

## Impact of Distributed PV Integration on Voltage Profile and Power Losses in a 66 kV Distribution Network

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### Abstract

This paper investigates the impact of integrating a 5 MW photovoltaic (PV) distributed generation unit into a 66 kV sub-transmission network in western Libya. The study aims to improve voltage profile and reduce active power losses through the proper integration of distributed PV generation. The electrical network was modeled using NEPLAN software based on real grid data obtained from the General Electricity Company of Libya (GECOL), while the PV system was designed and simulated using PVsyst according to local solar irradiation and temperature conditions. Two operating scenarios were evaluated: the base case without PV generation and the case with the integrated 5 MW PV system. Load-flow analysis was performed under peak demand conditions to assess network performance in terms of bus voltage profile and total active power losses. The simulation results demonstrated a significant improvement in voltage profile after PV integration, where the minimum bus voltage increased from 85.1% to 95.3%. In addition, total active power losses decreased from 1.209 MW to 0.93 MW, representing a reduction of approximately 23%. Furthermore, the proposed PV system contributes to reducing carbon dioxide (CO<sub>2</sub>) emissions through clean energy generation, highlighting its environmental benefits. The findings confirm that distributed PV integration can effectively enhance voltage regulation, minimize network losses, and support sustainable energy development in Libya's medium-voltage power networks.

تأثير دمج أنظمة الطاقة الشمسية الموزعة على مستوى الجهد وفوق القدرة في شبكة توزيع

بجهد 66 ك.ف

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الملخص: تتناول هذه الدراسة تأثير دمج نظام توليد موزع بالطاقة الشمسية الكهروضوئية بقدرة 5 ميغاوات ضمن شبكة نقل فرعية بجهد 66 ك.ف في المنطقة الغربية من ليبيا. وتهدف الدراسة إلى تحسين مستوى الجهد وتقليل الفواقد في القدرة الفعالة من خلال الدمج المناسب لأنظمة الطاقة الشمسية الموزعة. تم نمذجة الشبكة الكهربائية باستخدام برنامج NEPLAN بالاعتماد على بيانات حقيقية مقدمة من الشركة العامة للكهرباء، بينما تم تصميم ومحاكاة النظام الشمسي باستخدام برنامج PVsyst وفقاً لبيانات الإشعاع الشمسي ودرجات الحرارة المحلية. تمت

دراسة حالتين تشغيليتين، الأولى تمثل الشبكة الأساسية بدون توليد شمسي، والثانية بعد دمج نظام شمسي بقدرة 5 ميغاوات. كما تم إجراء تحليل تدفق الأحمال تحت ظروف الحمل الأقصى لتقييم أداء الشبكة من حيث مستوى الجهد والفواقد في القدرة الفعالة. أظهرت نتائج المحاكاة تحسناً ملحوظاً في مستوى الجهد بعد دمج النظام الشمسي، حيث ارتفع أقل جهد من 85.1% إلى 95.3%. بالإضافة إلى ذلك، انخفضت الفواقد الكلية في القدرة الفعالة من 1.209 ميغاوات إلى 0.93 ميغاوات، بنسبة تقارب 23%. كما ساهم النظام الشمسي المقترح في تقليل انبعاثات ثاني أكسيد الكربون ( $CO_2$ ) من خلال إنتاج طاقة نظيفة، مما يبرز الفوائد البيئية للطاقة الشمسية. تؤكد نتائج الدراسة أن دمج أنظمة الطاقة الشمسية الموزعة يمكن أن يسهم بفاعلية في تحسين تنظيم الجهد وتقليل فواقد الشبكة ودعم التنمية المستدامة في شبكات القدرة ذات الجهد المتوسط في ليبيا.

الكلمات المفتاحية:

التوليد الموزع، الأنظمة الكهروضوئية، فواقد القدرة، الطاقات المتجددة

## 1 Introduction

The increasing global demand for electrical energy, combined with growing environmental concerns and the depletion of fossil fuel resources, has accelerated the transition toward renewable energy technologies. Among the available renewable energy sources, photovoltaic (PV) systems have emerged as one of the most promising solutions due to their clean energy production, modular structure, and decreasing installation costs [1], [2].

In recent years, distributed generation (DG) has received considerable attention as an effective approach for improving the operational performance of electrical distribution and sub-transmission networks. Proper integration of distributed PV systems can contribute to voltage profile enhancement, reduction of active power losses, improvement of network efficiency, and mitigation of greenhouse gas emissions [3], [4].

The Libyan electrical power system continues to face several technical challenges, including voltage instability, high transmission losses, increasing load demand, and aging infrastructure. These challenges are more noticeable in inland regions located far from major generation stations. The Gharyan 66 kV sub-transmission network represents an important part of the electrical infrastructure in western Libya and frequently experiences voltage drop problems and increased active power losses during peak loading conditions [5].

Libya possesses significant solar energy potential due to its geographical location and high solar irradiation levels throughout the year. According to several studies and international energy reports, Libya is considered one of the most suitable regions in North Africa for large-scale solar energy applications [6]. Therefore, integrating distributed PV systems into medium-voltage networks can provide both technical and environmental benefits while supporting sustainable energy development.

Several previous studies have investigated the impact of distributed generation on electrical network performance. Most of these studies reported that optimal placement and sizing of DG units can significantly improve voltage stability and reduce network losses [7], [8]. However, limited studies have focused on medium-voltage sub-transmission networks in Libya using real network data and realistic PV generation models.

This study investigates the impact of integrating a 5 MW photovoltaic distributed generation unit into the Gharyan 66 kV sub-transmission network using NEPLAN and PVsyst software tools. The study evaluates the effect of PV integration on voltage profile improvement and active power loss reduction under peak demand conditions. In addition, the environmental impact of PV integration is assessed in terms of reducing carbon dioxide ( $CO_2$ ) emissions through clean energy generation.

## 2 Materials and Methods

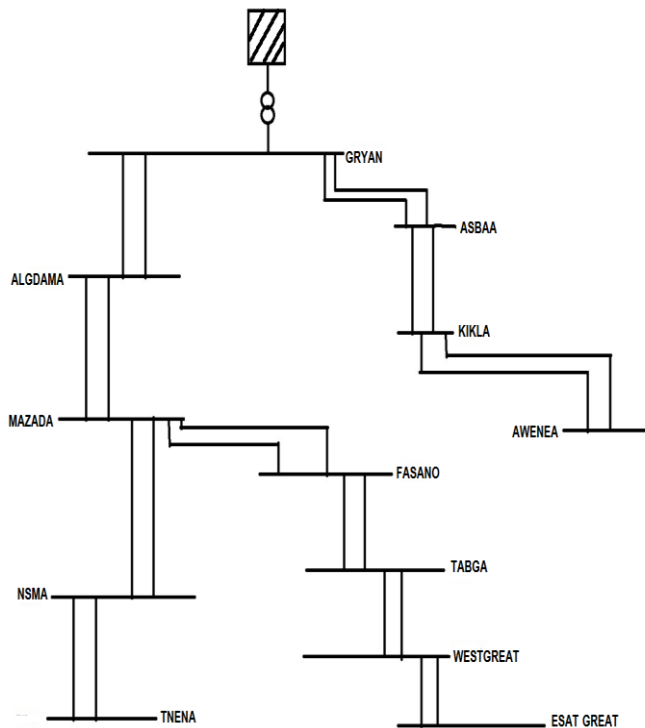
### 2.1 Study Network Description

The present study was conducted on the Gharyan 66 kV sub-transmission network located in western Libya. The selected network represents an important part of the regional electrical infrastructure and supplies power to several residential, commercial, and public service loads within the Gharyan area.

The network consists of multiple buses, transmission lines, transformers, and interconnected load centers operating under medium-voltage conditions. Due to the increasing electricity demand and the long distances between generation sources and load centers, the network experiences noticeable voltage drop problems and relatively high active power losses, especially during peak loading periods.

Real operational data of the network, including line parameters, bus data, transformer ratings, and load values, were obtained from the General Electricity Company of Libya (GECOL). These data were used to develop a realistic simulation model for load-flow analysis and network performance evaluation.

A single-line diagram of the studied Gharyan 66 kV network is illustrated in Figure 1. The network was selected as a practical case study to evaluate the impact of distributed photovoltaic integration on voltage profile improvement and active power loss reduction under actual operating conditions.



**Figure 1. Single-line diagram of the Gharyan 66 kV electrical distribution network.**

### 2.2 PV System Design Using PVsyst

The photovoltaic (PV) system considered in this study was designed and analyzed using PVsyst software, which is widely used for photovoltaic system sizing, performance analysis, and energy yield estimation [9]. The proposed PV plant was designed with a total installed capacity of 5 MW to support the studied 66 kV distribution network.

The PV system design was based on solar irradiation and meteorological data corresponding to the western region of Libya. Libya is characterized by high solar irradiation levels throughout the year, making photovoltaic energy one of the most suitable renewable energy resources for electrical power generation.

The designed PV system included photovoltaic modules, inverters, and associated electrical components. Appropriate design parameters such as module orientation, tilt angle, and inverter sizing were selected to maximize annual energy production and improve overall system performance under local environmental conditions.

The annual energy production and system performance indicators obtained from PVsyst were used as input data for evaluating the impact of distributed PV integration on the electrical network. The monthly energy generation profile obtained from the PVsyst simulation is illustrated in Figure 2.

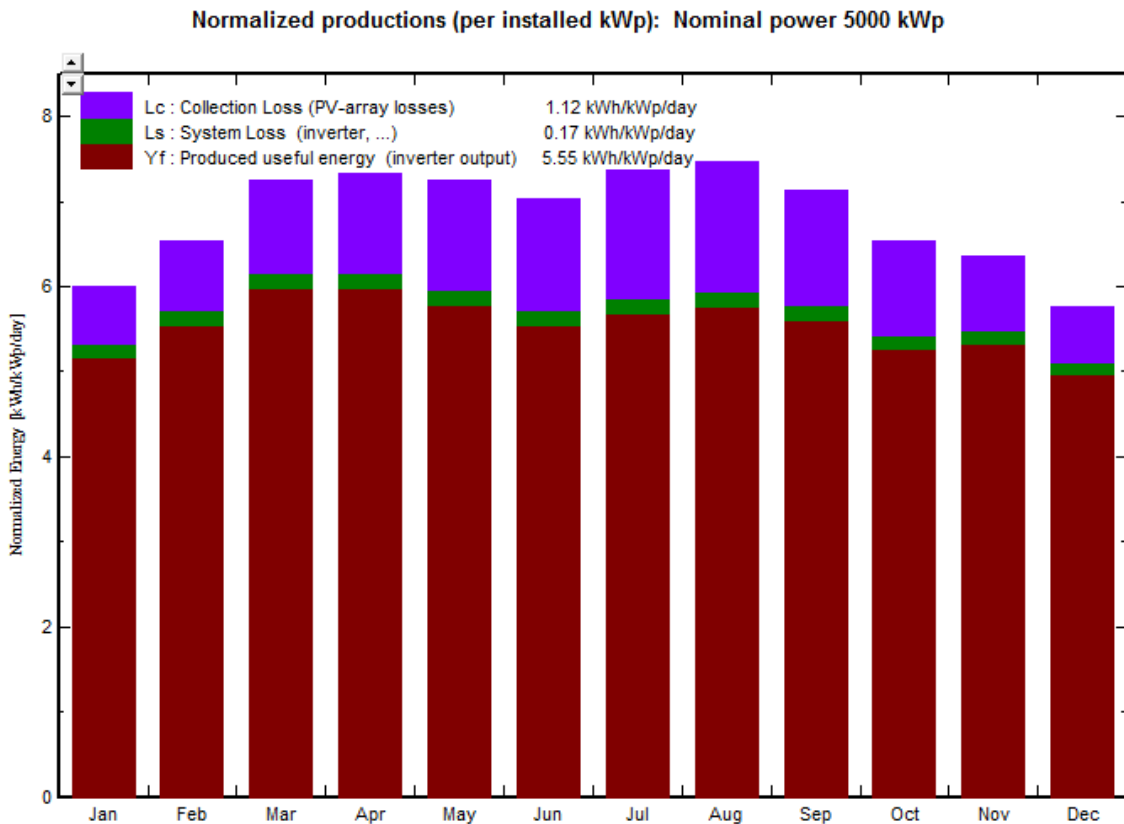


Figure 2. Monthly energy generation profile from PVsyst simulation.

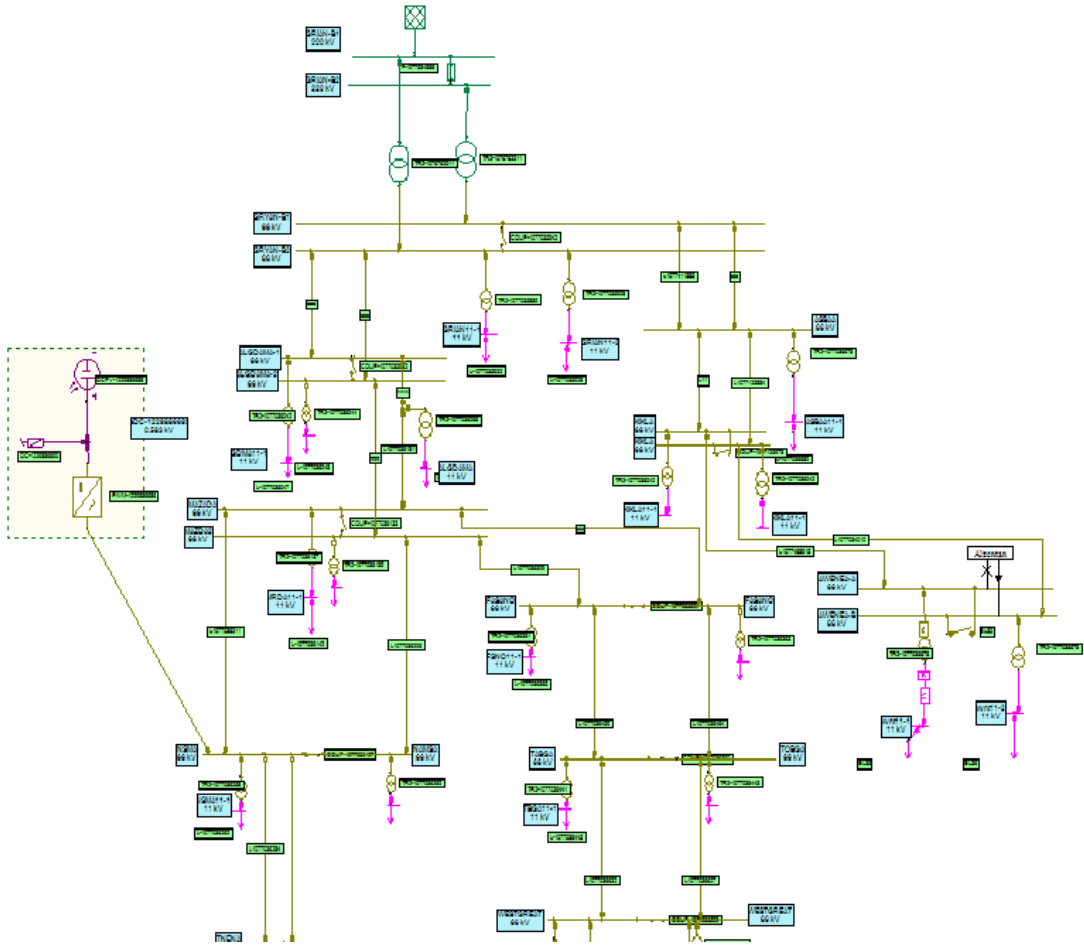
### 2.3 Network Modeling Using NEPLAN

The Gharyan 66 kV electrical network was modeled and analyzed using NEPLAN software, which is widely utilized for electrical power system analysis, load-flow calculations, and network performance evaluation [10].

The developed network model included buses, transmission lines, transformers, and connected load centers based on actual operational data obtained from the General Electricity Company of Libya (GECOL). Load-flow analysis was performed to evaluate the operational condition of the network before and after integrating the distributed PV generation system.

The load-flow calculations focused on analyzing bus voltage profiles and total active power losses under peak loading conditions. The simulation results obtained from NEPLAN were used to assess the technical effectiveness of the proposed PV integration in improving network performance and reducing system losses.

The distributed PV system was connected to the selected bus within the network according to the proposed integration scenario. Figure 3 illustrates the NEPLAN model of the studied electrical network.



**Figure 3. NEPLAN model of the studied 66 kV network with integrated PV generation.**

## 2.4 Simulation Scenarios

Two operating scenarios were considered in this study in order to evaluate the impact of distributed photovoltaic integration on the performance of the Gharyan 66 kV network.

The first scenario represents the base case of the electrical network without photovoltaic generation. This case was analyzed to determine the initial operating condition of the network, including voltage profile and active power losses under peak loading conditions.

The second scenario represents the network after integrating a 5 MW distributed photovoltaic system at the selected bus within the network. The proposed PV integration was evaluated using load-flow analysis to investigate its impact on voltage profile improvement and reduction of active power losses.

The comparison between both scenarios was carried out using the same loading conditions in order to ensure accurate assessment of the technical benefits achieved through distributed PV integration.

## **2.5 Performance Evaluation**

The performance of the studied electrical network was evaluated based on several technical indicators before and after integrating the distributed PV system.

The primary evaluation criterion was the voltage profile of network buses, where the voltage levels were analyzed to determine the effectiveness of the proposed PV system in improving voltage regulation and maintaining acceptable operating limits.

In addition, total active power losses within the network were calculated and compared for both operating scenarios. The reduction in active power losses was used as an indicator of network efficiency improvement resulting from distributed generation integration.

Furthermore, the environmental impact of the proposed PV system was evaluated through estimating the reduction in carbon dioxide (CO<sub>2</sub>) emissions achieved by replacing part of the conventional fossil-fuel-based electrical generation with clean solar energy.

## **3 Results**

### **3.1 Case 1: Base Case without PV Integration**

The first simulation scenario represents the original operating condition of the Gharyan 66 kV network without distributed photovoltaic generation. Load-flow analysis was performed using NEPLAN software under peak loading conditions in order to evaluate the voltage profile and active power losses of the network.

The simulation results indicated noticeable voltage drop problems at several buses within the network. The minimum bus voltage reached approximately 85.1%, which is below the acceptable operating limits for reliable electrical network operation. In addition, the total active power losses in the network were approximately 1.209 MW.

These results confirm that the studied network experiences operational challenges associated with voltage regulation and transmission losses, particularly during periods of high load demand.

### **3.2 Case 2: Network with 5 MW PV Integration**

The second simulation scenario was carried out after integrating a 5 MW distributed photovoltaic system into the selected bus of the Gharyan 66 kV network. The purpose of this case study was to evaluate the technical impact of distributed PV generation on network performance.

The load-flow analysis results showed a significant improvement in the voltage profile after PV integration. The minimum bus voltage increased from 85.1% to approximately 95.3%, indicating enhanced voltage regulation and improved network operating conditions.

Furthermore, the total active power losses decreased from 1.209 MW to approximately 0.93 MW, representing a reduction of nearly 23%. This reduction was mainly caused by decreasing the power transmitted through the network lines due to local generation support near load centers.

The monthly energy generation profile obtained from PVsyst simulation demonstrated the capability of the proposed PV system to produce clean electrical energy throughout the year.

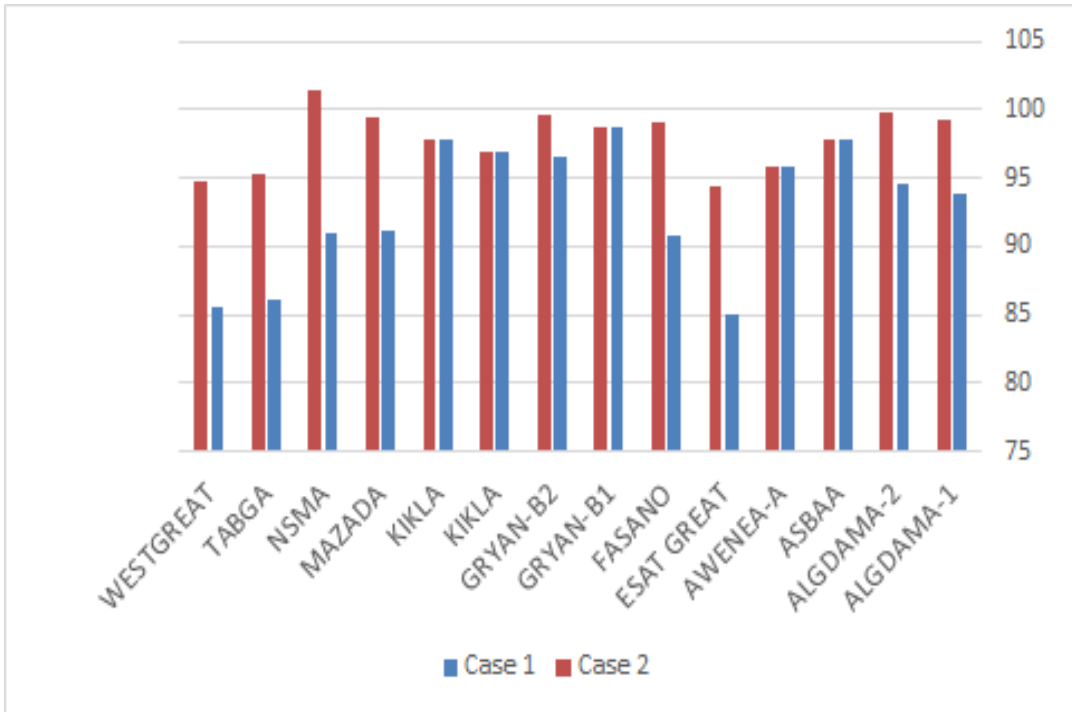
### **3.3 Comparison of Results**

A comparison between the two studied cases clearly demonstrates the positive technical impact of distributed photovoltaic integration on the Gharyan 66 kV network.

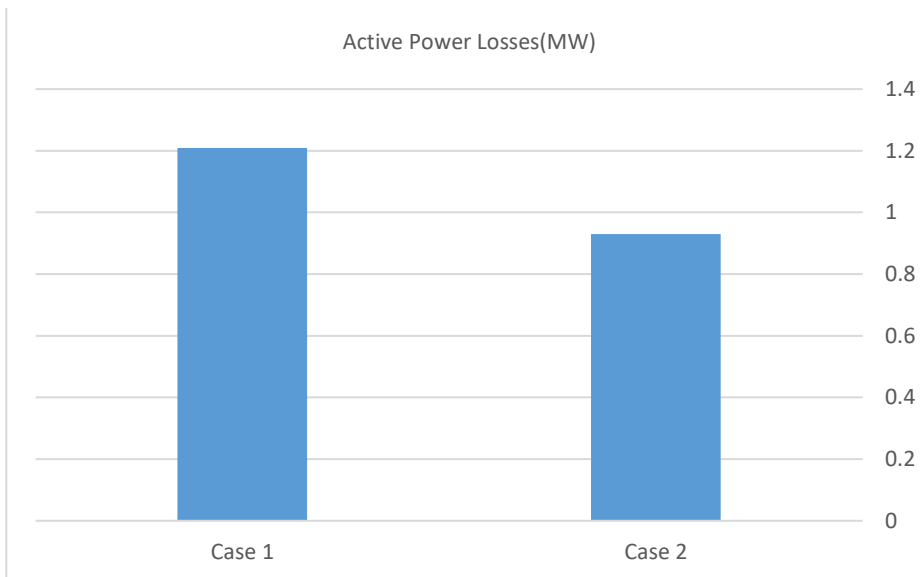
The integration of the 5 MW PV system improved the voltage profile across the network buses and significantly reduced the active power losses under peak demand conditions. The local

generation provided by the distributed PV system contributed to reducing line loading and improving the overall operational efficiency of the electrical network.

Figure 4 illustrates the voltage profile comparison before and after PV integration, while Figure 5 presents the reduction in active power losses achieved by the proposed distributed generation system.



**Figure 4. Voltage profile comparison for Case 1 and Case 2**



**Figure 5. Comparison of total active power losses**

## **4 Discussion**

The obtained results confirm that distributed photovoltaic integration can provide substantial technical benefits for medium-voltage electrical networks, especially in regions characterized by high solar energy potential, such as Libya.

The improvement in voltage profile observed in the second simulation case is mainly attributed to the local injection of active power near load centers. This reduced the dependency on distant conventional generation sources and minimized voltage drops along transmission lines. As a result, the network operated within more acceptable voltage limits after PV integration.

Similarly, the reduction in active power losses can be explained by the decrease in line currents resulting from local power generation. Since electrical losses are directly related to line current magnitude, reducing transmitted power through the network contributes significantly to improving system efficiency and lowering losses.

In addition to the technical improvements, the proposed PV system provides important environmental advantages through clean energy generation and reduction of carbon dioxide (CO<sub>2</sub>) emissions. This supports future renewable energy development strategies and contributes to reducing dependence on fossil-fuel-based electricity generation in Libya.

The study findings are consistent with several previous studies reported in the literature, which demonstrated that properly integrated distributed generation systems can improve voltage regulation and reduce network losses in medium-voltage electrical networks.

Overall, the results demonstrate that distributed photovoltaic integration represents an effective and practical solution for improving the operational performance, efficiency, and sustainability of Libya's electrical power networks.

## **5 Conclusion**

This study investigated the impact of integrating a 5 MW distributed photovoltaic generation system into the Gharyan 66 kV sub-transmission network using NEPLAN and PVsyst software tools. The study focused on evaluating the effect of distributed PV integration on voltage profile improvement, active power loss reduction, and environmental performance under peak loading conditions.

The simulation results demonstrated a clear improvement in the network voltage profile after integrating the proposed PV system. The minimum voltage level increased from 85.1% to 95.3%, indicating enhanced voltage regulation and improved network operational stability. In addition, total active power losses decreased from 1.209 MW to 0.93 MW, representing a reduction of approximately 23%.

The study also confirmed the environmental benefits of photovoltaic integration through reducing carbon dioxide (CO<sub>2</sub>) emissions and supporting clean energy generation. These findings highlight the potential role of distributed photovoltaic systems in improving the performance and sustainability of medium-voltage electrical networks in Libya.

Based on the obtained results, distributed PV integration can be considered an effective technical solution for improving the voltage profile, reducing network losses, and supporting future renewable energy expansion within the Libyan power system.

### **Conflict of Interest**

The author declares that there is no conflict of interest regarding the publication of this paper.

### **Authors' Contributions**

The author solely conducted the research work, including system modeling, simulation, analysis, and manuscript preparation.

## Funding

This research received no external funding.

## Data Availability

The data used in this study were obtained from the General Electricity Company of Libya (GECOL). Some data may be available from the author upon reasonable request.

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