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SAKARYA UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES

OPTIMAL PLACEMENT OF MULTIPLE DISTRIBUTED GENERATION UNITS IN A RADIAL DISTRIBUTION NETWORK IN AMMAN-JORDAN

MSc THESIS

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Electrical and Electronics Engineering Department

JANUARY 2023

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The thesis work titled "Optimal Placement of Multiple Distributed Generation Units in a Radial Distribution Network in Amman - Jordan" prepared by Mohammad AL-ZABEN was accepted by the following jury on 25/01/2023 by unanimously/majority of votes as a MSc THESIS in Sakarya University Graduate School of Natural and Applied Sciences, Electrical and Electronics Engineering Department, Electrical and Electronics Programme.

Thesis Jury

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(05/01/2023)

Mohammad AL-ZABEN

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Mohammad AL-ZABEN

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Sayfa

ABBREVIATIONS

ABS	**:** The Absolute Value.
DG	**:** Distributed Generation.
HV	**:** High Voltage.
LV	**:** Low Voltage.
MV	**:** Medium Voltage.
Nbr	**:** Number.
P.U	**:** Per Unit.
PF	**:** Power Factor.
PSO	**:** Particle Swarm Optimization.
TC	**:** Current Transformer.
THD	**:** Harmonic Distortion Rate.
TT	**:** Transformer neutral Earthed.
VD	**:** Voltage Deviation.
MATLAB	**:** MATrix LABoratory (A proprietary simulation software).
MATPOWER	**:** A tool for electric power system simulation and optimization**.**

SYMBOLS

ΔP_{irlos}	: Iron Losses.
I_1, I_2, I_3	: Phase Currents.
I_m	: The Average Current Value.
P_0	: Initial Power.
P_{DG}	: DG Power (kW).
PF_{DG}	: DG Power Factor.
P_L	: Power Load (kW).
P_N	: Rated Transformer Power.
P_c	: Power Consumed.
P_i	: Nominal Power.
P_{ins}	: The Installed Power.
P_m	: Maximum Power.
P_n	: Rated Transformer Power.
P_{sc}	: Short-Circuit Power.
P_u	: Power Used.
Q_{DG}	: DG Reactive Power (kVAR).
Q_L	: Reactive Power Load (kVAR).
S_L	: Apparent Power Load (kVA).
S_a	: Apparent Power.
Z_L	: Line Impedance.
Cos φ	: Power Factor.
P(t)	: Total Power.
X	: Rate of Change.
X	: Reactance of a Conductor (Ω/km)
R	: Resistance of Conductor (Ω /km)

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OPTIMAL PLACEMENT OF MULTIPLE DISTRIBUTED GENERATION UNITS IN A RADIAL DISTRIBUTION NETWORK IN AMMAN-JORDAN

SUMMARY

Keywords – Distribution System, Distributed Generation (DG), Optimal Allocation.

Recently, the Distributed Generation (DG) unit has become more prevalent due to its sustainable approach to generating clean electricity without using fossil fuels. One of the benefits of dealing with the DG is that integration may take place at more minor scales where individuals or businesses produce their power. The DG units are even more difficult when they are not located at optimal locations because improper sizing might lead to increased losses. Integration must be intelligent to guarantee that Distributed Generation units are properly located and scaled in accordance with economic restrictions.Integration must be intelligent to guarantee that Distributed Generation units are properly located and scaled in accordance with economic restrictions.

The concept of the DG is to use tiny electric power stations effectively linked to the electricity grid close to the load; it also increse voltage profile stability and minimize all losses, resulting in lower operating costs, fewer blackouts during peak hours, and a more sustainable electrical grid. units should be deployed effectively and accurately to prevent negative effects on electric networks in terms of voltage profiles and power losses across the system.

This thesis used the Particle Swarm Optimization (PSO) technique to determine the optimal position, power factor, and capacity of the DG units in a 5.6 MW radial system in Amman city. In order to tackle the system's optimization challenge, the particle swarm optimization approach was applied in the Matlab platform. The results for the four distinct power factor (PF) scenarios are presented in the tables and graphs. The results demonstrate that PSO may be utilized effectively for radial distribution system allocation challenges. The PSO algorithm was applied to the Radial Network in Amman, Jordan. This system will be explained in section 3.5 and figure 3.1, shows this system. Section 7 in the thesis shows the results of increasing the system's stability and reducing losses.

The following section will explain other methods writers and researchers have used to solve these problems Using different theories and algorithms.

This thesis supports the Jordanian Electricity Legislations, which aim to:

1. Exploitation and development of renewable energy sources to increase the percentage of their contribution to the total energy and achieve a safe supply of them and encourage investment in them.

2. Contribute to the protection of the environment and achieve sustainable development.

3. Rationalizing energy consumption and improving the efficiency of its use in different sectors.Using the renewable energy DG unit is supporting these Legislation.

This thesis has been divided into seven parts:

The first chapter is the previous one (Introduction). That part introduces the thesis and gives examples of the same idea based on different methods. The second chapter is about the electrical system; it about the electrical grid, then it gives information about electricity generation, electrical transmission, and Amman 51 bus radial distribution system. The third chapter is about the electrical distribution system; this chapter gives information about the MV and LV networks; it has included many sections to explain the MV and LV systems. The fourth chapter explains the PSO algorithm. Chapter five is on distribution substation and distributed generation. Chapter 6 shows the results; this chapter has four cases with all tables and figures. The last chapter is the conclusion, then the appendixes are at the end.

AMMAN-ÜRDÜN RADYAL DAĞITIM ŞEBEKESİNDE DAĞITIK ÜRETİM BİRİMLERİNİN OPTİMAL YERLEŞTİRİLMESİ

ÖZET

Anahtar Kelimeler – Dağıtım Sistemi, Dağıtık Üretim, Optimal Yerleşim.

Son zamanlarda, Dağıtık Üretim (DÜ), fosil yakıtlar kullanmaksızın temiz elektrik üretmeye yönelik sürdürülebilir yaklaşımı nedeniyle git gide daha yaygın hale gelmektedir. DÜ ile çalışmanın faydalarından biri de, entegrasyonun bireylerin veya işletmelerin kendi güçlerini ürettikleri daha küçük ölçeklerde gerçekleşebilmesidir. DG birimleri, optimal konumlara yerleştirilmediklerinde süreç çok daha da güçleşmektedir. Bunun sebebi yanlış boyutlandırma, ve kayıpların artması olabilmektedir. DG birimlerinin çevresel ve ekonomik kısıtlara göre en uygun şekilde yerleştirilmesi ve boyutlandırılması için akıllı entegrasyon gereklidir.

Dağıtık üretim, yük yakınındaki elektrik sistemine doğrudan bağlı küçük elektrik santralleri kullanma fikrinden gelişmektedir. Bu, kayıpları azaltır ve gerilim profillerinde kararlılığı artırabilir. Böylelikle işletme maliyetlerinde azalma, yoğun saatlerde daha az kesinti ve daha kararlı bir elektrik sistemi anlamına gelmektedir. Elektrik şebekeleri üzerindeki gerilim profillerinin ve şebekedeki güç kayıplarının olumsuz etkilerden kaçınmak için, DG üniteleri verimli ve hassas bir şekilde dağıtılmalıdır.

Bu araştırmada, Amman-Ürdün'deki 5,6 MW’lık radyal dağıtım sistemi üzerindeki DÜ birimleri için optimal yerleşimi, optimal güç faktörü ve boyutunu bulmak için Parçacık Sürü Optimizasyonu (PSO) yöntemi kullanılmaktadır. Böylelikle, ortaya çıkan güç kayıpları azaltılarak şebeke gerilim profilleri iyileştirilmiş olacaktır. Sistemin karmaşık optimizasyon problemini çözmek için MATLAB ortamında geliştirilen Parçacık Sürü Optimizasyon yöntemi uygulanmıştır. Farklı güç faktörlerine sahip dört farklı senaryo için sonuçlar tablo ve şekillerde verilmiştir. Sonuçlar, PSO'nun radyal dağıtım sistemi tahsis problemlerinde başarıyla kullanılabileceğini göstermektedir. En iyi senaryo, görünür güçte en büyük düşüşü sağlayan dördüncü senaryo olarak görülmüştür.

PSO algoritması, Ürdün-Amman'daki radyal dağıtım şebekesine uygulandı. Bu sistem bölüm 3.5'te açıklanmakta ve Şekil 3.1’de gösterilmektedir. Tezdeki 7. Bölüm, sistemin kararlılığının arttırılması ve kayıpların azaltılmasına ilişkin detaylı sonuçları göstermektedir.

Sürekli artan talebe ek olarak, dağıtım sistemleri önemli gerilim düşüşleri, yüksek güç kaybı ve düşük gerilim kararlılığı ile karşı karşıyadır. Günümüzde bu endişeler, elektrik üretim ve ulaşım sektörlerinde dağıtık jeneratörlere olan ilgiyi artırmıştır. (DG) üniteleri, yüksek güvenilirlik ve etkinliklerinin yanı sıra iletim ve dağıtım hatlarındaki yükü hafifletme potansiyelleri nedeniyle elektrik piyasalarında genel bir başarıdır.

Dağıtılmış üretimin geleneksel şebekelere dahil edilmesi, gücün şebeke içinde çift yönlü olarak akmasını sağlar. Buna göre, olumsuz şebeke etkilerini önlemek için DG üniteleri önemli bir çalışmadan sonra dahil edilmelidir. Şebeke boyunca DG'lerin doğru konumunu ve miktarını belirlemek, kayıpları azaltmak ve gerilim profilini iyileştirmek için en popüler ve yaygın olarak kullanılan yöntemdir.

Son araştırmalar, DG'nin en iyi düzenini aşağıdaki sırayla belirlemeyi amaçlamaktadır: Ullah ve arkadaşları, kayıpları azaltmak ve gerilim profilini iyileştirmek için (PSO) ve (PPSO) algoritmalarını kullanarak DG ünitelerinin optimum konumunu ve kapasitesini bulmak için bir analiz yöntemi sunmaktadır.

Montoya ve diğerleri, DG'lerin ideal konumunu ve kapasitesini belirlemek için, sorunun karma tamsayılı doğrusal olmayan programlama (MINLP) olarak tanımlandığı bir BONMIN çözücüsü ile genel bir cebirsel modelleme yaklaşımı (GAMS) önermiştir. Essallah ve arkadaşları DG'lerin optimum tasarımı için yeni bir teknik sunmuşlardır. Bu teknikte bilim insanları ideal yerleşimi bulmak için Gerilim-Kararlılık Marji-İndeksi (VSMI) yöntemini ve optimum kapasiteyi tahmin etmek için MATLAB-eğri-eşleştirme-ilk tahminini kullanmışlardır. Bulanık mantık tekniği Magadum ve Kulkarni tarafından DG'lerin uygun konumunu ve boyutunu bulmak için sunulmuştur. [9]. Genetik algoritma, DG'lerin optimum inşası için araştırmacılar [6 ve 10] tarafından sunulmuştur. Davda ve Parekh, DG entegrasyonunun dağıtım şebekesi üzerindeki etkisini araştırmıştır. Yaklaşımları, DG'lerin uygun konumunu ve boyutunu belirlemek için CYMDIST'de geliştirilmiştir [11, 12].

Bu tez, aşağıdakileri amaçlayan Ürdün Elektrik Mevzuatını desteklemektedir:

1. Yenilenebilir enerji kaynaklarının toplam enerjiye katkı oranını artırmak, güvenli bir şekilde tedarik edilmelerini sağlamak ve bu kaynaklara yatırımı teşvik etmek için bu kaynakların kullanılması ve geliştirilmesi.

2. Çevrenin korunmasına katkıda bulunulması ve sürdürülebilir kalkınmanın sağlanması.

3. Enerji tüketiminin rasyonelleştirilmesi ve farklı sektörlerde kullanım verimliliğinin artırılması. Yenilenebilir enerji kullanan DG birimi bu Mevzuatı desteklemektedir.

Bu tez yedi bölüme ayrılmıştır:

İlk bölüm bir önceki bölümdür (Giriş). Bu bölümde tez tanıtılmakta ve aynı fikrin farklı yöntemlere dayalı örnekleri verilmektedir. İkinci bölüm elektrik sistemi hakkındadır; elektrik şebekesi hakkındadır, daha sonra elektrik üretimi, elektrik iletimi ve Amman 51 bus radyal dağıtım sistemi hakkında bilgi verir. Üçüncü bölüm elektrik dağıtım sistemi hakkındadır; bu bölüm OG ve AG şebekeleri hakkında bilgi vermektedir; OG ve AG sistemlerini açıklamak için birçok bölüm içermektedir.

Dördüncü bölüm PSO algoritmasını açıklamaktadır. Beşinci bölüm dağıtım trafo merkezi ve dağıtık üretim üzerinedir. Altıncı bölüm sonuçları göstermektedir; bu bölümde tüm tablo ve şekillerle birlikte dört vaka bulunmaktadır. Son bölüm sonuç bölümüdür, ardından ekler yer almaktadır.

Bu tezde, dağıtım şebekesindeki kayıpları en aza indirmek için dört farklı duruma göre farklı sayıda DG ünitesi için güç faktörü, konum ve boyutlandırmanın optimum planlaması için PSO algoritması önerilmiştir.

Sonuç tabloları, 4. durumda 5 DG ünitesinin kullanılmasının, görünür güç azalmasına göre dağıtım şebekesine entegrasyon için en iyi seçim olduğunu göstermektedir.

Ayrıca, üçüncü durum (PSO algoritmasına dayalı Optimal Güç Faktörü ve Optimal DG Konumu ile Çalışan DG Ünitesi) için sonuçlar ilginçtir, 5 DG ünitesi kullanmak görünür güç azalmasını %94,26'ya çıkarmaktadır. Sonuçlara göre, en düşük görünür güç azalması %50'den fazla olduğu için, üç farklı senaryoya sahip dört farklı durumun gerçek hayatta kullanılabileceği söylenebilir.

Diğer algoritmalarla karşılaştırıldığında, simülasyonlarda kullanılan algoritma en basit ve en verimli olanlardan biridir ve MATPOWER ile MATLAB programı 2022 öğrenci sürümünde kullanılmıştır.

En az kayıpla (DG'ler) için ideal konumun seçilmesinde PSO algoritması etkinliğini ve hızlılığını göstermiştir. Sonuç olarak, dağıtılmış jeneratörlerin optimum konumda, boyutta, güç faktöründe ve yüklere yakınlıkta bulunması nedeniyle kayıplar en aza indirilmiştir.

51 otobüslü radyal dağıtım sistemi Amman'ın bir bölgesinden toplanmıştır.

Sistemde PSO optimizasyon algoritması başarılı bir şekilde uygulanmıştır. Sonuçlar DG üniteleri ile ve DG üniteleri olmadan karşılaştırmalı olarak verilmiştir. Optimum tahsis ve büyüklük belirlendikten sonra, Tablo 6.1,6.2,6.3 ve 6.4 aktif ve reaktif güç kayıplarındaki azalmanın dört durumda da %80'den fazla olduğunu ve bu çalışmanın başarılı olduğunu göstermektedir.

Önceki bölümlerde gösterildiği gibi bu çalışma Ürdün Elektrik Şirketi yönetmeliklerinin amaçlarını desteklemektedir:

- Toplam enerjiye katkılarını artırmak, bu kaynakların güvenli bir şekilde tedarik edilmesini sağlamak ve bunlara yatırımı teşvik etmek için yenilenebilir enerji kaynaklarının kullanılması ve geliştirilmesi.

- Çevrenin korunmasına katkıda bulunmak ve sürdürülebilir kalkınmaya ulaşmak.

- Enerji tüketiminin azaltılması ve çeşitli alanlarda kullanımının etkinliğinin artırılması.

Bu yaklaşım herhangi bir sayıda DG'ye uygulanabilir.

Yenilenebilir enerji kaynaklarına sahip şebekeden bağımsız radyal sistemler genellikle kararsızdır ve birçok olası kesintiye sahiptir; bu tezin 5.2 bölümünde gösterildiği gibi DG ünitelerinin avantajı, şebekeden bağımsız sistemleri daha kararlı ve kesintisiz olacak şekilde iyileştirebilir. Bu tez, gelecekte farklı durumlara sahip şebeke dışı sistemler için yeni senaryolara sahip olacak şekilde geliştirilebilir.

1. INTRODUCTION

In addition to the ever-increasing demand, the distribution systems are experiencing significant voltage dips, high power loss, and low voltage stability [1, 2]. Currently, these concerns have increased interest in distributed generators in the power generating and transportation industries [3]. (DG) units are overall achievement on the electricity markets due to their high dependability and effectiveness, as well as their potential to alleviate strain on transmission and distribution lines [4].

Incorporating distributed generation into traditional networks enables power to flow bidirectionally inside it. Accordingly, DG units must be incorporated after considerable study to prevent negative network effects [5]. Determining the correct position and amount of DGs across the network [6] is the most popular and widely utilized method for reducing losses and enhancing voltage profile.

Recent research aims to identify the best arrangement of DG in the following order: Ullah et al. provide a method of analysis to find the optimal location and capacity of DG units using the (PSO) and (PPSO) algorithms in order to decrease losses and enhance the voltage profile [7] .

To determine the ideal position and capacity of DGs, Montoya et al. [3] suggested a general algebraic modelling approach (GAMS) with a BONMIN solver where the issue was identified as mixed-integer nonlinear programming (MINLP). Essallah et al. introduced a novel technique for optimal design of DGs in which scientists utilized the Voltage -Stability Margin- Index (VSMI) method to find the ideal placement and MATLAB –curve- matching –initial guess to estimate the optimal capacity [8]. The fuzzy logic technique has been presented by Magadum and Kulkarni to find the appropriate position and size of DGs [9]. The genetic algorithm has been presented by researchers [6 and 10] for the optimum construction of DGs. Davda and Parekh investigated the impact of DG integration on the distribution network. Their approach was developed in CYMDIST to determine the appropriate position and size of DGs [11, 12].

This thesis used the Particle Swarm Optimization (PSO) technique to determine the optimal position, power factor, and capacity of the DG units in a 5.6 MW radial system in Amman city. In order to tackle the system's optimization challenge, the particle swarm optimization approach was applied in the Matlab platform. The results for the four distinct power factor (PF) scenarios are presented in the tables and graphs. The results demonstrate that PSO may be utilized effectively for radial distribution system allocation challenges. The PSO algorithm was applied to the Radial Network in Amman, Jordan. This system will be explained in section 3.5 and figure 3.1, shows this system. Section 7 in the thesis shows the results of increasing the system's stability and reducing losses [12].

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2. ELECTRICAL GRID

The electrical grid is a set of one or more power lines transporting electrical energy from generation centers to electricity consumers. Power lines operated at different voltage levels connected in substations. Substations allow it to distribute electricity and pass it from one line to another with the transformers.

An electrical network must also ensure the dynamic management of the whole electrical generation transmission, distribution, and consumption, implementing adjustments to ensure the system's stability.

Electrical energy is transported in high voltage or even very high voltage.

The distributor is obliged to solve any electrical problems. Thus, electricity distribution system operators are required to comply with the fundamental aspects of electricity supply, which are summarized as follows:

- Continuity of supply, where the distributor should ensure the availability of electricity at all times [13].
- Power quality (voltage and frequency quality).
- Quantity of the product, the distributor is contractually bound to respect a specific range of voltage variation around the nominal voltage (± 5% for the LV network in urban areas and ± 10% for the LV network in rural areas).

The electrical system in Jordan includes the main generating stations and transmission networks with a voltage of 132 and 400 kV that connect these stations with load centers in various regions of the Kingdom, in addition to the 400 kV interconnection line with Syria and the 400 kV submarine cable that connects the Jordanian network with the Egyptian grid, in addition to the National Control Center as well as the distribution networks that feed (99.9%) of the population.

The electrical system in Jordan also includes some private generating stations that can be synchronized with the other generating stations in the unified system and other private generating stations that serve their owners only and are not connected to the unified system.

The capacity of the generating stations operating in the electrical system was about 3186 MW at the beginning of 2012, but this capacity decreased to about 2900 MW during the summer due to high temperatures and in conjunction with the maximum load. The total length of the operating transmission lines with a voltage of 132 kV and above was (4121) km-circuit. The total installed capacity in the primary substations is (10303) MVA [13].

2.1. Electrical Transmission

2.1.1. Transportation and dispatch systems

The first of these systems is the transmission system, from 63 kV to 400 kV. The electrical networks have mesh and radial architecture. These structures allow increased operational safety when opening a line; having these mesh or radial structures allow the power flow to find a new path to bypass this faulty line and thus guarantee the continuity of the power supply downstream of the problem.

From the topographical and geographical point of view, the transmission networks are ensured, interconnections between regions at the national level and the changes (generate/consume) of electrical energy at the international level [14].

The second voltage level is the distribution network (MV), which ensures the transport of electricity reserves composed of energy drawn from the transmission network and smaller-scale production to consumption areas and some large industrial customers directly connected to it. These networks are mostly made up of overhead lines, each of which can transmit more than 60 MVA over distances of a few tens of kilometers. Their structure is either a closed loop or, most often open loop, but they can also end at certain transformer stations. These networks can be underground in crowded city areas for lengths not exceeding a few kilometers.

These networks supply the distribution networks through HV/MV transformer stations on the one hand and industrial users whose size (greater than 60 MVA) requires connection to this voltage on the other.

2.1.2. General characteristics of electrical transport

The vast majority of electricity grids transport electrical energy under the shape of three-phase systems; the arrangements and sizes characteristic of these systems are:

- Frequency: In the world, two distinct frequency values:
- 50 Hz characterizes European, Asian, Russian and Russian networks and African.
- 60 Hz characterizes American, Canadian, and Japanese networks
- Voltage levels [14].
- Different types of coupling.

2.2. Source Position

Source stations, generally fed by the HV network (sometimes directly through the transmission network at 63kv, 90kv, or 225kV), are the interface between the transmission/dispatch networks and distribution networks. They are constituted in case initial of a transformer powered by an MV and supplying itself or bus bars. In the second case, with the increase in service, a second transformer is added, and the substation is usually connected to a second arrival MV called "line guarantee." The third (and sometimes more) transformer is added to the double fastener in the final case.

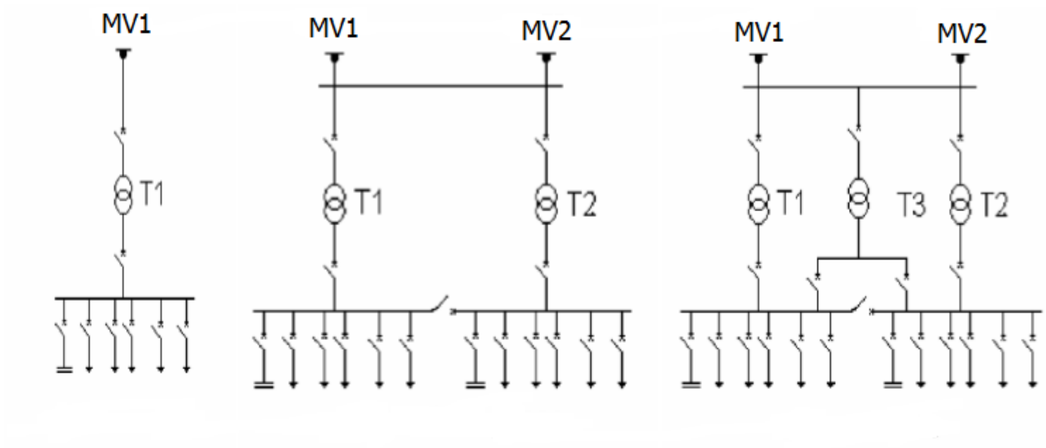

Figure 2.1. Schematic Diagrams of HV Source Stations.

The source post contributes to the following:

1. Measurement of energy flows (energy metering equipment).
2. At the price change by the centralized remote control
3. The security of the transmission network by the load shedding system.
4. To the quality and switched power supply by the automatic resetting, voltage adjustment, and reagent compensation systems.

2.3. Source Protection

The systems for protecting, commanding, and controlling source stations have evolved in technical stages. That indirect protection (electromechanical, then electronic) was succeeded by the analog level, whose deployment began in 1986. At the same time, digital technology was entering the source station's highly disruptive (electromagnetic) environment; initially, it was confined to modular command and control equipment: state recorder, local driving synoptic, remote control equipment, and emission management PLC at 175 Hz. The new structures must be equipped and replace old equipment requiring maintenance in operational conditions too expensive. This choice of digital technology for protections, PLCs, remote signaling, remote control, and telemetry aims to facilitate changes to the protection plan and to gain system reliability. The use of computer maintenance and configuration tools will facilitate interventions.

2.4. Distribution Networks

In Jordan, the nominal voltage of the MV distribution networks is 11 kV and 33 kV. This network supplies all customers mainly connected to this network; a Distribution System Manager manages its operation. Distribution networks mainly have a radial structure. Unlike a mesh structure, a radial structure is a tree structure; this tree structure considerably simplifies the protection system since the power transit is done unilaterally from the source station (HV / MV) to the (MV/ LV) substations and end consumers. This allows, in particular, the rapid localization and elimination of faults and the metering of energy at the source stations.

This structure is, therefore, ideally suited to a vertically integrated system in which production is centralized, and consumption is distributed. I will use single-line diagrams to represent my model and to do network analyses [14].

2.5. Network Topological Structures

2.5.1. Radial network

If the energy transported by a grid to the customers reaches it in a single journey, it is called radial distribution.

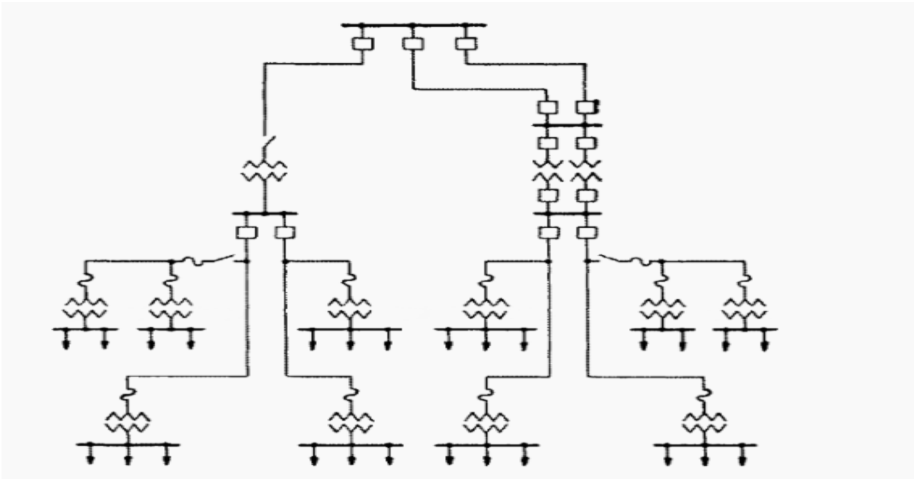

Figure 2.2. Diagram of a Radial Network.

2.5.2. Mesh network

Mesh networks are networks where all lines are looped, thus forming a structure analogous to the mesh of a net. They are used for low-voltage distribution networks and transmission networks [14].

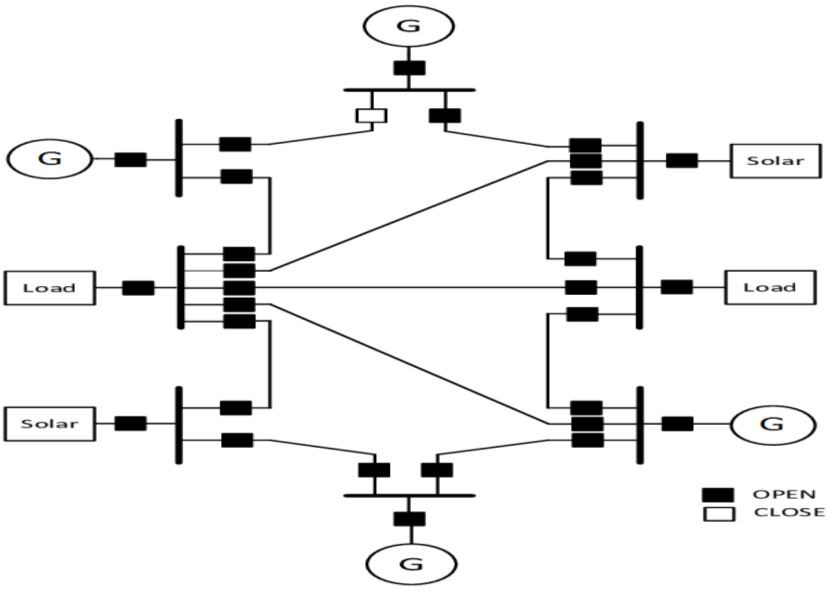

Figure 2.3. Diagram of a Mesh Network.

2.6. Overhead and Underground Power Lines

Electricity is distributed using overhead lines and underground cables. The choice of an overhead line in some cases or an underground cable in others depends on various factors: technical possibilities, the topology of the site, high costs of underground lines, as well as landscape protection and security of supply issues [14].

2.6.1. Overhead power lines

An overhead line consists of poles or pylons supporting isolated electrical circuits formed by three conductors. Insulators fix the conductors. These conductors are bare solid copper, have a cross-section of up to 50 mm^2, and are formed by a set of twisted wires for larger sections.

2.6.1.1. Overhead line towers

There are various types of construction for overhead line towers.

1. Wood poles:

The wood species used are almost always softwoods that are impregnated with antiseptic products to protect them against biological attacks by insects and fungi for more precision.

This standard sets the conditions relating to wood (pine, fir, spruce, Douglas fir, or larch), the methods of treatment of the poles, and their reception conditions [15].

2. Reinforced concrete columns:

Reinforced concrete columns are usually made by casting, including a longitudinal frame of steel rounds held by stirrups. The reinforcement is placed in the mold and suitably positioned using concrete wedges; this operation needs to be done with great care to avoid decentralization detrimental to the conservation of the pole (insufficient concrete covering) and its mechanical behavior.

3. Steel poles:

Whatever the effort applied, steel tubes and profiles lend themselves naturally to the manufacture of any kind of support or support element that can be desired (armament fittings for wood and concrete supports, posts formed of a simple iron beam or more complicated section, lattice pylons of all shapes and sizes). One of the exciting features of steel compound assemblies is that they can be transported and assembled by elements since their assembly is almost always carried out by bolting. In an element, some bar assemblies can be made by welding. This technique is frequently used on pylons made of tubular elements, where the realization of junction parts is very complex.

4. Aluminum alloy poles:

Some aluminum alloys (magnesium and silicon) have been used for constructing pylons, almost always in regions defined either by their aggressiveness (seaside or proximity to steel or chemical complexes) or their difficulties of access.

2.6.1.2. Conductor cables

To carry the current, conductive cables are carried by the pylons. The current used is three-phase. There are three cables (or cable harnesses) conductive per circuit. The lines are either single (one circuit) or double (two circuits per line of pylons). Each phase can use up to 4 conductive cables, called harnesses.

Conductor cables are "bare"; the air provides, i.e., their electrical insulation. The distance of the drivers from each other and the ground ensures that the isolation is well maintained.

Copper conductors are used less and less. Aluminum conductors or aluminum-steel alloys are generally used; there are also conductors composed of a central steel core on which aluminum strands are braided [15].

2.6.1.3. Cable guard

Guard cables do not conduct current. They are located above the conductors. They act as lightning rods above the line, attracting lightning strikes, and avoiding the lightning of drivers. They are usually made of steel. In the center of the steel, a rope is sometimes placed as a fiber optic cable that serves the operator's communication [15].

Figure 2.4. Optical Fiber Inserted into a Guard Cable.

2.6.1.4. Insulators

The insulation between the conductors and the pylons is provided by insulators (chains of isolators). These are made of Glass, ceramic, or synthetic material. Glass or ceramic insulators usually have a plate shape. They are combined to form chains of isolators. The higher line voltage means a more significant number of insulators in the chain.

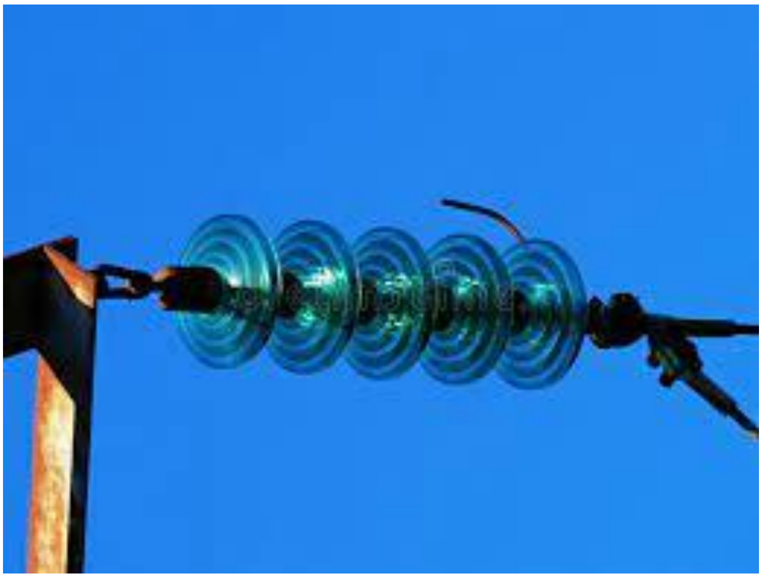

Figure 2.5. Glass Insulator.

2.6.1.5. Lightning arresters

Surge arresters are devices designed to limit the overvoltage imposed on transformers, instruments, and electrical machines by lightning and switching maneuvers. The upper part of the surge protector is connected to one of the wires of the line to be protected, and the lower part is connected to the ground by a low resistance grounding, usually less than one ohm.

Figure 2.6. Lightning Arrester.

2.6.1.6. Circuit breakers

A circuit breaker is intended to establish, support and interrupt currents, under its rated voltage (maximum mains voltage), under normal operating conditions and under specified abnormal conditions (short circuit). It is the protective device par excellence, capable of total intervention capacity without causing excessive overvoltage on the network [15].

Figure 2.7. Circuit Breaker.

2.6.1.7. Fuses

It is used either directly as a shut-off device or indirectly, connected to the secondary circuit of a current transformer, with a fusion contact giving a trip order to the circuit breaker. The major disadvantage of these devices is that they are damaged by defects and have low sensitivity. The operator must have many replacement fuses for the different calibers. The wide variety of electrical networks requires models of fuses of different types depending on the application [15].

These are:

- Interior-type fuses installed in MV panels upstream of transformers,
- External-type fuses for overhead transformers.
- Fuses immersed in the transformer tank.

Figure 2.8. Fuse.

2.6.2. Underground lines

The structure of underground networks is only one type of line: the ridges. These networks of short length and high cross-section of conductors are the seats of reduced voltage drop. As a result, and considering the incidents' importance, the provision will be made for resupply by neighboring networks or an emergency cable [15].

Figure 2.9. Underground lines.

2.6.3. Comparison between overhead and underground lines

Overhead lines are cheaper than cables. In the case of high voltage, some problems arise for long stretches of cable. On the other hand, cables are better protected against external damage (lightning, storm) than overhead lines. Failures are more quickly detectable on overhead lines. Repairs are simple for overhead lines; for cables, on the contrary, they require hard work. Overhead lines can still disturb the landscape [15].

2.7. Categories of Loads

Depending on the nature of the Loads, it could be classified depending on the blackout into three main categories:

- The first category: In this class, loads like hospitals and military zones allow less than two seconds of a blackout.
- The second category: For this class, loads, like factories, accept a blackout of fewer than two hours.
- The third category: In the latter category, the blackout may last more than 24 hours, like street lighting and homes [16].

3. ELECTRICAL DISTRIBUTION SYSTEM

Electrical distribution networks are essential in the electrical energy flow, which begins at generation plants and ends at private or industrial customers. Therefore, distribution networks distribute electrical energy from high-voltage substations to customers, adapting the voltage level if necessary [17].

3.1. The MV Network

The MV network is made up of all outputs from source positions. The number of outputs per source position varies from less than ten to fifty. The MV outputs supply the substations of customers connected with MV and the so-called MV/LV substations used to supply low-voltage customers.

The MV considering:

- The relatively low consumption load density in rural areas requires prolonged MV outputs. The 20 kV bearing made it possible to supply points far from existing source stations without excessive voltage drop and thus limited the number of HV/MV injections to be created.
- The possibility of reusing a significant part of the structures built according to the old 15 kV level, particularly underground HV cables in urban or peri-urban areas.
- Limited technological developments, compared to the 15kV bearing, make it possible to control the supply costs of new 20 kV equipment.

The general rule construction, the framework of an output MV is closed to allow for replenishing the customers following a cut due to an incident. This loop is also used to ensure the rescue of the source substation.

The protection regime of MV networks is grounding the neutral at a single point, to the HV / MV transformer of the source substation, via a resistor.

This arrangement must be gradually replaced by the compensated neutral technique (continuously variable impedance depending on the characteristics of the network). The neutral is, therefore, not distributed on the MV network [17].

Urban areas are served underground and rural areas (low density of electricity consumption) are fed by overhead or mixed lines - partly underground, partly overhead.

3.2. Composition Output of MV

The MV output cell comprises a part of bars powered by the HV transformer, the circuit breaker, which is the means of cutting, and the protection, which is composed of relays intended to receive the settings to be displayed which will subsequently control the operation of the circuit breaker (opening and closing), therefore supply or cut the electrical energy supply. Some disconnections are used to isolate the circuit breaker for possible maintenance actions [18].

3.3. The LV Network

The LV network is made up s from MV/LV transformer stations. Except in exceptional cases, the best structure is the simplest: less connectivity possible, less length possible. Some cutting points are nevertheless made and serve, among other things, to connect a generator. No looping is normally carried out on the LV network, as any additional length entails capital expenditure and an increased risk of incidents.

A rural substation, on a pole or in a simplified cabin, can supply one or two LV outputs. An urban station in a cabin, underground, or building can supply from one to eight outputs. The intensity limits the length of LV outputs, and permissible voltage drops 100 to 200 meters underground and a few hundred meters overhead.

In areas supplied underground, a MV/LV transformer station can serve:

- 120 to 150 individual houses (50 to 60 with electric heating).
- 250 to 300 dwellings in grouped collective buildings (100 to 130 with electric heating).

Overhead lines are constructed of bundles of insulated conductors on poles or facades. The structure of the LV network is radial, like the MV network. Emergency links between LV lines are reserved for exceptional cases. The protection mode is of the type.

"TT" transformer is neutral earthed, with networked neutral, neutral, and metal masses grounded by separate sockets [19].

The normalization of the LV voltage gave rise to significant voltage change programs between the 50s. They have led to the almost complete disappearance of the B1 127/220V voltage (less than 1 per thousand MV/LV substations delivers B1).

The LV connection is the structure between the LV network and the origin of the user's indoor installation. It serves only one user. The connections are made in single-phase (2 wires - 90 A), unless the needs of the user require it (three-phase machine) or if the network is not of sufficient capacity to serve in good conditions the power in single-phase.

At the point of connection of the connections to the LV network, there is no switchgear.

Since a user's power supply must be interrupted from the public domain, the cut-off point is located at the edge of his property. It usually consists of a set of fuses placed upstream of the count.

The service circuit breaker is a multi-function device that provides the following:

- Protection against short circuits.
- Differential protection.
- The cut-off functions at the border point between the network and inland installation.
- The function of limiting the demand to the value of the subscribed power.

3.4. Electricity Distribution Network Planning

The problem with planning electricity distribution networks is to develop the network at a lower cost in order to ensure the supply of consumers while respecting the following requirements:

The reliability and quality of the electricity supplied. This part defines all the planning objectives taken into account for the design of the distribution network architecture. This part begins with a description of the reliability criteria expressed in indices.

It presents the electro-technical criteria, and the end of this section is the presentation of the economic criteria [19].

3.4.1. Reliability indices

The SAIFI (System Average Interruption Frequency Index) reflects the system's frequency of defects (outages) by year and by customer. It can be calculated in an elementary way for a section (part of the network) bounded by two blackout organs using equation (3.1).

$$SAIFI_i = \frac{(Nbr\ customers\ cut)_i * (Nbr\ cuts)_i}{(Total\ number\ of\ customers)_i} \quad (3.1)$$

In equation (3.1), I use the ratings The National Board of Revenue "Nbr customer cuts," which is the number of customers who have blackout per year on this section, "Nbr cuts," which is the number of total cuts per year and "Total number of customers" which is the total number of customers still on the section considered.

In this case, if some consumers have electrical blackout more than once, each denomination is considered independent. Thus, SAIFI indicates how many times a year there have been cuts in the power supply of an average consumer. (SAIDI) gives the average duration of interruption of supply to a final consumer in a supply section of the network operator during the period considered. It is calculated by the formula (3.2).

$$SAIDI_i = \frac{(\text{Duration of the cut off})_i * (Nbr\ customers\ cut)_i * (Nbr\ \ cuts)_i}{(Total\ number\ of\ customers)_i} \quad (3.2)$$

The SNE index represents the Undistributed Energy during the duration of the blackouts (cut) per year for all customers in section i. This index is expressed by the formula (3.3) [19].

$$END_i = \frac{(Power\ off)_i * (\text{Duration of the cut off})_i * (Nbr\ cuts)_i}{(Total\ number\ of\ customers)_i} \quad (3.3)$$

It is evident that the lower the values of SAIFI, SAIDI, and END, the higher level of security of supply for customers. These criteria for evaluating network reliability may vary depending on network components such as blackout devices, location, topology, line length, and network operation.

However, these indicators are more than just a criterion for assessing the required level of reliable network operation. The index can also be defined, which combines the amount of power served and the total length of the customers' supply area. In other words, each network area has a specific length, L, and particular consumer demand for power P.

In order to have fair treatment and to limit the penalization of large quantities of customers by a high number of defects (statistically proportional to the length of the lines), the values of the product P×L (power × length) of each zone must not be very different.

3.4.2. Electrical criteria

In addition to the reliability criteria presented above, the electro-technical constraints of supply quality (maximum currents or voltage plan, presented in the following sections) must be respected [19]:

- Maximum current in a conductor:

The maximum current that a steady-state conductor can sustain is called permissible current. It depends on the conductor's cross-section and the maximum insulation temperature depending on external conditions. The resistance of the cable depends on the surface of the cable section. The larger the surface area of the cable section, the lower its resistance; therefore, the higher the current carrying capacity for the same Copper losses. Similarly, the higher the permissible temperature (or the permissible temperature increase over a set ambient temperature), the higher the current carrying capacity will be for the same section.

- Power Losses

The electrical losses, called the Copper effect, are related to the release of heat caused by the passage of an electric current in a conductor opposing its resistance.

For a conductor of linear resistance R (Ω/km), length L (km), traversed by a current I, and for some time Δt, power losses, and energy losses are expressed by formulas (3.4) -(3.5).

$$Losses_{power} = RI^2 \quad (W) \tag{3.4}$$

$$Losses_{Energy} = RI^2 \, \Delta t \ \ (W.h) \tag{3.5}$$

One of the planning objectives taken into account in this work is the minimization of total power losses in the conductors of the network. Voltage profile:

The voltage difference between two points in a circuit is designated by the voltage drop. Let Z_{ab} be the complex impedance of the conductor between nodes a and b and I_{ab} the complex current flowing from a to b. According to the generalized Ohm's law ΔV_{ab} is expressed by equation (3.6) [19].

$$\Delta V_{ab} = Z_{ab}.I_{ab} \quad (3.6)$$

Z_{ab}: Complex impedance.

I_{ab}: The complex current.

ΔV_{ab}: Voltage drop.

This voltage drop is proportional to the current flowing through the conductor multiplied by its impedance. In the case of a network with conventional loads, without decentralized production and few cables, the voltage recorded at the consumer nodes is lower than the voltage recorded at the source substation. One of the constraints on the operation of the network is the voltage profile. The laws require that the voltage on the medium-voltage distribution network remains within the limits of +/- 5% of the nominal voltage.

3.5. Amman 51 bus Radial Distribution System

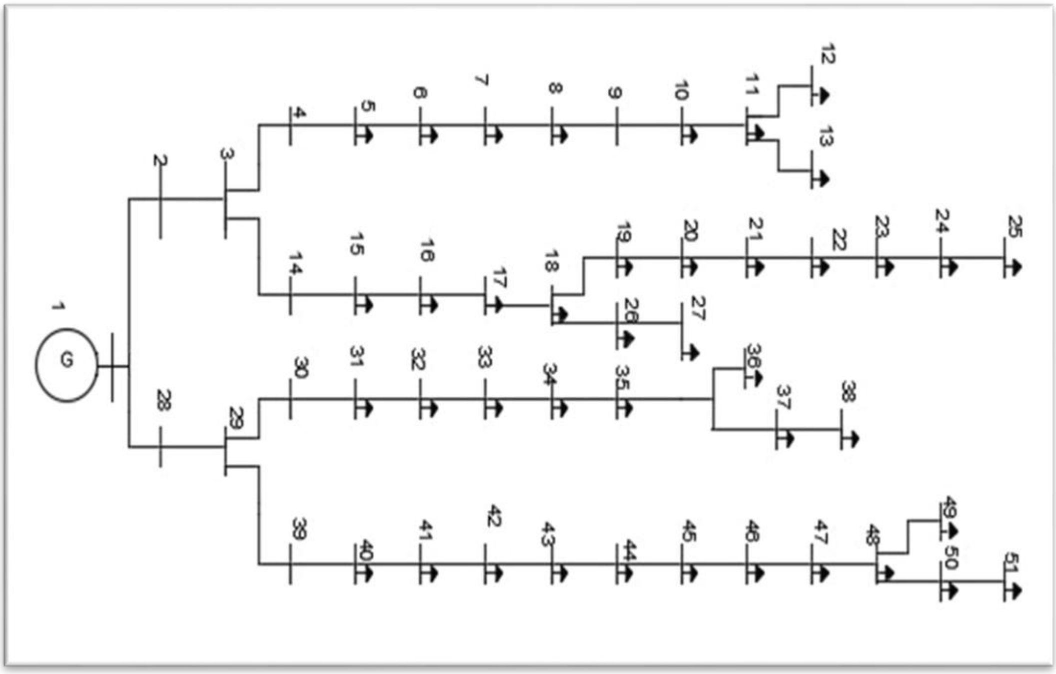

Figure 3.1. Single line Diagram of 51 bus Radial Distribution System in Amman.

The single-line diagram 51-bus radial distribution system illustrated in Figure 3.1 was chosen. The system's design requires a 35 kV operational voltage, 138.56 MVA, and 50 Hz frequency. Table [8.1] in the appendix gives the load and impedance for each bus. Without DG, it has 5.6 MW of total actual losses and 1.1 MVA of total reactive power for the system. It has total power losses without DG: 103.9 kW and total Reactive Power without DG: 202.3 kVAr.

This system located in the East of Amman city, it is radial system. This type of systems usually feed electric to a small area. As shown in Table 8.1 the largest distance is 8.21 km. It is between bus 1 to 2 and bus 1 to 28 both having the same distance.

After a field study, Jordanian Electric Company supplied us with different schemas. The system above is chosen for the tests since all the data are known with a radial topology at appropriate distances. This study will prove that the selected system is very convenient for optimization studies. That system will also be a candidate for other power distribution system studies.

4. PARTICLE SWARM OPTIMIZATION

The Particle swarm optimization (PSO) algorithm was developed in 1995 by James Kennedy, a psychologist, and sociologist, and Russell Eberhart, an electrical engineer. The technique is based on a group of “swarms “of elements randomly dispersed across a specified region to find the optimal solution within this space. The origins of this algorithm can be traced back to the term "artificial life," which dates back to the early 20th century and refers to the study of manufacturing systems that possess the essential characteristics of life, such as modeling the movement of birds or ants in the construction of colonies. There are two primary subdivisions of this term:

- Studies concerned with applying computational approaches to modeling biological events.
- Studies focused on biological processes and how to correctly apply them to solve computer issues, such as genetic algorithms and artificial neural networks [20].

The "flocks of birds" algorithm falls under the second category. However, it differs little from genetic algorithms, as it focuses on a different sort of biological system based on the cooperative behavior of individuals during their contact with their environment and one another.

To explain the PSO algorithm, this thesis will use the following illustration: there is a flock of birds searching for food in a specific area, where food is randomly distributed, and the birds do not know the exact location of the food; therefore, the best way to search for food is to disperse all the birds in the area and have them communicate with one another about the location of the food.

This is precisely what the algorithm does, as each bird within the algorithm is referred to as an element - or particle - and each element has a fitness value - or fitness value - and this value indicates the appropriateness of solving this element relative to the other elements, as this process is carried out with the assistance of a function known as the fitness function.

The objects' speeds also guide them in their pursuit of food. Several fundamental variables are used to process the information: the best trapping value recorded by the element and indicated as $pbest$, the best suitable value recorded inside the $gbest$ swarm, and the value of the best local location of an element relative to locally neighboring elements $Ibest$.

After determining the values of these variables, the following equations are used to modify the speed and position of the objects with each iteration:

$$v_{i+1}\{\,\} = v_i + c_1 * rand\{\,\} * (pbest\{\,\} - present_i\{\,\}) + c_2 * rand\{\,\} * (gbest\{\,\} - present_i\{\,\}) \quad (4.1)$$

$$present_{i+1}\{\,\} = present_i\{\,\} + v_i\{\,\} \quad (4.2)$$

The velocity of the element, the acceleration coefficients, and the location of the current element are represented by v, c, and present, respectively.

As shown, the first equation calculates the speed of the element based on multiple factors: the instantaneous speed in the previous iteration plus the value of the difference between the best suitable value of the element ($pbest$) and the current position, multiplied by acceleration coefficients and a random number between 0 and 1 (0.1). The second equation allows us to calculate the new element's position based on its previous speed and location. Algorithm (bird flocks) in straightforward steps:

The algorithm can be broken down into three primary steps:

- Determine the value of suitability for each element and the value of overall suitability.
- Update relevance values.
- Update the velocity and position of each object [21].

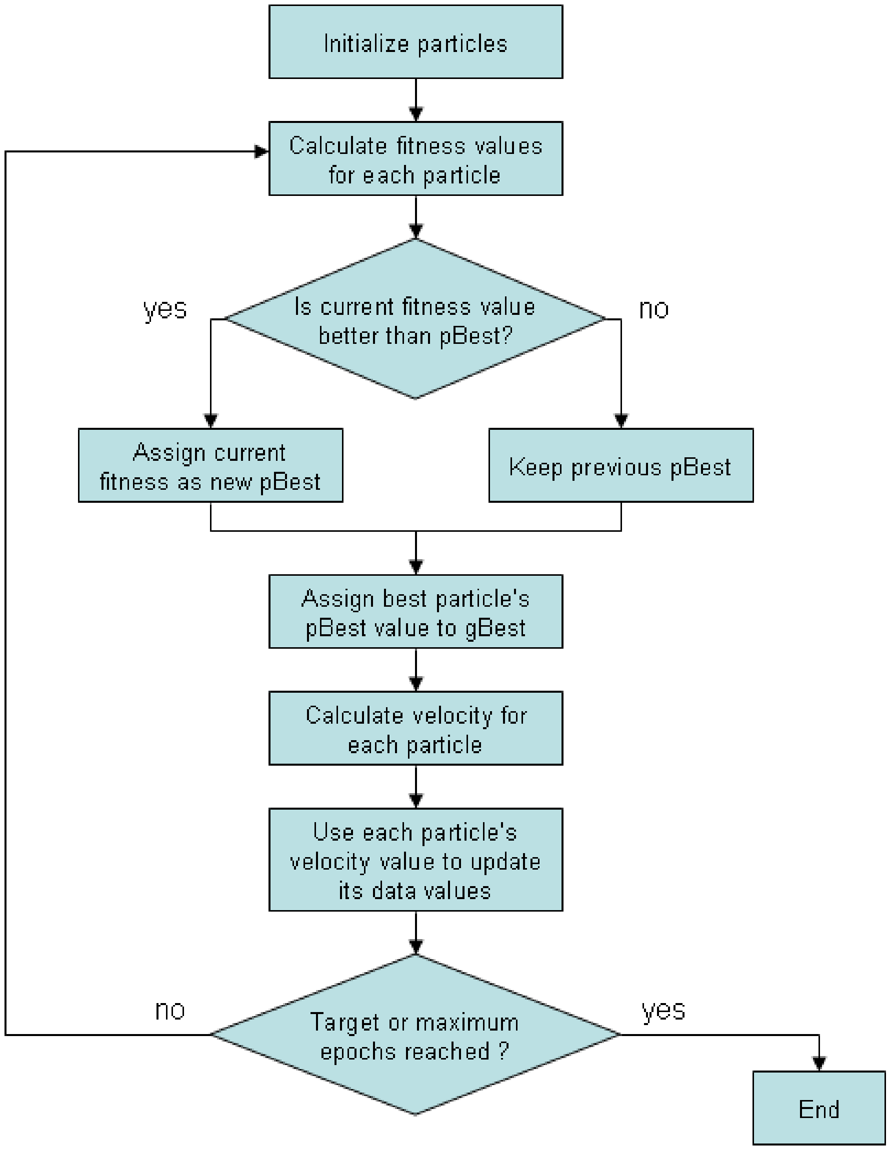

Figure 4.1. Flow Chart of the PSO Method.

The preceding figure depicts the algorithm's organizational structure. All elements are initially defined and assigned initial values. After calculating the suitability values for each element, the following condition is examined: "Is the current fit value greater than the prior one?" Then, we substitute the new element fit value for the overall swarm fit value, calculate the speed of the element, and determine whether the element has arrived at the optimal solution or not; if the element has arrived, the algorithm concludes, but if it has not, it begins again from the stage of calculating the new fit value. After becoming familiar with the algorithm's operation, this thesis found it basic and easy to develop and implement [21].

Model:

- In particle swarm optimization, each particle has an associated position, velocity, and fitness value.
- Each particle maintains a record of its best fitness position and bestfitness value.
- A record of the global best fitness position and global bestfitness value is kept[22].

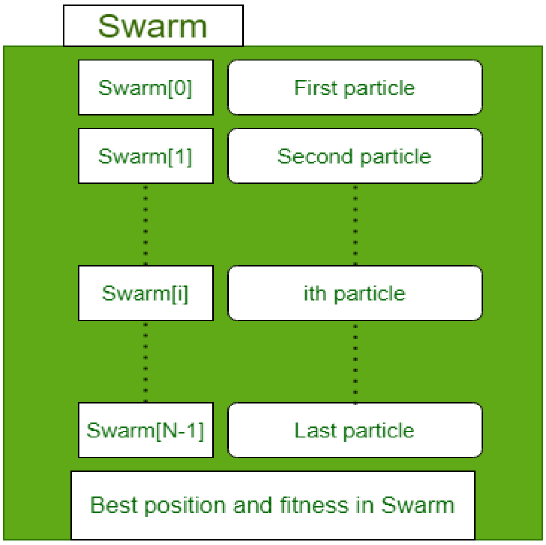

Figure 4.2. Data Structure to Store Swarm Population.

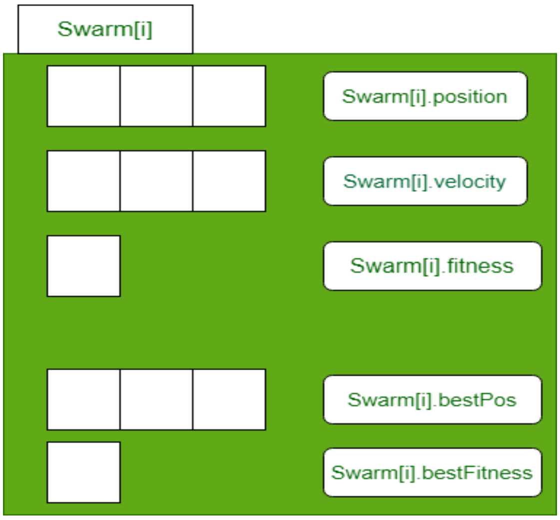

Figure 4.3. Data Structure to Store i_th Particle of Swarm.

Algorithm Parameters of the issue:

- Dimension count (d)
- Lower bound (minx)

- Upper bound (maxx)

The algorithm's hyper parameters are as follows:

- Maximum number of iterations (max_i_{ter})
- Total number of particles (N)
- Inertia (w)
- Particle cognition (C1)
- Swarm social influence (C2)

1. Algorithm:

```
Step1: Randomly initialize Swarm population of N particles Xi ( i=1, 2, …, n)
Step2: Select hyperparameter values
           w, c1 and c2
Step 3: For Iter in range(max_iter):  # loop max_iter times
            For i in range(N):  # for each particle:
               a. Compute new velocity of ith particle
                    swarm[i].velocity =
                         w*swarm[i].velocity +
                         r1*c1*(swarm[i].bestPos - swarm[i].position) +
                         r2*c2*( best_pos_swarm - swarm[i].position)
               b. If velocity is not in range [minx, max] then clip it
                        swarm[i].velocity = minx

                        best_fitness_swarm = swarm[i].fitness
         End -for
Step 4: Return best particle of Swarm
```

Figure 4.4. Example of the PSO Algorithm Code.

1. Benefits of PSO:
2. Unaffected by the scalability of design factors.
3. Derivative free.
4. Few algorithm parameters exist.
5. Extremely effective worldwide search engine
6. Easily parallelizable for processing in parallel.
7. Disadvantages of PSO:
8. Slow convergence at the stage of refined search (Weak local search ability) [23].

5. DISTRIBUTION SUBSTATION AND DISTRIBUTED GENERATION

5.1. Distribution Substation

The distribution substation is between the medium voltage MV and low voltage LV networks, lowering the MV voltage level to 230 V in single-phase and 400V in line to line. The essential characteristic of the distribution substation is its nominal transformer power (between a few tens of kilo volt-amperes and several mega volt-amperes), depending on the loads to be served. The electricity company owns it [24].

5.1.1. Main components of distribution substations

The distribution substations consisted essentially of three main components :

1. Step-down transformers MV/LV.
2. LV networks.
3. LV connection.

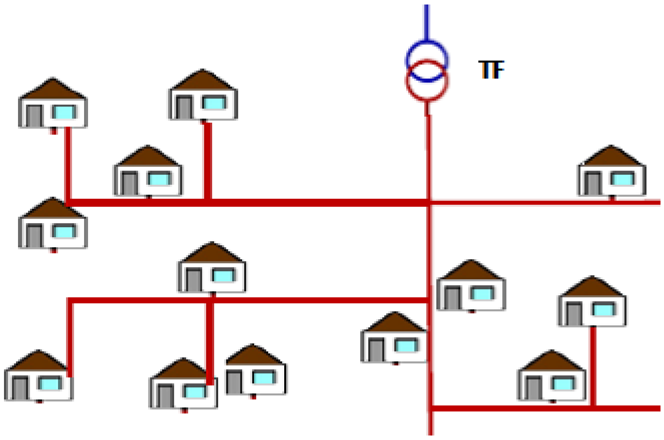

Figure 5.1. Distribution Substation Supplies LV Connections.

5.1.1.1. Step down transformers

The step down transformer is the most important part of the distribution systems. Its choice affects the configuration of the station and it is carried out on the basis of various factors.

Figure 5.2. MV/LV Transformers.

The size of an MV/LV transformer comes from the power calculated based on the number and type of loads [25].

Determination of potency:

The method of estimating the optimal power of the transformer could be complicated.

A power balance is established to determine the power demand (or absorbed) on the network. The installed power P_i (sum of the active powers in kW of the users)

The power used P_u (part of the power P_i in kW actually used) taking into account:

Maximum utilization factors of the loads (as they are not generally used it at full power).

Coefficients of simultaneity by groups of loads (because they do not work Generally all together).

The power called S_a corresponding to P_u (because the rated power of the transformer is given in apparent power in kVA while P_u is in kW) taking into account:

- Power factors.
- A backup margin of power.

5.1.1.2. The LV network

The LV network is made up of s from MV/LV transformer stations. Usually, in a rural, pole-based substation can supply one or two LV s. However, in a city can supply from one to eight s. The length of LV s is limited by the intensity and permissible voltage drops (a few hundred meters in the air). Currently, an MV/LV transformer station can serve 50 to 100 individual houses before the appearance of insulated twisted cables; LV networks are built bare asters copper on poles; from the nineties, this technique was replaced by a new technique more secure, modular and flexible. These are overhead lines in bundles of insulated conductors on poles or facades [25].

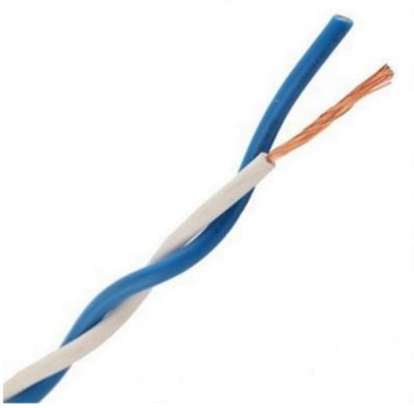

Figure 5.3. Twisted Cable of the LV Network.

The structure of the LV network is radial. Emergency links between LV lines are reserved for exceptional cases. The protection mode is of the type with neutral distributed in the network, neutral and metal masses being grounded by separate sockets.

In calculating the cross-section of conductors, the following three conditions must be taken into account:

- The charge density of the area and its scalability.
- Electrical stress thresholds (intensity and voltage).
- Mechanical resistance condition of conductors.

The economic cable section will be used systematically to optimize Copper losses. For any creation of a network intended to supply new users, or in all other cases (reinforcement, various modifications to be made to the network), the economic section below will be used, taking into account the maximum power transmitted.

Table 5.1. Maximum Power transmitted in Network.

	Twisted pair Network		
Economic section new network	35^2 Al	70^2 Al	150^2 Al
Maximum power transmitted in network	< 32 kW	< 50 kW	> 50 kW new line

5.1.1.3. The LV connection

The LV connection is between the LV network and the origin of the user's indoor installation [26].

Figure 5.4. Overhead LV Connections.

5.1.2. Study of the constraints of the MV/LV distribution substation

MV/LV distribution substations satisfy user demand by distributing electricity through LV distribution networks. Nevertheless, when demand exceeds a certain level, MV/LV transformer capacity and cables may be subject to current and/or voltage constraints.

The analysis and resolution of technical constraints will be conducted in the following order:

- Current constraint on the transformer;
- Intensity constraint on the network;
- Tension stress;
- Harmonic constraint [26].

An in-depth study of the distribution substation is essential to determine the causes and find solutions to ensure continuity and quality of service.

Indeed, removing a constraint upstream often makes it possible to remove a constraint downstream. Possible reinforcement solutions are:

- Replacement of the transformer.
- The change of section of the conductors.
- An increase in the number of outputs.

The creation of an additional HV/LV substation (Reduction of the length of the networks) [27].

The choice of solution is made using a techno-economic calculation, which takes into account:

- The investment itself related to the work to be carried out.
- Operating expenses (servicing, maintenance).
- The cost of electrical losses (Iron and Joule).
- The valuation of the failure suffered by users.

5.1.2.1. Intensity stress thresholds

The intensity constraints are examined by type of installation: MV/LV transformers, LV overhead lines, and LV connection. The data provided by the standards and stress thresholds in force are distinguished.

A. MV/LV transformers: By their construction, the transformers have a rated power corresponding to the power that can be delivered in a steady state.

In terms of overload, the following table gives the time limits not to be exceeded according to the importance of the overload and the ambient temperatures.

The transformer is sometimes required to hold more significant overloads but of exceptional characteristics, often unbalanced, due, for example, either to a resistant or distant short circuit on the LV network or to a momentary transfer of loads. The repetition of these overloads increases the temperature of the hot spot to values that can permanently affect the quality of the insulation.

B. LV network and connection: The current passing through an LV network conductor or connection shall be less than the permissible current to reduce warm-up in drivers. The risks for twisted lone drivers are the same as for cables. In principle, no overload is permissible [28].

5.1.2.2. Tension stress thresholds

Electrical equipment must operate in the 230 V range, + 6 % - 10 %. So, the supply of electrical energy must be respected, a voltage is delivered that varies per turn of the nominal voltage, namely:

- ±10% industrial or rural areas
- ±5% urban areas

LV network: The normalization of the LV voltage, after being fixed for a long time at 220/380V, the voltage to the B2 standard has increased to 230/400V, which is the operating voltage usual for domestic use.

The LV voltage thresholds imposed by the regulations at the input terminals of

The client installation is:

- 244 V single-phase and 423 V three-phase (+ 6% of the nominal voltage),
- 207 V single-phase and 358 V three-phase (-10% of the nominal voltage).

5.1.3. Calculation of technical constraints

5.1.3.1. Current and voltage imbalances

LV networks are usually three-phase; they power three-phase loads and many single-phase receptors. Therefore, the currents absorbed over the three phases are of different amplitudes, hence tension imbalances.

These voltage imbalances generate inverse current components that mainly cause stray braking torques and heating in the AC motors.

The highest rates are observed on LV networks powered by a Low power transformer with a majority of single-phase connections; This is the case of the top pole substations, which supply few LV subscribers in single-phase.

- LV imbalance rate calculation:

$$d1 = \frac{ABS(I_m - I_1)}{I_m} \times 100 \tag{5.1}$$

$$d2 = \frac{ABS(I_m - I_2)}{I_m} \times 100 \tag{5.2}$$

$$d3 = \frac{ABS(I_m - I_3)}{I_m} \times 100 \tag{5.3}$$

I_1, I_2, I_3 :Phase currents.

I_m: The average value.

ABS: The absolute value.

D : the Maximum value of d1, d2, d 3.   D ≤15%

5.1.3.2. Harmonic problem

At the LV distribution level, the harmonics problem also arose with the development of electronic applications. The harmonics are mainly caused by nonlinear charges (this non-linearity can be intrinsic, such as in the case of a saturated arc or magnetic core, or resulting from repeated commutations, power electronics components). Subjected to sinusoidal tension, a load nonlinear absorbs a deformed current whose harmonic components do not depend on First approximation, only on its own characteristics and not those of the network. This Charge, therefore, behaves as a source of harmonic currents.

The harmonic voltages then appear at the terminals of the Charge for each row h

harmonic:

$$\mathrm{U_h} = \mathrm{Z_h} \times \mathrm{I_h} \tag{5.4}$$

By denoting by I_1 the fundamental component of current, the series expansion Fourier gives:

$$I_h = \frac{I_1}{h} \tag{5.5}$$

By denoting by I_1 the fundamental component of current, the Fourier series expansion gives:

$$\mathrm{THD}(\%) = \frac{\sqrt{\sum_{\mathrm{h}=2}^{\mathrm{n}} \mathrm{I^2}_{\mathrm{h}}}}{\mathrm{I_1}} \times 100 \tag{5.6}$$

5.1.4. Calculation of economic constraints

5.1.4.1. Electrical energy losses

The general expression of the electrical losses of a MV/LV substation giving the losses of MV/LV transformer and Copper losses in a LV line of length "L" is:

$$\Delta P = \Delta P_{transform} + \Delta P_{\mathrm{length\ LV}} \tag{5.7}$$

5.1.4.2. Losses in the transformer

$$\Delta P = \Delta P_0 = \Delta P_{irlos} \tag{5.8}$$

Short circuit:

$$\Delta P_{joule} \gg \Delta P_{irlos} \Rightarrow \Delta P_{joule} = P_{SC} = 3 \times R_S \times I^2{}_N \tag{5.9}$$

$$\Delta \mathrm{P}_{\mathrm{joule}}(\mathrm{t}) = 3 \times \mathrm{R_S} \times \mathrm{I}^2{}_2 \tag{5.10}$$

Or

$$\frac{I_2(t)}{I_N} = \frac{P(t)}{P_N} \Rightarrow \Delta P_{joule}(t) = \left(\frac{P_{SC}}{\mathrm{P}^2{}_\mathrm{N}}\right) \times p(t) \tag{5.11}$$

So the losses of transformer are:

$$\Delta P_{transform} = \Delta P_{joule} + \Delta P_{irlos} = \left(\frac{P_{SC}}{\mathrm{P}^2{}_\mathrm{N}}\right) \times p(t) + P_{irlos} \tag{5.12}$$

Or

$P(t) = \sum_{i=1}^{n} P_i$ is the cumulative power demanded by the load (kW);

And the negligible iron losses, the transformer losses become:

$$\Delta P_{transform} = \left(\frac{P_{SC}}{\mathrm{P}^2{}_\mathrm{N}}\right) + \sum_{i=1}^{n} P_i \tag{5.13}$$

With:

- P_{SC} = Short circuit power.
- P_N = Rated transformer power.
- ΔP_{irlos} = Iron losses.
- P(t) = total power.

All this data is provided by manufacturers [29].

5.1.4.3. Copper Losses in a LV Line

$$\Delta P = 3R \int I^2\ (1)\ d1 \tag{5.14}$$

So:

$$\Delta P = 3krI^2L \tag{5.15}$$

With

$$K = \begin{cases} 1 & For\ a \text{ triangular load distribution} \\ 1/3 & \text{To load concentrated at the end of the line} \\ 8/15 & \text{For uniform load distribution} \end{cases}$$

Power losses in power line conductors were determined by the relationship:

Where

$$\Delta P_{linge} = \left[\frac{1}{U^2 \times cos^2(\boldsymbol{\varphi})}\right] \times \sum_{i=1}^{n}(P^2{}_i \times R_i \times L_i) \quad (5.16)$$

R_i, L_i are the linear strength and dipole length.

$P_i = \sum_{j=i}^{n} P_j$

Is the cumulative power demanded by the load (kW); Cos $\boldsymbol{\varphi}$ the power factor 0.9 [29].

The general expression of electrical losses becomes:

$$\Delta P = \left(\frac{P_{SC}}{\mathrm{P}^2{}_{\mathrm{N}}}\right) \times \sum_{i=1}^{n} P_i + \left[\frac{1}{U^2 \times cos^2(\boldsymbol{\varphi})}\right] \times \sum_{i=1}^{n}(P^2{}_i \times R_i \times L_i) \quad (5.17)$$

5.2. Distributed Generation

Distributed generation is considered concentrated energy resources in many and multiple places and depends many sources is distributed and have relatively small energy resources. The power produced ranges from the order of kilowatts to Megawatt [30].

Where capacity is generated in places close to consumption or within distribution facilities Local and connects directly with the local distribution network.

5.2.1. System concepts

Distributed generation technologies include Photovoltaic systems, natural gas engines, fuel cells, industrial turbines, microwave turbines, wind turbines, and electrical power storage systems. These technologies can form small stations or networks that can be used directly consumed.

Combined Heat and Power technology is used in the generation of electricity and heat, it has been used in some stations to convert a third of the energy used into electricity.

The rest of to heat as energy was generated from the burning of organic waste and as a result of the use of such integrated systems the efficiency of the system was raised from 30% to 70%.

5.2.2. System components

1. Industrial turbines and combustion turbines are systems that generate high heat and emit gases at high pressures to rotate electric turbines, and the efficiency of the simple cycle ranges from about 40%, so this high temperature can be used in the technology of Combined Heat and Power. Where energy is generated using steam by fossil fuels or interior heat land or by burning waste or wood [31].
2. Solar energy systems that use mirrors to reflect and concentrate sunlight for heating And obtaining high temperatures are used to drive turbines to generate electricity.
3. Fuel cells by reaching the hydrogen to the negative pole and oxygen to the positive pole, and thus the output is water and heat, and about 300 complex systems have been used in the world that depend on this technology with the ability of 100 to 200 kW and a significant reduction in radiation has been obtained And use it in heat generation and obtaining electricity so that the efficiency reaches about 40%.
4. Photovoltaic systems where direct sunlight is converted to Electric.
5. Wind energy systems convert wind energy into electrical energy.

Figure 5.5. shows the Integrated Distributed Generation System, its shows how each type of DG units could connect to the DC Bus.

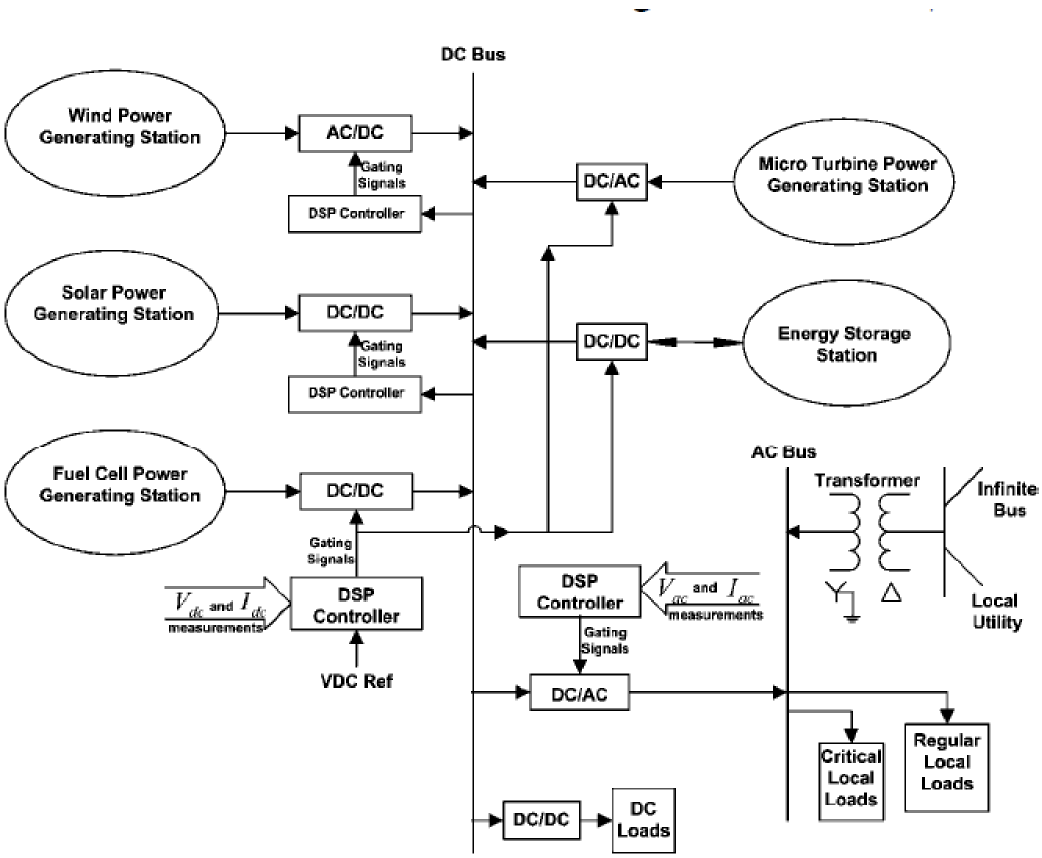

Figure 5.5. Integrated Distributed Generation System.

6. SIMULATION STUDIES

This part is included all the results and simulations, Four cases with different scenarios have been done for the radial network system in Amman.

Tables 6.1, 6.2, 6.3 and 6.4 have all the information that has been founded using MATLAB program. It includes the voltage deviation, power, reactive power and power factor for the DG units. In the first case the DG reactive power is 0 because the power factor is equal 1, the second case has used manual power factor equal 0.9 this number could be change. Third case has only one optimal power factor for all DG units based on the PSO algorithm but the fourth case each DG has separate power factor.

This thesis has used MATLAB program student version 2022, MATLAB program with MATPOWER to receive all system data that have been collected form the electrical company in Amman it is in Table 8.1, which are resistances and reactance's for the line between the bus bars, the section below will give some "MATLAB" codes that have been used to find the Tables.

```
Num_DG=input('Number of DG [1 to 5]:  ');
```

This order to choosing the DG number, in the fourth case 1, 3 and 5 DG units have been chosen, but it could be more number.

```
P_Factor=input('Power Factor between [0 to 1]:  ');
```

The code for choose the Power factor manually for the second case, it was 0.9 and it could be change.

```
for n=1:Num_DG
VarMin(n)=0;                 %  Lower Bound Size of DG
VarMin(n+Num_DG)=0;          %  Lower Bound Location of DG
VarMin(n+2*Num_DG)=1;        %  Lower Bound Location of DG
VarMax(n)= 1866;             %  Upper Bound Size of DG
VarMax(n+Num_DG)=51;         %  Upper Bound Location of DG
end
```

The previous code shows the upper and lower size of DG units, they are chosen manually depending on the number of DG, the total Power for the DGs should be more than 5.6 MW (The total system load), so if the DG number is one so the 5th line will be =5600 (kW) in the previous code it is equal 1866 and the DGs was three this is the idea of it.it also included the lower and higher location, this option fixed fall all cases it is between 0 to 51, it able to be change in the future.

```
VD=sum((1-Vb).^2)*100;
```

This code collects the voltage deviation (VD) for each bus and then sums it all together.

As mentioned in section 4 this thesis study based on PSO algorithm. This algorithm request all system date such as R,X and power load for each bus-bars then it compare it, after compare it the PSO algorithm code do a lot of simulation to choose the best size, location and power factor for the DG unit. I have run the program more than 50 time, and the program itself take order to do this simulations many time before show the results.

```
for n=1:Num_DG
P_Factor(n) = DG(n+3*Num_DG);
Reall = DG(n);
Reactivee = DG(n+Num_DG);
AP_Power = sqrt((Reall )^2 + (Reactivee)^2) ;
Ps(n) = AP_Power * P_Factor(n);
Qs(n)= (AP_Power * (sin (acos (P_Factor(n)))));
end
```

This code finding the Power load and reactive power load using the power fator and the apparent power for the radial system after adding DGs.

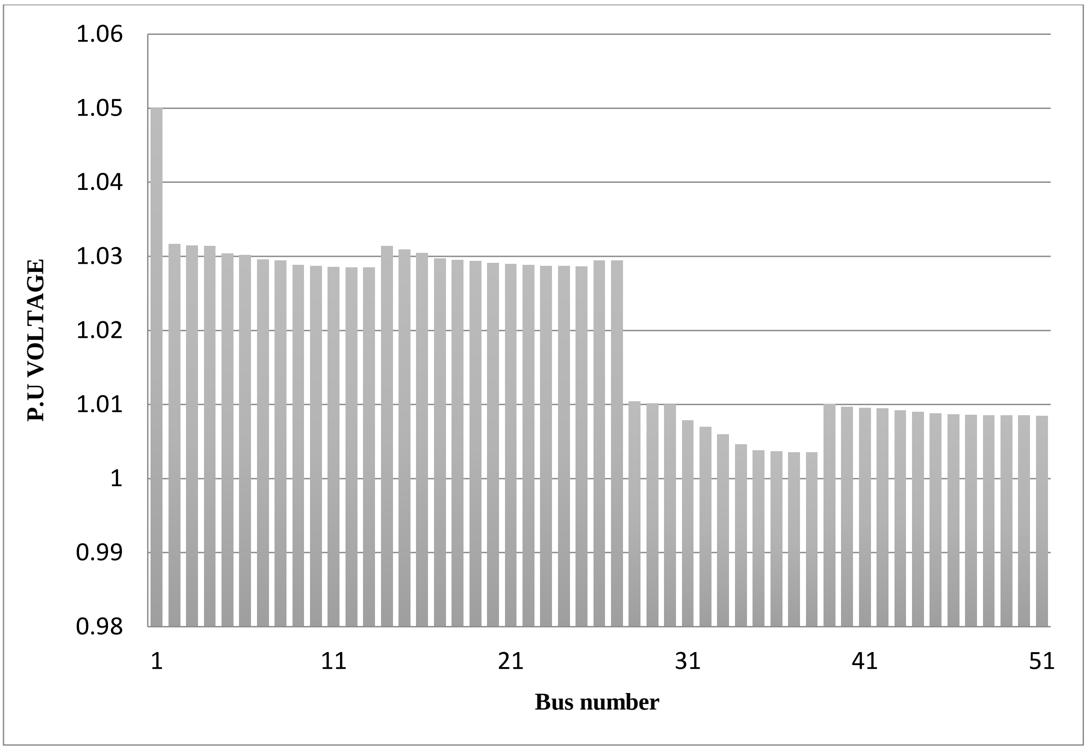

Figure 6.1. P.U bus voltage of the 51-bus system without DGs.

Comparing voltage profile in figure 6.2 ,6.3 ,6.4 and 6.5 show the deference between carves with or without DG units, it show how the system become more stable. Figure 6.1. Shows the voltage for each bus in PU without DGs.

6.1. First Case: DG Units Operate with Unity Power Factor and Optimal DG's Location Based on (PSO)

Table 6.1. System information before and after adding DG's For Case 1.

DG number	**DG Location**	**VD**	P_{DG} **kW**	Q_{DG} **kVAR**	PF_{DG}	P_L **kW**	Q_L **kVAR**	S_L **kVA**	S_L **reduction (%)**	**Min. voltage (bus)PU**
Without DG	-	-	-	-	-	103.9	202.3	227.42	-	-
1 DG	34	3.53	2636	0	1	47.54	93.48	104.87	53.89%	1.019
3 DGs	35 14 33	6.06	1679 1831 877	0	1	13.64	24	27.6	87.86%	1.027
5 DGs	31 38 21 9 34	6.96	1102 730 1104 1032 726	0	1	7.9	14.9	16.86	92.59%	1.030

Table 6.1. shows the apparent power loss reduction for the first case based on the PSO algorithm. The Apparent Power losses decreased when one DG unit was added to 53.89%. Then the apparent Power losses decrease to 87.86% when 3 DG units have been added. When 5 DG units have been added, the apparent Power losses decrease to 92.59%; these cases show the significant difference in the system in the first case.

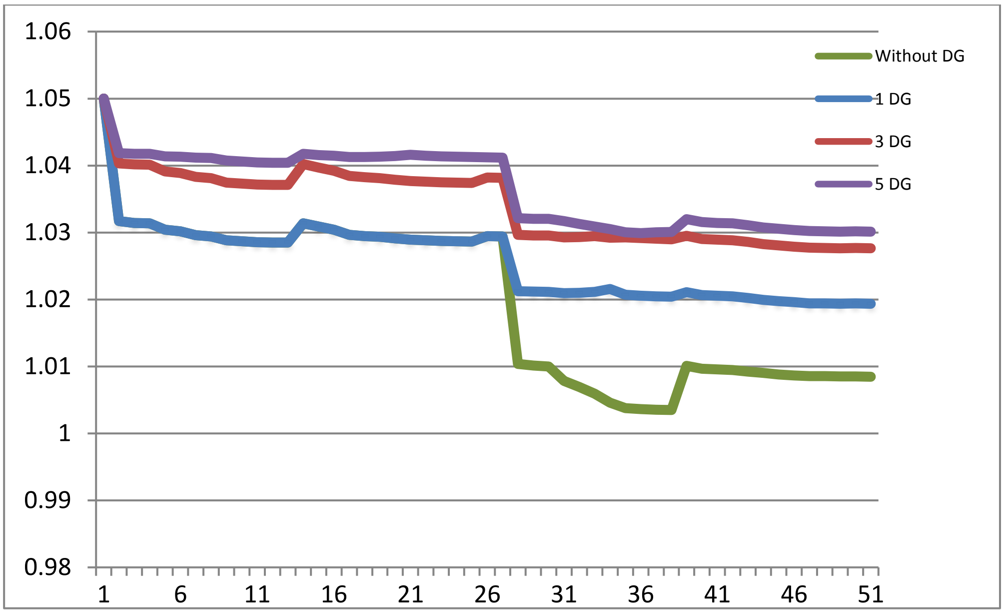

Figure 6.2. Comparison of Voltage Profile without DG, with one DG , 3 and 5 DGs for the First case.

6.2. Second Case: DG Units Operate with Fixed Power Factor PF=0.9 and Optimal DG's Location Based on (PSO)

Table 6.2. System Information Before and after Adding DGs For Case 2.

DG number	DG LOCATION	VD	P_{DG} kW	Q_{DG} kVAR	PF_{DG}	P_L kW	Q_L kVAR	S_L kVA	S_L reduction (%)	Min. voltage (bus)PU
Without DG	-	-	-	-	-	103.9	202.3	227.42	-	-
1	34	3.54	2639	1278	0.9	47.54	93.47	104.87	53.89%	1.019
3	35 8 32	6.1	1438 1680 1379	697 814 668	0.9	12.64	23.56	26.74	88.24%	1.028
5	10 20 31 34 37	6.85	1003 972 1008 840 896	486 471 488 407 434	0.9	7.47	14.26	16.1	92.92%	1.030

Table 6.2. shows the apparent power loss reduction for the first case based on the PSO algorithm. The Apparent Power losses decreased when one DG unit was added to 53.89%. Then the apparent Power losses decrease to 88.24% when 3 DG units have been added. When 5 DG units have been added, the apparent Power losses decrease to 92.59%; these cases show the significant difference in the system in the second case.

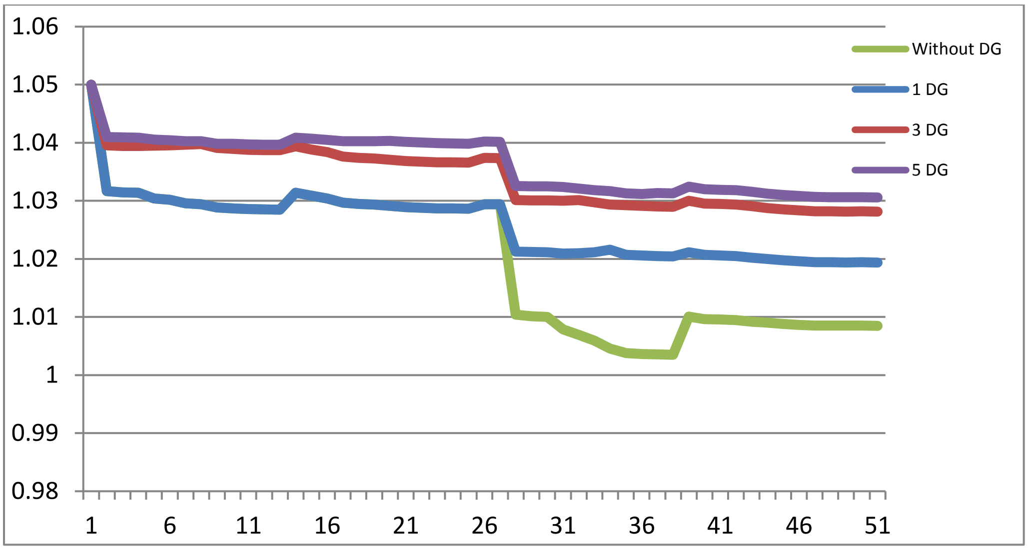

Figure 6.3. Comparison of Voltage profile without DG, with one DG , 3 and 5 DG's for the Second Case.

6.3. Third Case: DG Unit Operate with Optimal Power Factor and Optimal DG Location Based on (PSO)

Table 6.3. System Information before and after Adding DGs for Case 3.

DG number	DG Location	VD	P_{DG} kW	Q_{DG} kVAR	PF_{DG}	P_L kW	Q_L kVAR	S_L kVA	S_L reduction(%)	Min. voltage (bus)PU
Without DG	**-**		**-**	**-**	**-**	**103.9**	**202.3**	**227.42**	**-**	**-**
1	**34**	**3.72**	**2637**	**1364**	**0.89**	**48.19**	**93.49**	**105.18**	**53.89%**	**1.020**
3	**31** **35** **9**	**6.56**	**1448** **1490** **1866**	**0** **0** **0**	**1**	**11.23**	**21.39**	**24.16**	**89.38%**	**1.029**
5	**35** **21** **42** **10** **34**	**7.40**	**1055** **1104** **824** **1058** **958**	**7** **7** **5** **7** **6**	**0.99**	**6.08**	**11.56**	**13.06**	**94.26%**	**1.033**

Table 6.3. shows the apparent power loss reduction for the first case based on the PSO algorithm. The Apparent Power losses decreased when one DG unit was added to 53.89%. Then the apparent Power losses decrease to 89.38% when 3 DG units have been added. When 5 DG units have been added, the apparent Power losses decrease to 94.26%; these cases show the significant difference in the system in the third case.

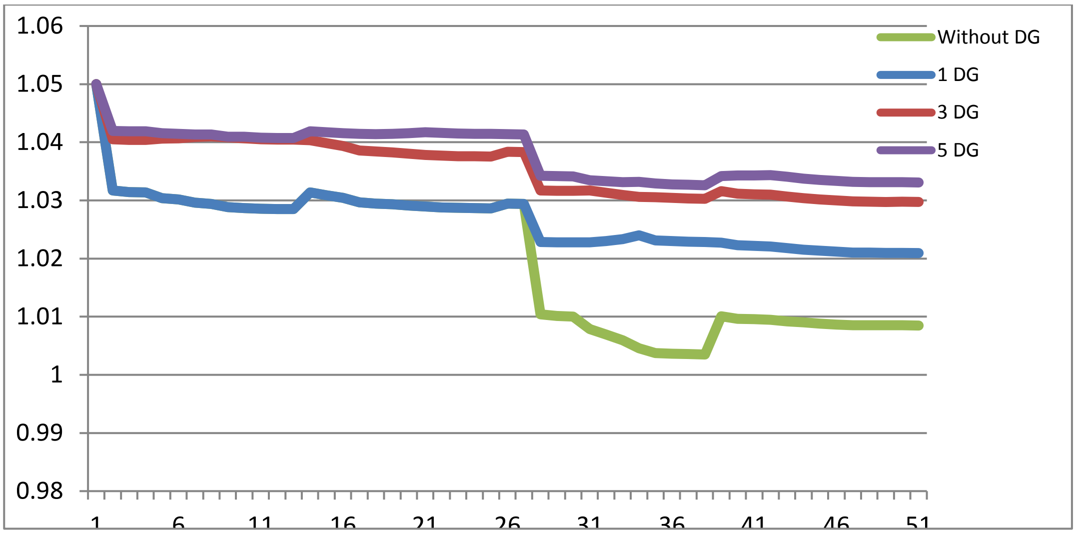

Figure 6.4. Comparison of Voltage profile without DG, with one DG , 3 DGs and 5 in the Third Case.

6.4. Fourth Case: Optimal PF and Location for Each DG Based on PSO

Table 6.4. System Information before and after Adding DG's For Case 4.

DG number	DG Location	VD	P_{DG} kW	Q_{DG} kVAR	PF_{DG}	P_L kW	Q_L kVAR	S_L kVA	S_L reduction(%)	Min. voltage (bus)PU
-	-	-	-	-	-	103.9	202.3	227.42	-	-
1	34	3.55	2639	394	0.989	48.1	93.34	105	53.82%	1.019
3	31	7.04	1045	770	0.80	11.15	20.13	23.01	89.88%	1.032
	35		1574	568	0.94					
	18		1866	0	1					
5	10	7.59	1121	0	1	5.55	10.48	11.86	94.78%	1.033
	37		1117	83	0.997					
	20		1121	3	1					
	44		602	75	0.992					
	33		1111	129	0.993					

Table 6.4. shows the apparent power loss reduction for the first case based on the PSO algorithm. The Apparent Power losses decreased when one DG unit was added to 53.82%. Then the apparent Power losses decrease to 89.88% when 3 DG units have been added. When 5 DG units have been added, the apparent Power losses decrease to 94.78%; these cases show the significant difference in the system in the third case.

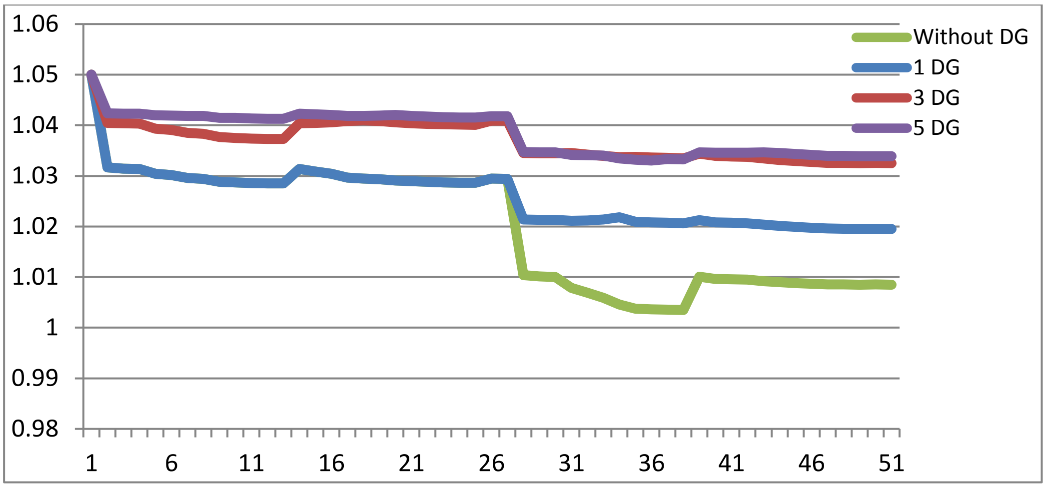

Figure 6.5. Comparison of voltage profile without DG, with one DG , 3 DGs and 5 in the fourth case

Active, Reactive Power and Power Factor is considered by optimization method, and they are not fixed in some cases.

```
for n=1:Num_DG
        P_Factor = DG(n+3*Num_DG);
        Reall = DG(n);
        Reactivee = DG(n+Num_DG);
        AP_Power = sqrt((Reall )^2 + (Reactivee)^2) ;
        Ps = AP_Power * P_Factor;
        Qs= (AP_Power * (sin (acos (P_Factor))));
        Pg(round(DG(n+2*Num_DG),0))=Pg(round(DG(n+2*Num_DG),0))+Ps;
        Qg(round(DG(n+2*Num_DG),0))=Qg(round(DG(n+2*Num_DG),0))+Qs;
end
```

The range for real, reactive power, and power factor:

Power between 0 - 5.600 MW depending on the number of DG's; it should not be more than 5.6 MW.

Power factor between 0 – 1; in the first and second cases, it's manual but in the third and fourth cases, it's optimal base on the PSO algorithm.

Determine the location from the first bus to bus number 51 optimally in all cases.

7. CONCLUSION AND RECOMMENDATION

In this thesis, the PSO algorithm was proposed for optimal planning of the power factor, location, and sizing for different numbers of DG units according to four different cases to minimize losses in the distribution network.

The result tables show that the case 4 using 5 DG units is the best choice for integrating with the distribution network according to the apparent power reduction.

Moreover, the results for the third case (DG Unit Operate with Optimal Power Factor and Optimal DG Location Based on PSO algorithm) are interesting, using 5 DG units increse the apparent power reduction to 94.26%. According to the results, it can be said that the four different cases with their three different scenarios able to be used in real life, since the lowest apparent power reduction is more than 50%.

In comparison to other algorithms, the algorithm employed in the simulations is one of the simplest and most efficient, it has been used in the MATLAB program 2022 student version with MATPOWER.

In selecting the ideal position for (DGs) with least losses, the PSO algorithm demonstrated its effectiveness and rapidity. As a result, losses were minimized due to the availability of distributed generators in the optimal position, size, power factor, and proximity to loads.

The 51-bus radial distribution system was collected from a district of Amman. In the system, the PSO optimization algorithm is successfully implemented. Results are given in comparison with and without the DG units. After optimal allocation and size determination, Tables 6.1,6.2,6.3 and 6.4 show that the reduction in active and reactive power losses are more than 80% in the four cases, making this study successful.

As shown on the previous sections this study supports the Jordanian Electricity Company regulations aims:

- Exploitation and advancement of renewable energy resources to enhance their contribution to total energy, provide a secure supply of these resources, and stimulate investment in them.

- Contribute to environmental protection and attain sustainable development.
- Reducing energy consumption and increasing the effectiveness of its usage in various areas.This approach can be applied to any number of DGs.

Off-grid radial systems that have renewable energy sources are usually unstable and have many possible blackouts; the advantage of the DG units, as shown in this thesis section 5.2 can improve the off-radial systems to be more stable and without blackout. This thesis could be upgraded to have new scenarios for off-grid systems with different cases in the future.

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APPENDICES

APPENDIX A. The Line and Load Data for the Radial Distribution Network Tables

APPENDIX B. The Line and Load Data for the Radial Distribution Network Figures

APPENDIX A. The Line and Load Data for the Radial Distribution Network Tables

Table Appendix A.1. The Line and Load Data for the Radial Distribution Network

Bus number	From Bus	To Bus	$P_{L\,(kw)}$	$Q_{L\,(kvar)}$	$R_{(\Omega)}$	$X_{(\Omega)}$
1	1	2	0	0	0.65	1.38
2	2	3	0	0	0.0101	0.0104
3	3	4	0	0	0.005	0.0052
4	4	5	0	0	0.0808	0.0832
5	5	6	78.81	14.07	0.0202	0.0208
6	6	7	101.02	18.56	0.0556	0.0572
7	7	8	161.38	30.47	0.0202	0.0208
8	8	9	161.38	31.01	0.0354	0.364
9	9	10	0	0	0.0202	0.0208
10	10	11	242.07	47.68	0.02525	0.026
11	11	12	80.03	15.89	0.0404	0.0416
12	11	13	161.38	32.3	0.0202	0.0208
13	3	14	322.7	64.59	0.005	0.0052
14	14	15	0	0	0.0404	0.0416
15	15	16	68.16	12.29	0.0404	0.0416
16	16	17	115.2	20.97	0.0707	0.0728
17	17	18	115.2	21.17	0.0202	0.0208
18	18	19	115.2	21.56	0.0202	0.0208
19	19	20	115.2	21.75	0.0404	0.0416
20	20	21	115.2	22.08	0.0404	0.0416
21	21	22	72.16	13.95	0.0303	0.0312
22	22	23	72.16	13.98	0.0303	0.0312
23	23	24	115.2	22.51	0.0202	0.0208
24	24	25	115.2	22.87	0.0404	0.0416
25	18	26	115.2	23.59	0.0202	0.0208
26	26	27	72.29	15.02	0.0404	0.0416
27	1	28	115.2	24.28	0.65	1.38
28	28	29	0	0	0.0101	0.0104
29	29	30	0	0	0.005	0.0052
30	30	31	0	0	0.101	0.104
31	31	32	354.2	66.89	0.0505	0.052
32	32	33	155.14	30.06	0.0606	0.0624
33	33	34	232.7	45.47	0.0909	0.0936
34	34	35	354.2	69.21	0.0707	0.0728
35	35	36	354.2	69.78	0.0404	0.0416
36	35	37	354.2	70.06	0.0404	0.0416
37	37	38	230.12	45.69	0.0202	0.0208
38	29	39	354.2	70.89	0.0101	0.0104
39	39	40	0	0	0.0808	0.0832
40	40	41	61.89	11.27	0.0202	0.0208
41	41	42	61.94	11.49	0.0202	0.0208
42	42	43	38.97	7.36	0.0707	0.0728
43	43	44	38.97	7.42	0.0354	0.364
44	44	45	61.89	11.99	0.0707	0.0728
45	45	46	38.97	7.49	0.0606	0.0624
46	46	47	61.89	12.19	0.0354	0.364
47	47	48	61.89	12.09	0.0101	0.0104
48	48	49	15.47	3	0.0354	0.364
49	48	50	61.89	12.39	0.0202	0.0208
50	50	51	15.47	3.17	0.0808	0.0832
51	0	0	61.94	12.87	0	0

APPENDIX B. The Line and Load Data for the Radial Distribution Network Figures

```
for n=1:Num_DG
   VarMin(n)=0;               % Decision Variables Lower Bound Size of DG
   VarMin(n+Num_DG)=1;        % Decision Variables Lower Bound Location of DG
   VarMax(n)= 5600;           % Decision Variables Upper Bound Size of DG
   VarMax(n+Num_DG)=51;   % Decision Variables Upper Bound Location of DG
   end
```

Figure Appendix B.1. MATLAB Code for one DG.

```
DG = round(GlobalBest.Position,0);
for n=1:Num_DG
        Reall = DG(n);
        Reactivee = DG(n+Num_DG);
        AP_Power = sqrt((Reall )^2 + (Reactivee)^2) ;
        Ps(n) = AP_Power * P_Factor;
        Qs(n)= (AP_Power * (sin (acos (P_Factor))));
end
```

Figure Appendix B.2. MATLAB Code to Find P and Q for the Fourth Case.

```
for i=1:no
    vb(i,1)=1.05 ;
end
for s=1:10
for i=1:no
    nlc(i,1)=conj(complex(P(i,1),Q(i,1)))/(vb(i,1));
end
nlc;
for i=1:br
    Ibr(i,1)=nlc(i+1,1);
end
```

Figure Appendix B.3. MATLAB Code for Drawing the PU Voltage 1.

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