إقرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

النظام الحديث في إدارة شبكة توزيع الكهرباء في محافظة رفح

Modern Electric Distribution Management System
Case Study: Rafah Governorate Distribution Grid

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Student name: Nadia Mohammed Mahdi — اسم الطالب: نادية محمد مهدي

Signature: Nadia — التوقيع: نادية محمد مهدي

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The Islamic University of Gaza
Deanship of Graduate Studies
Faculty of Engineering
Electrical Engineering Department

الجامعة الإسلامية – غزة
عمادة الدراسات العليا
كلية الهندسة
قسم الهندسة الكهربائية

Modern Electric Distribution Management System
Case Study: Rafah Governorate Distribution Grid

Submitted By
Nadia Mohammed Mahdi

In partial fulfillment of the requirements for the degree of
Master of Science in Electrical Engineering at
the Department of Electrical Engineering at the Islamic University of Gaza

Advisor
Dr. Assad Abu-Jasser

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النظام الحديث في إدارة شبكة توزيع الكهرباء في محافظة رفح

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وبعد المناقشة التي تمت اليوم الثلاثاء 20 محرّم 1434هـ، الموافق 2012/12/04م الساعة الحادية عشرة صباحًا، اجتمعت لجنة الحكم على الأطروحة والمكونة من:

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د. باسل محمود حمد	**مناقشًا داخليـًا**	....
د. إياد محمد أيوب أبو هدروس	**مناقشًا خارجيًا**	....

وبعد المداولة أوصت اللجنة بمنح الباحثة درجة الماجستير في **كلية *الهندسة*/ قسم الهندسة الكهربائية.**

واللجنة إذ تمنحها هذه الدرجة فإنها توصيها بتقوى الله ولزوم طاعته وأن تسخر علمها في خدمة دينها ووطنها.

والله ولي التوفيق ،،،

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أ.د. فؤاد علي العاجز

بسم الله الرحمن الرحيم

﴿قَالُوا سُبْحَانَكَ لَا عِلْمَ لَنَا إِلَّا مَا عَلَّمْتَنَا إِنَّكَ أَنتَ الْعَلِيمُ الْحَكِيمُ﴾

البقرة، الآية ٣٢

Abstract

Modern power distribution management system (DMS) is a real-time information system used to monitor and control all activities and functions in an electric distribution system. This system consists of many applications including: geographical information system (GIS), load flow analysis and customer information. It may include other applications depending on the distribution utility progress and its needs. This research work introduces the basic steps to build a modern power distribution management system for Rafah governorate which is chosen to be the study model since it suffers from poor technical status with ever increasing demand for electric power. The work done includes the load flow analysis of the Medium Voltage (MV) grid in Rafah using ETAP software which evaluates the technical status of the present distribution system. According to the simulation results, suitable solutions for most of the problems existing in the distribution network are proposed in order to properly manage the power demand growth, voltage enhancement and loss reduction. Moreover, the research presents a GIS model for the existing distribution feeders using ArcGIS software in which it highlights the applications and functions of GIS in an electrical distribution system. These applications include information processing, two and three-dimensional visualization of electrical objects on their geographical nodes, integration between ArcGIS and Google Earth, customer indexing (CI), network planning, and finally integration between the ArcGIS and ETAP. The results obtained show that developing a DMS enhances reliability and efficiency of the distribution grid in Rafah governorate and that it can be used as a reference model to be applied to all governorates in the Gaza Strip.

ملخص البحث

النظام الحديث في إدارة شبكة توزيع الكهرباء في محافظة رفح

يتكون النظام الحديث في إدارة شبكات توزيع الكهرباء من عدد من التطبيقات الفرعية مثل: نظام المعلومات الجغرافية (GIS)، برامج سريان الحمل(Load Flow)، و قد يشمل تطبيقات أخرى أكثر تقدما كنظام المراقبة و التحكم عن بعد اعتمادا على مدى تقدم منظومة التوزيع، إن اقتراح مثل هذا النظام للتطبيق على شبكة الضغط المتوسط بالمحافظة سيسهم في تحسين أداء الشبكة و الارتقاء بجودة الطاقة الكهربية مع توفير كافة البيانات اللازمة لتشخيص المشاكل و نقاط الضعف في هذه المنظومة و من ثم اقتراح الحلول المناسبة.

في هذه الأطروحة، تم استخدام برنامج **ETAP 7** لتقييم أداء وكفاءة شبكة التوزيع الحالية بمحافظة رفح وذلك من خلال دراسة سريان الحمل لمغذيات المحافظة الأربع ذات الجهد المتوسط. تشمل النتائج المستخلصة من هذه الدراسة: حساب تدفق القدرة الكهربائية الفعالة و الغير فعالة في خطوط التغذية، إضافة إلى احتساب المفاقيد الكهربية، و كذلك احتساب مقدار هبوط الجهد عند كل نقطة توزيع على المغذيات. بناء على النتائج المستخلصة تم طرح عدد من الحلول المناسبة، فتم اقتراح تحسين مستويات الجهد بثلاث طرق تشمل رفع جهد مصدر التغذية أو ضبط مغيرات الجهد لمحولات التوزيع و أخيرا باستخدام بنوك المكثفات التي تقوم أيضا برفع معامل القدرة للخطوط و كذلك تقليل مفاقيدها الكهربية.

وأخيراً تمّ تسليط الضوء على تطبيقات نظم المعلومات الجغرافيّة في مجال توزيع الطاقة الكهربية في المحافظة باستخدام برنامج **ArcGIS 9.3**، و تشمل تلك التطبيقات: الإظهار ثنائي و ثلاثي الأبعاد لمكونات الشبكة، الاستعلام و بناء التقارير و طباعة الخرائط، تصدير طبقات الشبكة المختلفة إلى برنامج **Google Earth**، تخطيط الشبكة، توثيق بيانات مشتركي شبكة الضغط المنخفض، و أخيرا التكامل بين برنامج سريان الحمل و برنامج نظم المعلومات الجغرافية من خلال تصدير و عرض بيانات سريان الحمل على الخريطة الجغرافية للمحافظة.

Dedication

To my mother and father who always pray to Allah to support me and achieve success during this work

To my husband for his support, motivation and inspiration

To my beloved daughters Nessma and Lama and to the memory of my beloved son Ahmed

To all who help and support me during my work even with an encouragement word

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Contents

CHAPTER 3: MODELING OF RAFAH POWER DISTRIBUTION GRID

CHAPTER 4: GIS APPLICATIONS FOR RAFAH ELECTRIC POWER DISTRIBUTION GRID

List of Figures

List of Tables

Abbreviations

ACSR	All Conductor Steel Reinforced
AMR	Automatic Metering Reading
CB	Circuit Breaker
CEDC	Canal Electricity Distribution Company
CIS	Customer Information System
CP	Concrete Pole
CSP	Channel Steel Pole
CU	Copper
DA	Distribution Automation
DMS	Distribution Management System
ESRI	Environmental Systems Research Institute
ETAP	Electric Transient Analysis Program
FA	Feeder Automation
GEDCO	Gaza Electrical Distribution Corporation
GIS	Geographic Information System
IEC	Israel Electricity Corporation
IEEE	Institute of Electrical and Electronics Engineers
IT	Intelligent Technology
KML	Keyhole Markup Language
kV	Kilo volt
LCUR	Line Current Unbalance Rate
LSP	Lattice Steel Pole
LV	Low Voltage
MV	Medium Voltage
OCP	Optimal Capacitor Placement
OMS	Outage Management Systems
ONAN	Oil Natural Air Natural
PF	Power Factor
PLC	Programmable Logic Controller
RTU	Remote Terminal Unit
SCADA	Supervisory Control and Data Acquisition
3D	Three-Dimensional
VAR	Volt Ampere Reactive
WP	Wooden Pole

Notations

P	Active power
Q	Reactive power
$\mathbf{V_d}$	Voltage drop
δ	Phase angle

CHAPTER 1

INTRODUCTION

1.1 Introduction

The electric load growth in Rafah governorate with a population of more than two hundred thousand needs a modern distribution management system. Along with the increasing development of power electronics and IT and communication technologies, the construction of a modern power distribution system is becoming an important development direction of electric power industry throughout the world. Evaluation of the existing distribution system is considered as the necessary initial step in understanding the primary issues and requirements of the system. It forms the basis for the assessment of future system needs and formulation of development proposals. Power system planning aims at identifying the preferred locations for new substations or overhead lines in order to allow the economic operation of a secure system. Computer aided network analysis techniques have been employed in this field. In power system analysis, load flow studies form an important tool for power system planning, economic scheduling, and control of the existing system as well as its future expansion. The weak network areas and related issues such as line capacity issues, voltage drop problems, technical and non-technical losses, and substation capacity issues should be identified to formulate proposals for network reinforcements and developments. Since power systems are spread geographically, their spatial attributes should be taken into account. GIS provides a rich set of functions to view the power system network superimposed on various layers and to explore the geospatial relations. In the process of system planning, it is crucial to provide correct information to people involved and help them understand the need for the additional power system facility. The most effective way to explain the new construction plan and its relationship with the environment is to display the plan on a geographic map. Together with the utilization of a database system, geographical representation of power systems will become an essential tool for utility decision makers.

This research presents a scheme for building the electric power medium voltage (MV) distribution network model of Rafah governorate and assesses its database using computer aided network analysis software and GIS techniques. Also, interactive intuitive visual simulation software for the analysis of electric power systems is presented including power flow through the grid and capacitor placement.

1.2 Statement of the Problem

The electrical power distribution network in Rafah suffers from several technical problems. It suffers from high power losses exceeding 25% , voltage fluctuations that exceed the acceptable levels of 10% and poor power factor on the MV grid according to GEDCO estimates. The high losses are caused by inadequate design of the network and due to highly overloaded feeders which are the main reason of high voltage drop. This unacceptable status of the present distribution network in Rafah with the absence of GIS in distribution management motivates toward creation of a DMS that can introduce interactive and developed solution techniques for most of the grid problems. This system requires a GIS which is the base system for all DMSs. In addition, it requires load flow analysis software to evaluate the technical status of the network.

1.3 Literature Review

Several authors and researchers have studied and investigated the GIS integration with SCADA, DMS and AMR in Electrical Utility for automated distribution systems. In the field of GIS and automation applications in power distribution system analysis and planning for Rafah governorate, no literature reviews were found. Thus the literature reviews in this field are collected from several places around the world. The following works had been carried out in fields of GIS and DMS for various case studies around the world.

■ **Igbokwe, J. I. and Emengini, E. J. (Nigeria, 2005):** this paper presents the use of GIS in management of electricity distribution facilities. It describes the automated system which is developed for National Electric Power Authority (NEPA), in Anambra State of Nigeria. The administrative street and electricity distribution network maps were collected from relevant agencies. Electricity distribution facilities spatial database was designed and created using relational database model approach. The paper maps were converted to digital form and then geo-referenced. After editing, maps were exported to ArcView 3.2a environment. The graphics were linked with the created spatial database. The developed system was put to the test by carrying out a number of GIS operations [1].

■ **Elizabeth Kaijuka (Uganda, 2005)**: this paper discusses the use of GIS in the planning process for rural electrification. The aim is to identify patterns of demand and priority areas of need. By creating a demand-side scenario, electricity can then be supplied to targeted areas. A cross-sectorial view is taken to examine the energy demand patterns using physical data and available country statistics that are then incorporated into a GIS master database. The initial priority demand-side sectors targeted, in terms of energy needs, are education and health [2].

■ **OlaniYI Saheed Salawudeen, Usman Rashidat (Germany, 2006):** this paper discusses the implementation of GIS technology by Power Holding Company of Nigeria, (PHCN). This project located and mapped all the facilities of PHCN. This mapping involves the collection of both the geometric and attributes data of those entities identified. This was done in collaboration with the staff at the distribution department of PHCN. Both geometric data and attribute data collected was entered into the system via MS Excel and later exported into ArcView GIS 3.2a. The end products are customized maps, tables, softcopy of the maps and project reports [3].

■ **Zhihong Liu, Guozhi Mao, Huaxing Yu, Wenjun Zhou (International Conference on Power System Technology, 2006):** this article describes the automation process of the power distribution system in the Yangjiaping Power Supply in Bureau. The power distribution automation project to be implemented includes 54 of 10 kV feeders, 42 switching stations, 39 ring net cabinets and branch boxes and 7 of 110 kV power stations, which satisfies the requirements of power distribution automation and management automation within the range of l0 kV supply area in the Yangjiaping Power Supply Bureau. The project began to be constructed in 2003 and all the construction tasks were completed in December 2005. The implemented system consists of several organic parts including power distribution network real-time monitoring, feeder automation, power distribution geographic information system, power distribution flow management system, power distribution information WEB release system and so on [4].

■ **Uday D. Kale, Rajesh Lad (India, 2006)**: this paper explains the need, approach and benefits of GIS, SCADA, DMS and AMR systems in electric utility. It discusses how the integration of GIS with SCADA /DMS and AMR, offer highly performance capabilities to deliver optimal services, all while meeting the organization's business improvement [5].

■ **Jingjing Lu, Da Xie, Member, and Qian Ai (IEEE, 2009):** in this paper, the smart grid concept and structure were presented. Typical diagram of smart grid was illustrated. Then, the current development of smart grid in United States and Europe were described, development ideas and the future trends in these countries were summarized and compared. Also a detailed introduction of current related projects in China was analyzed. Finally, the potential role of smart grid in future power grids in China was prospected and a new direction for China's Smart Grid development was charted [6].

■ **LIU Junyong, LIU Jichun, Lv Lin, ZHANG Peng, SHEN Xiaodong, HUANG Yuan, LI Chenxin, (China, 2010)**: this paper also elaborates the key technologies of building smart grid in self-healing distribution network, complete communication system, smart SCADA system and the utilization of new power supply and consumption facility, etc. Also, the paper looks into the future of building smart gird in the new Beichuan County [7].

Due to the absence of adequate precedent studies in power system analysis and planning for Rafah governorate and due to the deteriorated conditions of the existing network, new studies are necessary to analyze and evaluate the existing network using a new technology of GIS integrated with utility load flow analysis technologies.

1.4 Methodology

The procedures followed to accomplish this research are summarized as follow:

1. Data collection: the collected data involves the aerial map of Rafah Governorate, AutoCAD drawings of the electrical MV network, the electrical specifications of the

wires, cables and transformers used by GEDCO and the transformers loading measurements for both summer and winter seasons.

2. Load flow analysis: the one-line diagrams of the four main feeders of Rafah are drawn inside ETAP program in separate projects. The electrical specifications of the lines and transformers were entered to customized libraries in ETAP. Then different simulation processes were performed to evaluate the status of the grid completely.

3: GIS model construction: using AutoCAD drawings and aerial map of Rafah, a GIS model of the MV grid is constructed by ArcGIS software. The model is employed in various applications which highlight the advantages and functionalities of GIS in power distribution field.

1.5 Objectives of the Thesis

This thesis aims at building of a modern power distribution management system for the distribution grid in Rafah governorate. The proposed project includes basically GIS, load-flow analysis and SCADA systems respectively. Only the GIS and load-flow models of Rafah power distribution grid were carried out in this thesis. In each stage, it's intended to achieve a number of purposes. **In GIS stage,** it's decided to develop a database to document the data of the existing MV network using Microsoft Access 2010 program and then this database will be joined to the GIS model created by ArcMap 9.3. After that, the GIS model will be employed to various applications. These applications include planning of future projects using the geometric network analysis extension, visualizing results of analyses on a digital map in two-dimensional view and they also can be exported to Google-Earth environment. Also it can be helpful in map printing and evaluation reports of the existing grid. It's intended to get benefits from the statistical analysis tools in ArcGIS in research studies and load forecasting. Moreover, it's aimed to visualize the load-flow results on the GIS maps. **Network Analysis** aims to study power flow of the existing network to evaluate its performance and identify its technical problems. Then, proposing the suitable solution techniques.

1.6 Outlines of the Thesis

This thesis is covered in five chapters which are presented below and each one is described briefly. **Chapter one:** covers the introduction, literature review, aims and outlines of this thesis. **Chapter two:** introduces the basic components of a distribution system. It includes an introduction to the type of data that is necessary to model a distribution system. It presents some helpful approximate aspects in feeder analysis that are used to evaluate the performance of a distribution network. Also it discusses the smart grid and distribution automation concepts. **Chapter three:** introduces ETAP software which is used along this chapter to simulate the 22-kV network. It discusses the problems of the status of the existing 22-kV grid through simulation including the deficit in the power supply, power losses, low power factor and poor voltage levels. Considering the present technical situation of the grid evaluated by simulation, different technical solutions are suggested to improve the grid performance. **Chapter four:** contains the theoretical background of GIS. The applications of GIS technology in electric utility are illustrated in details. It presents a complete GIS model for the MV grid of Rafah using ArcGIS software, the most famous software used in GIS modeling field. The rest of the chapter employs the GIS model in various applications. **Chapter five:** contains the final conclusions and recommendations for future work.

CHAPTER 2

POWER DISTRIBUTION SYSTEM

2.1 Introduction

A distribution power system delivers the electrical power from the transmission system to customers in LV level. Any distribution substation ends with one or more of primary feeders which feed the distribution transformers. Primary feeders will be the subject of further description and discussion in this chapter. Increasing complexity of power grid and its management, growing demand and service quality expectations have triggered the next major step in the evolution of the power grid towards a "Smart Grid". It is an expected result of implementing new technologies in power systems, advanced meters, PLCs, GIS, and advanced communication technologies. Thus distribution organizations are increasingly turning to build the power smart grid to improve their operational processes. So we are interested to present such important concept.

2.2 Distribution System Components

The major components of an electric power system are divided into three main subsystems: generation, transmission and distribution. These components are shown in Figure 2.1.

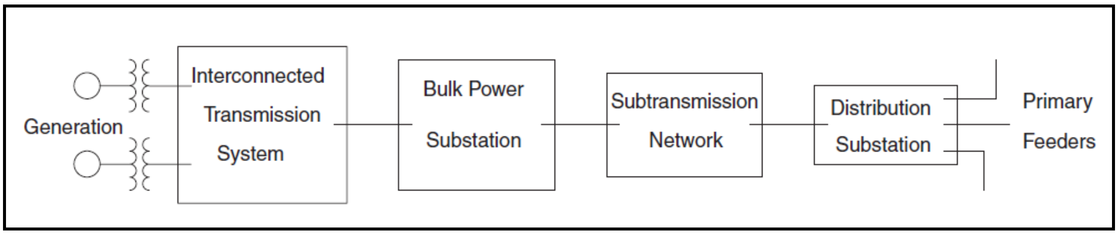


Figure 2.1: major components of power system

The distribution system typically starts with the distribution substation that is fed by one or more sub-transmission lines [8]. The primary distribution system comprises the facilities that deliver power from the distribution substation to the distribution transformers. These take the form of one or more distribution feeders or circuits emanating from the substation, each supplying a portion of the entire load served from that substation. With a rare exception, the feeders are radial in configuration [9]. Power distribution is normally done on the medium-voltage level, in the range of 6.6–33 kV. Three-phase power is transferred, mostly via overhead lines or 3-core MV power cables buried underground. Low-voltage distribution is also done over short distances in some localized areas [10].

2.2.1 Radial Feeders

Radial distribution feeders are characterized by having only one path for power to flow from the source (distribution substation) to each customer. A typical distribution system will be composed of one or more distribution substations consisting of one or more feeders. The loading of a distribution feeder is inherently unbalanced because of the large number of unequal single-phase loads that must be served. An additional unbalance is introduced by the non-equilateral conductor spacing of three-phase overhead and underground line segments. [8]

2.2.2 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. The feeder map should contain the following information: lines (overhead and underground), conductor sizes, distribution transformers, shunt capacitors, voltage regulators, switches and any other electrical equipment installed on the network for metering and monitoring or for any other purpose. Information from the map should define the physical location of the various devices. Electrical characteristics for each device have to be determined before the analysis of the feeder. In order to determine the electrical characteristics, the following basic data must be available:

1. Overhead and underground spacing.
2. Conductor parameters' tables including geometric mean radius (GMR), diameter, AC and DC resistances.
3. Transformer potential ratios, KVA ratings, impedance (R and X), load and no-load losses [8].

2.3 Feeder Power-Flow Analysis

A distribution feeder provides service to unbalanced three-phase, two-phase, and single-phase loads over untransposed three-phase, two-phase, and single phase line segments. This combination leads to three-phase line currents and line voltages being unbalanced. In order to analyze these conditions as precisely as possible, it will be necessary to model all three phases of the feeder accurately, however, many times only a "ballpark" answer is needed. When this is the case, some approximate methods of modeling and analysis can be employed. The analysis of a distribution feeder will typically consist of a study of the feeder under normal steady-state operating conditions (power-flow analysis). All of the approximate methods of modeling and analysis assume perfectly balanced three-phase systems. It also assumes that all loads are balanced three-phase, and all line segments three-phase and perfectly transposed. With these assumptions, a single line-to-neutral equivalent circuit for the feeder can be used. The power-flow analysis of a distribution feeder is similar to that of an interconnected transmission system. Typically, prior to the analysis, electrical engineer must know the three-phase voltages at the substation and the complex power of all of the loads and the load model (constant complex power, constant impedance, constant current, or a combination). Sometimes the input complex power supplied to the feeder from the substation is also must be known. A power-flow analysis of a feeder can determine the following by phase and total three-phase:

- Voltage magnitudes and angles at all nodes of the feeder.
- Line flow in each line section specified in kW and kvar, amperes and power factor.
- Power loss in each line section.
- Total feeder input kW and kvar.
- Total feeder power losses [8].

In solving a power flow problem, the system is assumed to be operating under balanced conditions and a single phase model is used. Four quantities are associated with each bus. These are voltage magnitude $|V|$, phase angle δ, real power P, and reactive power Q [11].

2.3.1 Power Flow Commercial Products

Considerable research has already been carried out in the development of computer programs for load flow analysis of large power systems. However, these general purpose programs may encounter convergence difficulties when a radial distribution system with a large number of buses is to be solved and, hence, development of a special program for radial distribution studies becomes necessary [12]. There are many commercial products for the purpose of power systems analysis. ETAP and PSSE are examples of such programs. In this research, ETAP 7.0.0 will be used to perform the load-flow analysis of Rafah Governorate MV network. We will have an idea about that software in chapter three.

2.4 Challenges in Feeder Performance Analysis

As a power distribution system load grows, the system power factor usually declines. Load growth and a decrease in power factor leads to a number of challenging problems such as: voltage regulation problems, increased system losses, power factor penalties and reduced system capacity [13]. Another challenge is the proper modeling of an electric power distribution system. That's because the volume of data involved for modeling the electric distribution system is huge. Then a modeling process requires large amounts of computer memory, and it is typically time consuming to conduct computation on the entire model [14].

2.5 Voltage Rating in Distribution Systems

Many utilities around the world use the IEC 60038 standard for voltage ratings in distribution utilities. Voltage drops along the primary line, the distribution transformer, and the secondary lines. According to this standard, the A.C. three-phase systems having a nominal voltage between 1 kV and 35 kV with 50 Hz frequency, under normal service conditions, it's recommended that the voltage at the supply terminals should not differ from the nominal voltage of the feeding sources by more than ±10 %. Specific for 22-kV distribution system, at which our network model in Rafah operates, the operating voltage shouldn't drop below 20 kV and rise up 24 kV for good quality [15]. One of a utility’s core responsibilities is to deliver voltage to customers within a suitable range, so utilities must regulate the voltage. On distribution circuits, voltage drops due to current flowing through the line impedances

[16]. In a radial feeder, the voltage drop through the feeder is approximately given according to equation 2.1 [17]:

$$V_d = IR\cos\theta + IX_L \sin\theta \tag{2.1}$$

Where

I : Current through the feeder
θ Power-factor angle
R Resistance of the feeder
X_L Reactance of the feeder

Distribution utilities have several ways to control steady-state voltage. The most popular regulation methods include:

- Substation load tap-changing transformers (LTCs)
- Substation feeder or bus voltage regulators
- Line voltage regulators
- Fixed and switched capacitors [16]

2.6 Advantages of Installation of Capacitors

The installation of capacitors in power systems has several benefits. Some of them are as follows:

- Power-factor improvement: they reduce the kVA demand, and hence, the tariff paid by customers for certain utilities. Moreover they reduce the line currents and hence reduce losses in the system. Further the installed capacity of the transformers and the kVA installed capacity of the utility are also reduced.
- Reactive support: in the distribution and transmission systems, when the systems are heavily loaded, they require kvar support from the capacitors to obtain an acceptable voltage level at the different buses by compensating for lagging reactive loads in the system [17].

The ideal size of the shunt capacitors used for improving the power factor is that which will make the annual cost of capacitors equal to the annual saving in purchased energy. It's more expensive to improve the power factor to unity from fairly high power factor such as 0.95 than to improve power factors such as 0.70 to 0.80 or 0.80 to 0.9 [18].

2.7 Smart Grid and Distribution Automation Concepts

The smart grid concept has been a very popular subject over the past few years. There is not a rigid definition of a smart grid, since it is a user specific design, dependent on the application needs and vision of the individual utility. Generally, the term smart grid refers to an advanced state of utility system infrastructure and operation, and the associated utility processes. The common themes of any smart grid design include:

- The need for automatic collection of data from multiple applications throughout the utility network.
- The need for adaptive integrated communication mediums that can handle data from multiple applications located throughout the utility infrastructure.
- The need for integration of application software suites so they share collected data in common dynamic databases [19].

The term distribution automation can be applied to many aspects of the electric power delivery system, from the control center to the substation, to the feeders and indeed to the customer revenue meters. As the IEEE defines, distribution automation (DA) is "a system that enables an electric utility to remotely monitor and operate distribution components in a real-time mode from remote locations [20]." Moreover, the term automation may imply nothing more than the ability to close or open a switch remotely. Technology has been applied to reduce the cost of such devices, thus improving the economics of their application [21]. There are three components of a system-wide distribution automation system. These include:

1. Control center-based control and monitoring systems, including distribution SCADA;
2. The data communications infrastructure required to acquire and transmit operating data to and from various network points in addition to substations; and
3. The various distribution automation field equipment ranging from remote terminal units (RTU) to intelligent electronic devices required to measure, monitor, control and meter power flow [20].

2.7.1 Feeder Automation

FA control is a general term for all remote control and automation of devices outside the substation and includes all devices along distribution feeders such as switches, voltage line regulator controls, feeder capacitor controls, and devices at the utility customer interface such as remotely read intelligent meters. The main objectives of feeder automation include:

Automated fault detection, isolation and service restoration: this is the most important function of FA in which the faulted feeder section can be detected, isolated and restored the service for the healthy sections within 20-30 seconds.

Transformer and feeder load transferring and balancing: this allows FA to automatically transfer loads among feeders or substation main transformers to balance feeder loads.

Scheduled sectional service interruption for maintenance: this allows the isolation of a feeder section remotely for maintenance without interrupting the service to other sections [22].

2.7.2 Planning the Smart Distribution System

The transition from the existing system to smart distribution system requires building new distribution lines, feeder ties, installing new smart switching/ protective devices, new distribution equipment, sensors, and meters for monitoring, controlling, and protecting the new lines. The improved methodologies and tools must help distribution engineers answer questions such as how many new smart devices, feeder ties, distribution lines, capacitor banks, voltage regulators, sensors, and other devices are needed and where they should be located. Moreover, the tools should provide decision makers with a means for assessing the costs and expected benefits of the proposed smart grid alternatives in various scenarios and levels of implementation [23].

2.7.3 Investment-Benefit Analysis of the Smart Grid

The investment construction of smart grid depends on the used applications of basic technologies, such as equipping the power grid with advanced power equipment, measurement and communication equipment, introducing information management systems and a variety of technologies as energy storage and decision-making control. The smart grid has indispensable potential economic advantages, which are mentioned in the following aspects:

- **Promoting the consumption of electric power**: this is due to introducing better services to customers.

- **Reducing maintenance cost:** the construction of smart grid will introduce the most advanced information and monitoring technology, so as to improve the utilization efficiency of the individual assets, realize the optimal system operation which leads to reduced cost of operation and maintenance of equipment.
- **Increasing the service life of equipment:** the operation mode of equipment will be optimized, and the service life will be prolonged. This is achieved since the smart grid uses advanced information integration platform, realizes on-line detection of equipment state, and timely introduces condition-based maintenance [24].

2.8 Summary

This chapter discusses the power distribution system, focusing on medium voltage feeder analysis. It presents the methodology should be followed to establish an accurate feeder model so that it can be ready for accurate power flow analysis. Also it highlights the challenges faced by distribution systems and the associated solution strategies. It introduces the concepts of smart grid and distribution automation. It illustrates the strategy to transfer from an existing distribution grid to a smart one. The smart grid has potential economic advantages, so the investment benefits of smart grid implementation was discussed in the last section.

CHAPTER 3

MODELING OF RAFAH POWER DISTRIBUTION GRID

3.1 Introduction

The results of a load flow analysis can be used for operational purposes to evaluate various operating states of an existing system. They can also be used in the planning stages to evaluate possible future extension projects. The results of the load flow are also used in the evaluation of the electrical, load, and operational constraints. This chapter presents a discussion of the results obtained by simulation using ETAP software. The problems and challenges faced by the existing network are analyzed and evaluated based on simulation. Those problems include the power deficit, high power losses, poor voltage levels and feeders' overloading. Then some solution techniques are suggested considering the system current state and future growth for different scenarios for each problem to obtain a full understanding of the system problems and solutions.

3.2 Description of the Existing Network

In Gaza Strip including Rafah governorate, the term medium voltage network refers to the 22-kV feeders. Rafah receives power through four feeders as shown in Figure 3.1 [25].

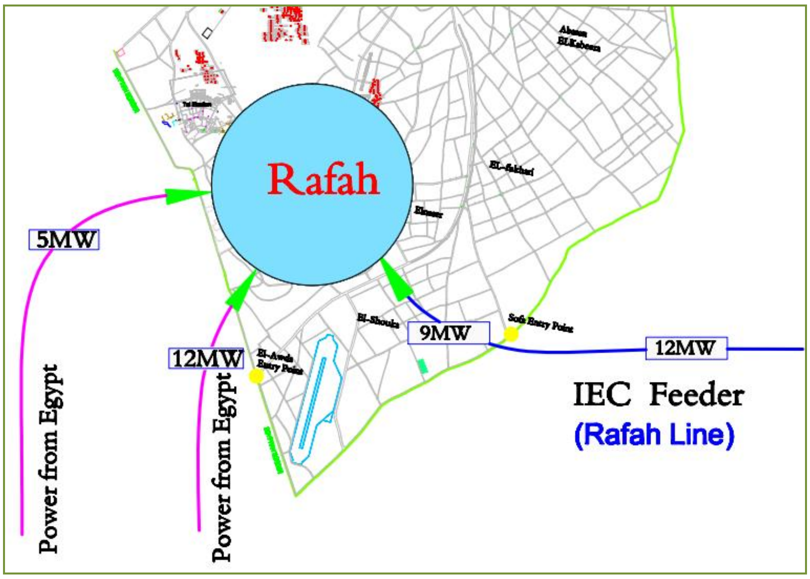


Figure 3.1: The main feeders of Rafah Governorate

Three of the feeders are from Egypt and owned to CEDC. They enter Rafah from its southern side. The first feeder has a maximum capacity of 5 MW. The second feeder has a maximum capacity of 12 MW, and it's divided into two feeders. The fourth feeder enters Rafah from its eastern side. It's owned by the Israeli Electric Company (IEC) and has a maximum capacity of 12 MW, only 9 MW feeds Rafah and the remaining MW feeds Khan Younis. Those feeders have various lengths, capacities and other specifications indicated in table 3.1.

Table 3.1: Distribution Feeders in Rafah Governorate till year 2011

Feeder Name	Capacity (MW)	Length (km)	No. of Transformers according to capacity (KVA)								Total
			100	160	250	315	400	630	800	1250	
Egyptian Feeder No.1	5	11.74	0	0	0	0	8	11	2	0	21
Egyptian Feeder No.2	5	9.64	1	0	0	0	2	20	5	0	28
Egyptian Feeder No.3	7	18.83	0	1	3	0	8	16	2	0	30
IEC Feeder	9	30.74	0	1	6	0	16	30	0	1	54
Total	26	70.95	1	2	9	0	34	77	9	1	133

All those feeders are governed by GEDCO, the unique electric distribution company in Gaza Strip. Medium voltage distribution system is stepped down to 400 volt at distribution transformers. The power is then distributed to individual consumers via low voltage distribution networks at 400-V. This network serves 22,038 customers which represents 12% of the total customers of GEDCO in year 2011. The MV network falls into two categories: overhead lines and underground cables. The MV network is fairly wide spread in Rafah with total length of about 68800 m feeding 133 of different sizes of distribution transformers. Moreover, the overhead lines cover about 93.8% of the overall length of the network. This is because the overhead network is much cheaper than the underground network. Most of the 22-kV lines are constructed using ACSR 150/25, ACSR 50/8 and ACSR 95/15 conductors. It's important to know that all the previous mentioned data of Rafah network represents the network status till to the end of 2011.

3.2.1 Problems and Issues of the Existing Network

The existing network suffers from many problems and deficiencies which need effort to be solved, so they need to be fixed at first. Those issues are identified as follows:

Inadequate capacity of existing feeder lines: there is no adequate capacity in the network to meet present and future demands. This is because some of the existing 22-kV lines are loaded at firm capacity levels and some are in fact overloaded due to electrical thefts. At present time, Rafah governorate suffers from a high deficit in the power supply by about 34% according to GEDCO technical reports. This percentage isn't accurate since it's estimated by inaccurate measurements. Thus no adequate excess capacity is available to meet contingencies and to meet the future demand.

Poor voltage levels: various parts of the distribution network are affected by poor voltage levels below the allowable limits. This has caused poor supply voltages to consumers in those areas, which results in poor performance of electrical equipment for both domestic and industrial consumers. This usually occurs at the end of the feeder lines.

Network losses: generally, power losses can be classified into two types: technical losses (electrical losses) and non-technical losses (non-electrical losses). Technical losses occur due to distribution substation, transformers and transmission lines. The non-technical losses caused by electrical thefts. There is no mechanism to evaluate non-technical losses due to absence of the effective system for energy metering. Specifically speaking about Rafah governorate, there are no accurate calculations of line losses. This high loss is caused by the following reasons:

1. Some of the lines are old or have defects and hence need maintenance.
2. There are overloaded lines and transformers in the network for long periods of time.
3. Illegal joints which exist in the transmission lines.
4. The lengths of some transmission lines are not proportional with their capacity; so in many cases there is a high voltage drop on the network.

3.3 ETAP Software Description

ETAP of Operational Technology, Inc. is for the design, simulation, and analysis of generation, transmission, and distribution power systems. ETAP software suite has various program modules like power system analysis, real-time simulation, advanced monitoring, optimization control, intelligent load shedding, energy usage cost analysis, and device coordination.

For a power distribution system, it's capable of calculating balanced and unbalanced load-flow. This analysis produces both detailed and summarized accounts of system losses, line flows, and voltage at every node or bus. The software is capable of recommending optimum capacitor placement, wire size upgrades, and changes in conductor configuration to satisfy user-defined restrictions on the system. ETAP Power Station family of programs is a fully integrated analysis tool used to design, maintain, and operate electric power systems in a totally graphical and virtual reality environment. Other integrated tools include ETAP PSMS for PowerStation Management System, ETAP STAR for System Protection and Device Coordination, and ETAP Panel Systems for panel system design and analysis [26].

3.3.1 Load Flow Analysis in ETAP Environment

The ETAP Load Flow Analysis module calculates the bus voltages, branch power factors, currents, and power flows throughout the electrical system. ETAP allows for swing, voltage regulated, and unregulated power sources with multiple power grids and generator connections. It is capable of performing analysis on both radial and loop systems. ETAP allows you to select from several different methods in order to achieve the best calculation efficiency [27].

3.3.2 Integration between ETAP and GIS

ETAP has a GIS module that automatically generates electrical one-line diagrams with the corresponding geographic maps of power generation, transmission and distribution systems. Electrical system data is synchronized from GIS into ETAP thereby maintaining the relationship between them. You can open unlimited views of GIS maps in ETAP, allowing you to manipulate GIS maps while working in ETAP. The analysis results are displayed on a one-line diagram and geographic maps providing a wonderful view of the power system within ETAP [26].

3.4 Modeling System Elements

This section demonstrates in details the modeling method in ETAP and the various components of the network. The electrical specifications of the components which are entered to ETAP are also described.

3.4.1 Modeling Method

System models can be created through a graphical-user-interface or by importing system information from a GIS model. The system is drawn node-by-node and line-by-line. The specific parameters can be entered for each component and can be either selected from a standard catalog of equipment or customized to fit the particular system component. Figure 3.2 depicts the user editing interface of ETAP software.

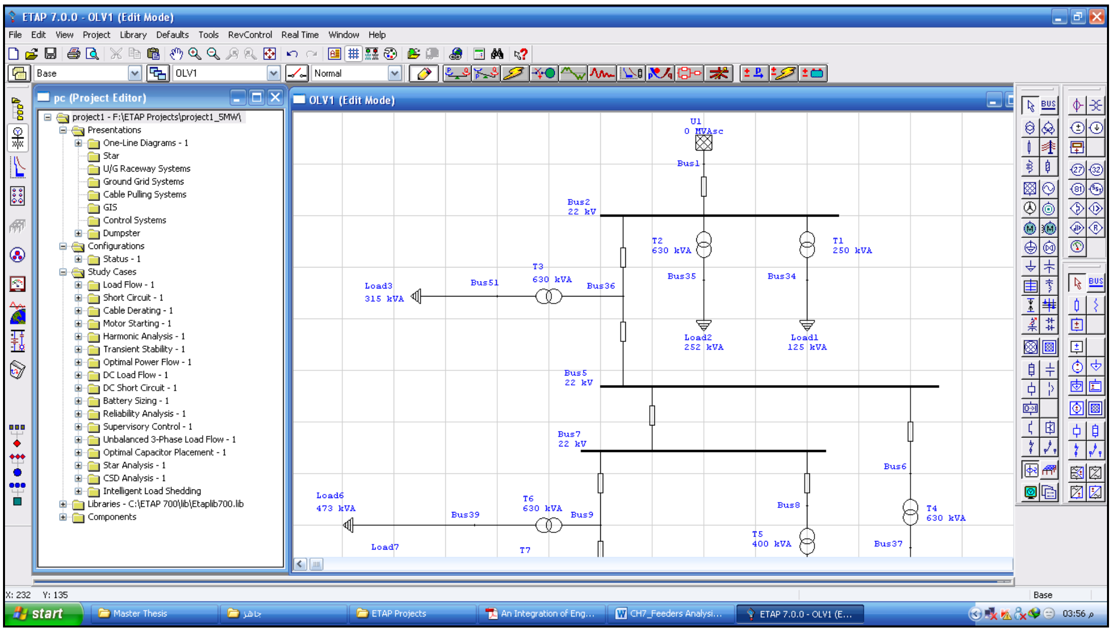


Figure 3.2: The interface of ETAP

The figure shows the one-line diagram window with all available menu bars in which each provides a list of menu options and drop-down lists of commands.

3.4.2 Source

In ETAP generators and power grids have four operating modes that are used in load flow calculations: swing mode, voltage control mode, Mvar control mode and power factor mode. The constant voltage node in ETAP is modeled as a swing mode. In this mode, the voltage is kept fixed; P and Q can vary based on the power demand. So GEDCO Company is modeled as a swing machine rated at 22-kV. Because of lack of measurement's data, then the source is assumed to be voltage balanced.

3.4.3 Transformers

There are 133 distribution transformers operating in Rafah. They're installed outdoor or indoor in special rooms. Generally, GEDCO have outdoor transformers in specified ratings: 250, 400, 630 and 800 KVA. In addition, the indoor transformers have higher rating values: 1250, 1600 or 2000 KVA. The tables of all transformers distributed over their feeders are given in details in appendix B. Those tables include the transformers' names, ratings and loading information. These transformers share some common technical specifications as shown in table 3.2.

Table 3.2: Technical specifications of installed transformers

Description	Requirements
Reference Manufacturing Standard	DIN42500
Type	3 phase oil immersed with conservator
Rated Frequency (Hz)	50
Cooling method	ONAN
Normal Voltage Between Phases at No Load (kV)	
HV	22
LV	0.4
Connection and Vector Group	
HV Winding	Delta
LV Winding	Star
Vector Group	Dyn11
Tapping Range on H.V Side	
Plus	1x2.5%
Minus	3x2.5%
Type of Tap Changer	Off Load
Winding Conductor Material	
HV winding Type	Copper
LV winding Type	Copper

The basic transformer data needed in ETAP are: type, rated frequency, cooling method, transformation ratio, KVA rating, per-unit impedance (%Z) and X/R data. Figure 3.3 describes one of the installed transformers.

Figure 3.3: One of the distribution transformers used by GEDCO

The Figure shows that the transformer is hold on a lattice steel pole (LSP)**.** The three phases are insulated by using porcelain and glass insulators.

3.4.4 Lines

Majority of the overhead lines are composed of ACSR conductors which exist in three sizes according to the German Sizes DIN 48 204 – APR 1984 Standard and they're 50/8, 95/15 and 150/25 mm². A little portion of the lines are composed of stranded copper conductor in only one size which is 35 mm². The electrical specifications of used overhead lines are given in tables A.1 and A.2 in appendix A. They're entered to customize Transmission Line Libraries in ETAP. One library is for ACSR conductors and the other is for Copper conductors. Figure 3.4 above shows the customized library of the ACSR conductors.

Aerial Line Library

Source Name: GEDCO_ACSR | Conductor Type: ACSR | Frequency: 50 | Base T1: 25 °C | Base T2: 50 °C | Ta: 20 °C | Tc: 75 °C | Impedance Unit: 1 km | mm²

Avail	Code	Size	Strands	Strand Dia.	Steel Strands	Strand Dia.,	OD	GMR	Ra T1	Ra T2	Xa	Xa'	Rdc	Weight	Strength
☑	ACSR_50/8	56.3	6	0.32	1	0.32	0.96	0.0017	0.58	0.709	0.357	0.2377	0.5946	1.922	3783.13
☑	ACSR_95/15	110	26	0.215	7	0.167	1.36	0.00134	0.306	0.373	0.341	0.2178	0.3058	3.756	7859.47
☑	ACSR_150...	173	26	0.27	7	0.21	1.71	0.00104	0.194	0.2373	0.326	0.2047	0.1939	5.933	12154

Figure 3.4: ACSR conductors' library

While Figure 3.5 shows the customized library of the Copper conductor.

Aerial Line Library

Source Name: GEDCO_Cu | Conductor Type: CU | Frequency: 50 | Base T1: 25 °C | Base T2: 50 °C | Ta: 20 °C | Tc: 75 °C | Impedance Unit: 1 km | mm²

Avail	Code	Size	Ampacity	Strands	Strand Dia.	OD	GMR	Ra T1	Ra T2	Xa	Xa'	Rdc	Weight	Strength	Comment
☑	CU_35	35	200	7	0.252	0.756	0.00257	0.4	0.7	0.3	0.25	0.5181	3.079	3216.54	

Figure 3.5: Copper conductors' library

The determination of the impedances for overhead lines is a critical step for analysis of the distribution feeders. Depending upon the distribution line configuration, line impedances are calculated in ETAP using some special equations. The configuration model of most lines is horizontal at nearly 12 m height and 1 m spacing between adjacent phases.

3.4.5 Loads

Since most of the loads are for domestic purposes and small part of them for industrial purposes, then all loads are modeled as static loads. Inductive loads aren't considered because of load variations between seasons and limited load measurements. For more accurate results, all type of loads should be considered. The transformers' loading data were given in percentage of the full load regardless of the load type. Then the loads are estimated in KVA values from the transformers full load rating. Due to lack of measurement's data, the loads are assumed to be balanced in simulation. Figure 3.6 shows the energy consumption in the year 2011 according to the usage class.

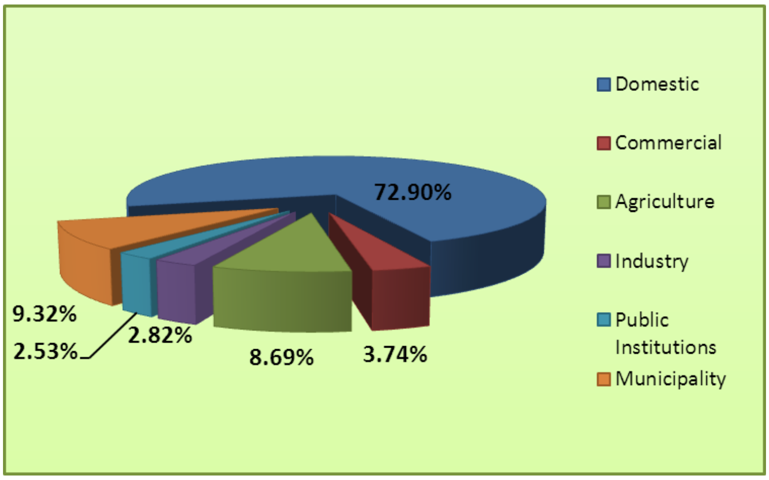


Figure 3.6: Customer classes in year 2011

The Figure indicates that 72.67% of the overall count of customers falls into domestic class. Thus the power factor is considered 0.85 as a suitable value for all different classes of customers.

3.5 Simulation Results and Analysis

Analysis of the existing network has been carried out by using ETAP Software version 7.0.0. It's used to evaluate the existing network performance under different scenarios and then to formulate suggestions for system improvements and developments. Major issues and deficiencies of the existing network have been identified through the load flow analysis module. Since all feeders in Rafah city are in radial configuration, then each feeder can be analyzed separately. The four feeders are simulated in separate projects. It’s worth to mention that the load shedding arrangement isn’t considered in simulation. It’s assumed that all loads are available in normal operating conditions. The one-line diagrams of each feeder are shown in Figures 3.7 - 3.10 respectively.

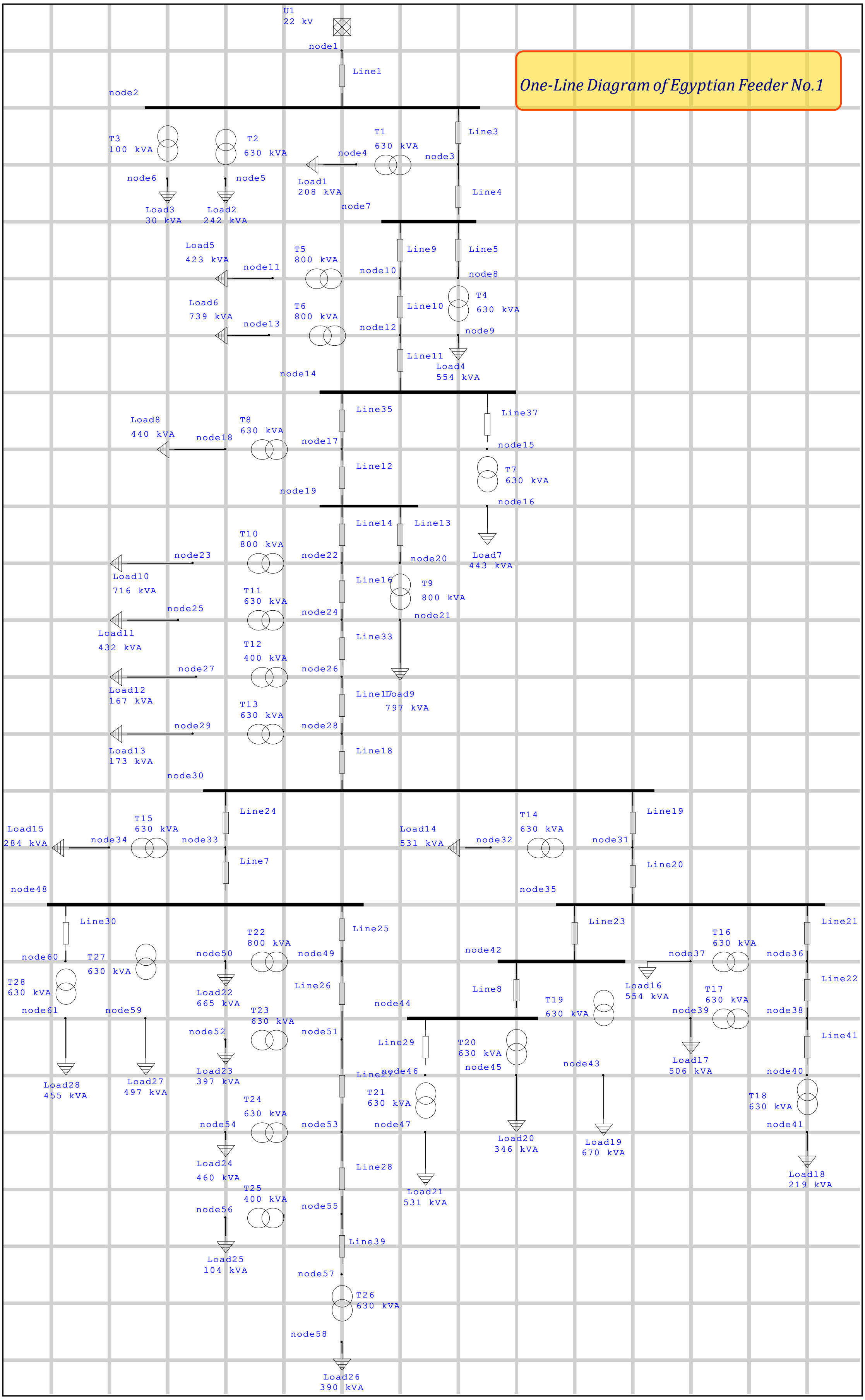


Figure 3.7: One-line diagram of Egyptian Feeder No. 1

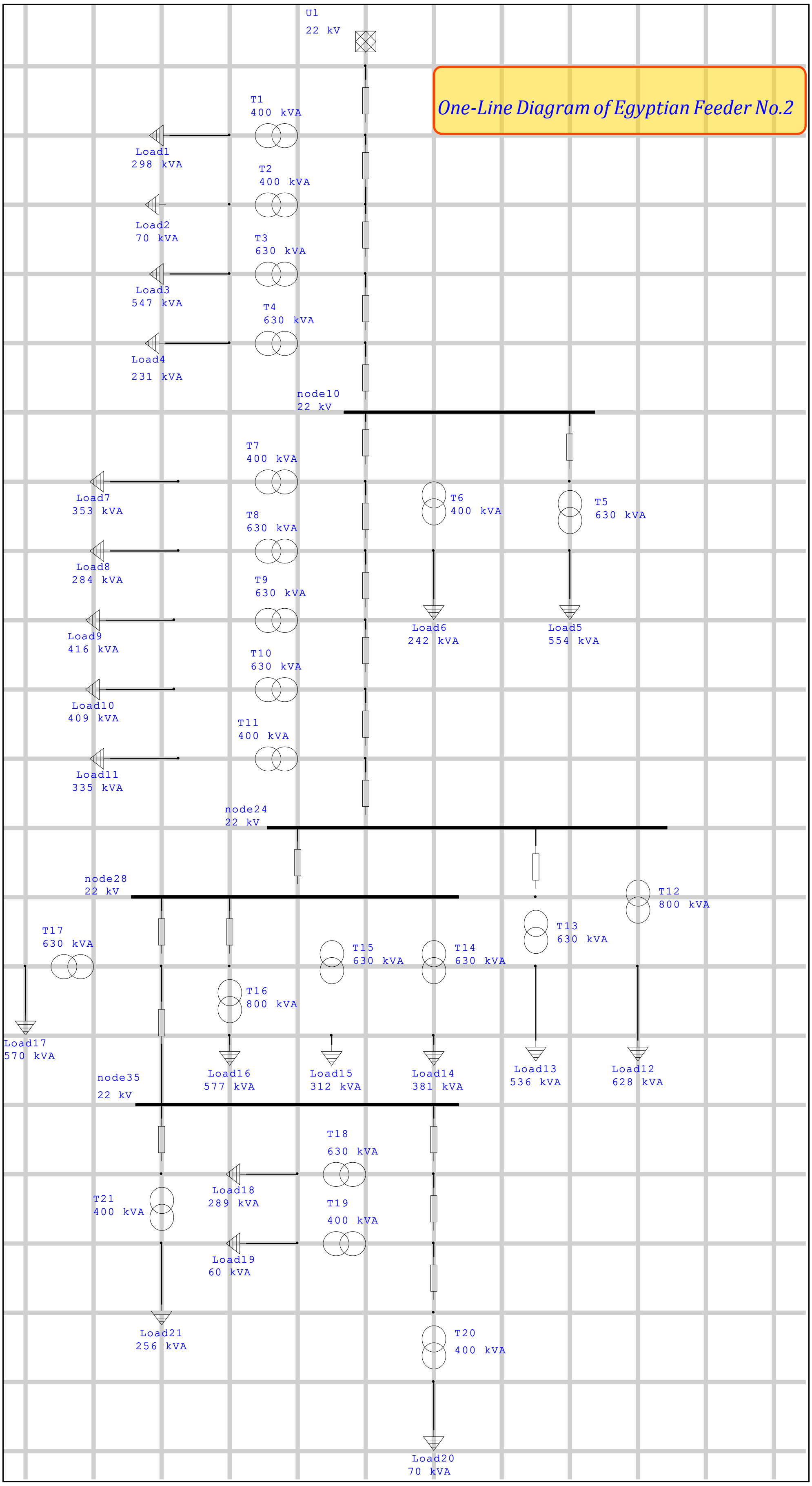


Figure 3.8: One-line diagram of Egyptian Feeder No. 2

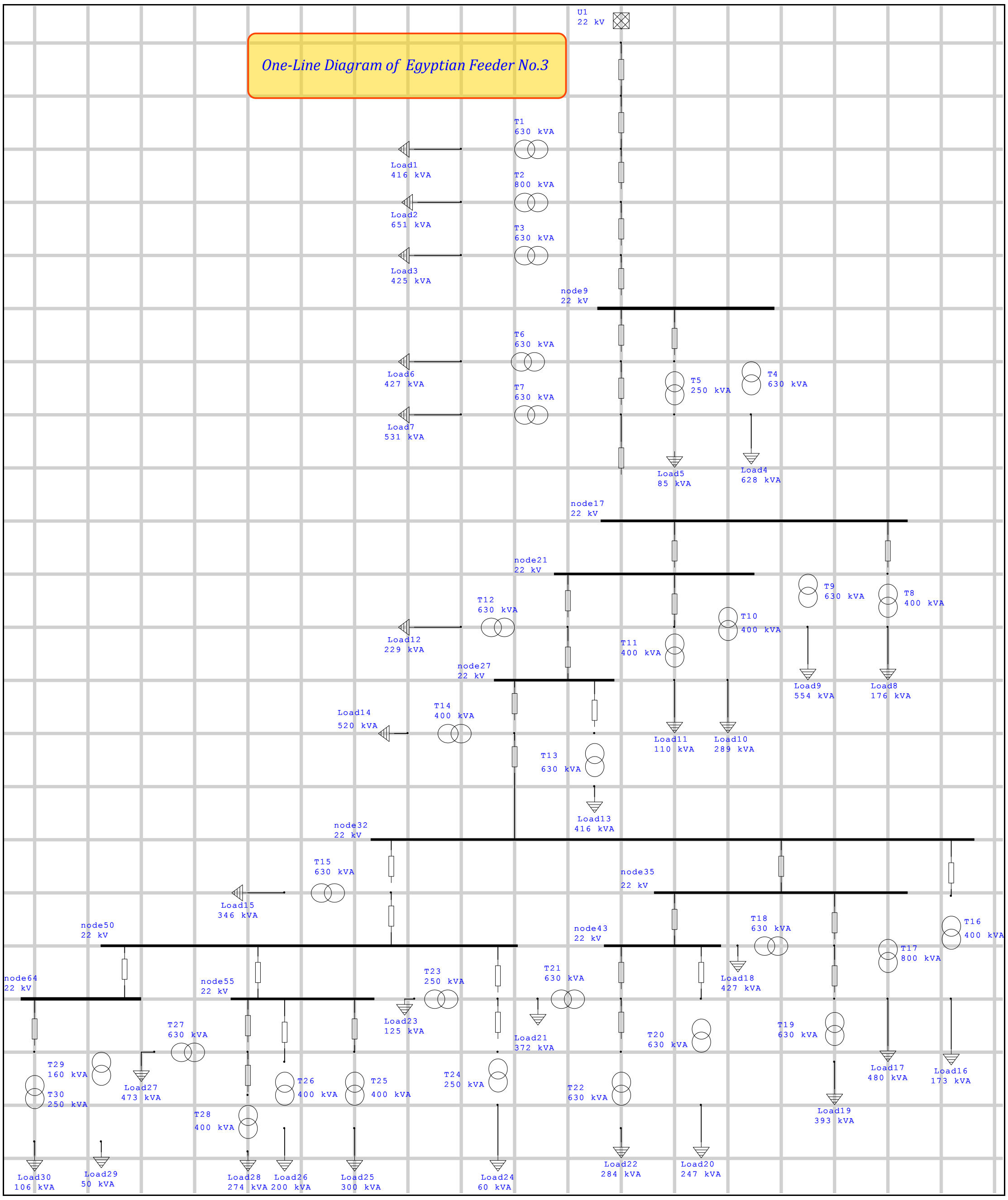


Figure 3.9: One-line diagram of Egyptian Feeder No. 3

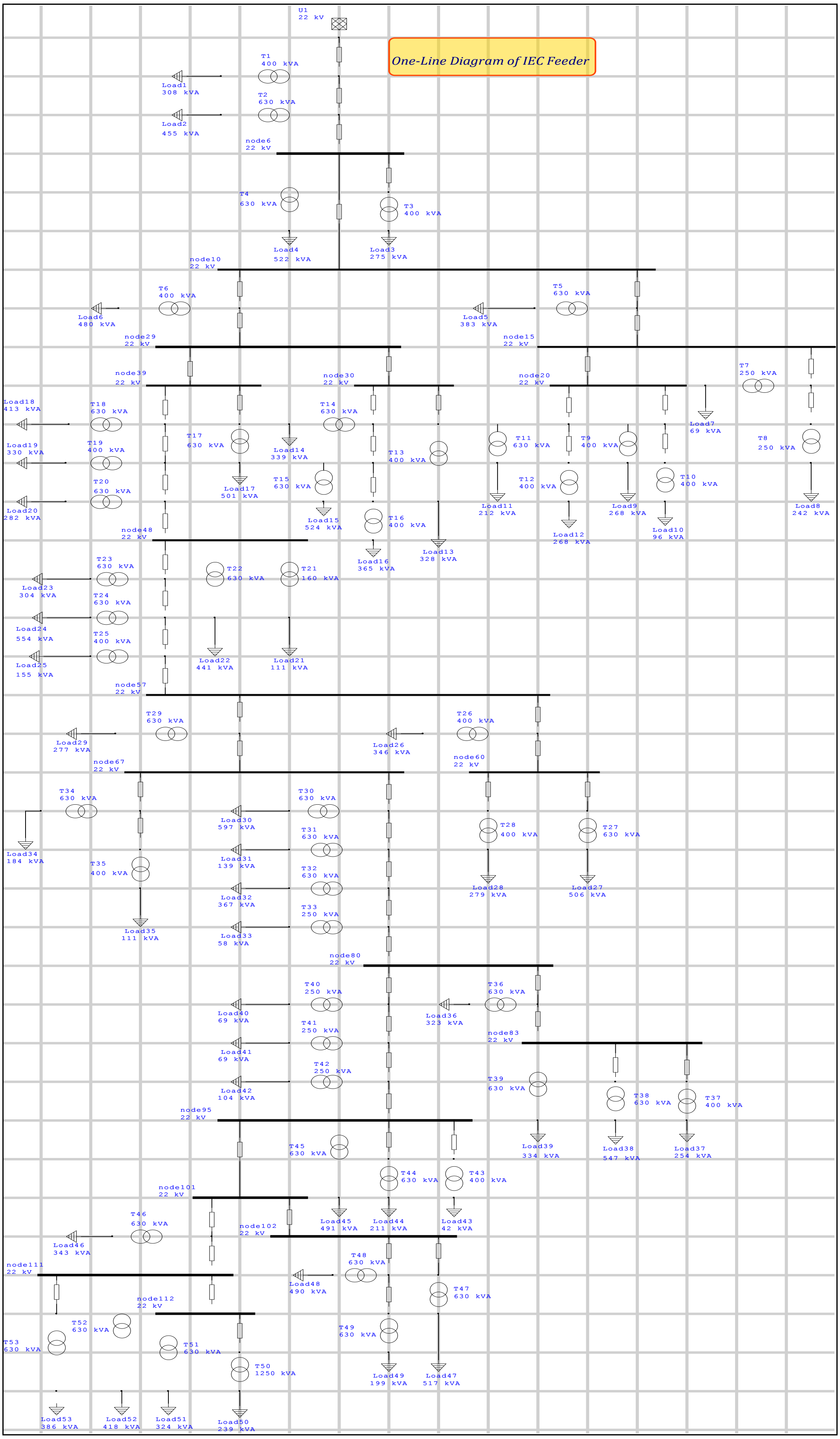


Figure 3.10: One-line diagram of IEC Feeder

The results of load flow module for all feeders are divided into three parts: the first part of the results is concerned with power demand and capacity issues, the second is related to the system losses, while the third part is for voltage magnitude and voltage drop at each node on the feeders. Numerical power flow results are given in details in Appendix C.

3.5.1 Evaluation of the Present Power Demand

Accurate assessment of the existing power demand is really a difficult task owing mainly to the restricted available power supply, while there is a continuous growth in customers' demand annually. This increase can be identified by a quick look at the energy sales curve shown in Figure 3.11 for the last decade which shows an average increase of 10.11% per year.

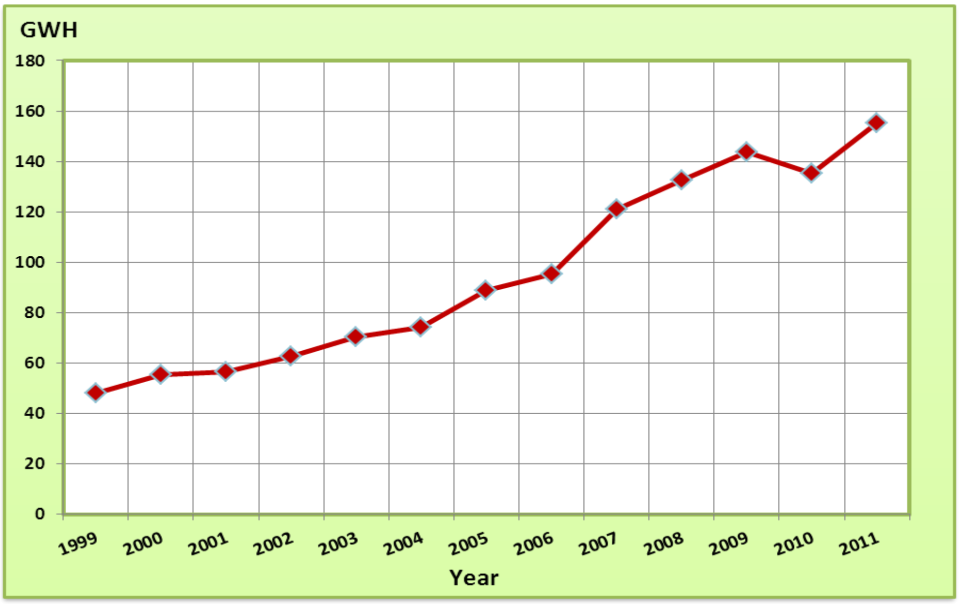


Figure 3.11: GWH consumption growth during the period 1999 - 2011

This situation produces a high deficit in the supplied power which enforces the administration of the technical department in GEDCO in Rafah branch to apply the load shedding arrangement in which it cuts the electricity service for at least 6 hours per day in normal loading cases. This outage affects everyday society activities in all living aspects, and has a severe impact on production levels in all sectors of the economy. Moreover the cut period may reach 12 hours per day in emergency cases when the Gaza power plant production stops due to lack of fuel. This situation leads to continuous reconfiguration of the feeders according to load changes. That's makes the periodic electrical measurements unreal as they don't represent the actual loads. In this study, power demand of the existing system has been carried out by ETAP regarding all the transformers' loading data available for both summer and winter seasons. The complete set of loading data is tabulated in appendix B. All available data in GEDCO about the present power demand are based on estimations. The total available demand is 26 MW while the maximum demand has reached 36.06 MW which means that there is about 38.69% of the required demand is unavailable. This is considered a severe deficit and hence requires quick solutions or the problem would be worse with increasing customer demand in the near future. Table 3.3 shows the peak demand of each feeder according to transformers' loading data in summer 2010.

Table 3.3: Total peak demand in summer 2010

Feeder Name	Available Power (MW)	Operating voltage (kV)					
		20.5		21.5		22	
		MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	5	7.90	5.31	8.69	5.84	9.10	6.12
Egypt Feeder 2	5	5.15	3.38	5.67	3.72	5.93	3.90
Egypt Feeder 3	7	7.48	5.21	8.23	5.73	8.61	6.00
Total of Egyptian Feeders	17	20.53	13.91	22.58	15.30	23.64	16.02
IEC (at 22-kV)	9	12.42	8.91	12.42	8.91	12.42	8.91
Total	26	32.95	22.81	35.00	24.20	36.06	24.92
%Active Power Deficit		26.72%		34.61%		38.69%	

Table 3.4 shows the average demand of each feeder according to transformers' loading data in summer 2010.

Table 3.4: Total average demand in summer 2010

Feeder Name	Available Power (MW)	Operating voltage (kV)					
		20.5		21.5		22	
		MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	5	6.43	4.25	7.07	4.68	7.40	4.90
Egypt Feeder 2	5	4.17	2.71	4.59	2.98	4.81	3.12
Egypt Feeder 3	7	6.15	4.19	6.77	4.61	7.09	4.83
Total of Egyptian Feeders	17	16.75	11.15	18.43	12.27	19.29	12.85
IEC (at 22-kV)	9	10.34	7.23	10.34	7.23	10.34	7.23
Total	26	27.09	18.38	28.76	19.50	29.63	20.08
% Active Power Deficit		4.18%		10.62%		13.95%	

Table 3.5 shows the required peak demand according to transformers' loading data of winter 2012.

Table 3.5: Total peak demand in winter 2012

Feeder Name	Available Power (MW)	Operating voltage (kV)					
		20.5		21.5		22	
		MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	5	8.08	5.46	8.88	6.00	9.30	6.28
Egypt Feeder 2	5	5.18	3.38	5.69	3.71	5.96	3.89
Egypt Feeder 3	7	6.30	4.29	6.93	4.72	7.25	4.94
Total of Egyptian Feeders	17	19.55	13.13	21.50	14.43	22.52	15.12
IEC (at 22-kV)	9	11.51	8.13	11.51	8.13	11.51	8.13
Total	26	31.06	21.26	33.01	22.56	34.03	23.25
% Active Power Deficit		19.46%		26.98%		30.87%	

While table 3.6 shows the average demand according to transformers' loading data of winter 2012.

Table 3.6: Total average demand in winter 2012

Feeder Name	Available Power (MW)	Rated Operating kV					
		20.5		21.5		22	
		MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	5	6.58	4.37	7.23	4.80	7.57	5.03
Egypt Feeder 2	5	4.19	2.70	4.61	2.97	4.82	3.11
Egypt Feeder 3	7	5.25	3.51	5.77	3.86	6.04	4.04
Total of Egyptian Feeders	17	16.01	10.58	17.61	11.64	18.44	12.18
IEC (at 22-kV)	9	9.55	6.58	9.55	6.58	9.55	6.58
Total	26	25.56	17.16	27.16	18.22	27.99	18.76
% Active Power Deficit		-		4.45%		7.64%	

The peak demand of each season was calculated according to the maximum loading measurements, while the average demand is given by equation 3.1:

$$\text{Average power demand} = \text{Peak power demand} \times \text{Load factor} \tag{3.1}$$

The load factor is a characteristic related to the demand factor, expressing the ratio of the average load or demand for a specified period of time to the maximum demand during the same period. Since there aren't enough measurements to derive a reasonably accurate load curve of the existing feeders in the system, then the load factor is estimated to be 0.8. This value seems to be suitable with the existence of high power deficit. This value is entered to ETAP as a diversity load factor of each node in the system and then it's considered in load flow calculation by multiplying it to each load. Since the rated voltage of the Egyptian feeders is highly fluctuating during the year, it was important to find the required demand considering three different cases of the operating voltage. The first case considers the average operating rated voltage during the year which equals 20.5 kV. The second case is interested in the newest measured value in January 2012 which is 21.5 kV. The last case was tested for the nominal voltage. The IEC feeder has a stable voltage at the nominal value, so this feeder is simulated only for 22-kV case. We notice that the total peak load during the year occurs in the summer season and it's more than the loading in the winter season by 6% at the same operating voltage. The largest demand occurs at the nominal voltage (22-kV) in the summer which reaches 36.06 MW and 24.92 Mvar while the available power is only 26 MW. We note the high reactive power demand which in average represents 69% of the active power demand and this is a clear sign of the poor power factor which equals 0.82 per unit in average.

3.5.2 Capacity Issues

Table 3.7 shows the available current on each feeder according the contracts done by the Palestinian energy authority. The Egyptian feeders feed the network with 59.88% of its available current by contracts while the rest is fed by the IEC. The actual maximum power available is about 26 MW and this ensures the supply power deficit percentages calculated in previous section. The maximum available power was calculated assuming the pf = 0.82 as obtained by simulation results. Then the available power = $\sqrt{3}V_L I_L \cos\theta = \sqrt{3} \times 22(\text{kV}) \times 835 \times 0.82 = 26.09\,\text{MW}$

The calculated value of the available power agrees with that given in the previous section. This ensures the accuracy of the assumed PF obtained by simulation.

Table 3.7: Available contracted current

Feeder Name	Maximum Available Current (A)	Maximum Available MW
Egypt Feeder 1	175	**5.47**
Egypt Feeder 2	140	**4.37**
Egypt Feeder 3	185	**5.78**
IEC Feeder	335	**10.47**
Total	**835**	**26.09**

The current demand is obtained for each feeder considering the peak loading circumstances in both seasons: summer and winter. The Egyptian feeders were tested for two cases: the average operating voltage and the nominal voltage; while the IEC feeder was simulated only at its average voltage which is the nominal value. This variation of simulation cases was necessary considering the voltage instability in the Egyptian feeders in contrast to voltage stability of the IEC feeder. In table 3.8, we can see the current peak demand in the summer season.

Table 3.8: Peak current demand in summer 2010

Feeder Name	Operating voltage (kV)					
	20.5			22		
	Loading (A)	%Loading	Status	Loading (A)	%Loading	Status
Egypt Feeder 1	268.1	109.09%	Overload	287.7	117.07%	Overload
Egypt Feeder 2	173.6	70.64%	Normal	186.3	75.81%	Normal
Egypt Feeder 3	257.7	104.86%	Overload	275.5	112.10%	Overload
IEC Feeder	-	-	-	386	157.06%	Overload

The average values were calculated regarding the same load factor used in the previous section in finding the power demand. Table 3.9 shows the average demand of summer season.

Table 3.9: Average current demand in summer 2010

Feeder Name	Operating voltage (kV)					
	20.5			22		
	Loading (A)	%Loading	Status	Loading (A)	%Loading	Status
Egypt Feeder 1	217.00	88.30%	Normal	232.90	94.77%	Normal
Egypt Feeder 2	140.00	56.97%	Normal	150.30	61.16%	Normal
Egypt Feeder 3	209.70	85.33%	Normal	216.10	87.93%	Normal
IEC Feeder	-	-	-	319.30	129.92%	Overload

By the same way table 3.10 presents the peak current demand in the winter season.

Table 3.10: Peak current demand in winter 2012

Feeder Name	Operating voltage (kV)					
	20.5			22		
	Loading (A)	%Loading	Status	Loading (A)	%Loading	Status
Egypt Feeder 1	274.4	111.65%	Overload	294.5	119.83%	Overload
Egypt Feeder 2	174.1	70.84%	Normal	186.8	76.01%	Normal
Egypt Feeder 3	214.6	87.32%	Normal	230.4	93.75%	Normal
IEC Feeder	-	-	-	369.8	150.47%	Overload

However, table 3.11 introduces the average current demand in winter 2012.

Table 3.11: Average current demand in winter 2012

Feeder Name	Operating voltage (kV)					
	20.5			22		
	Loading (A)	%Loading	Status	Loading (A)	%Loading	Status
Egypt Feeder 1	222.30	90.45%	Normal	238.60	97.09%	Overload
Egypt Feeder 2	140.40	57.13%	Normal	150.60	61.28%	Normal
Egypt Feeder 3	177.70	72.31%	Normal	190.70	77.60%	Normal
IEC Feeder	-	-	-	289.30	117.72%	Overload

By studying the above tables, we conclude that the only feeder operating in normal case along the year even with maximum loads is the Egyptian feeder No.2, then the Egyptian feeder No.3. But the Egyptian feeder No.1 and the IEC feeder are the most overloaded along the year. The IEC feeder is the most overloaded in percentage exceeds 110 in average loading and 150 in peak loading while it's known that the emergency rating of conductors are considered as 125% of their continuous thermal rating. It's clear that no adequate excess capacity is available to meet contingencies. There is no capacity in most of the lines to meet the future demand growth and this situation needs wise and quick solutions. Appendix C shows in details the loading data for every branch in the network.

3.5.3 Power Losses

The main principle behind the determination of system's loss revolves mainly in the amount of the unaccounted energy in comparison to the total purchased energy. The energy loss is calculated in KWH by using equation 3.2 and in percentage by equation 3.3:

$$\text{Unaccounted energy} = \text{Purchased energy} - \text{Sold energy} \quad (3.2)$$

$$\text{Energy loss } \% = \frac{\text{Unaccounted energy}}{\text{Purchased energy}} \times 100 \quad (3.3)$$

The percent system's loss of the electric utility indicates the distribution system performance. Distribution system's losses can be attributed to technical and non-technical. Non-technical losses are those caused mainly by human errors associated with erroneous meter readings and electricity thefts. Electricity thefts can be in the form of meter tampering, illegal connections to the network [28]. Electricity theft has the main contribution to the non-technical losses in Rafah and also all over Gaza Strip because of governance public culture. Technical losses in the system are those directly related to the physical characteristics of the electrical system components such as conductors and transformers. In technical loss estimation studies, the technical loss level is estimated using simulations of the network. Due to lack of information, the computation of power loss in Rafah was a difficult task and can't be accurately evaluated for enough long periods. All available data about purchased energy and sold energy during the period from year 2002 to year 2011 are summarized in table 3.12.

Table 3.12: Energy billing data for Rafah governorate

Year	*Purchased Energy*				Sold Energy (GWH)	GWH Loss	% Loss
	IEC	Egypt - 5MW	Egypt - 12 MW	Total (GWH)			
2002	76.803				62.864		
2003	63.205				70.243		
2004	63.351				74.230		
2005	74.315				88.626		
January-August 2006	46.541				63.7198		
September-December 2006	14.819	20.87	8.41	44.101	31.463		
2007	85.794	89.066	34.105	208.965	120.902	88.063	42.142
2008	72.645	97.641	36.73	207.016	132.436	74.580	36.026
2009					143.554		
January - June 2010					69.136		
July - December 2010		58.2569			66.040		
January - March 2011		31.7685			36.244		
April - December 2011					119.045		

We note the absence of the purchased energy data from the CEDC before 2006 since the only source of power exists during the period 1998-2006 was from the IEC. Also there is no information about the purchased energy from both the IEC and CEDC for the years 2009, first half of 2010 and 2011 because of political circumstances. The tariff for KWH of the purchased energy from IEC is 0.33 NIS while the tariff for KWH of the purchased energy from CEDE is 0.26 NIS. Then the cost of the lost energy in million NIS is evaluated regarding the rate of the purchased energy from the IEC or the CEDC to the total purchased energy as follows:

$$\text{Cost of annual lost energy in 2007} = (88.06\times10^{6}\times0.59\times0.26) + (88.06\times10^{6}\times0.41\times0.33) = 25.42 \quad \text{million NIS}$$

$$\text{Cost of annual lost energy in 2008} = (74.58\times10^{6}\times0.65\times0.26) + (74.58\times10^{6}\times0.35\times0.33) = 21.22 \quad \text{million NIS}$$

The system energy losses are simply considered as lost revenue which requires hard effort in applying loss mitigation techniques. It's valuable to direct this cost to development projects of the network. When a loss study is performed on a distribution utility, peak load conditions are often assumed in the first analysis. The peak losses were obtained by simulation for both summer and winter seasons for three cases of the operating voltage as assumed in the previous sections. The only complete billing data available is for the two years 2007 and 2008. Thus the GWH loss is only calculated for those years. As seen the annual percent of energy loss exceeds 36%. . The distribution power system losses are different from country to another. Ideally, it should be around 3 to 6%. In developed countries, it is not greater than 10%. However, in developing countries, the active power losses percentage is around 20%; for this reason, utilities in the electric sector are currently interested in reducing it in order to be more competitive [29]. This loss percent includes both technical losses and non-technical losses over the overall distribution system. The technical losses exist in both the MV network and the LV network. Also this power loss is divided into two categories: real and reactive power losses. Reducing the real power losses in distribution networks is an important aim for utilities as this is the predominant part of most customers' demand. Nevertheless, reactive power losses in distribution networks are still an important consideration because of its strong relation to voltage and power factor problems. In this thesis, the MV network losses were calculated by simulation, but the LV network losses is hard to obtain since it requires handling a large database. Table 3.13 shows the peak losses for summer season.

Table 3.13: Peak losses in summer 2010

Feeder Name	Operating voltage (kV)					
	20.5		21.5		22	
	MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	0.286	0.596	0.314	0.656	0.329	0.687
Egypt Feeder 2	0.133	0.271	0.146	0.298	0.153	0.312
Egypt Feeder 3	0.526	0.904	0.579	0.994	0.606	1.041
Total	**0.945**	**1.771**	**1.039**	**1.948**	**1.088**	**2.04**
IEC Feeder (at 22-kV)	1.482	2.128	1.482	2.128	1.482	2.128
Total	**2.427**	**3.899**	**2.521**	**4.076**	**2.57**	**4.168**
Peak Demand	**34.713**	**24.13**	**36.942**	**25.652**	**38.095**	**26.44**
%Losses	**6.99%**	**16.16%**	**6.82%**	**15.89%**	**6.75%**	**15.76%**

While table 3.14 shows the peak losses for winter season.

Table 3.14: Peak losses in winter 2012

Feeder Name	Operating voltage (kV)					
	20.5		21.5		22	
	MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	0.96	0.934	0.326	0.697	0.314	0.73
Egypt Feeder 2	0.127	0.25	0.14	0.275	0.146	0.288
Egypt Feeder 3	0.347	0.604	0.382	0.664	0.4	0.695
Total	**1.434**	**1.788**	**0.848**	**1.636**	**0.86**	**1.713**
IEC Feeder (at 22-kV)	1.19	1.733	1.19	1.733	1.19	1.733
Total	**2.624**	**3.521**	**2.038**	**3.369**	**2.05**	**3.446**
Peak Demand	**32.859**	**22.608**	**34.993**	**24.052**	**36.098**	**24.804**
%Losses	**7.99%**	**15.57%**	**5.82%**	**14.01%**	**5.68%**	**13.89%**

As expected the maximum losses occur in summer season due to higher environment temperatures. Also the losses decreased when the system operates at the nominal voltage. The peak percentage of summer losses is about 6.85% for active power and 15.94% for reactive power. Moreover, the peak percentage of winter losses is about 6.5% for active power and 14.49% for reactive power. This situation exceeds the maximum and the target of the allowable losses in a distribution system which should be between 3-6% at maximum as stated before for reliable performance. Fortunately, there is an easy method for determining the average losses.

This method defines the loss factor which is demonstrated by equation 3.4,

$$\text{Loss factor} = \frac{\text{Average losses}}{\text{Peak losses}} \tag{3.4}$$

The loss factor is related to the load factor in a nonlinear relationship which can be used to calculate the loss factor directly. Test made on typical electrical loads have revealed the following formula [30]:

$$\text{Loss factor} = (0.2 \times \text{load factor}) + (0.8 \times (\text{load factor})^2) \tag{3.5}$$

Thus our system $\text{loss factor} = (0.2 \times 0.8) + (0.8 \times 0.8^2) = 0.672$

The average losses obtained by simulation agree with that obtained by equation 3.4 and prove that the calculated value of the loss factor is correct.

Table 3.15 shows the average losses in summer 2010.

Table 3.15: Average losses in summer 2010

Feeder Name	Operating voltage (kV)					
	20.5		21.5		22	
	MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	0.192	0.401	0.211	0.441	0.216	0.455
Egypt Feeder 2	0.086	0.174	0.095	0.192	0.099	0.201
Egypt Feeder 3	0.352	0.599	0.387	0.659	0.405	0.690
Total	**0.630**	**1.174**	**0.693**	**1.292**	**0.720**	**1.346**
IEC Feeder (at 22-kV)	1.019	1.445	1.019	1.445	1.019	1.445
Total	**1.649**	**2.619**	**1.712**	**2.737**	**1.739**	**2.791**
Average Demand	**27.770**	**19.304**	**29.554**	**20.522**	**30.476**	**21.152**
%Losses	**5.94%**	**13.56%**	**5.79%**	**13.34%**	**5.71%**	**13.19%**

Also table 3.16 shows the average losses in winter 2012.

Table 3.16: Average losses in winter 2012

Feeder Name	Operating voltage (kV)					
	20.5		21.5		22	
	MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	0.195	0.412	0.214	0.453	0.224	0.474
Egypt Feeder 2	0.083	0.160	0.091	0.176	0.095	0.185
Egypt Feeder 3	0.239	0.406	0.263	0.447	0.276	0.468
Total	**0.517**	**0.978**	**0.568**	**1.076**	**0.595**	**1.127**
IEC (at 22-kV)	0.811	1.163	0.811	1.163	0.811	1.163
Total	**1.328**	**2.141**	**1.379**	**2.239**	**1.406**	**2.290**
Average Demand	**26.287**	**18.684**	**27.994**	**19.899**	**28.878**	**20.531**
%Losses	**5.05%**	**11.46%**	**4.93%**	**11.25%**	**4.87%**	**11.15%**

The average losses of the spring and autumn seasons are estimated by averaging the losses values of the summer and winter seasons and those values are tabulated below in table 3.17.

Table 3.17: Average losses in spring and autumn

Feeder Name	Average Losses					
	20.5 kV		21.5 kV		22-kV	
	MW	MVAR	MW	MVAR	MW	MVAR
Egypt Feeder 1	0.194	0.406	0.213	0.447	0.220	0.465
Egypt Feeder 2	0.085	0.167	0.093	0.184	0.097	0.193
Egypt Feeder 3	0.296	0.502	0.325	0.553	0.341	0.579
Total	**0.574**	**1.076**	**0.631**	**1.184**	**0.658**	**1.237**
IEC (at 22-kV)	0.915	1.304	0.915	1.304	0.915	1.304
Total	**1.489**	**2.380**	**1.546**	**2.488**	**1.573**	**2.541**
Average Demand	**27.029**	**18.994**	**28.774**	**20.210**	**29.677**	**20.842**
%Losses	**5.51%**	**12.53%**	**5.37%**	**12.31%**	**5.30%**	**12.19%**

The cost of energy losses is calculated by equation 3.6.

$$\text{Energy losses cost} = \text{kW Loss} \times \text{Load factor} \times \text{Time period in hours} \times \text{NIS/kWH} \qquad (3.6)$$

Using equation 3.6, the annual cost of technical losses is estimated in table 3.18 in million NIS.

Table 3.18: Cost estimation of the annual average losses in million NIS

Season	Operating voltage (kV)					
	20.5		21.5		22	
	MWH	MVARH	MWH	MVARH	MWH	MVARH
Spring & Autumn Loss Cost	1.559	2.454	1.610	2.551	1.634	2.598
Summer Loss Cost	0.853	1.350	0.882	1.404	0.896	1.431
Winter Loss Cost	0.889	1.204	0.712	1.158	0.716	1.181
Total Cost	3.301	5.008	3.204	5.113	3.246	5.211

The obtained costs are considerable values and need attention from GEDCO technical administration to save such costs for development projects of the network.

3.5.4 Voltage Levels

Voltage drop is the reduction in voltage in an electrical circuit between the source and load. So the voltage drop in the line depends on:

1. The power transmitted; as the power transmitted is increased, the voltage drop in the line also increases.
2. The load power factor.
3. The line impedances; the line impedances is directly dependent on the length of the feeder line.
4. The magnitude of the voltage distribution systems; voltage drop is higher with lower voltage distribution systems.

Poor voltage levels near the end points of the feeders are one of the common problems in the network. This reduces the reliability of the network and cause repeated complaints by the end consumers. There are many reasons cause this poor voltage levels including: operating under voltages below the nominal value at the sending end of the feeders especially at the Egyptian feeders, excessive feeder loads, improper selection of conductor sizes at some branches in the network, long length of feeders, and finally unplanned LV network expansion.

The percentage voltage obtained by the power flow solution at each node along the feeders is given in appendix C. Depending on the power flow results for both summer and winter seasons, voltage drop on each feeder of the 22-kV network is analyzed and presented in Figures 5.12 - 5.15. The percent voltage profile for summer season is seen to be better than it for winter season for the first Egyptian feeder. This situation is irregular regarding the loading circumstances in Gaza Strip, the expected is the converse as the summer loads are always higher than winter loads. But this situation occurs here since this feeder has higher current loading in winter as seen clearly in tables 3.10 and 3.11.

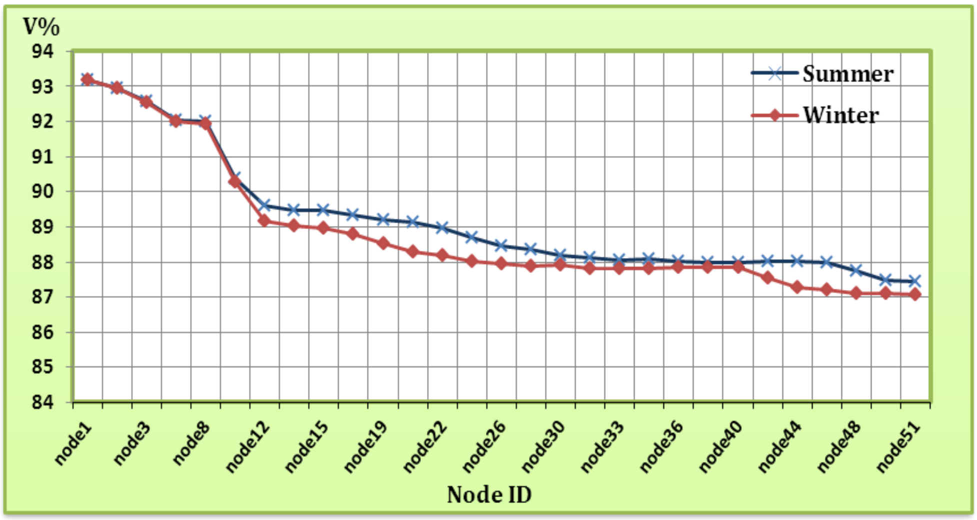


Figure 3.12: Percent voltage of the Egyptian feeder No. 1

The second Egyptian feeder also has the percent voltage profile for summer season better than it for winter season as shown in Figure 3.13. In general it has the best voltage profile in comparison with the others, since it has the smallest length with relatively low capacity and better loading situation.

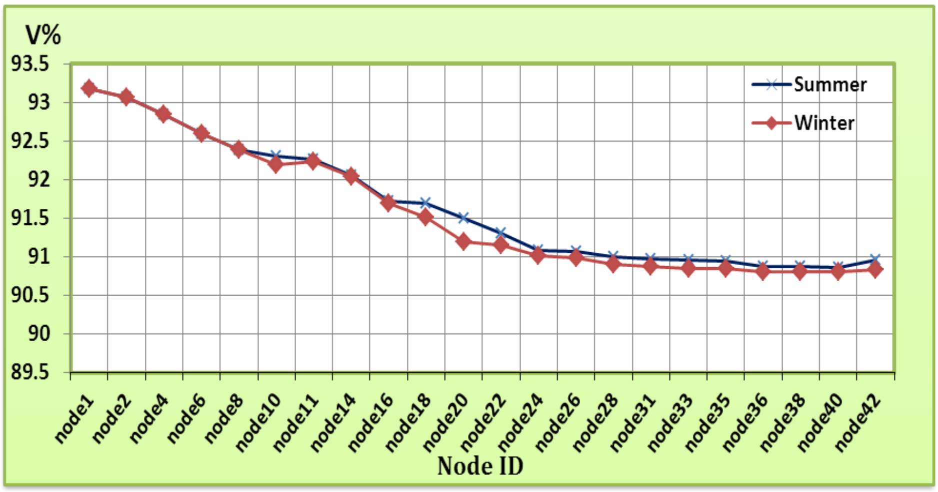


Figure 3.13: Percent voltage of the Egyptian feeder No. 2

Moreover, the percent voltage profile for summer season is worse than it in winter season for the third Egyptian feeder and IEC feeder. This resulted from higher loads in summer season and this can be also investigated from tables 3.10 and 3.11. The voltage profile of third Egyptian feeder is presented in Figure 3.14.

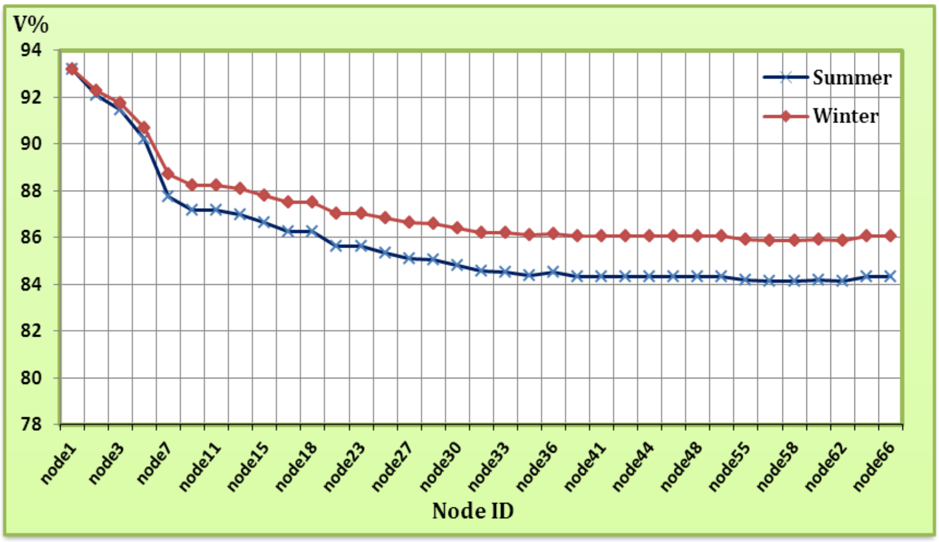


Figure 3.14: Percent voltage of the Egyptian feeder No. 3

While the voltage profile of the IEC feeder is presented in Figure 3.15.

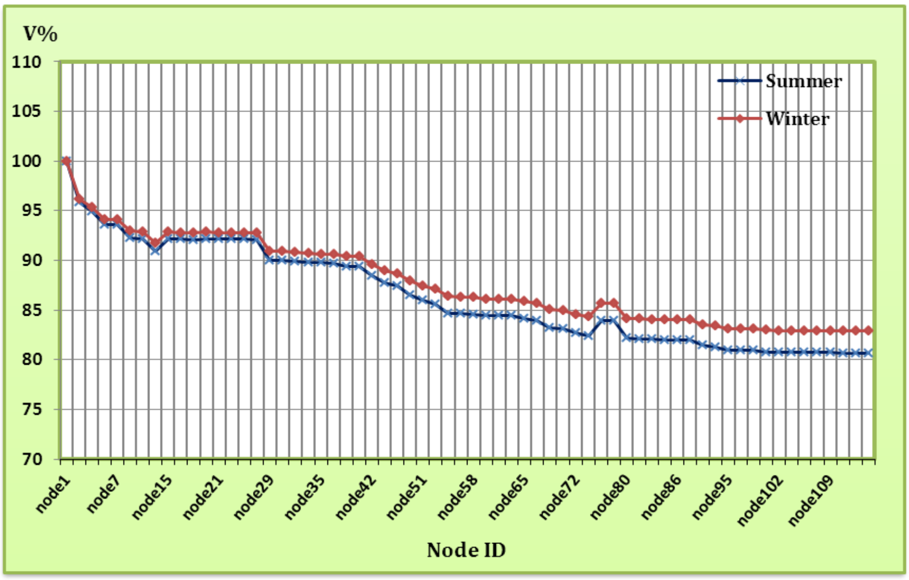


Figure 3.15: Percent voltage of the IEC feeder

It's important to note that the voltage drops to values below %90 of the nominal voltage in the first one third of the length of each feeder except the second Egyptian feeder which has the farthest point above 90%.

Table 3.19 shows feeders' nodes at which the voltage drops below 90% of the nominal voltage and their distance from the starting node of each feeder.

Table 3.19: Nodes with voltage drop below 90%

Feeder Name	Node ID	%Voltage	Distance from the feeder start point in Rafah (m)	% Feeder length
Egypt Feeder 1	node12	89.61	3113	26.5
Egypt Feeder 2	node42	90.91	9600	100
Egypt Feeder 3	node 7	87.75	5066	26.9
IEC Feeder	node30	89.97	7267	23.6

This fact indicates the bad performance of the voltage along the feeders which leads to poor voltage levels at the farthest ends of the feeders. Also it highlights the fact of high loading circumstances in the last two third of the feeders' length.

3.5.5 Power Factor

In section 3.5.1, the present power demand was evaluated and it was clear that the Mvar demand is relatively high in comparison to MW demand. This is directly indicates the poor power factor of the 22-kV network. Working under the same voltage cases, it's found that the power factor has a fixed value regardless of the operating voltage, so the power factor was obtained for each season and the simulation results are summarized in table 3.20.

Table 3.20: Power factor variations of the network

Feeder Name	Summer	Winter
Egypt Feeder 1	82.97 Lagging	82.86 Lagging
Egypt Feeder 2	83.6 Lagging	83.74 Lagging
Egypt Feeder 3	82.04 Lagging	82.64 Lagging
IEC Feeder	82.44 Lagging	81.68 Lagging

All power factor values are under 85%. The low value of power factor has a substantial effect on the magnitude of current flowing in the network. It leads to overheating of equipment due to the excess current flowing, higher electricity consumption when measured in VA, necessitate additional investment in system facilities to obtain the required kW, lower voltage level at the load, and increased power losses (resistive and reactive) throughout the system. Therefore, a low-power factor will result in inefficient energy usage and an excessive energy bill. Consequently, it introduced a penalty charge called power factor dues for GEDCO to be paid for the supplier company when the power factor drops below %92. According to the available purchased energy bills with power factor dues, it's found that GEDCO paid 74605.34 NIS to IEC Company in June 2007 as a penalty when the power factor was 0.887. This value was paid for only one month, so GEDCO administration should pay a great attention to power factor improvement to avoid such penalties. On the other hand, GEDCO demands a minimum of 92% power factor as an average for each monthly billing for its three-phase customers on LV network. It imposes a penalty charge for customers with power factor less than 92%. These penalties are paid by three phase customers only who are classified mainly as industrial and large institutions like hospitals. Table 3.21 shows the penalties cost paid to GEDCO in the last decade for low power factor [31].

Table 3.21: Power factor dues

Year	Power factor dues (NIS)
2000	1110.01
2001	2102.02
2002	9314.12
2003	7730.48
2004	12903.11
2005	26791.21
2006	62619.25
2007	52326.97
2008	54431.47
2009	80926.42
2010	68597.83
2011	47197.73

The table indicates that the power dues imposed by GEDCO in Rafah for year 2007 is less than that imposed by IEC in only one month; June 2007.

3.6 Solution Techniques

The previous sections presented all problems and deficiencies exist in the medium voltage network in the present time. In this section we are going to address and suggest solution techniques for the medium voltage network. The basis for most engineering decisions is economics, besides other social, scientific and environmental factors. So any planned project must be feasible from the economic point of view in order to justify money investments in that project.

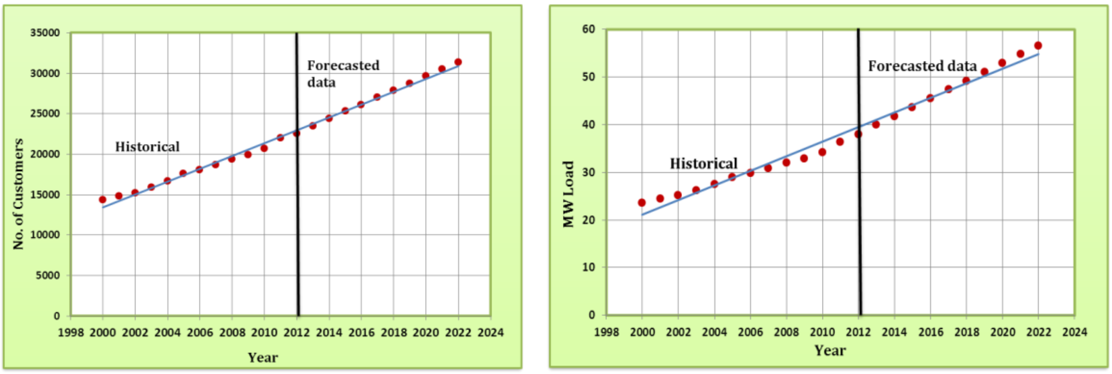
3.6.1 Managing the Growing Power Demand

The electric energy consumption rate in Rafah Governorate has been continuously increasing. In this situation, it is becoming more and more important for GEDCO to be able to meet efficiently the demands of its customers. This means that one of its goals is to be able to find an operating state for its highly unbalanced distribution network which minimizes the cost paid for the power supplier company, while satisfying the requirements of the customers. In order to satisfy the ever increasing energy demand, several actions have to be implemented. These actions have to be carried out in parallel. Those actions include the load balance and upgrading the supplied power according to the actual power demand. Also it's important to predict the future growth of the power demand to be taken into account in the upgrade and planning of new projects. So the forecasted growth in the power demand was evaluated for the coming ten years from 2012 to 2022. The resulted data are tabulated in table 3.22 below.

Table 3.22: Load forecasting during the period 2012 – 20 22

Year	No. of customers	Purchased GWH	KWH/Customer	MW Demand
2000	14325	55.52	3875.75	23.62
2001	14779	56.62	3831.25	24.37
2002	15235	62.86	4126.31	25.12
2003	15913	70.24	4414.20	26.24
2004	16635	74.23	4462.29	27.43
2005	17577	88.63	5042.20	28.98
2006	18096	95.18	5259.88	29.84
2007	18683	120.90	6471.23	30.81
2008	19355	132.44	6842.48	31.91
2009	19897	143.55	7214.85	32.81
2010	20706	135.18	6528.36	34.14
2011	22038	155.29	7046.44	36.34
2012	22554	168.28	7461.17	37.96
2013	23472	182.75	7786.11	39.96
2014	24433	197.46	8081.76	41.71
2015	25307	211.06	8340.27	43.63
2016	26085	222.93	8546.06	45.44
2017	27039	236.06	8730.28	47.32
2018	27904	247.44	8867.56	49.15
2019	28756	257.69	8961.43	51.02
2020	29633	270.48	9127.60	52.86
2021	30527	284.28	9312.26	54.72
2022	31383	299.13	9531.58	56.56

For a clearer visualization of the obtained results, they're presented in the next two Figures. Figure 3.16-(a) shows the growth of the annual customers. Note that the data points are in red color while their linearization line is drawn in blue color. The Figure shows that the annual customers' count is linearly increasing. The data from year 2000 to year 2011 are actual data obtained from the customers' accounts and services administration in GEDCO. The predicted data up to year 2022 were evaluated by excel "FORCAST" function which predicts the future values along a linear trend by using the existing values. It's perfectly suitable since the existing data has a linear behavior.



(a) **(b)**

Figure 3.16: Customer and demand growth
(a) Growth of the customers' counts (b) Growth of peak power demand in summer

Figure 3.16-(b) shows the long-term forecasting of summer peak power demand. The predicted values were also calculated by the excel function "FORCAST". Also it seems very suitable since the existing data has a linear behavior.

It's important to consider that the actual electricity demand is weather dependent. Consequently there is an annual increase of summer temperature year after year and this increases the summer demand. Thus we may expect that the unusual extreme hot coming summers may result in a greater electricity demand than forecast. Also the economy has a major impact on electricity demand since better economy affect the customers' demand by owning modern electrical appliances especially air-conditioners which have spread in the last two years, and are expected to spread larger in the coming years. Some other political constraints should be added to the forecasting analysis due to unusual political case lived in Gaza Strip. Load forecasting is a difficult task to be carried out in any area in Gaza Strip. This is due to the lack of needed data for such analysis; so the forecast was performed depending on the available data in a simple method. It's hoped that all required data for such study be available in the near future for better planning.

According to the power demand requirements, it's found that the preferred solution to support the existing load and the future demand growth is to install a new substation in Rafah as an extension to the Egyptian high voltage network. This solution is better than any suggestion of upgrading the existing feeders or upgrading the existing Egyptian feeders as it will not meet the future growth. On the other hand this solution enables a full control and protection of the feeders and hence the distribution network will be able to operate within the rated values; and then can handle the power demand of the area with the load growth. It's suggested also to turn the feeding source of the IEC feeder to the new substation; that will support the independency of the electric power field from the Israeli occupation. A wise proposition is to design this substation in a capacity covers the power deficit in both Rafah and Khan Younis governorates. The Palestinian Authority of Energy and Natural Resources in Gaza proposed a complete study of a project to install two new substations in Gaza Strip. The proposed project consists of three stages. Our concern is for the first stage since it works on meeting the full demand of both Rafah and Khan Younis governorates. The substation is intended to extend the Egyptian system and rated at 220/22 kV. It will have two of three winding power transformers rated at 60/75 MVA. The work done in this section supports this proposition since it will solve the problem of power deficit in Rafah. There are two remaining stages. They include construction of two additional substations with the same specifications as the south substation. All IEC feeders will be turned gradually to those substations along Gaza Strip. Besides this solution, the overloaded distribution lines have to be upgraded to larger sizes by reconductoring. Also the overloaded distribution transformers have to be replaced with units of larger capacities.

3.6.2 Load Balancing

Three-phase, four-wire distribution system has been widely used to facilitate low voltage supply to single-phase and three-phase loads. This mixed loading in the secondary distribution system may result in serious phase unbalance [32]. In urban and rural networks of 0.4 kV, voltage imbalances are mainly caused by connections of domestic single phase lighting systems and single phase domestic electrical appliances of low power rating [33]. Unbalanced loads are the main cause of unbalanced voltages on distribution circuits and thus a great deal can be gained by attempting to distribute single-phase loads equally across all three phases. Under unbalanced conditions, the power system will incur more losses and heating effects, and be less stable [34]. Also in this case, the distribution line currents are unbalanced and cause unequal voltage drop on the distribution lines such that the load bus voltages are unbalanced [35]. Moreover this may overload the neutral conductor and the highest loaded phase. The phase unbalances increases line losses, deteriorates system voltage profile, overloads system phases, decreases system capacity, performs malfunctioning of protective relays, causes saturation problem in the distribution transformers, increases communication interference, decreases efficiency and life of appliances, and hence deteriorates power quality [32]. Load imbalance classified as a voltage and current unbalance. Therefore, utility administration must monitor and record both voltage and current to determine the extent of the load imbalance in a system. The more data available to analyze, the more likely energy-savings are realized. It's unrealistic to obtain a perfectly balanced three-phase distribution network, but it's so important to keep the three-phase circuits as closely balanced as possible to prevent the bad effects of imbalance as mentioned above. Balancing is accomplished by selecting the phase of the supply for each load so that the total load is distributed as evenly as possible between the phases for each section along the feeders. Phase load imbalance of LV networks is highly exists in Rafah network. This problem resulted from many reasons summarized as below:

1. The random planning of the LV networks.
2. The absence of the technical studies concerning the load balance in the network.
3. The voltage unbalance of the Egyptian feeders along the year.
4. Cutting and reconnection of the electric current to customers are done randomly by technicians without any concern to load balance aspect.

The measurements given in appendix B including tables B.5 - B.8 describe the current loading on the three phases of each transformer in winter 2012 at peak times. All work done with concern to current balance only since there are no available measurements for the voltage unbalance. The total power demand is calculated by hand based on those measurements representing the unbalanced loading case. The voltage values used in calculations were taken from ETAP power flow results since the voltage measurements weren't available. Then the total power demand is calculated for the balanced loading case. The calculations done are presented in appendix D. By investigation of the tables in appendix D, it's seen clearly that the line current unbalance rate in average is 6.37% for the Egyptian feeder No.1, 9.99% for the Egyptian feeder No.2, 7.21% for the Egyptian feeder No.3, and 5.76% for the IEC feeder. Where the line current unbalance rate (LCUR) is calculated by equation 3.7:

$$LCUR\% = \frac{\text{Max line current deviation from average}}{\text{Average line currents}} \times 100 \tag{3.7}$$

It's noted that the current imbalance exceeds the standard limit of LIUR which equals 3% at maximum. Also noting tables in appendix D, it's concluded that the degree of imbalance varies along the length of each feeder; some parts are considered in balance case while others suffer imbalance. Another important notice is that there is a specific phase along discrete parts of the feeder's length has the maximum deviation from the balance current magnitude. This ensures the random planning of the LV network in which the electric current is connected to the customer from the nearest phase. This behavior done by GEDCO technicians is one of the basic causes of the load imbalance in the network. Figure 3.17 indicates the capacity release which can be obtained through balancing loads on the LV network.

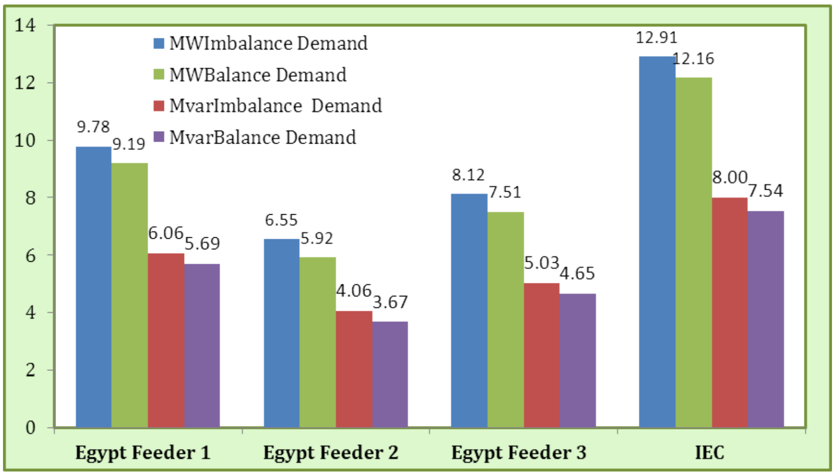


Figure 3.17: Power demand in balanced and unbalanced loads

The figure shows that the load balance can release about 7% of the active and reactive powers. It's clear from this result how balance between phases tends to equalize the phase loading by reducing the largest phase peak while increasing the load on the other phases. This equal distribution releases feeder capacity that can be used for future load growth without need for feeder reconductoring and also provides more reserve loading capacity for emergency loading conditions. Consequently, balancing reduces feeder losses because any phase peak reduction affects the phases' losses with proportionality to the square of the current magnitude. Also it directly reduces the system losses created by the neutral current in the neutral conductor which can reach high values in imbalance case. In addition to previously mentioned it improves voltage on a feeder by equalizing the voltage drops on each phase along the feeder. It's worth keeping in mind that balancing over a range of loading levels is not a practical proposition because the load connections are not switchable between phases. Consequently, balancing is targeted for what is considered the feeder mean peak loading pattern over all seasons of loading. A practical approach is to identify the conditions that give rise to the most severe imbalances between phases and endeavor to achieve the best balance for that loading condition. The use of switched capacitors affects the feeder reactive power flow and hence the total phase current.

It's valuable to mention that ETAP has a special tool box used in unbalanced power flow which calculates the bus voltages, branch power factors, currents, and power flows for individual phases throughout the electric power system. It handles both radial and loop systems. It can't be used in this study since the program needs full description about the types of the connected lumped loads on each phase and these data aren't available. The unbalanced load model is used to model unbalanced loading for three different types: motor load, static load, and constant current load [27].

3.6.3 Voltage Improvement

Voltage improvement is considered as power quality issue and there are several techniques can be used to improve the voltage profile of the feeders especially to correct the voltage drop at the far ends of the feeders. In this section three approaches are followed separately for voltage improvement including raising the substation voltage, adjustment of tap-changer settings of the transformers and finally installation of capacitor banks. They're tested by simulation to stand on their advantages and disadvantages.

Approach 1: Raising the Voltage at the Feeder Sending-End

The most intuitive way in voltage improvement is to raise the voltage at the sending end node. Even though the voltage control is done only from the substations, this method is implemented based upon request from technical department of Rafah branch. It's possible in handling the Egyptian feeders only due to available contact with the Egyptian substation dispatcher. Moreover, the communication with the Egyptian substation dispatcher is unavailable sometimes. This difficult situation supports strongly the proposition of installation of new substation in Rafah such that GEDCO has the full control on feeders. Using this method it's important to raise the voltage to a value suits the different loading scenarios, so that it doesn't lead to overvoltage during the off-peak loading periods. The system is tested for summer loading case. After different tries, it's found that the suitable raised value of the substation voltage of the Egyptian feeders is 22.5 kV. Figures 3.18 - 3.20 show the voltage profiles of the Egyptian feeders before and after raising the sending end voltage regarding both the peak and average loading cases. Figure 3.18 shows the improvement of the first Egyptian feeder. The voltage profile has been raised to operate in the range 97% - 102% of the nominal voltage in maximum and average loading conditions respectively.

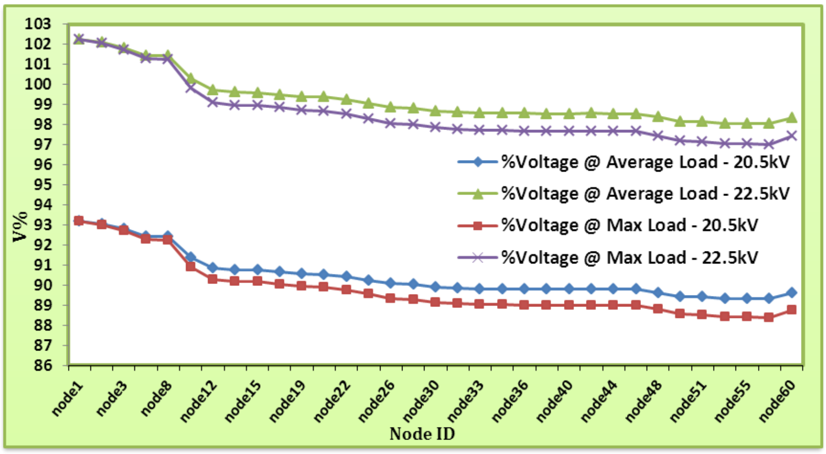


Figure 3.18: Voltage profiles of the 1st Egyptian Feeder

While Figure 3.19 indicates that the voltage profile of the second Egyptian feeder.

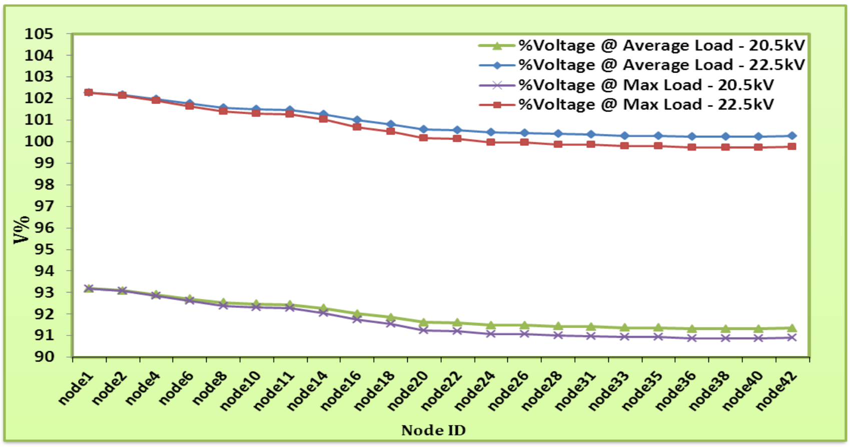


Figure 3.19: Voltage profiles of the 2nd Egyptian Feeder

The voltage profile is enhanced to operate between 100% - 102% of the rated voltage in maximum and average loading conditions respectively. But we can avoid this method in this feeder since it operates in the allowable range even in peak loading. Figure 3.20 indicates that the improvement realized on the third Egyptian feeder is less than that obtained for the previous two feeders. The voltage profile has been raised to operate in the range 93% - 102% of the nominal voltage in maximum and average loading conditions respectively.

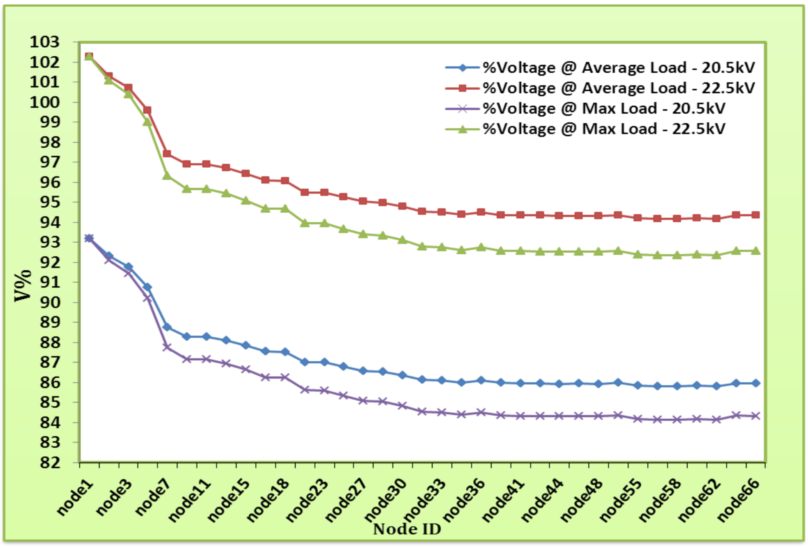


Figure 3.20: Voltage profiles of the 3rd Egyptian Feeder

Since the IEC feeder suffer more voltage drop than Egyptian feeders due to higher loading and longer length, and then it's found that it needs to be raised to higher voltage. It's raised to 23 kV as a suitable value for the feeder to operate within the allowable range of voltage in peak and off-peak loading and the effect of raising the sending-end voltage is presented in Figure 3.21.

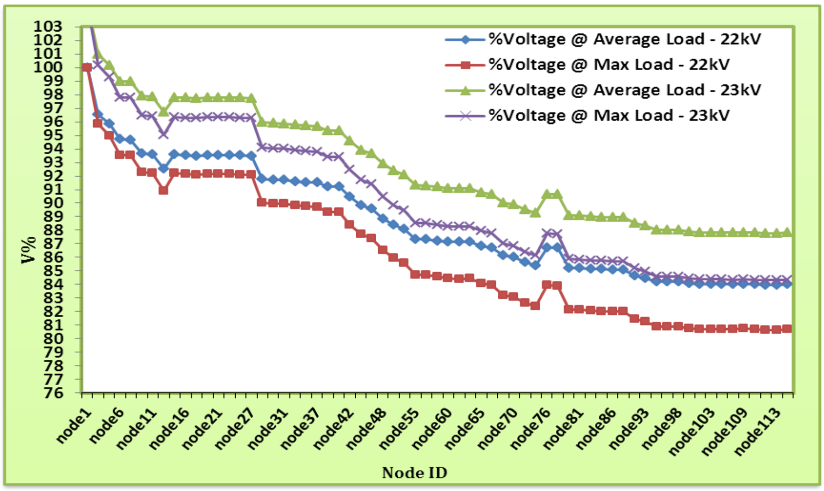


Figure 3.21: Improvement of voltage profile on IEC feeder

It shows that the voltage profile is improved at the farthest point of the feeder where the voltage drops to 87.2% and 84.3% of the nominal value in average loading and peak loading cases respectively. It can be improved further but at the expense of higher current and power demand. Figure 3.22 indicates the increased power demand.

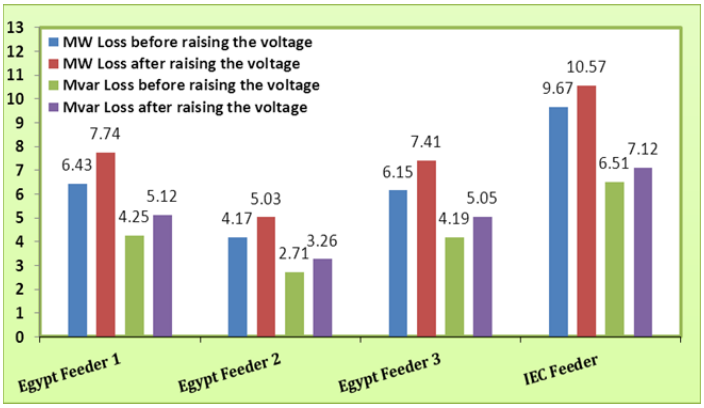


Figure 3.22: MW demand variations

Moreover, Figure 3.23 shows the increase in the current which consequently increases the power losses.

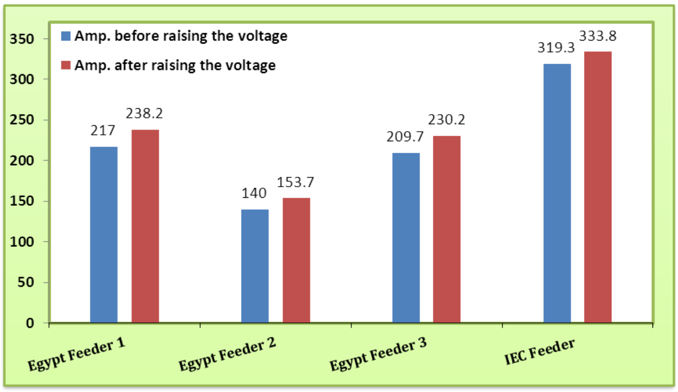


Figure 3.23: Current demand variations

Figure 3.24 indicates the strong effect of raising the sending end voltage on increasing the feeders' losses because of line currents increment.

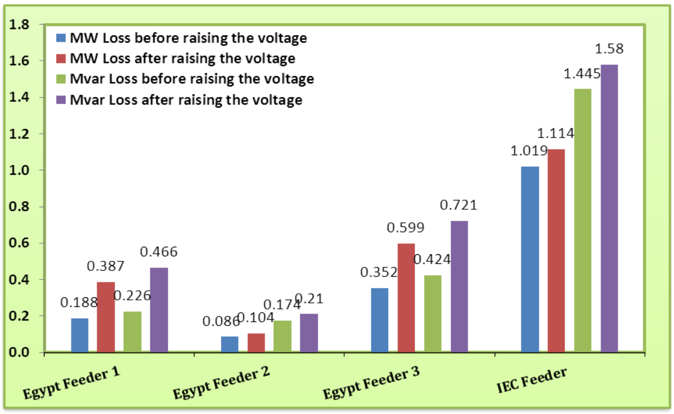


Figure 3.24: Power losses variations

Considering all what mentioned above, this approach must be applied carefully.

<u>Approach 2:</u> Adjustment of Transformers' Taps Setting

Another method can be used to enhance the voltage levels along the feeders in the LV side is to readjust the transformers' taps changer. As stated in table 5.2, the transformers' tap changer is on high tension side and can be stepped to +1x2.5% or to -3x2.5%. Since the nominal value of the system is 22kV, then each step can raise or lower the voltage rating by 0.55 kV. The tap changer must be adjusted to suitable settings to suit both light and heavy loading cases. The Egyptian feeder No.1 is tested for this method in summer loading case and the voltage profile along the LV nodes is shown in Figure 3.25.

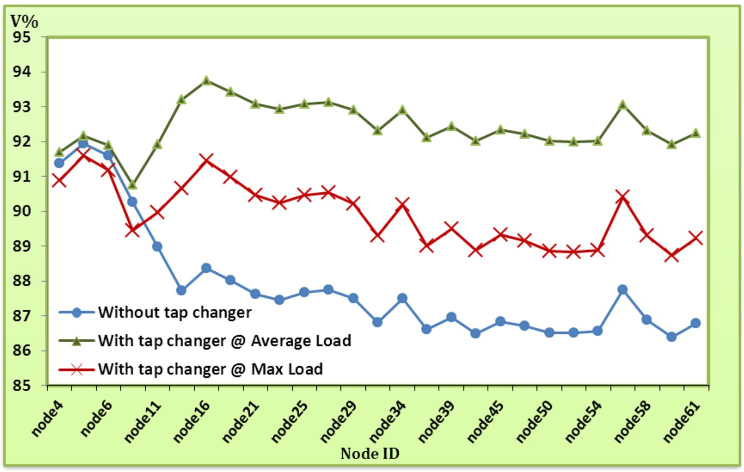


Figure 3.25: Voltage profile variations by adjusting transformer's tap-changer settings

All transformers connected to LV nodes that suffer from voltage drop below 90% of the nominal value, their tap changers are adjusted to -3x2.5% position of their tap changers. The voltage profile is found for three cases: without change in tap changer position, with tap changer adjustment in average loading and peak loading. It's seen clearly how much the voltage profile is improved. This method is practical to some extent and can be applied under the control of technical department in Rafah. But it needs to be applied with high attention to avoid overvoltage at light loading condition. The same as previous method, the voltage improvement is achieved at the expense of higher current loading and thus higher power demand and losses. It needs effort since the transformers are off-loading tap changer, so tap changer have to be changed manually. Moreover this solution is followed from time to time according to loading variations. This work is done depending on actual measurements. On the other hand the simulation enable us to perform different scenarios and choosing the best settings of the tap changers with full prediction of its effect on power demand and current loading. Table 3.23 clarifies the effects of this method on power demand, current demand and power losses.

Table 3.23: Effect of transformer's tap changer on network demand at 20.5 kV

State	MW Flow	Mvar Flow	Amp. Flow	Loss MW	Loss Mvar
Without tap setting at average load	6.426	4.253	217	0.188	0.387
Without tap changer at peak load	7.897	5.313	268.1	0.286	0.596
Tap changer at average load	7.004	4.653	236.8	0.222	0.449
Tap changer at peak load	8.597	5.81	292.2	0.337	0.691

Approach 3: Installation of Capacitor Banks

Placement of capacitors has been considered mainly to enhance the line voltage levels above 90% of the nominal voltage, power factor correction, and reduce the losses. Power factor correction permits additional loads to be added and served by the existing system. In case if the transformers or cables get overloaded, improving the power factor will be the most economical way to reduce the current and therefore eliminate overload condition. This can be clearly investigated by the equations:

$$S_{new} = \frac{PF_{initial}}{PF_{final}} \times S_{old} \tag{3.8}$$

$$I_{new} = \frac{S_{new}}{\sqrt{3}V} \tag{3.9}$$

Distribution losses in a facility can be reduced by the addition of capacitors as indicated by equation below [36].

$$\text{Loss reduction\%} = \left[1 - \left(\frac{PF_{initial}}{PF_{final}}\right)^2\right] \times 100 \tag{3.10}$$

The voltage rise produced on a system by corrective capacitors enables more KWH for consumption, so more revenue is attained by utility. Location of capacitors is predicted by the load concentration and reactive power demand. The shunt capacitors are available into two types: ‘fixed’ and ‘switched’ banks. Fixed capacitors have fixed rating value. Switched type capacitors consist of several capacitor banks, which can be automatically switched ‘on’ or switched ‘off’ depending on the voltage level. Hence this type is recommended due to possibility of high load variations caused by load shedding operations. This approach is applied for the Egyptian feeder No.1 which has the worst technical evaluation among the Egyptian feeders. It's tested under summer loading condition. By simulation it's found that when the feeder operates at the nominal voltage, its farthest MV node approaches 20.36 kV and the LV node reaches 0.364 kV at the peak loading of summer. Thus operating at the nominal voltage avoids any voltage drop below the minimum allowable value, and so there is no need for capacitors for voltage improvement. Moreover, the power factor of the MV lines still in the range 81% - 84%, this means high VAR demand and high losses. When operating below the nominal voltage with average and peak loading cases, the voltage level at the end of the feeder drops slightly below 90% to values in the range 87% - 89%. Also the power factor falls in the range 83% - 85%. Thus the network needs VAR compensation by capacitors' installation for both voltage and power factor improvement to reduce voltage drop, release capacity and decrease losses. The total VAR amount was calculated by hand such that the minimum value of power factor of the MV network is 92. This value is the minimum power factor value to eliminate penalty money imposed when operating with a lower power factor. Also the places of heavy VAR were determined to install capacitors there. After hard study and running different simulation scenarios for capacitor placement, it's found that the best choice for maximal technical enhancement with economic is to install only one MV switched bank, while 10 capacitor banks are installed on the LV networks.

The fixed capacitors should be installed in the MV network near the load-centers places. When the loads are uniformly distributed, a rule of thumb states the total required VAR equals to 2/3 of the total VAR demand. Also it states that the compensation capacitors should be placed at the last 1/3 of the feeder's length. There are other factors that affect the installation place such as: available area on the network and good ventilation. Their ratings are calculated considering the lowest Mvar demand of the load cycle. Their ratings are chosen to be 200 Kvar or 300 Kvar.

The switched capacitors ratings are calculated based on the maximum Mvar demand of the load cycle. Their values equal the difference between the maximum Mvar and the fixed capacitors' ratings. The chosen rating for the switched bank capacitor is 1200 Kvar.

After installing the capacitor banks, the feeder was tested for a combination of different operating scenarios including under voltage of the sending end, overvoltage of the sending end both at minimum and maximum loading cases. The load flow simulation indicates that the capacitors operates with its full rating without leading to under voltage or overvoltage conditions and this is what we are searching for. Figure 3.26 shows the enhancement of the voltage profile after installing the capacitor banks regarding different cases of the sending end voltage at the average loading condition. It can be seen clearly how much the voltage profile is enhanced in comparison to voltage profile presented in section 3.5.4.

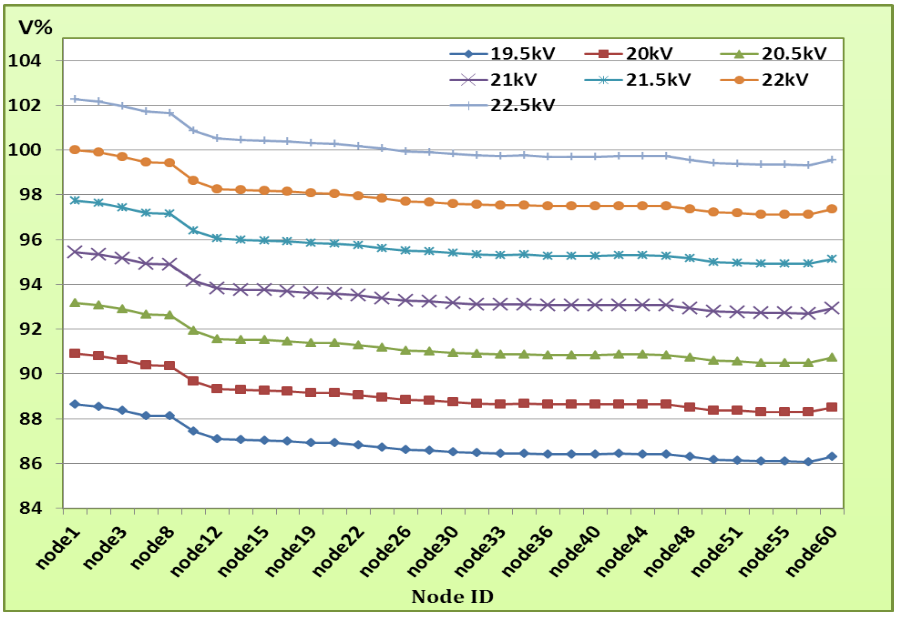


Figure 3.26: Voltage improvement by capacitors placement

Not only the voltage levels are improved, but also the power factor at the sending end is increased from 83.39% to 96.17%. Another advantage is that the current loading is decreased; hence the power losses are decreased. Moreover, the increased power factor increases the feeder capacity by capacity release which lowers the consumed KWH annually as shown in table 3.24.

Table 3.24: Capacitor banks and power carrying capability

Before adding capacitors					*After adding capacitors*					*Capacity release (MVA)*	
Sending end PF%	Average Loading 20.5 kV				Sending end PF%	Average Loading 20.5 kV				Peak. Load	Avg. Load
	MW	Mvar	MW Loss	Mvar Loss		MW	Mvar	MW Loss	Mvar Loss		
83.39	6.43	4.25	0.188	0.387	96.17	6.58	1.87	0.153	0.324	1.044	0.86

The capacitors' banks are highly cost, so the project of capacitor placement needs an economic evaluation study. The investment cost of this project must be considerable in comparison to profit obtained in the near future. The cost of capacitors combines fixed cost and running cost. The fixed cost is the cost paid for the purchase and installation of capacitor with its accessories while the running cost is the annual maintenance cost. However, for calculating the simple payback period is calculated by equation 3.11:

$$\text{Payback period} = \frac{\text{Investment cost}}{\text{Saving cost}} \quad (3.11)$$

It's worth mention that the life period for the capacitors is 15-20 years. *In USA, the capacitors are implemented if the payback period is only from 3 to 5 years. Every project should have a Figure of economic benefit.* Table 3.25 shows the capacitors' placement information including the candidate buses for placement with their data.

Table 3.25: Capacitors' placement results

Candidate Buses		Capacitor Information						
ID	Rated kV	Rated kvar/ Bank	Rated kV	No. of Banks	Total Kvar	Cost ($)		
						Installation	Purchase	Operation/ Year
node19	22	1200	22	1	1200	600	18000	600
node 39	0.4	100	0.4	2	200	600	3000	600
node 43	0.4	100	0.4	2	200	600	3000	600
node 45	0.4	100	0.4	2	200	600	3000	600
node 47	0.4	100	0.4	2	200	600	3000	600
node 50	0.4	100	0.4	2	200	600	3000	600
node 52	0.4	100	0.4	2	200	600	3000	600
node 54	0.4	100	0.4	3	300	600	4500	600
node 56	0.4	100	0.4	2	200	600	3000	600
node 58	0.4	100	0.4	3	300	600	4500	600
node 59	0.4	100	0.4	2	200	600	3000	600
node 61	0.4	100	0.4	2	200	600	3000	600
Total				25	3600	7200	54000	7200

Table 3.26 presents the cost summary of the installed capacitors' banks. It's seen that the payback period is 4 years and in the fifth year the pure profit starts.

Table 3.26: Capacitors placement cost summary

Year	Cost (NIS)		Saving due to loss reduction (NIS)		
	Installation	Operation	Loss reduction	Yearly profit	Accumulative profit
1	226440	26640	85848	-167232	-167232
2	0	26640	85848	59208	-108024
3	0	26640	85848	59208	-48816
4	0	26640	85848	59208	10392
5	0	26640	85848	59208	69600

More accurate results can be obtained if some aspects have been taken into consideration when such project is planned; they include the energy prices change and the load growth during the payback period which need hard effort in a specific study. Thus in this economic evaluation, the energy price is assumed to be fixed at 0.28 NIS and the load in its summer average loading case. Those considerations should be taken into account to obtain a justified economic project.

3.7 Summary

In this chapter, a detailed technical evaluation of the present network is carried out by using ETAP software. The simulation results clarify the deficiencies and problems faced by the network. Based on the obtained results, some technical solutions are suggested to help in the network improvement. The solutions are tested by simulation. The proposed solutions were suggested considering the financial investment cost and profits such that the solutions are acceptable from the economic view.

CHAPTER 4

GIS APPLICATIONS FOR RAFAH ELECTRIC POWER DISTRIBUTION GRID

4.1 Introduction

Since power systems are spread geographically, their spatial attributes should be considered to help in system planning. The geographical representation of power systems has become a necessary tool for utility decision makers. GIS provides a rich set of functions to view the power system grid superimposed on various layers including transformers, overhead and underground network, and the other components of the network. The capability of GIS for displaying and analyzing information provides a powerful tool for deep understanding of the system problems, so it can be used for development of suitable solutions [37]. This chapter presents some of the GIS functions to the power distribution grid of Rafah governorate.

4.2 GIS Concept

Geographic information systems, in a narrow definition, are computer-based systems for the integration, storage, querying, analysis, modeling, reporting and mapping of geographically-referenced data. In a more broad definition it is a digital system for the acquisition, management, analysis and visualization of spatial data for the purposes of planning, administering and monitoring the natural environment. The main parts of any GIS system are shown in Figure 4.1 [38].

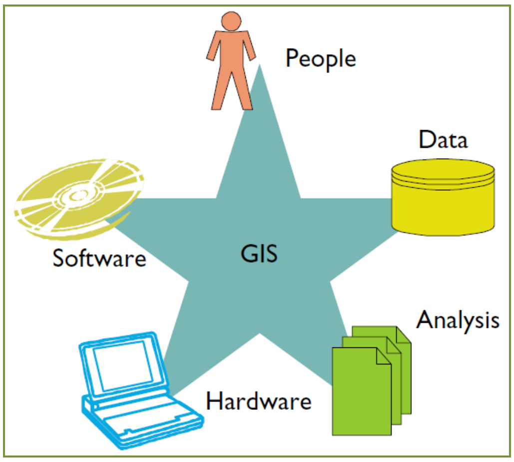


Figure 4.1: GIS components

4.3 GIS Functions to the Electric Utility

GIS is now being used for mapping and modeling of electric utility network systems including the generation, transmission and distribution utilities. GIS has a wide range of functions that can be used in planning and management of power distribution systems. Some of these functions are explained in the next sections.

4.3.1 Information Processing

The parameters of the conductors and protective devices such as conductor type, length, construction and device type are stored in attribute tables. Thus, GIS developers can create interfaces that can be used for data query facility and provide accurate information to the utility operational staff. The information can be in the nature of reports of network components (poles, conductors, underground cable segments etc.) or location information etc. [39].

4.3.2 Optimization of Electric Distribution Networks Design in GIS

The main objective of distribution system planning is to ensure that the growing demand for electricity can be satisfied in an optimum design that's mainly achieved with minimum cost [40]. The route of a transmission line must be selected such that pass through minimum curves to give the best engineering and economic solution. The optimal connection of the particular customer to an existing secondary system must satisfy the following two technical constraints:

1. The shortest possible length of connection due to voltage drop that may be permitted.
2. Reserve in load capacity of substation due to customer load.

When a route is selected, it's tested on several technical constraints (voltage drop, cable and route load, investment costs, etc.) [41].

4.3.3 Customer Indexing

In consumer indexing GIS can effectively manages information of the electricity distribution system. It can be used to store a huge database involving attributes of each consumer such as location, load category, the feeding line, and also determines the supplying transformer [42]. By the integration between GIS and customer accounts and billing system, the GIS database can store the energy consumption data of each customer, and then it can be used to analyze every consumer consumption pattern. This also can be used in load forecasting studies. With periodic update of the electrical network and consumer database, it results in improved load management.

4.3.4 Maintenance

Let us assume that the system engineer has to send a cable jointer in the field that has to access a certain underground cable joint. The engineer can take the digitized map of the area, mark a small portion of that area in the neighborhood of the joint. This printed map will show, to the jointer, the location of the joint with proper distance. These references make the work of the technician easier and quicker [39]. Thus using GIS save both time and effort in all maintenance works.

4.3.5 Reduction of Outage Time in Distribution Networks

By using the GIS, the dispatcher is enabled to make a decision how to proceed with switching operations for service restoration and load redistribution purposes during system faults. Since the switching related information is all saved in the GIS database, then the dispatcher can quickly and conveniently localize and operate the switch to isolate the faulted area and restore the service from other feeders [43].

4.3.6 Integration between GIS and SCADA

The SCADA system needs the information which can be obtained from GIS mainly including the geography graph background information, the off-line graph information and the power distribution equipment parameter information. The integration of distribution network SCADA system and GIS can be used in direct viewing of the electrical power system in current running status with the equipment geographical position information and the equipment parameters which needed by the dispatcher in real time [44].

4.4 Rafah Governorate Model in GIS

Computer aided network analysis tools had been employed in this thesis to assess the performance of the electrical distribution system in Rafah governorate. The first step in the network analysis includes GIS technology. The engine software used for this step is *ArcGIS-Arc Info 9.3* which is described in the next subsection.

4.4.1 ArcGIS-ArcInfo Software

ArcInfo was first designed by ESRI Corporation in 1969, and has been available on the market since 1982. It is one of the most widely used GISs. It offers a rich set of spatial functions. ArcInfo offers a variety of capabilities such as data acquisition, exchange, and spatial analysis. Moreover, it offers more specific tools for topological structuring, among them powerful tools for thematic data distribution into coverage, entity extraction from coverage, and geometric correction. The functional power of ArcInfo is enriched with other tools for thematic analysis, network analysis, and terrain modeling [45].

The remaining part of this chapter will cover all the work done for modeling Rafah Governorate MV network. The work was divided into three stages: database preparation, GIS project of Rafah Governorate MV network, and GIS applications to the MV grid.

4.4.2 Preparing the Database

The collected data of Rafah Governorate network is stored in a database program prepared by Microsoft Access 2010. The designed database has a graphical user interface. The main window shown in Figure 4.2 includes the spatial information including: pole code, area, street name, and additional notes.

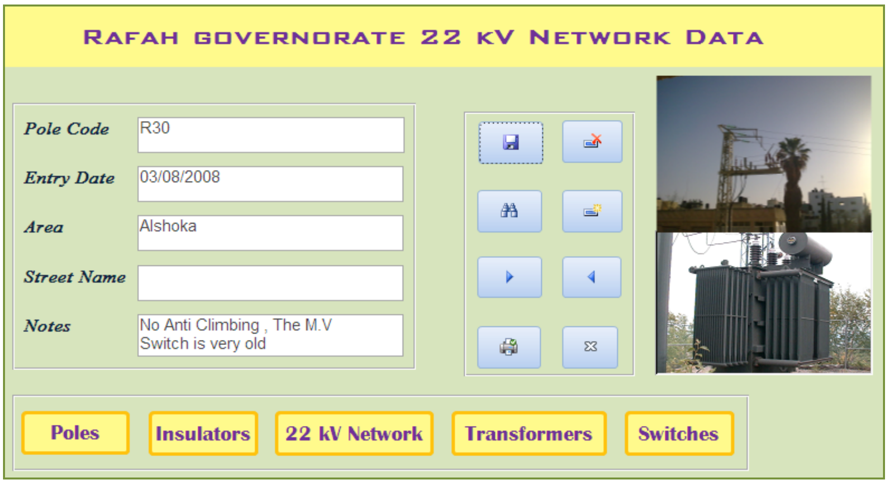


Figure 4.2: The main window of the database program

There are five additional separate windows to store the various data of the network components. Figure 4.3 shows poles' data. The descriptive data includes: code, installation year, feeding provider and feeding line name.

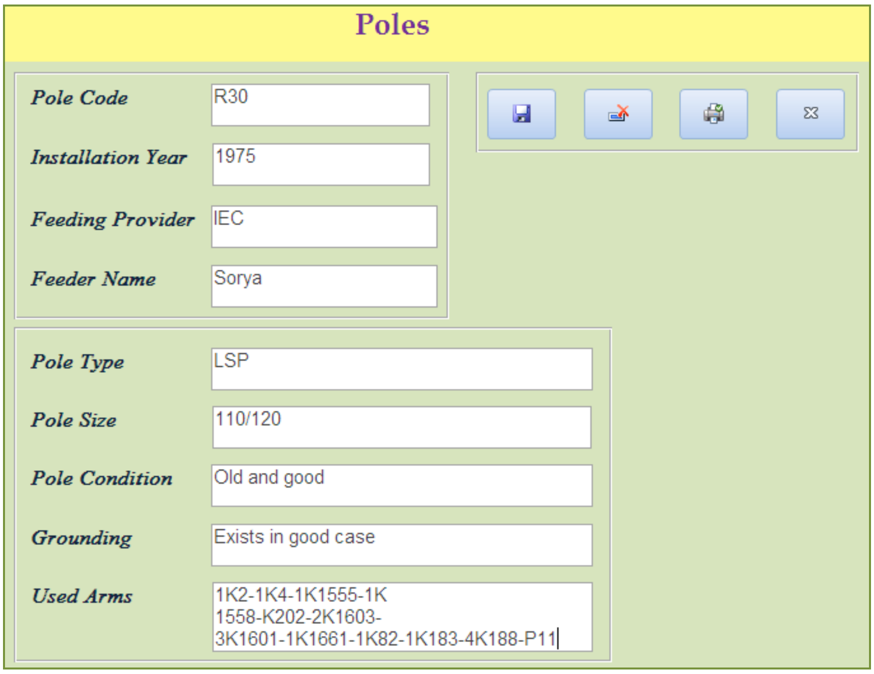


Figure 4.3: Pole data window

Figure 4.4 displays the insulators information. It contains the quantities of the various insulator types such as: 33 kV, 24 kV, 0.4-kV, tension glass, polymer, and porcelain insulators.

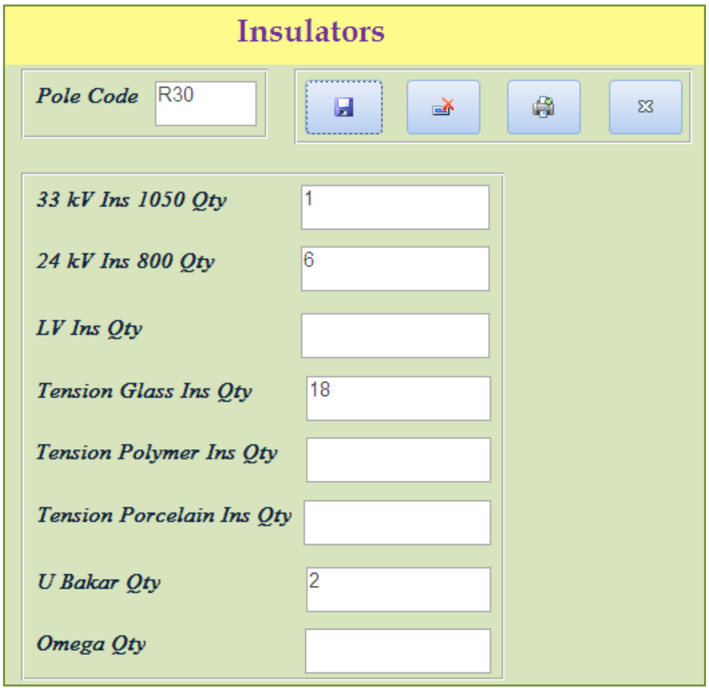


Figure 4.4: Insulators window

While Figure 4.5 displays the data for the 22-kV network. It describes the conductor type, size and length. Also it describes the status of the network, number of joints and the existence of the neutral line.

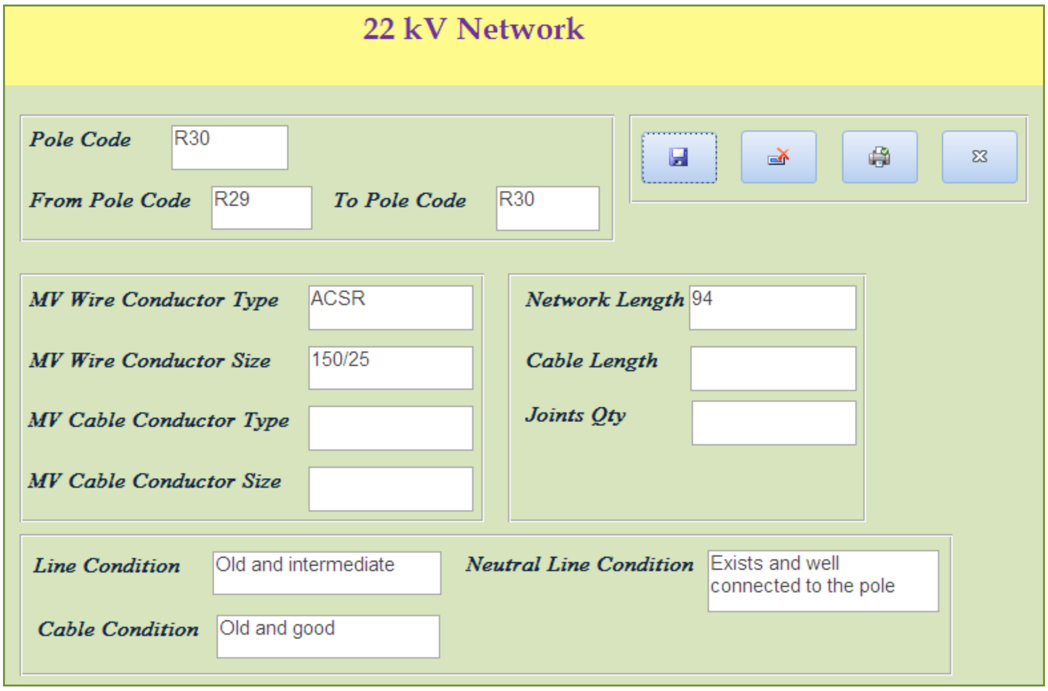


Figure 4.5: The 22-kV Network window

In Figure 4.6, we see the information about the transformers. It includes the transformer name, rating and fuses.

Figure 4.6: Transformers window

The last window is for switches data and shown in Figure 4.7. It presents the data for the MV switches, LV switches, their directions, types and fuses.

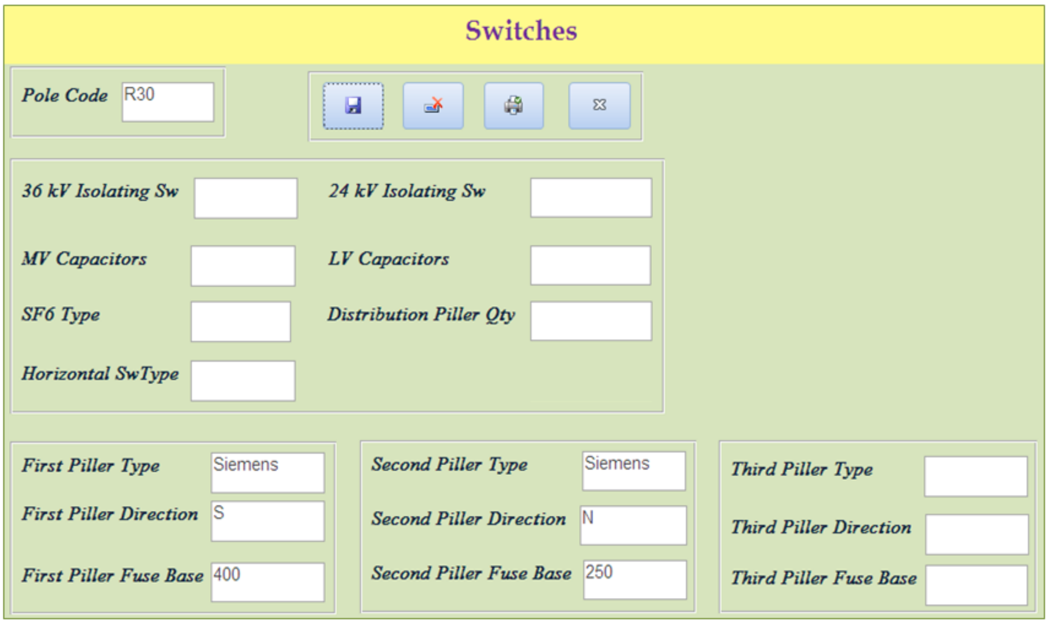


Figure 4.7: Switches window

4.4.3 Construction of GIS Model

An aerial map for Rafah Governorate is exported to ArcGIS/Arc Info 9.3 software and is used as the base map which is used to be the real geographic background of all analysis layers. An aerial photograph is any photograph taken vertically from an aircraft using a highly-accurate camera. Figure 4.8 shows the aerial map of Rafah governorate.

Figure 4.8: The aerial map of Rafah Governorate

The Geographic Coordinate System: GCS_Palestine_1923 is chosen to be the reference coordinate system for the GIS model of Rafah governorate.

The data of the network components including: overhead lines, underground cables, transformers and circuit breakers were all obtained from the studies and documentation branch of the technical administration in GEDCO.

4.4.4 Modeling Procedures

The first step to build the GIS system is constructing the single line diagram using ArcMap tools using the shape files. The shape files that represent the network nodes and lines are exported to individual feature classes using ESRI tools. These shape files were used to build the geodatabase and the geometric network. The second step is the joining process between the database and the map features depending on unique identifier which is selected to be the pole code in our case. The third step is building the geodatabase using ArcCatalog. This step is done simply by loading the shape files into a personal geodatabase. Up to this point, the GIS model is ready for analysis. Figure 4.9 displays the exact structure of the geodatabase utilized as it appears inside the ArcCatalog. As seen the geodatabase contains three datasets: points, polylines and polygons. Point's dataset includes the feature classes of various types of poles. Polygons dataset contains the buildings feature class. Finally, the polyline dataset contains three feature classes: the streets, underground cables and overhead lines.

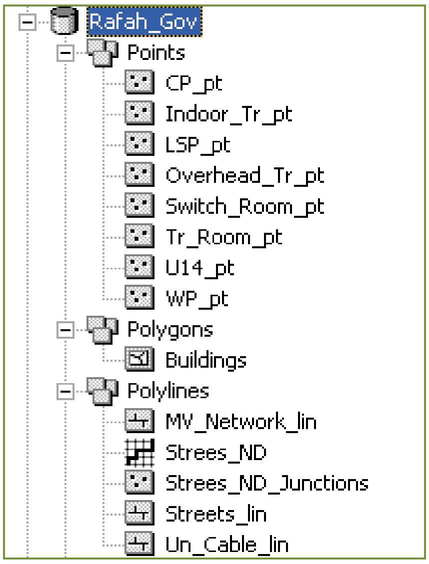


Figure 4.9: Geodatabase tree inside ArcCatalog 9.3

Once the datasets were loaded into the geodatabase, they could then participate in a special relationship called a ***geometric network***. Geodatabase feature classes are used as the data sources to define the geometric network. The feature classes in the feature dataset are used as the data sources for network junctions and edges. The network connectivity is based upon the geometric coincidence of the feature classes used as data sources. Now, let's see the implementation of the above steps. The electric elements of the MV networks are imposed into various layers, so that each layer can be analyzed separately when needed. The constructed layers include: overhead transformers, indoor transformers, lattice steel poles (LSP), channel steel poles (CSP), wooden poles, concrete poles, overhead network and underground network. Also a layer for streets is constructed such that it will be used in the network planning as it will be illustrated later. It's important to mention that theses separate layers can be grouped and imposed into fewer layers for easier analysis. These layers are shown respectively in the following figures. Figure 4.10 shows the 22-kV network; the overhead and the underground lines.

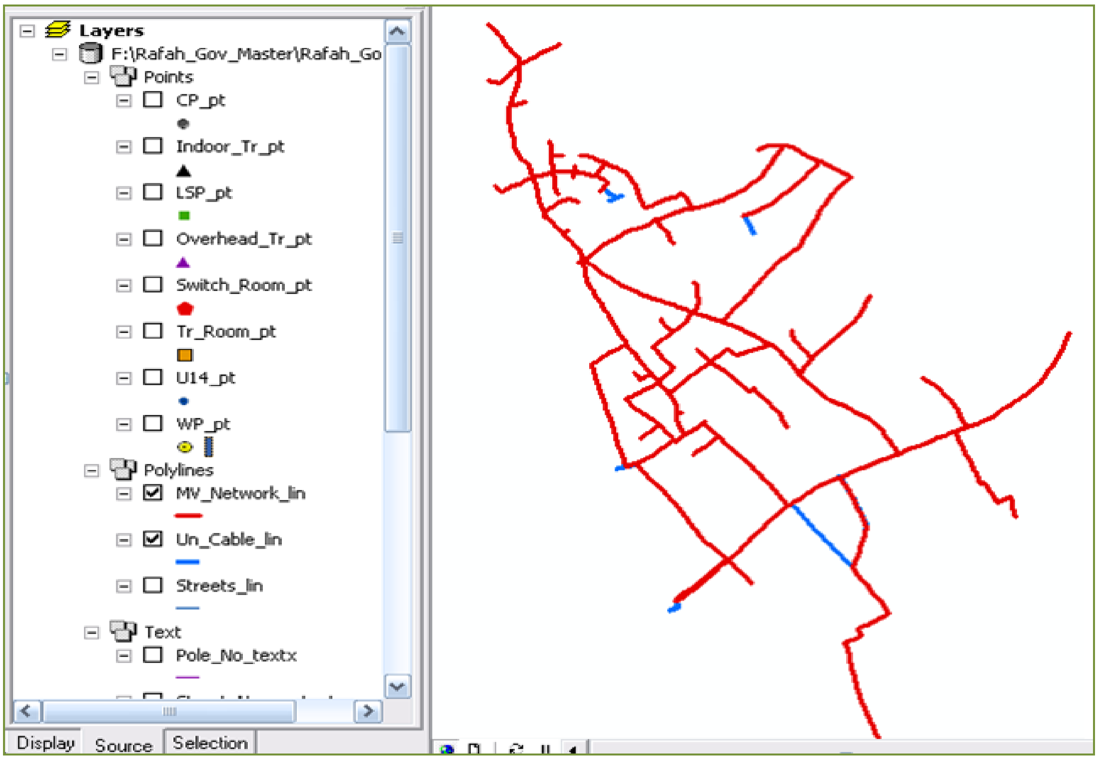


Figure 4.10: The 22-kV network layer

In the figure, the overhead network appears in red color while the underground layer in blue color.

Figure 4.11 displays the overhead transformers layer superimposed into the overhead network.

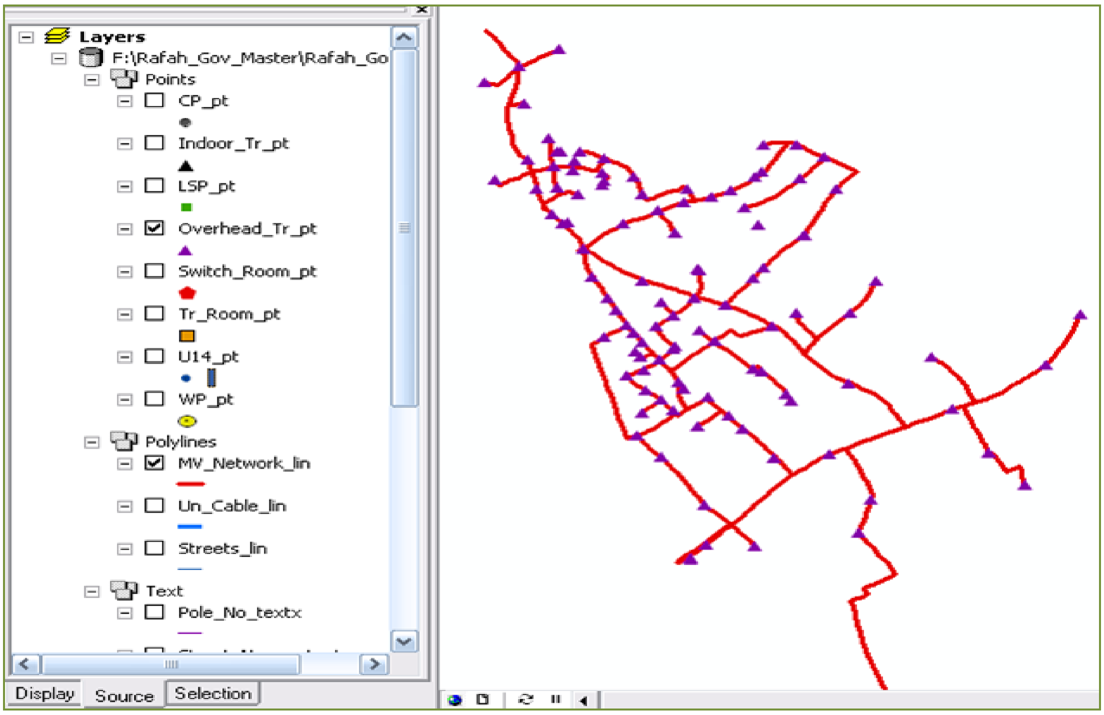


Figure 4.11: The overhead transformer layer

Figure 4.12 displays the LSP layer superimposed into the overhead network.

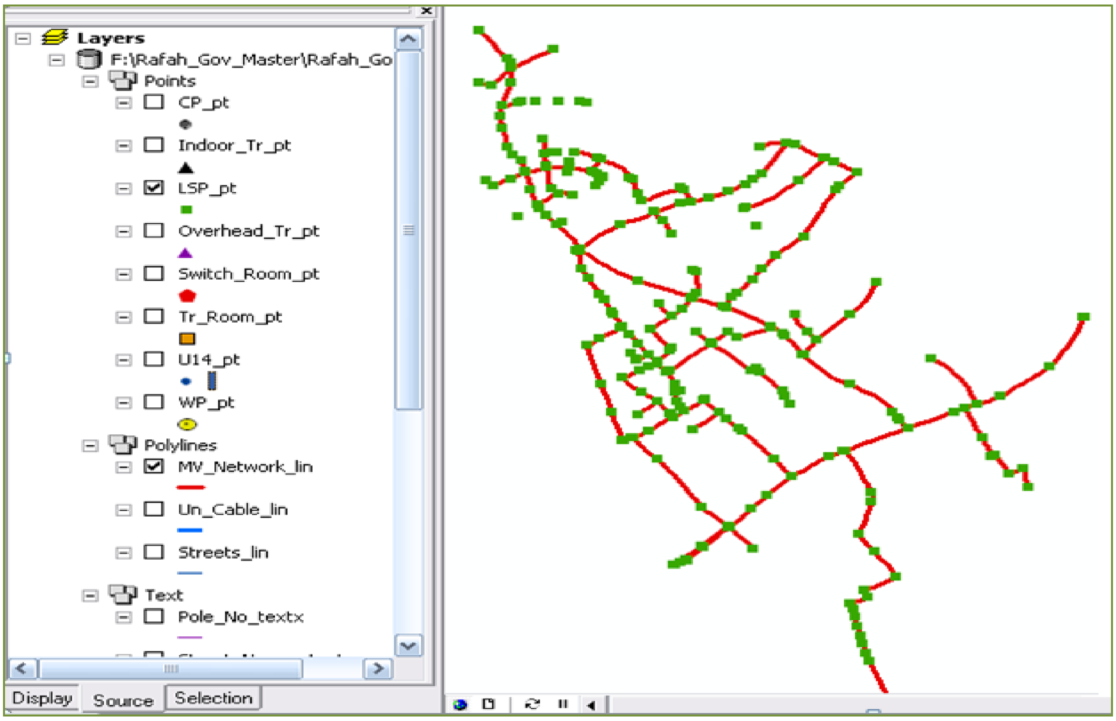


Figure 4.12: The LSP layer

Figure 4.13 displays the CSP layer superimposed into the overhead network.

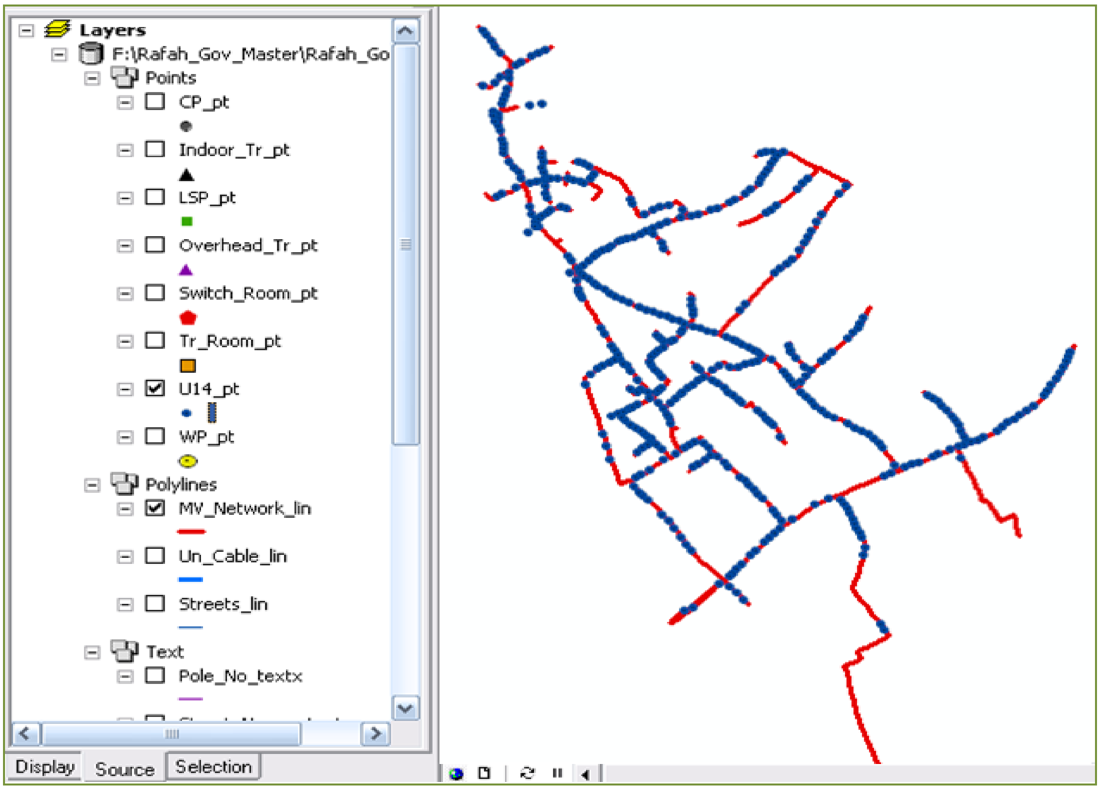


Figure 4.13: The CSP layer

Figure 4.14 displays the concrete poles layer superimposed into the overhead network.

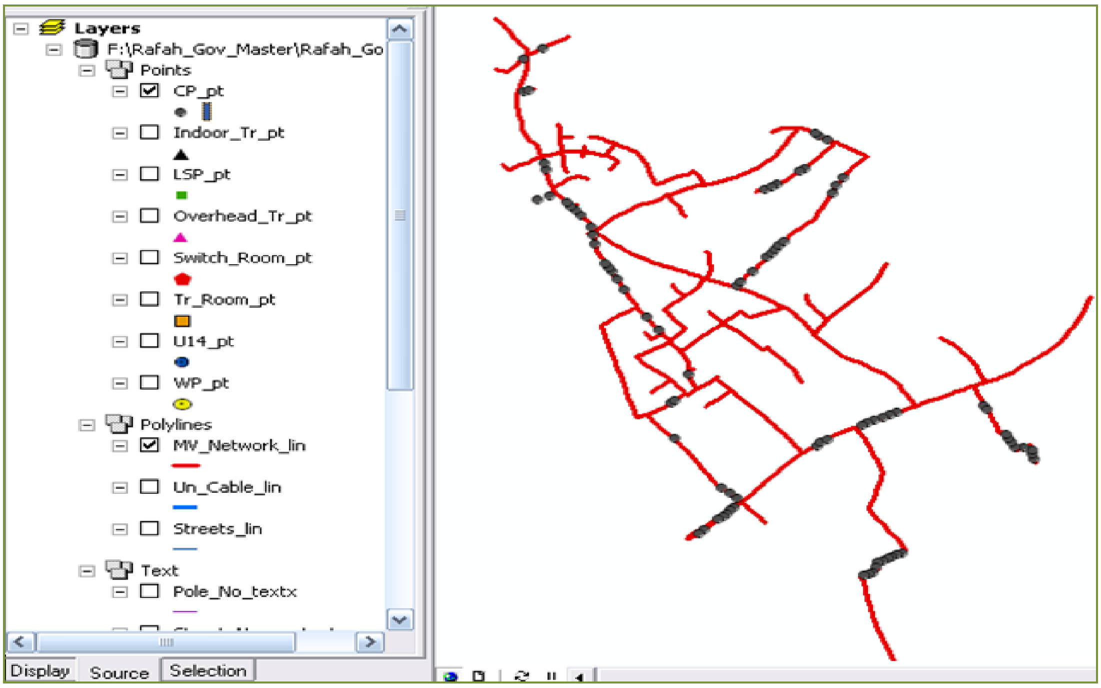


Figure 4.14: The Concrete poles layer

Figure 4.15 displays the wooden poles layer superimposed into the overhead network.

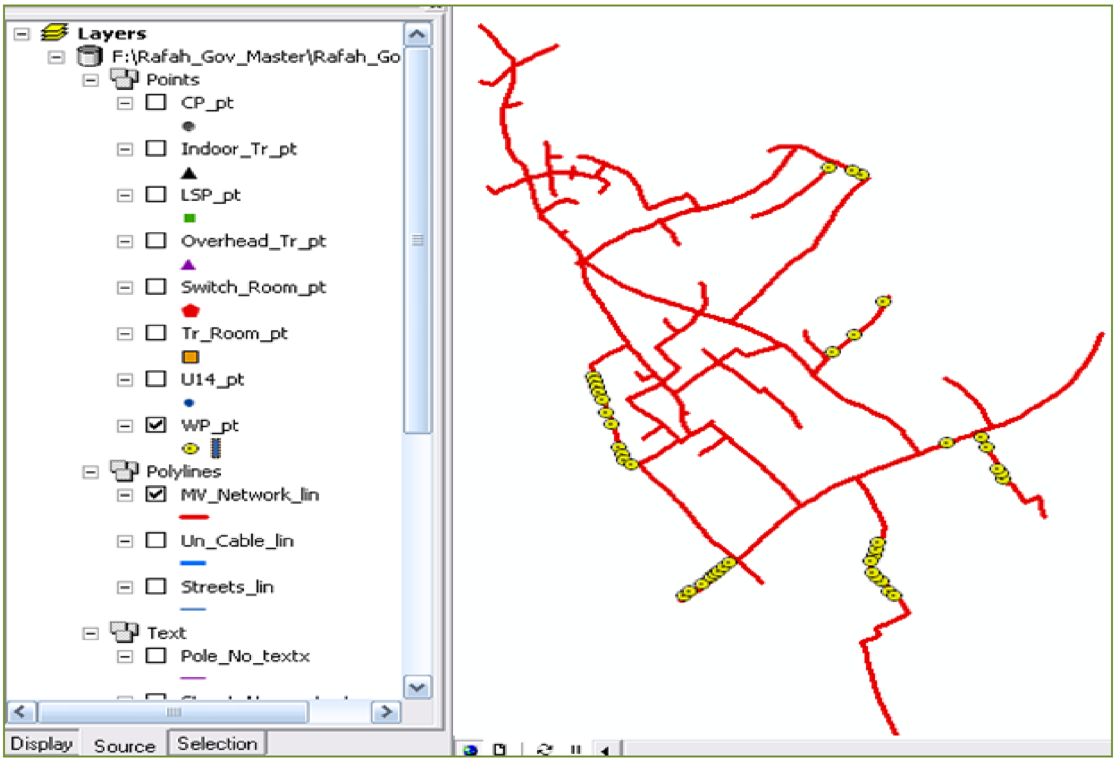


Figure 4.15: The Wooden poles layer

Figure 4.16 displays the streets layer.

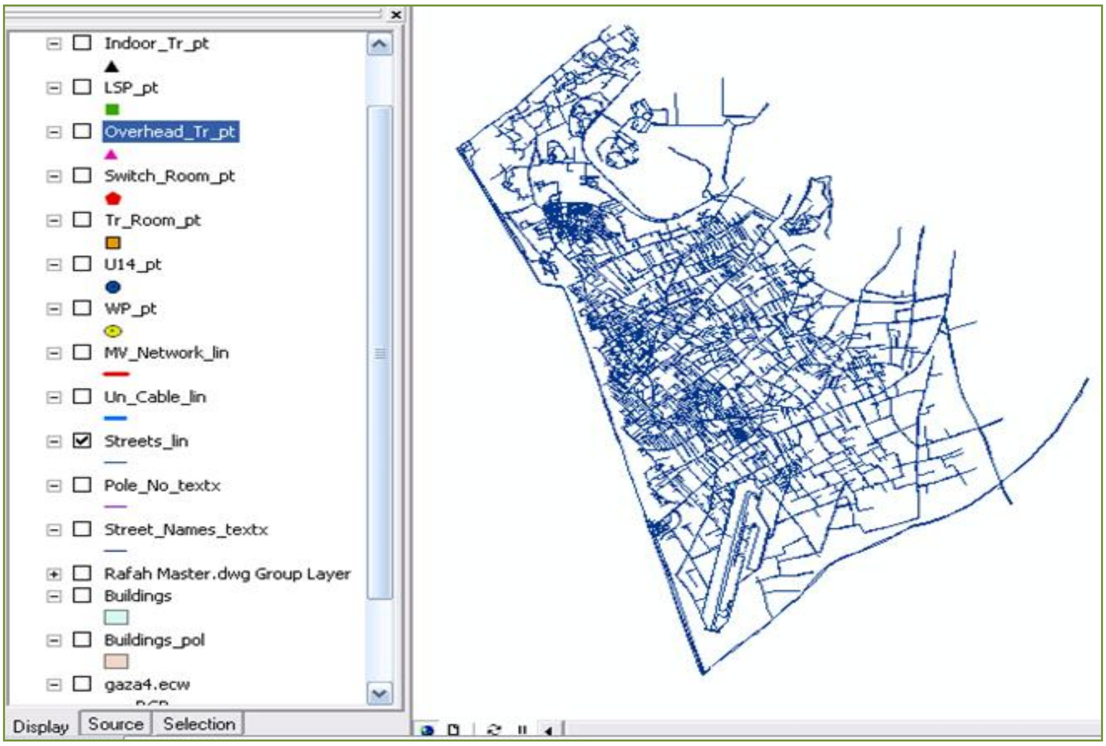


Figure 4.16: The streets layer

As mentioned before, user can merge more than one layer into a larger layer for specific analysis purposes. In Figure 4.17, we can see the streets layer, LSP layer, CSP layer and wooden poles layer are displayed onto the aerial map layer which appears as a background for the all other layers.

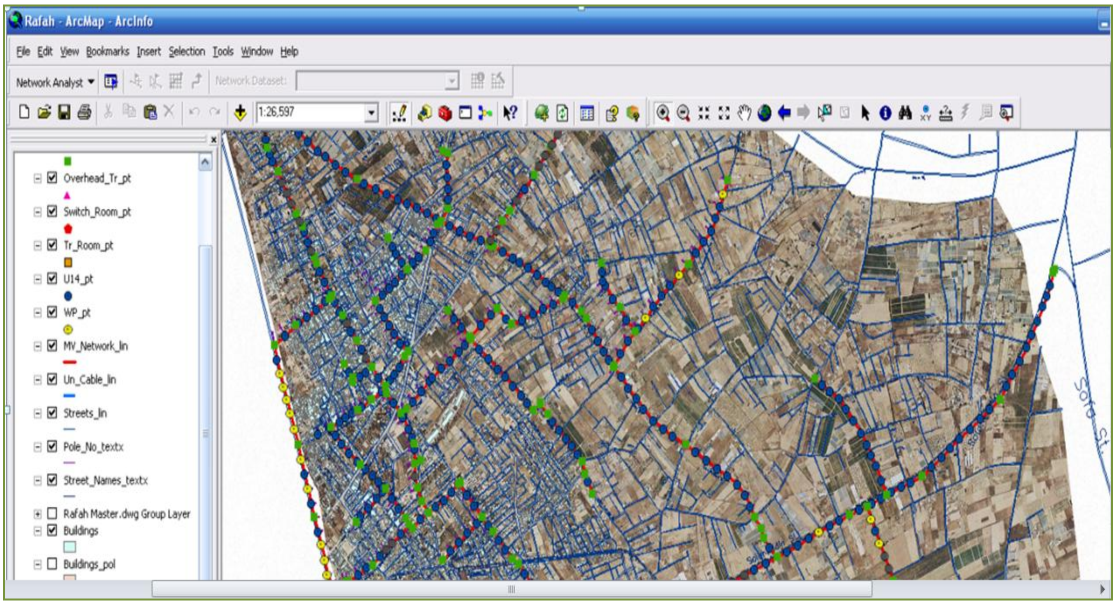


Figure 4.17: Merging more than one layer into one layer

Next, the above layers or in other words the shape files are imported into the personal geodatabase named *Rafah_Gov.mdb* which is shown in Figure 4.9. Then the database tables of Rafah network are imported into the same geodatabase and joined to the attribute tables of the different shape files according to unique values which are chosen to be the pole codes. When the joining operation is done for some layer, then the attribute table will contain the imported database. Figure 4.18 shows the attribute table of the concrete poles layer before the joining process.

* OBJECTID	* Shape	LAYER	* Pole_No
1	Point	R-POINT H.V C.P	R78
2	Point	R-POINT H.V C.P	R79
3	Point	R-POINT H.V C.P	R80
4	Point	R-POINT H.V C.P	R81
5	Point	R-POINT H.V C.P	R82
6	Point	R-POINT H.V C.P	R85
7	Point	R-POINT H.V C.P	R56
8	Point	R-POINT H.V C.P	R55
9	Point	R-POINT H.V C.P	R54
10	Point	R-POINT H.V C.P	R128
11	Point	R-POINT H.V C.P	R127
12	Point	R-POINT H.V C.P	R126
13	Point	R-POINT H.V C.P	R124
14	Point	R-POINT H.V C.P	R122
15	Point	R-POINT H.V C.P	R121
16	Point	R-POINT H.V C.P	R120
17	Point	R-POINT H.V C.P	R119
18	Point	R-POINT H.V C.P	R111
19	Point	R-POINT H.V C.P	R112
20	Point	R-POINT H.V C.P	R95
21	Point	R-POINT H.V C.P	R94

Record: 1 Show: All Selected

Figure 4.18: The attribute table of the concrete poles layer before the join process

Figure 4.19 shows the attribute table of the concrete poles layer after the joining process.

Attributes of CP_pt

OBJE	Shape	LAYER	Pole_No	_Installation	Pole_Type	Pole_Heig	Pole_Condition	Grounding	Feeding_P	Feeder_Na	Used_Arms	Unused_Arms
1	Point	R-POINT H.V C.P	R78	1982	Concrete	m ١٤	Old and good	Does not exist	Egypt	٥Mega-١٢	١K41-6K81	<Null>
2	Point	R-POINT H.V C.P	R79	1982	Concrete	m ١٤	Old and good	Does not exist	Egypt	٥Mega-١٢	١K41-6K81	<Null>
3	Point	R-POINT H.V C.P	R80	1982	Concrete	m ١٤	Old and good	Does not exist	Egypt	٥Mega-١٢	١K42-6K81	<Null>
4	Point	R-POINT H.V C.P	R81	1982	Concrete	m ١٤	Old and good	Does not exist	Egypt	٥Mega-١٢	١K41-6K81	<Null>
5	Point	R-POINT H.V C.P	R82	1982	Concrete	m ١٤	Old and good	Does not exist	Egypt	٥Mega-١٢	١K41-6K81	<Null>
6	Point	R-POINT H.V C.P	R85	1982	Concrete	m ١٤	<Null>	Does not exist	Egypt	٥Mega-١٢	١K42-6K81	<Null>
7	Point	R-POINT H.V C.P	R56	1975	Concrete	m ١٤	Old and good	Does not exist	Israel	٥Mega-١٢	١K23-6K81	<Null>
8	Point	R-POINT H.V C.P	R55	1975	Concrete	m ١٤	Old and good	Does not exist	Israel	٥Mega-١٢	١K23-6K81	<Null>
9	Point	R-POINT H.V C.P	R54	1975	Concrete	m ١٤	Old and good	Does not exist	Israel	٥Mega-١٢	١K23-6K81	<Null>
10	Point	R-POINT H.V C.P	R128	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K23-6K81	<Null>
11	Point	R-POINT H.V C.P	R127	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K23-6K81	<Null>
12	Point	R-POINT H.V C.P	R126	2006	Concrete	m ١٠	Old and good	Does not exist	Israel	Sorya	١K23-6K81	<Null>
13	Point	R-POINT H.V C.P	R124	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K66-6K81	<Null>
14	Point	R-POINT H.V C.P	R122	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K23-6K81-2X65	<Null>
15	Point	R-POINT H.V C.P	R121	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K23-6K81-1X65	<Null>
16	Point	R-POINT H.V C.P	R120	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K23-6K81-1X65	<Null>
17	Point	R-POINT H.V C.P	R119	2006	Concrete	m ١٠	New	Does not exist	Israel	Sorya	١K23-6K81-1X65	<Null>
18	Point	R-POINT H.V C.P	R111	2005	Concrete	m ١٠	Old and good	Does not exist	Israel	Sorya	١K42-6K81	<Null>
19	Point	R-POINT H.V C.P	R112	2005	Concrete	m ١٠	Old and good	Does not exist	Israel	Sorya	١K23-6K81	<Null>
20	Point	R-POINT H.V C.P	R95	1980	Concrete	m ١٤	Old and good	Does not exist	Israel	Sorya	١K23-6K81	<Null>

Record: 0 Show: All Selected Records (0 out of 84 Selected) Options

Figure 4.19: The attribute table of the concrete poles layer after the join process

It's clearly seen that all the concrete poles data including the pole height, pole condition, feeding source, and other data are all stored in the attribute table of that layer, so it becomes ready for queries.

4.5 GIS Applications for Rafah Power Distribution System

The following cases are studied for GIS applications implemented on the existing network of Rafah Governorate.

Case 1: Reports and Data Query

- ***Identify Tool:*** We can use the "**Identify Tool**" to display the stored information associated with any element of the map. The stored data of the selected element appears in a pop-up window as shown in Figure 4.20.

Figure 4.20: The "Identify Tool" window

- ***Selection by Attributes:*** ArcGIS enables users to make unlimited data queries. These queries are easily done by using the ArcGIS tool "**Select by Attributes**". Of course, the first step before doing any query, user must join the database to the attribute tables of the maps' features according to unique identifiers. As an example, let's query about the count of LSP of the size 70/80. This can be easily done by selecting the layer of LSP, opening the attribute table of the layer and selecting the elements that possess the required attribute.

Figure 4.21 depicts the LSP whose size is '70/80' in blue color.

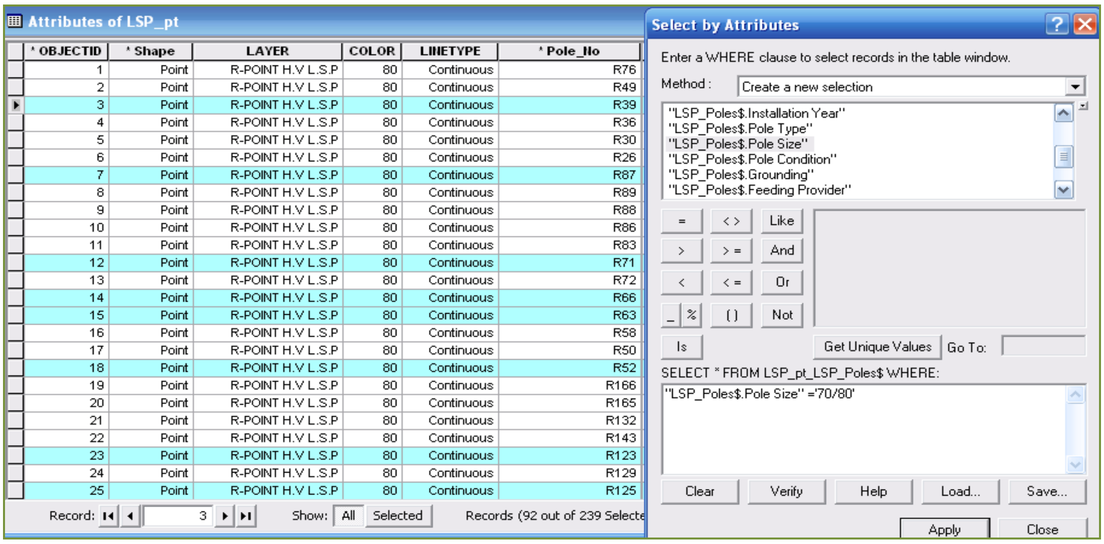


Figure 4.21: Using the "Select by Attributes" tool for LSP sizes query

Another example is shown in Figure 4.22 in which the count of concrete poles of 14 meters height is calculated. It's seen that there are 73 poles out of the 83 concrete poles of this height.

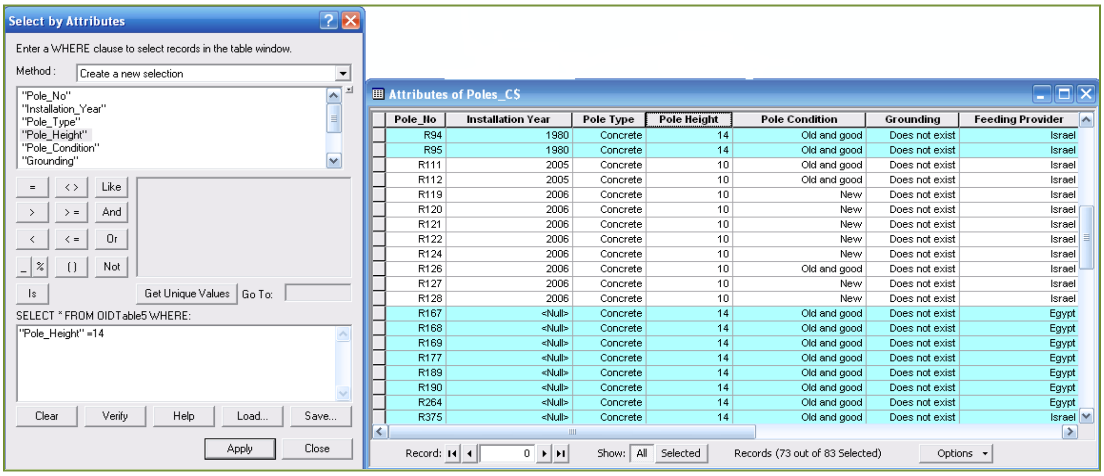


Figure 4.22: Using the "Select by Attributes" tool for concrete poles height query

Also, the selected data can be viewed in the LSP layer in blue color on their geographical distribution as shown in Figure 4.23.

Figure 4.23: The selected data on LSP layer

Using the tool "**Select by Attributes**", many data queries are done to obtain a complete description of the MV network in Rafah governorate. These queries help the electric distribution company to evaluate the financial assets. All of the extracted data are arranged in the following collection of tables. Table 4.1 classifies the feeders with concern to their feeding sources.

Table 4.1: The existing feeders according to the feeding source

Feeder Name	Feeding source	Length(m)
Egypt Feeder No.1	CEDC	11738
Egypt Feeder No.2	CEDC	9645
Egypt Feeder No.3	CEDC	18831
IEC Feeder – Sorya – F9	IEC	30740
Total		70954

Table 4.2 shows the classification of the grid regarding to the used conductors'.

Table 4.2: The existing 22-kV network conductors' types and lengths

Network Type	Length (m)
ACSR 150/25	29056
ACSR 50/8	27093
ACSR 95/15	6486
Total of ACSR Cables Length	**62636**
CU 35	1932
Overhead Lines	64568
Underground Cables	4239
Total of MV Network Length	**68807**

In table 4.3, we can see the transformers classified according to their installation, rated voltage, and power rating.

Table 4.3: The existing transformers

Installation	Rated Voltage (kV)	Rated Power (KVA)	Quantity
Indoor	22/0.4	630	2
Indoor	22/0.4	1250	1
Outdoor	22/0.4	250	12
Outdoor	22/0.4	315	1
Outdoor	22/0.4	400	44
Outdoor	22/0.4	630	45
Total			**105**

Table 4.4 presents the installed MV switches and their quantities.

Table 4.4: Existing MV isolating switches

Description	Quantity
36 KV Isolating Switch With Built-in Arc Interrupter	77
24 KV Isolating Switch With Built-in Arc Interrupter	60
Total	**137**

Table 4.5 indicates the different types of the electrical poles, their sizes, lengths and quantities.

Table 4.5: The existing electrical poles

Pole Description	Quantity
1. Lattice Steel Poles	
Hot Galvanized L.S.P 60/70, 12m long	8
Hot Galvanized L.S.P 70/80, 12m long	92
Hot Galvanized L.S.P 80/90, 12m long	62
Hot Galvanized L.S.P 90/110, 12m long	46
Hot Galvanized L.S.P 110/120, 12m long	9
Hot Galvanized L.S.P 120/130, 12m long	18
Hot Galvanized L.S.P 130/140, 12m long	1
Hot Galvanized L.S.P 140/150, 12m long	3
Total of Lattice Steel Poles	**239**
2. Channel Steel Poles	
Hot Galvanized C.S.P U14, 12m long	425
3. Wooden Poles	
Wooden Pole, 14m	31
Wooden Pole, 12m	4
Wooden Pole, 10m	5
Total of Wooden Poles	**40**
4. Concrete Poles	
Concrete Pole, 14m long	73
Concrete Pole, 10m long	10
Total of Concrete Poles	**83**
Total Pole Quantity	**787**

Moreover, the attribute tables of feature classes can contain attached various types of files. This can be done be adding ***hyperlinks*** of specified files to a feature. As an example, Figure 4.24 presents a photo of a transformer attached to its representative point on the map.

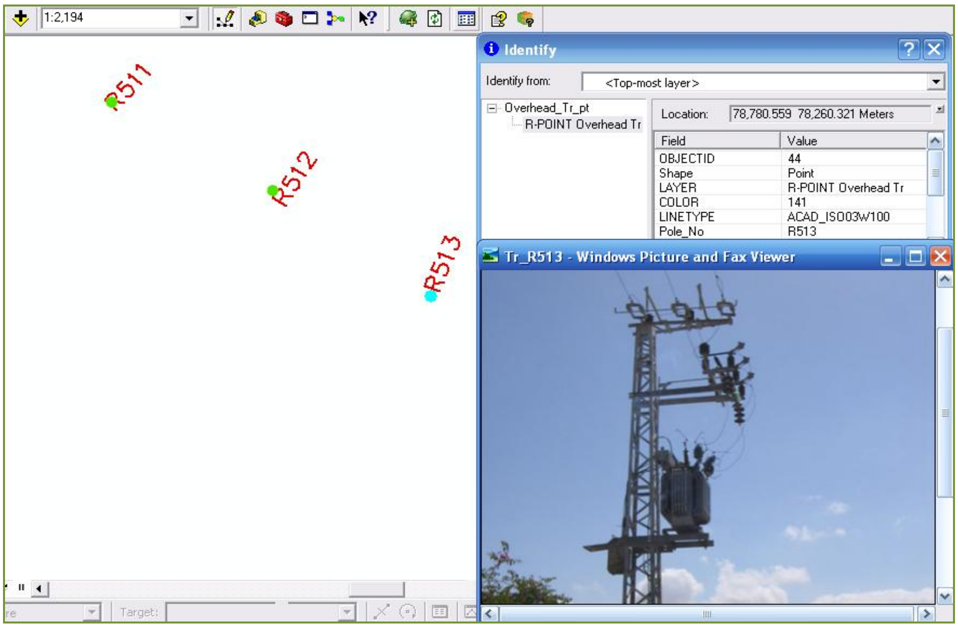


Figure 4.24: Transformer photo attached to a feature point

Also you can attach other types of files. Figure 4.25 shows a PDF file attached to a pole feature.

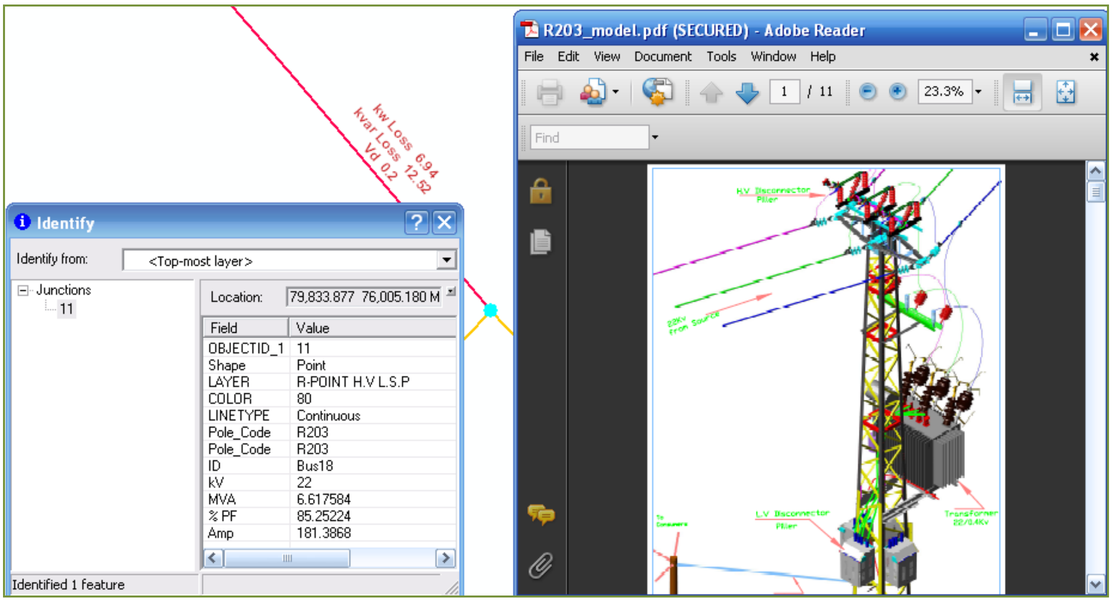


Figure 4.25: PDF file attached to a feature point

- ***Graphs and statistics:*** ArcGIS enables users to create multiple graphs representing relations between the map features. These graphs can be established using the "**Graph Wizard**" tool. In Figure 4.26, you can see the classification of the overhead transformers according to their ratings.

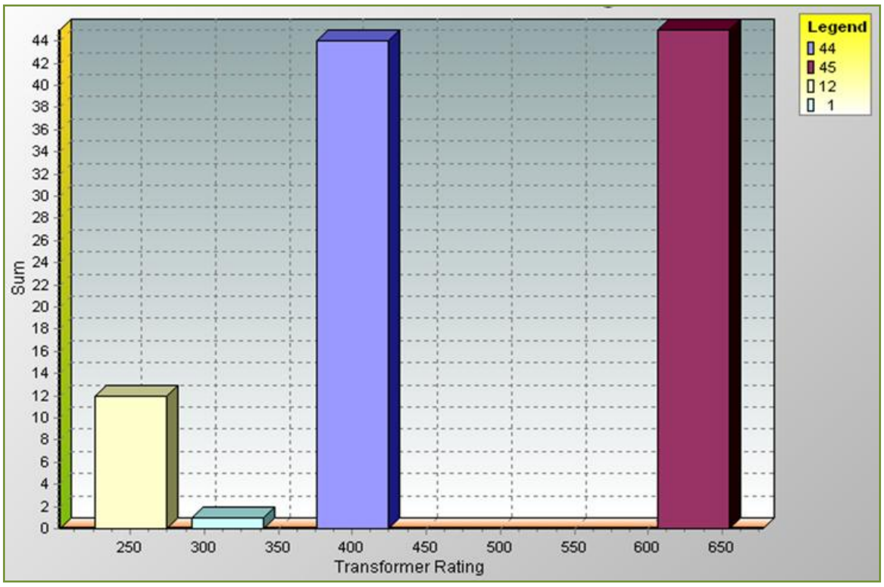


Figure 4.26: Available ratings of the overhead transformers

However, Figure 4.27, you can see the classification of the LSP according to their sizes.

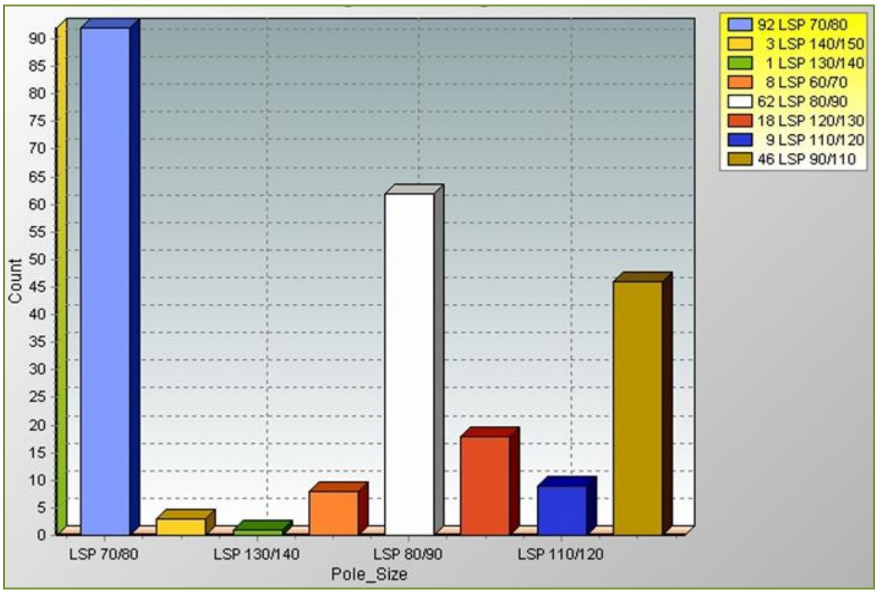


Figure 4.27: Various sizes of LSP layer in bars format

Figure 4.28 represents the same values shown in the figure 4.26, but in percentage format using Pie figure. These values are calculated by "**Field Calculator**" tool which is available for use inside the attribute table of LSP layer.

This tool can be used for applying a desired equations based on relations between different field values.

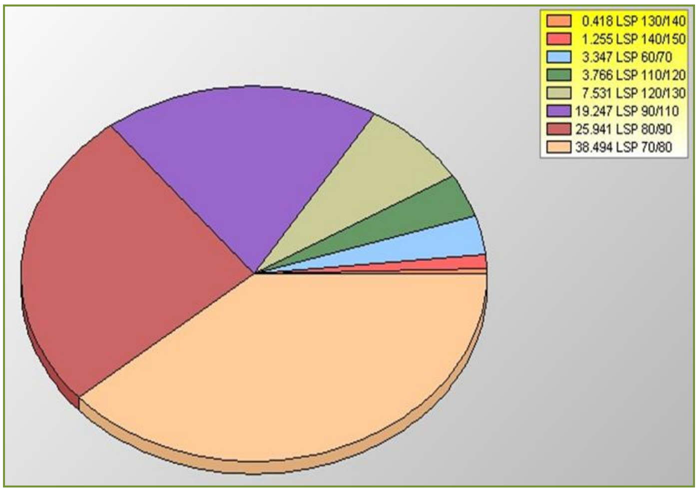


Figure 4.28: Various sizes of LSP layer in pie format

Moreover, Figure 4.29 shows the classification of the overhead network according to the conductor type.

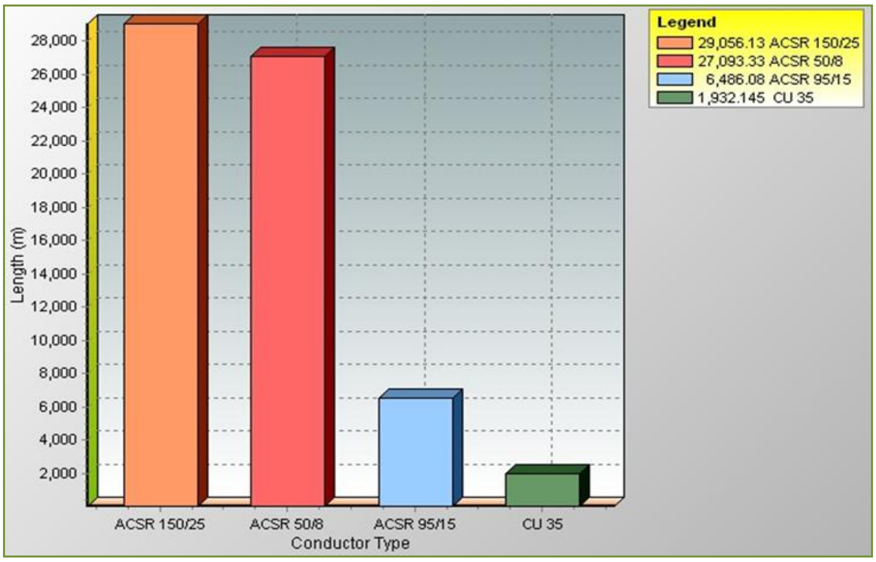
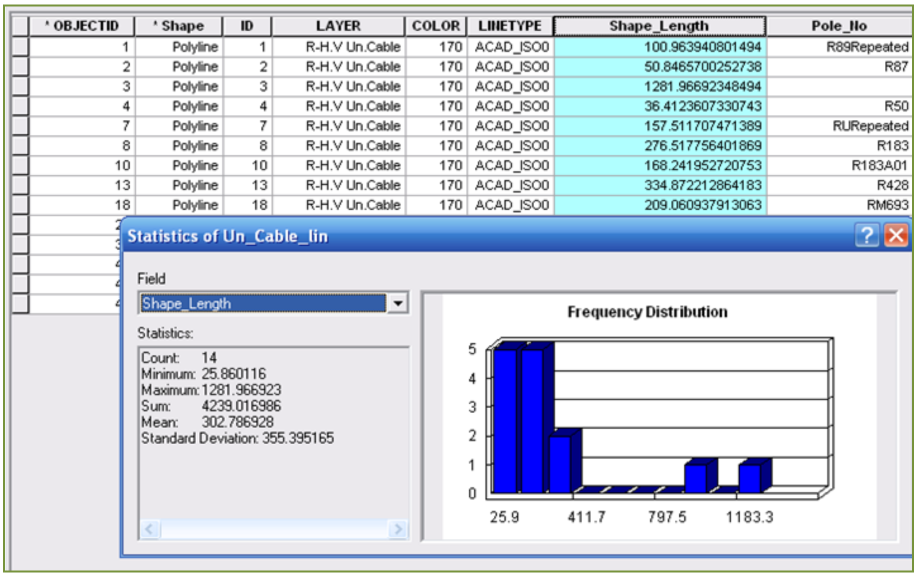


Figure 4.29: The overhead network conductors' classes

Also, in ArcGIS we can use the "**statistics**" tool which displays summary of some statistical values for any data field in an attribute table of interest. With this tool, we can choose which field we interested in to perform some statistics. In this tool window, we can see the count of the records in specified field. It also calculates the minimum, the maximum, the sum, the mean and finally the standard deviation values. Moreover, it provides a figure that represents the distribution classes of the field values. For example; let's compute the length of the underground network. Figure 4.30 displays the calculated length.



* OBJECTID	* Shape	ID	LAYER	COLOR	LINETYPE	Shape_Length	Pole_No
1	Polyline	1	R-H.V Un.Cable	170	ACAD_ISO0	100.963940801494	R89Repeated
2	Polyline	2	R-H.V Un.Cable	170	ACAD_ISO0	50.8465700252738	R87
3	Polyline	3	R-H.V Un.Cable	170	ACAD_ISO0	1281.96692348494	
4	Polyline	4	R-H.V Un.Cable	170	ACAD_ISO0	36.4123607330743	R50
7	Polyline	7	R-H.V Un.Cable	170	ACAD_ISO0	157.511707471389	RURepeated
8	Polyline	8	R-H.V Un.Cable	170	ACAD_ISO0	276.517756401869	R183
10	Polyline	10	R-H.V Un.Cable	170	ACAD_ISO0	168.241952720753	R183A01
13	Polyline	13	R-H.V Un.Cable	170	ACAD_ISO0	334.872212864183	R428
18	Polyline	18	R-H.V Un.Cable	170	ACAD_ISO0	209.060937913063	RM693

Figure 4.30: Using the "statistics" tool to calculate the length of the underground MV network

- ***Map Printing:*** ArcGIS offers an interesting environment for maps preparation before printing. This environment is available to every ArcMap project when it's displayed in **"*Layout window*"**. In this environment, user can format the map with various tools including addition of titles, legend, north arrows, scale bar and pictures with beautiful coloring properties. Also one can add charts and graphs to maps. These formatting capabilities are clearly displayed in the Figures 4.31 - 4.33.

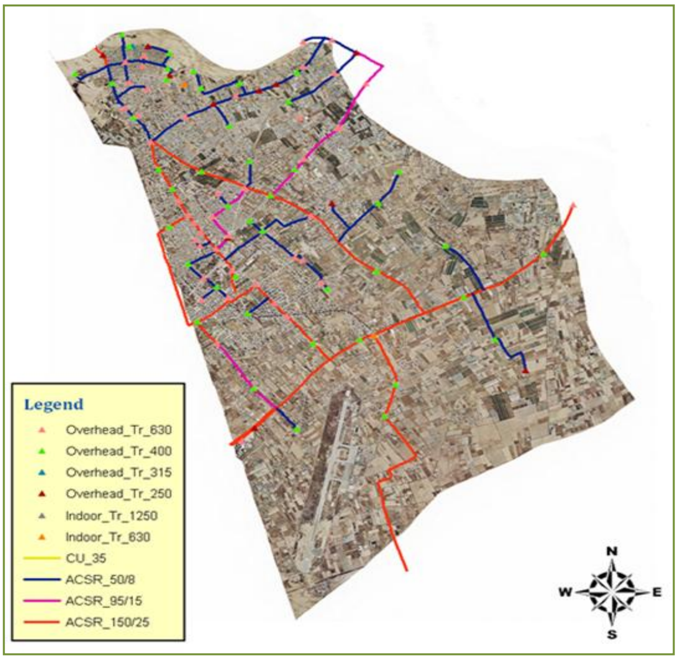


Figure 4.31: Map printing model 1

Figure 4.31 shows the MV grid on the aerial background with the installed overhead transformers and overhead conductors. Another example is shown in Figure 4.32 where the MV grid is displayed on the aerial background with the existing different poles.

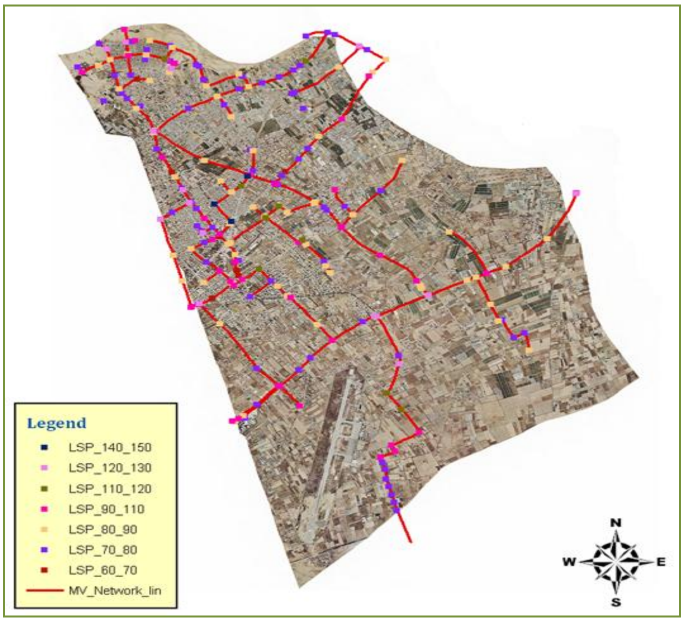


Figure 4.32: Map printing model 2

Figure 4.33 where the MV grid is displayed with the overhead transformers and their classification graph.

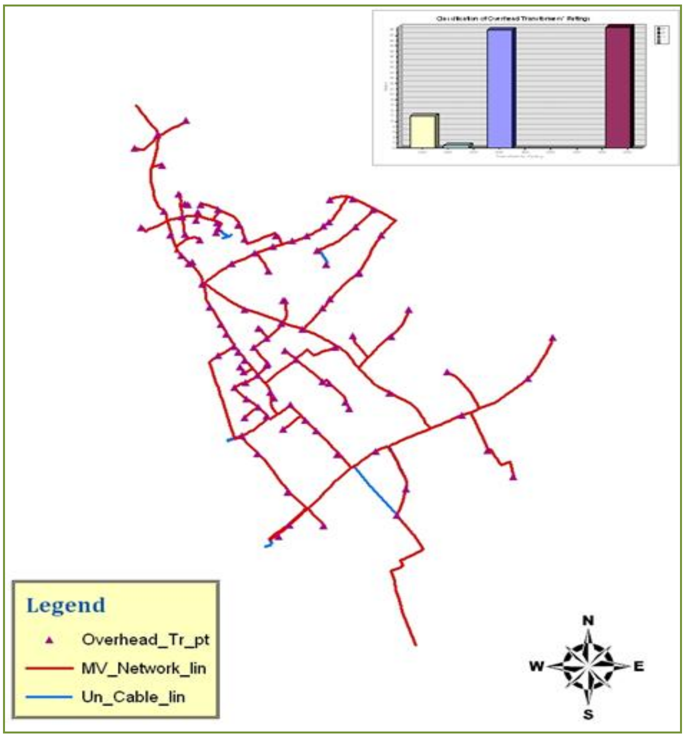


Figure 4.33: Map printing model 3

Map printing is considered a very useful function to engineers and technician workers when doing their maintenance works as discussed in section 4.3.4.

Case 2: 3D Visualization

ArcGIS has the ability to present the layers in 3D for more realistic views. We can see the 3D view of the concrete poles layer in Figure 4.34.

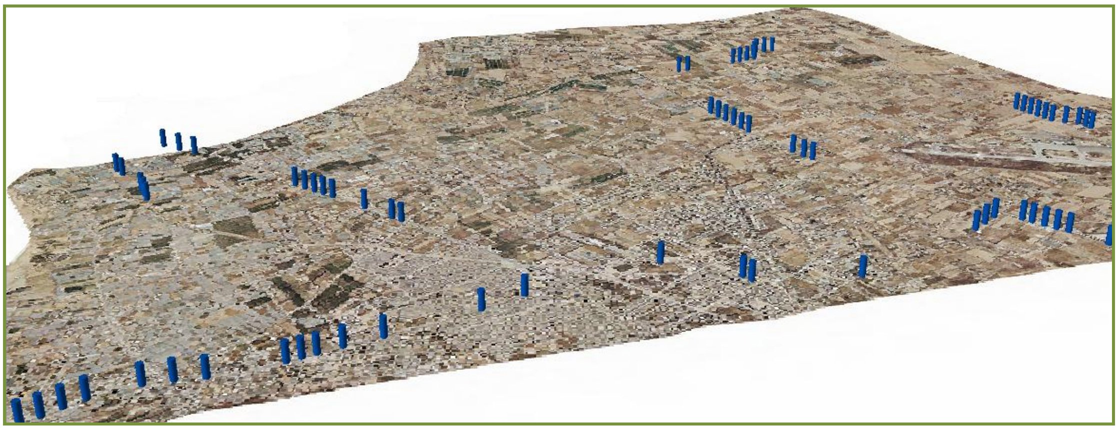


Figure 4.34: The 3D visualization in ArcScene

Case 3: ArcGIS-Google Earth Integration

ArcGIS desktop applications and the geodatabase can be used to define, manage, and create Keyhole Markup Language (KML) content that's used for defining the display of the spatial data in the Google Earth program. Figure 4.35 displays the streets layer exported from ArcGIS to Google Earth.

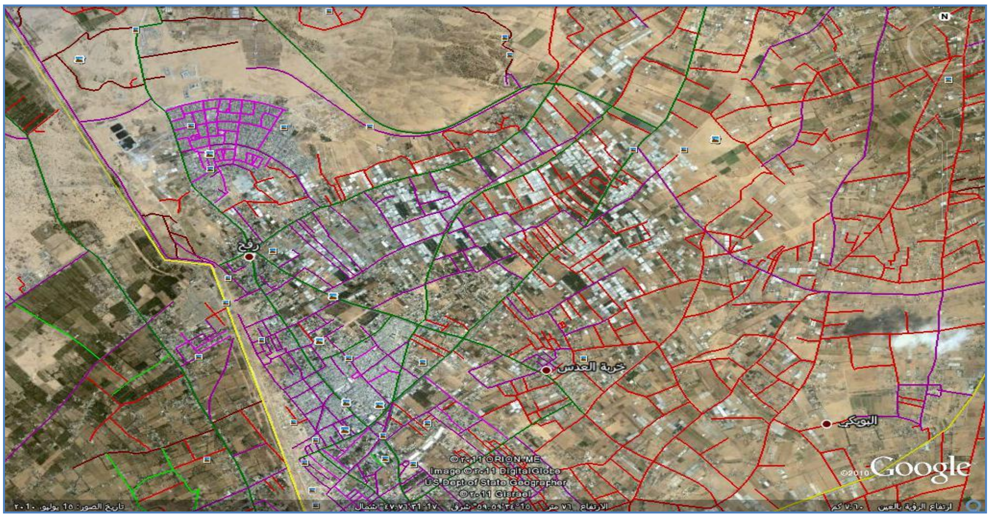


Figure 4.35: The streets layer exported to Google-Earth

Exporting data from ArcGIS to Google Earth involves exporting all the associated data stored in attribute tables of these layers. Thus user can use the identify tool in the Google Earth program to display the information associated with the identified element as shown in Figure 5.36 in which the Egyptian switch room layer appears with its data.

Figure 4.36: Attribute data exported to Google-Earth

Case 4: Network Analyst Tool

Network analysis is a special type of line analysis involving a set of interconnected lines. Typical networks include themes such as roads and pipelines. ArcGIS has a special extension toolbox to perform network analysis functions. It allows you to build a network dataset and perform analyses on it. Its functions can be defined by the following functions:

● ***Optimal Routing:*** it is the process of delineating the best route to get from one location to one or more locations. The "best route" could be the shortest, the quickest, or the most esthetic.

● ***Finding Closest Facilities:*** this is a special type of optimal routing problem where you are trying to find the closest points to a given location. Typically the points are called *facilities* and the given location is called an *event* location [46].

● ***Vehicles Routing Problem:*** various organizations use a fleet of vehicles to serve a set of orders. Each organization needs to determine which orders (homes, restaurants, or inspection sites) should be served by each route (truck or inspector) and in what sequence the orders should be visited [47].

The network analyst toolbox is used to solve the shortest path problem. This leads to better economic savings. The steps performed for establishing a network dataset are as follow:

1. Use ArcCatalog to create and build a network dataset from the streets feature class stored within a geodatabase. After establishing the network dataset of the streets shape-file, 'Streets_ND', is added to ArcCatalog along with the system junctions shape-file 'Streets_ND_Junctions'. Figure 4.37 shows the components of the network dataset.

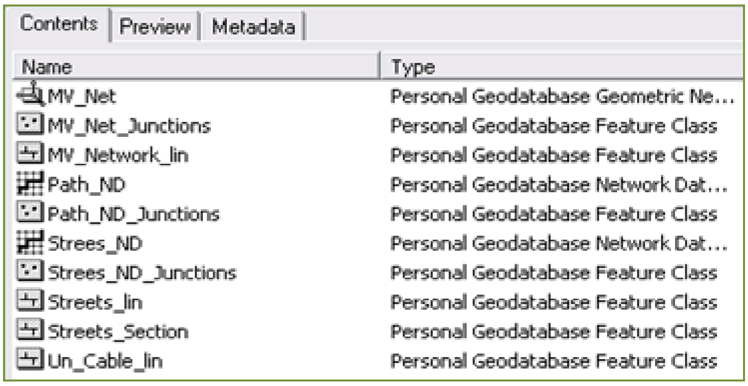


Figure 4.37: Creation of the "Streets_ND" network dataset in ArcCatalog

2. Define connectivity rules and network attributes for the network dataset. Network Connectivity defines how features that participate in a network connect to each other. The default connectivity for a network dataset places all sources in one connectivity group and assigns all edge sources endpoint connectivity.
3. Perform various network analyses in ArcMap using the Network Analyst toolbar which is shown in Figure 4.38.

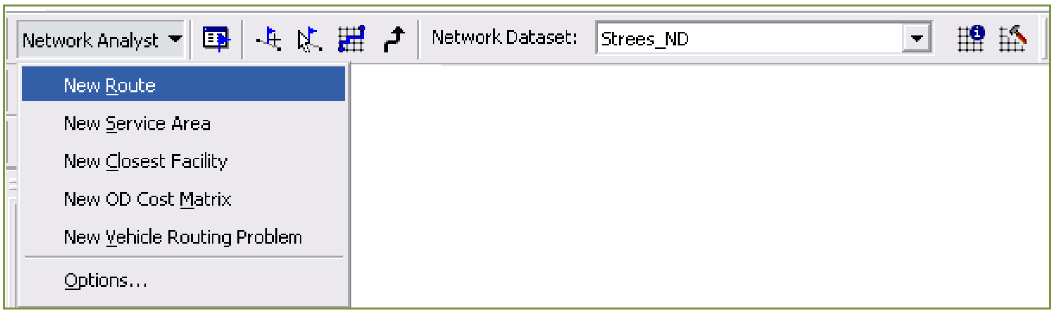


Figure 4.38: Network Analyst Toolbox in ArcMap

The functions of each component of the toolbox are shown in Table 4.6.

Table 4.6: Network Analyst toolbar buttons and their functions

Button	Name	Function
	Network Analyst Window	Shows/Hides the Network Analyst Window
	Create Network Location Tool	Creates a network location
	Select/Move Network Location Tool	Selects and moves network locations
	Solve	Runs the current analysis
	Directions Window	Displays the Directions window
	Network Identify	Identifies network elements
	Build entire network dataset	Builds a network dataset for the full extent

Now, suppose that we have a customer in a specific place and we want to provide him with the electricity service. The optimal solution of this problem must satisfy two conditions; the first is to choose the shortest path from the transformer point to the customer, the second is that the chosen transformer must have enough capacity. This problem can be solved using the network analyst extension toolbox in ArcGIS. An example of such problem is shown in Figure 4.39. The red circles in the figure represent the available distribution transformers in that area superimposed on a portion of the streets layer. The customer place is identified by label 1 while the transformer node is labeled 2. Assuming that all transformers in that area have enough capacity, then the optimal solution is tested for the shortest path condition which is seen in blue color.

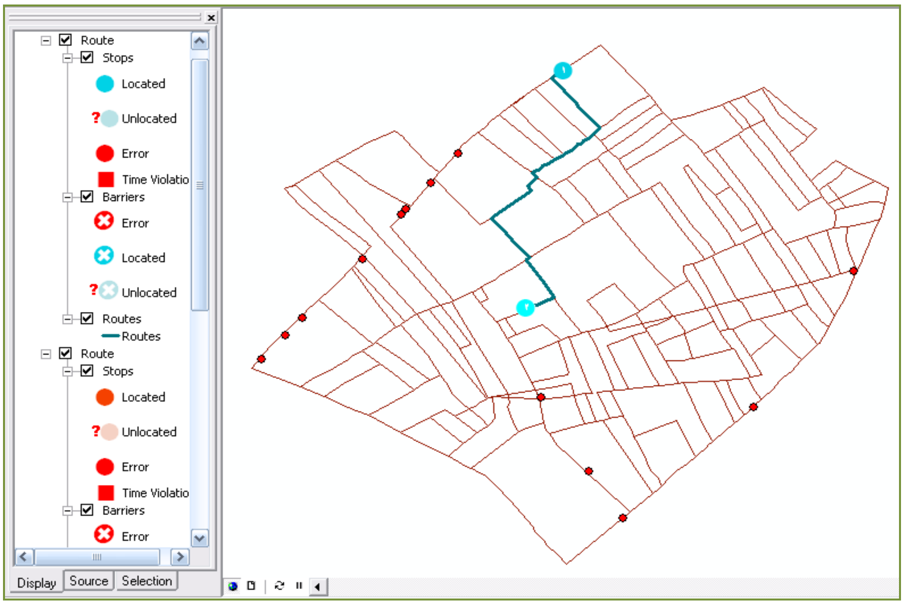


Figure 4.39: The shortest path solution

Since the solution may be tested for other constraints other than the shortest distance like voltage drop or even population density in the area. Then we have find alternative solutions and this can be obtained easily by the network analyst tool box by placing a barrier through the path of the first solution. Next run the ***'solve'*** command of the network analyst tool for the second time to find an alternative solution which is presented in Figure 4.40.

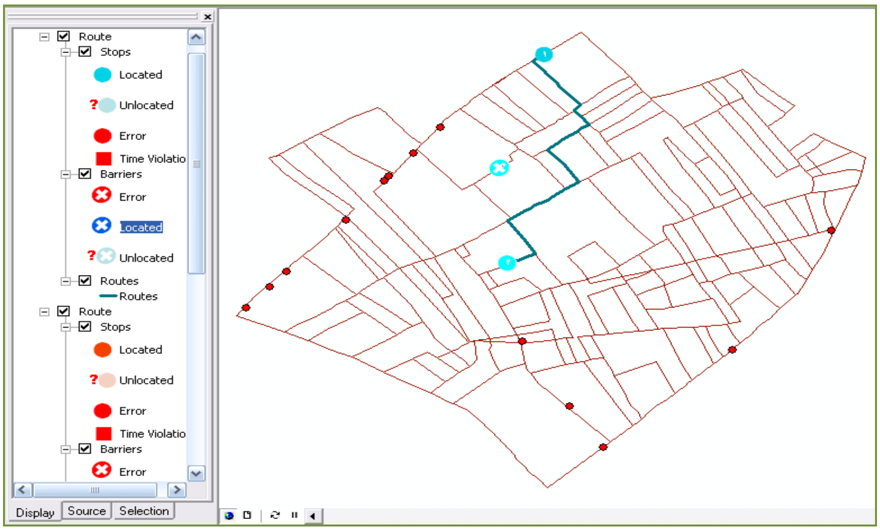


Figure 4.40: The alternative path solution

The length of the solved route can be calculated and displayed as shown in Figure 4.41.

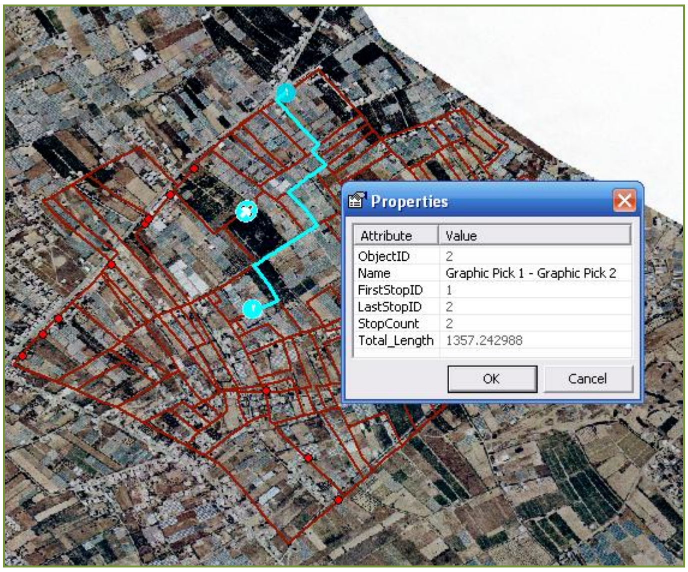


Figure 4.41: The calculated length of the solved route

The network analyst toolbox can be used for finding closest facilities and vehicles routing problems in directing maintenance technicians groups. The efficiency is clearly felt in developed distribution networks.

Case 5: Customer Indexing

Consumer Indexing (CI) is a method for enumerating the total number of consumers in a utility and tagging them to their respective poles, transformers, and feeders. So by this method, the exact location of a consumer and its supplying source can be determined [48]. In Consumer Indexing with the help of GIS and GPS technology, a simple model has been created to represent this important application. The study model was chosen from Gaza town with the help of Gaza municipality. A great project of CI was carried out by Gaza municipality. In this project all houses and streets and water network in Gaza were indexed using GIS and GPS technology. This project takes nearly ten years of hard and continuous work including data collection, data entry and building a complete computerized system to save the collected data and connecting it to many other subsystems such as billing subsystem. Since this system in carried out only in Gaza town, then I choose a work sample from Gaza. This system helps me to get a real data to work on it sine it's georeferenced by GPS technology. The study model was carried out for a small area restricted to only one transformer consumers of the Sea Feeder. It includes 30 houses exist in Kamal Nasser Street numbered 8390 in west Gaza. The consumer database was entered to ArcGIS software, which is used for identification of every consumer location in the selected model. This database is then connected to their bills in GEDCO. Thus additional information required about any of those customers is easily found by their bills' numbers. The database includes every consumer coordinates, consumer name and its address, feeder name, and transformer name. For more professional work, this database can be designed to include more details and then connected to different departments in GEDCO such as and billing and customer information department and maintenance branches. The main purpose of this database is that whenever a fault occurs, then with the help of this database, maintenance technicians of GEDCO can easily find out the faulted segment of the feeder, transformer number, and pole number, through which it is connected. Then the fault source can be exactly determined and handled.

A portion of the customer database is shown in Table 4.7.

Table 4.7: Customer database

Customer Name	Building Number	Municipality Bill Number	Electric Bill Number	Transformer Name
حسن العبد ابراهيم الشيخ احمد	18	29658	10129658	Darabaih
عزيزة يونس احمد مسلم	2	36924, 45061	10136924	Darabaih
فارس فوزي غزال الغزالي	22	36158	10136158	Darabaih
حسن اسماعيل حسن ياسين	24	24562	10124562	Darabaih
نبيل عبد الرحمن جبريل درابيه	25	24849	10224849	Darabaih
بركة ديب محمد عوض	27	24846	10124846	Darabaih
رياض محمود خليل أبو العيس	31	24844	10124844	Darabaih
شحدة حسين درويش النجار	32	24553	10224553, 10124553	Darabaih
إبراهيم محمد أحمد السموني	33	24843	10124843	Darabaih
عامر كمال محمد الزايغ	37	24837, 24838	10224837, 10124838	Darabaih
سمارة محمود حسن البياري	39	24836, 50196	10124836	Darabaih
معين أحمد محمد مراد	4	50340	10153183	Darabaih
حمدي سعيد حامد مدوخ	41	24835, 61886	10124835	Darabaih

The houses of the sample consumers have been digitized and displayed as a separate layer named 'BUILDINGS' as shown in Figure 4.42.

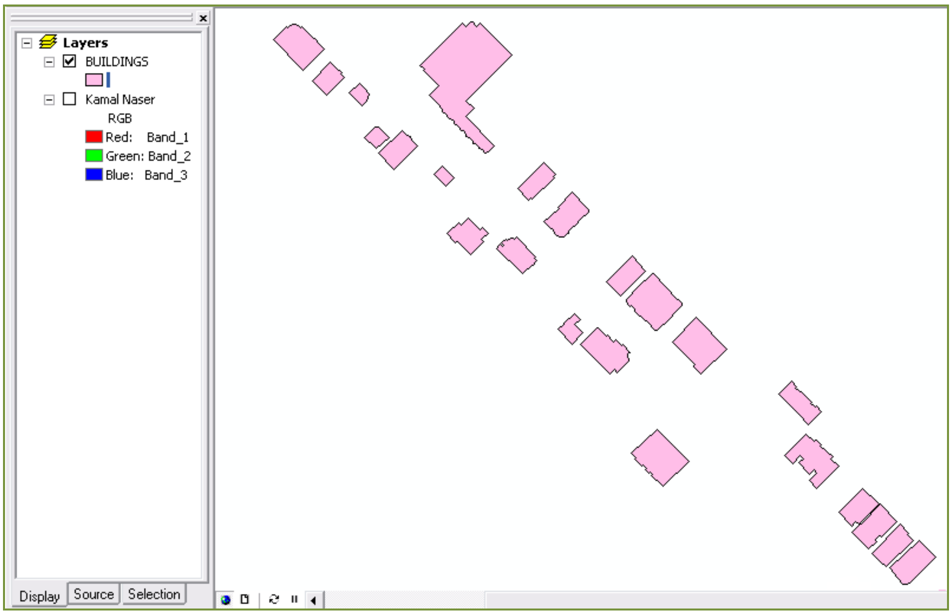


Figure 4.42: Digitized image of customer houses

The data mentioned in table 4.7 was joined with the attribute table of the 'BUILDINGS' layer. Then we can query about any customer by its electric bill number. Also clicking on any consumer's house, then the stored information will be highlighted. One sample result is given in the Figure 4.43.

Figure 4.43: Sample result of customer query

Case 6: Exporting Power-Flow Results to ArcGIS

In the previous chapter, the 22-kV network of Rafah was analyzed using ETAP program. Since this program can export load-flow results to different formats including excel sheets, then they can be imported by ArcGIS geodatabase. Thus we can display load-flow results on an ArcGIS map and use ArcGIS to perform another analysis issues on the results for more understanding.

- ***Data visualization*:** the visualization of load-flow data is done using "***Labeling***" function. This function can be used to visualize node ID, node voltage, MW flow, Mvar flow, MW loss and Mvar loss values in different colors and sizes. All these data accompany its geographic objects; nodes or lines. Figure 4.44 represents such type of visualization which is performed for a portion of the Egyptian Feeder No.1.

It shows the transformers rating data in different colors for each distinct value, amperes flow in each junction in different sized symbols and voltage drop in each branch with a unique color for each class of values.

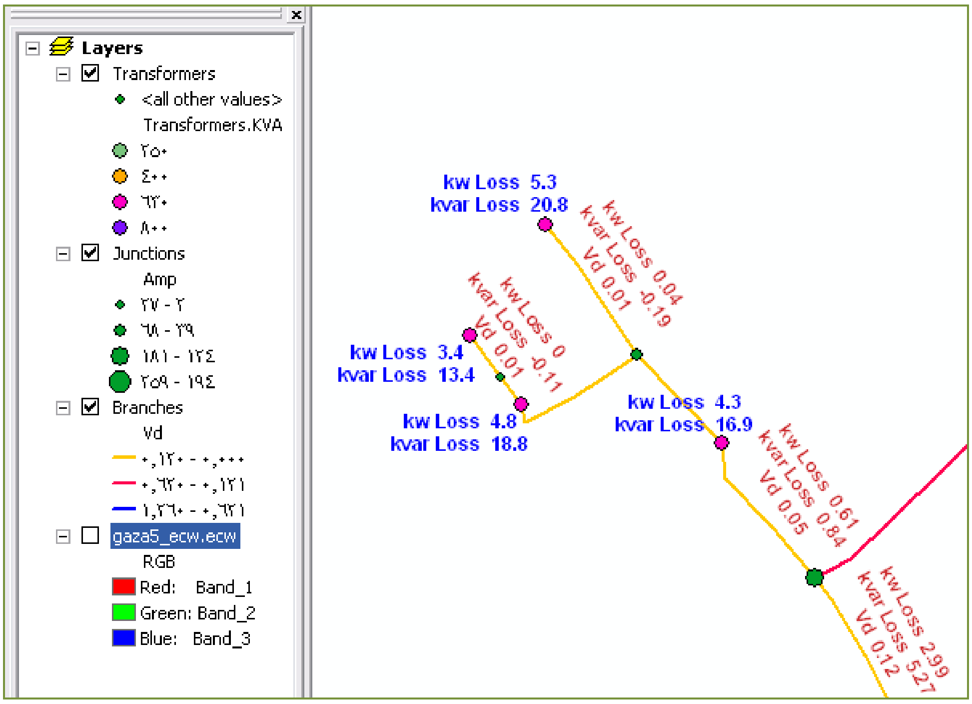


Figure 4.44: Load-flow results displayed on ArcGIS map

- ***Histogram analysis*:** The Exploratory Spatial Data Analysis (ESDA) environment allows you to graphically investigate your dataset to gain a better understanding of it. Each ESDA tool provides a different view of the data and is displayed in a separate window. The Histogram tool is an important tool which provides a one-variable description of your data. It displays the frequency distribution for the dataset of interest and calculates summary statistics. The frequency distribution is a bar shaped graph that displays how often observed values fall within certain intervals or classes [49]. We can specify the number of classes of equal width that should be used in the histogram. The relative proportion of data that falls in each class is represented by the height of each bar. With the histogram tool, we can examine the shape of the distribution by direct eye observation. Clicking on any bar of the histogram figure, then the features with values fall in the range specified by that bar will highlight. In Figure 4.45 we can see the frequency distribution of the voltage magnitude at some nodes of the Egyptian Feeder No. 1. Also on the same figure we can see the power factor distribution in degraded colors on its background. This effect is performed by using Inverse Distance Weighted (IDW) analysis. IDW is a method of interpolation that estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The closer point to the center of the cell being estimated, the more influence, or weight, it has in the averaging process. Thus, IDW assumes that each measured point has a local influence that diminishes with distance. It weights the points closer to the prediction location greater than those farther away, hence the name is inverse distance weighted [50].

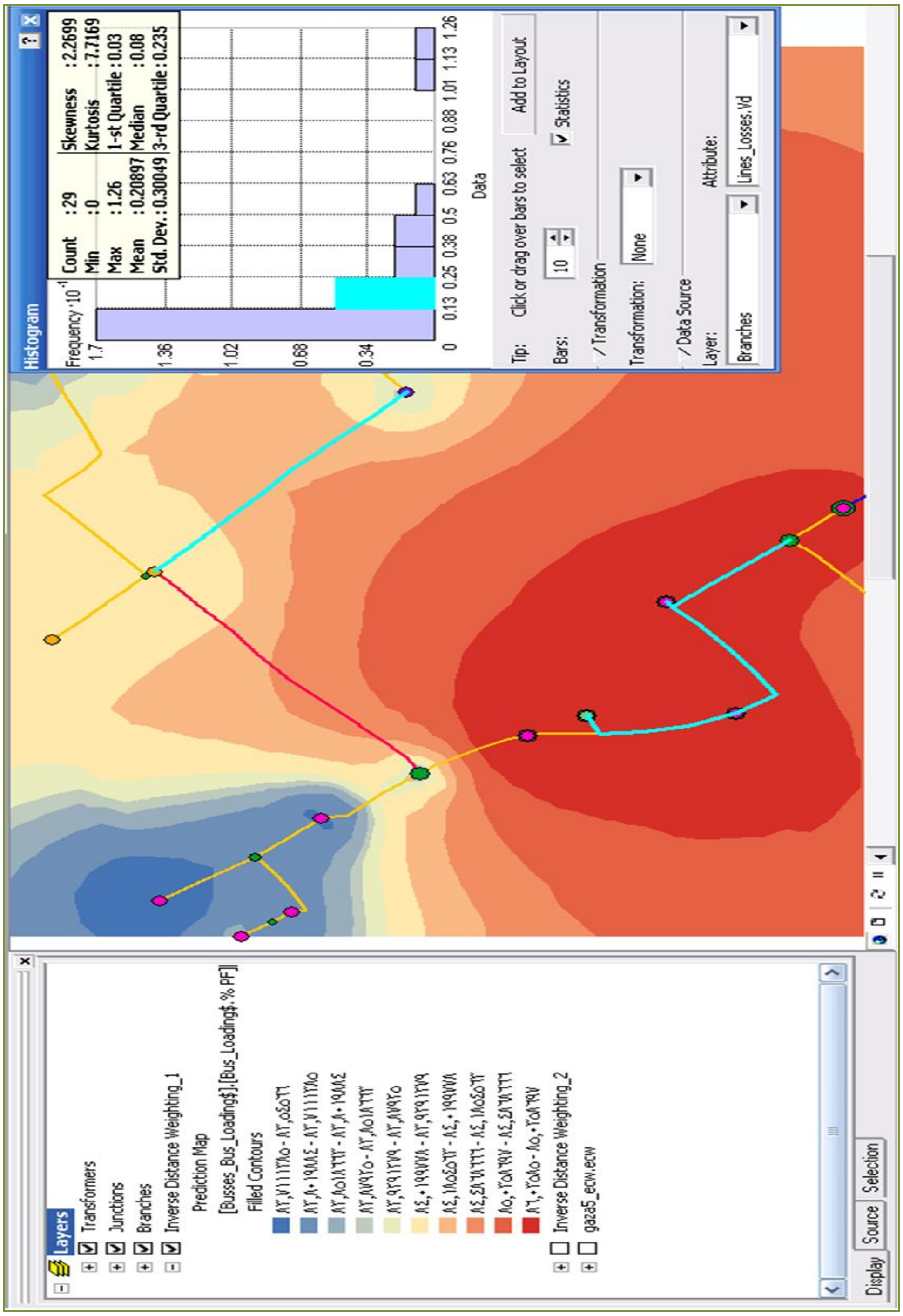


Figure 4.45: Histogram analysis of Egyptian Feeder No. 1

4.6 Summary

This chapter presents the definition of the GIS system and its various applications of to an electric distribution system. It illustrates in details the followed steps in constructing the GIS model of the electric distribution grid in Rafah governorate by using ArcGIS 9.3 software. Then the constructed model is analyzed and exploited in a number of applications in the field of electricity distribution. These applications include: data query, 3D visualization of maps, integration between GIS and Google-Earth, histogram analysis. Finally a combination between ArcGIS software and ETAP software is presented in which the power flow results obtained by simulation is exported to ArcGIS and displayed on Rafah's GIS map.

CHAPTER 5

CONCLUSIONS

Rafah governorate receives 26 MW amount of electric power from four feeders at 22-kV. Their one-line diagrams are drawn and their parameters are entered to ETAP software. Then they're exploited in different simulation and analytical processes to evaluate the performance of the grid. For each process the program produces detailed information of the system losses, line power flows, and voltage level at every node or bus. Running balanced load-flow module for various processes for each feeder, the 22-kV grid is completely evaluated.

It has been found that the there is a high deficit in the power supply which reaches 38.7% at summer peak loading. Also the grid suffers from imbalance loading conditions in the LV networks. The line current unbalance is about 7.4% in average to all feeders. Moreover, the percentage voltage drop obtained by feeders and lines power flow solution falls below 90% of the nominal value in the first one-third of the feeders' length except the second Egyptian feeder. The voltage profile is enhanced by three techniques: raising the sending end voltage, changing the tap settings of the distribution transformers, and installation of capacitor banks. The resulted average energy losses obtained through simulation are used in their cost estimation which equals 3.3 million NIS for MWH and 5 million NIS for MVAR. It's observable that the percentage of reactive power loss is approximately about 1.6 times more than the active power loss and this is due to the nature of the lines which normally have the value of X/R larger than unity and these losses are reduced using capacitor banks. In addition, the existing gird has a poor lagging power factor in all 22-kV feeders which stays in the range {81 – 84%}. The first Egyptian feeder is tested for capacitor placement technique.

ArcGIS 9.3 software package is used in this thesis to construct a GIS model of Rafah distribution grid. It's used to store a database of the network elements mapped to their coordinates. The database is then ready for query and reporting functions. GIS layers are displayed into two and three-dimensional views and they're exported to Google

Earth. The network analyst toolbox is used in optimal routing of the distribution feeders by choosing the shortest path between a transformer and new customer. Customer indexing application is implemented for a small area restricted to customers of only one transformer in Kamal Nasser Street. Moreover, the simulation power flow results are exported to ArcGIS and displayed on a Rafah digital map allowing analyzing the data using contour and histogram tools. The research results produce a simple DMS that can be applied to other governorates and it can be developed to higher functionality. In order to extend thesis work to other governorates with additional reliability, it's recommended to follow the summarized steps:

- Using ETAP software in the evaluation and analysis of the distribution network in Gaza Strip and using the power station version of the program for the management of the proposed substations.
- Studying the unbalanced three phase load flow of the distribution network. This requires a full description of the connected loads and their demand in all loading circumstances for all seasons. Unbalanced power flow results in more accurate outcomes and thus more accurate planning.
- Using optimal power flow and optimal capacitor placement modules in research and development studies carried for network development.
- Applying the GIS capabilities on the electric distribution system for the rest governorates in Gaza Strip.
- Integrating GIS with SCADA System.

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Appendix – A

Specifications of Overhead Lines

Table A.1: Aluminum Conductor Steel Reinforced (ACSR)

German Sizes – Standard DIN 48 204 – APR 1984

Area					Stranding & Wire Diameter		Overall Diameter	Weight			Breaking Load	DC Resistance at 20° C	Current Rating
Nominal													
Aluminium	Steel	Aluminium	Steel	Total	Aluminium	Steel		Aluminium	Steel	Total			
mm²	mm²	mm²	mm²	mm²	mm	mm	mm	kg/km	kg/km	kg/km	kN	ohm/km	A
16	2.5	15.27	2.54	17.8	6/1.80	1/1.80	5.4	42	20	62	5.81	1.8793	105
25	4	23.86	3.98	27.8	6/2.25	1/2.25	6.8	65	32	97	9.02	1.2028	140
35	6	34.35	5.73	40.1	6/2.70	1/2.70	8.1	94	46	140	12.70	0.8353	170
44	32	43.98	31.67	75.7	14/2.00	7/2.40	11.2	122	250	373	45.46	0.6573	
50	8	48.25	8.04	56.3	6/3.20	1/3.20	9.6	132	64	196	17.18	0.5946	210
50	30	51.17	29.85	81.0	12/2.33	7/2.33	11.7	141	237	378	44.28	0.5644	
70	12	69.89	11.40	81.3	26/1.85	7/1.44	11.7	193	91	284	26.31	0.4130	290
95	15	94.39	15.33	109.7	26/2.15	7/1.67	13.6	260	123	383	35.17	0.3058	350
95	55	96.51	56.30	152.8	12/3.20	7/3.20	16.0	266	466	714	80.20	0.2992	
105	75	105.67	75.55	181.2	14/3.10	19/2.25	17.5	292	599	899	106.69	0.2736	
120	20	121.57	19.85	141.4	26/2.44	7/1.90	15.5	336	158	494	44.94	0.2374	410
120	70	122.15	71.25	193.4	12/3.60	7/3.60	18.0	337	564	904	98.16	0.2364	
125	30	127.92	29.85	157.8	30/2.33	7/2.33	16.3	353	238	590	57.86	0.2259	425
150	25	148.86	24.25	173.1	26/2.70	7/2.10	17.1	411	194	604	54.37	0.1939	470
170	40	171.77	40.08	211.9	30/2.70	7/2.70	18.9	475	319	794	77.01	0.1682	520
185	30	183.78	29.85	213.6	26/3.00	7/2.33	19.0	507	239	744	66.28	0.1571	535
210	35	209.06	34.09	243.2	26/3.20	7/2.49	20.3	577	273	848	74.94	0.1380	590
210	50	212.06	49.48	261.5	30/3.00	7/3.00	21.0	587	394	979	92.25	0.1363	610
230	30	230.91	29.85	260.8	24/3.50	7/2.33	21.0	638	239	874	73.09	0.1249	630
240	40	243.05	39.49	282.5	26/3.45	7/2.68	21.8	671	316	985	86.46	0.1188	645
265	35	263.76	34.09	297.8	24/3.74	7/2.49	22.4	728	274	998	82.94	0.1094	680
300	50	304.26	49.48	353.7	26/3.86	7/3.00	24.5	840	396	1233	105.09	0.0949	740
305	40	304.62	39.49	344.1	54/2.68	7/2.68	24.1	843	317	1155	99.30	0.0949	740
340	30	339.29	29.85	369.1	48/3.00	7/2.33	25.0	983	242	1174	92.56	0.0851	790
380	50	381.70	49.48	431.2	54/3.00	7/3.00	27.0	1056	397	1448	120.91	0.0757	840
385	35	386.04	34.09	420.1	48/3.20	7/2.49	26.7	1067	277	1336	104.31	0.0748	850
435	55	434.29	56.3	490.6	54/3.20	7/3.20	28.8	1203	450	1647	136.27	0.0666	900
450	40	448.71	39.49	488.2	48/3.45	7/2.68	28.7	1233	320	1553	120.19	0.0644	920
490	65	490.28	63.55	553.8	54/3.40	7/3.40	30.6	1356	510	1860	152.85	0.0590	960
550	70	549.65	71.25	620.9	54/3.60	7/3.60	32.4	1520	572	2085	167.42	0.0526	1020
560	50	561.70	49.48	611.2	48/3.86	7/3.00	32.2	1553	401	1943	146.28	0.0514	1040
680	85	678.58	85.95	764.5	54/4.00	19/2.40	36.0	1868	702	2564	209.99	0.0426	1150

Table A.2: Bare Copper Conductor (Hard Drawn).

Nominal Sectional Area	Number & Diameter of Wire	Overall Diameter	Maximum Conductor Resistance @ 20°C	Breaking Strength	Allowable Ampacities in Free Air	Cable Weight (approx)
mm²	No. / mm	mm	Ω / km	kgf	A	kg / km
10	7/1.35	4.05	1.8054	438	90	90
16	7/1.70	5.10	1.1385	694	125	143
25	7/2.14	6.42	0.7185	1,076	160	227
35	7/2.52	7.56	0.5181	1,459	200	314
50	7/3.02	9.06	0.3589	2,095	250	452
50	19/1.78	8.90	0.3825	2,021	250	428
70	19/2.14	10.70	0.2646	2,921	310	618
95	19/2.52	12.60	0.1918	3,961	380	858
120	19/2.85	14.25	0.1492	5,067	440	1,097
150	37/2.25	15.75	0.1238	6,289	510	1,334
185	37/2.52	17.64	0.0981	7,713	585	1,673
240	61/2.25	20.25	0.0752	10,369	700	2,200
300	61/2.52	22.68	0.0600	12,717	800	2,760
400	61/2.85	25.65	0.0469	16,266	900	3,350
500	61/3.20	28.80	0.0370	20,506	1,110	4,451

Appendix – B

Transformers' Loading Data

Summer 2010 Measurements

Table B.1: Transformers of Egyptian Feeder No.1

Transformer Name	Rating (KVA)	Load (KVA)	%Load
Almabaar 1	630	315	50%
Almabaar 2	250	125	50%
Almabaar 3	630	252	40%
Al Shoka Al Janobi	630	472.5	75%
George	630	472.5	75%
Al Kurd	630	630	100%
Abu Nahla	630	504	80%
Al Falogi	400	280	70%
Almaslakh	630	567	90%
Dair Yaseen	630	441	70%
Alsaati	630	567	90%
Alsentral	630	441	70%
Aldakhlyea	630	378	60%
Almohafaza	250	150	60%
Al Shaheed 1	400	300	75%
Al Shaheed 2	400	360	90%
Tabas	800	560	70%
Aljnenah Pump	630	504	80%
Abu Youssef Alnajjar 1	630	472.5	75%
Abu Youssef Alnajjar 2	400	80	20%
Almahmom	630	378	60%
Dowar Alawda	630	567	90%
Al Balawi	630	598.5	95%
Abu Hashem	630	535.5	85%
Almatafi	630	630	100%
Alkhazan	630	504	80%
Keer	630	567	90%

Table B.2: Transformers of Egyptian Feeder No.2

Transformer Name	Rating (KVA)	Load (KVA)	%Load
Algas	400	320	80%
Aljamaai	630	630	100%
Aljawazat	630	693	110%
Suq Alhalal	400	320	80%
Bahlol	630	504	80%
Fathi 1	400	380	95%
Fathi 2	630		Unused
Almasri	630	535.5	85%
Islamic Bank	400	320	80%
School A	630	598.5	95%
Berka	630	630	100%
Aldokhny	630	472.5	75%
Noqerah Abu	630	535.5	85%
Salem Waterwell 1	630		Unused
Salem Waterwell 2	630		Unused
Shaikh Aleed	630	535.5	85%
Alqassas	630	441	70%
Alsiamat Waterwell	400	120	30%
Almohandseen	400	120	30%
Alsawadah	400	260	65%

Table B.3: Transformers of Egyptian Feeder No.3

Transformer Name	Rating (KVA)	Load (KVA)	%Load
Alsalam Alsharqi	630	441	70%
Alsalam Algharbi	800	640	80%
Alabed Jaber	630	567	90%
Khawla	630	598.5	95%
Altahleya Alkuwaiti	250		Unused
Alemam Ali Mosque	630	567	90%
Alkateba	630	504	80%
Dowar Zurob	630	630	100%
Mohammed Atwa	400	440	110%
Abu Diaa	250	125	50%

Mohammed Atwa Pump	630	126	20%
Ber 124	400	300	75%
Alaksada	400	440	110%
Sewerage Pump	400	400	100%
Abu Alsaeed	400	460	115%
Aliskan Alqadeem	400	380	95%
Ber Aliskan	630	504	80%
UNRWA Ber	630	630	100%
Abu Asaker	800	640	80%
Alsakka	630	441	70%
Jaser	630	535.5	85%
Alandalos	630	630	100%
Abu Ataya	250	200	80%
TR1	250		Unused
W1	160	48	30%
W2	250	125	50%
Almawasi Alqadeem	630	567	90%
Almawasi Albahar	250	250	100%
Almawasi Alshamaly	400	360	90%
Almawasi Aljanobi	400	380	95%

Table B.4: Transformers of IEC Feeder.

Transformer Name	Rating (KVA)	Load (KVA)	%Load
Atyea	400	240	60%
Zalata	400	380	95%
Almashroa	630	535.5	85%
Alribat	400	300	75%
Alassar	630	409.5	65%
Ghassan Kanafani	400	240	60%
Sofa	400	280	70%
Tareq Abu Alhussein	400	220	55%
Alfaqasa	400		Unused
Aldamaki	630	535.5	85%
Aljawayea Almelaha	630	441	70%
Abu Ghali	400	300	75%

Hamza	630	535.5	85%
Dowar Alkherba	630	504	80%
Alzohor	400	280	70%
Alshatawi	630	472.5	75%
Almasrein	400	252	63%
Misabih	630	441	70%
Abu Madi	250	187.5	75%
Mazyed	400	264	66%
Morag	630	504	80%
Abu Taha	630	630	100%
Abed Alaal	400	320	80%
Abar Alshoka	630	472.5	75%
Alnaser 1	630	189	30%
Alnaser 2	400	200	50%
Alfokhri	400	240	60%
Khaled Alshaer	630	504	80%
Islamic Institute	250	75	30%
Hajaj	630	441	70%
Alkholod 1	630	378	60%
Alkholod 2	400	260	65%
Isa Zurob	630	567	90%
Alhashash	250	75	30%
Abu Zohri	250	75	30%
Barhom	250	125	50%
Alaytam	630	535.5	85%
Bader 1	630	567	90%
Bader 2	400	300	75%
Bader 3	630	378	60%
Bader 4	1250	812.5	65%
Bader 5			Unused
East Canada	630	535.5	85%
West Canada	630	504	80%
Dihleez	400	260	65%
Alqadesyya	630	315	50%
Aliskan Algadeed		0	
Almasri	400	400	100%

Winter 2012 Measurements

Table B.5: Transformers of Egyptian Feeder No.1

Transformer Name	S_{Rating} (KVA)	I_{Rating} (A)	R (A)	S (A)	T (A)	Average (A)	S_{Load} (KVA)	%Loading
Almabaar 1	630	909.35	300	300	300	300.00	208	32.99%
Almabaar 2	630	909.35	350	350	350	350.00	242	38.49%
Almabaar 3	100	144.34	40	40	45	41.67	29	28.87%
Al Shoka Al Janobi	630	909.35	830	820	750	800.00	554	87.97%
George	800	1154.73	610	620	600	610.00	423	52.83%
Al Kurd	800	1154.73	950	1100	1150	1066.67	739	92.37%
Abu Nahla	630	909.35	675	650	580	635.00	440	69.83%
Almaslakh	800	1154.73	1150	1200	1100	1150.00	797	99.59%
Alsaati	800	1154.73	1050	1000	1050	1033.33	716	89.49%
Almohafaza	400	577.37	275	250	200	241.67	167	41.86%
Alsentral	630	909.35	260	240	250	250.00	173	27.49%
Abu Youssef Alnajjar 1	630	909.35	640	700	650	663.33	460	72.95%
Abu Youssef Alnajjar 2	400	577.37	150	150	150	150.00	104	25.98%
Aljnenah Pump	630	909.35	570	550	600	573.33	397	63.05%
Tabas Al	800	1154.73	880	950	1050	960.00	665	83.14%
Shaheed 1 Al	630	909.35	710	600	660	656.67	455	72.21%
Shaheed 2 Al	630	909.35	700	750	700	716.67	497	78.81%
Dowar Alawda	630	909.35	850	700	750	766.67	531	84.31%
Al Balawi	630	909.35	850	750	800	800.00	554	87.97%
Abu Hashem	630	909.35	500	450	550	500.00	346	54.98%
Alkhazan	630	909.35	730	720	740	730.00	506	80.28%
Almatafi	630	909.35	950	850	1100	966.67	670	106.30%
Keer	630	909.35	850	800	650	766.67	531	84.31%
Aldakhlyea	630	909.35	380	400	450	410.00	284	45.09%
Al Huda Mosque	630	909.35	300	350	300	317	219.39	34.82%
Almahmom	630	909.35	490	650	550	563.33	390	61.95%
Dair Yaseen	630	909.35	650	650	620	640.00	443	70.38%
Al Falogi	630	909.35	650	620	600	623.33	432	68.55%

Table B.6: Transformers of Egyptian Feeder No.2

Transformer Name	S_{Rating} (KVA)	I_{Rating} (A)	R (A)	S (A)	T (A)	Average (A)	S_{Rating} (KVA)	%Loading
Algas	400	577.37	410	400	480	430	297.90	74.48%
Aljamaai	630	909.35	750	850	800	800	554.24	87.97%
Aljawazat	630	909.35	700	950	720	790	547.31	86.87%
Fathi 1	400	577.37	300	400	350	350	242.48	60.62%
Fathi 2	630	909.35	350	350	300	333	230.93	36.66%
Suq Alhalal	400	577.37	480	500	550	510	353.33	88.33%
Bahlol	630	909.35	450	380	400	410	284.05	45.09%
Almasri	630	909.35	580	620	600	600	415.68	65.98%
Islamic Bank	400	577.37	450	450	550	483	334.85	83.71%
School A	630	909.35	550	620	600	590	408.75	64.88%
Berka	800	1154.73	850	920	950	907	628.14	78.52%
Salem Waterwell 1	630	909.35	500	550	600	550	381.04	60.48%
Salem Waterwell 2	630	909.35	400	500	450	450	311.76	49.49%
Noqerah Abu	800	1154.73	750	800	950	833	577.33	72.17%
Aldokhny	630	909.35	720	900	700	773	535.77	85.04%
Aleed Shaikh	630	909.35	750	920	800	823	570.41	90.54%
Alqassas	630	909.35	350	500	400	417	288.67	45.82%
Alsiamat Waterwell	400	577.37	90	85	85	87	60.04	15.01%
Alsawadah	400	577.37	340	420	350	370	256.34	64.08%
Almohandseen	400	577.37	95	110	100	102	70.43	17.61%
Khaled Keshta	400	577.37	100	100	100	100	69.28	17.32%

Table B.7: Transformers of Egyptian Feeder No.3

Transformer Name	S_{Rating} (KVA)	I_{Rating} (A)	R (A)	S (A)	T (A)	Average (A)	S_{Load} (KVA)	%Loading
Alsalam Alsharqi	630	909.35	600	700	500	600	415.68	65.98%
Alsalam Algharbi	800	1154.73	970	950	900	940	651.23	81.40%
Alabed Jaber	630	909.35	690	550	600	613	424.92	67.45%
Khawla	630	909.35	850	920	950	907	628.14	99.70%
Altahleya Alkuwaiti	630	909.35	120	120	120	120	83.14	13.20%
Alemam Ali Mosque	630	909.35	550	600	700	617	427.23	67.81%
Alkateba	630	909.35	800	600	900	767	531.15	84.31%
Dowar Zurob	630	909.35	800	750	850	800	554.24	87.97%
Mohammed Atwa	400	577.37	400	400	450	417	288.67	72.17%
Mohammed Atwa Pump	400	577.37	150	185	140	158	109.69	27.42%
Ber 124	630	909.35	300	340	350	330	228.62	36.29%
Alaksada	400	577.37	800	700	750	750	519.60	129.90%
Alandalos	630	909.35	500	700	600	600	415.68	65.98%
Jaser	630	909.35	600	600	650	617	427.23	67.81%
Abu Asaker	800	1154.73	630	700	750	693	480.34	60.04%
Aliskan Alqadeem	630	909.35	570	540	500	537	371.80	59.02%
Aliskan Ber	630	909.35	380	450	400	410	284.05	45.09%
UNRWA Ber	630	909.35	370	350	350	357	247.10	39.22%
Sewerage Pump	400	577.37	250	250	250	250	173.20	43.30%
Alsaeed Abu	630	909.35	500	500	500	500	346.40	54.98%
Abu Ataya	250	360.85	250	250	250	250	125.00	50.00%
Almawasi Aljanobi	400	577.37	500	550	600	550	300.00	75.00%
Almawasi Alshamaly	400	577.37	450	410	400	420	200.00	50.00%
Almawasi Albahar	400	577.37	420	400	365	395	273.66	68.41%
Almawasi Alqadeem	630	909.35	530	500	500	510	472.50	75.00%
W1	160	230.95	75	75	70	73	50.81	31.75%
W2	250	360.85	150	150	160	153	106.23	42.49%
TR1	250	360.85	85	85	85	85	58.89	23.56%
Alsakka	630	909.35	650	550	500	567	392.59	62.32%
Abu Diaa	400	577.37	240	270	250	253	175.51	43.88%

Table B.8: Transformers of IEC Feeder.

Transformer Name	S_{Rating} (KVA)	I_{Rating} (A)	R (A)	S (A)	T (A)	Average (A)	S_{Rating} (KVA)	%Loading
Atyea	400	577.37	400	380	553	444.33	308	76.96%
Zalata	630	909.35	567	710	695	657.33	455	72.29%
Almashroa	630	909.35	750	780	730	753.33	522	82.84%
Alassar	630	909.35	609	550	500	553.00	383	60.81%
Abu Moammar 1	250	360.85	100	100	100	100.00	69	27.71%
Abu Moammar 2	250	360.85	350	350	350	350.00	242	96.99%
Tareq Abu Alhussein	400	577.37	425	345	390	386.67	268	66.97%
Almelaha Aljawayea	630	909.35	820	700	750	756.67	524	83.21%
Aldamaki	630	909.35	500	520	450	490.00	339	53.88%
Abed Almaksoud	400	577.37	450	470	500	473.33	328	81.98%
Almasri	400	577.37	650	750	685	695.00	481	120.37%
Alribat	400	577.37	380	400	410	396.67	275	68.70%
Hamza	630	909.35	720	750	700	723.33	501	79.54%
Dowar Alkherba	630	909.35	640	550	600	596.67	413	65.61%
Alzohor	400	577.37	580	400	450	476.67	330	82.56%
Alshatawi	630	909.35	460	410	350	406.67	282	44.72%
Abu Madi	160	230.95	160	160	160	160.00	111	69.28%
Misabih	630	909.35	660	600	650	636.67	441	70.01%
Morag	630	909.35	775	825	800	800.00	554	87.97%
Alnaser 1	630	909.35	275	260	260	265.00	184	29.14%
Alnaser 2	400	577.37	180	150	150	160.00	111	27.71%
Isa Zurob	630	909.35	750	820	800	790.00	547	86.87%
Hajaj	630	909.35	470	480	450	466.67	323	51.32%
Khaled Alshaer	630	909.35	540	550	500	530.00	367	58.28%
Alfokhri	630	909.35	200	200	200	200.00	139	21.99%
Abar Alshoka	630	909.35	866	870	850	862.00	597	94.79%
Islamic Institute	250	360.85	85	85	80	83.33	58	23.09%
Abu Hadaid	630	909.35	400	400	400	400.00	277	43.99%
Dehlez	400	577.37	250	220	200	223.33	155	38.68%
Abu Taha	400	577.37	460	540	500	500.00	346	86.60%
Alhashash	250	360.85	100	100	100	100.00	69	27.71%
Abu Zohri	250	360.85	100	100	100	100.00	69	27.71%
Barhoum	250	360.85	150	150	150	150.00	104	41.57%
Alkholod 1	630	909.35	515	480	450	481.67	334	52.97%
Alkholod 2	400	577.37	350	370	380	366.67	254	63.51%

Eastern Canada	630	909.35	750	720	650	706.67	490	77.71%
Western Canada	630	909.35	800	750	690	746.67	517	82.11%
Alaytam	630	909.35	750	715	660	708.33	491	77.89%
Bader 1	630	909.35	500	485	500	495.00	343	54.43%
Bader 2	630	909.35	660	600	550	603.33	418	66.35%
Bader 3	630	909.35	600	550	520	556.67	386	61.22%
Bader 4	1250	1804.27	350	355	330	345.00	239	19.12%
Bader 5	630	909.35	500	475	430	468.33	324	51.50%
Aliskan Aljaded	630	909.35	294	320	300	304.67	211	33.50%
TR2	400	577.37	60	60	60	60.00	42	10.39%
Alfaqasa	400	577.37	135	150	130	138.33	96	23.96%
Abu Ghali	400	577.37	530	550	500	526.67	365	91.22%
Ghassan Kanafani	630	909.35	300	290	330	306.67	212	33.72%
Alqadesyya	630	909.35	310	300	250	286.67	199	31.52%
Mazyed	630	909.35	475	440	400	438.33	304	48.20%
Almasrein	400	577.37	330	275	300	301.67	209	52.25%
Sofa	400	577.37	350	390	420	386.67	268	66.97%
Abed Alaal	400	577.37	380	410	420	403.33	279	69.86%
Abu Omar	630	909.35	740	720	730	730.00	506	80.28%

Appendix – C

ETAP Power Flow Results

Summer Results

Table C.1: Branch power flow results of the Egyptian feeder No.1

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	7.975	5.371	270.8	82.94	0.18	11.11	17.398
Line3	Line	7.692	5.18	261.7	82.94	0.31	17.81	27.863
Line4	Line	7.449	5.009	254.1	82.98	0.43	22.452	41.186
Line5	Line	0.33	0.214	11.19	83.91	0.04	0.151	-0.549
Line7	Line	1.729	1.117	60.71	83.99	0.24	4.929	1.8
Line8	Line	0.713	0.465	25.12	83.74	0.02	0.112	-0.107
Line9	Line	7.096	4.754	243	83.08	1.36	73.448	115
Line1	Line	6.702	4.432	232	83.41	0.64	33.201	51.76
Line1	Line	6.253	4.106	217.5	83.59	0.11	5.574	8.667
Line1	Line	5.532	3.625	192.8	83.64	0.1	4.302	6.651
Line1	Line	0.374	0.245	13.04	83.69	0.04	0.188	-0.45
Line1	Line	5.153	3.374	179.8	83.66	0.2	7.998	12.311
Line1	Line	4.773	3.118	166.8	83.72	0.2	7.491	11.471
Line1	Line	4.475	2.914	156.9	83.8	0.08	2.735	4.169
Line1	Line	4.183	2.723	146.8	83.81	0.13	4.206	6.372
Line1	Line	2.199	1.439	77.4	83.68	0.07	1.17	1.545
Line2	Line	1.831	1.197	64.49	83.7	0.04	0.588	0.707
Line2	Line	0.713	0.465	25.09	83.75	0.05	0.402	-0.109
Line2	Line	0.327	0.212	11.49	83.85	0.01	0.024	-0.075
Line2	Line	1.118	0.732	39.4	83.67	0.03	0.285	0.158
Line2	Line	1.979	1.277	69.37	84.02	0.12	2.903	1.147
Line2	Line	1.299	0.84	45.74	83.98	0.24	3.703	0.989
Line2	Line	0.937	0.604	33.04	84.06	0.04	0.445	0.026
Line2	Line	0.613	0.394	21.61	84.16	0.08	0.605	-0.316
Line2	Line	0.309	0.197	10.9	84.3	0.01	0.044	-0.156
Line2	Line	0.366	0.239	12.91	83.69	0.01	0.022	-0.176
Line3	Line	0.194	0.125	6.829	83.99	0.01	0.032	-0.315
Line3	Line	4.581	2.988	160.3	83.76	0.2	7.097	10.836
Line3	Line	5.952	3.907	207.3	83.6	0.13	5.785	8.977
Line3	Line	0.295	0.191	10.23	83.98	0.01	0.019	-0.275
Line3	Line	0.244	0.157	8.604	84.13	0.02	0.069	-0.408
Line4	Line	0	0	0.003	0	0	0	-0.097
T1	Transf.2W	0.225	0.144	7.553	84.27	1.32	1.288	5.099
T2	Transf.2W	0.182	0.116	6.092	84.41	1.07	0.838	3.317
T3	Transf.2W	0.09	0.057	3.005	84.32	1.41	0.646	1.995
T4	Transf.2W	0.33	0.214	11.19	83.91	1.97	2.827	11.195
T5	Transf.2W	0.321	0.208	11.03	83.91	1.94	2.747	10.877

T6	Transf.2W	0.417	0.274	14.5	83.55	2.55	4.746	18.793
T7	Transf.2W	0.295	0.191	10.23	83.98	1.8	2.362	9.353
T8	Transf.2W	0.414	0.273	14.46	83.55	2.55	4.72	18.693
T9	Transf.2W	0.374	0.245	13.04	83.69	2.3	3.84	15.207
T10	Transf.2W	0.373	0.244	13.02	83.69	2.29	3.827	15.153
T11	Transf.2W	0.185	0.119	6.439	84.05	1.89	1.854	5.728
T12	Transf.2W	0.099	0.063	3.452	84.19	1.62	0.853	2.634
T13	Transf.2W	0.289	0.187	10.13	83.98	1.78	2.315	9.169
T14	Transf.2W	0.367	0.24	12.92	83.69	2.27	3.769	14.927
T15	Transf.2W	0.247	0.159	8.666	84.13	1.52	1.695	6.712
T16	Transf.2W	0.386	0.253	13.6	83.62	2.39	4.176	16.536
T17	Transf.2W	0.327	0.212	11.49	83.84	2.02	2.981	11.805
T19	Transf.2W	0.405	0.266	14.29	83.55	2.52	4.611	18.261
T20	Transf.2W	0.347	0.226	12.22	83.76	2.15	3.368	13.338
T21	Transf.2W	0.366	0.239	12.91	83.69	2.27	3.761	14.893
T22	Transf.2W	0.358	0.235	12.71	83.62	2.04	2.495	14.445
T23	Transf.2W	0.323	0.21	11.43	83.84	2.01	2.95	11.68
T24	Transf.2W	0.303	0.197	10.73	83.91	1.88	2.598	10.287
T25	Transf.2W	0.066	0.041	2.302	84.66	0.67	0.237	0.732
T26	Transf.2W	0.244	0.157	8.604	84.13	1.51	1.671	6.618
T27	Transf.2W	0.231	0.151	8.159	83.79	2.39	2.976	9.196
T28	Transf.2W	0.194	0.125	6.829	83.99	2	2.085	6.442

Table C.2: Branch power flow results of the Egyptian feeder No.2

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line	Line	5.153	3.382	173.6	83.6	0.11	3.906	7.067
Line	Line	4.922	3.228	166	83.62	0.23	7.721	13.935
Line	Line	4.425	2.882	149.7	83.8	0.21	10.417	5.891
Line	Line	0.436	0.286	14.82	83.58	0.04	0.184	-0.249
Line	Line	3.712	2.415	125.9	83.82	0.25	10.545	5.882
Line	Line	3.479	2.265	118.4	83.8	0.32	12.469	6.914
Line	Line	3.119	2.032	106.5	83.78	0.2	7.074	3.874
Line	Line	2.745	1.789	93.95	83.78	0.28	6.84	7.198
Line	Line	2.333	1.518	80.05	83.81	0.03	0.661	0.673
Line	Line	2.12	1.376	72.7	83.88	0.13	2.456	2.43
Line	Line	0.322	0.209	11.06	83.91	0.02	0.047	-0.266
Line	Line	1.371	0.886	47.01	83.99	0.08	0.994	0.766
Line	Line	0.363	0.238	12.52	83.68	0.03	0.105	-0.216
Line	Line	1.006	0.648	34.51	84.1	0.07	0.629	0.282
Line	Line	0.643	0.411	22.03	84.28	0	0.026	-0.014
Line	Line	0.466	0.298	15.97	84.26	0.06	0.306	-0.317
Line	Line	0.383	0.246	13.14	84.14	0	0.018	-0.033
Line	Line	0.083	0.052	2.835	84.59	0	0.005	-0.236
Line	Line	0.177	0.114	6.082	84.12	0.02	0.024	-0.822
Line	Line	4.415	2.876	149.7	83.79	0.09	4.28	2.421
Line	Line	4.914	3.214	166	83.69	0.24	8.348	15.068
T1	Transf.2W	0.227	0.147	7.628	83.92	2.24	2.602	8.039
T3	Transf.2W	0.48	0.318	16.32	83.4	2.88	6.01	23.8
T5	Transf.2W	0.435	0.286	14.82	83.55	2.61	4.959	19.639
T6	Transf.2W	0.263	0.172	8.943	83.72	2.63	3.576	11.049
T7	Transf.2W	0.222	0.144	7.544	83.92	2.21	2.545	7.863
T8	Transf.2W	0.347	0.226	11.86	83.83	2.08	3.173	12.566
T9	Transf.2W	0.367	0.239	12.56	83.76	2.21	3.563	14.109
T10	Transf.2W	0.406	0.264	13.91	83.83	2.74	6.697	16.542
T11	Transf.2W	0.213	0.142	7.353	83.19	3.66	4.079	12.604
T12	Transf.2W	0.424	0.279	14.63	83.55	2.58	4.833	19.14
T13	Transf.2W	0.322	0.209	11.06	83.91	1.94	2.763	10.94
T16	Transf.2W	0.363	0.238	12.52	83.68	2.01	2.419	14.007
T17	Transf.2W	0.362	0.236	12.48	83.76	2.2	3.517	13.927
T18	Transf.2W	0.083	0.052	2.836	84.59	0.83	0.36	1.111
T19	Transf.2W	0.3	0.194	10.31	83.98	1.81	2.398	9.496
T20	Transf.2W	0.083	0.052	2.835	84.59	0.83	0.359	1.111
T21	Transf.2W	0.177	0.114	6.082	84.12	1.78	1.654	5.11

Table C.3: Branch power flow results of the Egyptian feeder No.3

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	7.477	5.212	256.7	82.04	1.07	55.64	102
Line2	Line	7.075	4.864	246.4	82.4	1.27	80.598	91.381
Line3	Line	6.571	4.493	231.6	82.55	2.45	116	212
Line5	Line	0.077	0.049	2.787	84.32	0.01	0.005	-0.24
Line6	Line	6.1	4.049	218.9	83.32	0.59	26.514	48.519
Line7	Line	5.703	3.757	205.6	83.5	0.2	8.294	15.15
Line8	Line	5.345	3.514	193	83.56	0.33	12.985	23.671
Line9	Line	5.022	3.288	181.8	83.66	0.37	13.917	25.315
Line11	Line	4.55	2.964	165.2	83.79	0.65	35.335	20.18
Line12	Line	0.078	0.049	2.815	84.71	0	0.002	-0.073
Line13	Line	4.177	2.723	152.8	83.77	0.26	13.212	7.518
Line14	Line	3.984	2.6	146.3	83.75	0.25	12.102	6.87
Line15	Line	0.37	0.243	13.65	83.6	0.06	0.255	-0.346
Line16	Line	3.602	2.35	132.6	83.75	0.27	11.673	6.585
Line17	Line	3.334	2.175	123.1	83.76	0.29	11.667	6.545
Line18	Line	0.232	0.152	8.605	83.65	0.04	0.115	-0.487
Line19	Line	1.822	1.19	67.54	83.72	0.15	3.406	1.725
Line20	Line	1.269	0.827	47.02	83.78	0.04	0.393	0.521
Line21	Line	1.004	0.652	37.17	83.87	0.16	1.2	1.214
Line23	Line	0.9	0.586	33.41	83.83	0.17	1.95	0.403
Line24	Line	0.219	0.143	8.152	83.72	0.04	0.114	-0.438
Line25	Line	0.208	0.135	7.735	83.79	0.04	0.096	-0.512
Line26	Line	0.471	0.308	17.55	83.74	0	0.029	-0.013
Line28	Line	0.57	0.37	21.14	83.88	0.04	0.3	-0.064
Line29	Line	0.878	0.573	32.6	83.71	0.06	0.679	0.169
Line30	Line	0.364	0.239	13.54	83.57	0.02	0.11	-0.149
Line31	Line	0.513	0.334	19.06	83.8	0.01	0.089	-0.035
Line32	Line	0.294	0.191	10.9	83.83	0.01	0.019	-0.045
Line34	Line	0.144	0.094	5.355	83.65	0.04	0.066	-0.628
Line36	Line	0.258	0.167	9.567	83.98	0.01	0.024	-0.08
Line38	Line	0	0	0.007	0	0	0	-0.244
Line44	Line	7.422	5.11	256.7	82.37	0.65	43.193	49.007
Line47	Line	0.102	0.065	3.776	84.43	0	0.004	-0.084
Line49	Line	0.074	0.047	2.725	84.32	0	0.002	-0.085
T1	Transf.2W	0.304	0.196	10.37	83.98	1.82	2.429	9.62
T2	Transf.2W	0.423	0.28	14.75	83.43	2.37	3.361	19.459
T3	Transf.2W	0.356	0.233	12.72	83.69	2.24	3.654	14.472
T4	Transf.2W	0.37	0.243	13.33	83.62	2.35	4.012	15.888
T6	Transf.2W	0.35	0.229	12.61	83.69	2.22	3.589	14.213
T7	Transf.2W	0.31	0.202	11.2	83.83	1.97	2.831	11.21
T8	Transf.2W	0.077	0.049	2.787	84.32	1.3	0.556	1.717
T9	Transf.2W	0.381	0.25	13.86	83.55	2.44	4.335	17.167
T10	Transf.2W	0.261	0.172	9.561	83.52	2.81	4.087	12.629
T11	Transf.2W	0.078	0.049	2.815	84.71	0.49	0.179	0.708
T12	Transf.2W	0.179	0.116	6.568	83.99	1.92	1.929	5.96
T13	Transf.2W	0.37	0.243	13.66	83.55	2.41	4.213	16.685
T14	Transf.2W	0.256	0.168	9.474	83.52	2.79	4.013	12.4
T15	Transf.2W	0.265	0.175	9.852	83.45	2.9	4.339	13.408
T16	Transf.2W	0.232	0.152	8.605	83.65	2.53	3.311	10.23

T17	Transf.2W	0.37	0.245	13.8	83.43	2.22	2.942	17.035
T18	Transf.2W	0.312	0.203	11.58	83.76	2.04	3.026	11.983
T19	Transf.2W	0.258	0.167	9.567	83.98	1.68	2.066	8.181
T20	Transf.2W	0.364	0.239	13.54	83.55	2.39	4.141	16.397
T21	Transf.2W	0.22	0.144	8.169	83.72	2.4	2.984	9.219
T22	Transf.2W	0.294	0.191	10.9	83.83	1.92	2.681	10.616
T25	Transf.2W	0.219	0.143	8.152	83.72	2.39	2.971	9.181
T26	Transf.2W	0.208	0.135	7.735	83.79	2.27	2.675	8.266
T27	Transf.2W	0.328	0.214	12.21	83.69	2.15	3.363	13.317
T28	Transf.2W	0.144	0.094	5.355	83.65	2.52	2.051	6.339
T29	Transf.2W	0.029	0.018	1.053	84.59	0.77	0.124	0.383
T30	Transf.2W	0.074	0.047	2.725	84.32	1.27	0.531	1.641

Table C.4: Branch power flow results of the IEC feeder.

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	11.51	7.905	386	82.44	1.4	119	188
Line2	Line	11.86	8.208	395.2	82.25	0.88	76.518	121
Line3	Line	12.41	8.906	401	81.26	4.17	368	581
Line4	Line	10.79	7.328	366	82.74	1.26	103	162
Line5	Line	1.051	0.668	35.42	84.39	0.09	0.701	0.149
Line6	Line	9.641	6.498	330.6	82.92	1.38	102	160
Line7	Line	0.763	0.483	25.7	84.5	0.02	0.087	-0.089
Line8	Line	0.244	0.156	8.249	84.18	0.05	0.153	-1.087
Line9	Line	0.156	0.101	5.291	83.79	0.04	0.067	-1.203
Line10	Line	0.519	0.328	17.47	84.54	0.01	0.047	-0.19
Line11	Line	0.155	0.098	5.217	84.48	0.04	0.069	-1.273
Line13	Line	0.364	0.233	12.3	84.26	0.05	0.147	-1.445
Line14	Line	0.17	0.109	6.576	84.27	0.01	0.021	-0.179
Line16	Line	9.272	6.163	321.4	83.28	0.87	62.083	97.712
Line17	Line	1.015	0.654	35.2	84.08	0.07	0.903	0.088
Line18	Line	8.194	5.411	286.2	83.45	0.69	43.946	68.996
Line19	Line	0.168	0.108	5.835	84.15	0.02	0.047	-0.658
Line20	Line	0.846	0.546	29.38	84.01	0.14	1.374	-0.102
Line21	Line	0.491	0.316	17.06	84.12	0.08	0.484	-0.576
Line22	Line	0	0	0.011	0	0	0	-0.341
Line23	Line	7.407	4.837	262.5	83.73	0.72	52.818	50.909
Line24	Line	7.177	4.672	256.2	83.81	0.28	20.282	19.538
Line25	Line	6.86	4.46	245.6	83.84	0.91	61.884	59.548
Line26	Line	6.411	4.15	231.7	83.95	0.57	36.838	35.387
Line27	Line	5.89	3.793	214.8	84.07	0.9	53.891	51.645
Line28	Line	5.682	3.643	209.1	84.18	0.02	1.154	0.561
Line29	Line	0.884	0.576	32.71	83.78	0.12	1.351	0.119
Line30	Line	0.517	0.336	19.14	83.88	0.12	0.781	-0.539
Line31	Line	0.33	0.216	12.24	83.69	0.03	0.126	-0.303
Line32	Line	0.187	0.121	6.921	83.92	0	0.005	-0.047
Line33	Line	4.796	3.066	176.4	84.26	0.57	34.427	16.581
Line34	Line	4.541	2.907	168.2	84.22	0.16	9.021	4.333
Line35	Line	4.303	2.759	159.8	84.18	0.73	40.305	19.302
Line36	Line	3.994	2.565	149.7	84.14	0.15	7.462	3.558
Line37	Line	3.849	2.474	144.5	84.13	0.41	20.589	9.791

Line38	Line	3.547	2.281	133.9	84.11	0.29	13.199	6.236
Line39	Line	3.491	2.247	132.3	84.08	0.22	10.014	4.726
Line40	Line	2.504	1.613	95.34	84.06	0.52	16.954	7.643
Line41	Line	2.446	1.579	93.77	84	0.22	7.051	3.171
Line42	Line	0.229	0.144	8.456	84.54	0.02	0.063	-0.344
Line43	Line	0.117	0.075	4.338	84.32	0.02	0.026	-0.585
Line44	Line	7.8	5.114	274	83.63	0.92	70.094	67.623
Line45	Line	0.068	0.043	2.614	84.32	0.01	0.006	-0.338
Line46	Line	0.35	0.228	12.27	83.76	0	0.003	-0.031
Line47	Line	2.552	1.642	96.94	84.09	0.16	5.221	2.359
Line48	Line	0.216	0.139	7.199	83.99	0.01	0.01	-0.335
Line49	Line	2.004	1.298	77.44	83.94	0.14	3.709	1.592
Line50	Line	2.37	1.533	91.15	83.97	0.34	10.799	4.831
Line51	Line	0.929	0.6	35.33	83.99	0.04	0.48	0.08
Line52	Line	0.433	0.283	16.85	83.69	0.01	0.074	-0.162
Line53	Line	0.666	0.43	25.35	84.01	0.07	0.603	-0.086
Line55	Line	0.144	0.093	5.487	84.12	0.02	0.036	-0.467
Line56	Line	0.311	0.203	11.89	83.69	0.04	0.178	-0.427
Line57	Line	0.725	0.47	28.07	83.95	0.06	0.614	-0.005
Line58	Line	1.275	0.827	49.38	83.91	0.03	0.57	0.19
Line59	Line	6.214	4.011	225.8	84.02	0.34	21.543	20.68
Line61	Line	0.269	0.175	10.43	83.83	0.01	0.029	-0.091
Line62	Line	0.456	0.295	17.65	83.98	0.01	0.068	-0.053
Line63	Line	0.195	0.126	6.625	84.05	0.02	0.036	-1.372
Line64	Line	0.973	0.629	37.67	83.96	0.05	0.664	0.143
Line66	Line	0.204	0.131	7.868	84.12	0	0.013	-0.074
Line67	Line	0	-0.001	0.026	0	0	0	-0.922
Line68	Line	0.609	0.395	23.6	83.88	0.04	0.253	-0.177
Line70	Line	0.198	0.128	6.904	83.99	0.03	0.079	-0.775
T1	Transf.2W	0.182	0.117	5.926	84.19	1.73	1.57	4.852
T2	Transf.2W	0.279	0.182	9.199	83.72	2.7	3.784	11.691
T3	Transf.2W	0.216	0.139	7.199	83.99	2.11	2.317	7.159
T4	Transf.2W	0.383	0.25	12.84	83.76	2.26	3.723	14.741
T5	Transf.2W	0.288	0.185	9.737	84.05	1.71	2.14	8.475
T6	Transf.2W	0.268	0.176	9.257	83.65	2.72	3.831	11.839
T7	Transf.2W	0.088	0.056	2.977	84.32	1.39	0.634	1.959
T8	Transf.2W	0.156	0.101	5.291	83.79	2.48	2.003	6.189
T9	Transf.2W	0.155	0.099	5.231	84.25	1.53	1.223	3.781
T11	Transf.2W	0.168	0.108	5.697	84.19	1.67	1.451	4.484
T12	Transf.2W	0.195	0.126	6.625	84.05	1.94	1.962	6.063
T13	Transf.2W	0.168	0.108	5.835	84.15	1.71	1.522	4.704
T14	Transf.2W	0.354	0.231	12.33	83.76	2.17	3.432	13.591
T15	Transf.2W	0.292	0.189	10.18	83.98	1.79	2.339	9.263
T16	Transf.2W	0.198	0.128	6.904	83.99	2.02	2.131	6.585
T17	Transf.2W	0.35	0.228	12.27	83.76	2.16	3.396	13.446
T18	Transf.2W	0.323	0.21	11.43	83.83	2.01	2.949	11.679
T19	Transf.2W	0.177	0.114	6.309	84.05	1.85	1.78	5.499
T20	Transf.2W	0.297	0.192	10.62	83.91	1.87	2.546	10.082
T21	Transf.2W	0.116	0.075	4.172	83.98	1.96	1.245	3.847
T22	Transf.2W	0.272	0.176	9.813	83.98	1.72	2.174	8.608
T23	Transf.2W	0.161	0.103	5.836	84.11	1.71	1.523	4.705

T24	Transf.2W	0.303	0.197	11.06	83.83	1.94	2.763	10.943
T25	Transf.2W	0.154	0.099	5.666	84.12	1.66	1.435	4.435
T26	Transf.2W	0.366	0.241	13.59	83.55	2.39	4.166	16.496
T27	Transf.2W	0.33	0.216	12.24	83.69	2.15	3.382	13.392
T28	Transf.2W	0.187	0.121	6.921	83.92	2.03	2.141	6.617
T29	Transf.2W	0.221	0.142	8.201	84.12	1.44	1.518	6.012
T30	Transf.2W	0.269	0.174	10.11	83.91	1.78	2.307	9.136
T31	Transf.2W	0.137	0.088	5.138	84.19	1.5	1.18	3.647
T32	Transf.2W	0.282	0.183	10.69	83.83	1.88	2.577	10.205
T33	Transf.2W	0.043	0.027	1.607	84.59	0.75	0.185	0.571
T34	Transf.2W	0.112	0.07	4.127	84.56	0.72	0.385	1.523
T35	Transf.2W	0.117	0.075	4.338	84.32	1.27	0.841	2.6
T36	Transf.2W	0.262	0.17	9.976	83.91	1.75	2.246	8.895
T37	Transf.2W	0.144	0.093	5.487	84.12	1.61	1.346	4.16
T38	Transf.2W	0.311	0.203	11.89	83.69	2.09	3.191	12.638
T39	Transf.2W	0.21	0.135	8	84.12	1.4	1.445	5.721
T40	Transf.2W	0.042	0.027	1.599	84.59	0.75	0.183	0.565
T41	Transf.2W	0.042	0.026	1.589	84.59	0.74	0.181	0.558
T42	Transf.2W	0.069	0.044	2.625	84.32	1.23	0.493	1.524
T44	Transf.2W	0.068	0.043	2.614	84.32	1.22	0.489	1.51
T45	Transf.2W	0.287	0.187	11.11	83.76	1.95	2.785	11.028
T46	Transf.2W	0.301	0.197	11.71	83.69	2.06	3.094	12.253
T47	Transf.2W	0.269	0.175	10.43	83.83	1.83	2.457	9.728
T48	Transf.2W	0.285	0.186	11.08	83.76	1.95	2.77	10.97
T49	Transf.2W	0.17	0.109	6.576	84.27	1.15	0.976	3.865
T50	Transf.2W	0.433	0.283	16.85	83.69	1.67	2.3	16.329
T51	Transf.2W	0.175	0.112	6.758	84.25	1.18	1.031	4.082
T52	Transf.2W	0.16	0.104	6.21	83.99	1.82	1.724	5.327
T53	Transf.2W	0.204	0.131	7.868	84.12	1.38	1.397	5.533

Winter Results

Table C.5: Branch power flow results of the Egyptian feeder No.1

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	9.874	6.808	337.8	82.33	0.23	17.29	27.224
Line3	Line	9.613	6.625	329.6	82.34	0.39	28.256	44.473
Line4	Line	9.399	6.463	323.4	82.4	0.55	36.353	66.988
Line5	Line	0.473	0.313	16.18	83.46	0.06	0.316	-0.464
Line7	Line	2.317	1.516	82.69	83.68	0.32	9.144	3.905
Line8	Line	0.69	0.451	24.61	83.7	0.02	0.108	-0.107
Line9	Line	8.889	6.083	307.2	82.53	1.73	117	185
Line10	Line	8.419	5.668	295	82.95	0.82	53.689	84.353
Line11	Line	7.776	5.184	274.1	83.21	0.15	8.856	13.889
Line12	Line	7.041	4.687	249	83.24	0.13	7.172	11.217
Line13	Line	0.625	0.427	22.3	82.6	0.07	0.549	-0.26
Line14	Line	6.408	4.249	226.7	83.34	0.25	12.712	19.814
Line16	Line	5.833	3.849	206.6	83.47	0.25	11.493	17.843
Line17	Line	5.33	3.503	189.6	83.57	0.09	3.994	6.175
Line18	Line	5.185	3.408	184.6	83.57	0.16	6.656	10.276
Line19	Line	2.63	1.734	93.9	83.49	0.08	1.722	2.43
Line20	Line	2.212	1.457	79.04	83.52	0.05	0.883	1.183
Line21	Line	1.005	0.658	35.85	83.65	0.07	0.821	0.107
Line22	Line	0.572	0.372	20.39	83.81	0.01	0.075	-0.048
Line23	Line	1.207	0.798	43.2	83.43	0.04	0.342	0.256
Line24	Line	2.549	1.664	90.74	83.74	0.16	4.967	2.177
Line25	Line	1.565	1.026	56.1	83.65	0.29	5.57	1.937
Line26	Line	1.053	0.682	37.72	83.91	0.04	0.58	0.099
Line27	Line	0.743	0.481	26.62	83.92	0.1	0.918	-0.144
Line28	Line	0.386	0.249	13.83	84.06	0.02	0.072	-0.137
Line29	Line	0.415	0.274	14.84	83.47	0.01	0.029	-0.16
Line30	Line	0.355	0.232	12.73	83.69	0.03	0.112	-0.267
Line33	Line	5.476	3.605	194.3	83.52	0.24	10.426	16.139
Line35	Line	7.407	4.935	261.5	83.22	0.16	9.208	14.423
Line37	Line	0.361	0.236	12.65	83.72	0.01	0.03	-0.253
Line39	Line	0.303	0.197	10.89	83.87	0.03	0.11	-0.375
Line41	Line	0.176	0.112	6.231	84.37	0	0.008	-0.091
T1	Transf.2W	0.186	0.118	6.241	84.4	1.09	0.879	3.482
T2	Transf.2W	0.217	0.139	7.278	84.3	1.27	1.196	4.734
T3	Transf.2W	0.027	0.017	0.904	84.54	1.12	0.178	0.44
T4	Transf.2W	0.473	0.313	16.19	83.4	2.86	5.918	23.434
T5	Transf.2W	0.353	0.231	12.26	83.7	1.96	2.32	13.431
T6	Transf.2W	0.589	0.4	20.87	82.74	3.38	6.727	38.949
T7	Transf.2W	0.361	0.236	12.65	83.72	2.23	3.615	14.315
T8	Transf.2W	0.357	0.233	12.55	83.73	2.21	3.555	14.08
T9	Transf.2W	0.624	0.427	22.31	82.56	3.62	7.69	44.522
T10	Transf.2W	0.563	0.381	20.09	82.81	3.25	6.233	36.091
T11	Transf.2W	0.346	0.226	12.24	83.75	2.15	3.382	13.393
T12	Transf.2W	0.135	0.086	4.76	84.29	1.39	1.013	3.131

T13	Transf.2W	0.141	0.089	4.956	84.5	0.87	0.554	2.195
T14	Transf.2W	0.416	0.274	14.86	83.47	2.62	4.987	19.747
T15	Transf.2W	0.227	0.146	8.055	84.18	1.41	1.465	5.8
T16	Transf.2W	0.432	0.286	15.47	83.4	2.73	5.4	21.382
T17	Transf.2W	0.396	0.261	14.16	83.54	2.5	4.528	17.931
T18	Transf.2W	0.176	0.112	6.231	84.37	1.09	0.876	3.47
T19	Transf.2W	0.517	0.346	18.59	83.07	3.29	7.8	30.886
T20	Transf.2W	0.275	0.178	9.776	84	1.72	2.157	8.542
T21	Transf.2W	0.415	0.274	14.84	83.47	2.62	4.974	19.696
T22	Transf.2W	0.507	0.341	18.39	82.96	2.97	5.223	30.239
T23	Transf.2W	0.309	0.201	11.1	83.85	1.95	2.783	11.022
T24	Transf.2W	0.356	0.233	12.81	83.67	2.25	3.702	14.658
T25	Transf.2W	0.083	0.052	2.942	84.56	0.86	0.387	1.196
T26	Transf.2W	0.303	0.197	10.89	83.87	1.91	2.679	10.61
T27	Transf.2W	0.387	0.254	13.88	83.57	2.44	4.346	17.209
T28	Transf.2W	0.355	0.232	12.73	83.69	2.24	3.658	14.484

Table C.6: Branch power flow results of the Egyptian feeder No.2

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	5.176	3.379	174.1	83.74	0.11	3.928	7.107
Line2	Line	4.96	3.235	167	83.76	0.23	7.815	14.108
Line3	Line	4.51	2.924	152.3	83.91	0.22	10.79	6.109
Line4	Line	0.385	0.252	13.08	83.72	0.03	0.143	-0.273
Line5	Line	3.774	2.45	127.9	83.88	0.26	10.89	6.084
Line6	Line	3.52	2.285	119.6	83.87	0.32	12.741	7.073
Line7	Line	3.308	2.152	112.9	83.83	0.21	7.948	4.385
Line8	Line	3.013	1.962	103.1	83.8	0.31	8.239	8.803
Line10	Line	2.724	1.773	93.53	83.8	0.04	0.903	0.95
Line11	Line	2.501	1.624	85.86	83.87	0.15	3.425	3.543
Line12	Line	0.363	0.237	12.49	83.76	0.02	0.06	-0.251
Line13	Line	1.712	1.105	58.77	84.02	0.1	1.553	1.408
Line14	Line	0.389	0.255	13.43	83.58	0.03	0.12	-0.206
Line15	Line	0.847	0.544	29.07	84.13	0.06	0.446	0.074
Line16	Line	0.463	0.293	15.84	84.48	0	0.013	-0.028
Line17	Line	0.289	0.183	9.875	84.51	0.04	0.117	-0.426
Line18	Line	0.09	0.056	3.079	84.88	0	0.001	-0.043
Line19	Line	0.049	0.03	1.659	84.76	0	0.002	-0.238
Line20	Line	0.174	0.112	5.984	84.13	0.02	0.023	-0.822
Line21	Line	4.334	2.813	146.8	83.88	0.09	4.116	2.325
Line23	Line	4.901	3.189	165.3	83.82	0.24	8.278	14.938
T1	Transf.2W	0.212	0.137	7.116	83.99	2.09	2.264	6.995
T2	Transf.2W	0.051	0.032	1.697	84.76	0.49	0.129	0.398
T3	Transf.2W	0.383	0.25	12.97	83.74	2.28	3.794	15.026
T4	Transf.2W	0.165	0.104	5.542	84.46	0.97	0.693	2.745
T5	Transf.2W	0.385	0.252	13.08	83.72	2.3	3.862	15.293
T6	Transf.2W	0.17	0.109	5.755	84.18	1.68	1.481	4.575
T7	Transf.2W	0.244	0.159	8.301	83.81	2.44	3.081	9.519
T8	Transf.2W	0.199	0.127	6.748	84.34	1.18	1.028	4.07
T9	Transf.2W	0.287	0.185	9.802	84.04	1.72	2.169	8.588

T10	Transf.2W	0.281	0.18	9.587	84.2	1.88	3.18	7.854
T11	Transf.2W	0.222	0.148	7.678	83.1	3.82	4.448	13.744
T12	Transf.2W	0.423	0.279	14.61	83.46	2.35	3.298	19.094
T13	Transf.2W	0.363	0.237	12.49	83.76	2.2	3.521	13.944
T14	Transf.2W	0.26	0.167	8.933	84.12	1.57	1.801	7.133
T15	Transf.2W	0.214	0.137	7.338	84.28	1.28	1.215	4.813
T16	Transf.2W	0.389	0.255	13.43	83.58	2.16	2.788	16.141
T17	Transf.2W	0.384	0.251	13.24	83.68	2.33	3.957	15.671
T18	Transf.2W	0.198	0.126	6.797	84.33	1.19	1.043	4.13
T19	Transf.2W	0.042	0.026	1.423	84.8	0.41	0.091	0.28
T20	Transf.2W	0.049	0.03	1.659	84.76	0.48	0.123	0.38
T21	Transf.2W	0.174	0.112	5.984	84.13	1.75	1.601	4.947

Table C.7: Branch power flow results of the Egyptian feeder No.3

ID	Type	MW Flow	Mvar Flow	Amp Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	6.298	4.292	214.6	82.64	0.89	38.905	71.022
Line2	Line	5.94	4.001	204.8	82.94	1.05	55.729	62.836
Line3	Line	5.45	3.65	189.8	83.09	2	77.671	141
Line5	Line	0.112	0.071	3.988	84.4	0.01	0.01	-0.244
Line6	Line	5.097	3.331	180.1	83.71	0.48	17.946	32.601
Line7	Line	4.626	3.003	164.1	83.88	0.16	5.28	9.55
Line8	Line	4.348	2.817	154.4	83.93	0.26	8.308	14.979
Line9	Line	4.005	2.584	142.5	84.03	0.29	8.542	15.326
Line11	Line	3.538	2.271	126.1	84.16	0.5	20.581	11.539
Line12	Line	0.07	0.044	2.491	84.63	0	0.001	-0.075
Line13	Line	3.268	2.1	117.1	84.13	0.2	7.762	4.324
Line14	Line	3.116	2.004	112	84.11	0.19	7.093	3.934
Line15	Line	0.257	0.166	9.275	84.04	0.04	0.117	-0.444
Line16	Line	2.851	1.834	102.7	84.1	0.21	7.003	3.845
Line17	Line	2.534	1.624	91.38	84.19	0.21	6.425	3.469
Line18	Line	0.107	0.068	3.862	84.41	0.02	0.023	-0.563
Line19	Line	1.351	0.868	48.89	84.13	0.11	1.785	0.766
Line20	Line	1.069	0.685	38.65	84.2	0.03	0.265	0.277
Line21	Line	0.856	0.548	30.95	84.21	0.13	0.832	0.491
Line23	Line	0.759	0.487	27.49	84.16	0.14	1.32	0.09
Line24	Line	0.182	0.117	6.608	83.99	0.03	0.075	-0.476
Line25	Line	0.123	0.078	4.44	84.32	0.02	0.031	-0.573
Line26	Line	0.453	0.292	16.47	84.03	0	0.025	-0.016
Line28	Line	0.501	0.323	18.17	84.08	0.04	0.222	-0.119
Line29	Line	0.556	0.354	20.09	84.32	0.04	0.258	-0.086
Line30	Line	0.153	0.097	5.515	84.43	0.01	0.018	-0.212
Line31	Line	0.403	0.258	14.59	84.24	0.01	0.052	-0.06
Line32	Line	0.175	0.112	6.33	84.34	0	0.006	-0.055
Line34	Line	0.166	0.107	6.046	84.07	0.04	0.084	-0.646
Line36	Line	0.24	0.155	8.717	84.09	0.01	0.02	-0.086
Line38	Line	0.055	0.035	1.948	84.54	0	0.001	-0.248
Line44	Line	6.259	4.221	214.7	82.91	0.54	30.203	34.098
Line47	Line	0.096	0.061	3.479	84.51	0	0.004	-0.088
Line49	Line	0.065	0.042	2.363	84.42	0	0.002	-0.089

T1	Transf.2W	0.289	0.186	9.828	84.04	1.72	2.18	8.634
T2	Transf.2W	0.435	0.288	15.08	83.4	2.42	3.513	20.34
T3	Transf.2W	0.276	0.178	9.704	84.02	1.7	2.125	8.417
T4	Transf.2W	0.397	0.261	14.13	83.55	2.49	4.506	17.844
T5	Transf.2W	0.055	0.035	1.948	84.54	0.91	0.271	0.838
T6	Transf.2W	0.273	0.176	9.678	84.01	1.7	2.114	8.372
T7	Transf.2W	0.335	0.218	11.94	83.77	2.1	3.22	12.749
T8	Transf.2W	0.112	0.071	3.988	84.4	1.16	0.711	2.197
T9	Transf.2W	0.346	0.226	12.41	83.72	2.18	3.474	13.757
T10	Transf.2W	0.18	0.116	6.456	84.02	1.89	1.864	5.758
T11	Transf.2W	0.07	0.044	2.491	84.63	0.73	0.277	0.857
T12	Transf.2W	0.144	0.091	5.163	84.47	0.9	0.602	2.383
T13	Transf.2W	0.257	0.166	9.275	84.04	1.63	1.942	7.69
T14	Transf.2W	0.311	0.207	11.34	83.25	3.34	5.746	17.756
T15	Transf.2W	0.213	0.136	7.702	84.2	1.35	1.339	5.302
T16	Transf.2W	0.107	0.068	3.862	84.41	1.13	0.667	2.06
T17	Transf.2W	0.292	0.19	10.63	83.82	1.7	1.745	10.106
T18	Transf.2W	0.261	0.168	9.457	84.01	1.66	2.019	7.995
T19	Transf.2W	0.24	0.155	8.717	84.09	1.53	1.715	6.792
T20	Transf.2W	0.153	0.097	5.515	84.43	0.96	0.687	2.719
T21	Transf.2W	0.228	0.146	8.259	84.14	1.45	1.54	6.096
T22	Transf.2W	0.175	0.112	6.33	84.34	1.11	0.904	3.582
T25	Transf.2W	0.182	0.117	6.608	83.99	1.94	1.952	6.032
T26	Transf.2W	0.123	0.078	4.44	84.32	1.3	0.881	2.723
T27	Transf.2W	0.287	0.186	10.44	83.91	1.83	2.458	9.733
T28	Transf.2W	0.166	0.107	6.046	84.07	1.77	1.634	5.051
T29	Transf.2W	0.031	0.02	1.118	84.58	0.82	0.14	0.432
T30	Transf.2W	0.065	0.042	2.363	84.42	1.1	0.399	1.234

Table C.8: Branch power flow results of the IEC feeder.

ID	Type	MW Flow	Mvar Flow	Amp. Flow	% PF	% V_d	kW Losses	kvar Losses
Line1	Line	10.56	7.163	351.2	82.76	1.27	98.626	155
Line2	Line	10.965	7.485	362.3	82.59	0.8	64.313	101
Line3	Line	11.511	8.129	369.8	81.68	3.84	313	493
Line4	Line	9.883	6.633	332	83.03	1.14	84.329	133
Line5	Line	1.096	0.695	36.63	84.45	0.09	0.75	0.213
Line6	Line	8.703	5.805	295.4	83.19	1.23	81.08	127
Line7	Line	0.822	0.519	27.48	84.55	0.02	0.099	-0.072
Line8	Line	0.219	0.141	7.367	84.13	0.05	0.122	-1.119
Line9	Line	0.169	0.111	5.72	83.69	0.04	0.078	-1.215
Line10	Line	0.603	0.38	20.13	84.6	0.01	0.062	-0.169
Line11	Line	0.259	0.165	8.698	84.39	0.06	0.191	-1.231
Line13	Line	0.343	0.217	11.48	84.44	0.05	0.128	-1.499
Line14	Line	0.115	0.072	4.29	84.54	0.01	0.009	-0.195
Line16	Line	8.297	5.463	284.2	83.52	0.77	48.564	76.197
Line17	Line	1.052	0.679	36.13	84.05	0.08	0.952	0.105
Line18	Line	7.196	4.708	248.1	83.68	0.6	33.031	51.622
Line19	Line	0.221	0.144	7.627	83.89	0.03	0.08	-0.655
Line20	Line	0.83	0.535	28.52	84.03	0.13	1.295	-0.157

Line21	Line	0.597	0.387	20.59	83.9	0.1	0.705	-0.483
Line22	Line	0.025	0.015	0.913	84.86	0	0.001	-0.359
Line23	Line	6.502	4.212	227	83.93	0.63	39.494	37.861
Line24	Line	6.249	4.036	219.5	84	0.24	14.885	14.253
Line25	Line	6.05	3.904	213	84.02	0.79	46.556	44.531
Line26	Line	5.652	3.633	200.6	84.12	0.49	27.618	26.351
Line27	Line	5.072	3.244	181.4	84.24	0.76	38.433	36.491
Line28	Line	4.937	3.146	177.9	84.33	0.01	0.836	0.402
Line29	Line	0.689	0.445	24.95	84.01	0.09	0.786	-0.183
Line30	Line	0.479	0.309	17.33	84.03	0.11	0.641	-0.647
Line31	Line	0.307	0.2	11.17	83.83	0.03	0.105	-0.328
Line32	Line	0.17	0.11	6.175	84.06	0	0.004	-0.049
Line33	Line	4.247	2.701	153	84.38	0.49	25.887	12.329
Line34	Line	4.051	2.58	146.8	84.35	0.14	6.872	3.263
Line35	Line	3.862	2.463	140.3	84.31	0.64	31.063	14.692
Line36	Line	3.48	2.218	127.3	84.33	0.12	5.399	2.529
Line37	Line	3.39	2.162	124.2	84.31	0.36	15.21	7.106
Line38	Line	3.158	2.016	116.2	84.29	0.25	9.95	4.611
Line39	Line	3.113	1.989	115	84.26	0.19	7.565	3.501
Line40	Line	2.211	1.412	81.95	84.27	0.44	12.525	5.41
Line41	Line	2.158	1.381	80.46	84.22	0.19	5.192	2.233
Line42	Line	0.182	0.114	6.568	84.72	0.02	0.038	-0.372
Line43	Line	0.068	0.043	2.475	84.62	0.01	0.009	-0.619
Line44	Line	6.828	4.439	236.5	83.84	0.79	52.252	50.155
Line45	Line	0.122	0.077	4.556	84.51	0.01	0.018	-0.35
Line46	Line	0.335	0.218	11.61	83.84	0	0.003	-0.033
Line47	Line	2.256	1.44	83.45	84.29	0.14	3.869	1.678
Line48	Line	0.2	0.129	6.65	84.07	0.01	0.009	-0.342
Line49	Line	1.66	1.065	62.3	84.16	0.11	2.401	0.93
Line50	Line	2.092	1.341	78.22	84.2	0.3	7.953	3.393
Line51	Line	0.85	0.546	31.51	84.12	0.04	0.382	0.024
Line52	Line	0.138	0.087	5.167	84.61	0	0.007	-0.231
Line53	Line	0.66	0.425	24.49	84.06	0.07	0.562	-0.125
Line55	Line	0.148	0.095	5.494	84.14	0.02	0.036	-0.491
Line56	Line	0.315	0.206	11.76	83.74	0.04	0.174	-0.454
Line57	Line	0.682	0.441	25.69	84	0.06	0.514	-0.071
Line58	Line	0.975	0.624	36.62	84.25	0.02	0.314	0.057
Line59	Line	5.431	3.483	193.7	84.18	0.29	15.852	15.101
Line61	Line	0.291	0.189	10.99	83.8	0.01	0.032	-0.096
Line62	Line	0.391	0.251	14.71	84.09	0.01	0.047	-0.068
Line63	Line	0.19	0.122	6.392	84.09	0.02	0.034	-1.396
Line64	Line	0.779	0.498	29.27	84.26	0.04	0.401	0.003
Line66	Line	0.219	0.141	8.251	84.11	0	0.014	-0.078
Line67	Line	0.069	0.044	2.32	84.67	0.01	0.01	-0.93
Line68	Line	0.323	0.205	12.11	84.43	0.02	0.066	-0.358
Line70	Line	0.244	0.159	8.441	83.77	0.04	0.118	-0.772
T1	Transf.2W	0.234	0.151	7.593	83.96	2.23	2.577	7.964
T2	Transf.2W	0.34	0.22	11.15	83.95	1.96	2.808	11.118
T3	Transf.2W	0.2	0.129	6.65	84.07	1.95	1.977	6.109
T4	Transf.2W	0.378	0.246	12.59	83.79	2.21	3.576	14.161
T5	Transf.2W	0.273	0.176	9.172	84.11	1.61	1.899	7.519
T6	Transf.2W	0.325	0.215	11.14	83.39	3.28	5.549	17.145

T7	Transf.2W	0.05	0.031	1.666	84.63	0.78	0.199	0.614
T8	Transf.2W	0.169	0.111	5.72	83.69	2.69	2.34	7.232
T9	Transf.2W	0.19	0.122	6.393	84.09	1.87	1.827	5.646
T10	Transf.2W	0.069	0.044	2.32	84.67	0.68	0.241	0.743
T11	Transf.2W	0.153	0.097	5.112	84.51	0.89	0.59	2.336
T12	Transf.2W	0.19	0.122	6.392	84.09	1.87	1.827	5.645
T13	Transf.2W	0.221	0.144	7.627	83.89	2.24	2.601	8.037
T14	Transf.2W	0.231	0.148	7.949	84.21	1.39	1.426	5.648
T15	Transf.2W	0.352	0.229	12.17	83.79	2.14	3.343	13.24
T16	Transf.2W	0.244	0.159	8.441	83.77	2.48	3.186	9.844
T17	Transf.2W	0.335	0.218	11.61	83.84	2.04	3.043	12.051
T18	Transf.2W	0.273	0.176	9.526	84.04	1.67	2.048	8.111
T19	Transf.2W	0.214	0.139	7.511	83.89	2.2	2.522	7.794
T20	Transf.2W	0.185	0.118	6.48	84.35	1.13	0.948	3.753
T21	Transf.2W	0.071	0.045	2.507	84.06	1.84	0.703	2.171
T22	Transf.2W	0.28	0.181	9.971	83.98	1.75	2.244	8.887
T23	Transf.2W	0.193	0.123	6.878	84.3	1.2	1.068	4.228
T24	Transf.2W	0.343	0.224	12.35	83.72	2.17	3.443	13.633
T25	Transf.2W	0.096	0.061	3.471	84.47	1.01	0.539	1.665
T26	Transf.2W	0.21	0.137	7.628	83.83	2.24	2.602	8.039
T27	Transf.2W	0.307	0.2	11.17	83.83	1.96	2.819	11.161
T28	Transf.2W	0.17	0.11	6.175	84.06	1.81	1.705	5.267
T29	Transf.2W	0.17	0.108	6.162	84.36	1.08	0.857	3.394
T30	Transf.2W	0.352	0.231	12.97	83.62	2.28	3.797	15.036
T31	Transf.2W	0.084	0.053	3.079	84.68	0.54	0.214	0.847
T32	Transf.2W	0.217	0.14	8.012	84.15	1.4	1.449	5.737
T33	Transf.2W	0.035	0.022	1.275	84.68	0.59	0.116	0.359
T34	Transf.2W	0.113	0.072	4.103	84.57	0.72	0.38	1.505
T35	Transf.2W	0.068	0.043	2.475	84.62	0.72	0.274	0.846
T36	Transf.2W	0.19	0.121	7.026	84.25	1.23	1.114	4.412
T37	Transf.2W	0.148	0.095	5.494	84.14	1.61	1.349	4.17
T38	Transf.2W	0.315	0.206	11.76	83.74	2.07	3.122	12.365
T39	Transf.2W	0.196	0.125	7.255	84.23	1.27	1.188	4.705
T40	Transf.2W	0.041	0.026	1.509	84.63	0.7	0.163	0.503
T41	Transf.2W	0.04	0.025	1.501	84.63	0.7	0.161	0.498
T42	Transf.2W	0.06	0.038	2.247	84.44	1.05	0.361	1.116
T43	Transf.2W	0.025	0.015	0.913	84.86	0.27	0.037	0.115
T44	Transf.2W	0.122	0.077	4.556	84.51	0.8	0.469	1.855
T45	Transf.2W	0.278	0.181	10.47	83.86	1.84	2.474	9.796
T46	Transf.2W	0.196	0.125	7.35	84.21	1.29	1.22	4.829
T47	Transf.2W	0.291	0.189	10.99	83.8	1.93	2.724	10.788
T48	Transf.2W	0.276	0.179	10.43	83.87	1.83	2.453	9.715
T49	Transf.2W	0.115	0.072	4.29	84.54	0.75	0.415	1.645
T50	Transf.2W	0.138	0.087	5.167	84.61	0.51	0.216	1.535
T51	Transf.2W	0.185	0.118	6.944	84.25	1.22	1.089	4.311
T52	Transf.2W	0.237	0.153	8.923	84.03	1.57	1.797	7.117
T53	Transf.2W	0.219	0.141	8.251	84.11	1.45	1.537	6.086

Appendix – D

Balanced and Unbalanced Loading Calculations

Table D.1: Power demand in unbalanced and balanced loads for the Egyptian feeder No.1.

ID	Transformer Name	V_{L-L} (kV) By ETAP	Unbalanced Load						Balanced Load		
			R (A)	S (A)	T (A)	LIUR	P_{MAX} (kW)	Q_{MAX} (Kvar)	Amp. (A)	P_{MAX} (kW)	Q_{MAX} (Kvar)
T1	Almabaar 1	0.384	300	300	300	0.00%	169.60	105.11	300.00	169.60	105.11
T2	Almabaar 2	0.385	350	350	350	0.00%	198.38	122.95	350.00	198.38	122.95
T3	Almabaar 3	0.385	40	40	45	8.00%	25.51	15.81	41.67	23.62	14.64
T4	Al Shoka Al Janobi	0.374	830	820	750	3.75%	457.01	283.23	800.00	440.50	272.99
T5	George	0.371	610	620	600	1.64%	338.65	209.87	610.00	333.18	206.49
T6	Al Kurd	0.361	950	1100	1150	7.81%	611.20	378.79	1066.67	566.91	351.34
T7	Abu Nahla	0.365	675	650	580	6.30%	362.72	224.80	635.00	341.23	211.47
T8	Almaslakh	0.358	1150	1200	1100	4.35%	632.48	391.97	1150.00	606.12	375.64
T9	Alsaati	0.359	1050	1000	1050	1.61%	554.96	343.93	1033.33	546.15	338.48
T10	Almohafaza	0.365	275	250	200	13.79%	147.78	91.58	241.67	129.86	80.48
T11	Alsentral	0.366	260	240	250	4.00%	140.10	86.83	250.00	134.71	83.49
T12	Abu Youssef Alnajjar 1	0.356	640	700	650	5.53%	366.88	227.37	663.33	347.67	215.46
T13	Abu Youssef Alnajjar 2	0.362	150	150	150	0.00%	79.94	49.54	150.00	79.94	49.54
T14	Aljnenah Pump	0.358	570	550	600	4.65%	316.24	195.99	573.33	302.18	187.28
T15	Al Tabas	0.354	880	950	1050	9.38%	547.23	339.14	960.00	500.33	310.07
T16	Al Shaheed 1	0.358	710	600	660	8.12%	374.21	231.92	656.67	346.10	214.50
T17	Al Shaheed 2	0.357	700	750	700	4.65%	394.19	244.30	716.67	376.67	233.44
T18	Dowar Alawda	0.358	850	700	750	10.87%	448.00	277.65	766.67	404.08	250.43
T19	Al Balawi	0.357	850	750	800	6.25%	446.75	276.87	800.00	420.47	260.59
T20	Abu Hashem	0.361	500	450	550	10.00%	292.31	181.16	500.00	265.74	164.69
T21	Alkhazan	0.358	730	720	740	1.37%	390.03	241.72	730.00	384.76	238.45
T22	Almatafi	0.355	950	850	1100	13.79%	574.91	356.30	966.67	505.22	313.11
T23	Keer	0.358	850	800	650	10.87%	448.00	277.65	766.67	404.08	250.43
T24	Aldakhlyea	0.363	380	400	450	9.76%	240.49	149.04	410.00	219.11	135.79
T25	Al Huda Mosque	0.364	300	350	300	10.53%	187.56	116.24	316.67	169.70	105.17
T26	Almahmom	0.357	490	650	550	15.38%	341.63	211.73	563.33	296.08	183.50
T27	Dair Yaseen	0.365	650	650	620	1.56%	349.29	216.47	640.00	343.92	213.14
T28	Al Falogi	0.362	650	620	600	4.28%	346.42	214.69	623.33	332.21	205.88
Total							**9782**	**6062**	**17281**	**9188**	**5694**

Table D.2: Power demand in unbalanced and balanced loads for the Egyptian feeder No.2

ID	Transformer Name	V_{L-L} (kV) By ETAP	Unbalanced Load						Balanced Load		
			R (A)	S (A)	T (A)	LIUR	P_{MAX} (kW)	Q_{MAX} (Kvar)	Amp. (A)	P_{MAX} (kW)	Q_{MAX} (Kvar)
T1	Algas	0.382	410	400	480	11.63%	270	167	430.00	241.83	149.87
T2	Aljamaai	0.377	750	850	800	6.25%	472	292	800.00	444.03	275.18
T3	Aljawazat	0.379	700	950	720	20.25%	530	329	790.00	440.80	273.19
T4	Fathi 1	0.380	300	400	350	14.29%	224	139	350.00	195.81	121.35
T5	Fathi 2	0.384	350	350	300	5.00%	198	123	333.33	188.45	116.79
T6	Suq Alhalal	0.376	480	500	550	7.84%	304	189	510.00	282.32	174.96
T7	Bahlol	0.380	450	380	400	9.76%	252	156	410.00	229.38	142.15
T8	Almasri	0.377	580	620	600	3.33%	344	213	600.00	333.02	206.39
T9	Islamic Bank	0.366	450	450	550	13.79%	296	184	483.33	260.44	161.41
T10	School A	0.375	550	620	600	5.08%	342	212	590.00	325.73	201.87
T11	Berka	0.372	850	920	950	4.78%	520	322	906.67	496.56	307.74
T12	Salem Waterwell 1	0.375	500	550	600	9.09%	331	205	550.00	303.65	188.19
T13	Salem Waterwell 2	0.376	400	500	450	11.11%	277	172	450.00	249.10	154.38
T14	Abu Noqerah	0.372	750	800	950	14.00%	520	322	833.33	456.40	282.85
T15	Aldokhny	0.373	720	900	700	16.38%	494	306	773.33	424.67	263.19
T16	Shaikh Aleed	0.371	750	920	800	11.74%	503	311	823.33	449.71	278.70
T17	Alqassas	0.376	350	500	400	20.00%	277	172	416.67	230.65	142.94
T18	Alsiamat Waterwell	0.379	90	85	85	3.85%	50	31	86.67	48.36	29.97
T19	Alsawadah	0.374	340	420	350	13.51%	231	143	370.00	203.73	126.26
T20	Almohandseen	0.379	95	110	100	8.20%	61	38	101.67	56.73	35.16
T21	Khaled Keshta	0.387	100	100	100	0.00%	57	35	100.00	56.98	35.31
Total							**6554**	**4062**	**10708**	**5918**	**3668**

Table D.3: Power demand in unbalanced and balanced loads for the Egyptian feeder No.3

ID	Transformer Name	V_{L-L} (kV) By ETAP	Unbalanced Load						Balanced Load		
			R (A)	S (A)	T (A)	LIUR	P_{MAX} (kW)	Q_{MAX} (Kvar)	Amp.	P_{MAX} (kW)	Q_{MAX} (Kvar)
T1	Alsalam Alsharqi	0.378	600	700	500	16.67%	389.56	241.42	600.00	333.90	206.94
T2	Alsalam Algharbi	0.370	970	950	900	3.19%	528.39	327.47	940.00	512.05	317.34
T3	Alabed Jaber	0.365	690	550	600	12.50%	370.78	229.79	613.33	329.59	204.26
T4	Khawla	0.360	850	920	950	4.78%	503.51	312.05	906.67	480.54	297.81
T5	Altahleya Alkuwaiti	0.366	120	120	120	0.00%	64.66	40.07	120.00	64.66	40.07
T6	Alemam Ali Mosque	0.362	550	600	700	13.51%	373.07	231.21	616.67	328.65	203.68
T7	Alkateba	0.360	800	600	900	17.39%	477.01	295.62	766.67	406.34	251.83
T8	Dowar Zurob	0.358	800	750	850	6.25%	448.00	277.65	800.00	421.65	261.32
T9	Mohammed Atwa	0.357	400	400	450	8.00%	236.52	146.58	416.67	219.00	135.72
T10	Mohammed Atwa Pump	0.362	150	185	140	16.84%	98.60	61.10	158.33	84.38	52.30
T11	Ber 124	0.360	300	340	350	6.06%	185.50	114.96	330.00	174.90	108.39
T12	Alaksada	0.346	800	700	750	6.67%	407.52	252.56	750.00	382.05	236.77
T13	Alandalos	0.356	500	700	600	16.67%	366.88	227.37	600.00	314.47	194.89
T14	Jaser	0.354	600	600	650	5.41%	338.76	209.95	616.67	321.39	199.18
T15	Abu Asaker	0.354	630	700	750	8.17%	390.88	242.25	693.33	361.35	223.94
T16	Aliskan Alqadeem	0.355	570	540	500	6.21%	297.91	184.63	536.67	280.49	173.83
T17	Ber Aliskan	0.356	380	450	400	9.76%	235.85	146.17	410.00	214.89	133.18
T18	UNRWA Ber	0.357	370	350	350	3.74%	194.47	120.52	356.67	187.46	116.18
T19	Sewerage Pump	0.357	250	250	250	0.00%	131.40	81.43	250.00	131.40	81.43
T20	Abu Alsaeed	0.356	500	500	500	0.00%	262.06	162.41	500.00	262.06	162.41
T21	Abu Ataya	0.355	250	250	250	0.00%	130.66	80.98	250.00	130.66	80.98
T22	Almawasi Aljanobi	0.351	500	550	600	9.09%	310.05	192.15	550.00	284.22	176.14
T23	Almawasi Alshamaly	0.354	450	410	400	7.14%	234.53	145.35	420.00	218.89	135.66
T24	Almawasi Albahar	0.352	420	400	365	6.33%	217.66	134.89	395.00	204.70	126.86
T25	Almawasi Alqadeem	0.352	530	500	500	3.92%	274.66	170.22	510.00	264.30	163.80
T26	W1	0.357	75	75	70	2.27%	39.42	24.43	73.33	38.54	23.89
T27	W2	0.356	150	150	160	4.35%	83.86	51.97	153.33	80.36	49.81
T28	TR1	0.358	85	85	85	0.00%	44.80	27.76	85.00	44.80	27.76
T29	Alsakka	0.355	650	550	500	14.71%	339.72	210.54	566.67	296.17	183.55
T30	Abu Diaa	0.362	240	270	250	6.58%	143.90	89.18	253.33	135.01	83.67
Total							**8121**	**5033**	**14238**	**7509**	**4654**

Table D.4: Power demand in unbalanced and balanced loads for the IEC feeder.

ID	Transformer Name	V_{L-L} (kV) By ETAP	Unbalanced Load						Balanced Load		
			R (A)	S (A)	T (A)	LIUR	P_{MAX} (kW)	Q_{MAX} (Kvar)	Amp. (A)	P_{MAX} (kW)	Q_{MAX} (Kvar)
T1	Atyea	0.376	400	380	553	24.46%	306.12	189.72	444.33	245.97	152.44
T2	Zalata	0.374	567	710	695	8.01%	390.94	242.28	657.33	361.94	224.31
T3	Almashroa	0.368	750	780	730	3.54%	422.59	261.90	753.33	408.15	252.95
T4	Alassar	0.365	609	550	500	10.13%	327.26	202.82	553.00	297.16	184.17
T5	Abu Moammar 1	0.368	100	100	100	0.00%	54.18	33.58	100.00	54.18	33.58
T6	Abu Moammar 2	0.360	350	350	350	0.00%	185.50	114.96	350.00	185.50	114.96
T7	Tareq Abu Alhussein	0.364	425	345	390	9.91%	227.76	141.15	386.67	207.21	128.42
T8	Almelaha Aljawayea	0.354	820	700	750	8.37%	427.36	264.86	756.67	394.36	244.40
T9	Aldamaki	0.357	500	520	450	6.12%	273.31	169.38	490.00	257.54	159.61
T10	Abed Almaksoud	0.354	450	470	500	5.63%	260.59	161.50	473.33	246.69	152.88
T11	Almasri	0.354	650	750	685	7.91%	390.88	242.25	695.00	362.22	224.48
T12	Alribat	0.369	380	400	410	3.36%	222.74	138.04	396.67	215.49	133.55
T13	Hamza	0.353	720	750	700	3.69%	389.78	241.56	723.33	375.92	232.97
T14	Dowar Alkherba	0.352	640	550	600	7.26%	331.67	205.55	596.67	309.21	191.63
T15	Alzohor	0.347	580	400	450	21.68%	296.30	183.63	476.67	243.51	150.92
T16	Alshatawi	0.350	460	410	350	13.11%	237.03	146.90	406.67	209.55	129.87
T17	Abu Madi	0.344	160	160	160	0.00%	81.03	50.22	160.00	81.03	50.22
T18	Misabih	0.345	660	600	650	2.09%	335.23	207.76	636.67	323.38	200.41
T19	Morag	0.340	775	825	800	3.13%	412.96	255.93	800.00	400.45	248.18
T20	Alnaser 1	0.340	275	260	260	3.77%	137.65	85.31	265.00	132.65	82.21
T21	Alnaser 2	0.340	180	150	150	12.50%	90.10	55.84	160.00	80.09	49.64
T22	Isa Zurob	0.328	750	820	800	3.80%	395.97	245.40	790.00	381.49	236.42
T23	Hajaj	0.332	470	480	450	2.86%	234.62	145.40	466.67	228.10	141.36
T24	Khaled Alshaer	0.333	540	550	500	3.77%	269.64	167.11	530.00	259.84	161.03
T25	Alfokhri	0.338	200	200	200	0.00%	99.52	61.68	200.00	99.52	61.68
T26	Abar Alshoka	0.331	866	870	850	0.93%	423.96	262.75	862.00	420.06	260.33
T27	Islamic Institute	0.335	85	85	80	2.00%	41.92	25.98	83.33	41.10	25.47

T28	Abu Hadaid	0.339	400	400	400	0.00%	199.64	123.72	400.00	199.64	123.72
T29	Dehlez	0.341	250	220	200	11.94%	125.51	77.78	223.33	112.12	69.49
T30	Abu Taha	0.336	460	540	500	8.00%	267.12	165.55	500.00	247.34	153.29
T31	Alhashash	0.333	100	100	100	0.00%	49.03	30.38	100.00	49.03	30.38
T32	Abu Zohri	0.331	100	100	100	0.00%	48.73	30.20	100.00	48.73	30.20
T33	Barhoum	0.329	150	150	150	0.00%	72.66	45.03	150.00	72.66	45.03
T34	Alkholod 1	0.331	515	480	450	6.92%	250.97	155.53	481.67	234.72	145.47
T35	Alkholod 2	0.330	350	370	380	3.64%	184.62	114.42	366.67	178.14	110.40
T36	Eastern Canada	0.324	750	720	650	6.13%	357.76	221.72	706.67	337.08	208.91
T37	Western Canada	0.324	800	750	690	7.14%	381.61	236.50	746.67	356.17	220.73
T38	Alaytam	0.325	750	715	660	5.88%	358.86	222.40	708.33	338.92	210.05
T39	Bader 1	0.327	500	485	500	1.01%	240.71	149.18	495.00	238.30	147.69
T40	Bader 2	0.325	660	600	550	9.39%	315.80	195.71	603.33	288.68	178.91
T41	Bader 3	0.326	600	550	520	7.78%	287.97	178.47	556.67	267.17	165.58
T42	Bader 4	0.330	350	355	330	2.90%	172.47	106.89	345.00	167.61	103.88
T43	Bader 5	0.327	500	475	430	6.76%	240.71	149.18	468.33	225.47	139.73
T44	Aliskan Aljaded	0.329	294	320	300	5.03%	155.00	96.06	304.67	147.57	91.46
T45	TR2	0.331	60	60	60	0.00%	29.24	18.12	60.00	29.24	18.12
T46	Alfaqasa	0.368	135	150	130	8.43%	81.27	50.37	138.33	74.95	46.45
T47	Abu Ghali	0.353	530	550	500	4.43%	285.84	177.15	526.67	273.71	169.63
T48	Ghassan Kanafani	0.368	300	290	330	7.61%	178.79	110.80	306.67	166.15	102.97
T49	Alqadesyya	0.329	310	300	250	8.14%	150.15	93.06	286.67	138.85	86.05
T50	Mazyed	0.345	475	440	400	8.37%	241.26	149.52	438.33	222.64	137.98
T51	Almasrein	0.350	330	275	300	9.39%	170.04	105.38	301.67	155.44	96.34
T52	Sofa	0.364	350	390	420	8.62%	225.08	139.49	386.67	207.21	128.42
T53	Abed Alaal	0.337	380	410	420	4.13%	208.38	129.14	403.33	200.11	124.02
T54	Abu Omar	0.337	740	720	730	1.37%	367.15	227.54	730.00	362.19	224.46
Total							**12912**	**8002**	**24048**	**12162**	**7537**