UNIVERSITE KASDI MERBAH OUARGLA
Faculté des Sciences Appliquées

Département de Génie Electrique

Mémoire
MASTER ACADEMIQUE
Domaine : Sciences et technologies
Filière : Electrotechnique
Spécialité : Réseaux électriques
Présenté par :
Mihoubi Abdelali Gherbi Salim

Thème :

Optimal Allocation and sizing of Dispersed Generation for minimizing active losses using Harris Hawks Optimization

Soumis au jury composé de :

M^r Boudjella Houari	MCB	President	UKM Ouargla
M^r Larouci Benyekhlef	MCB	Examiner	UKM Ouargla
M^r Sadaoui Fares	MCA	Rapporteur	UKM Ouargla
M^r Hachemi Ahmed Tidjani	Doctornt	Co-rapporteur	UKM Ouargla

Année universitaire 2021/2022

ACKNOWLEDGEMENTS

*First, I thank« **ALLAH »** , who gave me strength, courage and patience during all these years of study, to be able to complete this humble work.*

Special thanks to my father for their support Unconditional during these long years of study.

*Our sincere thanks to our trainer **Dr. Sadaoui Fares** and **Hachemi Ahmed Tidjani** for their great availability during various bid requests and their valuable advice for the development of this project.*

*I would also like to thank all teachers and officials in the University's Kasdi Merbah and **Electrical Engineering** department and barrier for their assistance and support.*

I have a great pleasure to dedicate this modest work To my Beloved Mother , my Dear Father to my Dear sisters , brothers , uncles , aunts and cousins,To all my Friends To all my Teachers from primary school to my last year of university And to all with whom I spent wonderful moments.

Thank you to all our friends who were there in times of doubt and tension, especially ***Hachemi Ahmed Tidjani****.*

Mihoubi abdelali

I express my deep thanks to My Grandfather, My Parents, My Sisters, My Brothers,and all my family members for the motivation, inspiration and support in boosting my moralwithout which I would have been in vain.

Gherbi Salim

ملخص

مع نمو شبكات التوزيع وتعقيدها دعت الحاجة الى إيجاد حلول بديلة للرفع من أداء الأنظمة الكهربائية .وأحد هذه الحلول هو دمج المولدات المتناثرة في شبكات التوزيع الكهربائي .ويعرض هذا العمل الاستخدام الأمثل لتشغيل شبكات التوزيع في وجود مصادر الطاقة المتجددة (النوع الكهروضوئي)، كان علينا حل مشكلة تتمثل في تحديد موقع المصادر اللامركزية في الشبكة وحجمها الأمثل لغرض تقليل الخسائر النشطة باستخدام باستخدام تقنية تحسين صقور هاريس (HHO) ذات الهدف الواحد. من أجل اختبار البرامج المطورة وتم تنفيذ التطبيقات على الشبكات IEEE 33 و 85 عقدة.

كلمات مفتاحية : التوليد المشتت ، التحسين الأحادي الهدف ، خسائر الطاقة النشطة ، شبكة التوزيع الكهربائية، تحسين صقور هاريس

Résumé

Avec la croissance des réseaux de distribution et leur complexité progressive, il est nécessaire de trouver des solutions alternatives pour augmenter la performance des systèmes électriques.Une des solutions est l’intégration des générateurs dispersés dans les réseaux de distribution électriques. Ce travail présente l’optimisation du fonctionnement des réseaux de distribution en présence de sources d’énergie renouvelable de type photovoltaïque. En effet, nous avons résolu un problème d’optimisation qui consiste à déterminer l’emplacement et le dimensionnement optimal d’une source décentralisée dans le réseau pour objectif de minimiser les pertes actives en utilisant l’algorithme de buse de Harris. Afin de tester les programmes développés, des applications ont été effectuées sur les réseau IEEE 33 et 85 noeuds.

Mots-clés: Génération Dispersée, Optimisation Mono-Objectif, pertes de puissance actives, Réseau électrique de distribution, Optimisation de Harris Hawks.

Abstract

With the growth of distribution networks and their progressive complexity, it is necessary to find alternative solutions to increase the performance of electrical systems. One of these solutions is the integration of dispersed generators in the electrical distribution networks. This work presents the optimization of the distribution networks wich the presence of renewable energy sources (solar power plant). Indeed , we solved a optimization problem which consist in determining the optimal location and sizing of distributed generation in the network using the Harris Hawks method. The objective function considered is the minimization of active power losses. In order to test the developed programs, applications were performed on IEEE 33 and 85 bus systems.

Keywords: Dispersed Generation, Single-Objective Optimization, active power losses, Distribution electrical grid, Harris Hawks Optimization.

LIST OF SYMOLS

T&D	:	transmission and distribution systems
RDN	:	Radial distribution network
P	:	Active power
P_0	:	Active power at the nominal voltage
CHP	:	Combined heat and power
Q	:	Reactive power
Q_0	:	Reactive power at the nominal voltage
V	:	Load bus voltage
V_0	:	Load nominal voltage
n_p	:	Load exponents for active power
n_q	:	Load exponents for reactive power
BFS	:	Backward/Forward Sweep
I	:	Electrical Current at each node (A)
S	:	Superficial power
Z	:	Line impedance
R	:	Resistive component of line impedance
x	:	Reactive component of line impedance
BIBC	:	Bus-Injection to Branch Current
B	:	line resistive
Vr	:	line reactive
Vs	:	sending node voltage
DG	:	Dispersed Generation

SI	:	Stability Index
N_{line}	:	Total number of line sections
V_i	:	Complex voltage at the i^{th} bus
VSI_i	:	Voltage Stability Index for bus i^{th}
VSI_{min}	:	Minimum VSI value of all the buses
$S_L\,(i)$	:	Line loading of branch i^{th}
$S_L^{max}\,(i)$	:	Maximum permissible loading limit of branch i^{th}
P_{Source}	:	Total active power supplied by main source
P_{DG}	:	Total active power supplied by DG
P_{Load}	:	Total active system load demand
P_{Loss}	:	Total active system losses
Q_{Source}	:	Total reactive power supplied by main source
Q_{DG}	:	Total reactive power supplied by DG
Q_{Load}	:	Total reactive system load demand
Q_{Loss}	:	Total reactive system losses

TABLE OF CONTENTS

Chapter I: Distribution System: Modeling and Analysis

Chapter II: Problem Formulation & Optimization

Chapter III: Simulation Results and Discussions

List of Figures

List of Tables

General Introduction

INTRODUCTION

Electrical energy is essential for the existence of the civilized world today. The Present power system results from a long-term development that has started 125 years ago and is still going on [1].

Electrical power systems all over the world experience substantial changes in the principles and philosophy of operation. Some of these changes are related with advances in technology, for instance.

Reakthroughs in communication, development of power electronics, digital processors and protection devices. Other changes are linked to liberalization of electricity markets. The aim is to create a competitive market with a large number of independent participants instead of one monopoly, which fully controls generation, transmission and distribution of electrical energy.

The necessity for reduction of CO_2 emissions in the atmosphere, current primary energy shortage, acceptance problems with nuclear power after the nuclear accident in Chernobyl and the new deregulated market trigger more attention to be paid to renewable energy sources and dispersed energy generation. But the most drastic change is initiated by the Kyoto Protocol. The objective of this international political agreement is the “stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system .

The share of dispersed generation technology in overall power generation has been increased substantially compared with the share before some years ago. Having dispersed generation close to the loads can reduce transmission and distribution costs, including delayed equipment upgrades and loss reduction and reduced voltage sags.
One of the major impacts is the change of the distribution network nature from passive (containing only loads) to active (containing a mixture of loads and small to medium-scale generators).

The objective of this memory is to propose evolutionary techniques to solve the optimal sizing and location of DG, considering minimization of active power losses on the distribution power system; The memory is organized in the following format:

Chapter 1 explores general informations on the power system by detailing the distribution networks and its power flow methods then the dispersed generation and its applications are introduced.

In the second chapter we describe the considered optimization problem. Also, we describe Harris Hawks method applied to solve this problem.

In the last chapter, we présent the results of the Harris Hawks Optimization algorithm on distributed electrical networks to find the optimum size and location for a decentralized solar power plant type.

Chapter I

Distribution System: Modeling and Analysis

I.1 Introduction

Power flow analysis is a basic and necessary tool for any electrical system under steady state condition to determine the exact electrical performance. The load flow analysis gives us the sinusoidal steady state condition of the fully system voltages (voltage magnitudes and angles), real power and reactive power generated and line losses [2,3]. This analysis is essential for the continuous evaluation of the existing power system and effective planning of alternatives for system expansion to meet increased load demand in future. These analyses require the calculation of numerous load flows for both normal and emergency operating conditions. The load flow studies are helpful to confirm selected switchgear, transformer, and cable sizing. These studies should also be used to confirm adequate voltage profiles during different operating conditions, such as heavily loaded and lightly loaded system conditions. Load flow studies can be used to determine the optimum size and location of DG and capacitors for power factor correction. The results of load flow studies are also starting points for other system studies.

In the last few decades, a number of efficient and reliable load flow methods for transmission systems are available are as follows such as:

- ✓ Gauss-Seidel method with admittance matrix (YGS)
- ✓ Gauss-Seidel method with impedance matrix (ZGS)
- ✓ Newton-Raphson (NR) method
- ✓ Decoupled Newton-Raphson (DNR)
- ✓ Fast Decoupled Newton-Raphson (FDNR)

The analysis of distribution systems is an important area of activity as distribution systems is the final link between a bulk power system and consumers. The mentioned methods usually fail to analyze distribution networks [4], because the variables for the load flow analysis of distribution systems are different from that of transmission systems. Where the distribution network is radial in nature and have high R/X ratio, whereas the transmission system is loop in nature having high X/R ratio. For this reason the conventional method does not converge for the distribution networks [5].

But before we study the power flow in distribution network we need to know from what constitute distribution network?

I.2 Development of distribution system

The classical power system is sub-divided into three (3) major sections: generation (production), transmission and distribution system. However, the inter-relation between the transmission and distribution systems can be sub-divided into several subsections as showing in figure I.1. The distribution level of the power system feeds from the sub-transmission and features the branched loads of the system.

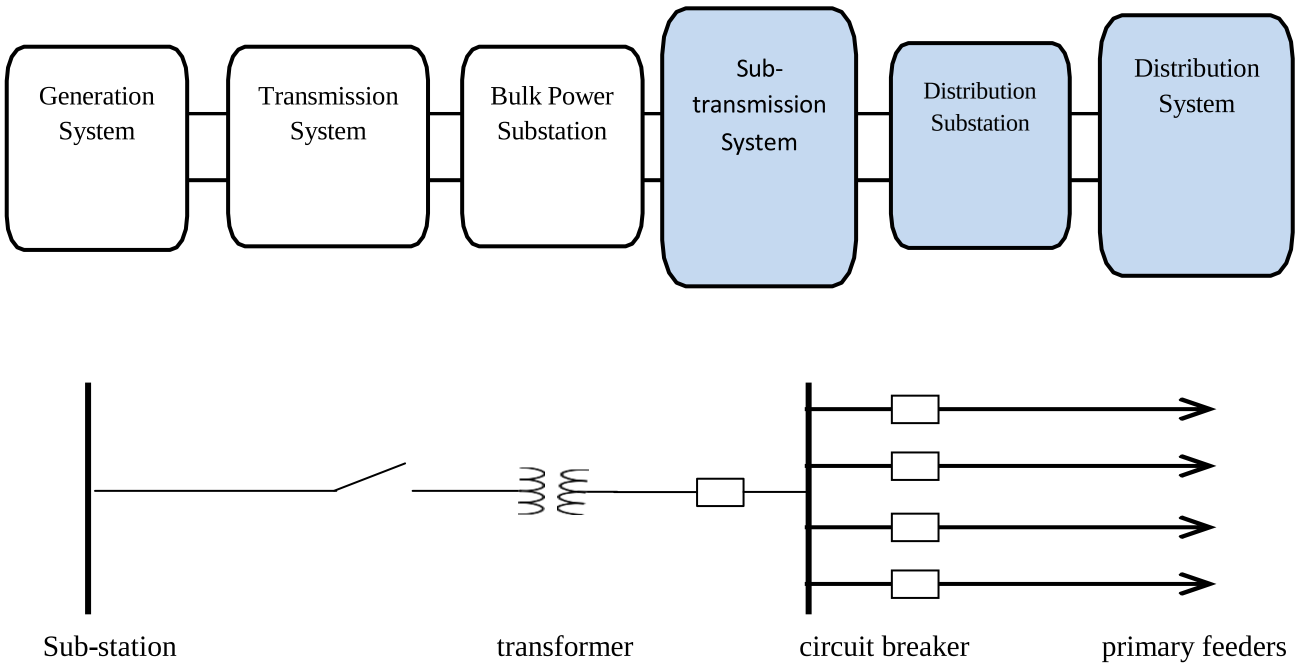

Figure I.1- Structure of the power system network

The delivery system can be defined as system binding the transmission system and the points of the consumers. In general, the distribution system is the electric system between the sub-station supplied by the transmission system and the counters of the consumers. It is generally composed of drivers of the distributers and the principal services.

I.2.1 Distribution Substations

The distribution system is fed through distribution substations. These substations have an almost infinite number of designs based on consideration such as load density, high side and low side voltage, land availability, reliability requirements, load growth, voltage drop, cost and losses, etc.

I.2.2 The Distribution System

The distribution system typically starts with the distribution substation that is fed by one or more sub- transmission lines. In some cases the distribution substation is fed directly from a high-voltage transmission line, in which case there is likely no sub transmission system. Each distribution substation will serve one or more primary feeders. With a rare exception, the feeders are radial, which means that there is only one path for power to flow from the distribution substation to the user.

I.2.3 Distribution Feeders

There are three basic types of distribution system designs: Radial, Loop, or Network. As one might expect, one can use combinations of these three systems, and this is frequently done. The Radial distribution system is the cheapest to build, and is widely used in sparsely populated areas. A radial system has only one power source for a group of customers. A power failure, short-circuit, or a downed power line would interrupt power in the entire line, which must be fixed before power can be restored.

A loop system, as the name implies loops through the service area and returns to the original point. The loop is usually tied into an alternate power source. By placing switches in strategic locations, the utility can supply power to the customer from either direction. If one source of power fails, switches are thrown (automatically or manually), and power can be fed to customers from the other source. The loop system provides better continuity of service than the radial system, with only short interruptions for switching. In the event of power failures due to faults on the line, the utility has only to find the fault and switch around it to restore service.

The fault itself can then be repaired with a minimum of customer interruptions. The loop system is more expensive than the radial because more switches and conductors are required, but the resultant improved system reliability is often worth the price.

Network systems are the most complicated and are interlocking loop systems. A given customer can be supplied from two, three, four, or more different power supplies. Obviously, the big advantage of such a system is added reliability. However, it is also the most expensive. For this reason it is usually used only in congested, high load density municipal or downtown areas [6].

I.2.4 Distribution Feeder Map

The analysis of a distribution feeder is important to an engineer in order to determine the existing operating conditions of a feeder, and to be able to play the “what if scenarios of future changes to the feeder”. Before the engineer can perform the analysis of a feeder, a detailed map of the feeder must be available. A sample of such a map is shown in figure I.2. This map contains most of the following information [7]:

1. Lines (overhead and underground)
    a. Where
    b. Distances
    c. Details
    d. Conductor sizes (not shown on this map)
    e. Phasing

2. Distribution transformers
    a. Location
    b. kVA rating
    c. Phase connection
3. In-line transformers
    a. Location
    b. kVA rating
    c. Connection
4. Shunt capacitors
    a. Location
    b. kVA rating
    c. Phase connection
5. Voltage regulators
    a. Location
    b. Phase connection
    c. Type (not shown on this map)
    d. Single-phase
    e. Three-phase

Figure I.2 123-bus test feeder

6. Switches
    a. Location
    b. Normal open/close status

I.3 Distribution system load modeling

In conventional load flow studies, it is presumed that active and reactive power demands are specified constant values, regardless of the amplitude of voltages in the same bus. In actual power systems operation, different categories and types of loads such as residential, industrial and commercial loads might be present. The nature of these types of loads is such that their Active and reactive powers are dependent on the voltage and frequency of the system. Moreover, load characteristics have significant effects on load flow solutions and convergence ability. Common static load models for active and reactive power are expressed in a polynomial or an exponential form. The characteristic of the exponential load models can be given as:

$$P = P_0\left(\frac{V}{V_0}\right)^{n_p} \tag{I.1}$$

$$Q = Q_0\left(\frac{V}{V_0}\right)^{n_q} \tag{I.2}$$

Where n_p and n_q stand for load exponents, P_0 and Q_0 stand for the values of the active and reactive powers at the nominal voltages. V and V_0 stand for load bus voltage and load nominal voltage, respectively. Special values of the load exponents can cause specific load types such as 0: constant power, 1: constant current and 2: constant impedance. Common values for the exponents of the model for different load components are given in Table I.1 from [8].

Table I.1 Common values of exponents for different static load models

Load Component	n_P	n_q
Battery Charge	2.59	4.06
Fluorescent Lamps	2.07	3.21
Constant Impedance	2	2
Air Conditioner	0.5	2.5
Fluorescent lighting	1	3
Constant Current	1	1
Resistance Space Heater	2	0
Pumps, Funs other Motors	0.08	1.6
Incandescent lamps	1.54	0
Compact fluorescent lamps	1	0.35
Small industrial motors	0.1	0.6
Large industrial motors	0.05	0.5
Constant power	0	0

I.4 Load flow methods

The most important load flow methods, which can be applied to new distribution networks, are categorized to six groups: Newton-Rephson (NR) based methods, Gauss Seidel based methods, super position based methods, compensated backward/forward sweep methods, optimization based methods and artificial intelligence based methods. figure I.3.

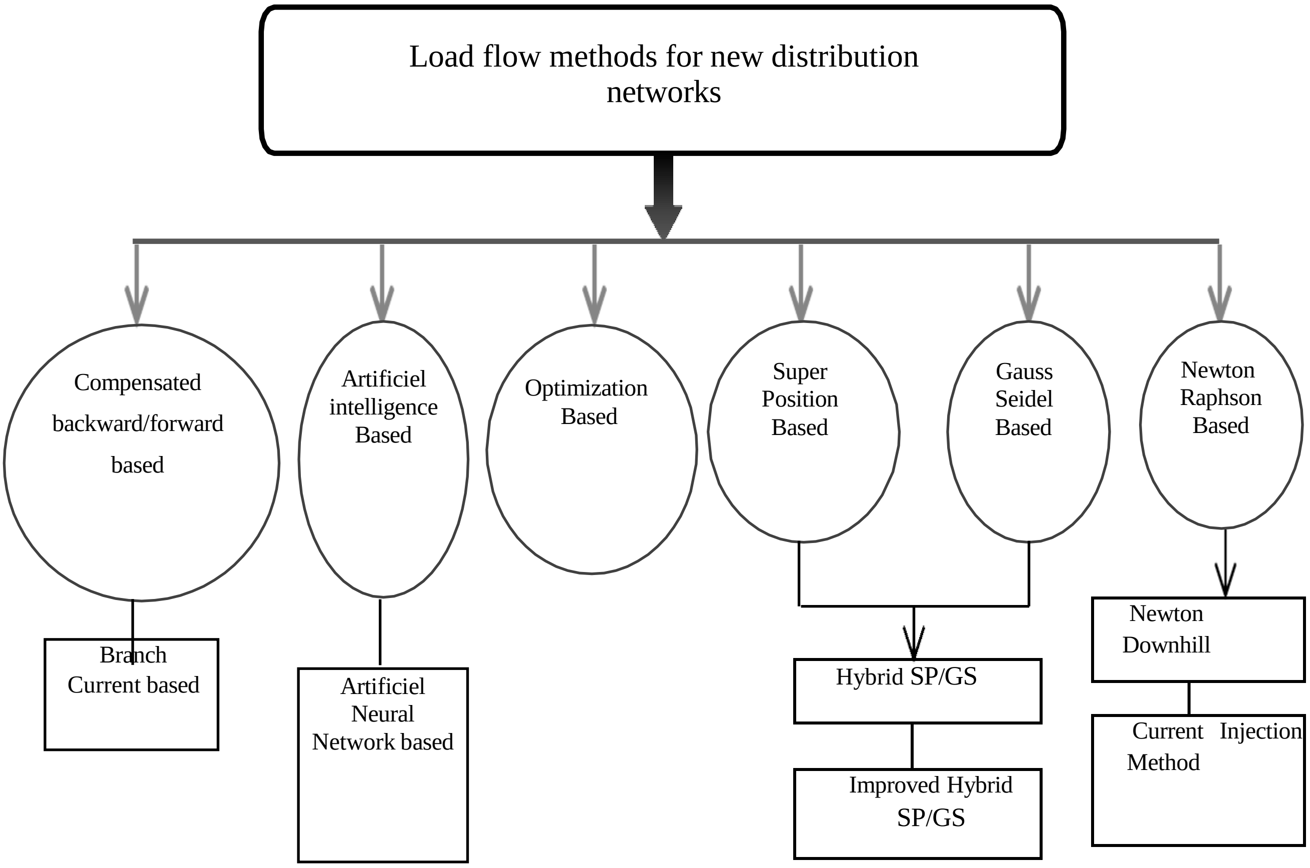

Figure I.3 Classification of load flow methods for new distribution

I.4.1 Load Flow Analysis of Radial Distribution Network:

The load flow of a single source network can be solved iteratively from two sets of recursive equations. The first set of equations for calculation of the power flow through the branches starting from the last branch and proceeding in the backward direction towards the root node. The other set of equations are for calculating the voltage magnitude and angle of each node starting from the root node and proceeding in the forward direction towards the last node.

Backward/Forward Sweep (BFS) methods are usually used in practice. BFS methods do not need Jaobian matrix unlike NR methods. Therefore BFS is considered from fastest methods to calculate power flow. The load current at each node is computed by:

$$I_n = \left(\frac{S_n}{V_n}\right)^* \qquad (\mathrm{I}.3)$$

- *Backward Propagation*

The updated effective power flows in each branch are obtained in the backward propagation computation by considering the node voltages of previous iteration. It means the voltage values obtained in the forward path are held constant during the Backward propagation and updated power flows in each branch are transmitted backward along the feeder using backward path. This indicates that the backward propagation starts at the extreme end node and proceeds towards source node.

- *Forward Propagation*

The purpose of the forward propagation is to calculate the voltages at each node starting from the feeder source node. The feeder substation voltage is set at its actual value. During the forward propagation the effective power in each branch is held constant to the value obtained in backward walk.

The forward and backward sweep process is continued until the difference between the computed and specified voltage at the source is within a given tolerance. The next example explain how it is work BFS method

Example:

A single-phase lateral is shown in figure I.4.

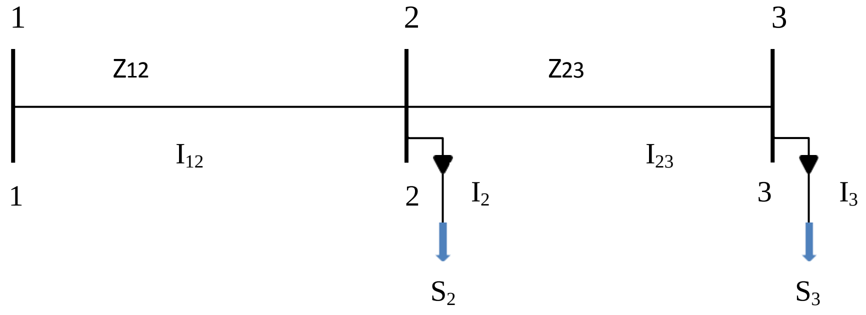

Figure I.4 Single-phase lateral**.**

The impedance of the line segment 1-2 is:

$Z_{12} = 0.1705 + j0.3409\ (\Omega)$

The impedance of the line segment 2-3 is:

$Z_{23} = 0.2273 + j0.4545\ (\Omega)$

The loads are:

S2= 1500 +j750 (kVA)

S3= 900 +j500 (kVA)

The source voltage at Node 1 is 7200 V.

- Compute the node voltages after one full iteration.

The forward sweep begins by assuming the voltage at Node 3 to be $7200\ \angle 0$ V.

The load current at Node 3 is computed to be:

$$I_3 = \left(\frac{(900 + j500) \cdot 1000}{7200\angle 0}\right)^* = 143.0\angle - 29.0\ (\mathrm{A})$$

The current flowing in the line section 2-3 is

$I_{23} = I_3 = 143.0\ \angle -29.0\ (\mathrm{A})$

The voltage at Node 2 is computed to be:

$V_2 = V_3 + Z_{23} . I_{23} = 7200\ \angle 0 + (0.2273 + j0.4545).\ 143.0\ \angle -29.0$

$= 7260.1\angle 0.32\ \mathrm{V}$

The load current at Node 2 is:

$$I_2 = \left(\frac{(1500 + j750) \cdot 1000}{72601\angle 0.32}\right)^* = 2310\angle - 26.3\ (\mathrm{A})$$

The current in line segment 1-2 is:

$I_{12} = I_{23} + I_2 = 373.9\angle -27.3\ (\mathrm{A})$

If the error is less than a specified tolerance, the solution has been achieved. If the error is greater than the tolerance, the backward sweep begins. A typical tolerance is 0.001 per unit, which on a 7200-V base is 7.2 V. Since the error in this case is greater than the tolerance, the backward sweep begins by setting the voltage at Node 1 to the specified source voltage:

$$V_1 = V_s = 7200 \angle 0 \text{ (V)}$$

Now the voltage at Node 2 is computed using this value of the Node 1 voltage and the computed line current in the forward sweep current:

$$V_2 = V_1 - Z_{12} . I_{12} = 7200 \angle 0 - (0.1705 + j0.3409).\ 373.9 \angle -27.2$$

$$= 7085.4 \angle -0.68 \text{ (V)}$$

The backward sweep continues by computing the next downstream voltage. All of the currents computed in the forward sweep are used in the backward sweep.

$$V_3 = V_2 - Z_{23} . I_{23} = 7026.0 \angle -1.02 \text{ (V)}$$

This completes the first iteration. At this point the forward sweep will be repeated, only this time starting with the new voltage at Node 3 rather than the initially assumed voltage.

However, several works was completed on the analysis of flows of load of the distribution networks, but the choice of a method of solution for a practical system is often difficult, because:

- The X/R in Radial network X>>R.

The structure of many distribution systems is like a tree with several laterals and sub-laterals. The root of the tree is the feeding node or supplying substation such as illustrate in figure I.5.

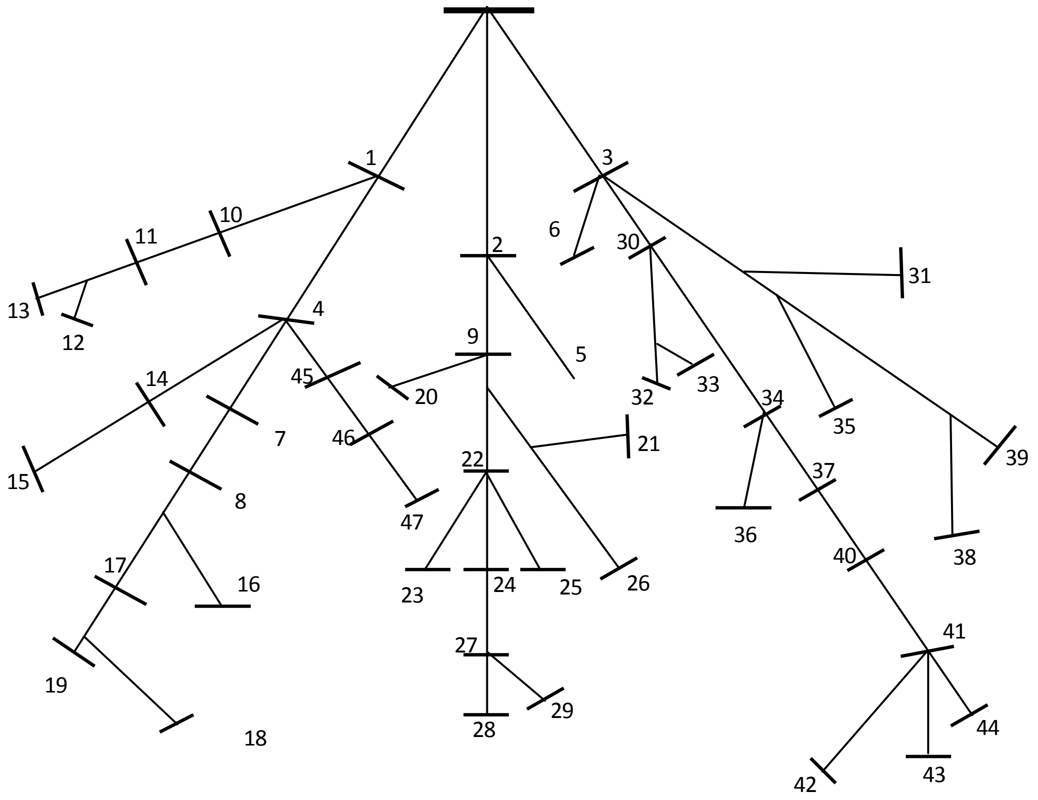

Figure I.5 Radial distribution network with branch numbering

Thus for a reliable analysis it is necessary to develop a method acceptable and be fast with the execution.

Due to this special structure of distribution systems, topographical method is used for identifying the nodes beyond all branches which helps to find the exact current flowing through all branches. From famous method to analysis load flow for this kind of structure we find the method which is based on the Bus-Injection to Branch Current (BIBC) matrix. In this method for the solution of weakly meshed networks, first break the interconnected grid at the number of breakpoints in order to convert it into one radial network. Each breakpoint will open one single loop. The radial network is solved efficiently by direct application of Kirchhoff's voltage and current law [9].

Bus-Injection to Branch Current (BIBC) Matrix

Figure I.6 depicts a simple distribution system that used as a case study for designing the relationship matrix. The power injection is converted to an equivalent current injection required for developing the relationship between bus current injection and branch current [10]

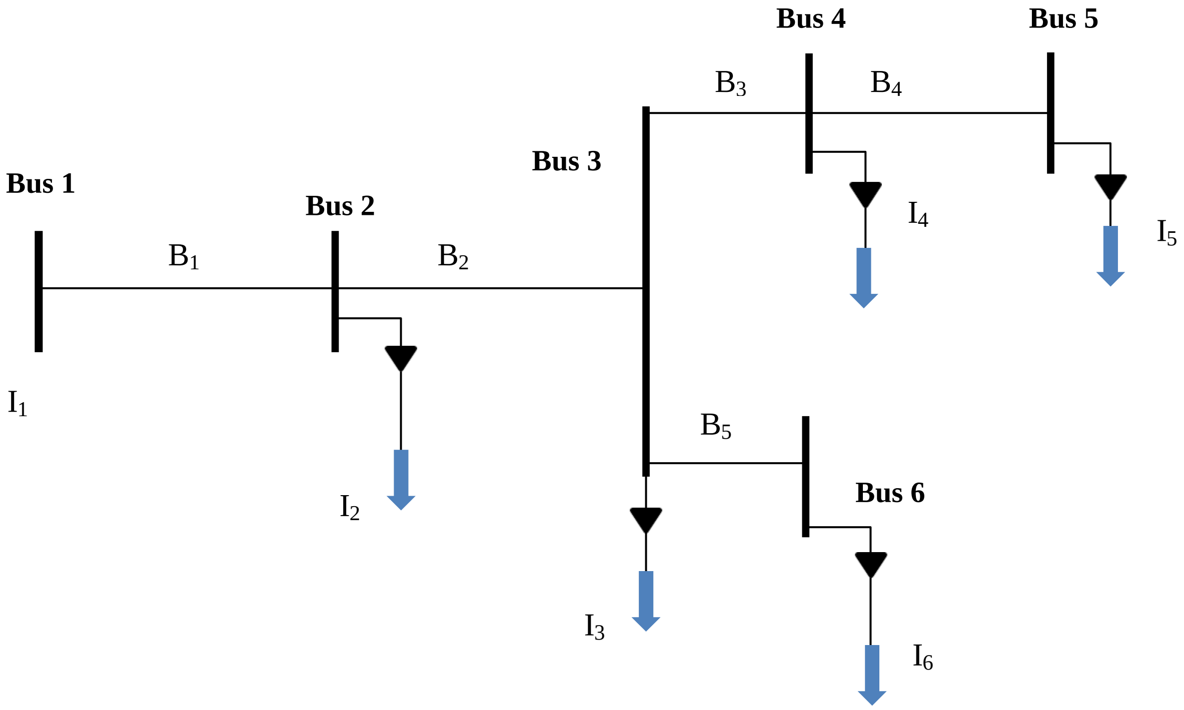

Figure I.6 6-bus distribution system

The load current can be calculated using their active and reactive powers as:

$$\mathrm{I_i} = \left(\frac{P_i + Q_i}{V_i}\right)^* \tag{I.4}$$

Where and are the real power and imaginary powers at i^{th} node, is the node voltage obtained in load flow analysis. The set of equations can be written by applying Kirchhoff's current law (KCL) to the distribution network. The branch injection branch current (BIBC) calculates by the following method.

a) The branch currents can be expressed as in equation (I.5):

$B_1 = I_2 + I_3 + I_4 + I_5 + I_6$

$B_2 = I_3 + I_4 + I_5 + I_6$

$B_3 = I_4 + I_5$

$B_4 = I_5$

$B_5 = I_6$ (I.5)

b) The relationship between BIBC can be expressed by:

$$\begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \\ B_5 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_2 \\ I_3 \\ I_4 \\ I_5 \\ I_6 \end{bmatrix} \tag{I.6}$$

c) The matrix form for equation (I.6) can be expressed as in equation (I.7)

$$[B] = [BIBC][I] \tag{I.7}$$

Where BIBC is bus i on to branch current injection matrix, the BIBC matrix is an upper triangular matrix and contains values of 0 and +1 only. The receiving end bus voltages are found by a forward sweep through the ladder network using the generalized equation (I.8).

$$Vr\,(i) = Vs\,(i) - Z\,(i).B\,(i) \qquad \text{(I.8)}$$

Where Vr and Vs are the receiving and sending node voltage respectively, Z is line impedance between node r and s and B is branch courant of line Z.

I.5 Distributed generation

I.5.1 Definition

The connection to the network of new producers has led to new concepts in EPS (Electric Power System). During the last years, terms like Decentralized Generation, Distributed Generation or Dispersed Generation have appeared in the EPS literature.

There isn't one criterion to define each term, each association, group or author have each own definition and from those definitions the research work is developed. Dispersed Generation is defined in [11] as every production, different than centralized units (smaller power), that is connected to the transmission, sub-transmission and distribution systems which is based on non-conventional energies (wind, solar…) or conventional of small power (fuel cells, storage of energy…) with a power below 200 MW.

According to Electric Power Research Institute (EPRI) defines DG as generation froma few kilowatts up to 50 MW“ [12].

In references [11-13] suggested an approach towards a general definition of Distributed generation. The general definition for distributed generation suggested here is:

- Distributed generation refers to relatively small-scale generators that produce several kilowatts (kW) to tens of megawatts (MW) of power and are generally connected to the grid at the distribution or substation levels.

The distributed generation technology is divided in two categories: renewable and nonrenewable. [14]:

I.5.2 *Renewble technologies include*

A. Solar power

This type of renewable energy comes directly from the capture of solar radiation. Specific sensors are used to absorb the energy of the sun's rays and redistribute it according to two main modes of operation:

Solar photovoltaic (photovoltaic solar panels): solar energy is captured for the production of electricity.

Solar thermal (solar water heater, heating, solar thermal panels): the heat from the sun's rays is captured and redistributed, and more rarely is used to produce electricity .

B. Solar thermal energy

Solar thermal energy comes from the heat transmitted by the sun by radiation, with the aim of heating a fluid (liquid or gas). The energy received by the fluid can then be used directly (domestic hot water, heating, etc.) or indirectly (production of water vapor to drive alternators and thus obtain electrical energy, production of cold, etc.). Figure (I.7) shows an example of a solar water heater [15].

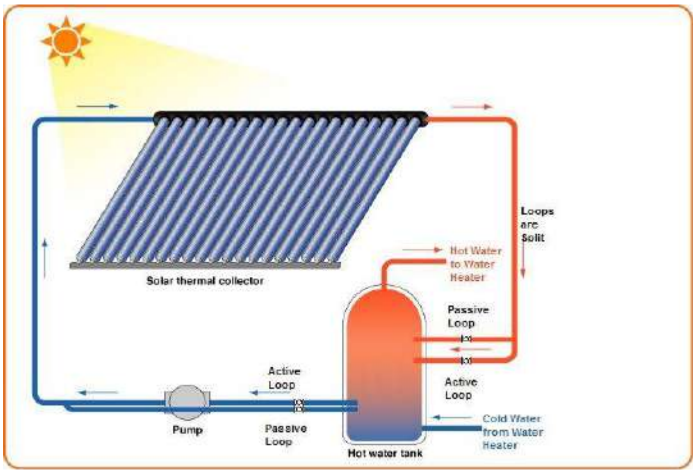

Figure I.7: Example of a solar water heater

C. Photovoltaic solar energy

Photovoltaic solar energy comes from the conversion of sunlight into electricity within semiconductor materials such as silicon or covered with a thin metallic layer. These photosensitive materials have the property of releasing their electrons under the influence of an external energy,this is the photovoltaic effect.

The energy is brought by the photons, (components of light) which collide with the electrons and release them, inducing an electric current. This direct current of micro power calculated in watt peak (Wp) can be transformed into alternating current thanks to an inverter.

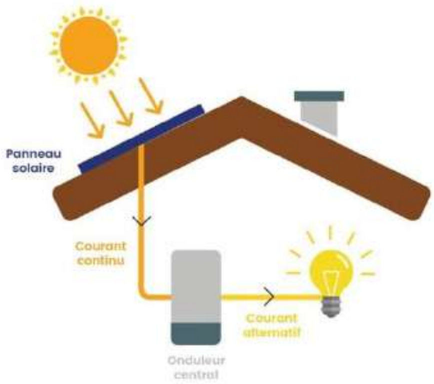

Figure I.8: Photovoltaic Solar Panel

D. Wind power

Wind power is top-down energy from the medieval windmill. The first wind turbine was commissioned in France in Dunkirk in 1990. This energy is developed with the electric wind turbine.

In the case of wind power, the kinetic energy of the wind drives a generator that produces electricity. There are several types of wind renewable energies: onshore wind turbines, off-shore wind turbines, floating wind turbine but the principle remains globally the same for all these types of renewable energies.

Figure I.9: Kabertène wind farm

I.5.3 *Nonrenewable technologies include*

A. Energy storage

A distributed energy resource is not limited to the generation of electricity but may also include a device to store distributed energy. Distributed energy storage systems (DESS) applications include several types of battery, pumped hydro, compressed air, and thermal energy storage. Access to energy storage for commercial applications is easily accessible through programs such as energy storage as a service (ESaaS).

Energy storage is at the heart of current challenges, whether to optimize energy resources or to promote access to them. It allows to adjust the "production" and the "consumption" of energy by limiting the losses.The energy, stored when its availability is higher than the needs, can be restored at a time when the demand proves to be greater. Faced with the intermittency or fluctuation of production of certain energies, for example renewables, this operation also makes it possible to meet a constant demand.

Figurer I.10*:* UK's energy storage pipeline passes 16GW

B. Micro turbines

Micro turbines are energy generators whose capacity ranges from 15 to 300 kW. Their basic principle comes from open cycle gas turbines, although they present several typical features, such as: variable speed, high speed operation, compact size, simple operability, easy installation, low maintenance, air bearings, low NOX emissions and usually a recuperator (Hamilton, 2001).Micro turbines came into the automotive market between 1950 and 1970. The first micro turbines were based on gas turbine designed to be used in generators of missile launching stations, aircraft and bus engines, among other commercial means of transport. The use of this equipment in the energy market increased between 1980 and 1990, when the demand for distributed generating technologies increased as well (LISS, 1999). [16].

Figure I.11: Micro turbines - an overview

DG an be used in an isolated way, supplying the consumer's local demand, or in an integrated way, supplying energy to the remaining of the electric system. In distribution systems, DG can provide benefits for the consumers as well as for the utilities, especially in sites where the central generation is impracticable or where there are deficiencies in the transmission system [12].

The Table I.2 and Table I.3 provide an overview of generation types usually connected at different distribution voltage levels and different ratings of distributed generation [12, 17].

Table I.2 Common voltage connection levels for different types of DG/RES

Usual connection voltage level	Generation Technology
HV **(usually 38-150 kV)**	_ Large industrial CHP Large-scale hydro _ Offshore and onshore wind parks _ Large PV _
MV **(usually 10-36 kV)**	_ Onshore wind parks Medium-scale hydro _ Small industrial CHP Tidal wave systems _Solar thermal and geothermal systems _ Large PV _ _
LV (< 1kV)	_ Small individual PV, Small-scale hydro _ Micro CHP, Micro wind

Table I-3 Different ratings of distributed generation

Categories	Ratings
Micro-distributed generation	1W $\leq$ DG size 5kW
Small distributed generation	5kW $\leq$ DG size 5MW
Medium distributed generation	5MW $\leq$ DG size 50 MW
Large distributed generation	50 MW $\leq$ DG size 300 MW

It often offers a valuable alternative to traditional sources of electric power for industrial, commercial and residential applications so it appears as an alternative that utility planners should explore in their search for the best solution to electric supply problems. The main reasons for the increasingly widespread use of DG can be summed up as follows [12]:

- DG units are closer to customers so that T&D costs are avoided or reduced.
- T&D costs have risen while DG costs have dropped: as a result the avoided costs produced by DG are increasing.
- The latest technology has made available plants with high efficiency and ranging in capacity from few kW to hundreds of MW of different DGs.
- It is easier to find sites for small generators.
- Natural gas, often used as fuel in DG stations, is distributed almost everywhere and stable prices are to be expected.
- Usually, DG plants require shorter installation times and the investment risk is not so high.
- The liberalization of the electricity market contributes to creating opportunities for new utilities in the power generation sector.
- DG offers great values as it provides a flexible way to choose a wide range of combinations of cost and reliability.

Parallel to the introduction of DG, when distribution system planning and DG impact are considered, the greatest attention should be paid in the sitting and sizing of DG units because their installation in non-optimal locations can result both in an increasing of power losses and in a reducing of reliability levels.

I.5.4 Distributed generation applications

The application of various DG technologies depends on the user's individual requirements. Distributed generation installations theoretically can improve reliability, reduce costs, reduce emissions, and improve power quality (see Table I.4) [9, 11, 14]:

Table I.4 Theoretical Benefits of Distributed Generation

Reliability and Security Benefits	• Increased security for critical load • Relieved transmission and distribution congestion • Reduced impacts from physical or cyber attacks • Increased generation diversity
Economic Benefits	• Reduces costs associated with power losses • Deferred investments for generation, transmission, or distribution upgrades • Lower operating costs due to peak shaving • Reduced fuel costs due to increased overall efficiency • Reduced land use for generation
Emission Benefits	• Reduced line losses • Reduced pollutant emissions
Power Quality Benefits	• Voltage profile improvement • Reduced flicker • Reduced Harmonic distortion

.

I .6 Conclusion

In this chapter, we have begun by providing an overview on different types of distribution networks as well as their structures and characteristics. Next, different methods of load flow calculation in distribution power systems and particularly those concerning radial distribution networks were cited. Since Backward / Forward Sweep (BFS) methods are usually used in practice, we have chosen then in this study a method based on BFS and using Bus-Injection to Branch Current (BIBC) Matrix.

In the last section, we have specified many definitions of dispersed generation and we have provided an overview from references of generation types usually connected at several distribution voltage levels and DG different ratings. Finally, various distributed generation applications were summarized on giving theoretical benefits as reliability, security, economic, emission and power quality.

Chapter II

Problem Formulation & Optimization

II.1 Introduction

In power systems, developed techniques and methods are used to optimize the performance of the system. The distributed generation has become a viable solution to the many challenges facing the power industry.

In evaluating the impact of DG on a distribution power system, the placement and sizing of the it has a tremendous impact on power losses, voltage levels, and reliability. Finding the optimal distributed generator sizing and placement is a complex problem with many variables to take into consideration [18].

Many techniques and methods have been developed to solve the optimal sizing and placement of distributed generation, the **metaheuristics** presents the most popular and the most used methods to solve this kind of problems (optimization problem).

II.2 Problem Formulation

Finding the optimal distributed generator sizing and placement is an optimization problem with nonlinear objective function that has equality and inequality constraints. The proposed objective function includes: reducing real (active) power losses, and assist in balancing the current of system in a given radial distribution network [19, 20].

II.2.1 Active power loss

In radial distribution networks, each receiving bus is fed by only one sending bus. (Figure II.1),

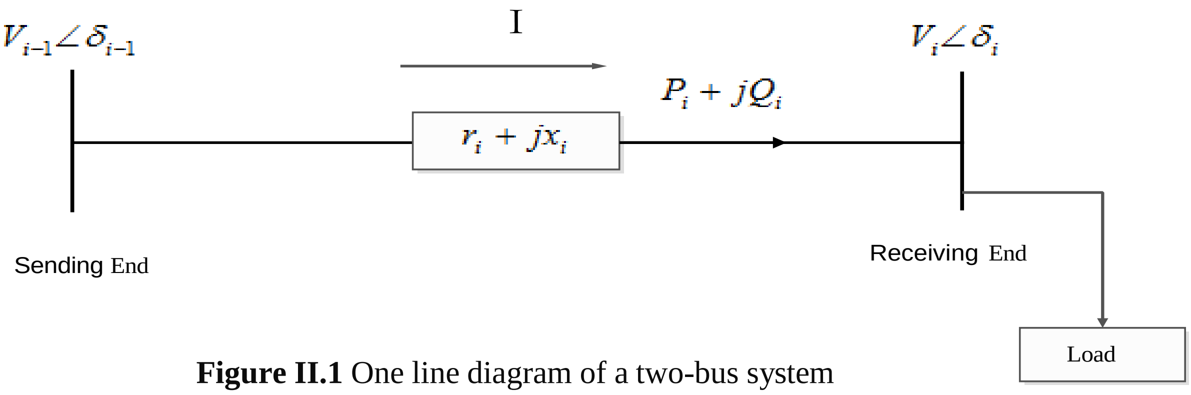

Figure II.1 One line diagram of a two-bus system

The line losses between the receiving and sending end buses $P_{loss(i)}$ can be calculated using Eq (II.1):

$$P_{\text{loss}\ (i)} = \quad r_i \cdot \left(\frac{(P_i + jQ_i)}{V_i}\right)^2 \tag{II. 1}$$

Therefore the first objective function is calculated as follows:

$$f_1 = (P_{\text{loss}}) = \sum_{i=1}^{N_{\text{line}}} \big(P_{\text{loss}}\ (i)\big) = \sum_{i=1}^{N_{\text{line}}} r_i \cdot I_i^2 \tag{II. 2}$$

$$f2 \ = VSI_i = V_{i-1}^4 - 4 \cdot (P_i x_i - Q_i r_i)^2 - 4 \cdot (P_i r_i + Q_i x_i)^2 \tag{II. 3}$$

Where:

Real (P_{loss}) : Total active line loss.

I : Current in i^{th} line section.

R : Resistive component of line impedance.

X : Reactive component of line impedance.

N_{line} : Total number of line sections.

V_I : Complex voltage at the i^{th} bus.

P_i , Q_i : Active and reactive power injections at the i^{th} bus.

II.2.2 System Constraints

The power system is designed to operate within certain system constraints. These constraints are designed to ensure safe and reliable operation of the power system. In order to obtain practical results, optimization location and sizing of DG is subject to the following constraints [19, 21]:

Power Flow constraints:

$$P_{Source} + P_{DG} \ = \ P_{Load} + P_{Loss} \tag{II.4}$$

$$Q_{Source} + Q_{DG} = \ Q_{Load} + Q_{Loss} \tag{II.5}$$

$$V_{min}^i \leq V_i \leq V_{max}^i \tag{II. 6}$$

- *Distributed Generator Constraints:*

$$0 \leq DG \text{ size } (P_{DG}) \leq \sum_{i=2}^{N_{Bus}} P_{Di} \qquad (\text{II}.7)$$

$$2 \leq DG \text{ Location } \leq N_{Bus} \qquad (\text{II}.8)$$

II.3 Definition of optimization

Maximizing or minimizing some of the functions in relation to a set, often representing a range of choices available in a given situation. The function allows a comparison of the different choices for determining which may be "best" [22].

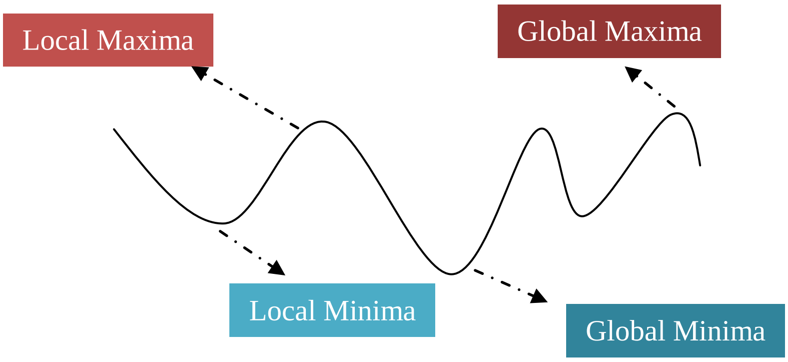

Figure II.2: Local and Global Optimal Solution

Common applications: minimum cost, maximum profit, best approximation, optimum design, optimal management or control, variation principles.

Optimization techniques can be classified in many ways, following figure presents the classification of it [23].

II.4 Background to Metaheuristics

Metaheuristics are designed to tackle complex optimization problems where other optimization methods have failed to be either effective or efficient. These methods have come to be recognized as one of the most practical approaches for solving many complex problems, and this is particularly true for the many real-world problems that are combinatorial in nature. The practical advantage of **metaheuristics** lies in both their effectiveness and general applicability.

The metaheuristic approach to solving such problem is to start by obtaining an initial solution or an initial set of solutions, and then initiating an improving search guided by certain principles. The structure of the search has many common elements across various methods. In each step of the search algorithm, there is always a solution (or a set of solutions) [24]. The classification of metaheuristics methods is shown in next figure.

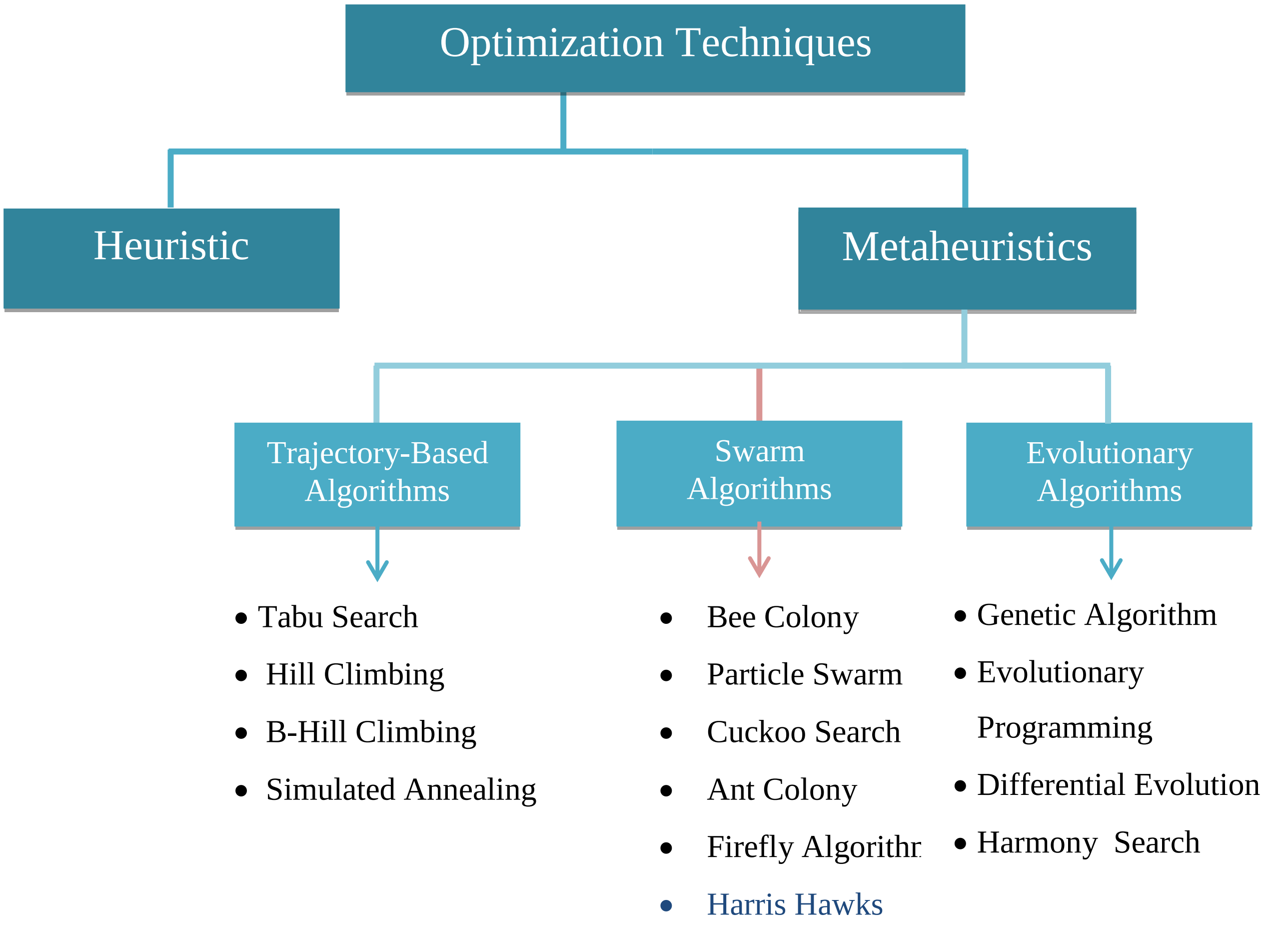

Figure II.3 Classification of optimization techniques

II.5 Harris hawk's optimization

Harris Hawks Optimization (HHO) is a novel population-based, nature-inspired algorithm. It has been published by future generation computer system (FGCS) in 2019.

HHO's main inspiration is the cooperative behavior and the Harris Hawks chasing style in nature which is called "surprise pounce", known also as "seven kills'' strategy. In this smart strategy, many hawks cooperatively hunt the prey from various directions in attempt to surprise it. The attack may be accomplished easily by catching the surprised prey within few seconds. But usually, in consideration to the prey's escape capabilities and behaviors, the seven kills may require multiple, short-length, quick dives near the prey during several minutes.

Figure II.4: Harris hawks detecting and chasing the prey

Harris hawks can show a variety of chasing patterns based on the dynamic nature of scenarios and escaping patterns of the prey. The main advantage of these cooperative strategies is that the Harris' hawks are able to exhaust the trapped rabbit, which increases its vulnerability. Moreover, by perplexing the escaping prey, it cannot recover its defensive capabilities and finally one of the hawks captures the tired prey. This work mimics these dynamic patterns and behaviors mathematically to develop an optimization algorithm [25].

II.5.1 Harris hawks optimization phases

A. Exploration phase

In HHO, the Harris' hawks perch randomly on some locations and wait to detect a prey based on two strategies:

$$X(t+1) = \begin{cases} X_{rand}(t) - r_1|X_{rand}(t) - 2r_2X(t)| & q \geq 0.5 \\ \left(X_{rabbit}(t) - X_m(t)\right) - r_3\left(LB + r_4(UB - LB)\right) & q < 0.5 \end{cases} \quad (\text{II}.9)$$

$X(t+1)$ Represents the position vector of the hawks in the next iteration t, $X_{rabbit}(t)$ is the position of the rabbit, $X(t)$ is the current position vector of the hawks,r_1, r_2, r_3, r_4 and q are random numbers inside (0, 1), which are updated each iteration, LB and UB show the upper and lower bounds of variables, $X_{rand}(t)$ is a randomly selected hawk from the current population, and $X_m(t)$ is the average position of the current population of hawks.

B. Transition from exploration to exploitation

To model this step, the energy of a rabbit is modeled as:

$$E = 2E_0\left(1 - \frac{t}{T}\right) \qquad \text{(II. 10)}$$

And E indicates the escaping energy of the prey, T is the maximum number of iterations, and E_0 is the initial state of its energy.

C. Exploitation phase

a. *Soft besiege:*

This behavior is modeled by the following rules:

$$X(t+1) = \Delta X(t) - E|JX_{rabbit}(t) - X(t)| \qquad \text{(II. 11)}$$

Where $\Delta X(t)$ is the difference between the position vector of the rabbit and the current location in iteration, J represents the random jump strength of the rabbit throughout the escaping procedure, its value changes randomly in each iteration to simulate the nature of rabbit motions.

b. *Hard besiege:*

In this situation, the current positions are updated using Eq. (II. 12).

$$X(t+1) = X_{rabbit}(t) - E|\Delta X(t)| \qquad \text{(II. 12)}$$

c. *Soft besiege with progressive rapid dives:*

To perform a soft besiege, we supposed that the hawks can evaluate (decide) their next move based on the following rule in Eq. (II. 13).

$$Y = X_{rabbit}(t) - E|JX_{rabbit}(t) - X(t)| \qquad \text{(II. 13)}$$

But Y and Z are obtained using the new rules in the following Eq. (II. 17) , (II. 18).

$$Y = X_{rabbit}(t) - E|JX_{rabbit}(t) - X_m(t)| \qquad \text{(II. 14)}$$

$$Z = Y + S \times LF(D) \qquad \text{(II. 15)}$$

We supposed that they will dive based on the LF-based patterns using the following rule:

$$Z = Y + S \times LF(D) \qquad \text{(II. 16)}$$

Where D is the dimension of problem and S is a random vector by size 1 × D and LF is the levy flight function.

Hence, the final strategy for updating the positions of hawks in the soft besiege phase can be performed by Eq. (II. 15).

$$X\,(t+1) = \begin{cases} Y \; if F(Y) < F\big(X(t)\big) \\ Z \; if F(Z) < F\big(X(t)\big) \end{cases} \qquad \text{(II. 17)}$$

d. *Hard besiege with progressive rapid dives:*

In hard besieged situation, the following rule is performed in Eq. (II. 16).

$$X(t+1) = \begin{cases} Y \; if F(Y) < F\big(X(t)\big) \\ Z \; if F(Z) < F\big(X(t)\big) \end{cases} \qquad \text{(II. 18)}$$

Harris Hawks Optimization's algorithm

The algorithm of this HHO is reported as follows [25]:

HHO's Algorithm

```
Inputs: The population size $N$ and maximum number of iterations $T$
Outputs: The location of rabbit and its fitness value
Initialize the random population $X_i$(i = 1,2, ... ,$N$)
While (stopping condition is not met) do
        Calculate the fitness values of hawks
          Set $X_{rabbit}$ as the location of rabbit (best location)
For (each hawk ($X_i$)) do
Update the initial energy $E_0$ and jump strength $J$        ► $E_0$=2rand ()-1, $J$=2(1-rand ())
            Update the $E$ using Eq. (II. 9)
   If (|$E$| ≥ 1) then                                        ► Exploration phase
```

```
            Update the location vector using Eq. (II. 9)
    if ($|E| < 1$) then                                        ▶Exploitation phase
    if ($r \geq 0.5$ and $|E| \geq 0.5$) then                     ▶soft besiege
            Update the location vector using Eq. (II. 11)
    else if ($r \geq 0.5$ and $|E| < 0.5$) then                   ▶Hard besiege
            Update the location vector using Eq. (II. 12)
    else if ($r < 0.5$ and $|E| \geq 0.5$) then    ▶Soft besiege with progressive rapid dives
            Update the location vector using Eq. (II. 17)
    else if ($r < 0.5$ and $|E| < 0.5$) then    ▶Hard besiege with progressive rapid dives
            Update the location vector using Eq. (II. 18)
Return $X_{rabbit}$
```

II.6 Conclusion

In this chapter, we have identified the problem as finding the localization and the size of the active power produced for DG to reduce the active power loss, and to improve the voltage profile in a radial distribution network. The formulation of the problem has been detailed explicitly.

Finally, and after defining the optimization and classifying the meta-heuristics, a novel method called Harris Hawks Optimization (HHO) was chosen for our case study and explained in details.

Chapter III

Simulation Results and Discussions

III.1 Introduction

In this chapter, we will see the results of HHO algorithm on distributed electrical networks to find the optimum size and location for a decentralized solar power plant type.

The standard IEEE 33 and 85 bus distribution test systems are used in this study to evaluate the efficacy of the proposed method. The standard IEEE 33 shown in figure III.01 contains 33 buses and 32 branches. It is a radial system with a total load of 3715 KW and 2300 KVAR [26]. The structure of 85 nodes radial distribution system is shown in figure III.02. It contains 84 branches and 85 buses (one slack bus + 84 loads), with total load of 2570.3 KW and 2622.1 Kvar.

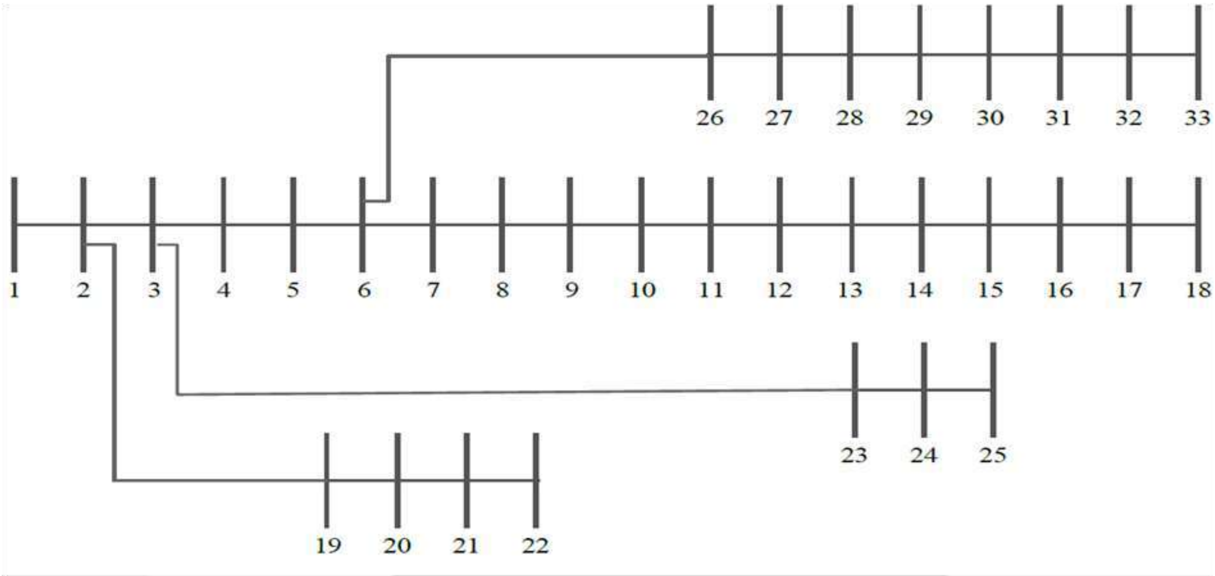

Figure III.01 the structure of 33 nodes radial distribution system

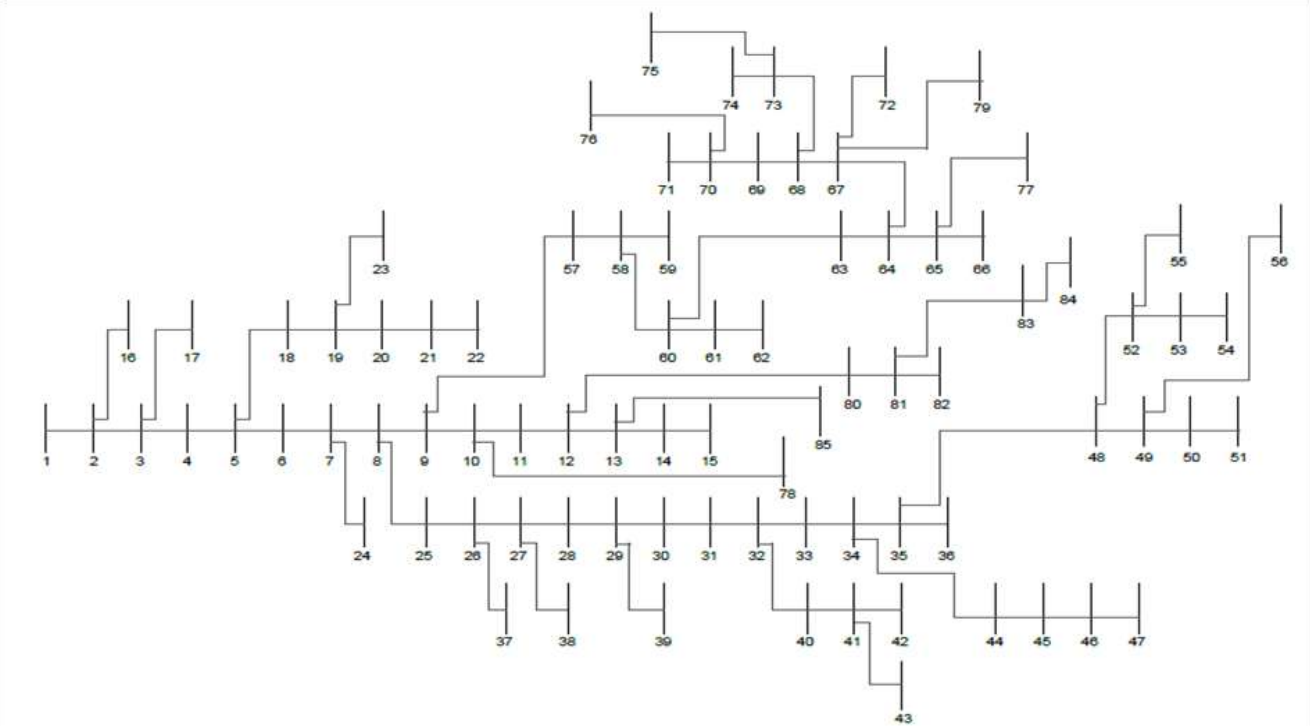

Figure III.02 The structure of 85 nodes radial distribution system

The table represents the results of “85 bus test system”, We notice after placement of DG at bus 8 with an optimal size of 2374.33538 kw total active power losses are reduced from 316.1 kW to 175.51724 kW which represents a decrease of value of VSI increased from 0.5764 (pu) to 0.74241019 (pu).

Table III.01 85 bus results

	Real power loss (kW)	Minimum value of VSI (pu)	Optimal Bus	DG Optimal Size (kW)
Without DG	316.1	0,5764	_	_
with DG	175.51724	0.74241019	8	2374.33538

The figure represents the values of the Reactive losses in each line before and after integration of DG in electrical network 85 bus, where we notice a decrease in the reactive losses in the electric lines, and this indicates an improvement in the value of the total reactive losses.

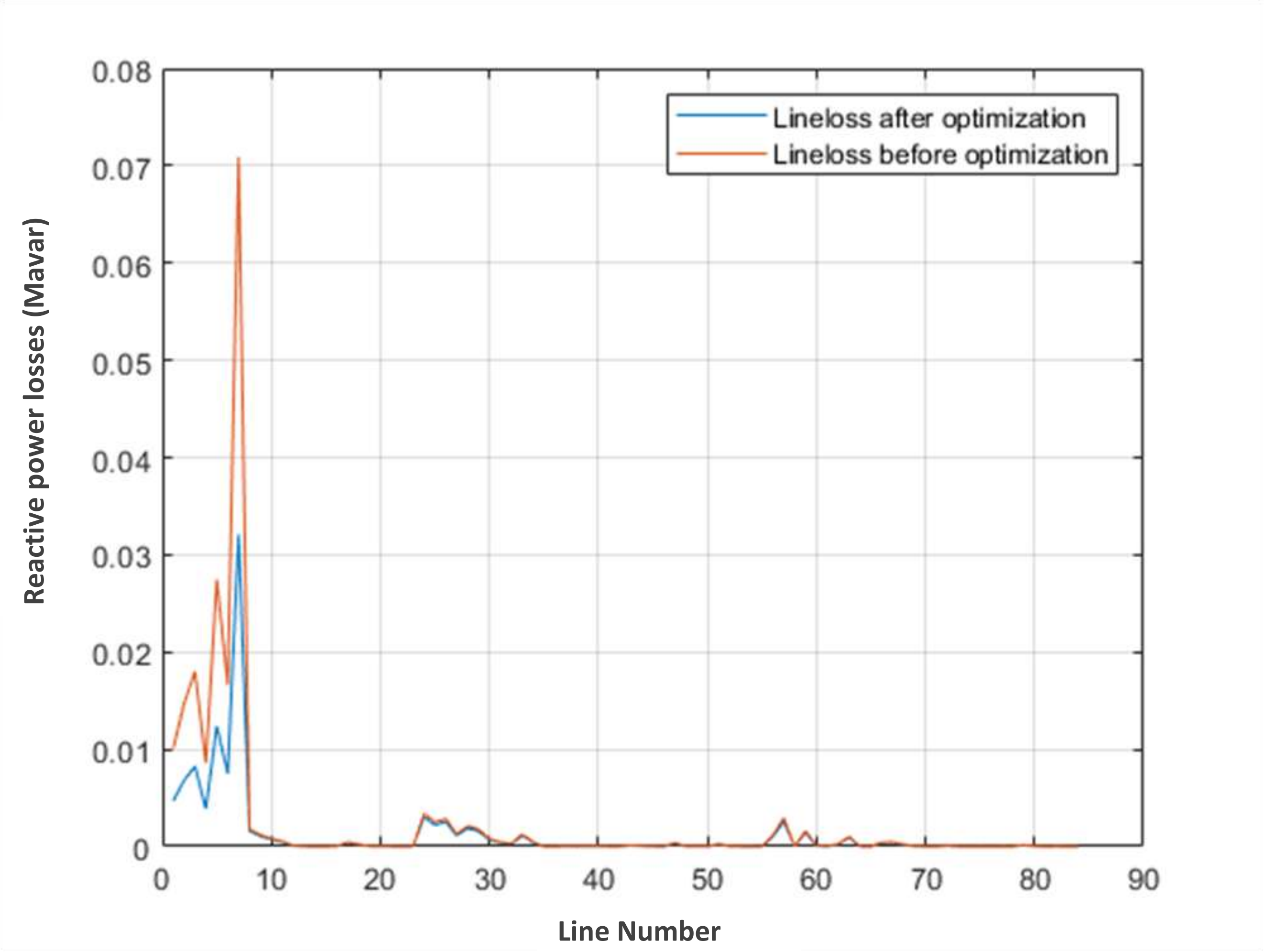

Figure III.03 Reactive Line losses before and after optimization in 85 systems

The figure represents the values of the active losses in each line before and after integration of DG in electrical network 85 bus, where we notice a decrease in the active losses in the electric lines, and this indicates an improvement in the value of the total reactive losses.

.

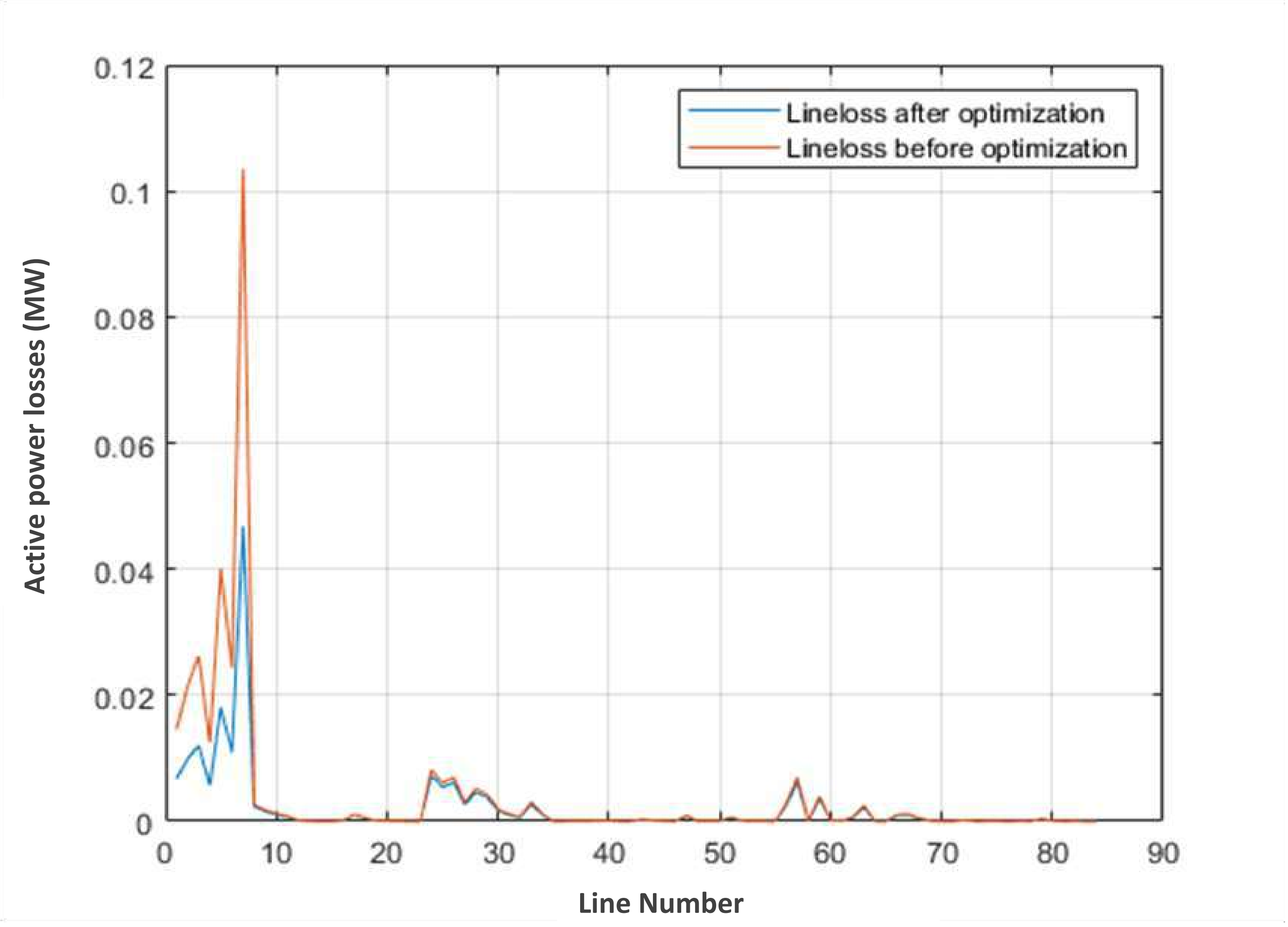

Figure III.04 Active Line losses before and after optimization in 85 systems

The figure represents the voltage profile before and after optimization in 85 system where we note the minimum value of voltage increased from 0,872 (Pu) to 0.93 (Pu).

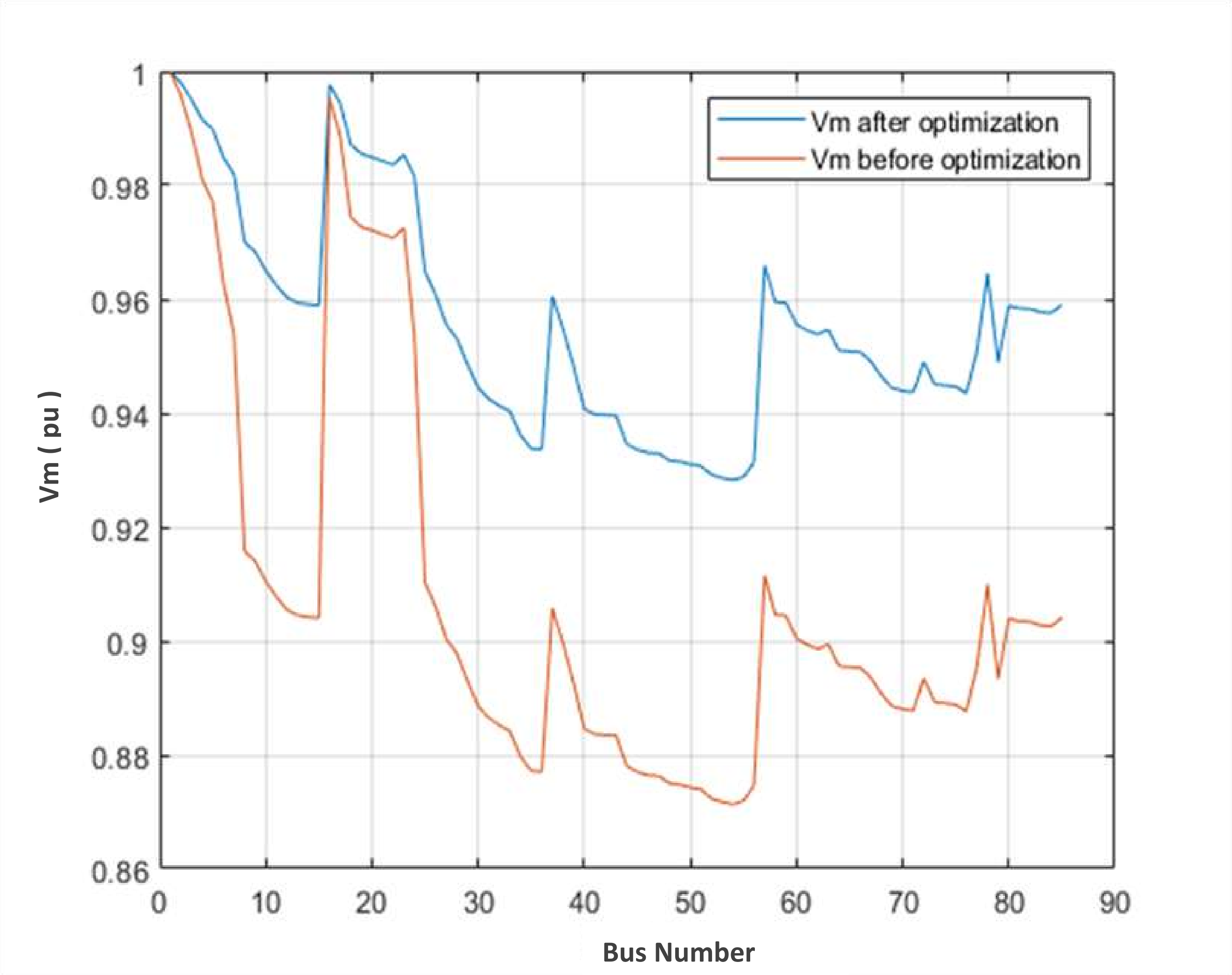

Figure III.05 Voltage profile before and after optimization in 85 systems.

The figure represents Voltage Stability Index (VSI) before and after optimization in 85 system, we note the minimum value of VSI increased from 0.5764 to 0.74 .

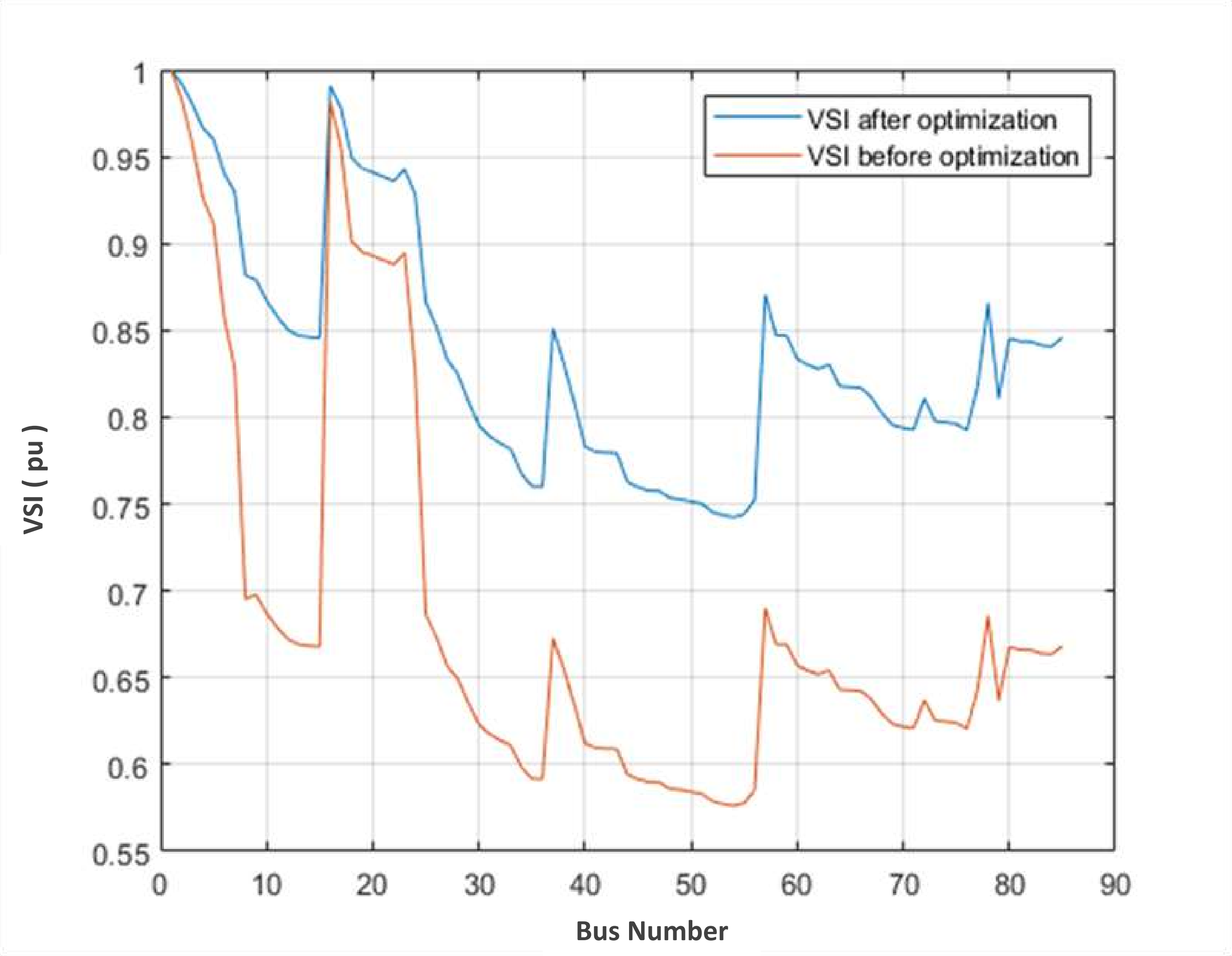

Figure III.06 Voltage Stability Index (VSI) before and after optimization in 85 systems

The table represents the results of "33 bus test system", we notice after placement of DG at bus 6 with an optimal size of 2590.53476 kw total, active power losses are reduced from 211 kW to 111 kW which represents a decrease of 47.4 %, and minimum value of VSI increased from 0.66717 (pu) to 0.7887 (pu).

Table II.02 33 bus results

	Real power loss (KW)	minimum value of VSI (pu)	Optimal Bus	DG Optimal size (KW)
Without DG	211	0.66716	_	_
with DG	111.0	0.7887	6	2590.53476

The figure represents the voltage profile (Vm) before and after optimization in 33 system where we note the minimum value of voltage increased from 0,905 (Pu) to 0.943 (Pu).

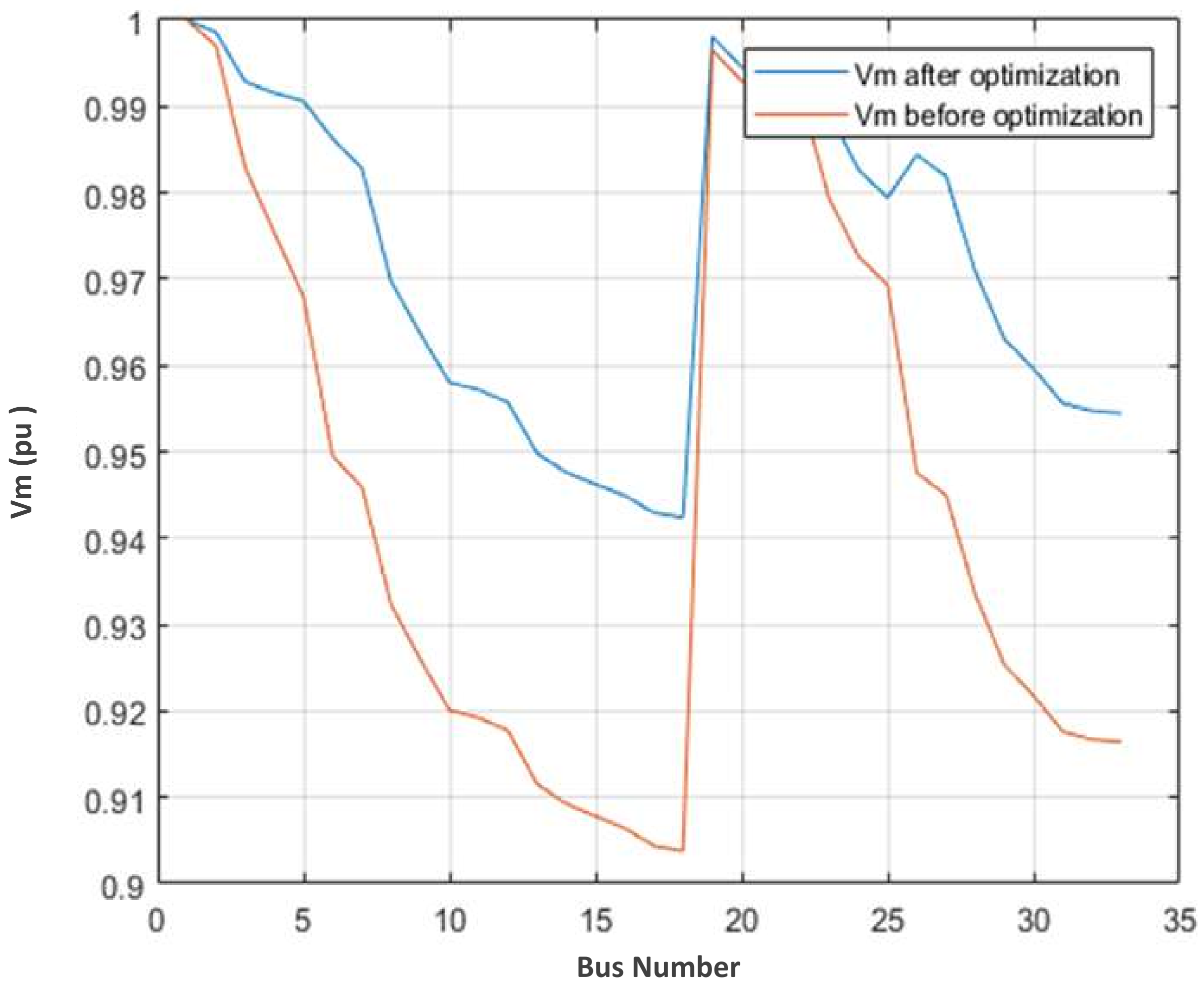

Figure III.07 Voltage profile before and after optimization in 33 systems

The figure represents the values of the active losses in each line before and after integration of DG in electrical network 33 bus, where we notice a decrease in the active losses in the electric lines, and this indicates an improvement in the value of the total reactive losses.

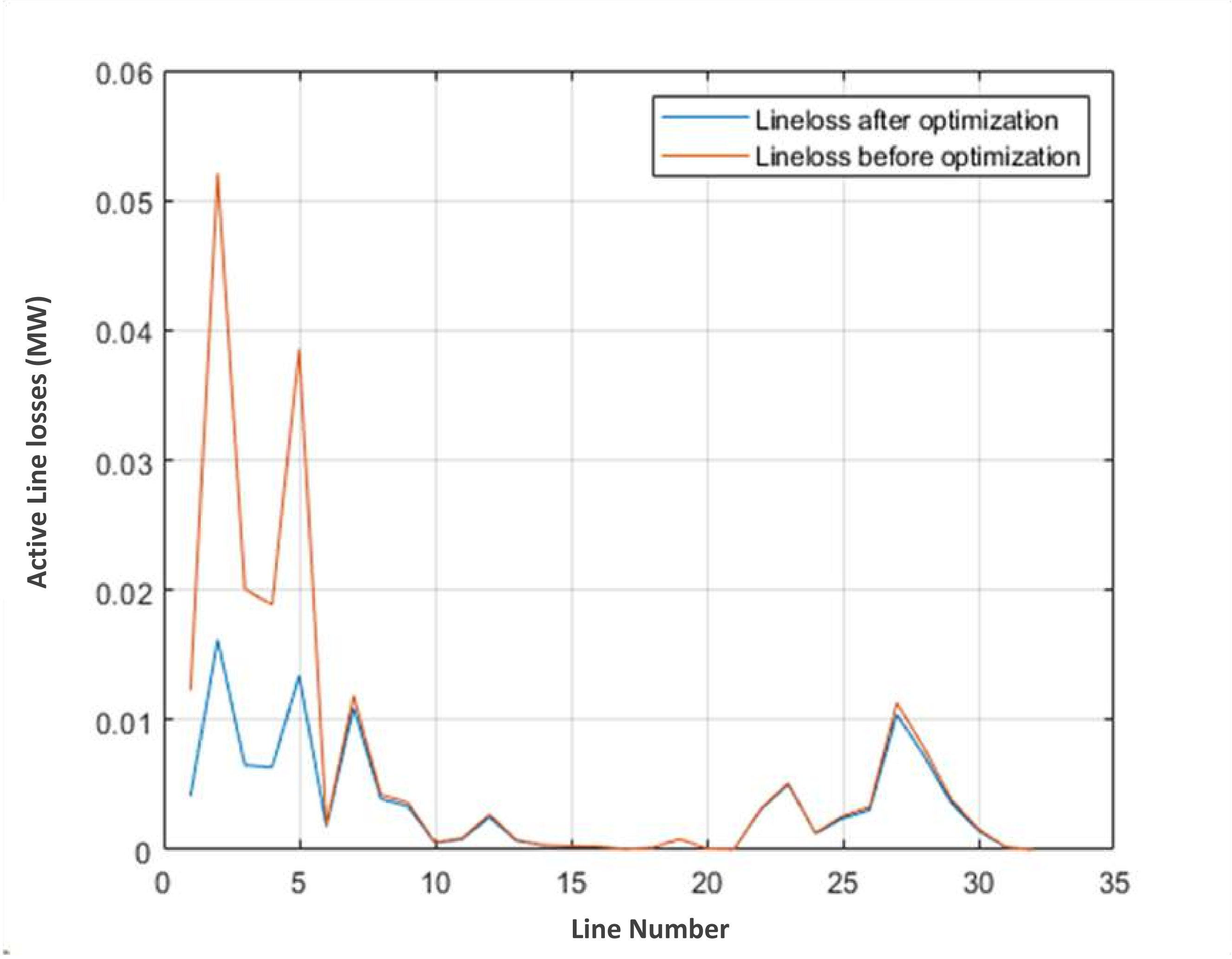

Figure III.08 Active Line losses before and after optimization in 33 systems

The figure represents the values of the Reactive losses in each line before and after integration of DG in electrical network 33 bus, where we notice a decrease in the reactive losses in the electric lines, and this indicates an improvement in the value of the total reactive losses.

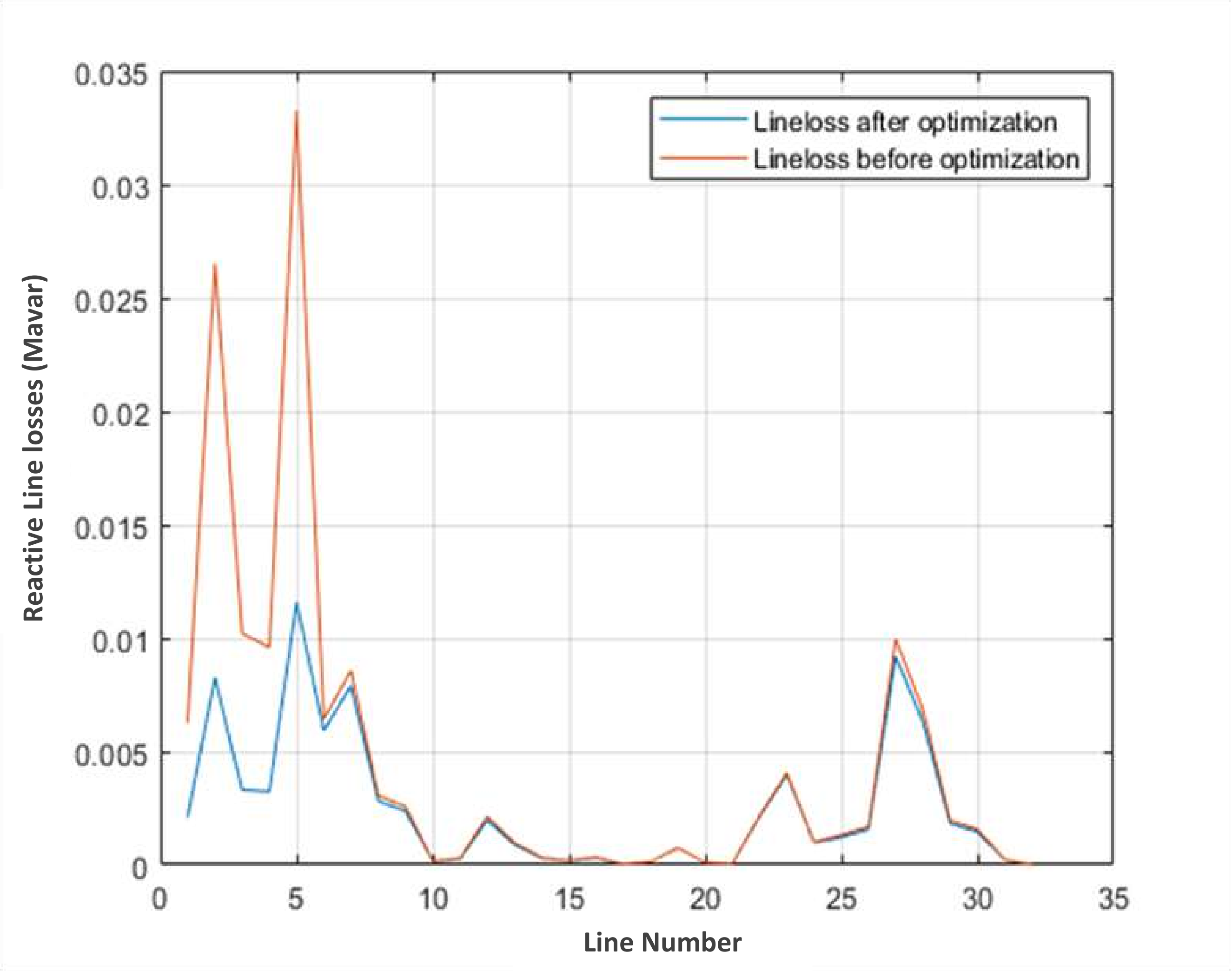

Figure III.09 Reactive Line losses before and after optimization in 33 systems.

The figure represents Voltage Stability Index (VSI) before and after optimization in 33 system, we note the minimum value of VSI increased from 0.66717 (pu) to 0.7887 (pu).

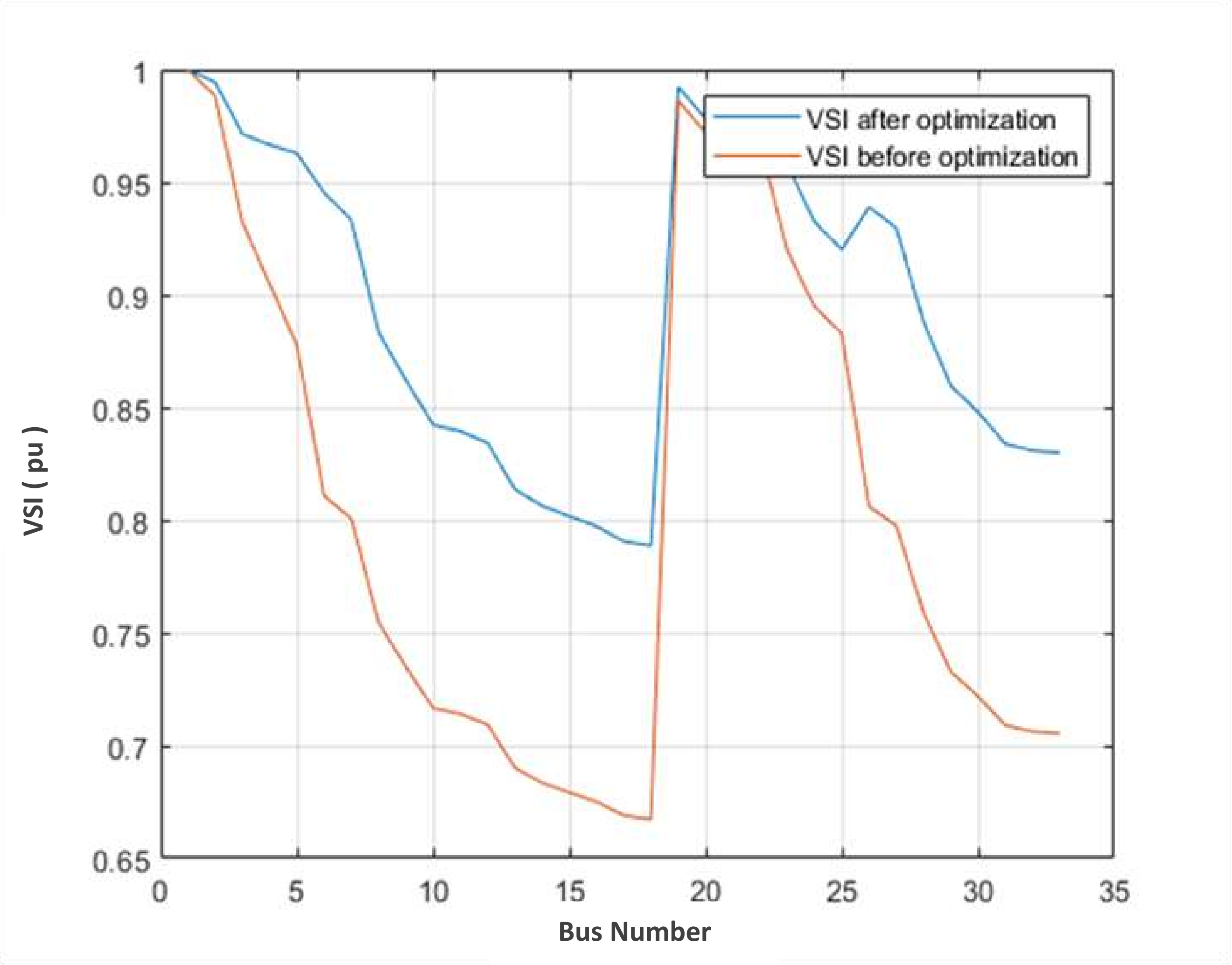

Figure III.10 Voltage Stability Index (VSI) before and after optimization in 33 systems

The graphs represent the value of losses before and after merging the DG shown in Tables 1 and 2 in electrical networks 33 and 85, which shows the effectiveness of the optimization method in reducing the value of losses

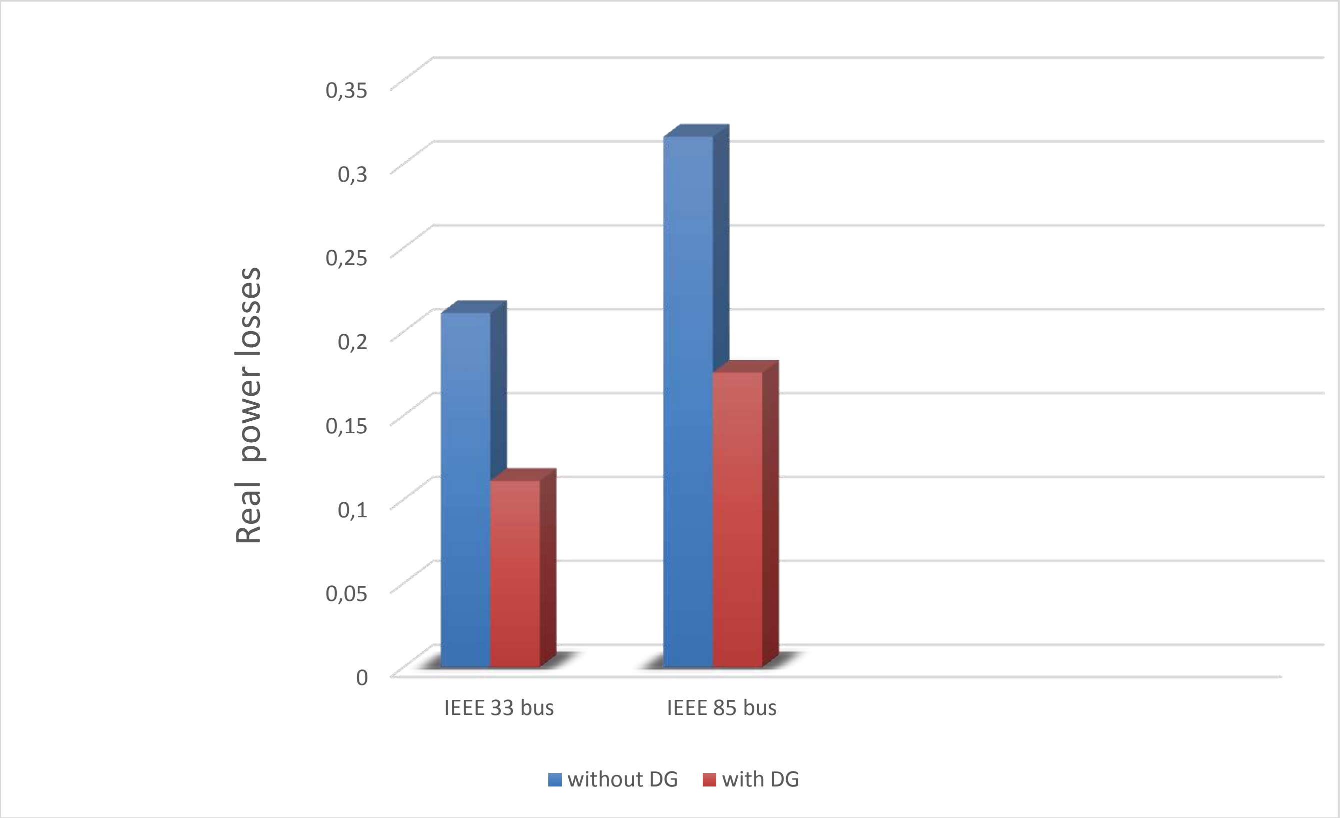

Figure III.11 Real power losses before and after optimization in 85 and 33 bus system

We can see the HHO method converges after a satisfactory number of generations which is on average less than 5 iterations. So, we can say that the HHO method is a method characterized by good convergence.

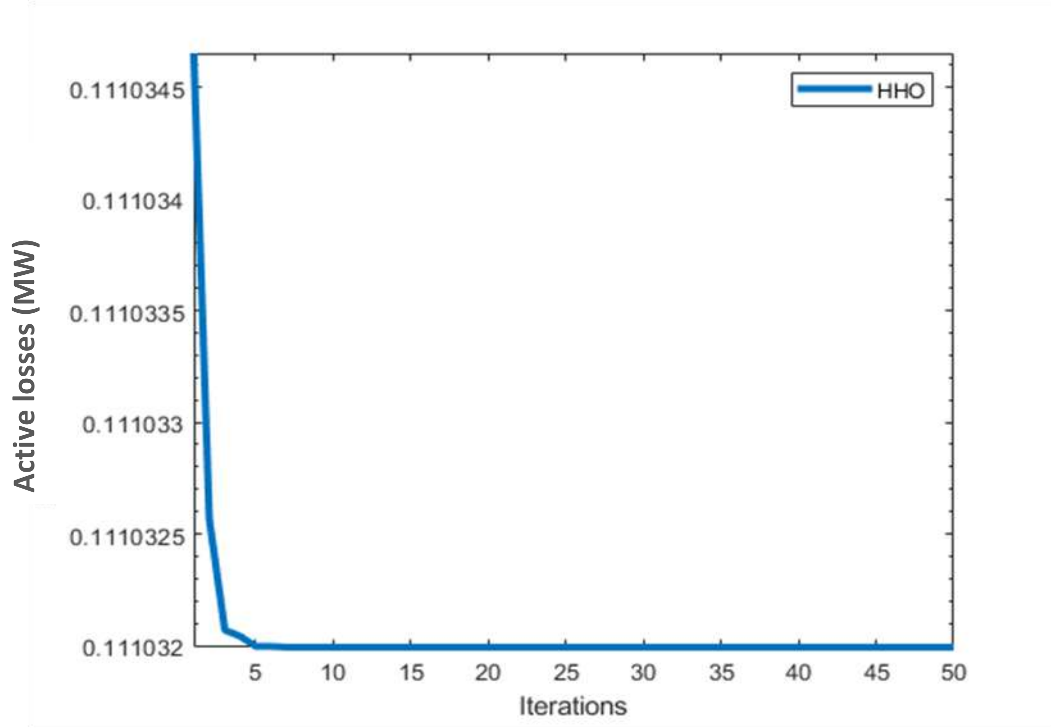

Figure III.12 convergence characteristic of the HHO method whose objective function is to minimize active losses in 33 bus system

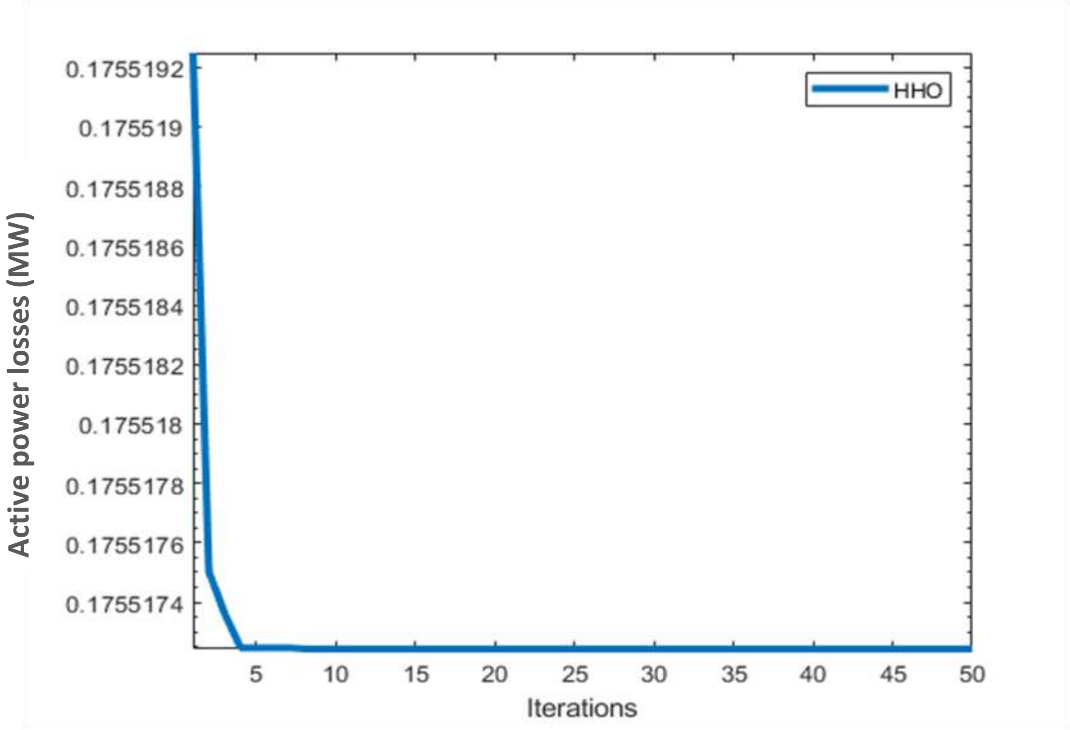

Figure III.13 convergence characteristic of the HHO method whose objective function is to minimize active losses in 85 bus system

III.2 Discussion

III.2.1 Impact of addition of DG on voltage profile

For radial distribution systems, unidirectional power flow from the substations to the customers can be assumed. The highest voltage can be expected at the substations whereas the lowest voltage occurs at the customer points of connection. Hence, the voltage is decreasing from the substation along the feeders to the customers.

When DG is connected in the distribution system, the voltages at all the nodes improve. As can be seen in: Figure III.05 and Figure III.07

III.2.2 Impact of Addition of DG on power losses

Power injections from DG change network power flows thereby modifying energy losses. Electrical line loss occurs when current flows through transmission and distribution systems. The magnitude of the loss depends upon amount of current flow and line resistance. Therefore, line loss can be decreased by reducing either line current or resistance or both. If DG is used to provide energy locally to the load, the line loss can be reduced because of decrease in current flow in some part of the network. As can be seen in Figure III.04 and Figure III.08.

III.2.3 Impact of Addition of DG on Voltage Stability Index (VSI)

Voltage stability is the ability of a system to maintain voltage so that when load Admittance is increased, load power will increase and so that both power and voltage are controllable. Where the injection of energy leads to an increase in the value of VSI as can be seen in Figure III.06 and Figure III.10

III.3 Conclusion

The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can result in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. For that reason, the use of an optimization method capable of indicating the best solution for a given distribution network is very useful.

General Conclusion

Technological advancements in power system, a progressive national energy policy and economic considerations will continue to be key factors in the spreading and implementation of distributed generation on the power system. Optimal DG sizing and placement on a distribution power system will play a critical role in providing valuable information concerning the impact of DG on a distribution power system.

Charging scheduling was designed using a newly developed optimization strategy, and after defining the optimization and classifying the meta-heuristics, a novel method called Harris Hawks Optimization (HHO) was chosen for our case study and explained in details
The proposed algorithms were tested on, 33-bus and, 85-bus radial distribution test systems. The results proved the efficiency of this method for enhancement of voltage profile, reduction of active power losses and also an increase in voltage stability margin.

Finally, the application of dispersed generators throughout the power systems will come up with the growing demand for electricity in distribution network and self-sufficient in terms of power production and achieving energy savings. The DG is best suited for demand side management programs.

References

References

[1] Vanco Janev , " Implementation and evaluation of a distribution load flow algorithm for networks with distributed generation ", Semester Work , EEH - Power Systems Laboratory Swiss Federal Institute of Technology, Zurich in March 2009.

[2] Nivedita Nayak," Load Flow Analysis Using Newton-Raphson Method ", International Journal of Engineering Research and Applications (IJERA) ISSN: 2248- 9622, March 2014.

[3] Makwana Nirbhaykumar N, " Methods for Load Flow Analysis of Weakly Meshed Distribution System ", International Journal of Scientific and Research Publications, Volume 2, Issue 3, March 2012 , ISSN 2250-3153, March 2012.

[4] M. Sedghi, M. Aliakbar-Golkar, " Analysis and Comparison of Load Flow Methods for Distribution Networks Considering Distributed Generation International Journal of Smart Electrical Engineering, Vol.1, No.1, Winter 2012.

[5] Jaydeep Chakavorty , Mukul Gupta," A New Method of Load−Flow Solution of Radial Distribution Networks ", International Journal of Electronics and Communication Engineering. ISSN 0974-2166 Volume 5, pp. 9-22, Number 1 (2012).

[6] Apoorva Saxena, " Load flow analysis of radial distribution networks with reduced data preparation" partial fulfillment of the requirements for the award of degree of Master Of Engineering in Power Systems & Electric Drives, Thapar University, Patiala ,2008.

[7] William H. Kersting," Distribution System Modeling and Analysis", Electric power engineering series, 2002 by CRC Press LLC, International Standard Book Number 0- 8493-0812-7.

[8] Ulas Eminoglu, M. Hakan Hocaoglu, " A new power flow method for radial distribution systems including voltage dependent load models ", Science direct: Electric Power Systems Research 76 (2005) 106–114, May 2005.

[9] T. Goïzel, U. Eminoglu, M.H. Hocaoglu, " A tool for voltage stability and optimization (VS&OP)in radial distribution systems using matlab graphical user interface (GUI) ", Science direct: Simulation Modelling Practice and Theory 16 (2008) 505–518, February 2008.

[10] Siti Mariam Mohd Shokri, Muhammad Murtadha Othman, Muhd Azri AbdulRazak, Ismail Musirin, " A Direct Approach Used for Solving the Distribution Systemand Harmonic Load Flow Solutions ", 2013 IEEE 7th International Power Engineeringand Optimization Conference (PEOCO2013), Langkawi, Malaysia, pages 708 – 713 June2013.

[11] Miguel Angel Fontela Garcia, " Interaction des Roseau de transport et dedistribution en presence de production decentralisee ", Doctorat prepared with Grenoble Electronic engineering Laboratory (G2Elab), July, 2008.

[12] Rajkumar Viral, D.K. Khatod, " Optimal planning of distributed generation systems
In distribution system:A review ", Renewable and Sustainable Energy Reviews Volume16, Issue 7, Pages 5146–5165 , 2012.

[13] Shilpa Kalambe, Dr. Ganga Agnihotri , Aashish Kumar Bohre, "An analytical approach for multiple dg allocation in distribution system ", Electrical and Electronics Engineering: An International Journal (ELELIJ) Vol 2, No 3, August 2013.

[14] H. B. Puttgen, P. R. Macgregor, F. C. Lambert, "Distributed Generation: Semantic
hype or the Dawn of a new Era? ", IEEE Power and Energy Magazine, ISSN 1540-7977,
January/February 2003.

[15] H.Moouloud, K.Aissa, "study and sizing of a converter dedicated to photovoltaic systems", end of academic master's dissertation, mouloud mammeri university of tizi-ouzou, 06 / 07 / 2017.

[16] FROM THE EDITED VOLUME، Progress in Gas Turbine Performance، Edited by Ernesto Benini.

[17] Gunnar LORENZ, " Active Distribution System Management :A key tool for the smooth integration of distributed generation", A EURELECTRIC paper, Union of the
Electricity Industry–EURELECTRIC , FEBRUARY 2013.

[18] P. Chiradeja and R. Ramakumar, "An Approach to Quantify the Technical Benefits of Distributed Generation ", IEEE transactions on energy conversion, vol. 19, no. 4, december 200.

[19] Derrick Dewayne Cherry, " Optimal placement of distributed generation on a power system using particle swarm optimization" , A Dissertation to request :Degree of Doctor in Electrical Engineering, Mississippi State University, Mississippi, USA, May 2012.

[20] M. Abedini, F. Samaie, MH. Moradi , A. Ashrafi , M. Ajdardel, " Evolutionary Computation based Distributed Generation capacity and placement of Hamadan Power Networks in Iran ", Technical Journal of Engineering and Applied Sciences (TJEAS), TJEAS Journal-2013-3-19/2498-2507,ISSN 2051-0853 ,Mars- 2013.

[21] R. D. Mohammedi · A. Hellal · S. Arif · M. Mosbah, " Optimal DG placement and sizing in radial distribution systems using NSGA-II for power loss minimization and voltage stability enhancement ”, International Review of Electrical Engineering ;Nov/Dec2013, Vol. 8 Issue 6, p1806,2013.

[22] M. Pant, “Particle Swarm Optimization, Department of Applied Science and Engineering,” Saharanpur Campus of IIT Roorkee. 2009.

[23] X. Yang. Nature Inspired Metaheuristic Algorithms. 2nd Edition, Luniver Press, 2010.

[24] Sigurdur Ólafsson , " Metaheuristics ", Handbook on Simulation, Handbooks in Operations Research and Management Science VII, Elsevier, 633-654,2006.

[25] A. Heidari, S. Mirjalili, H. Faris, I. Aljarah, M. Mafarja, H. Chen, “Harris hawks Optimization: Algorithm and Applications”, Future Generation Computer Systems,2019.

[26] Kashem, M. A., Ganapathy, V., Jasmon, G. B., & Buhari, M. I. (2000, April). A novel method for loss minimization in distribution networks. In DRPT2000. International conference on electric utility deregulation and restructuring and power technologies. Proceedings (Cat. No. 00EX382) (pp. 251-256). IEEE.