IMPACT OF HIGH PENETRATION OF SOLAR PV DISTRIBUTED GENERATION ON KARABUK UNIVERSITY LOW VOLTAGE NETWORK

2022
MASTER THESIS
ELECTRICAL AND ELECTRONICS
ENGINEERING

Abbas Falah Hasan AL-GBURI

Thesis Advisor
Assist. Prof. Dr. Mohammad Abdullah
Mohammad ALMOKHTAR

IMPACT OF HIGH PENETRATION OF SOLAR PV DISTRIBUTED GENERATION ON KARABUK UNIVERSITY LOW VOLTAGE NETWORK

Abbas Falah Hasan AL-GBURI

T.C.
Karabuk University
Institute of Graduate Programs
Department of Electrical and Electronics Engineering
Prepared as
Master Thesis

Thesis Advisor
Assist. Prof. Dr. Mohammad Abdullah Mohammad ALMOKHTAR

KARABUK

July 2022

I certify that in my opinion the thesis submitted by Abbas Falah Hasan AL-GBURI titled "IMPACT OF HIGH PENETRATION OF SOLAR PV DISTRIBUTED GENERATION ON KARABUK UNIVERSITY LOW VOLTAGE NETWORK " is fully adequate in scope and in quality as a thesis for the degree of Master of Science.

Assist. Prof. Dr. Mohammad Abdullah Mohammad ALMOKHTAR ....
Thesis Advisor, Department of Electrical and Electronics Engineering

This thesis is accepted by the examining committee with a unanimous vote in the Department of Electrical and Electronics Engineering as a Master of Science thesis. July, 9, 2022

Examining Committee Members (Institutions)		Signature
Chairman	: Assist. Prof. Dr. Mustafa GÖKDAĞ (KBÜ)	....
Member	: Assist. Prof. Dr. Mohammad ALMOKHTAR (KBÜ)	....
Member	: Assoc. Prof. Dr. Osman ÇİÇEK (KASÜ)	....

The degree of Master of Science by the thesis submitted is approved by the Administrative Board of the Institute of Graduate Programs, Karabuk University.

Prof. Dr. Hasan SOLMAZ ....
Director of the Institute of Graduate Programs

“I declare that all the information within this thesis has been gathered and presented in accordance with academic regulations and ethical principles and I have according to the requirements of these regulations and principles cited all those which do not originate in this work as well.”

Abbas Falah Hasan AL-GBURI

ABSTRACT

M. Sc. Thesis

IMPACT OF HIGH PENETRATION OF SOLAR PV DISTRIBUTED GENERATION ON KARABUK UNIVERSITY LOW VOLTAGE NETWORK

Abbas Falah Hasan AL-GBURI

Karabük University
Institute of Graduate Programs
The Department of Electrical and Electronics Engineering

Thesis Advisor,
Assist. Prof. Dr. Mohammad Abdullah Mohammad ALMOKHTAR
July 2022, 69 pages

The installed cost of photovoltaic (PV) systems has reduced over the last years. Such systems can be installed either on land or on the roof as well as floating on water. Today, most integration of PV systems into the power system network is mostly seen on the low voltage distribution network. This inclusion is seen to bring both technological and environmental benefits to the traditional distribution network due to its reduction the pollution, low maintenance, minimization of transmission loss, and stress reduction on the power system. However, high integration brings some negative impacts on the system such as voltage rise, reverse power flow, harmonics, and increased power losses. Therefore, the limits of PV penetration in low voltage networks need to be determined to support the investment and to help the Distribution Network Operators to provide safe and reliable interconnection of PV distributed generation. Karabuk University was taken as a case study in this thesis. Electrical Transient Analyzer Program (ETAP) software was used to simulate the power system of Karabuk University’s electrical network. According to the simulation results, the voltage profile was improved and the feeder losses decreased as the PV penetration increased. The total harmonic distortion was increasing as the PV penetration increased. And finally, we concluded that the PV penetration level at Karabuk university must not exceed 75%.

Key Words : Distribution generation, penetration level, photovoltaics, power quality, renewable energy systems.
Science Code : 90544

ÖZET

Yüksek Lisans Tezi

GÜNEŞ PV DAĞITILMIŞ ÜRETİMİN YÜKSEK PENETRASYONUNUN KARABÜK ÜNİVERSİTESİ ALÇAK GERİLİM ŞEBEKESİ ÜZERİNE ETKİSİ

Abbas Falah Hasan AL-GBURI

Karabük Üniversitesi
Lisansüstü Eğitim Enstitüsü
Elektrik - Elektronik Mühendisliği Anabilim Dalı

Tez Danışmanı,
Assist. Prof. Dr. Mohammad Abdullah Mohammad ALMOKHTAR
Haziran 2022, 69 sayfa

Fotovoltaik (PV) sistemlerinin kurulu maliyeti son yıllarda azalmıştır. Bu sistemler karada veya çatıda kurulabileceği gibi su üzerinde yüzerek de yapılabilmektedir. Günümüzde, PV sistemlerinin güç sistemi ağına çoğu entegrasyonu, çoğunlukla alçak gerilim dağıtım şebekesinde görülmektedir. Bu dahil etmenin, kirliliği azaltması, düşük bakım gerektirmesi, iletim kaybını en aza indirmesi ve güç sistemi üzerindeki stresi azaltması nedeniyle geleneksel dağıtım şebekesine hem teknolojik hem de çevresel faydalar sağladığı görülmektedir. Ancak yüksek entegrasyon, sistem üzerinde voltaj yükselmesi, ters güç akışı, harmonikler ve artan güç kayıpları gibi bazı olumsuz etkileri beraberinde getirmektedir. Bu nedenle, yatırımı desteklemek ve Dağıtım Şebekesi Operatörlerinin PV dağıtılmış üretimin güvenli ve güvenilir ara bağlantısını sağlamalarına yardımcı olmak için alçak gerilim şebekelerinde PV penetrasyon sınırlarının belirlenmesi gerekir. Bu tezde Karabük Üniversitesi örnek olay olarak alınmıştır. Karabük Üniversitesi elektrik şebekesinin güç sisteminin simülasyonu için Elektriksel Geçici Analiz Programı (ETAP) yazılımı kullanıldı. Simülasyon sonuçlarına göre, PV penetrasyonu arttıkça gerilim profili iyileştirilmiş ve fider kayıpları azalmıştır. PV penetrasyonu arttıkça toplam harmonik distorsiyon artıyordu. Ve son olarak Karabük üniversitesindeki PV penetrasyon seviyesinin %75'i geçmemesi gerektiği sonucuna vardık.

Anahtar Kelimeler : Dağıtım üretimi, penetrasyon seviyesi, fotovoltaikler, güç kalitesi, yenilenebilir Enerji Sistemleri.

Bilim Kodu **:** 90544

ACKNOWLEDGMENT

At first and before everyone I would like to thank God who helped me to complete this study. After that I would like to thank my father and mother who supported me, and I would like to give thanks to my advisor, Assist. Prof. Dr. Mohammad Abdullah Mohammad ALMOKHTAR, for his great interest and assistance in preparation of this thesis.

CONTENTS

Page

Page

LIST OF FIGURES

Page

LIST OF TABLES

ABBREVITIONS

DG : Distribution generation
RES : Renewable energy sources
PV : Photovoltaic
FIT : Feed in traffic
ETAP : Electrical Transient Analyzer Program
DC : Direct current
AC : Alternating current
SWER : Single Wire Earth Return
OpenDSS : Open Distribution Simulation Software
LV : Low Voltage
OLTC : On Load Tap Changer
EPRI : Electric Power Research Institute
ANSI : American National Standard Institute
THD : Total Harmonic Distortion
IHD : Individual Harmonic Distortion
MPPT : Maximum Power Point Tracking
VOC : Open Circuit Voltage
PWM : Pulse-width modulation
P&O : Perturb and Observe

PART 1

INTRUDUCTION

PV systems have become more affordable to install in recent years. The global population and energy consumption are growing rapidly, especially in emerging nations. Electrical energy is one of the most fundamental human requirements. At present, fossil fuels still account for the dominant part of the global primary energy. However, conventional energy sources will not be able to supply increased electricity demand in the long run. Furthermore, over the last few decades, rising conventional fuel prices and unwelcome climate change have compelled governments all over the world to begin converting to renewable energy (RE) generation to assure a secure, inexpensive, ecologically clean, and long-term power supply [1]. RE sources (RES) can be utilized as centralized generation assets or deployed close to demand points in what is called distributed generations (DG). Among several renewable energy systems technologies, PV solar power generation is considered one of the most widely used and well-proven methods of generating power from solar radiation [2]. Solar PV has grown at a 25-35 percent on annual pace over the last decade, making it one of the fastest-growing energy sources [3]. By the end of 2019, the global capacity of solar PV installations had surpassed 627 GW. Figure1.1 shows the global growth of solar PV energy over the past years, along with the largest countries in installing and generating electricity from solar PV energy.

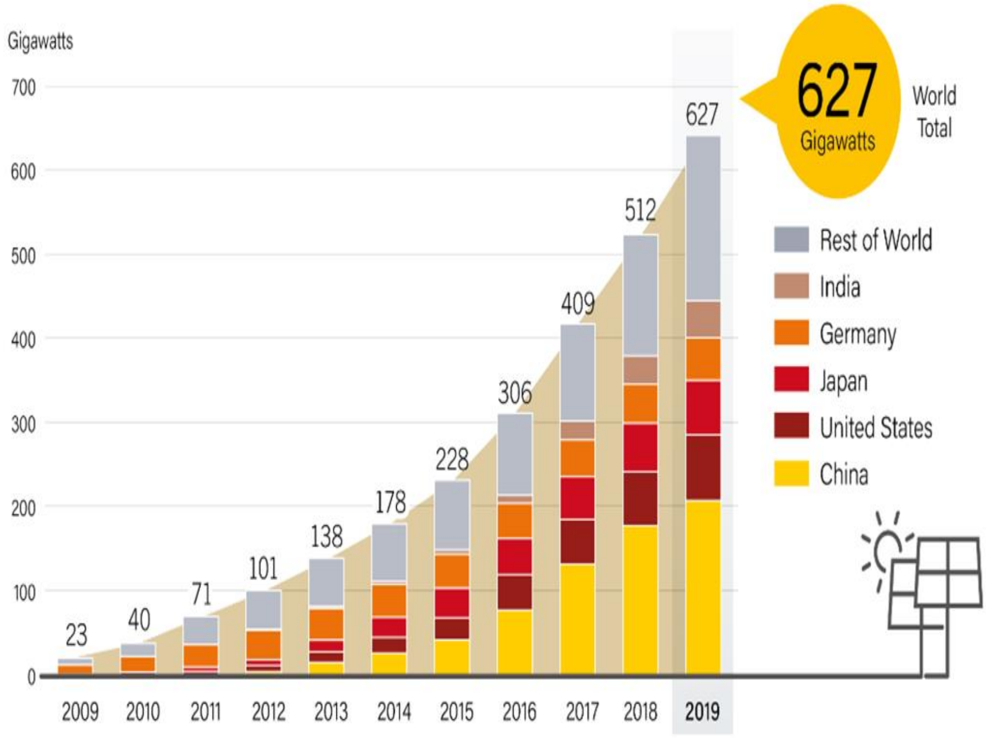


Figure 1.1. Global Solar PV Capacity until 2019 [4].

PV systems are extensively utilized in a variety of applications, ranging from small cells in calculators that require a little amount of electricity to huge-scale PV facilities that tens of megawatts of power. Although PV systems have a wide range of uses, their primary use is in power production, whether in grid-connected or off-grid systems. Off-grid PV systems are frequently used to supply remote loads which do not have grid accessibility to the power grid. Solar PV systems that are grid-connected can be positioned close to the load for power generation, eliminating transmission and distribution expenses [5]. The use of grid-connected solar generators has increased significantly in recent decades. The need to deploy grid-connected PV systems stems from a number of factors, including global warming, pollution, and the need to reduce the reliance on fossil fuel supplies. Moreover, utilities and consumers might profit from the installation of these systems in cases where newly discovered technologies have prompted them to begin using distributed energy resources such as PV systems. The prosumer utilizing a solar PV system can sell its clean energy back to the utility grid at a premium price benefiting from one of the renewable energy policies such as Feed-in Tariff (FiT) or net metering, etc. [6].

1.1. GRID-CONNECTED PV SYSTEMS

The integration of PV systems into the power system network is now largely noticeable in the distribution and transmission network. The number of grid-connected solar panels installed throughout the world is increasing. The continual improvement of the PV system and inverter efficiency, as well as cheap costs owing to various government advantages such as loans, funds, subsidies, and incentives such as FiT, are the primary causes for this growth [7]. Furthermore, there are other advantages to the use of PV systems in conjunction with electrical power systems, including [8]:

1. Increased voltage stability throughout the system.
2. Reducing the flow of reactive power.
3. Reduction of power loss.
4. Contamination reduction.
5. Lowering maintenance costs and investment deferments of power system expansion.

A number of requirements must be followed in order to acquire all the aforementioned advantages, such as:

1. The PV system should be strategically placed.
2. Appropriate PV system sizing.

If one or more of these requirements are not met, the advantages may be negated, as will be detailed in this study. In fact, high adoption of PV systems as distributed generations may also lead to negative consequences in the distribution system and also the power system as a whole and the main idea of this research work is to study different aspects of increasing the integration of renewable energy specifically the solar PV systems in the power system.

1.2. PROBLEM STATEMENT

The use of large-scale PV generators can have an impact on power networks and pose major issues that must be addressed. High integration may have an adverse effect on the grid, such as voltage increase, reverse power flow, and harmonics. As a result, the amount of penetration of distributed generating systems in the power system must be critically assessed. PV power systems are of great interest, and their impact on the current transmission or distribution system must be extensively analyzed before any integration into the power system may take place.

1.3. OBJECTIVE OF THE RESEARCH

Karabuk University has begun installing PV power generators on some of its buildings; yet, the effect of the increasing number of such systems is not investigated. The objective of this research is to study the effect of high penetration of solar PV supply acting as distributed generations on the Karabuk university’s low voltage power system. In this research study, Electrical Transient Analyzer Program (ETAP) software is used to simulate the power system of Karabuk University. Simulation results of Karabuk University with different levels of PV penetration will be acquired and power quality will be evaluated.

1.4. METHODOLOGY OF THE WORK

Data concerning the electrical power grid of Karabuk University are collected. Data include electrical demand, line data, transformers ratings, etc. Then, Karabuk university’s low voltage grid using ETAP software is modeled. PV power generators with different penetration levels are modeled and integrated into the simulated network. After that, the load flow and harmonic analysis were conducted without and with PV penetration in the simulation. The results of the simulation without PV penetration are compared with the case where different levels of PV penetration are considered. In the end, the allowable PV penetration level for Karabuk university is identified. The methodology's flow chart is illustrated in Figure 1.2.

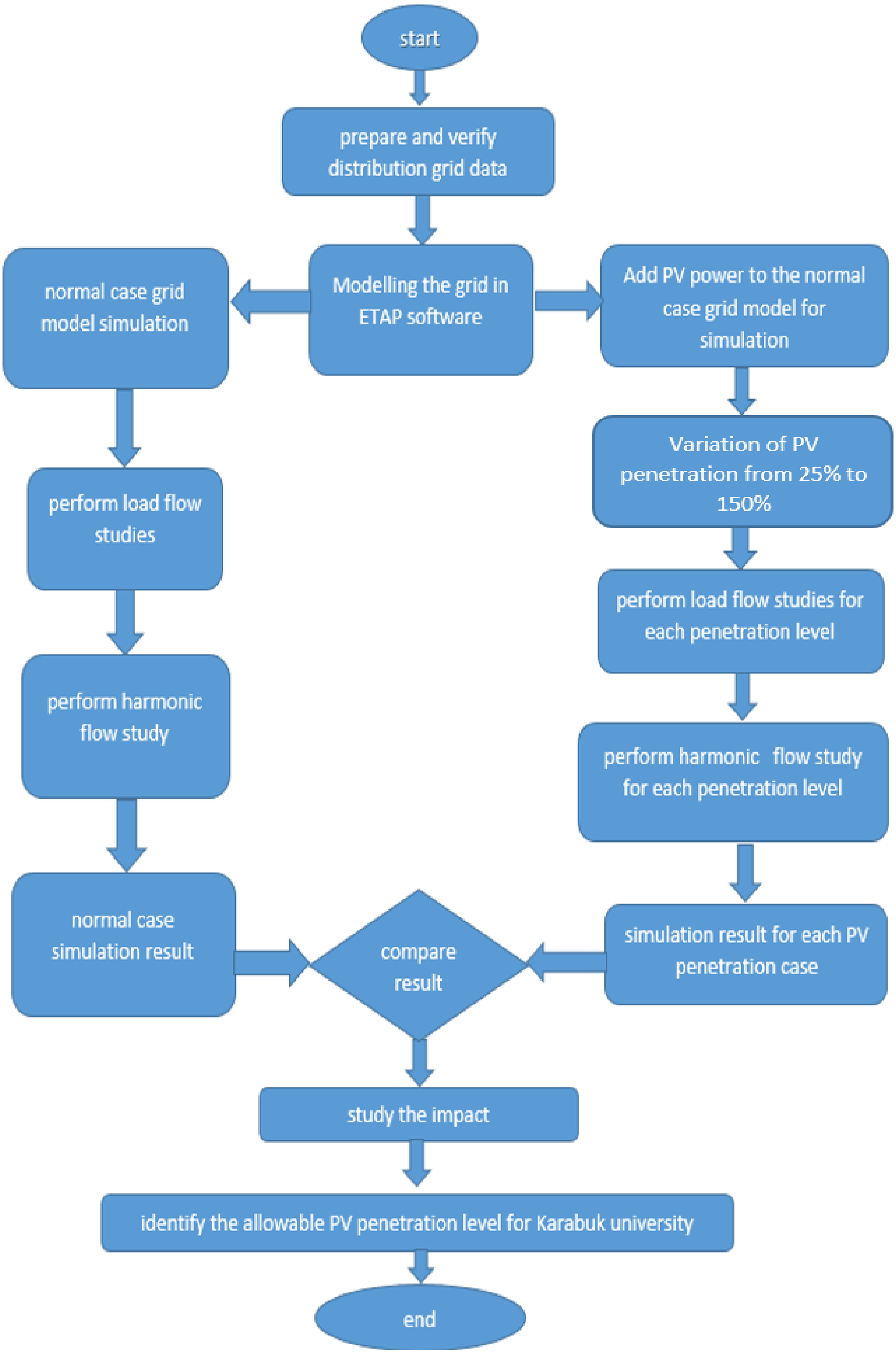


Figure 1.2. Flow Chart of Systematic Methodology.

1.5. OVERVIEW OF THE THESIS

The thesis is subdivided into five sections; the first part provides an introduction, research problem, objectives, and the methodology followed by this research. In the second chapter, a survey of the available literature on the subject is presented. Detailed data and modeling of the research are introduced in chapter 3. Simulation results are analyzed in chapter 4. In the fifth part of the thesis, the main conclusion and future work are summarized.

PART 2

LITRUCTURE REVIEW

Solar energy technology is one of the world's fastest growing power producing technologies. Over the years, the cost of solar energy production has been decreasing, and utilization rates have begun to increase, and these developments have attracted the attention of researchers and have led them to focus more on PV power rather than other energy sources. Advances in technology, as well as worries concerns about climate change, are prompting companies and clients to increase their usage of PV systems especially the grid-connected ones. Moreover, the fluctuation of these systems' output power may offer certain issues to the operation of the electric network.

2.1. LOAD FLOW STUDY

Load flow is an essential tool used by electrical specialists for managing and organizing in order to establish the optimal running for distributed power systems power exchange between utility firms. For a long time, load flow analyses were performed using a special-purpose analog computer known as an ac network analyzer, but high-speed computers have since superseded them. The transition from an ac network analyzer to a digital computer has led to increased flexibility, cost savings, and faster operation. However, the network analyzer is still employed in the early phases of design. During the last decades, electrical engineers have been working on power quality improvement using new software tools. Recent discoveries in electrical engineering sciences have resulted in a revolution in the field of electrical engineering, thanks to the development of powerful computer-based software [9].

Load flow techniques may take a long time to compute; as a result, the continual fluctuations in power demand and generation preclude attaining an exact result for a load flow solution. A load flow study's key outcomes are the magnitude and phase angle of the voltage at each bus, as well as the active and reactive power flow within every line [10].

Transformers, lines, generators, protection and control, and loads are the main components of the electrical power system. When these components are linked together, they constitute a system for securely converting large amounts of energy to electrical form, transferring and distributing it, and providing it to the client in a useable form. A load flow is a method by which engineers and technicians establish the system's orderly functioning in order to supply energy to the consumer. It is, indeed, a system that necessitates a systemic response. Following the creation of detailed models for each key component, the load flow tools combine these models and execute the calculations required to estimate the voltage state of the system and the power flows from bus to bus.

Under steady-state conditions, power flow studies give a systematic mathematical technique for determining the different bus voltages, phase angles, active and reactive power flows across various branches, generators, transformer settings, and load. The power system is represented by an electric circuit that includes generators, a transmission network, and a distribution network. The ensuing power equations, termed as power flow equations, become non-linear and must be solved iteratively and numerically. Numerical methods are ways of phrasing mathematical problems such that they may be solved using arithmetic operations, and they typically offer just an approximate answer. Hand calculations are adequate for estimating the operational parameters of little individual circuits, however precise estimates of load flows or short circuit analyses are impracticable without the use of computer systems. Significance of load flow analysis in power system:

1. Within a steady state, we could acquire the voltage magnitudes and angles at every bus. It is important since these magnitudes of the bus voltages should always be maintained within a specified range. The real as well as reactive power

flow over each line may be estimated at the moment that the bus voltage magnitudes and angles are determined utilizing the load flow.

2. The losses inside a particular line may also be computed using the difference in power flow between the transmitting and receiving ends.
3. Researchers also can recognize over as well as under load issues based on the line flow.
4. A load flow of a power system is wanted to determine the optimal operating of the present system and to plan for future system growth.
5. It aids in the design of a new power grid.
6. It aids in the reduction of system losses and the selection of transformer taps for cost-effective operation.

2.2. LOAD FLOW STUDY APPROACHES

Digital computers were first utilized to determine load flow in the mid-1950s. Various methods for calculating load flow have been utilized. The creation of these approaches is primarily motivated by the fundamental requirements of load flow computation, like convergence qualities, obtain accurate, memory requirements, ease, and flexibility of application. With the introduction of rapid and huge capacity digital computers, all forms of power system analysis, involving load flow, will now be done easily [11].

Load flow issue is a mathematical issue involving the solution of a set of nonlinear algebraic equations. In general, its solution cannot bypass some level of iteration. As a result, dependable convergence becomes the most important condition of a load flow computation technique. As the size of power systems continues to rise, the dimension of load flow equations has gotten fairly vast. We cannot guarantee that any mathematical approach will reach a valid solution for problems with such enormous dimensions. This condition necessitates the quest for more trustworthy approaches by academics and scholars in the field of power system analysis. The digital computer had progressed to the second generation by the early 1960s. Computer memory and computation performance have significantly improved, creating ideal circumstances for the implementation of the impedance method. The numerical method gives a means for finding solutions using a computer; consequently, it is necessary to decide which numerical method is quicker and further trustworthy so as to obtain better results with regard to load flow analysis.

The Gauss–Seidel iterative approach centered on a nodal admittance matrix was frequently utilized in the beginning of employing digital computers to address power system load flow issues. This method's idea is straightforward, and its memory requirements are minimal. These characteristics made it appropriate for the level of computer and power system theory at the time. unfortunately, the method convergence is insufficient. When the size of the system grows greater, the numeral of iterations rises dramatically, and the iteration process sometimes fails to converge. Because of this issue, the sequential substitution approach focused on the nodal impedance matrix was used, and this method is known as the impedance method.

The digital computer had advanced to the second generation by the beginning of the 1960s. Computer memory and computation performance have dramatically become better, creating ideal circumstances for the implementation of the impedance approach. The impedance matrix is a complete matrix. The impedance technique necessitates the computer to store the impedance matrix, which reflects the power network's structure and characteristics. As a result, it needs a large size of computer memory. moreover, every member in the impedance matrix must be acted on in each iteration, resulting in a g processing overhead [12].

The impedance method enhanced convergence and handled several load flow issues that the Gauss–Seidel method couldn't. As a result, the impedance approach became extensively used and made significant contributions to power system design, operation, and research. The impedance method's primary disadvantage is its big memory required and processing overhead. The greater the system, lead to further the faults. To address this shortcoming, the solution approach depends on the impedance matrix was devised [13]. This approach separates a huge system into multiple tiny local systems, and just the impedance matrices of these local systems, as well as the impedances of the lines connecting these local systems, are registered in the computer. As a result, the memory need and processing stress are considerably reduced.

The Newton–Raphson technique [14] is another strategy for processing the incapability of the impedance method. The Newton method is a popular strategy in mathematics for resolving nonlinear equations with a significant level of convergence. The Newton method's computing performance can be greatly improved if the sparsity of the Jacobean matrix is utilized in the iterative phase. Because of the optimal order elimination approach [15], Since its introduction in the mid-1960s, the Newton approach has outperformed the impedance technique in terms of convergence, memory requirement, and computation quickness. This method is yet the preferred approach for calculating load flow and is frequently used these days.

Since the 1970s, the calculation of the load flow method has evolved in a variety of directions. The rapid decoupled technique, often known as the P Q decoupled method, is the most effective of them. This approach is simpler and more efficient algorithmically than the Newton method, and hence more common in many situations [16]. Load flow calculation research has been quite active in the last 20 years. Many contributions aim to enhance the Newton method and the PQ decoupled method's convergence properties. In addition to the advancement of artificial intelligence theory, the genetic algorithm, artificial neural network algorithm, and fuzzy algorithm have been introduced to load flow analysis [17]. However, these new versions and technologies are still not capable of replacing the Newton technique and the PQ decoupling approach. Because power system scales continue to rise and the need for online computation becomes higher pressing, parallel computing methods are currently being explored intensely and may become an important research subject [18].

2.3. SOLAR PV TECHNOLOGY

Solar PV power, an important renewable energy source, has seen growth in installations in most countries of the globe [19]. This is due to the Sun's copious sunshine beaming on the world each year, making the conversion of this source to useable sustainable electric power a key priority for the majority of developed and developing countries. A solar cell is used in a solar PV system to convert the energy (thermal and radiant) in sunshine into direct current (DC) electricity [20]. Figure 2.1 depicts a straightforward mechanism for converting sunlight to electric power.

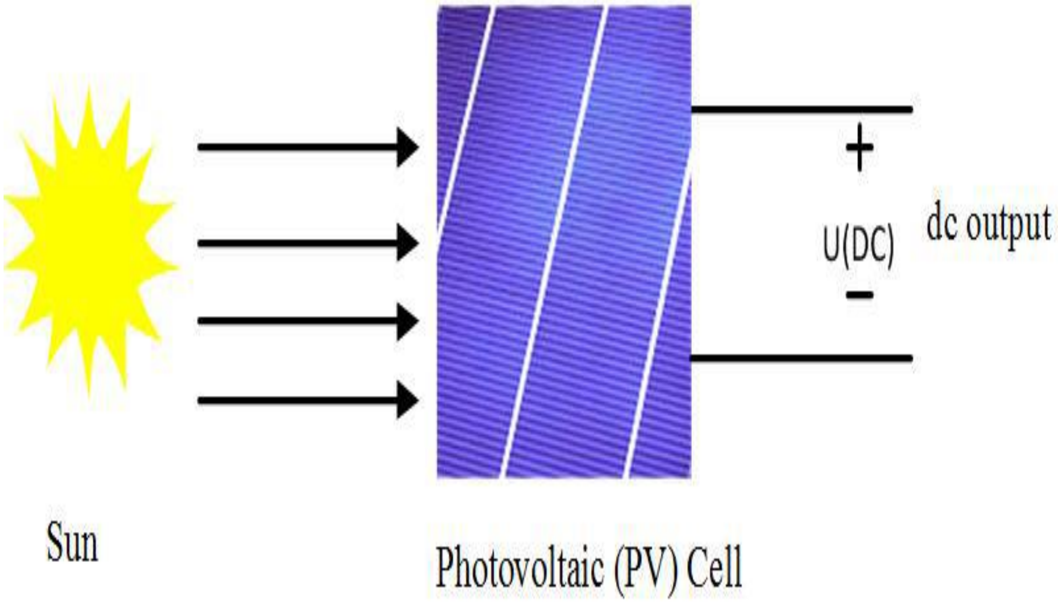


Figure 2.1. PV Cell System.

This solar cell's substance is silicon, which is semi-conductive in nature. Mono-crystalline, poly-crystalline, and amorphous silicon are the materials used in the bulk of solar cells today [21]. A single cell's current and voltage are extremely tiny. For larger voltage and current, the cells are linked in series to maximize output voltage and in order to get higher output current. A solar PV module is made up of cells, and a PV array is consisting of modules for high voltage, current, and power production. A solar PV array is made up of modules that are linked in series and parallel. Because direct current electricity is produced, it may be applied in two ways. The first method is to establish a grid of DC loads that can use the produced DC electricity. The second method is to link power conditioning equipment (power electronics converters) to convert produced DC electricity to alternating current (AC). This is due to the fact that the majority of electrical loads nowadays use AC electricity. Figure 2.2 depicts a full solar PV array configuration with power conditioning components for converting to AC output power.

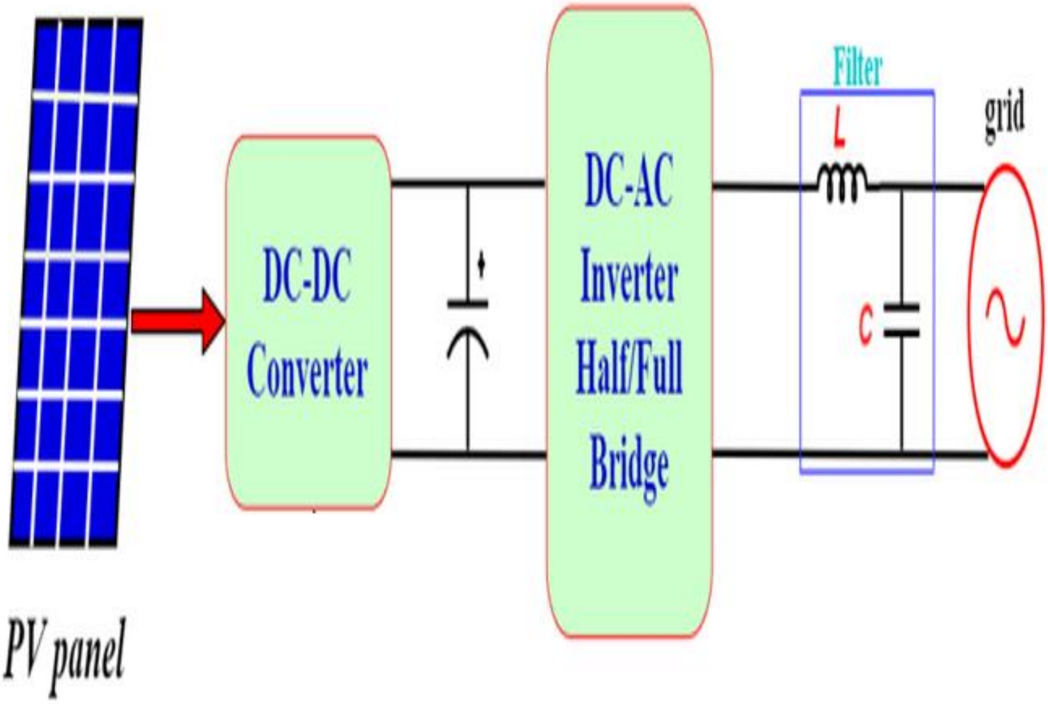


Figure 2.2. Typical Complete Solar PV System.

The output dc voltage and current vary as the array's irradiation and temperature change. The DC-DC converter provides the stability of the DC provided to the dc-ac inverter. The inverter transforms DC to AC, which might be a single or three phases depending on the application. At the inverter's output, wires, filter circuits, and a transformer are added for grid integration.

2.4. PV SYSTEM INTEGRATION IMPACT ON THE UTILITY GRID

The PV grid connected systems are often deployed to improve the operation of the electric grid by dropping power wastage and enhancing the network's voltage. That is not always the situation, since these systems can have a lot of detrimental influence on the grid, mainly if the systems penetration level is significant. Power as well as voltage variations problems, harmonic distortion, Deficiencies in defensive mechanisms, and overloading as well as under loading are all examples of harmful influences [22].

The investigation of the possible effects of PV systems on the electric grid is now a subject of discussion that is attracting vast interest from academics as well as energy providers. The fundamental cause for the relevance of this topic is because an overall rating of these influences, as well as suggesting practical solutions to any difficulties that may occur as a result of installing PV systems, is viewed as a crucial move in allowing more people to use solar power.

2.4.1. Reverse Power Flow and Voltage Impact

High penetration of PV-DG during light load conditions can result in reverse power flow at section, substation transformer, and feeder levels [23]. Some fault conditions can also create significant reverse power flows which have to be sensed and cleared by system protection devices. This situation usually affects the operations of voltage regulators and over-current protection devices because their traditional designs only allow a unidirectional power flow. The introduction of PV-DG can cause voltage rise, fluctuations or unbalance out of limit, as specified by IEEE Std. 1547-2003 and ANSI C84.1 (0.95-1.05 p.u.) [24]. The integration of a huge proportion of PV generators into a utility grid creates a considerable rise in voltage levels owing to backward power flow, which may be viewed as a serious technical fault.

For example, in Australian Single Wire Earth Return (SWER) networks, the influence of different PV system penetration levels and sizes on steady state voltage was examined and modeled. It has been demonstrated that in significant penetrations, this type of network frequently encounters voltage increases [25].

In [26], the European Low Voltage Test Feeder was chosen to study the influence of high PV penetration in terms of voltage unbalance, voltage rise, and reverse power flow using The Open Distribution Simulation Software (OpenDSS) program. Two scenarios were used in the simulation. Firstly, a maximum of 100 % PV penetration is spread unevenly throughout all three phases on various buses using a PV profile with cloudless sky irradiance. Secondly, a maximum of 100 % PV penetration is spread unevenly throughout all three phases on separate buses with substantial irradiance fluctuation. From the simulation results, voltage rises and voltage unbalance were experienced in both scenarios. Besides that, the second scenario had a greater influence on the distribution system than the first. This PV power penetration behavior might lead protective devices to lose coordination for tripping during fault circumstances.

The study in [27] used the Open Distribution Simulation Software to simulate the low voltage (LV) network of a residential area in Malaysia. The PV penetration level was performed from 0-200 %. The results revealed that when the generation of PV electricity exceeds the demand, the voltage will rise, but it remains within the permissible limit except for the small feeder distance and the strong cable rating.

In [28], a model of a typical UK LV power grid was used to perform the assessment with grid-connected PV systems that have a high penetration utilizing MATLAB/Simulink. Different scenarios for 25, 50, and 100 % penetration level have been considered under various loading conditions as well as the voltage profile across the 230/400 V feeder has been determined. From the simulation result, the first and second scenarios with 25 % and 50 % penetration respectively indicated that the voltage level is still within the legal limits. On the contrary, the third scenario that involved 100 % penetration indicated that the voltage level increased above the threshold of the voltage magnitude 230/400 V from 11.00 a.m. until 2.00 p.m.

An investigation of the effect of high PV penetration on the power network in various weather conditions in Kuala Lumpur was examined in [29]. The meteorological data were provided by the Malaysian Meteorological Department. A PV system of 1.8 MW capacity was connected to a 16-bus to examine the system and simulated utilizing Matlab/Simulink software. Various penetration levels particularly 6 %, 12 %, and 18 % were simulated. It was found that active power produced via the PV system created voltage starts rising, voltage flicker and power factor lowering.

In [30], a study was performed in a 13-bus IEEE test distribution feeder with different penetration levels. The study reported that the penetration with a low level enhances the voltage profile and decreases the overall losses in the system due to a reduction in the overall power consumption from the substation. However, when the penetration level overtakes the integration limits, the voltage range put up by The American National Standards Institute (ANSI) got violated such as overvoltage, voltage instability, and the system losses begin to increase. The influence of high PV penetration in the LV grid was decreased by using voltage control for example smart inverter control method, on-load tap changer (OLTC), and FACTS devices.

The effect of PV grid connected system in terms of voltage execution and losses by using OpenDss simulator software was investigated in [31]. In the study, IEEE 13-bus was used. From the simulation results, it is concluded that the penetration levels from 10 % to 50 % led to voltage perfection, and 86 % penetration represents the ultimate penetration that could be connected to the system without causing voltage violation. The losses of the system were decreased until lower losses at 90 % and 100 % penetration due to the load power being the same as the power of the PV system. After 100% PV penetration the losses began to increase, but it was yet lower than the system without PV connection. Beyond 170% PV penetration the losses exceeded the losses of the grid without PV connection.

In [32], the system of 70 kV transmission and 10 kV distribution feeders was simulated by Matlab and OpenDSS program with the Instability of high solar PV power. It was found that each hour the PV system produced different power, creating voltage fluctuations in both the distribution and transmission systems.

The authors in [33] studied the impact of PV-DG integrated into three Swedish LV grids. PV systems rated between 1 and 5 kWp per household were connected to the grids. From load flow simulation it was stated that whenever the PV penetration rises the voltage also rises at the buses of the three grids but it is still within the nominal limit.

In [34], a study of the impact of high PV penetration levels on solar power variation subject to cloud shadows was carried out. In this study, OpenDSS and Matlab were used to simulate the Electric Power Research Institute (EPRI) test feeder. The study reported that 20% PV penetration at a single location resulted in severe flicker and voltage limit violation. On the other hand, when the PV systems are well distributed, the voltage violations are not even found at a 50 % PV penetration level.

2.4.2. Impact on Power Losses

The quantity of electricity lost in any grid varies greatly according to the grid architecture. The magnitude of losses is directly proportional to the magnitude of power flows. The advent of PV has changed the way the distribution network is used, with extra unusual and two directional power flows. As a result, the presence of PV systems and the resulting changed power flows might have a major influence on power losses [35].

PV systems may offer an opportunity to reduce power losses at low to moderate penetration levels. If feeder losses are considerable, adding a lot of modest capacity of PV units will have a significant beneficial effect on the losses and will greatly improve the system. Normally, it is considered that losses reduce as generation feeds nearby clients. PV integration can help to minimize maximum congestion in power lines, as they can also help to reduce losses when placed close to local load centers. This means that network repairs, which have become essential as load demands increase, might be postponed by the installation of local PV systems [36].

On the other hand, line losses tend to grow large Scale PV penetration levels and inadequate synchronicity between supply and local load for a variety of reasons. Under significant PV penetration, the loading on distribution lines may be larger than under typical feeder loading circumstances. Feeder capacity is restricted because of the thermal properties of overhead wires and cables, which cannot be surpassed. If feeder capacity limitations are surpassed, the distribution grid experiences local over-loading and the network experiences high pressure i.e., Overload in the distribution system grid. This circumstance necessitates grid improvements; it is a costly approach for integrating PV. Another issue that might be contributing to the rise in grid losses is a reduction of local reactive power supply from capacitor banks (if they were turned off owing to a voltage increase). Furthermore, the increased nodal voltage caused by large PV penetration would raise the losses of distribution grid transformers [37].

In [38], the researchers provided combined low voltage network losses and overall transformer loading reductions for an exemplary metropolitan network as increasing in PV penetration from 30 % to 50 % because of the huge quantities of opposite power flows at 50 % penetration, lowering of loss was not linear to penetration levels, and transformer loading was minimized during sun hours.

The authors in [38] installed two balancing inverters having centralized and decentralized controllers to reduce distribution grid losses. The central control took into account the voltage drops across the line, which are affected by the line current, whereas the decentralized control took into account the absolute values of the decentralized voltage readings. The distribution network losses were decreased by around 10 % as a result of the optimum control.

The effect of various DGs like solar PV and wind systems was investigated in [40]. The study discovered that System losses are minimized with growing DG penetration until a minimal amount is achieved and then continue to climb with maximizing penetration level, with losses larger than the base case. The authors found that controlling voltage and reactive power, whether supplied or absorbed via the PV inverter, should help to decrease energy losses.

2.4.3. Harmonic Impact

Harmonics are any frequencies other than the main frequency that occur in the system. In other terms, harmonics show on power lines as a distortion on the desired sinusoidal waveform. The rising usage of solar power plants has resulted in a rise in the use of power electronic equipment, such as DC/AC converters. Inverters are the name given to these power electrical equipment. Inverters are primarily used to convert direct current to alternating current and to serve as a bridge between renewable energy and the grid. In power plants, inverter-based technologies and various non-linear loads are employed to create harmonics in the system.

Because of the ever-increasing usage of the equipment, the power electronics such as changeable speed motor drives, UPS systems, power converters, rectifiers, and other power electronic instruments, the system voltage and current power quality are severely impacted in a variety of ways. Higher frequency components begin to circulate in power networks, distorting the wave patterns of voltage and current. These higher frequency components are integer multipliers of the fundamental frequency and are referred to as harmonics. Nonlinear loads are harmonic emitting equipment that consists of power electronic switching devices, transformers, motors, fluorescent lights, arc furnaces, and a variety of else instruments. Such gadgets generate major issues with the system's power quality.

Harmonics in every power system causes a number of issues and effects, including device Overheating, reduced power factor of devices, poor quality of electronic systems, unexpected behavior of protection systems, disruptions with communication systems, resonance to many devices causing failure of these devices, noise, the turbulence of electrical motors, as well as other impacts.

A PV solar inverter is typically thought of as a continuous harmonic current generator. The researchers in [39] studied harmonics produced (including current as well as voltage) and their impact on system stability by a PV solar inverter or multiple solar PV inverters.

PV systems, as addressed earlier, comprise PV panels, a boost converter, a DC/AC inverter, and an interface LC filter [40]. Because of the rapid growth of PV technology, a varied range of PV inverter technologies utilizing a variety of control approaches is now commercially accessible in the market. Depending mostly on the control strategy employed, the size of the PV system, and the grid voltage harmonics, the harmonics produced by such inverters will then be divergent. Harmonics injected into the grid must fulfill requirements in order to maintain stable grid power quality. Nonetheless, these PV inverters interact poorly in the real network [41].

In [42], a PQ analyzer (Topas 1000) was put in two places of a 20 kV rural distribution grid in southwest Spain. A PV plant with a total capacity of 995 kW is located 4 kilometers from the substation. At the substation, data was collected over two time periods (with or without PV generation linked to the system) and a comparison is performed throughout the two monitoring periods. Then, at the PCC, the efficiency of the PV injected electricity into the network was assessed. For the two points when the PV system operates at maximum power values, it was demonstrated that reactive power consumption has increased in the grid via the PV-connected system and the power factor has decreased to unacceptable levels because the PV system has supplied the majority of active power demanded by the customers, lowering the need for the active power of the network, and the total harmonic distortion index (THDI) reached extremely high values.

Another study [43] on the harmonic impact in grid connected PV systems within Manisa, Turkey using the Pspice simulation program was conducted. The obtained results showed that the harmonic distortion decreases when the PV generators are located close to the transformer. Moreover, the study recommended that the inverters accompanying PV systems should be selected carefully because the inverters affected the harmonic levels, therefore using an inverter with higher harmonics will cause an increase in the current harmonic distortion.

The IEEE-13 bus distribution grid was simulated using the PSCAD software tool to research the harmonic effect with high PV penetration [44]. From the simulation result, it was concluded that the voltage as well as current harmonic distortion increased following the increase of PV penetration.

A review of the harmonic impact of PV integration was provided in [45]. The authors concluded that the current and voltage THD increased with the increase in penetration level of PV generation. During the integration of PV generation in a different location in the grid, it was noticed that the current and voltage THD was higher at the distant end of the feeder and also lower at the start of the feeder.

A rooftop PV system with different penetration levels was connected to the low voltage distribution system in Thailand and the harmonic impact was studied [46]. DIgSILENT Power Factory program was used to simulate the system. The simulation result showed that the total harmonic distortion exceeded the standard whenever the PV penetration integrated into the grid is more than 60 %.

In [47], real measurements from four urban sites with high PV penetration connected to the grid were investigated in terms of allowable PV penetration, power quality, harmonic, and power flow across the transformer. The first site Solarsiedlung “Am Schlierberg”, Freiburg, Germany consists of 440 kWp PV array connected to the grid through 160 inverters. The obtained results revealed that the voltage raised 5V above the nominal voltage and the total harmonic distortion was below the standard level. The second site, Holiday park Bronsbergen, is located in The Netherlands with a 315 kW total PV capacity. The experiment showed no unexpected voltage change and the 11th or 15th harmonic order is above the standards limit. The third site, Mayersloot, site is located at Langedijk, Heerhugowaard with 130 kWp total PV power. From the measurement result, it was found that the voltage was varying between 235 and 242 V and is considered within the acceptable level. It was also concluded that the harmonic issue occurs when there is a resonance issue. The fourth site, Soleil-Marguerite, is located in Lyon, France with 13 kW total PV power. The experiment exhibited that the voltage was within the standard range and the voltage harmonic was low and below the limit.

In [48], the DIgSILENT Power Factory tool was used to simulate and analyze the impact of a rooftop PV generator that was installed with different penetration levels to the grid. From the simulation results, it was reported that the PV penetration of more than 60% violated the THD limit in the LV distribution system.

The harmonic effect on the LV network in the Netherlands with high PV penetration was explored in [49]. Modeling of 96 house network involved three scenarios. In the first scenario, each home has a Solar panel as well as a linear load, in the second scenario, each house has a Solar panel as well as one nonlinear load (RL), and in the third scenario, every house has a Solar panel as well as four nonlinear loads (2 RL as well as 2 RC). According to the simulation results, it was reported that the inclusion of non-linear loads, particularly RC-type loads, that may be located mainly in a wide range of electronic equipment, increased THD.

PART 3

DATA AND MODELLING

In this chapter, collected data are presented and realistic modeling of the PV system, load demand, and transmission network was accomplished to explore the influence of PV systems on different power quality characteristics in the context of the power distribution system. This chapter discusses the basic theory and thorough modeling of several grid-connected PV system components such as the PV source, maximum power point tracking approaches, DC to DC converter, and DC to AC inverter. The specifics of the design and modeling of Karabuk University's low voltage grid with and without PV integration will be acquired after that. This chapter also explains and demonstrates ETAP simulations of the whole system.

3.1. GRID CONNECTED PV SYSREM

Solar PV systems that are grid-connected convert sunlight into alternating current power. Figure 3.1 depicts the basic block diagram of a grid-connected PV system. Arrays of solar PV panels, a boost converter, and an inverter with maximum power point tracking (MPPT) comprise the system. Excess electricity from grid-connected PV systems may be fed into the grid and consumed by other customers.

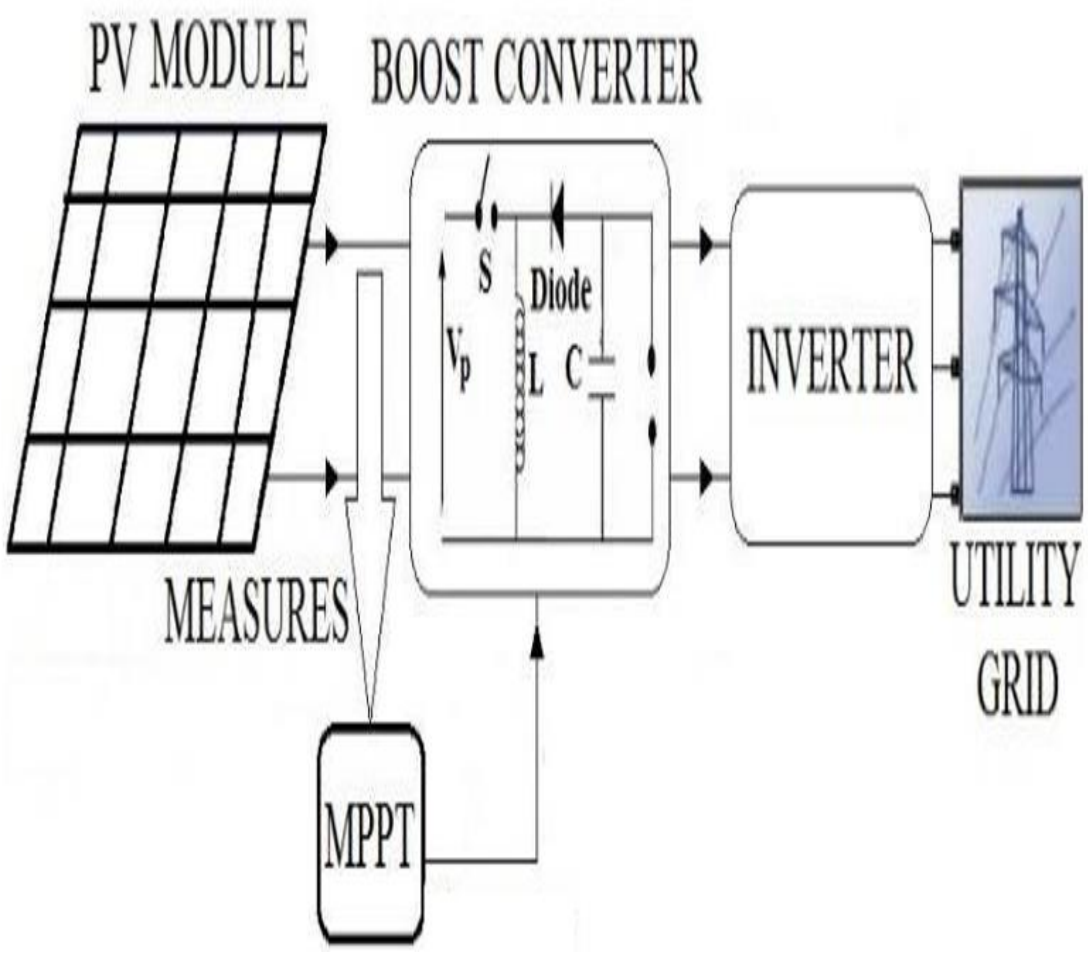


Figure 3.1. Block Diagram of Grid Connected PV System.

Solar cells are usually connected in series to make a solar module, which will then be connected in series to make a string. Then, the strings are joined in a PV array by connecting them in parallel. The number of modules within every string is determined by the array's needed voltage level. The amount of strings is determined by the array's current rating need.

The output of the PV module is modest; however, a converter is employed to meet the load needs. Because the output of a PV cell is DC, a DC-DC converter is used. These converters are used to modify the voltage level of the input. At the output, the desired voltage is attained. The interaction of the converter with the PV module is critical, hence a good converter is necessary. They act as a charge controller, linking the MPP tracker and PV module to the load [50].

Maximal power extraction is sought for optimal use of PV installations. The goal is to determine the voltage that corresponds to the greatest power production under various irradiation and temperature conditions during the day. When solar panels are put without any optimization techniques, power is wasted. Sun irradiation fluctuates often, limiting the optimal utilization of solar panels. As a result, the MPPT approach is used to harvest the most power from the panel at all times. The goal of this approach is to determine the panel operating voltage that corresponds to maximum power extraction at the load [51].

Inverters convert DC power to AC one. Single-phase voltage source inverters are utilized for low-voltage applications, whereas three-phase voltage source inverters are used for medium to high-voltage applications. Current, phase, frequency, and voltage must always be adjustable in voltage source inverter applications. The goal of this control scheme is to provide as pure a sinusoidal output as feasible in the specified phase, voltage, and frequency [52].

3.2. DESCRIPTION OF CASE STUDY

Karabuk University's campus as shown in Figure 3.2 hosts about 53,000 people, including students, faculty, and staff; hence, its electricity usage is high. There are some future challenges such as increasing power consumption, indirect carbon emissions, and the cost of maintaining and improving a complicated distribution system that serves a huge campus population. Karabuk University's administration effectively worked to cut down energy usage and power management expenses by incorporating solar PV panels into the university's utility system as shown in Figure 3.3 Photovoltaic panels are now being installed in all major buildings of the Karabuk University campus; therefore, the PV penetration level is changed and the effect of the change on the low voltage network needs to be studied.

Figure 3.2. Karabuk university main campus.

Figure 3.3. Installing PV system in Karabuk university.

The power supply substation of BAŞKENT EDAS A.Ş provides power to the Karabuk University campus. Figure 3.4 depicts the modeled one-line diagram of the university electric power grid. Karabuk university grid consists of nine transformers, each transformer serves several building and is distributed around different area inside the university.

Table 3.1. Karabuk University power station transformer technical specifications.

Power of transformer (MVA)	75
Transformer primary voltage (kV)	154
Transformer secondary voltage (kV)	34.5
Relative short circuit voltage	11.3 %
Relative short circuit voltage	0.7 %
Nominal voltage (kV)	34.5

Table 3.2. The distribution center transformer's technical specifications.

Distribution center transformer power(kVA)	7600
Transformer primary voltage (kV)	34.5
Transformer secondary voltage (kV)	0.4
Relative short circuit voltage	3.9 %
Nominal voltage (kV)	0.4

Table 3.3. Cable specification from of Karabuk university network.

Nominal cross-section	3 X 120
Diameter	95 mm^2
resistance R	0.153 ohm/km
Inductance L	0.39 mH/km

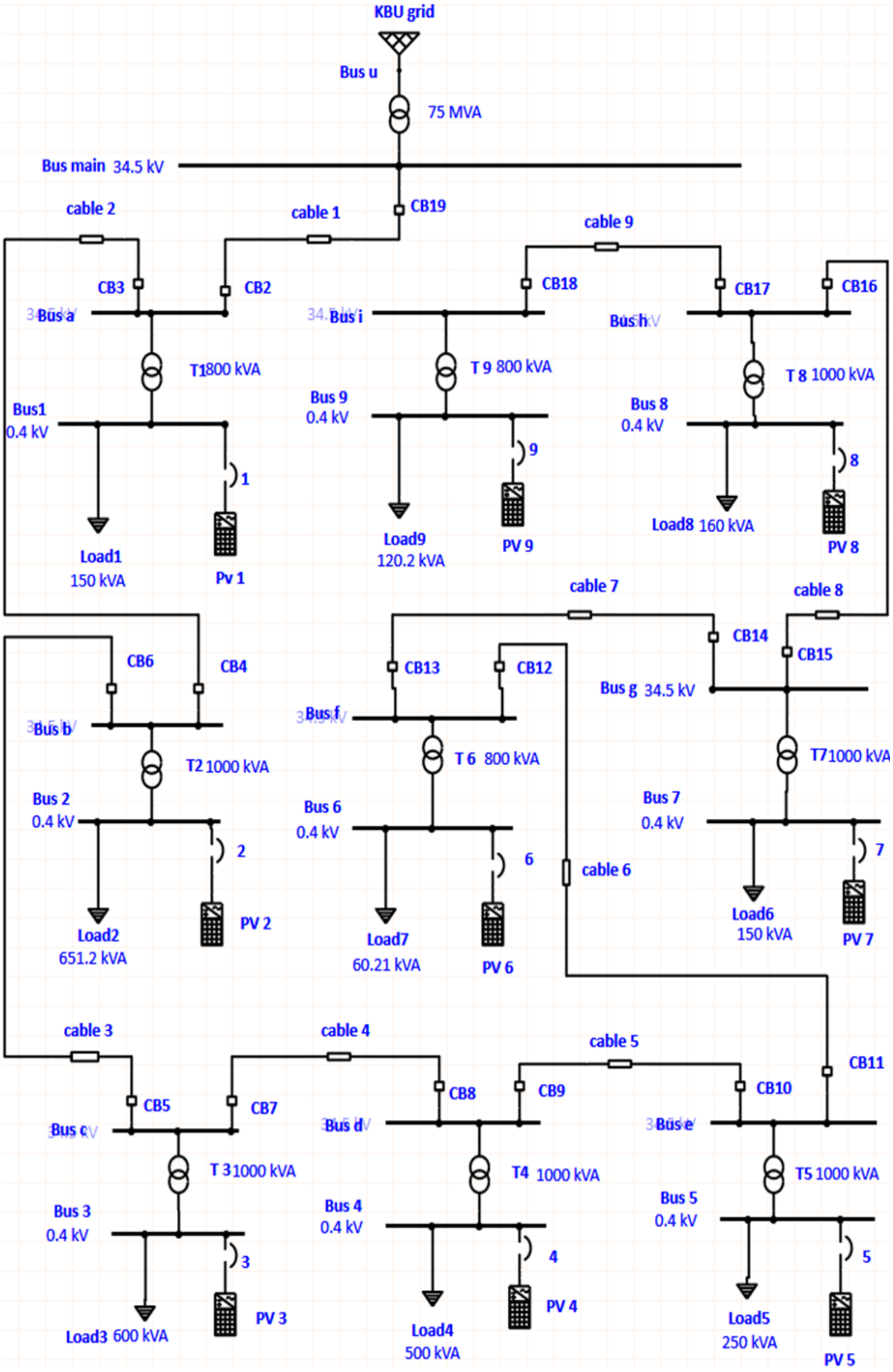


Figure 3.4. One-line diagram of Karabuk University.

Table 3.4. The peak consumption load for each of the nine buses of Karabuk university.

Load number	Peak consumption power in kVA
Load 1	150
Load 2	651.2
Load 3	600
Load 4	500
Load 5	250
Load 6	60.21
Load 7	150
Load 8	160
Load 9	120.2

3.3. DEFINITION OF PV PENETRATION

There is no one, universally accepted description of PV penetration limitations. It differs significantly across studies, with few taking it simply as the percentage of installations with PV systems to the total number of load demand in the area under investigation [53]. We discovered research in which it was defined as the ratio of roof area used for PV installation to total space available, whereas others estimated it as the percentage of grid-connected PV peak capacity to feeder’s load capacity [54]. In this thesis penetration level is adopted as:

$$\text{PV penetration} = \frac{\text{Peak PV power}}{\text{Peak consumption power}} \tag{3.1}$$

Table 3.5. The PV power for each penetration level used in the simulation.

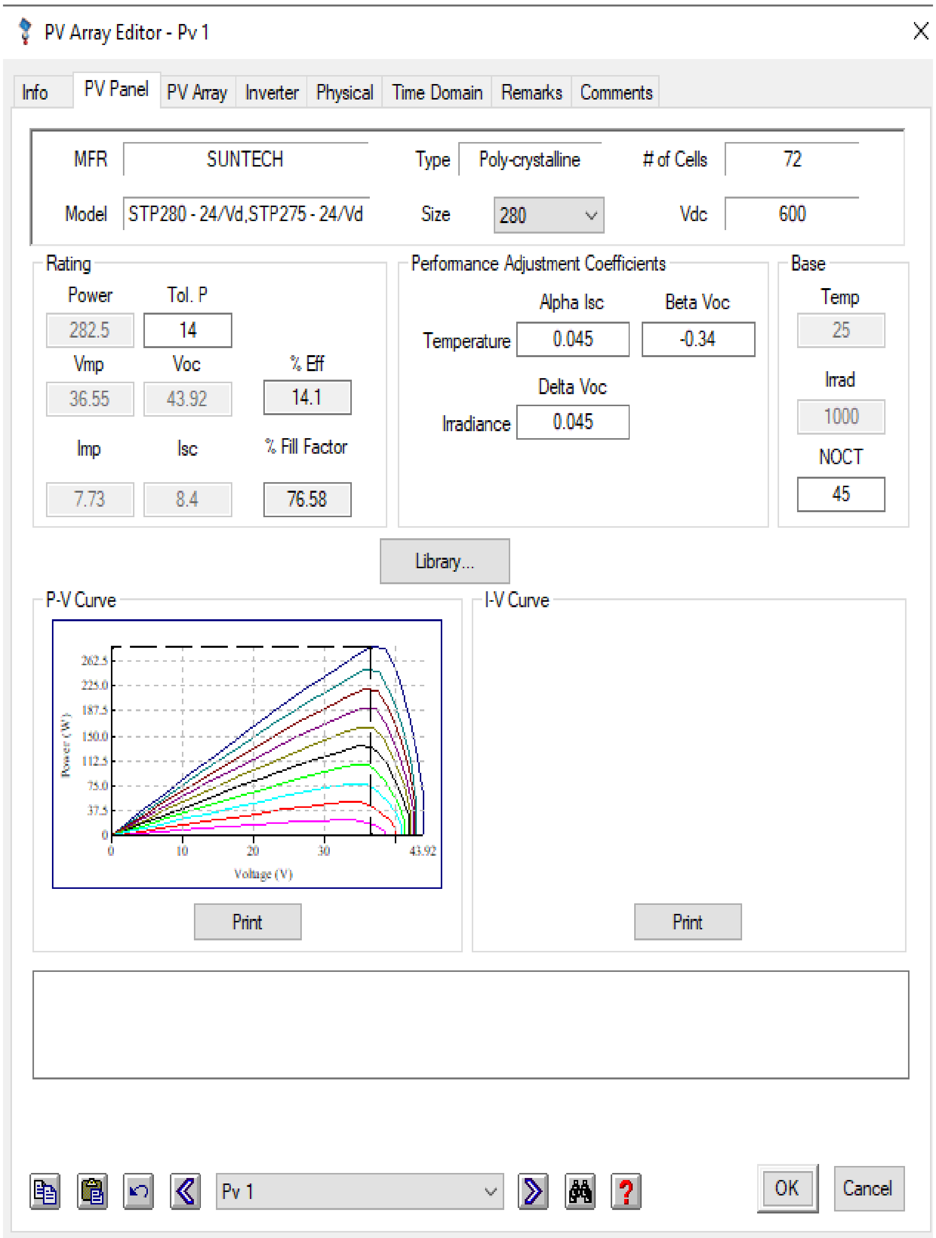
Penetration level / **PV power in kW**	25%	50%	80%	100%	125%	150%
PV 1	38	75	120	150	188	225
PV 2	163	325	520	650	812	975
PV 3	150	300	480	600	750	900
PV 4	125	250	400	500	625	750
PV 5	63	125	200	250	313	375
PV 6	15	30	48	60	75	90
PV 7	37.5	75	120	150	188	225
PV 8	40	80	128	160	200	240
PV 9	30	60	96	120	150	180

3.4. ETAP SOFTWARE

ETAP is an exclusive tool for analyzing AC and DC electrical power systems. ETAP is used by engineers at a lot of companies and electric utilities throughout the world for designing, analyzing, repairing, and operating electrical networks. ETAP is favored over other software programs since it incorporates all of the capabilities necessary for electrical study. This program has a special aspect that it includes a centralized database system in which all of the analysis that has been performed is kept, and this data can subsequently be easily downloaded using Microsoft Access [55].

3.4.1. PV System in ETAP Software

PV arrays are essential equipment in the field of renewable energy in power grids. Individual PV panels are shown in series and parallel with the converter as well as an inverter in the ETAP PV Array library, which also displays PV power summation. The electrical description of the PV panel may be defined from the PV panel, as illustrated in Figure 3.5.



MFR: SUNTECH
Type: Poly-crystalline
# of Cells: 72
Model: STP280 - 24/Vd,STP275 - 24/Vd
Size: 280
Vdc: 600

Rating

Power	Tol. P	
282.5	14	
Vmp	**Voc**	**% Eff**
36.55	43.92	14.1
Imp	**Isc**	**% Fill Factor**
7.73	8.4	76.58

Performance Adjustment Coefficients

	Alpha Isc	Beta Voc
Temperature	0.045	-0.34
	Delta Voc	
Irradiance	0.045	

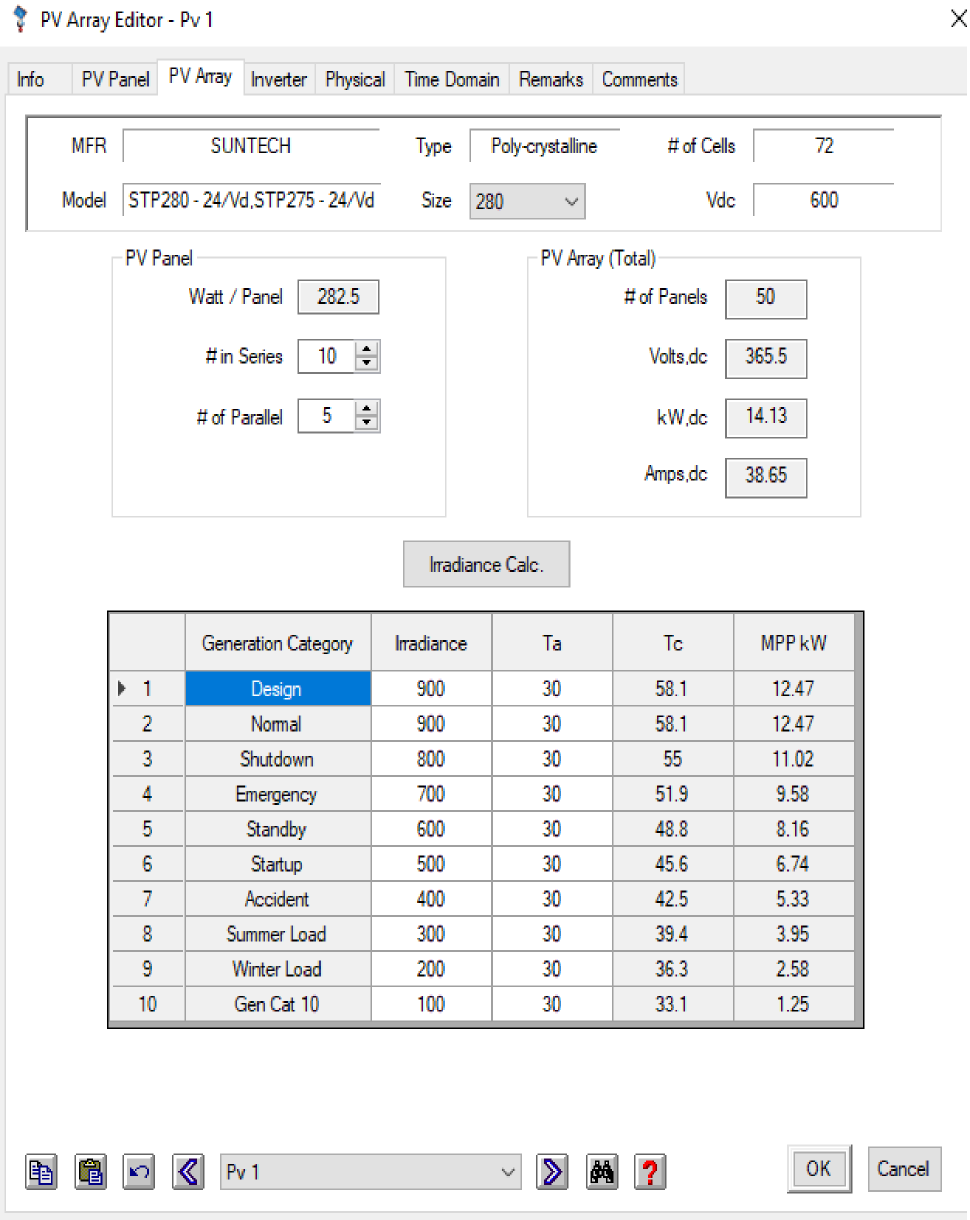
Base
Temp: 25
Irrad: 1000
NOCT: 45

Pv 1

Figure 3.5. PV Array editor in ETAP.

PV panel was selected from the ETAP library for this simulation. Because of its characteristics, the SUNTEACH 24/Vd.STP275-24/Vd model was chosen. The characteristics of the power-voltage curve and current-voltage curve is shown on the PV Panel page at various levels of solar irradiance.

The solar panel's electrical requirements are defined on the PV Array page of the PV Array Editor as shown in Figure 3.6 In this window, the rated power of each individual panel in watts, the number of PV panels linked in parallel and series, the total number of panels by multiplying the number of parallel and series linked PV panels, the total DC power in kW, the DC voltage of all PV panels connected in series, and the total DC current all PV panels connected in parallel.



MFR: SUNTECH
Type: Poly-crystalline
# of Cells: 72
Model: STP280 - 24/Vd,STP275 - 24/Vd
Size: 280
Vdc: 600

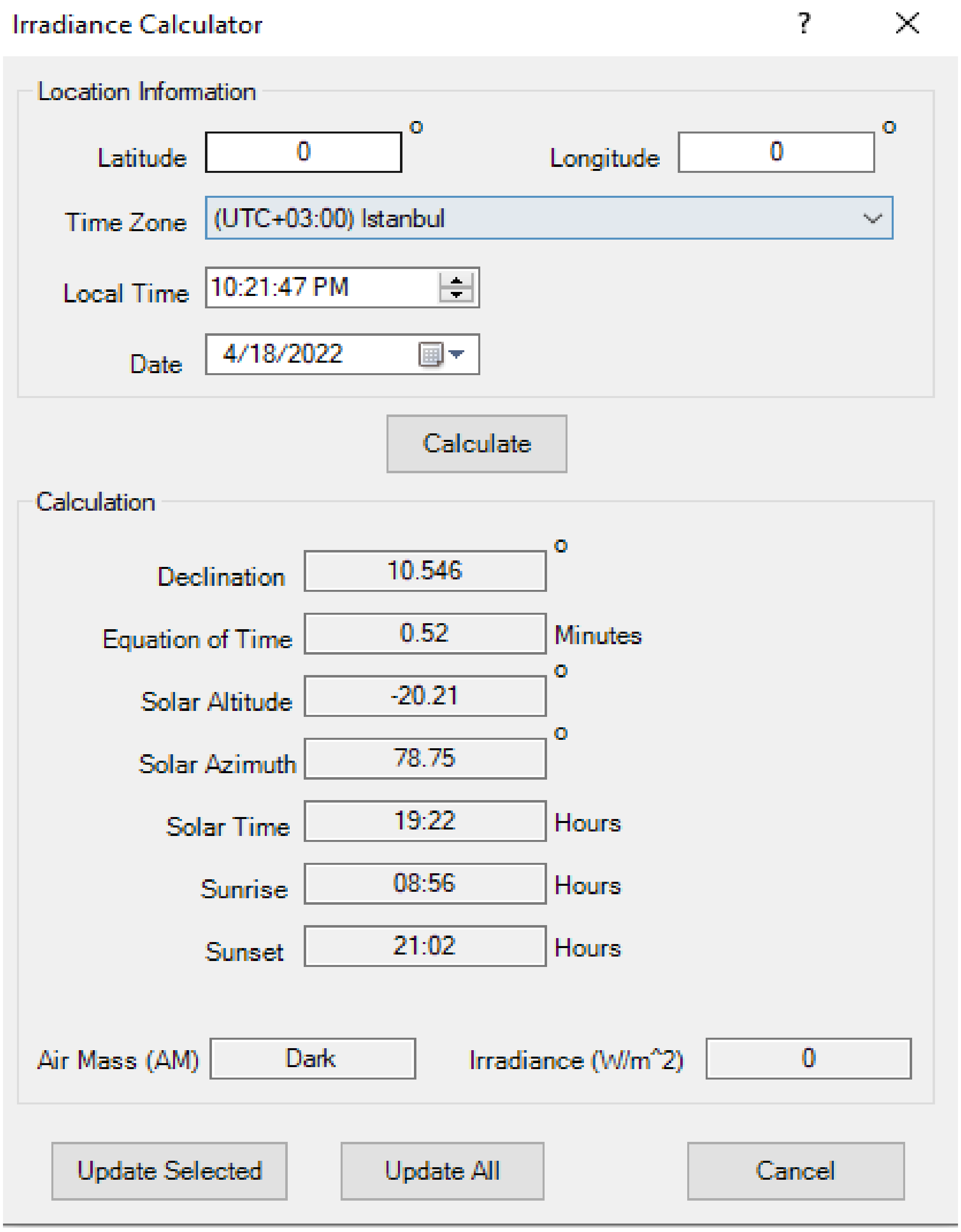
PV Panel
Watt / Panel: 282.5
in Series: 10
of Parallel: 5

PV Array (Total)
# of Panels: 50
Volts,dc: 365.5
kW,dc: 14.13
Amps,dc: 38.65

	Generation Category	Irradiance	Ta	Tc	MPP kW
1	Design	900	30	58.1	12.47
2	Normal	900	30	58.1	12.47
3	Shutdown	800	30	55	11.02
4	Emergency	700	30	51.9	9.58
5	Standby	600	30	48.8	8.16
6	Startup	500	30	45.6	6.74
7	Accident	400	30	42.5	5.33
8	Summer Load	300	30	39.4	3.95
9	Winter Load	200	30	36.3	2.58
10	Gen Cat 10	100	30	33.1	1.25

Figure 3.6. PV array editing window.

In this window, a table contains a list of the ten generation categories, irradiance, the ambient temperature, cell temperature, and the PV panel output peak power. The irradiance calculator under this window refers to the best experienced irradiance. The irradiance calculator is based on the information given by the user as well as the date and time. After clicking on it the page in Figure 3.7 shows up.



Irradiance Calculator

Location Information

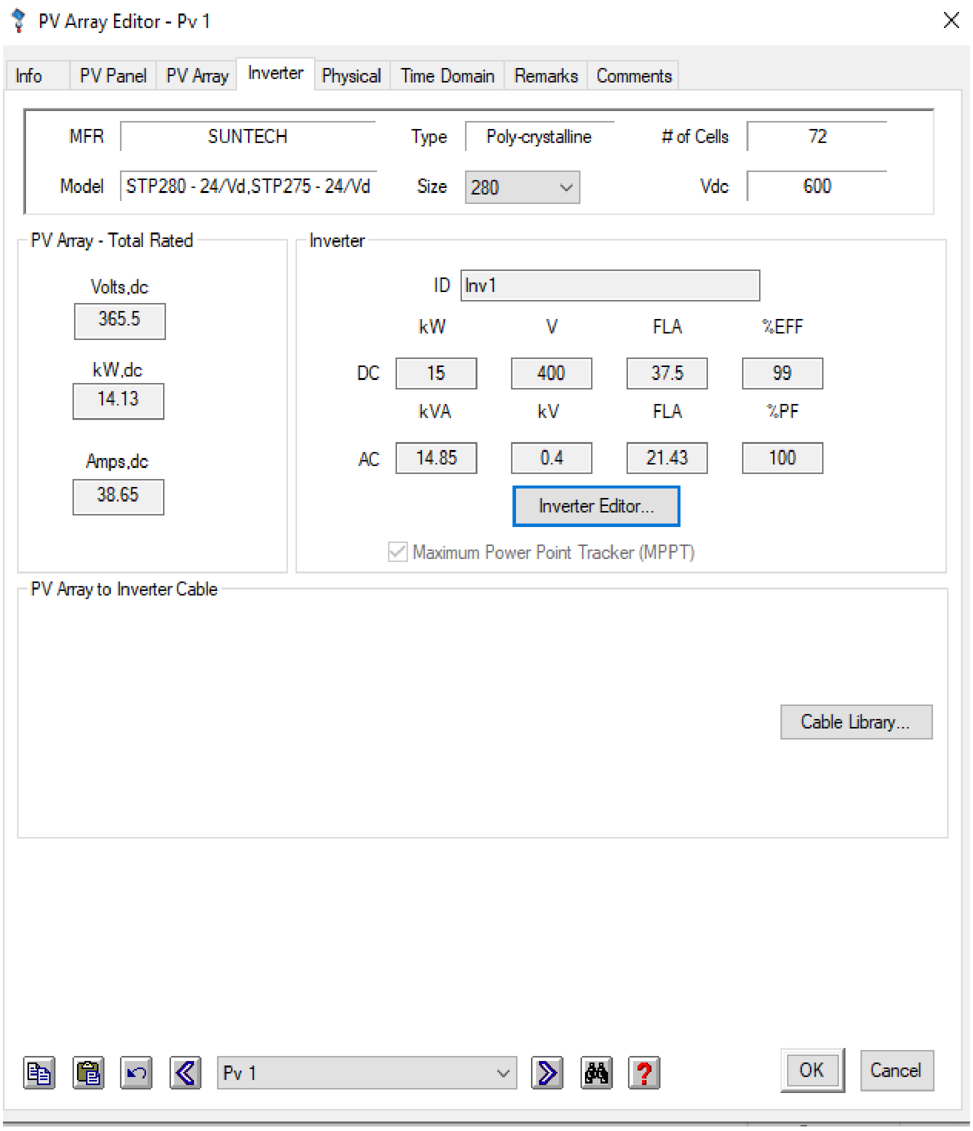
Latitude 0 °
Longitude 0 °
Time Zone (UTC+03:00) Istanbul
Local Time 10:21:47 PM
Date 4/18/2022

Calculation

Declination 10.546 °
Equation of Time 0.52 Minutes
Solar Altitude -20.21 °
Solar Azimuth 78.75 °
Solar Time 19:22 Hours
Sunrise 08:56 Hours
Sunset 21:02 Hours
Air Mass (AM) Dark
Irradiance (W/m^2) 0

Figure 3.7. Irradiance calculator in ETAP.

The next process of the PV array editor is the inverter, as shown in Figure 3.8 In the inverter editor, the electrical characteristics of the inverter such as the DC ratings, AC ratings, and efficiency can be adjusted as per the user's preference and choice.



MFR: SUNTECH
Type: Poly-crystalline
# of Cells: 72
Model: STP280 - 24/Vd,STP275 - 24/Vd
Size: 280
Vdc: 600

PV Array - Total Rated

Volts,dc: 365.5
kW,dc: 14.13
Amps,dc: 38.65

Inverter

ID: Inv1

	kW	V	FLA	%EFF
DC	15	400	37.5	99
	kVA	kV	FLA	%PF
AC	14.85	0.4	21.43	100

☑ Maximum Power Point Tracker (MPPT)

PV Array to Inverter Cable

Pv 1

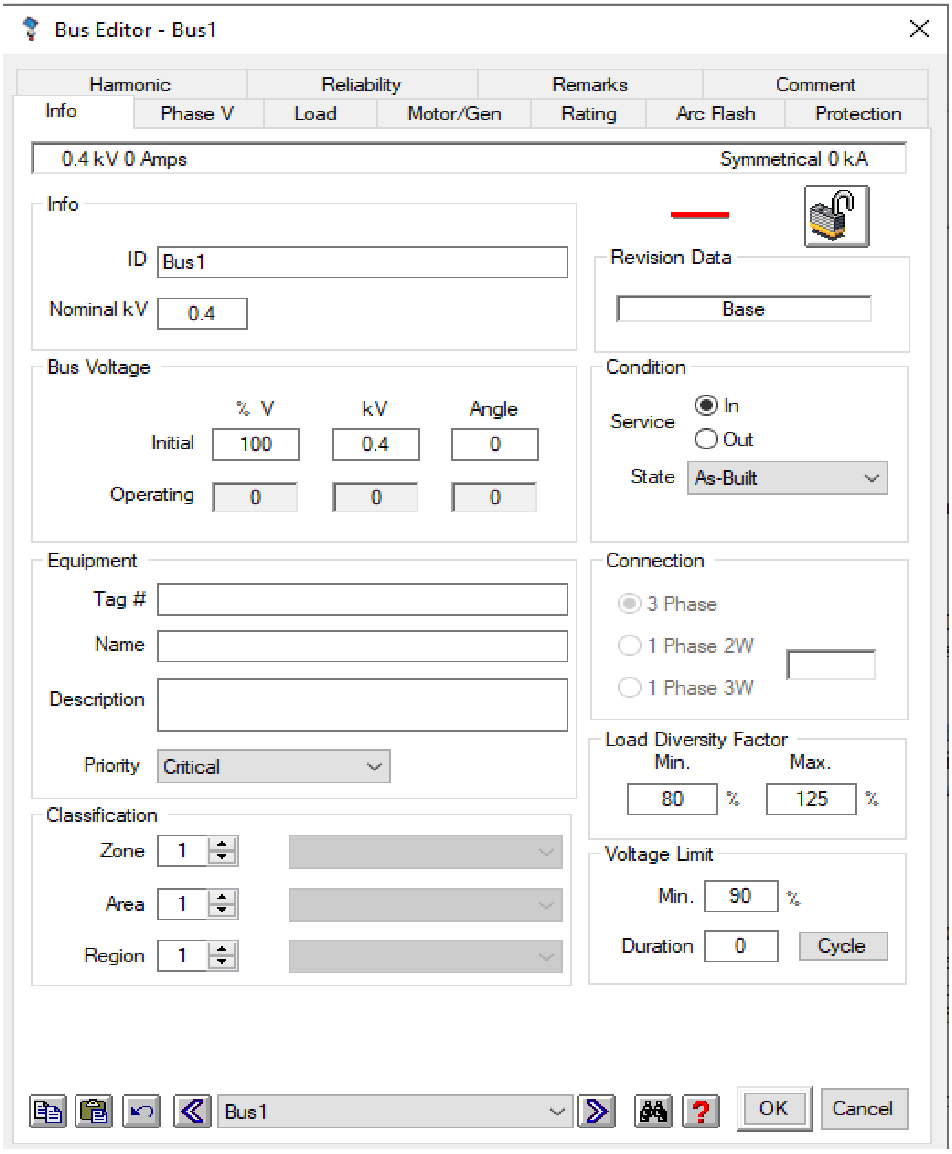
Figure 3.8. Inverter window of PV Array Editor.

The next step in the PV array editor is the physical page which refers to the physical structural data of the PV panel; for example, length, breadth, depth, and weight are defined on the editor's physical page. If the PV array is chosen from the library, the physical structural information of the PV panel is preset. If the PV array is not chosen from the library, this information is user-defined.

3.4.2. Bus Bar Simulation in ETAP Software

A bus bar is a metallic bar made mostly of highly conductive material which is utilized in switchgear, panel boards, and other applications. It offers a lot of benefits for load flow systems. PV buses, PQ buses, and slack buses are the three types of buses available. The slack bus is also known as the infinite bus because it has a higher capacity than the other buses. It serves as a reference bus for calculating phase voltages for other buses [56].

In ETAP software the specifications of the bus can be set by the bus editor page as shown in Figure 3.9 From this editable page the nominal voltage, Initial/Operating Voltage (Magnitude and Angle), Diversity Factors (Maximum and Minimum), and other settings can be adjusted conforming to our grid.



Bus Editor - Bus1

0.4 kV 0 Amps   Symmetrical 0 kA

Info

ID: Bus1

Nominal kV: 0.4

Revision Data

Base

Bus Voltage

	% V	kV	Angle
Initial	100	0.4	0
Operating	0	0	0

Condition

Service: ● In ○ Out

State: As-Built

Equipment

Tag #:

Name:

Description:

Priority: Critical

Connection

● 3 Phase
○ 1 Phase 2W
○ 1 Phase 3W

Load Diversity Factor

Min. 80 %   Max. 125 %

Classification

Zone: 1

Area: 1

Region: 1

Voltage Limit

Min. 90 %

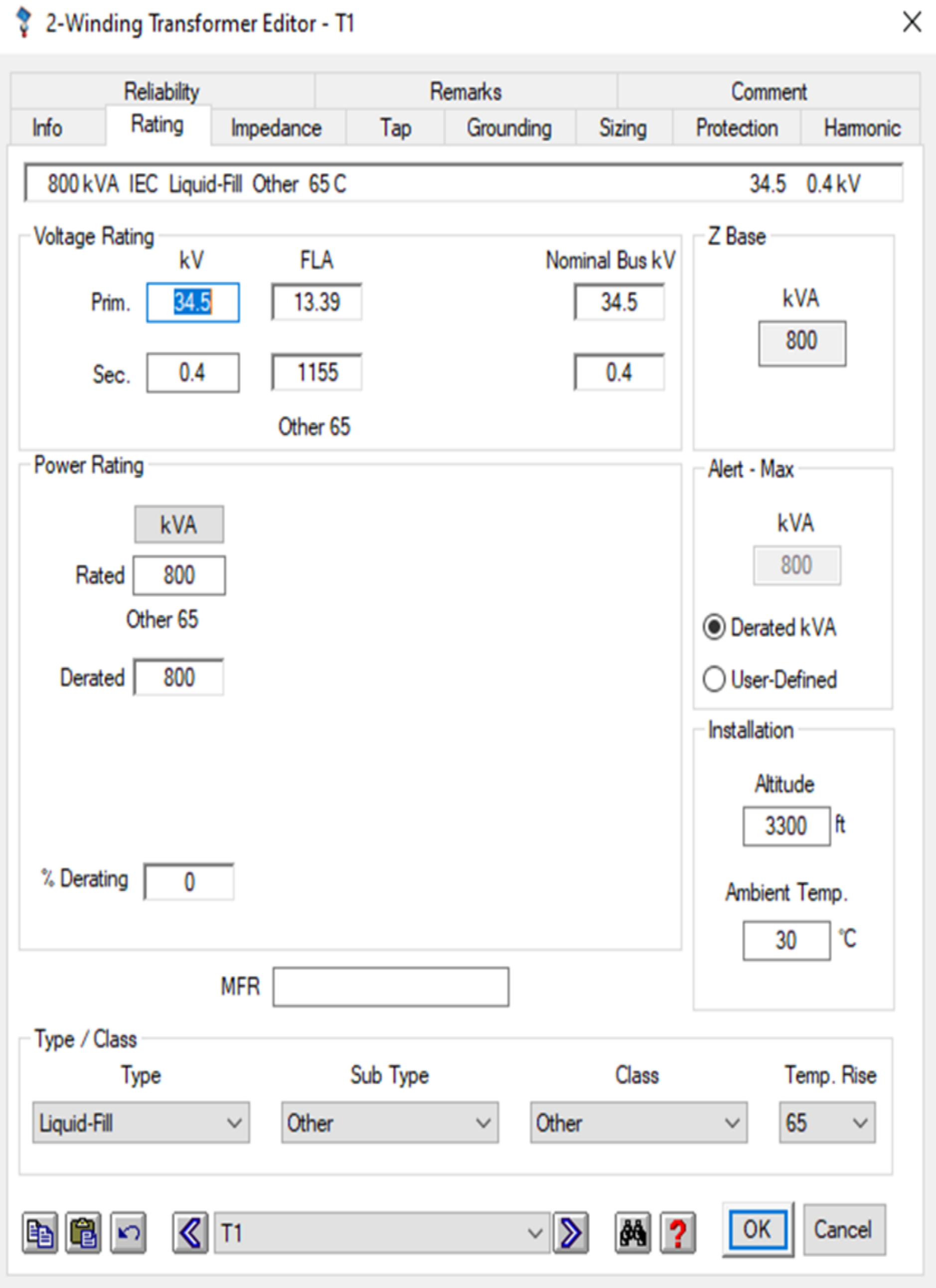
Duration: 0 Cycle

Bus1

Figure 3.9. Voltage node editor page.

3.4.3. Transformer Modeling in ETAP

A transformer is a stationary electromagnetic device made up of windings with magnetic cores. Power is transferred via transformers at a similar frequency but with various voltages and currents. Transformers are essential components of electrical energy distribution and transmission networks. Their design is determined by their intended use. Transformers are classified into a variety of categories based on their intended function [57]. In ETAP software the specification of the transformer can be set from the 2-winding transformer editor. The primary and secondary voltage ratings of the transformer in kilovolts and the transformer power rating can be specified on the rating page based on grid information as shown in Figure 3.10 (a) from the impedance page the positive and zero sequence impedances and the R/X ratio can be edited as shown in Figure 3. 10 (b).



800 kVA IEC Liquid-Fill Other 65 C 34.5 0.4 kV

Voltage Rating

	kV	FLA	Nominal Bus kV
Prim.	34.5	13.39	34.5
Sec.	0.4	1155	0.4

Other 65

Z Base: kVA 800

Power Rating

Rated kVA 800

Other 65

Derated 800

% Derating 0

Alert - Max: kVA 800

● Derated kVA

○ User-Defined

Installation

Altitude 3300 ft

Ambient Temp. 30 °C

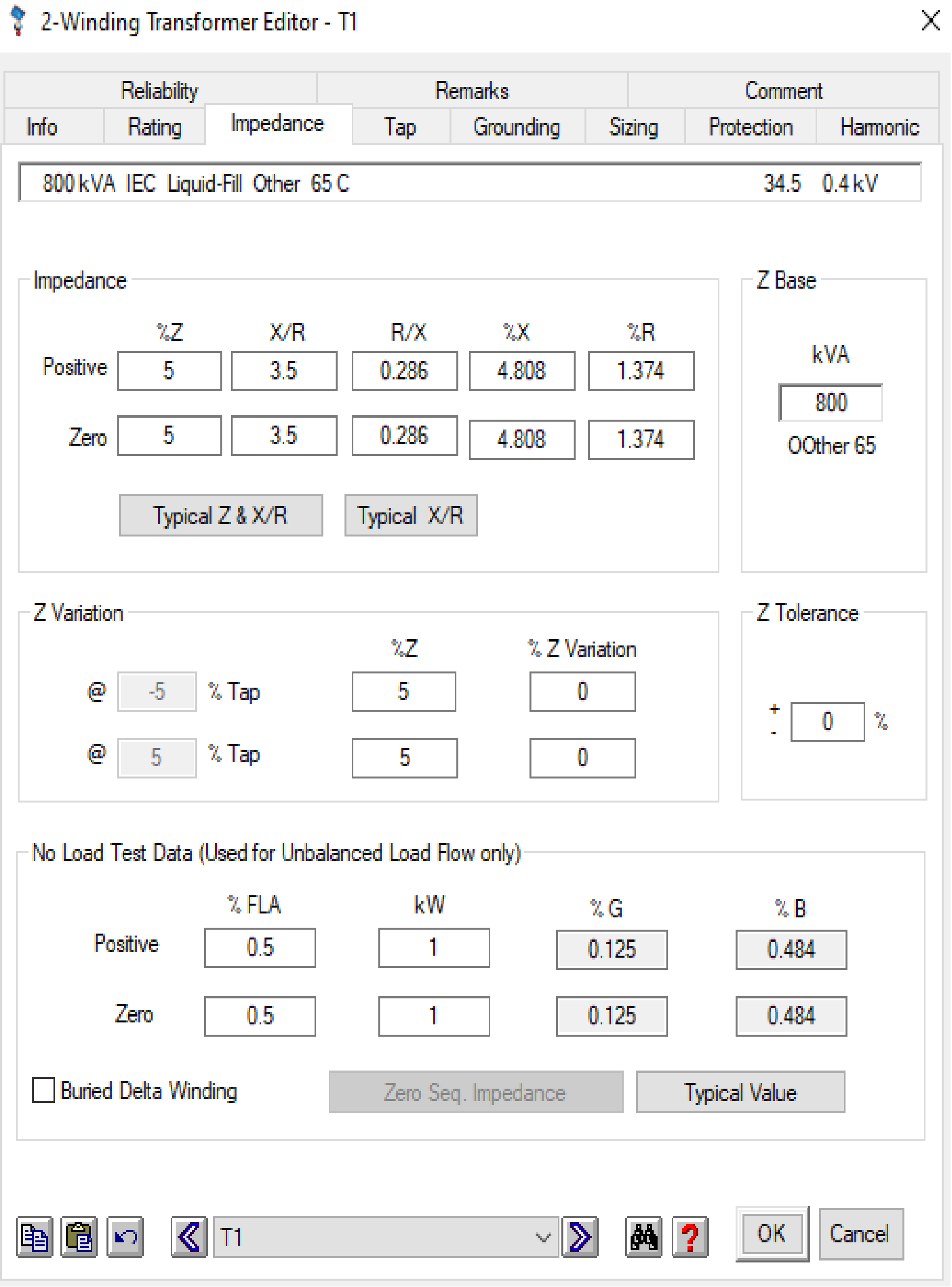
MFR

Type / Class

Type	Sub Type	Class	Temp. Rise
Liquid-Fill	Other	Other	65

T1

(a)



2-Winding Transformer Editor - T1

800 kVA IEC Liquid-Fill Other 65 C 34.5 0.4 kV

Impedance

	%Z	X/R	R/X	%X	%R
Positive	5	3.5	0.286	4.808	1.374
Zero	5	3.5	0.286	4.808	1.374

Z Base

kVA: 800

OOther 65

Z Variation

		%Z	% Z Variation
@	-5 % Tap	5	0
@	5 % Tap	5	0

Z Tolerance

± 0 %

No Load Test Data (Used for Unbalanced Load Flow only)

	% FLA	kW	% G	% B
Positive	0.5	1	0.125	0.484
Zero	0.5	1	0.125	0.484

☐ Buried Delta Winding

T1

(b)

Figure 3.10. Transformer page with rating setting in (a) and impedance setting in (b).

3.4.4. Load Modelling in ETAP

Low voltage loads are generally represented as lump loads. The term "lump load" refers to a network that includes many types of loads such as resistive, capacitive, and inductive loads. The lump load in our modeling environment is made up of motors and resistive loads, allowing the user to choose how many portion of the load should be resistive and inductive [58]. The lumped load editor page of the simulation program allows to change of the motor load and static load, as well as the rated values of kVAR, kW, and power factor as shown in Figure 3.11.

0 MVA 0 kV (50% Motor 50% Static)

Model Type: Conventional

Rated kV: 0

Ratings

MVA	MW	Mvar	% PF	Amp
0	0	0	85	0

Load Type

Constant kVA: 0 — 50 % — 100

Constant Z: 100 — 50 % — 0

	Loading		Motor Load		Static Load	
	Category	%	MW	Mvar	MW	Mvar
1	Design	100	0	0	0	0
2	Normal	100	0	0	0	0
3	Brake	0	0	0	0	0
4	Winter Load	0	0	0	0	0
5	Summer Load	0	0	0	0	0
6	FL Reject	0	0	0	0	0

Operating 0 0 0 0 MW + jMvar

Figure 3.11. lumped load editable window.

3.5. LOAD FLOW ANALYSIS USING ETAP

The Load Flow Analysis in the ETAP program is based on the voltages of all buses, power factors of the branches, currents, and power flows that propagate across the electrical system. As a swing, voltage controlled, and unregulated power sources, various voltage sources, as well as different power networks and generator types can be used. ETAP software allows doing a load flow study for both radial and loop electrical system designs. ETAP additionally offers a number of load flow analysis approaches from which the user can select the best fit for his specific study [59].

ETAP has four load flow calculation methods: Adaptive Newton-Raphson, Newton-Raphson, Fast-Decoupled, and Accelerated Gauss-Seidel. These four alternative load flow calculation methods have varied convergence requirements, which implies that they may each be utilized in a given context to get better results with less inaccuracy. Each of these load flow calculation techniques may be chosen depending on the system structure, generating type, loading situation, and initial bus voltage value.

Newton's method is mathematically superior conditioned to the Gauss-Seidel method and is less prone to divergence with condition problems. For large power systems, the Newton-Raphson method is found to be more efficient and Practical. The number of iterations required to obtain a solution is independent of the system size, but more functional evaluations are required at each iteration. Throughout continuous iterations, the Newton-Raphson technique estimates the load flow using the following load flow equation:

$$\begin{bmatrix}\Delta P\\ \Delta Q\end{bmatrix}\begin{bmatrix}J1 & J2\\ J3 & J4\end{bmatrix}=\begin{bmatrix}\Delta\delta\\ \Delta V\end{bmatrix} \tag{3.2}$$

P and Q in this equation indicate the real and reactive powers of various buses, respectively. The actual and reactive power are created as a result of a discrepancy between the calculated and real bus voltage values. ΔV and $\Delta\delta$ denote the magnitude and angle vectors of the bus voltage, respectively. The elements of the Jacobin matrix are represented by J1 through J4 [60].

The unique convergence feature of the Newton-Raphson technique distinguishes it from other load flow calculation methods. In general, this approach has a substantially faster convergence time than other load flow computation methods, making it much faster. It also has the benefit of having some convergence characteristic requirements that specify the convergence limit for bus real power and reactive power faults. This specification ensures that the required error limitations defined by the user for the load flow analysis are properly controlled [61]. Although the Newton-Raphson approach is directly dependent on the initial voltage of the buses, effective initial bus voltage selection can prevent severe inaccuracy and convergence. That is why ETAP employs several Gauss-Seidel iterations to estimate the right beginning values for the bus voltages to be utilized in the Newton-Raphson approach [62].

In general, for a typical power system bus:

$$I_i = \sum_{j=1}^{n} Y_{ji} V_j \tag{3.3}$$

In the preceding equation, j denotes bus i. When we express this equation in polar form, we get:

$$I_i = \sum_{j=1}^{n} |Y_{ji}| |V_j| \angle \theta_{ij} + \delta_j \tag{3.4}$$

At bus i the complex power is:

$$P_i - jQ_i = V_i^* I_i \tag{3.5}$$

Substituting I_i

$$P_i - jQ_i = |V_i| \angle -\delta_i \sum_{j=1}^{n} |Y_{ij}| |V_j| \angle \theta_{ij} + \delta_j \tag{3.6}$$

$$P_i = \sum_{j=1}^{n} |Y_{ij}|\,|V_j|\,\big|V_i\big| \ \cos(\theta_{ij}-\delta_i+\delta_j) \tag{3.7}$$

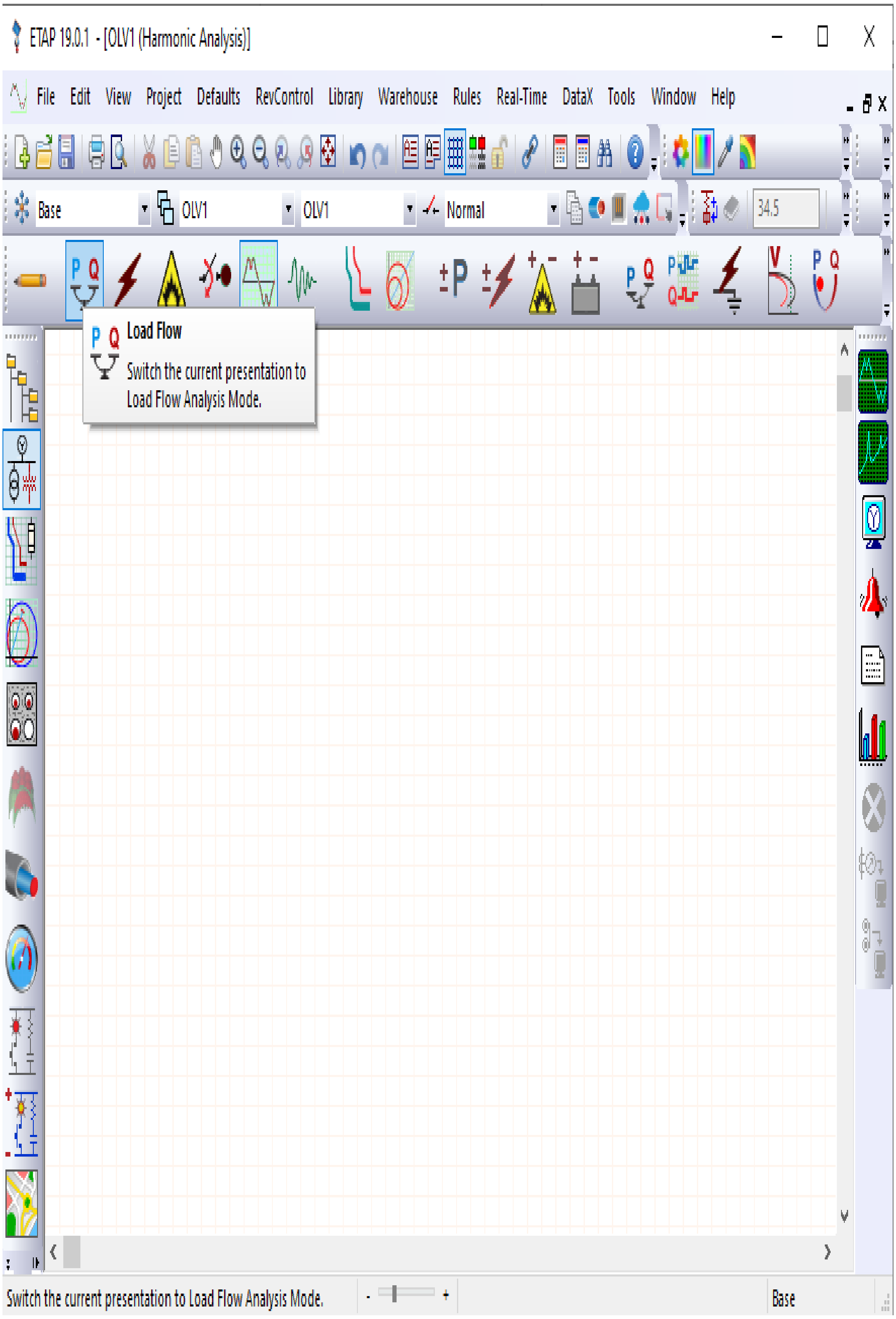
$$Q_i = -\sum_{j=1}^{n} |Y_{ij}|\,|V_j|\,\big|V_i\big| \ \sin(\theta_{ij}-\delta_i+\delta_j) \tag{3.8}$$

Equations 3.7 and 3.8 constitute a set of a nonlinear algebraic equations in terms of the independent varieties, voltage magnitude in per unit, and phase angle in radians. expanding 3.7 and 3.8 in Taylor's series about the initial estimate and neglecting all higher order terms results in the following set of linear equations. When we expand in the Taylor Series while ignoring higher order, we get:

$$\left[\begin{array}{c} \Delta P_2^{(K)} \\ \vdots \\ \Delta P_n^{(K)} \\ \hline \Delta Q_2^{(K)} \\ \vdots \\ \Delta Q_n^{(K)} \end{array}\right] = \left[\begin{array}{ccc|ccc} \frac{dP_2^{(K)}}{d\delta_2} & \cdots & \frac{dP_2^{(K)}}{d\delta_n} & \frac{dP_2^{(K)}}{d|V_2|} & \cdots & \frac{dP_2^{(K)}}{d|V_n|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{dP_n^{(K)}}{d\delta_2} & \cdots & \frac{dP_n^{(K)}}{d\delta_n} & \frac{dP_n^{(K)}}{d|V_2|} & \cdots & \frac{dP_n^{(K)}}{d|V_n|} \\ \hline \frac{dQ_2^{(K)}}{d\delta_2} & \cdots & \frac{dQ_2^{(K)}}{d\delta_n} & \frac{dQ_2^{(K)}}{d|V_2|} & \cdots & \frac{dQ_2^{(K)}}{d|V_2|} \\ \vdots & \ddots & \vdots & \vdots & \ddots & \vdots \\ \frac{dQ_n^{(K)}}{d\delta_2} & \cdots & \frac{dQ_n^{(K)}}{d\delta_n} & \frac{dQ_n^{(K)}}{d|V_2|} & \cdots & \frac{dQ_n^{(K)}}{d|V_n|} \end{array}\right] \left[\begin{array}{c} \Delta\delta_2^{(K)} \\ \vdots \\ \Delta\delta_n^{(K)} \\ \hline \Delta\left|V_2^{(K)}\right| \\ \vdots \\ \Delta\left|V_n^{(K)}\right| \end{array}\right] \tag{3.9}$$

3.6. LOAD FLOW SIMULATION USING ETAP

Clicking on the button of load flow analysis to operate in load flow mode after creating the one-line diagram of Karabuk University. Figure 3.12 shows the ETAP main window after clicking in load flow. To view the load flow results, press the run load flow button, which is visible on the load flow bar. When executing the load flow analysis, the results will be shown on a single-line diagram, as seen in the Figure 3.13. In this work, different PV penetration levels started from 25% to 150% connected to the low voltage grid of Karabuk University to see the effect on the voltage, power factor, and feeder losses.



Load Flow

Switch the current presentation to Load Flow Analysis Mode.

Switch the current presentation to Load Flow Analysis Mode.

Figure 3.12. ETAP main window ready for load flow study.

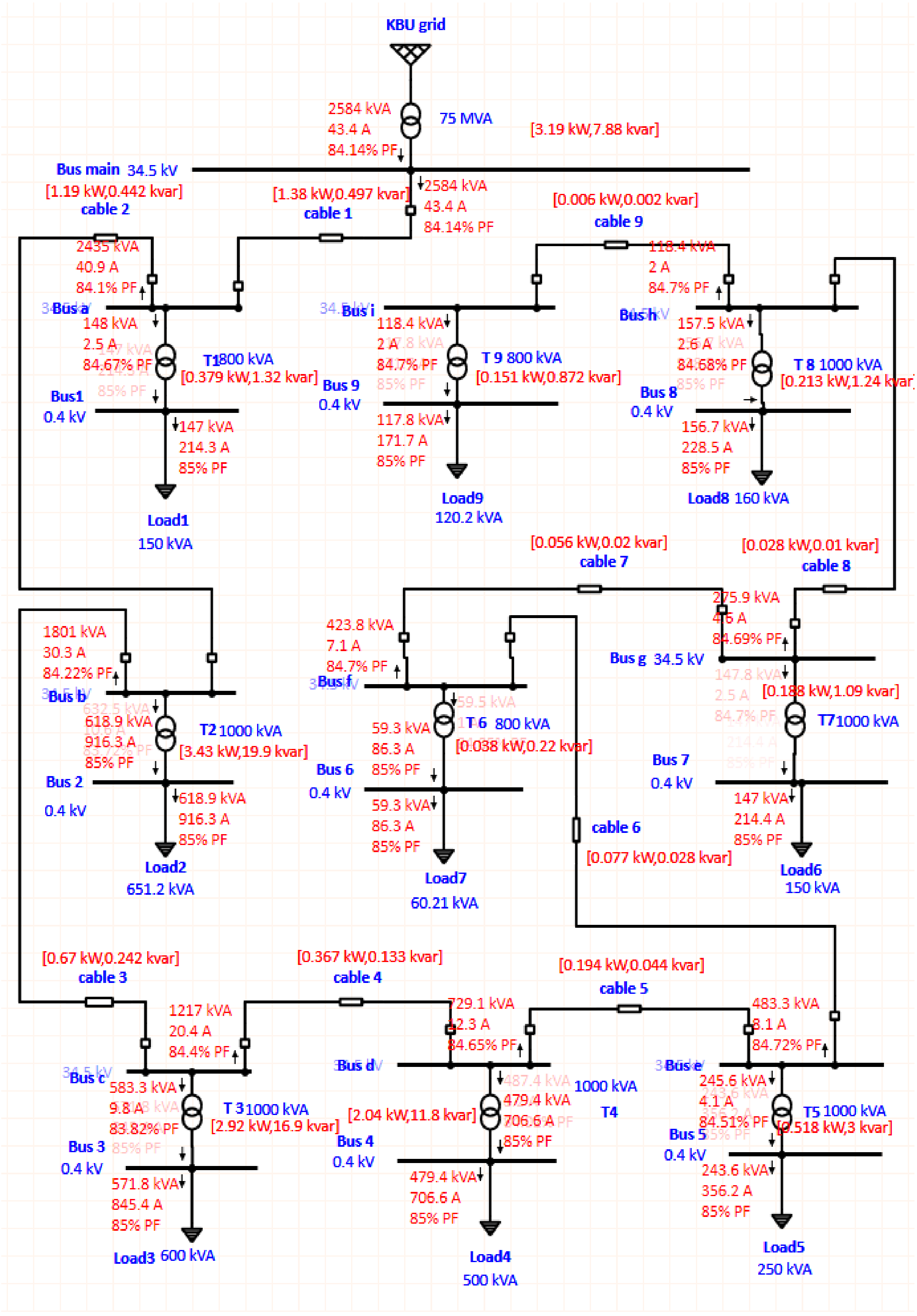


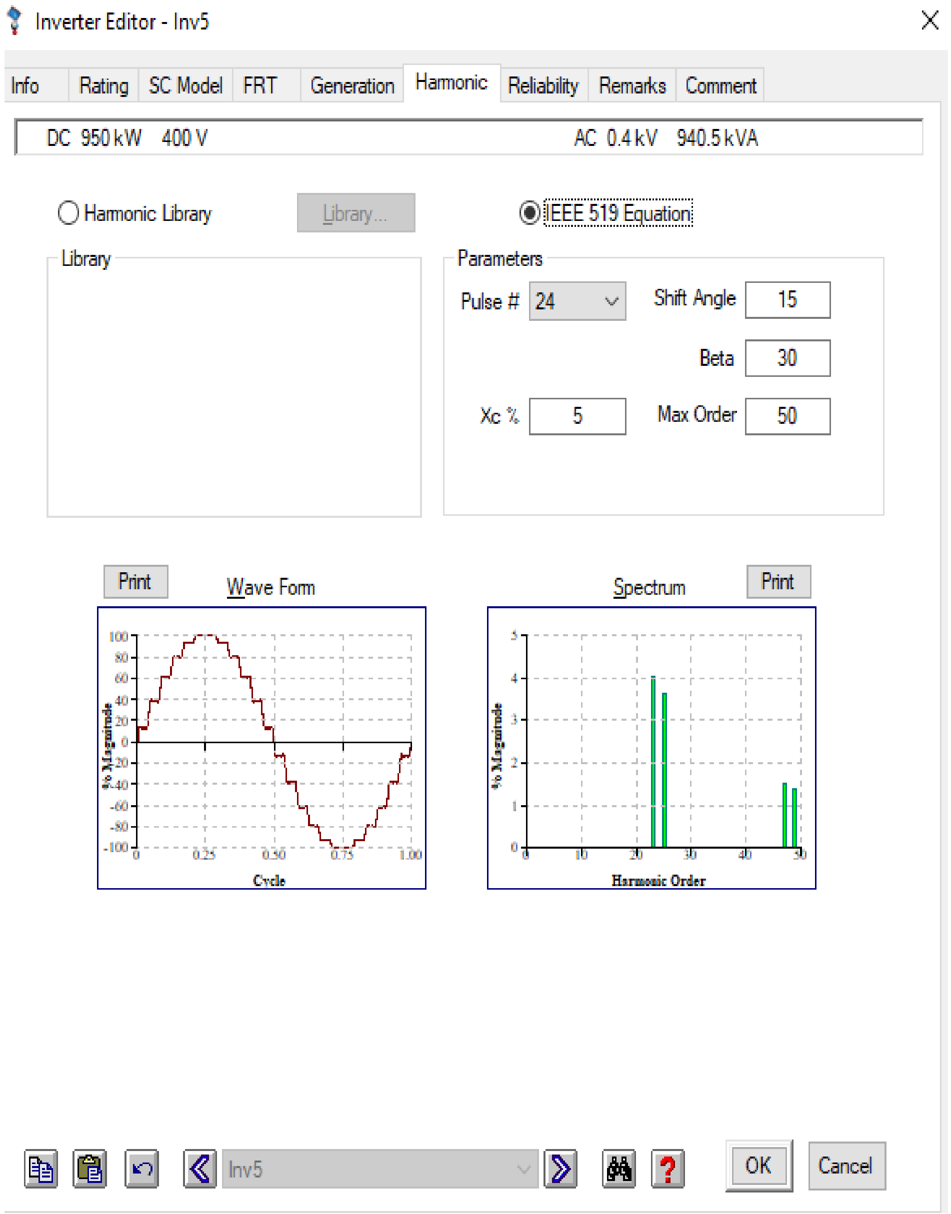
Figure 3.13. One-line diagram after running the load flow.

3.7. HARMONIC FLOW SIMULATION USING ETAP

Harmonics were presented earlier in this work and they present one of the most important problems in power systems. Using ETAP's Harmonic Modelling method, operators may evaluate harmonic current and voltage sources, define harmonic problems, build and test filters, and report harmonic voltage and current distortion limit breaches. The Harmonic Load Flow Analysis initially computes the load flow at the fundamental frequency. The basic load flow data serve as the foundation for the fundamental bus voltages and branch currents, which are then utilized to determine other harmonic indices. The current injection approach is then used by ETAP to provide a load flow solution for each harmonic frequency where a harmonic source occurs. All low order frequencies from the 2nd to the 15th, as well as distinctive harmonics from the 17th to the 73rd, are measured. Impedance components can be modified based on harmonic frequencies and component type. The determined bus THD and IHDs are compared to the user-specified limitations throughout the Bus editor, and flags are added in the text report next to the related bus in the Harmonic Information section when violations are identified [63].

The components of the power system must be accurately recognized and simulated for efficient harmonic analysis. These components are modeled in numerous ways depending upon the nature as well as behavior. Nonlinear loads are often represented as current and voltage sources with harmonic frequencies since they are effectively injecting harmonic currents or applying harmonic voltages at the supplied sites.

To represent a nonlinear element as a harmonic voltage source, the user can use the library button and Harmonic Library Quick Pick Editor on the Harmonic page of that component to pick an appropriate harmonic voltage library. A nonlinear load's harmonic page is shown in Figure 3.14.



DC 950 kW 400 V
AC 0.4 kV 940.5 kVA

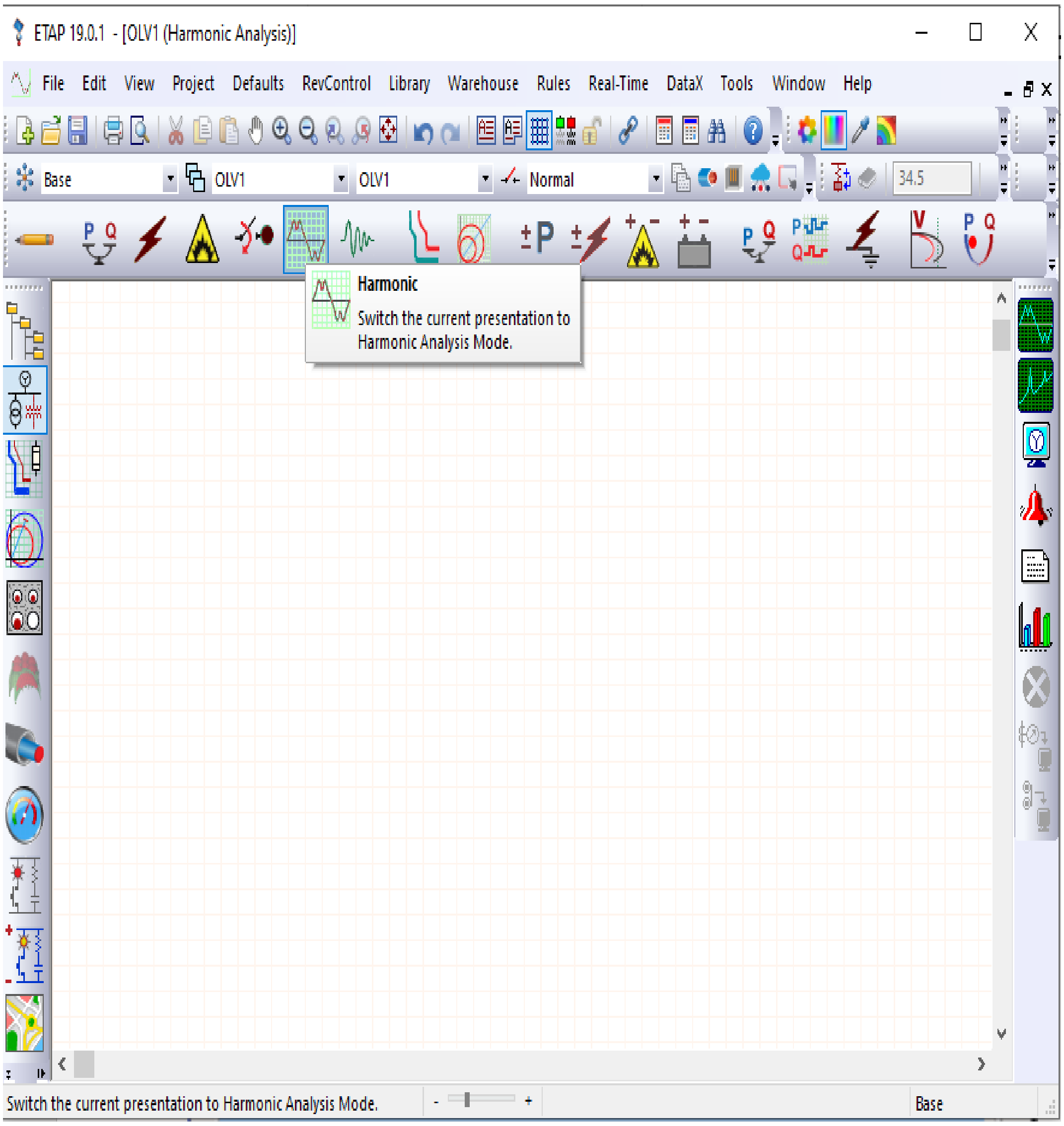
○ Harmonic Library
● IEEE 519 Equation

Pulse # 24
Shift Angle 15
Beta 30
Xc % 5
Max Order 50

Figure 3.14. Nonlinear load's harmonic page.

However, it is important to notice here that modern power inverters provide high power quality factors. The injected harmonics by such inverters are mostly high order harmonics that can be filtered easily [64].

To examine the harmonic effect, the user clicks on the Harmonic Analysis study mode button, the study toolbar appears on the screen. This toolbar may examine any power network intended for Harmonic Analysis, and the results can be found visually or analytically. The image in Figure 3.15 is the ETAP main window after activating the Harmonic Analysis module.



Harmonic

Switch the current presentation to Harmonic Analysis Mode.

Switch the current presentation to Harmonic Analysis Mode.

Figure 3.15. ETAP main window after activating the Harmonic Analysis module.

After executing the harmonic analysis, the results will be shown on a single line diagram, as seen in Figure 3.16 From the single line diagram, the THD and the voltage is appearing for the nine buses.

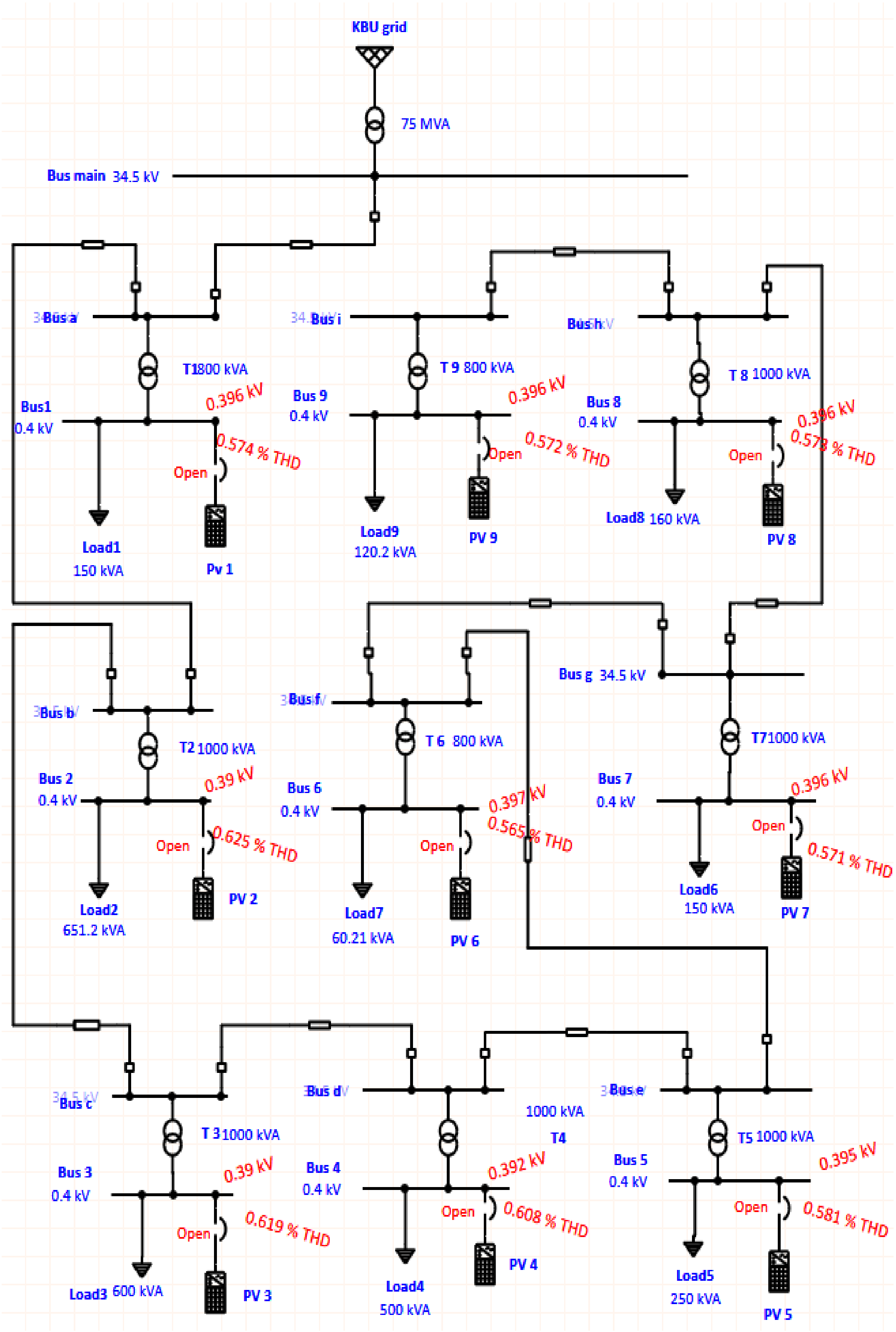


Figure 3.16. One-line diagram after running the harmonic.

PART 4

RESULTS AND DISSCUSION

In this chapter, the load flow and harmonic analysis using ETAP were carried out to study the effect of high penetration of PV into Karabuk University’s electrical distribution network. Different penetration levels starting from 25 to 150% were introduced in the simulation and the result was discussed.

4.1. SIMULATION RESULTS

After running the load flow and harmonic analysis, the bus voltage, power, current flow, power factor, and THD of the branches are all presented on the single-line diagram. To examine the performance of the Karabuk university power grid and to trigger any violation, the results from the load flow and harmonic analysis were compared without PV connection and with different PV penetration levels. Figure 4.1 shows the load flow analysis with 150% PV penetration and Figure 4.2 shows the harmonic analysis with 150% PV penetration.

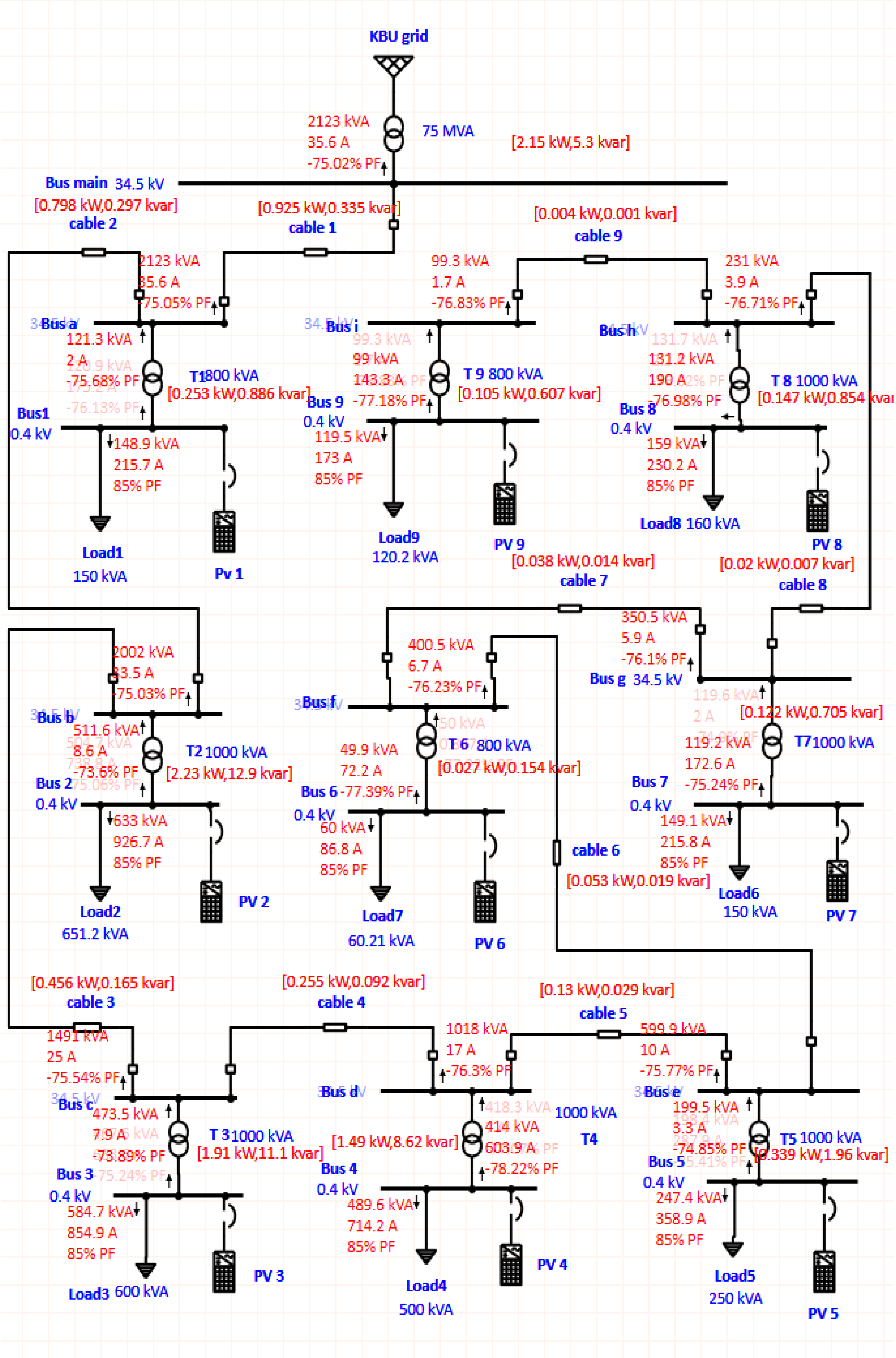


Figure 4.1. Load flow analysis with 150% PV penetration.

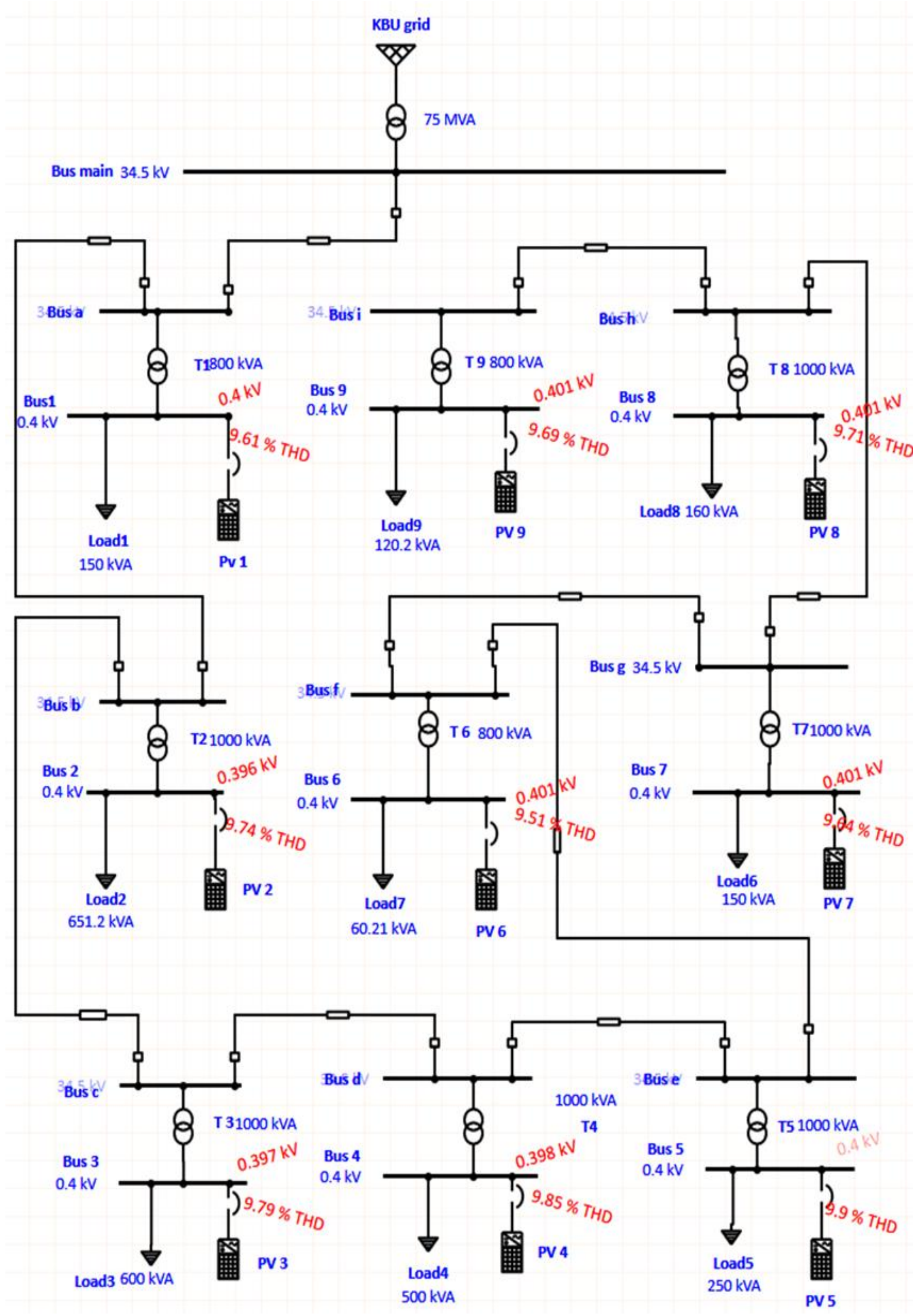


Figure 4.2. Harmonic analysis with 150% PV penetration.

Installing the PV systems to each bus of the grid bring different effect on the voltage of the buses, the active and reactive power, the branches and power factor, as well as the cables losses and THD.

4.1.1. Voltage Impact

From the simulation results, it is experienced that the voltage of the buses increases when the PV penetration level increases. Figure 4.3 illustrates the voltage of the nine buses without PV penetration, with 20% PV penetration, and 50% PV penetration. The increase of the voltage at different nodes remains within the statutory limit.

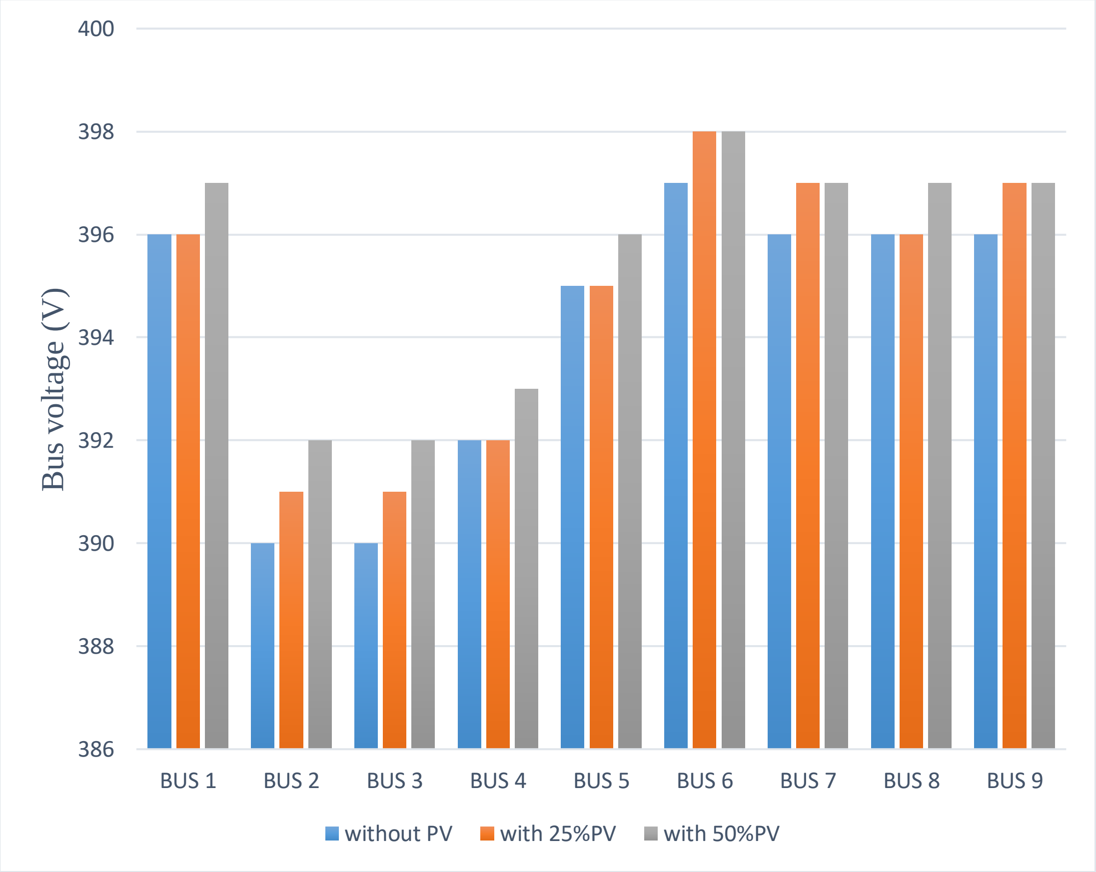


Figure 4.3. The voltage of the nine buses without PV penetration, with 20% PV penetration, and 50% PV penetration.

Figure 4.4 shows the voltage of the nine buses without PV penetration, with 75% PV penetration, and 100% PV penetration. Similarly, the increase of the voltage at the specified buses remains within the statutory limit.

Figure 4.4. The voltage of the nine buses without PV penetration, with 80% PV penetration, and 100% PV penetration.

Moreover, Figure 4.5 exhibits the voltage of the nine buses without PV penetration, with 125% PV penetration, and 150% PV penetration. It is observed that the voltage is within the acceptable limit.

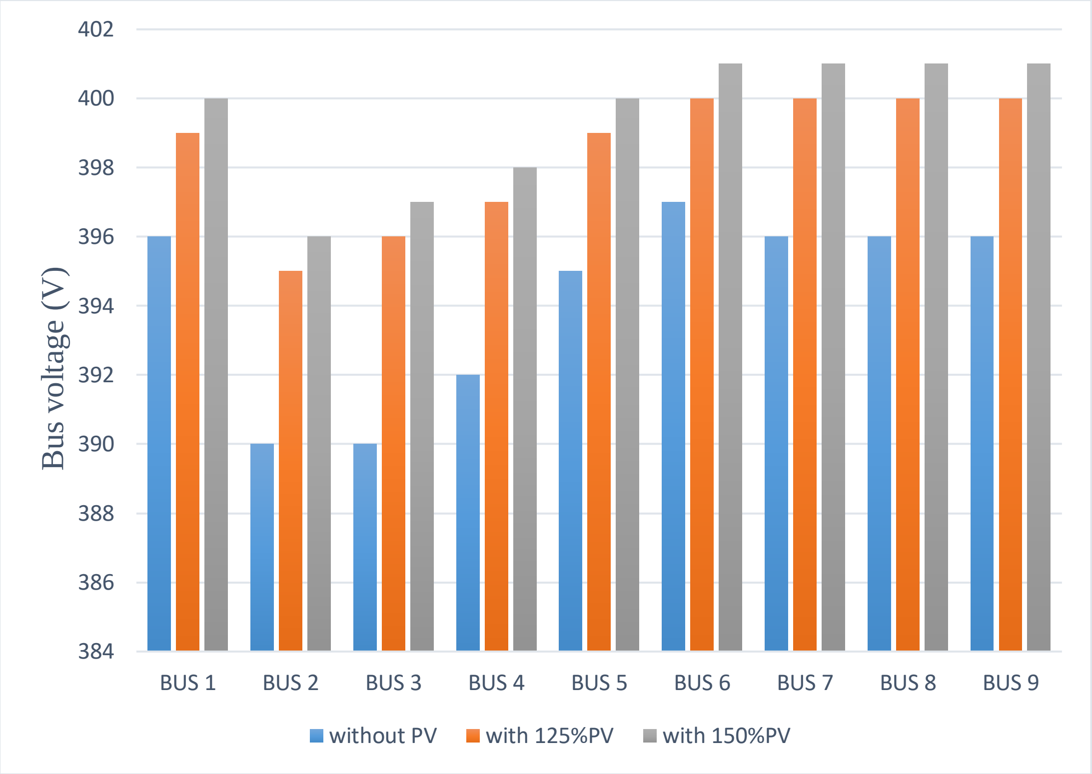


Figure 4.5. The voltage of the nine buses without PV penetration, with 125% PV penetration, and 150% PV penetration.

4.1.2. Feeder Losses Effect

As mentioned earlier, the power losses decrease when the PV penetration increase. Figure 4.6 shows the cable losses without PV penetration, with 25% PV penetration, and with 50% PV penetration. On the other hand, Figure 4.7 displays the cable losses without PV penetration, with 75% PV penetration, and with 100% PV penetration. It is observed that the power loss decreases as the PV penetration increases. Figure 4.8 shows the cable losses without PV penetration, with 125% PV penetration, and with 150% PV penetration.

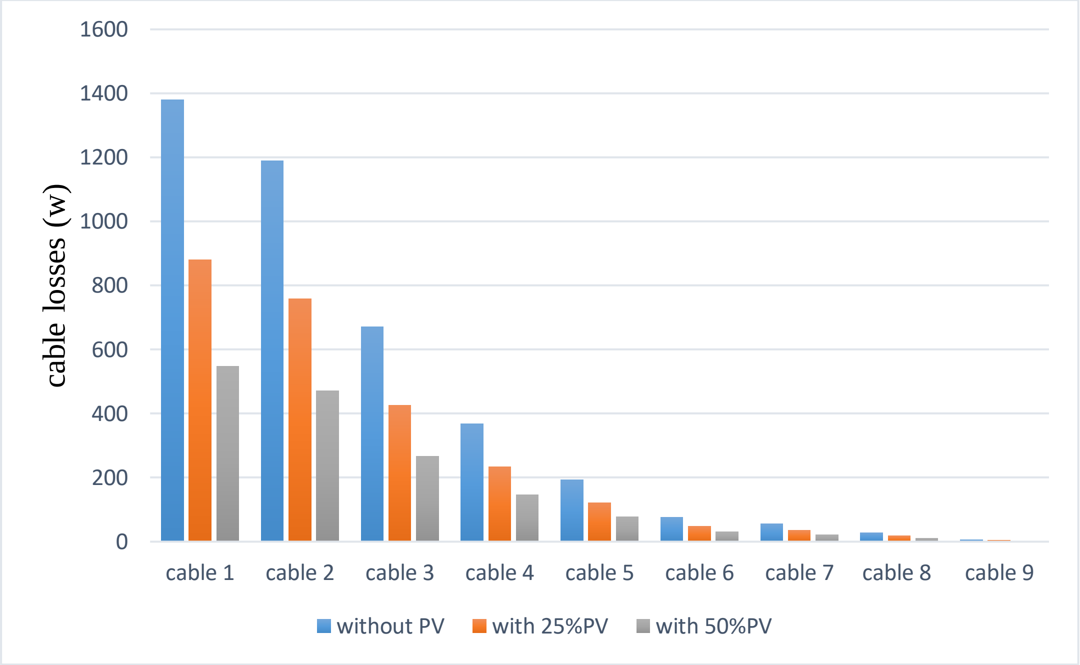


Figure 4.6. The cable losses without PV penetration, with 25% PV penetration and with 50% PV penetration.

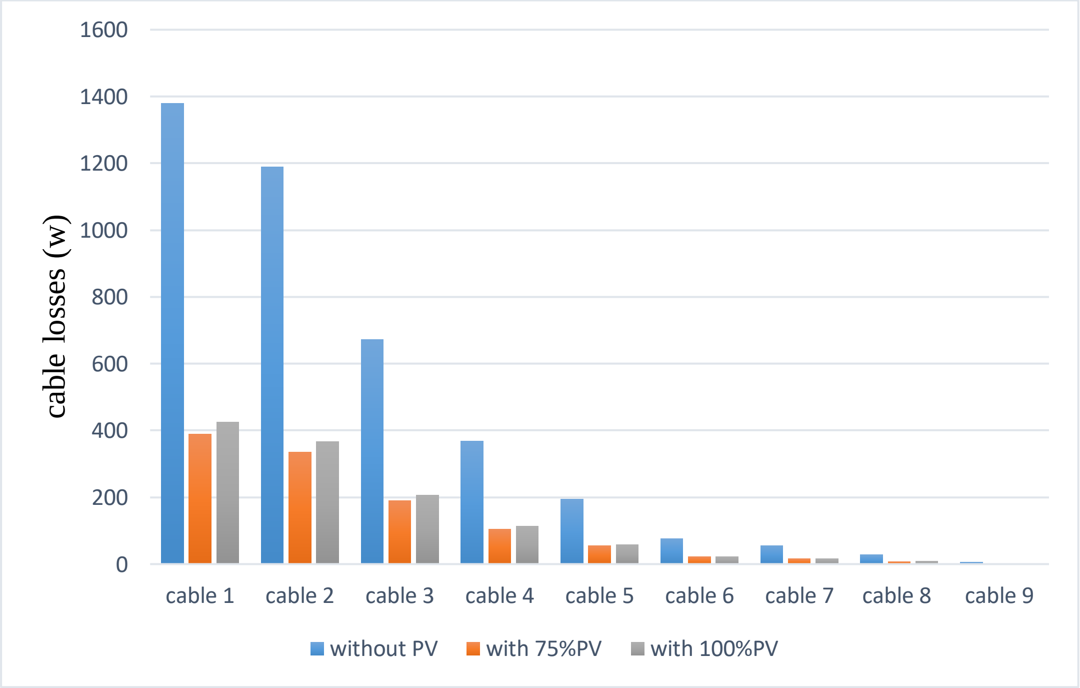


Figure 4.7. The cable losses without PV penetration, with 75% PV penetration and with 100% PV penetration.

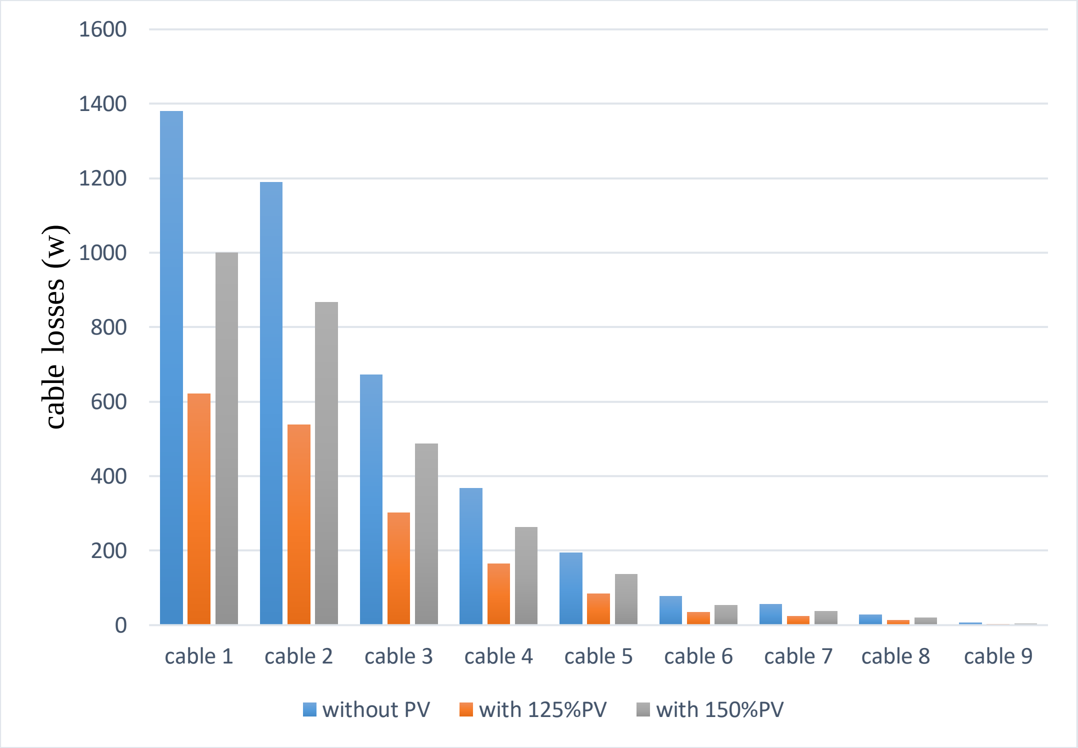


Figure 4.8. Cable losses without PV penetration, with 125% PV penetration and with 150% PV penetration.

From the result, it can be concluded that the power losses are high at the beginning of the feeder due to high power transmission. At the end of the feeder, the power losses reduce due to less power transmission. By adding a PV system to the grid the losses decrease as the PV penetration increase because the load demand is fulfilled by the PV power. Therefore, the demand for power from the substation is reducing and thus the power transmission will decrease. Moreover, when the PV penetration increases to more than the load demand level the losses started to rise, due to the reverse power flow but it is still less than the power losses without PV penetration as shown in Figure 4.9.

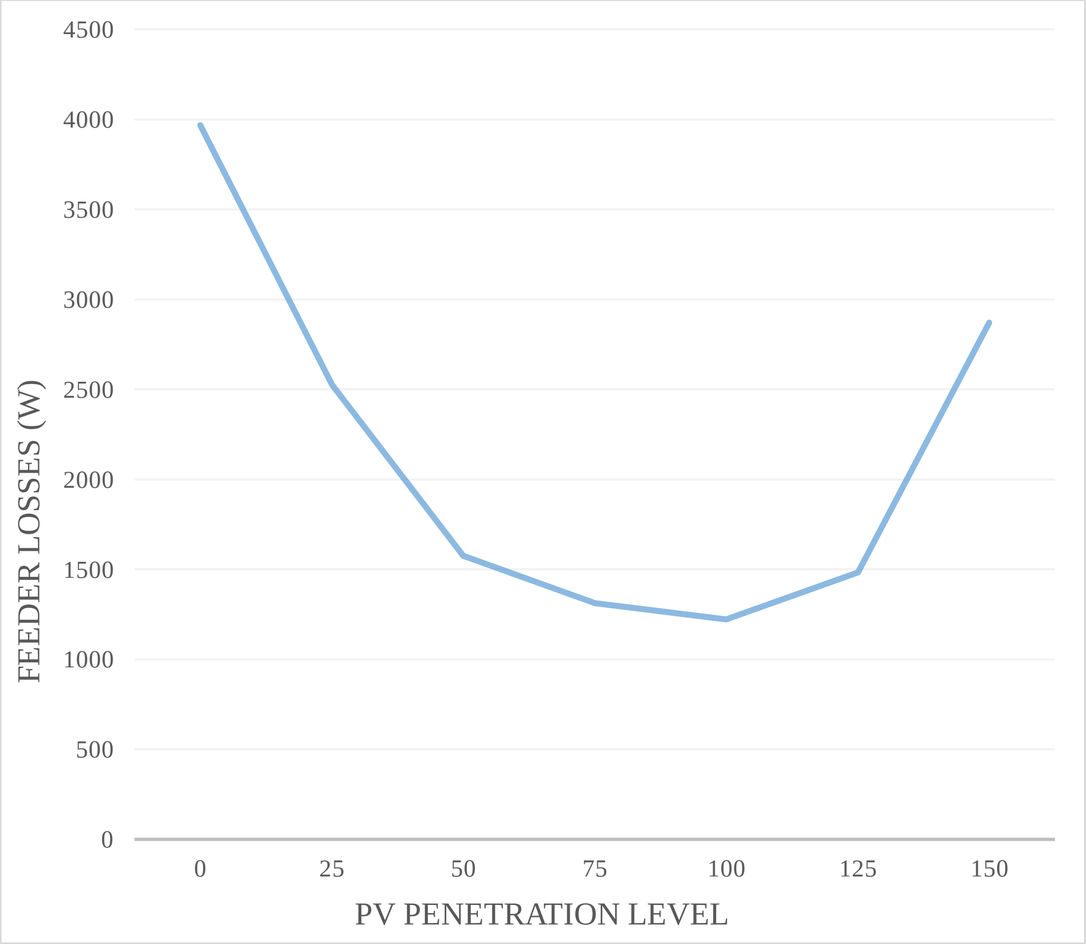


Figure 4.9. Feeder losses with different PV penetration.

4.1.3. Penetration Effect on Power Factor

The power factor is an important parameter because it is crucial for economic operation and quality transmission of electric power. Increased power from the PV system generates a drop in power factor. This is maybe interpreted from the increased active power from the PV system without any generation of reactive power. As a result, the power factor decreases since the grid delivers less active power while maintaining the same amount of reactive power as shown in Figure 4.10 and Figure 4.11 shows the effect of different PV penetration levels on the power factor of the Karabuk university grid. With further involvement of PV generation, the power factor even goes negative and becomes the leading Power factor.

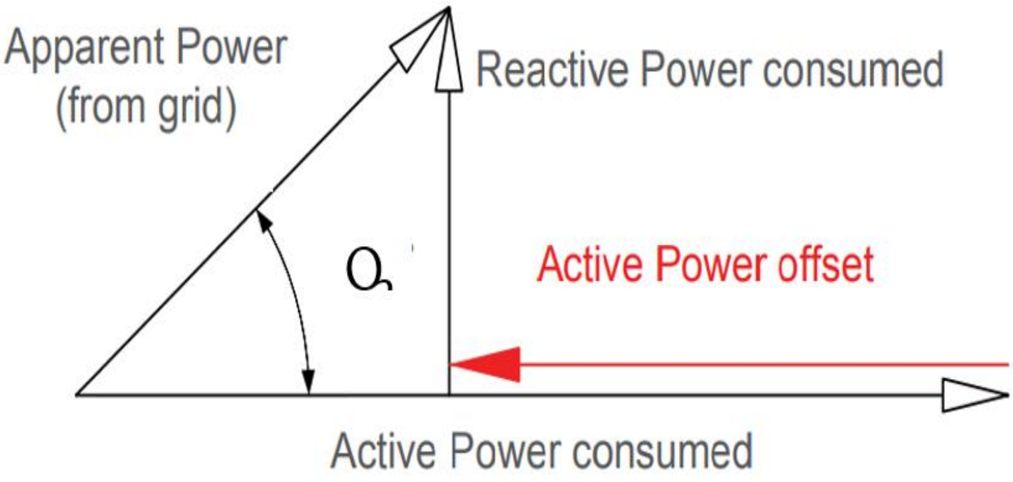


Figure 4.10. The active-reactive power relationship.

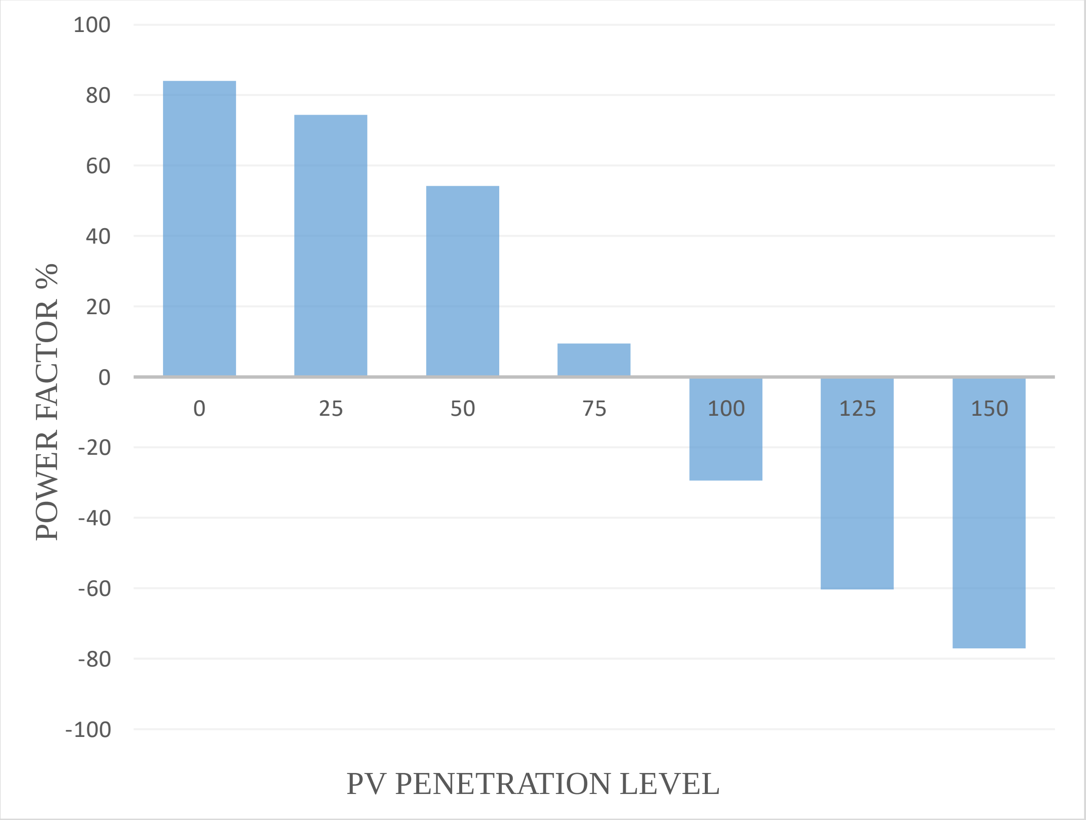


Figure 4.11. Effect of different PV penetration level on the power factor of Karabuk University grid.

4.1.4. Effect on Harmonic

Harmonic flow in ETAP was performed and the result includes THD for all the buses after connecting to the PV system. Figure 4.12 and Figure 4.13 show the THD with different PV penetration levels.

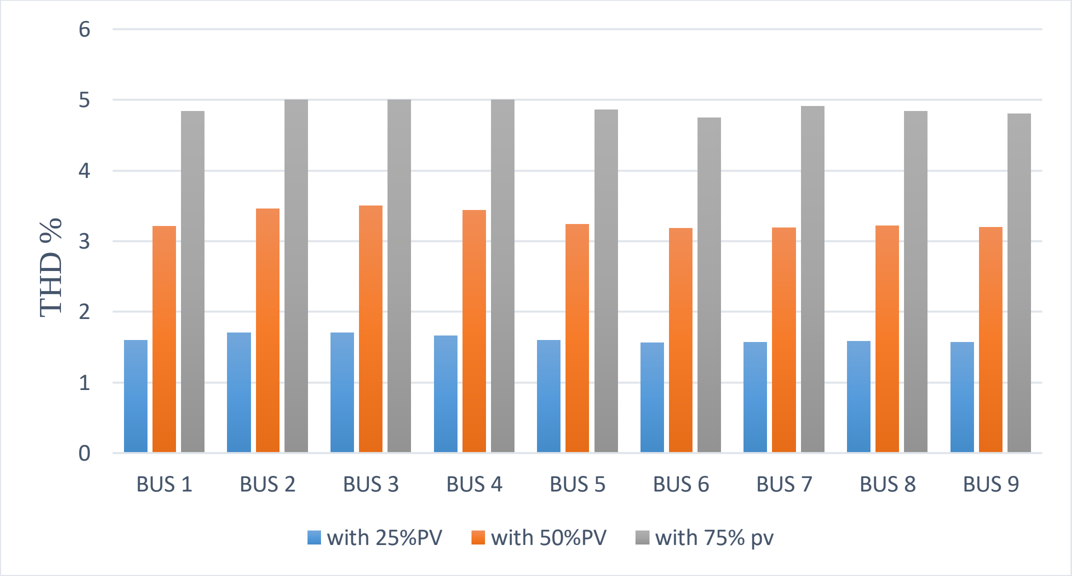


Figure 4.12. THD of all buses after PV system installation.

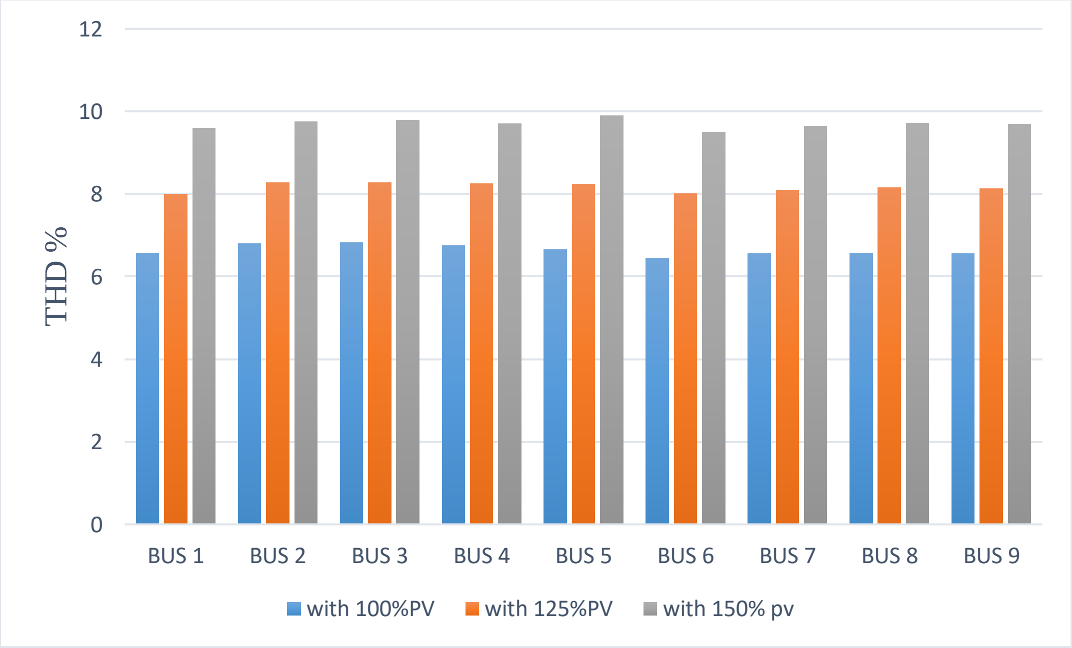


Figure 4.13. THD of all buses after PV system installation.

From the previous figures, it can be noticed that the THD at 25%, 50%, and 75% PV penetration is within the allowable limit but it exceeds the limit when the PV penetration is more than 75% due to the highly harmonic injected from the PV inverter to the grid.

Figure 4.14 exhibits the waveform of all buses without PV connection. It can be noticed that the voltage waveform is a perfect sinusoidal wave because there is no harmonic effect from the PV inverter.

Figure 4.14. Voltage waveform of all buses without PV connection.

Figure 4.15 illustrates the voltage waveform of all buses with a 25% PV penetration level. The waveform is a little distorted due to the penetration level is not high. The same thing at 50% and 75% PV penetration the voltage waveform is a little distorted. However, when the PV penetration exceeds 75% PV penetration the waveform is highly distorted due to the high harmonic injected by the PV inverter. Figure 4.16 shows the voltage waveform of all buses with 100% PV penetration its noticed that the waves are highly distorted.

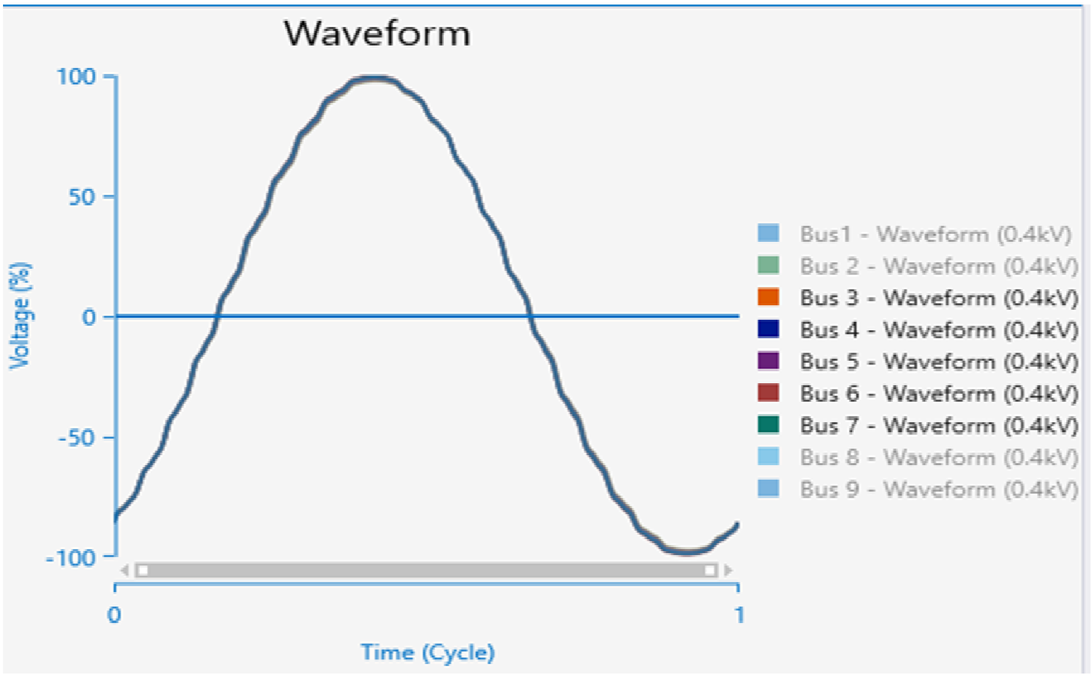


Figure 4.15. Voltage waveform of all buses at 25% PV penetration level.

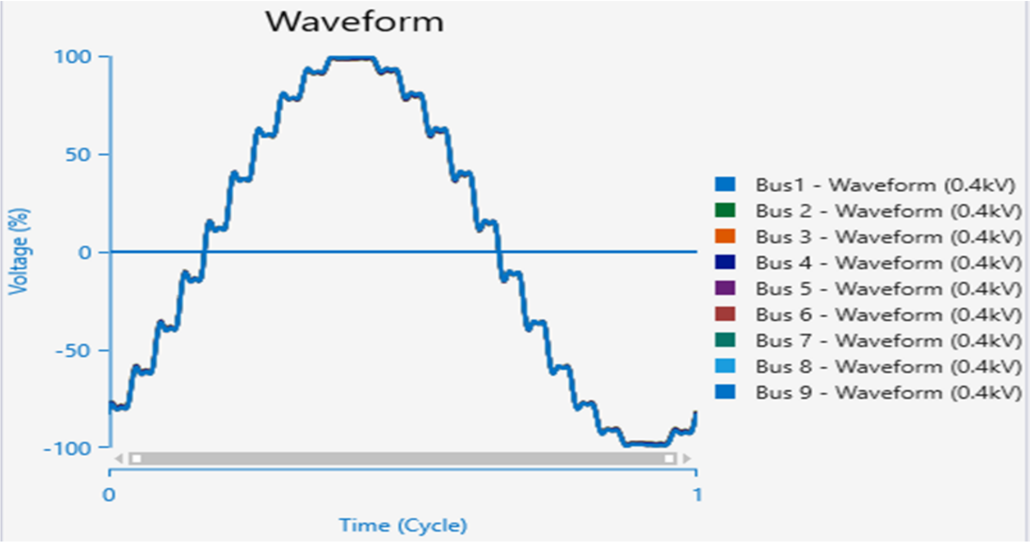


Figure 4.16. Voltage waveform of all buses with at 80% PV penetration level.

PART 5

CONCLUSION AND FUTURE WORK

In this part, the conclusion of this work as well as the future work was explained.

5.1. CONCLUSION

Solar PV systems are seen as one of the most dependable alternative energy sources for producing electrical energy since they rely on one of the Earth's natural resources, sunlight. With the increase in penetration of distributed solar PV systems in existing low voltage (LV) distribution networks, power quality has become a key focus. Although PV systems can help the distribution network to fulfill local energy demand, they can also have a detrimental influence. Turkey has a lot of solar energy and has a lot of potential for solar PV plants. In this thesis, Electrical Transient Analyzer Program (ETAP) software was used to simulate the Karabuk university’s low voltage grid. Load flow analysis and harmonic analysis are performed with different PV penetration levels in order to examine their effect on the grid. From the obtained results, it was found that raising the PV penetration causes an increase in the voltage. Moreover, the losses of the branches were decreased as the PV penetration level increased but when the PV penetration exceeds 100% the losses began to increase but it was still lower than the losses without PV penetration. Furthermore, the power factor of the system decreases when the PV penetration increases. From the harmonic analysis of the grid, it was concluded that the THD increases as the PV penetration increases. For these reasons, it is recommended that the PV penetration level at Karabuk University must not exceed 75%.

5.2. FUTURE WORK

In the future, the research might be expanded to investigate:

1. Short circuit and stability analysis.
2. Methods for mitigating the power quality issues at high PV penetration level.
3. Possibility of having multiple renewable energy sources.

REFERENCES

1. Almaktar, M., Hasimah, A. and Mohammad, Y., “Economic and Environmental Analysis of a Grid-connected Solar Photovoltaic System in Malaysia”, ***Indian Journal of Advanced in Electrical Engineering***, 1.1: 11-32 (2013).

2. Almaktar, M. and Mohamed, S., “Prospects of renewable energy as a non-rivalry energy alternative in Libya”, ***Renewable and Sustainable Energy Reviews***, 143: 110852 (2021).

3. Liu, E. and Jovan, B., “Distribution system voltage performance analysis for high-penetration photovoltaics”, ***National Renewable Energy Lab.(NREL)***, Golden, United States (2008).

4. Internet: Renewables now, “Renewables 2021 Global Status Report”, **http://www.ren21.net/status-of-renewables/global-status-** (2021).

5. Kouro, S. and Et, A., “Grid-connected photovoltaic systems: An overview of recent research and emerging PV converter technology”, ***IEEE Industrial Electronics Magazine***, 9.1: 47-61 (2015).

6. Almaktar, M. and Et, Al., “Economic Study on the Implementation of Feed in Tariff for Photovoltaic Technology in Libya”, 1100.12: 0-22 (2018).

7. Hara, R. and Et, A., “Demonstration grid-connected photovoltaic projects in Japan”, ***Proceedings of the IEEE Power and Energy Magazine***, 77-85 (2009).

8. Steffel, S. J. and Et, A., “Integrating solar generation on the electric distribution grid”, ***IEEE Transactions on Smart Grid***, 3.2: 878-886 (2012).

9. Dubey, A., “Load flow analysis of power systems”, ***International Journal of Scientific & Engineering Research*** **(**2016).

10. Martinez, J. A. and Jean, M., “Load flow calculations in distribution systems with distributed resources. A review”, ***2011 IEEE power and energy society general meeting***, ***IEEE*** (2011).

11. Afolabi, O. A. and Et, Al., “Analysis of the load flow problem in power system planning studies”, ***Energy and Power Engineering***, 7.10: 509 (2015).

12. Gilbert, G. M., Bouchard, D. E. and Chikhani, A. Y., “A comparison of load flow analysis using DistFlow, Gauss-Seidel, and optimal load flow algorithms”, ***Conference Proceedings. IEEE Canadian Conference on Electrical and Computer Engineerin***g, 850-853 (1998)

13. Stott, B., “Review of load-flow calculation methods”, ***Proceedings of the IEEE***, 62.7: 916-929 (1974).

14. Andretich, R. G. and Et, A., “The piecewise solution of the impedance matrix load flow”, ***IEEE Transactions on Power Apparatus and Systems***, 10: 1877-1882 (1968).

15. Afolabi, O. A. and Et, A., “Analysis of the load flow problem in power system planning studies”, ***Energy and Power Engineering***, 7.10: 509 (2015).

16. Variz, A. M., José, L. R. and Nelson, M., “Improved representation of control adjustments into the Newton–Raphson power flow”, ***International journal of electrical power & energy systems***, 25.7: 501-513 (2003).

17. Stott, B. and Ongun, A., “Fast decoupled load flow”, ***IEEE transactions on power apparatus and systems***, 3: 859-869 (1974).

18. Lo, K. L., Lin, Y. J. and Siew, W. H., “Fuzzy-logic method for adjustment of variable parameters in load-flow calculation”, ***IEE Proceedings-Generation, Transmission and Distribution***, 146.3: 276-282 (1999).

19. Ondraczek, J., Nadejda, K. and Anthony, P., “WACC the dog: The effect of financing costs on the levelized cost of solar PV power”, ***Renewable Energy***, 75: 888-898 (2015).

20. Neville, R. C., “Solar energy conversion: the solar cell”, **Elsevier** (1995).

21. Bucher, E., “Solar cell materials and their basic parameters”, ***Applied physics***, 17.1: 1-26 (1978).

22. Crăciun, B. and Et, A., “Overview of recent grid codes for PV power integration”, ***International Conference on Optimization of Electrical and Electronic Equipment (OPTIM)***, IEEE (2012).

23. Hasheminamin, M. and Et, A., “Index-based assessment of voltage rise and reverse power flow phenomena in a distribution feeder under high PV penetration”, ***IEEE Journal of Photovoltaics***, 5.4: 1158-1168 (2015).

24. Emmanuel, M., “Interconnection Impact Analysis of Solar Photovoltaic Systems with Distribution Networks” (2018).

25. Liu, Y. and Et, A., “Distribution system voltage performance analysis for high-penetration PV”, ***2008 IEEE Energy 2030 Conference***, IEEE (2008).

26. Baharin, K. and Et, A., “High PV Penetration Impact on European-based LV Residential Network”, ***Telecommunication Computing Electronics and Control***, 16.4: 1375-1382 (2018).

27. Tie, C. and Chin, K., “Impact of grid-connected residential PV systems on the Malaysia low voltage distribution network”, ***2013 IEEE 7th International Power Engineering and Optimization Conference (PEOCO)***, IEEE (2013).

28. Ali, S., Pearsall, N. and Putrus, G., “Impact of high penetration level of grid-connected photovoltaic systems on the UK low voltage distribution network”, ***International Conference on Renewable Energies and Power Quality*** (2012).

29. Farhoodnea, M. and Et, A., “Power quality analysis of grid-connected photovoltaic systems in distribution networks”, ***Przeglad Elektrotechniczny (Electrical Review)***, 2013: 208-213 (2013).

30. Singh, R., Pushkar, T. and Kuwar, Y., “Impact of solar photovoltaic penetration in distribution network”, ***2019 3rd International Conference on Recent Developments in Control, Automation & Power Engineering (RDCAPE)***, IEEE (2019).

31. Ibraheem, W., Chin, K. and Mohd, R., “Impact of photovoltaic (PV) systems on distribution networks”, ***International Review on Modeling and Simulations (I. RE. MO. S.)***, 7.2: 298-310 (2014).

32. Putra, J. and Isnaeni, M., “Impact of high penetration of Photovoltaic Generation on voltage fluctuation of transmission and distribution systems”, ***2015 2nd International Conference on Information Technology, Computer, and Electrical Engineering (ICITACEE)***, IEEE (2015).

33. Widén, J. and Et, A., “Impacts of distributed photovoltaics on network voltages: Stochastic simulations of three Swedish low-voltage distribution grids”, Electric ***power systems research***, 80.12: 1562-1571 (2010).

34. Tzartzev, R., Mack, G. and Jay, P., “Impact of high-penetration PV on distribution feeders”, ***2012 3rd IEEE PES Innovative Smart Grid Technologies Europe (ISGT Europe)***. IEEE (2012).

35. Keane, A., “Integration of distributed generation”, PhD Thesis, ***University College Dublin*** (2007).

36. Thomson, M. and Infield, D. G., “Impact of widespread photovoltaics generation on distribution systems”, ***IET Renewable Power Generation***, 1.1: 33-40 (2007).

37. Weckx, S., Gonzalez, C. and Johan, D., “Reducing grid losses and voltage unbalance with PV inverters”, ***2014 IEEE PES General Meeting| Conference & Exposition***, IEEE (2014).

38. Quezada, V., Rivier, A. and Gomez, S., “Assessment of energy distribution losses for increasing penetration of distributed generation”, ***Transactions on power systems***, 21.2: 533-540 (2006).

39. Vasanasong, E. and Spooner, E. D., “The effect of net harmonic currents produced by numbers of the Sydney Olympic Village's PV systems on the power quality of local electrical network”, ***2000 International Conference on Power System Technology. Proceedings (Cat. No. 00EX409)***, Vol. 2. IEEE (2000).

40. Villalva, M., Jonas R. and Ernesto, R., “Comprehensive approach to modeling and simulation of photovoltaic arrays”, ***IEEE Transactions on power electronics***, 24.5: 1198-1208 (2009).

41. Schlabbach, J., “Harmonic current emission of photovoltaic installations under system conditions”, ***2008 5th International Conference on the European Electricity Market***, IEEE (2008).

42. González, P. and Et, A., “Impact of grid connected photovoltaic system in the power quality of a distribution network”, ***Doctoral Conference on Computing, Electrical and Industrial Systems***, Springer, Berlin, Heidelberg (2011).

43. Çelebi, A. and Metin, Ç., “The effects of harmonics produced by Grid connected photovoltaic systems on electrical networks”, ***Universities Power Engineering Conference (UPEC) Proceedings of*** (2011).

44. Chidurala, A., Tapan K. and Mithulananthan, N., “Harmonic impact of high penetration photovoltaic system on unbalanced distribution networks–learning from an urban photovoltaic network”, ***IET Renewable Power Generation***, 10.4: 485-494 (2016).

45. Vinayagam, A. and Et, A., “Harmonics assessment and mitigation in a photovoltaic integrated network”, ***Sustainable Energy, Grids and Networks*** 20: 100264 (2019).

46. Poosri, O., Chalie, C., “Harmonics impact of rooftop photovoltaic penetration level on low voltage distribution system”, ***International Journal of Electronics and Electrical Engineering***, 4.3 (2016).

47. Cobben, S., Gaiddon, B. and Laukamp, H., “Impact of Photovoltaic Generation on Power Quality in Urban Areas with High PV Population: Results from Monitoring Campaigns”, ***Intelligent Energy Europe***, Brussels, Tech, Rep. *EIE/05/171/SI2* 420208 (2008).

48. Poosri, O. and Chalie C., “Harmonics impact of rooftop photovoltaic penetration level on low voltage distribution system”, ***International Journal of Electronics and Electrical Engineering***, 4.3 (2016).

49. Benhabib, M. C. and Myrzik, J. M. A., Duarte, J. L., “Harmonic effects caused by large scale PV installations in LV network”, ***2007 9th International Conference on Electrical Power Quality and Utilisati****on*, IEEE, (2007).

50. Kabala, M., “Application of distributed DC/DC electronics in photovoltaic systems”, PhD Thesis, ***Colorado State University*** (2017).

51. Salam, Z. and Jubaer, A., Benny, S., “The application of soft computing methods for MPPT of PV system: A technological and status review”, ***Applied energy***, 107: 135-148 (2013).

52. Chen, Y. and Keyue, S., “Three-phase boost-type grid-connected inverter." ***IEEE Transactions on Power Electronics***, 23.5: 2301-2309 (2008).

53. Aziz, T. and Nipon, K., “PV penetration limits in low voltage networks and voltage variations”, ***IEEE Access***, 5: 16784-16792 (2017).

54. Mukwekwe, L., Chitra, V. and Innocent, E., “A review of the impacts and mitigation strategies of high PV penetration in low voltage networks”, ***2017 IEEE PES Power Africa***, 274-279 (2017).

55. Bamdad, E., “High penetration photovoltaic system analysis”, ***California state University of Northridge***, (2014).

56. Canova, Aldo and Luca, G., “Numerical and analytical modeling of bus bar systems”, ***IEEE Transactions on Power Delivery***, 24.3: 1568-1578 (2009).

57. Kulkarni, V. and Khaparde, S. A., “Transformer engineering”, ***Marcel Dekker***, New York (2004).

58. Azmy, M., István E. and Sowa, P., “Artificial neural network-based dynamic equivalents for distribution systems containing active sources”, ***IEE Proceedings-Generation, Transmission and Distribution***, 151.6: 681-688 (2004).

59. Prabhu, J., and Et, A., “Design of electrical system based on load flow analysis using ETAP for IEC projects”, ***2016 IEEE 6th International Conference on Power Systems (ICPS)***, IEEE, (2016).

60. Ghiasi, M., “A detailed study for load flow analysis in distributed power system”, ***International Journal of Industrial Electronics Control and Optimization***,1.2: 153-160 (2018).

61. Mumtaz, M., and Et, A., “Load flow analysis of cigre benchmark model using etap”, ***Proceedings of the International Conference on Renewable, Applied and New Energy Technologies***, ICRANET (2018).

62. Mahdi, M., “Power flow analysis of Rafah governorate distribution network using ETAP software”, ***International Journal of Physical Sciences***,1.2: 019-026 (2013).

63. Bhuiyan, N., “Power System Harmonic Analysis using ETAP”, ***Brunel University*** (2011).

64. Kamel, M., “New inverter control for balancing standalone micro-grid phase voltages: A review on MG power quality improvement”, ***Renewable and Sustainable Energy Reviews***,63: 520-532 (2016).

RESUME

Abbas Falah Hasan AL-GBURI was born in Baghdad 1994 and he finished primary, intermediate, and high school in this city. After finishing school, he joined the College of Engineering at AL NAHRAIN University in 2014. Then in 2020, he started at Karabuk University Electrical and Electronics Engineering to complete his M. Sc. education.