy) the international demand for energy has been growing progressively. This demand, which is expected to increase by about 30% for 2040 as compared to 2010, has been driven by the demographic and economic growth, mainly related to emerging economies, especially in Asia [6].

1.2 Problem Statement

The power system (PS) losses in transmission lines systems vary with numerous factors depending on system configuration, such as level of losses through transmission and distribution lines, transformers, capacitors, insulators, etc. Power losses can be divided into two categories, real power loss and reactive power loss. The resistance of lines causes the real power loss, while reactive power loss is produced due to the reactive elements. Normally, the real power loss draws more attention for the utilities, as it reduces the efficiency of transmitting energy to customers.

Many research has been done to reduce active power loss, however with this induction DGs in power system grid, these losses can be important to same extant, moreover increased fuel cost and the need to develop environmentally friendly technologies that can be a remedy to mitigate the emission of greenhouse gases and worldwide climate changes.

1.3 Objective of Study

The main objective of the study is to improving real power losses using DGs, the objective of this project can be broken down into:

i. To investigate the power flow and real power losses for power system.
ii. To measure Sensitivity Analysis of real power losses.

iii. To mitigate the real power losses.

1.4 Study Scope

Scope of this study can be broken down into several subtasks:

i. Developing of methods for calculating the real power losses in the power system with the objective function of loss.
ii. Developing of methods for evaluating optimal location of DGs.
iii. The main software used to measure the sensitivity and analyze the results is Matlab program.
iv. To test the developed program on (IEEE 30-Busbar).

1.5 Significance of Study

It is expected to attract to get results for reducing real power losses by using DGs units. Better understanding of the flow of electric power on transmission lines investigate the power losses along transmission lines. The help of computer software gives an insight into the major problems on electric power transmission. The minimization of losses on electric power transmission lines using an optimization technique provides a solution in a compact form, to the major problem encountered in power transmission.

1.6 Organization of Study

This Project study is organized is six chapters. Chapter 1 is an introduction to this study, which includes a statement of the problem, background study, objective of study and project scope. Chapter 2 is covers about the literature review. Chapter 3 is discussing on methods and procedures used. Chapter 4 contains the results and analysis of the obtained results summarizes. Fnally Chapter 5 contains the conclusion and future works.

CHAPTER 2

LITERATURES REVIEW

2.1 Introduction

Energy is a basic necessity for the economic development of a nation. There are different forms of energy, but the most important form is the electrical energy. A modern and civilized society is so much dependent on the use of electrical energy. Activities relating to the generation, transmission and distribution of electrical energy have to be given the highest priority in the national planning process of any nation because of the importance of electrical energy to the economic and social development of the society. In fact, the greater of per capital consumption of electrical energy in a country, the higher the standard of living of its people. Therefore, the advancement of a country is measured in terms of its per capital consumption of electrical energy. power plants' planning in a way to meet the power network load demand is one of the most important and essential issues in power systems [7].

In general, transmission lines have two primary objectives: the first is to transmit electrical energy from the generators to the load within single utility, and the second is to provide paths for electrical energy centres a to flow between utilities [8]. Therefore, computation and reduction of transmission losses in these power networks are of great concern to engineers. a lot of research works have been carried out on the above listed aspects [7].

2.2 Losses in Transmission lines

From the physical principles of electric power transmission, when a conductor is subjected to electric power, electric current flows in the medium. Resistance to the

flow produces heat (thermal energy) which is dissipated to the surroundings. This power loss is referred to as Ohmic loss [9]. Ohmic loss otherwise known as line loss on power transmission occurs as a result of resistance of conductors against current flow. The effective resistance of the transmission line is a function of the current on the line. This is because of the heat produced in the conductor resulting from current flow, and this leads to a temperature rise in the conductor's. This rise in temperature increases the resistance of the conductor and consequently the losses on the line [10]. The power losses could take off a sizeable portion of the transmitted power since transmission lines usually span a long distance, sometimes several hundred kilometres [9]

The resistance R of a line conductor having resistivity ρ (Ω/m), length l (m) and a (m^2) area of cross section is given by:

$$R = \rho l / a$$

One way to reduce use power losses to reduce the current carrying in transmission lines, but this way is limited because the high cost of HV transformers, however, there is another way by using Distributed Generation (DGs).Usually located near load centres.in this case not only transmission losses are kept low but also existing transmission capacity is not occupied [11].

2.3 Distributed Generation (DGs)

The term (DGs) otherwise known as embedded generation (EG) in some quarters, is generally defined as any source of electric energy of limited capacity that is directly connected to the existing network on the customer site of the meter. The existing network could be a distribution network or a sub-transmission network. At present, there is no consensus on what exactly the rating of DGs as well as the voltage level at the point of common coupling (PCC) to the grid should be. The definitions of these two parameters somewhat vary from country to country and from one research group to another. For example, while Portugal pegs the capacity limit of DGs to 10 MW that can be connected at any voltage level, Austria defines DGs as an electric energy source of up to 10 MW to be connected at the MV level. In France, DGs is defined in capacity as greater than 40 MW and connected at 225 kV voltage level. Spain allows the DGs capacity to go up to 50% of the feeder capacity .So far, Australia has been

able to practically install the largest size of 130 MW DGs at 132 kV on its power grid, while Denmark allows the utility to decide the voltage level of connection for DGs units ranging from less than 2 MW to greater than 50 MW. On the other hand, the working group of CIGRE (International Council on Large Electric Systems) defines DGs as a source of electric energy of maximum capacity of less than 50–100 MW . Although the capacity limit is not clearly stated for Germany, UK and The Netherlands, the voltage levels at PCC are defined as up to 132 kV for UK, up to 110 kV for Germany and up to 150 kV for the Netherlands [12] .

Based on these varying capacity limits, in [13] suggested various classifications of DGs based on their capacities as micro DGs of 1 W to less than 5 kW, small DGs of 5 kW to less than 5 MW, medium DGs of 5 MW to less than 50 MW, and large DGs of 50 MW to less than 300 MW. This classification is a welcome idea since it encompasses all various definitions given by different groups/countries. There can be various other criteria which can form the basis for defining DGs. Some of these are shown in Figure 2.1.

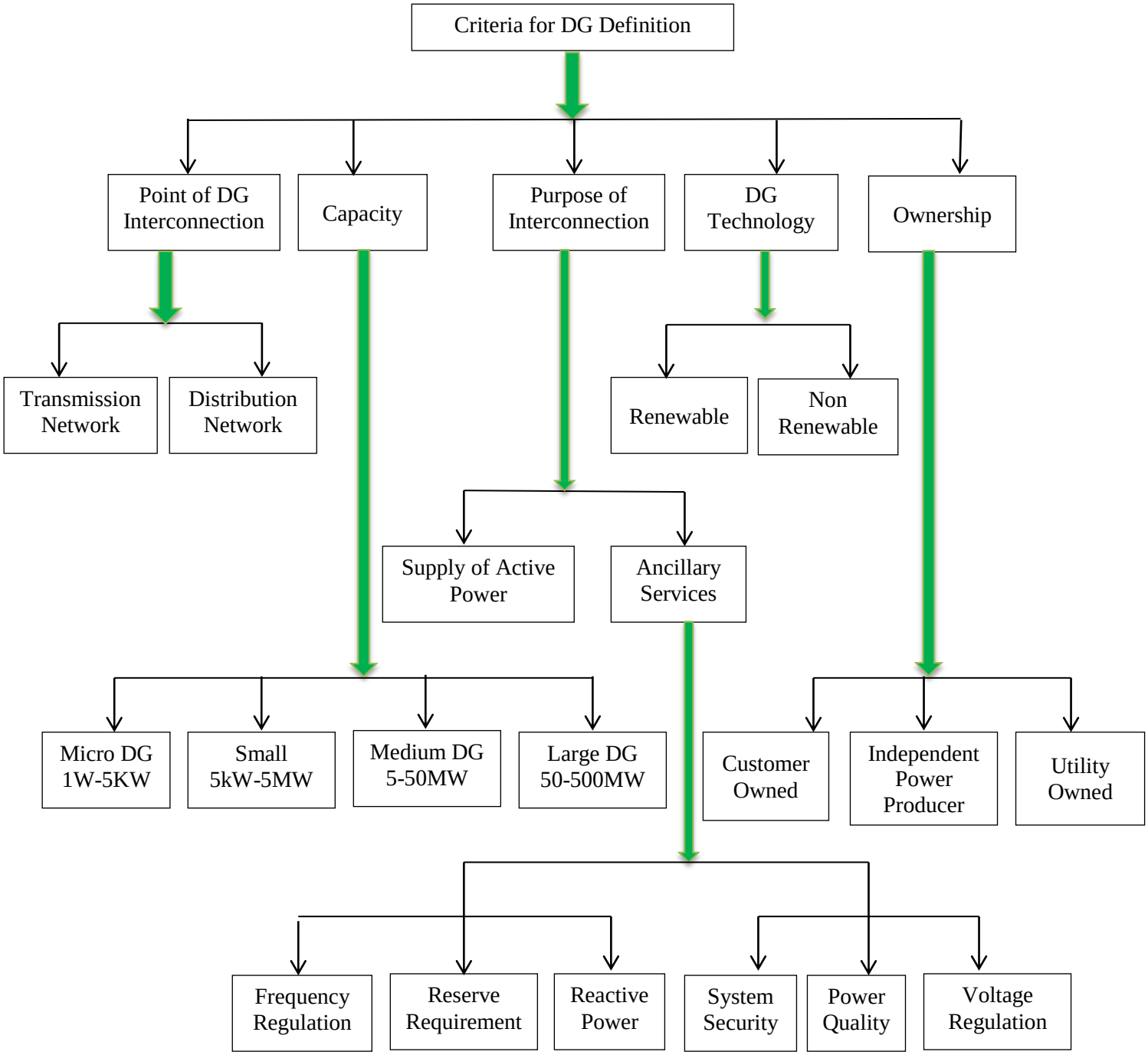

Figure 2.1 criteria for classification of DGs

2.4 Overview of Distributed Generation Technologies

Traditionally, diesel generators were considered synonymous to distributed generation due to their low cost and high reliability. However environmental issues

and high fuel cost associated with diesel generators has always been a cause of concern. Over the years there has been a significant improvement in the development of broad array of other DGs technologies.

The DGs technologies can be broadly classified as renewable energy based, non-renewable energy and energy storage. Various DGs technologies are depicted in Figure. 2.2.

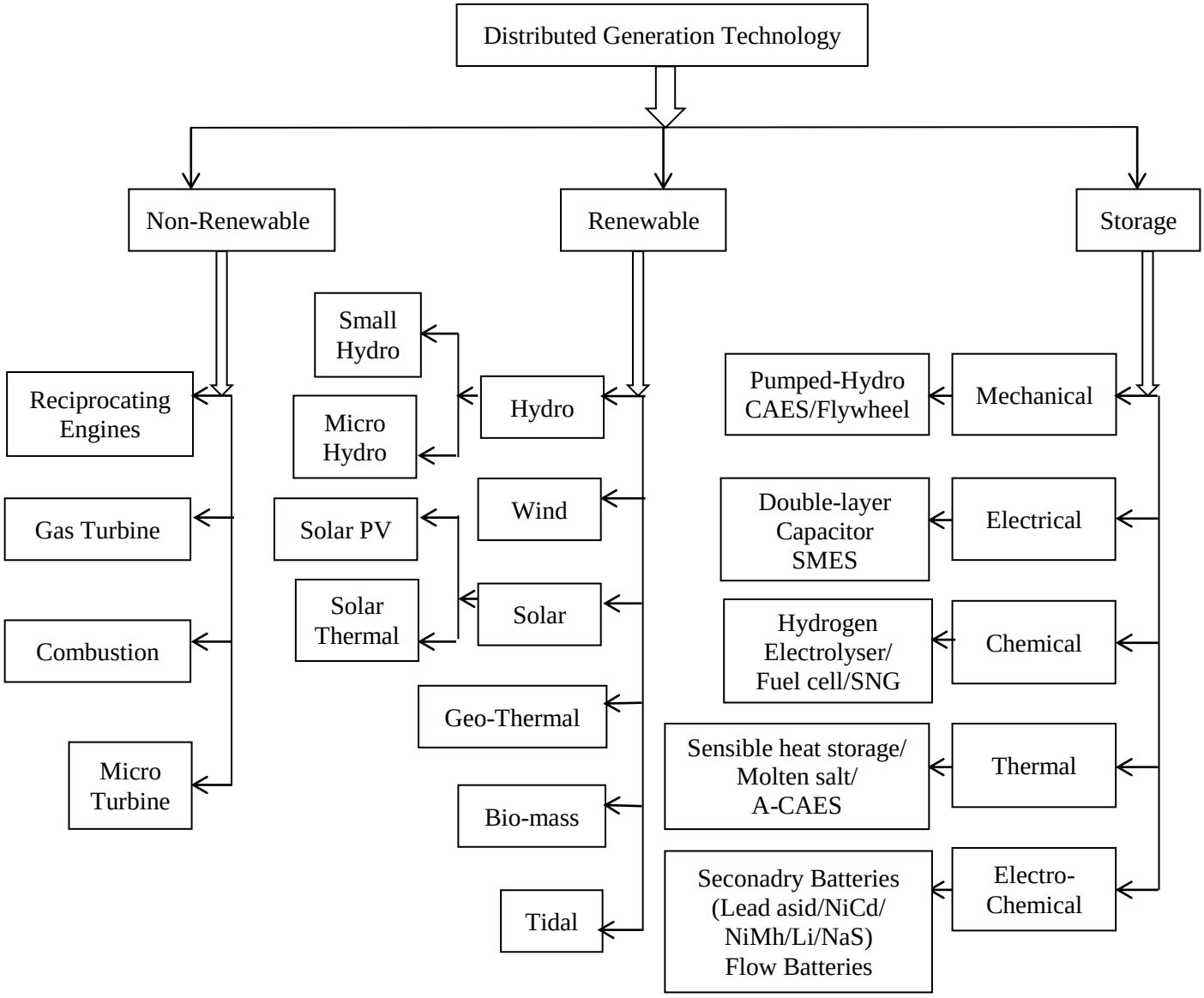

Figure 2.1: Distributed generation technologies

2.4.1 Non-renewable DGs Sources

The most popular DG_s technology based on non-renewable sources is diesel generator which belongs to the category of reciprocating engines. Diesel generators are quite suitable for autonomous application. They can be started and shut down almost spontaneously owing to low inertia thus making them a viable choice for back up applications. Technological developments over the last decade have given way to two new fossil fuel based technologies viz. micro turbines and fuel cell. Micro turbines are mechanically simple, single shaft, high speed devices. Natural gas is the primary fuel used in micro turbines although biogas is also being pursued. It is a developing technology wherein an increase in efficiency and decline in operating cost is expected. Micro turbines are not very environment friendly owing to harmful emissions. Nevertheless, the emissions from natural gas are relatively lower in comparison with that of other fossil fuels. Fuel cells are well suited for distributed generation applications. Fuel cells are fast gaining popularity since they are efficient and environment friendly [14].

2.4.2 Renewable DGs Sources

In addition to being replenishable, the chief reason for popularity of renewable energy sources (RES) is its availability worldwide over wide geographical areas. This is quite unlike conventional resources (oil, natural gas) which are concentrated in specific countries. The RES comprise of photovoltaic (PV), wind, hydro, geo-thermal, tidal and bio fuel. Recent years have seen a significant increase in deployment of RES based DGs to grid. This is mainly attributed to two reasons:

1-the costs associated with RES based generation and storage is now on declining trend thus giving way to their large scale deployment on the grid.

2- the traditional architecture of grid being based entirely on central generation is weakening, giving way to a modular architecture comprising of interconnected microgrids with distributed generation.

2.4.2 Energy Storage Technologies

The power from RES such as PV and wind is dependent on meteorological conditions prevailing at that moment. Electrical energy storage can bridge the gap between power from these sources and load by supplying power during the periods of unavailability as well as storing the excess power during high periods of wind and sun. A wide range of storage technologies based on mechanical, chemical and physical principle are available.

2.5 Previous works

Researchers have developed a mathematical model to determine power losses over typical transmission lines [1], as the resultant effect of ohmic and corona power losses, the flow of current and voltage along the lines are taking into account. For minimization of power losses on transmission lines, the classical optimization techniques aided the formulation of an optimal strategy.

Particle Swarm Optimization (PSO) has used for optimal placement of Distributed Generation (DG) and it is efficiently minimizing the total real power loss with transmission line limits and constraints satisfaction [15]. The methodology used is accurate and fast in determining the sizes and locations. The methodology is tested on a 26 bus system. By installing DG at all potential locations, the total power loss of the system has been reduced drastically with system voltage profile improvement.

To enhance voltage stability and to reduce network losses simultaneously, researchers have used a Bifurcation method for finding the locating and sizing of DGs [4]. First, vulnerable buses from voltage stability point of view are determined using bifurcation analysis as the best locations to install DGs. Number of DGs is so chosen that system voltage profile is brought into the given permissible voltage security limits. Then, the global optimal size of DGs is determined employing the dynamic programming search method.

Authors in have shown that [16], although it is considered that DG reduces losses and improves system voltage profile is not always true. They have presented a GA-IPSO based approach which utilizes combined sensitivity factor analogy to optimally locate and size a multi-type DG in IEEE 57-bus test system with the purpose of reducing power losses and improving the voltage profile. The multi-type DG can

operate as; type 1 DG (DG generating real power only), type 2 DG (DG generating both real and active power) and type 3 DG (DGs generating real power and absorbing reactive power). It further shown that though the system losses reduced and the voltage profile improved with the location of the first DG, as the number of DGs increases this is not the case. It reached a point where any further increase in number of DGs in the network results to an increased in power losses and a distortion in voltage profile.

In [17], researchers have investigated the problem of multiple DGs placement to attain a high loss drop in large-scale primary distribution systems. An Improved Analytical (IA) method is proposed. This method is based on IA expressions to calculate the optimal size of four different DG types and a methodology to identify the best location for DG allocation. A technique to get the optimal power factor is presented for DG capable of delivering real and reactive power. Moreover, Loss Sensitivity Factor (LSF) and Exhaustive Load Flow (ELF) methods are also introduced. Results show that IA method is effective as compared with LSF and ELF solutions.

New hybrid of OPF and JFPSO technique has used [18]. These methods only need a predefined number of DGs to connect and it offers the optimal location and size of DGs simultaneously. This method, hybrid of optimal power flow (OPF) and JFPSO technique, finds the best combination of sites within a distribution networks. Among a large number of combinations for a given network, it agrees searching the best locations to connect a number of DG units. The simulation results have shown that this method allows reduced losses and costs.

A local loss reduction method based on injected power sensitivity has been proposed in [19]. In order to meet the requirements of safety and economic, this method can reduced the loss in local lines quickly and effectively by adjusting the injected active power of generator nodes and the injected reactive power of reactive power compensation nodes. First, this method recognized the loss reduction rate model which can transform the line loss rate reducing problem into the problem of adjusting the power injection. Then, it determined the generator nodes and the reactive power compensation nodes which need to adjust during the process of the loss reduction by sensitivity calculation. Lastly, it calculated the tuning of injected power based on the principle of equal and opposite tuning in pairs.

Optimal Proposed Approach (OPA) using genetic algorithm (GA) has been presented to determine the optimal sitting and sizing of DG with multi-system constraints to achieve a single or multi-objectives [20]. The Linear Programming (LP) is used not only to confirm the optimization results attained by GA but also to explore the influences of varying ratings and locations of DG on the objective functions. To test the ability of the OPA, a real section of the West Delta sub-transmission network is used. The results reveal that the proper sitting and sizing of DG are important to improve the voltage profile, increase the spinning reserve, reduce the power flows in critical lines and reduce the system power losses.

By using a sensitivity-based method, the researchers in [21] assesses the influence of DGs on the active and reactive power losses of the system. From one base case power flow solution, it is possible to approximate the active and reactive power losses for a new generator connected at any bus for any combination of active power injection, and also for any operating power factor. The analytical method can be easily to judge the effects of varying the location, generation level and operating mode of the generators. Moreover, a numerical index is also suggested to quantify the influence of multi-distributed generators on power losses. The method is tested on a 70-bus distribution network. The simulations results are compared with those gained by the repetitive power flow solutions in order to validate the results found by the sensitivity-based method. Before it is connected to a power grid and to maintain the stability and reliability of existing system effectively, optimal location and size of the DG selection is an essential procedure. However, the systematic and key rule for this issue is still a vulnerable question; a method to regulate the optimal locations of multiple DGs is suggested by considering power loss [22]. Also, their optimal sizes are determined by using the Kalman Filter (KF) algorithm.

To deal with this optimization problem, the researchers used KF algorithm was applied when the optimal sizes of multiple DGs are selected, the computation efforts might be significantly increased with many data samples from a large-scale power system because the entire system must be analyzed for each data sample. The suggested process based on the KF algorithm seized the only few samples. Therefore, dramatically, it reduced the computational requirement during the optimization procedure [22].

Table 2.1 Previous Studies

No. `	year	Author	Title	Publication				Outcome	Tools		Remarks
				journal	Vol.	No.	PP		Tools	Technique	
1	2014	Bamigbola	Mathematical modeling of electric power flow and the minimization of power losses on transmission lines	Applied Mathematics and Computation	24	01	214 - 221	Minimize real power losses	Matlab	mathematical model for determining power losses	The traditional optimization method is employed for the minimization of power losses on transmission lines, thus giving a solution which on implementation is sure to yield the optimal operating strategy.
2	2013	Bhumkittip,et al	Optimal Placement and Sizing of Distributed Generation for Power Loss Reduction using Particle Swarm Optimization	Energy Procedia	43	01	307 - 317	power Loss Reduction	Matlab /Simulink	Particle Swarm Optimization	Single DG placement is used to find the optimal DG location and its size which corresponding to the maximum loss reduction.
3	2013	Esmaili,et al	Optimal placement of distributed generations considering voltage stability and power losses with observing	Applied Energy	113	01	1252-1260	Reduces power losses	Matlab	Separately optimized method	Installing more DGs does not always help decrease power losses. Consequently, grid losses should be observed in the placement of DG units.

			voltage-related constraints								

No.`	year	Author	Title	Publication				Outcome	Tools		Remarks
				journal	VOL	No	PP		Tools	Technique	
4	2013	Julius ,et al	Effects of Distributed Generation penetration on system power losses and voltage profiles	International Journal of Scientific and Research Publications	03	12	1-8	System loss reduction	Matlab /Simulink	Genetic Algorithm	The system power losses reduced with the introduction on DGs into the network up to an optimal number where any further DG inclusion resulted to an increase in system power losses. .
5	2013	Hung, Duong ,et al	Multiple distributed generator placement in primary distribution networks for loss reduction	Transactions on industrial Electronics, IEEE	60	04	1700 - 1708	Power Loss Reduction	An improved analytical	An improved analytical (IA) method	The operating power factor of DG units for minimizing losses has been found to be closer to the power factor of combined load of the respective system. This could be a good guidance for operating DG units that have the capability to deliver both real and reactive power for minimizing losses
6	2012	GomezGo, et al	Optimization of distributed generation systems using a new discrete PSO and OPF	Electric Power Systems Research	84	1	174 - 180	Optimal site and size of distributed generation	Matlab /Simulink	hybrid method	This paper introduces a new hybrid method, which employs discrete particle swarm optimization (PSO) and optimal power flow (OPF) to overcome this shortcoming.

No.`	year	Author	Title	Publication				Outcome	Tools		Remarks
				Journal	VOL	No	PP		Tools	Technique	
7	2012	Jing Liu, et al	A Local Loss Reduction Method Based on Injected Power Sensitivity	Power and Energy Engineering Conference (APPEEC)			1-4	R educe the loss	Matlab	Injected Power Sensitivity	This paper shows the advance of this method, such as small adjustment range, fast calculation speed, obvious effect of local loss reduction.
8	2010	Abou El-Ela, et al	Maximal optimal benefits of distributed generation using genetic algorithms	Electric Power Systems Research	80	07	869 - 877	reduce the system power losses	Matlab /Simulink	Genetic Algorithm (GA).	The proposed approach has been applied efficiency to subsets of DG benefits, which Are Voltage Profile Improvement (VPI), spinning reserve increasing (SRI), Power flow Reduction (PFR) And Line-Loss Reduction (LLR).
9	2009	Ayres, et al	Evaluation of the impact of distributed generation on power loses by using a sensitivity-based method	Power & Energy Society General Meeting			1-6	mpact of DGs on power losses	Matlab	Sensitivity-Based method	The effects of varying the location, generation level and operating mode of the generators can be easily assessed by using the analytical method. Moreover, a numerical index to quantify the impact of multi-distributed generators on power losses is also proposed
10	2009	Lee, Soo-Hyoung, et al	Selection of optimal location and size of multiple distributed generations by using Kalman filter algorithm	Power Systems, IEEE Transactions on	24	3	1393-1400	Power loss minimization	Matlab /Simulink	Kalman filter algorithm	The proposed procedure based on the Kalman filter algorithm took the only few samples, and therefore reduced the computational requirement dramatically during the optimization process.

CHAPTER 3

METHODOLOGY

3.1 Introduction

The world is witnessing a transition from its present centralized generation paradigm to a future increased share of DGs. Integration of RES based distributed generators is seen as a solution to decrease reliance on depleting fossil fuel reserves, increase energy security and provide an environment friendly solution to growing power demand. The planning of PS incorporating DGs has to take into account various factors such as nature of DGs technology, impact of DGs on operating characteristics of PS and economic considerations [14].

In this chapter we will determine the optimum locations for installing DGs units depending on an algorithm to calculate the optimal locations. In addition, the percent reduction in power loss will be calculated.

This study is for test case (IEEE-30 Bus) for both maximum and minimum loads and for several selected locations of the network is used.

3.2 Calculating the Losses of Real Power

Power systems designed with several generators interconnected with one another by long transmission lines are suffer from high losses. These losses depend on the current and resistances in transmission lines. The losses usually referred as thermal losses. While the resistance is usually a fixed value, the current is a variable which is a compound function of the system (grid) arrangement, generator locations and loads.

This work is concerned with the real power as it is directly related to transmission losses. The system power losses (P_{Loss}) can be expressed as follows:

$$P_{Loss} = \sum_{i=1}^{N} P_{Gi} - \sum_{i=1}^{N} P_{Li} \tag{3.1}$$

Where

P_{Gi} : real power generated at bus (i).
P_{Li} : real power load at bus (i).

The losses in equation (3.1) may be difficult to solve analytically. Alternatively, many methods were introduced to calculate the real losses, one of which is discussed below:

$$P_{Loss} = \sum_{i=1}^{N} \sum_{\substack{j=1 \\ j \neq i}}^{N} G_{ij} [|V_i|^2 + |V_j|^2 - 2|V_i||V_j| Cos(\delta_i - \delta_j)] \tag{3.2}$$

Where

G_{ij} are the conductance of the line

V_i and V_j are the voltages at bus i and j;

δ_i & δ_j are the phase angle of voltage at the ith and the jth bus, respectively

N Total number of buses

3.3 Mathematical Analysis of the Problem

The proposed formula aims at finding the derivatives of the real loss relative to the real injected power at the load buses represented by the small size generator units. These derivatives will be considered as indices for the locations that would have the most and the least effect on the efficiency of reducing power losses in the grid (system).

Buses of the grid were numbered in a way that suits the proposed formula. i.e. bus number (1) was considered as a slack (N_S) bus and was followed by (N_L) total number of bus loads and (N_G)) total number of bus generator bus, where (N) represents the total number of buses. Therefore

$N = N_S + N_L + N_G$

The solution using this method requires constructing a vector $[D]$ representing the partial derivatives of the real loss relative to the voltage angles $\frac{\partial P_{Loss}}{\partial \delta_{N \neq 1}}$ and the

voltages of bus loads $\frac{\partial P_{Loss}}{\partial |V_N|_{N\neq 1}}$ and for all buses except the slack bus because it is assumed constant. The equation for vector $[D]$ can be written as follows:

$$[D]=\begin{bmatrix} \frac{\partial P_{Loss}}{\partial \delta_2} \\ \frac{\partial P_{Loss}}{\partial \delta_3} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial \delta_N} \\ \frac{\partial P_{Loss}}{\partial |V_2|} \\ \frac{\partial P_{Loss}}{\partial |V_3|} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial |V_{N_L+1}|} \end{bmatrix} \tag{3.3}$$

Since equation (3.3) depends on the values and the angles of the system voltages, hence these values can be derived to find the elements of the vector [D]. Therefore:

$$\frac{\partial P_{Loss}}{\partial \delta_i} = 2\sum_{\substack{j=1 \\ j\neq i}}^{N} G_{ij}[|V_i||V_j|\mathrm{Sin}(\delta_i-\delta_j)] \tag{3.4}$$

$$\frac{\partial P_{Loss}}{\partial V_i} = 2\sum_{\substack{j=1 \\ j\neq i}}^{N} G_{ij}[|V_i|-|V_j|\mathrm{Cos}(\delta_i-\delta_j)] \tag{3.5}$$

While [SEN] represents the sensitivity vector which gives the variation in the real loss $\frac{\partial P_{Loss}}{\partial P_N}$ relative to the real power injected at all buses except for the slack bus also gives the variation in the real loss relative to the re-active power injected at all buses $\frac{\partial P_{Loss}}{\partial Q_{N_L+1}}$ except for the slack bus

$$[SEN]=\begin{bmatrix} \frac{\partial P_{Loss}}{\partial P_2} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial P_N} \\ \frac{\partial P_{Loss}}{\partial Q_2} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial Q_{N_L+1}} \end{bmatrix} \tag{3.6}$$

We also need to construct a Jacobean matrix $[Jac]$ which results from the last iteration of the load formula, which can be written as follows:

$$[Jac]=\begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \cdots & \frac{\partial P_2}{\partial \delta_N} & \frac{\partial P_2}{\partial V_2} & \cdots & \frac{\partial P_2}{\partial V_{N_L+1}} \\ \vdots & & \vdots & \vdots & & \vdots \\ \frac{\partial P_N}{\partial \delta_2} & \cdots & \frac{\partial P_N}{\partial \delta_N} & \frac{\partial P_N}{\partial V_2} & \cdots & \frac{\partial P_N}{\partial V_{N_L+1}} \\ \frac{\partial Q_2}{\partial \delta_2} & \cdots & \frac{\partial Q_2}{\partial \delta_N} & \frac{\partial Q_2}{\partial V_2} & \cdots & \frac{\partial Q_2}{\partial V_{N_L+1}} \\ \vdots & & \vdots & \vdots & & \vdots \\ \frac{\partial Q_{N_L+1}}{\partial \delta_2} & \cdots & \frac{\partial Q_{N_L+1}}{\partial \delta_N} & \frac{\partial Q_{N_L+1}}{\partial V_2} & \cdots & \frac{\partial Q_{N_L+1}}{\partial V_{N_L+1}} \end{bmatrix} \tag{3.7}$$

The elements of this matrix can be found using equations (3.8) and (3.9) below:

$$\frac{\partial \mathrm{P_i}}{\partial \delta_\mathrm{j}} = -\left|\mathrm{V_i V_j Y_{ij}}\right| \mathrm{Sin}\,(\theta_{\mathrm{ij}} + \delta_\mathrm{j} - \delta_\mathrm{i}) \tag{3.8}$$

where

Y_{ij} Bus admittance matrix

θ_{ij} admittance angle

$$\frac{\partial \mathrm{Q_i}}{\partial \left|\mathrm{V_i}\right|} = -2\left|\mathrm{V_i}\right|\mathrm{B_{ii}} - \sum_{\substack{\mathrm{j=1} \\ \mathrm{j \neq i}}}^{\mathrm{N}} \left|\mathrm{V_j Y_{ij}}\right| \mathrm{Sin}\,(\theta_{\mathrm{ij}} + \delta_\mathrm{j} - \delta_\mathrm{i}) \tag{3.9}$$

where

B_{ii} Imaginary part of complex admittance diameter

Then

$$[\text{Jac}]^{T}\,[\text{SEN}] = [\text{D}] \tag{3.10}$$

Where $[\text{Jac}]^{T}$ transpose matrix for Jacobean matrix

$$\therefore\ [\text{SEN}] = [\text{Jac}]^{T^{-1}}\,[\text{D}] \tag{3.11}$$

Where $[\text{Jac}]^{T^{-1}}$ inverse matrix for Jacobean matrix

$$\therefore \begin{bmatrix} \frac{\partial P_{Loss}}{\partial P_2} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial P_{N_{L+1}}} \\ \frac{\partial P_{Loss}}{\partial Q_2} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial Q_{N_L+1}} \end{bmatrix} = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} \cdots\cdots \frac{\partial P_N}{\partial \delta_2} & \frac{\partial Q_2}{\partial \delta_2} \cdots\cdots \frac{\partial Q_{N_L+1}}{\partial \delta_2} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ \frac{\partial P_2}{\partial \delta_N} \cdots\cdots \frac{\partial P_N}{\partial \delta_N} & \frac{\partial Q_2}{\partial \delta_N} \cdots\cdots \frac{\partial Q_{N_L+1}}{\partial \delta_N} \\ \frac{\partial P_2}{\partial V_2} \cdots\cdots \frac{\partial P_N}{\partial V_2} & \frac{\partial Q_2}{\partial V_2} \cdots\cdots \frac{\partial Q_{N_L+1}}{\partial V_2} \\ \vdots \quad\quad \vdots & \vdots \quad\quad \vdots \\ \frac{\partial P_2}{\partial V_{N_L+1}} \cdots\cdots \frac{\partial P_N}{\partial V_{N_L+1}} & \frac{\partial Q_2}{\partial V_{N_L+1}} \cdots\cdots \frac{\partial Q_{N_L+1}}{\partial V_{N_L+1}} \end{bmatrix}^{-1} \begin{bmatrix} \frac{\partial P_{Loss}}{\partial \delta_2} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial \delta_2} \\ \frac{\partial P_{Loss}}{\partial V_2} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial V_{N_L+1}} \end{bmatrix} \tag{3.12}$$

The first elements $[PSEN]$ from $(\frac{\partial P_{Loss}}{\partial P_2} - \frac{\partial P_{Loss}}{\partial P_{N_{L+1}}})$ of the sensitivity vector [SEN] matrix represent the partial derivatives of the real loss function relative to the active power at all load buses can be written as below:

$$[PSEN] = \begin{bmatrix} \frac{\partial P_{Loss}}{\partial P_2} \\ \frac{\partial P_{Loss}}{\partial P_3} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial P_{N_L+1}} \end{bmatrix} \tag{3.13}$$

While The second elements $[QSEN]$ from $(\frac{\partial P_{Loss}}{\partial Q_2} - \frac{\partial P_{Loss}}{\partial Q_{N_L+1}})$ of the sensitivity vector [SEN] matrix represent the partial derivatives of the imaginer loss function relative to the reactive power at all load buses can be written as below :

$$[QSEN] = \begin{bmatrix} \frac{\partial P_{Loss}}{\partial Q_2} \\ \frac{\partial P_{Loss}}{\partial Q_3} \\ \vdots \\ \frac{\partial P_{Loss}}{\partial Q_{N_L+1}} \end{bmatrix} \tag{3.14}$$

3.4 Test Case System

The proposed approach is tested on the standard 30 bus IEEE test system, and its parameter can be seen in appendix A.

3.5 Flowchart of Design

The figure 3.1 show the steps of power flow calculation A & B while the figure 3.2 show the steps of find SEN matrix.

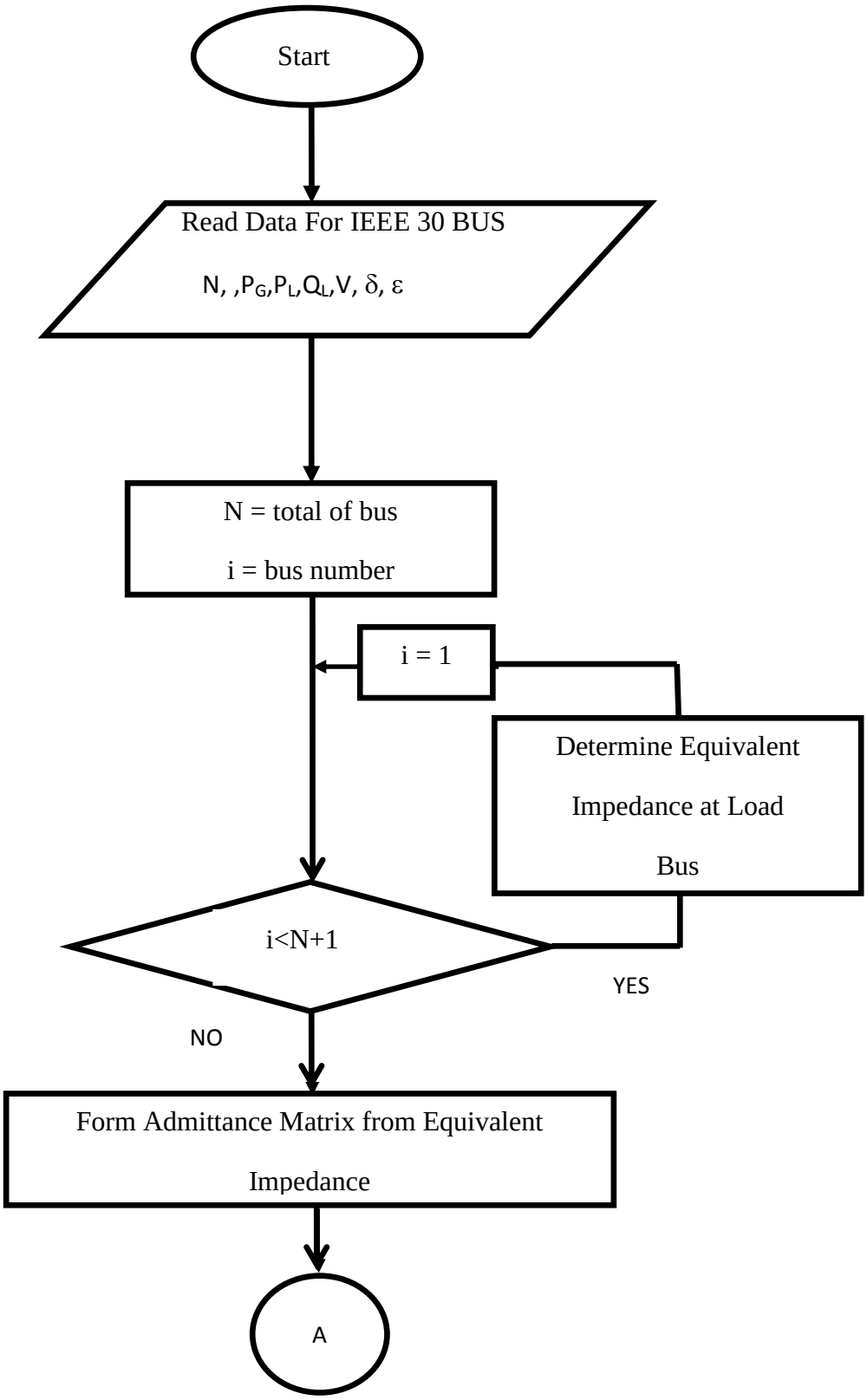

Figure 3.1 : Flow chart of power flow calculation

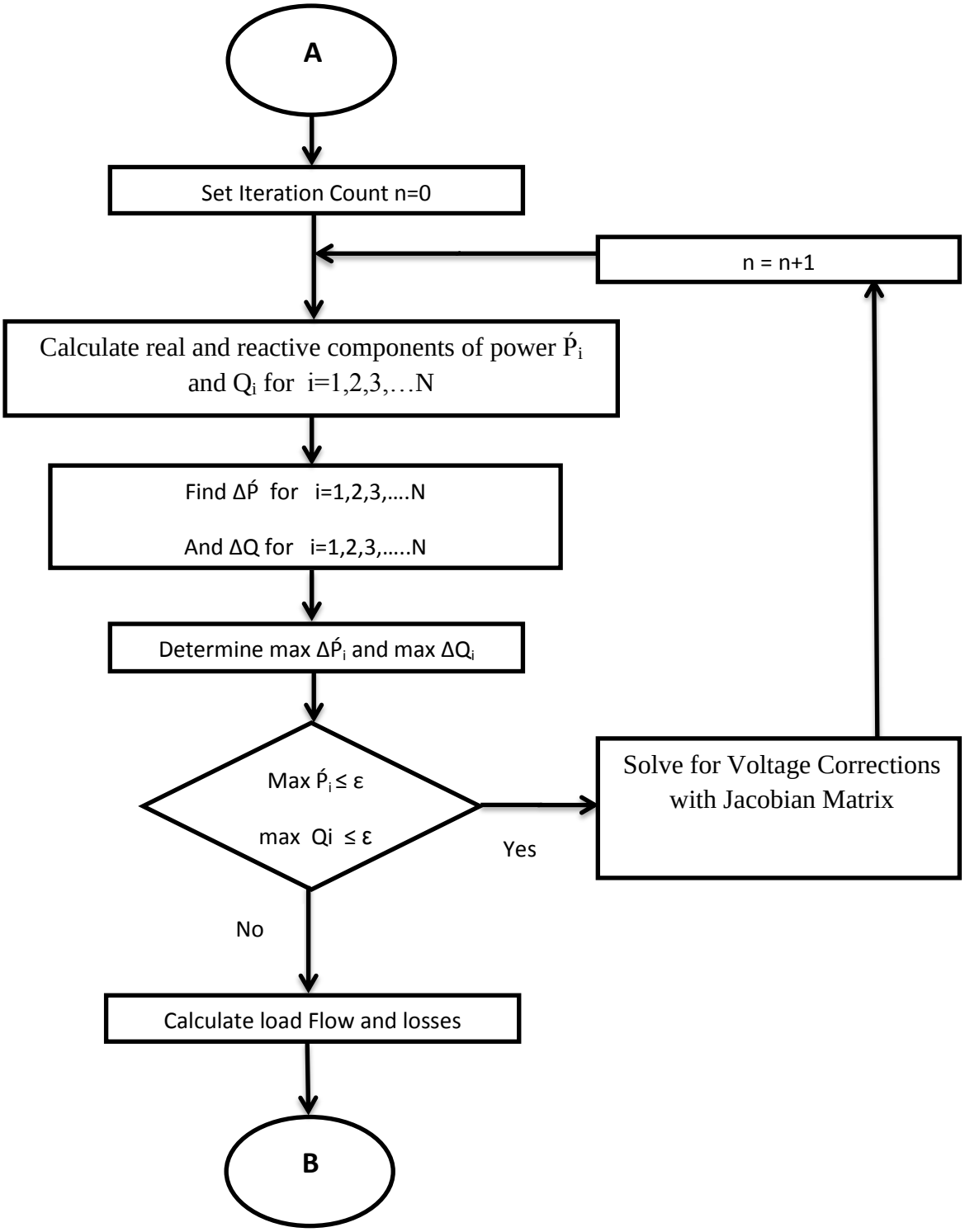

Figure 3.1: Flow chart of power flow calculation B

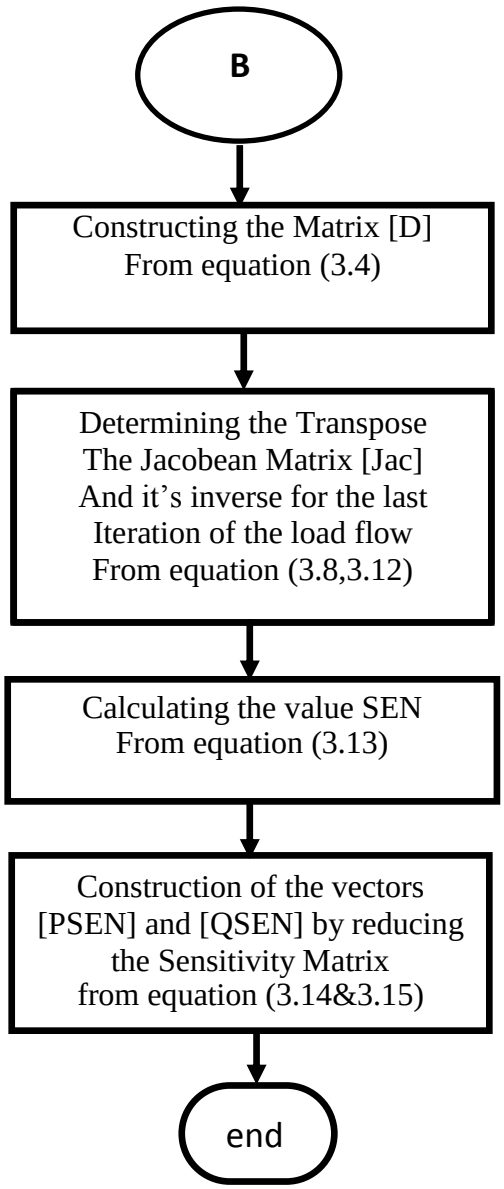

Figure 3.2: Flow Chart of Find SEN Matrix

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