

## Voltage profile and power losses of 11 kV Erbil city distribution power system incorporated with Solar Photovoltaic System

**Barzan Abdulqadir Muhammed**

Electrical Department, College of Engineering, Salahaddin University, Erbil, Kurdistan Region, Iraq

Email: [Barzan.Muhammed@su.edu.krd](mailto:Barzan.Muhammed@su.edu.krd)

**Asst. Prof. Aree Akram Muhammed**

Electrical Department, College of Engineering, Salahaddin University, Erbil, Kurdistan Region, Iraq

Email: [Aree.Muhammed@su.edu.krd](mailto:Aree.Muhammed@su.edu.krd)

### ARTICLE INFO

#### **Article History:**

Received: 20/4/2025

Accepted: 16/7/2025

Published: Summer 2026

#### **Keywords:**

*Solar photovoltaic systems; Electrical Transient Analyzer Program; voltage profile; power losses; distributed generation.*

#### **Doi:**

10.25212/lfu.qzj.11.3.48

### ABSTRACT

The rapid growth in electricity demand in Erbil city due to the city's massive expansion has led to significant challenges in the distribution power system. This increase has resulted in various issues within the distribution power system, including voltage profile drops, power losses, and a decline in power quality. To minimize the losses and raise the voltage to acceptable levels, Renewable Energy Sources (RES), particularly solar photovoltaic (PV) systems, could be placed within the system in optimum locations. In this paper, the problematic points in the 11 kV system were identified, and a Solar Photovoltaic System with a capacity of 1 MW was incorporated into the 11 kV bus bars to reduce the power loss and increase the voltage profile in the locations that suffer from voltage drop, using the Electrical Transient Analyzer Program (ETAP) software. This implementation led to a significant improvement in voltage levels that are compatible with international standards and the Ministry of Electricity of the Kurdistan Region's objectives, which permits a  $\pm 10\%$  voltage fluctuation in 11 kV distribution networks. In addition to the reduction in power losses by 5.18 % compared to the system without Solar Photovoltaic System integration. However, installing a 1 MW Solar

Photovoltaic system requires a suitable area of lands. In cases where such space is not available, the best option is to utilize flexible alternating current transmission systems (FACTS) devices. While flexible alternating current transmission systems devices only work with reactive power, Solar Photovoltaic systems can control both active and reactive power, making it a more comprehensive option when possible.

## 1. Introduction

Three subsystems, associated with electricity generation, transmission, and distribution, normally manage the flow of electric power from a producing station to the load premises (Aman et al., 2022b). Different types of power-producing facilities, including hydropower plants, thermal power plants, and nuclear power plants, are used to supply the ever-increasing demand for electric power from industrial and residential customers. Conventional power plants are frequently located in distant locations far from consumer loads (Prasad et al., 2023; Sun & Yu, 2023). Transmission lines and feeders transfer power from the producing station to the dispersed load. Figure 1 shows an electrical generating station, followed by a transmission system and, finally, a distribution system.

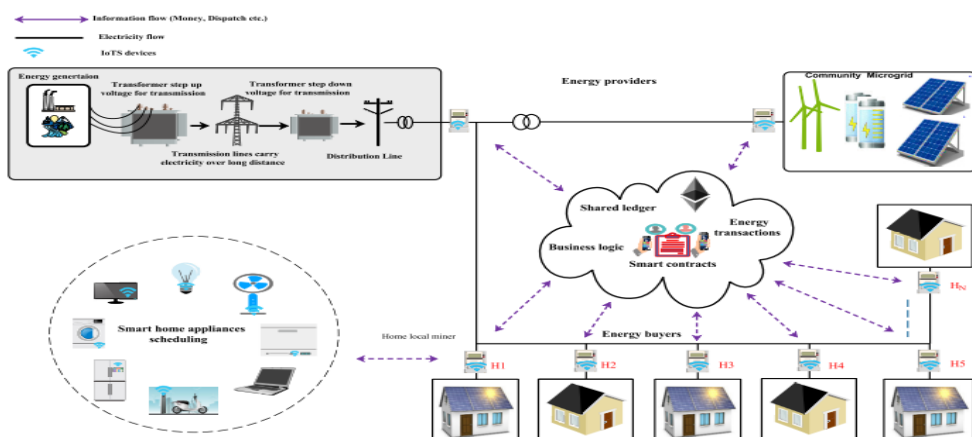


Figure (1): Electrical power system components: generation, transmission, and distribution.

(Afzal et al., 2020)

However, due to several circumstances, a significant proportion of power is lost. Energy data sources (Biswal et al., 2021) indicate a 1.40% annual increase in electricity demand. According to the US Department of Energy, fossil fuels generate 78.40 % of all power.

Nuclear power accounts for 2.60% of total electrical energy, while nonconventional sources, including geothermal, wind, and solar, contribute 19.0%. Increasing the use of fossil fuels for power generation is not feasible due to their limited availability and the negative impact on the environment. Developing new non-fossil fuel power facilities, such as hydro or nuclear, is time-consuming and expensive (Shkrabets et al., 2021). Optimizing established power-generating systems can minimize power losses (PLs) and enhance voltage profiles, reducing the need for power production units to be quickly. This paper investigates how distribution system components affect PLs and voltage profiles after distributed generation (DG) injection, intending to reduce power losses and improve system efficiency.

To evaluate the suggested optimization technique, the electrical transient analyzer program (ETAP) is used to conduct simulations using real data from the grid stations. ETAP was used to simulate and assess a bus-bar distribution system. The research paper is organized as follows. Section two discusses the impacts of distributed generation on distribution networks, as well as a proposed strategy for improving the voltage pattern and reducing power losses caused by solar PV system injection. Section three describes the mathematical modeling of the proposed task. Section four presents an analysis of the test feeder and its working method, and explores the modeling of the distributed generation unit in terms of a solar PV system. Section five presents and discusses the results.

## **2. Literature Review**

(Mahato et al., 2024) Focused on reducing these losses, capacitors and distributed generation (DGs), especially solar photovoltaic (PV) systems, are carefully dispersed throughout the system. This project is dedicated to lowering power losses and enhancing the voltage profile by doing a thorough study that optimizes the placement of capacitors and distributed generation along the distribution feeder. (Ikram et al., 2024) The major things this study looks at are the load flow and short-circuit analysis of a radial distribution feeder, which is largely made utilizing ETAP. The electrical distribution system is the last and most important aspect of a power system. It makes sure that customers always have access to steady, uninterrupted electricity. (Mansaray et al., 2024) This study shows a way to connect many DSPs to the current and expanding Freetown distribution networks using a power flow-based strategy that uses Newton-Raphson's algorithm in the ETAP tool. The analysis found the best places to inject power into the network and the best places to host it to reduce active power loss and optimize bus voltage profiles. (Jaleel & Abd, 2023) In this study, has been focused adding distributed generator units (DG) to the distribution system to fix these difficulties. One of the most common ways to make the distribution system more reliable, lower power losses, and raise bus voltage is to put distributed generator units in the right area and size. This study used Enhanced Particle Swarm Optimization (EPSO) to discover the best size and location for DG units to cut down on power losses and raise the bus voltage level. It also used the Transient Electricity Analyzer (ETAP) to check how reliable the distribution system network is. (Wahhab & Muhammed, 2023) In this study, has been focused voltage unbalance and line overload have become harder to fix because so many things have been done to make the electric system better. You can find out about voltage control when you generate, transport, or use electricity. Reactive current unbalance is a big cause of voltage instability when the power system is under stress. (Saaklayen et al., 2023), where the authors created a formula to determine the best size for distribution networks (DNs) with various PL configurations. (Ali et al., 2022) In this paper, the author has been this article

looks at numerous methods, such as combining wind power, solar power, and reactive power injection by adding FACTS devices. Using simulation models made in MATLAB, these methods are used on the IEEE 57 bus system with normal data. So, the findings of the study of these methods have been compared to each other. (Li et al., 2022) These costs can be lowered by placing DG near the load site. Integrating a DG unit into the system can also help with peak shaving and power stability reduction. However, no analysis is provided for the size and ideal position for the optimization process. Many ideas have been proposed to reduce PLs, such as in (Salman et al., 2022) explain the shuffled frog jumping method to evaluate PLs and suitable DN size, while (Aman et al., 2022b) discuss strategies to optimize and reduce PLs in DNs. The elephant herding optimization method was used by (Bhargava et al., 2021) to look at the best distribution sizes and PLs, while (Normanyo & Amankwaa, 2020) used adaptive neuro-fuzzy logic to estimate them. However, the offered methodologies require a sophisticated framework for the study. (Shkrabets et al., 2021) Conventional approaches are effective but time-consuming for real-world situations. Heuristic methods simplify difficulties and provide effective solutions. In dispersed generating systems, electricity has a radial structure and unidirectional behavior. Increased demand has a negative influence on the voltage profile, resulting in PLs in both transmission and distribution networks. (Bhattacharjee, 2021; Pal et al., 2020) To reach this goal, different methods are used to find the best location and size for the distributed generating unit, which improves how well the distribution system works. (Berdugo Sarmiento, 2020) DNs, a low-complexity solution to improving power quality utilizing a two-bus Thevenin equivalent model, have been presented in. (Tahir et al., 2019) In this study, putting capacitors in the right places is a common way to make these things better. Optimal capacitor placement (OCP) is needed to get the most out of reducing the effects of inductive load. The goal is to lower the system's costs while improving the voltage profile, power factor, and power losses. (Aman et al., 2018) This research looks at how both large and small DGs that are not deterministic affect the voltage profile. By adding reactors and making the cables' cross-sectional area bigger, the voltage profile changes were lessened. ETAP used detailed

simulations to model and evaluate the Kohat road grid station in Peshawar, Pakistan. DG development is displayed globally at two levels: research and development (R&D) advancement and project expansion utilizing the Scopus database. Over the past decade, there has been a significant rise in research on optimizing DG deployment utilizing renewable energy resources. The examination of published studies has led to an increase in DG installations. The emergence of DGs from renewable energy resources may be attributed to four main drivers: environmental, economic, technological, and technical. While the rise of DGs brings benefits, it also poses economic and technological obstacles due to aggressive integration. Transitioning from unidirectional to bidirectional electricity with a certain voltage level will impact grid stability and power system quality. When selecting DG-injected capacity, it's important to consider not only the cost and benefits but also the optimal placement and size to minimize system power losses. Numerous optimization strategies, including conventional and intelligent search, have been used to address energy issues in the literature. These approaches are classified as analytical, gradient, second-order, iterative, and heuristic.

### **3. Mathematical Modelling**

The Newton-Raphson method (Aman et al., 2022a; Kashyap et al., 2020; MORSHED & AHMED) is one of the most effective iterative methods for solving power flow equations due to its numerical robustness and low computational complexity. This method involves solving two nonlinear equations with unknown variables  $Y_1$  and  $Y_2$  approximating the roots of a real-valued function efficiency. We begin by setting two working variables  $Y_1$  and  $Y_2$  to match the target values

$B_1$  and  $B_2$ :

$$G_1(Y_1, Y_2) = B_1 \quad (1)$$

Similarly,

$$G_2(Y_1, Y_2) = B_2 \quad (2)$$

We can express these equations using the first-order Taylor expansion:

$$B_1 = G_1(Y_1^{(0)} + \Delta Y_1^{(0)}, Y_2^{(0)} + \Delta Y_2^{(0)}) \quad (3)$$

$$B_2 = G_2(Y_1^{(0)} + \Delta Y_1^{(0)}, Y_2^{(0)} + \Delta Y_2^{(0)}) \quad (4)$$

Expanding and retaining only the first-order partial derivatives:

$$B_1 \approx G_1(Y_1^{(0)}, Y_2^{(0)}) + \Delta Y_1^{(0)} \left( \frac{\partial G_1}{\partial Y_1} \right)^{(0)} + \Delta Y_2^{(0)} \left( \frac{\partial G_1}{\partial Y_2} \right)^{(0)} \quad (5)$$

$$B_2 \approx G_2(Y_1^{(0)}, Y_2^{(0)}) + \Delta Y_1^{(0)} \left( \frac{\partial G_2}{\partial Y_1} \right)^{(0)} + \Delta Y_2^{(0)} \left( \frac{\partial G_2}{\partial Y_2} \right)^{(0)} \quad (6)$$

In Jacobian matrix form:

$$\begin{bmatrix} \Delta B_1^{(0)} \\ \Delta B_2^{(0)} \end{bmatrix} = \begin{bmatrix} \left( \frac{\partial G_1}{\partial Y_1} \right)^{(0)} & \left( \frac{\partial G_1}{\partial Y_2} \right)^{(0)} \\ \left( \frac{\partial G_2}{\partial Y_1} \right)^{(0)} & \left( \frac{\partial G_2}{\partial Y_2} \right)^{(0)} \end{bmatrix} \begin{bmatrix} \Delta Y_1^{(0)} \\ \Delta Y_2^{(0)} \end{bmatrix} \quad (7)$$

Where:

$$\Delta B_1^{(0)} = B_1 - G_1(Y_1^{(0)}, Y_2^{(0)})$$

$$\Delta B_2^{(0)} = B_2 - G_2(Y_1^{(0)}, Y_2^{(0)})$$

This is the standard form of the Newton-Raphson update. For a power system with N buses, the voltage at bus D is given by:

$$V_D = \frac{1}{Y_{DD}} \left[ \frac{P_D - jQ_D}{V_D^*} - \sum_{n=1}^N Y_{Dn} V_n \right] \quad (8)$$

Expanding this:

$$P_D - jQ_D = \left( Y_{DD} V_D + \sum_{n=1}^N Y_{Dn} V_n \right) V_D^* \quad \text{for } n \neq D \quad (9)$$

If  $n = D$ , the equation simplifies to:

$$P_D - jQ_D = V_D^* \sum_{n=1}^N Y_{Dn} V_n \quad (10)$$

Separating real and imaginary parts:

$$P_D = \Re \left\{ V_D^* \sum_{n=1}^N Y_{Dn} V_n \right\} \quad (11)$$

$$Q_D = -\Im \left\{ V_D^* \sum_{n=1}^N Y_{Dn} V_n \right\} \quad (12)$$

To refine the voltage values at buses, reactive  $Q_D$  is evaluated using Equation (12). Voltage and admittances are expressed in polar form:

$$V_D = |V_D| \angle \delta_D, \quad V_n = |V_n| \angle \delta_n, \quad Y_{Dn} = |Y_{Dn}| \angle \theta_{Dn} \quad (13)$$

Substituting into Equation (10):

$$P_D - jQ_D = \sum_{n=1}^N |V_D| |V_n| |Y_{Dn}| \angle (\theta_{Dn} + \delta_n - \delta_D) \quad (14)$$

Real and imaginary components give

$$P_D = \sum_{n=1}^N |V_D| |V_n| |Y_{Dn}| \cos(\theta_{Dn} + \delta_n - \delta_D) \quad (15)$$

$$Q_D = \sum_{n=1}^N |V_D| |V_n| |Y_{Dn}| \sin(\theta_{Dn} + \delta_n - \delta_D) \quad (16)$$

In the Newton-Raphson method applied to power systems:

$$\Delta B_1^{(0)} = \Delta P_D = P_{Dspec} - P_{Dcalc} \quad (17)$$

$$\Delta B_2^{(0)} = \Delta Q_D = Q_{Dspec} - Q_{Dcalc} \quad (18)$$

$$\Delta Y_1^{(0)} = \Delta \delta_D^{(0)} \quad (19)$$

$$\Delta Y_2^{(0)} = \Delta |V_D|^{(0)} \quad (20)$$

### 3.1 Jacobian Matrix in Power Flow Analysis

The Jacobian matrix  $J$  in Newton-Raphson power flow analysis consists of four submatrices that represent the sensitivity of active and reactive power mismatches to changes in bus voltage magnitude and phase angle:

$$J = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix} \quad (21)$$

Where:

$\frac{\partial P}{\partial \delta}$  and  $\frac{\partial Q}{\partial \delta}$ : partial derivatives of real and reactive power concerning bus voltage angle.

$\frac{\partial P}{\partial |V|}$  and  $\frac{\partial Q}{\partial |V|}$ : partial derivatives of real and reactive power concerning voltage magnitudes.

This Jacobian is updated at each iteration using the current estimates of voltage magnitudes and angles to compute improved values.

### 3.2 Fitness Function

(Aman et al., 2022a) The method also considers the benefits of Distributed Generation (DG) unit integration, such as loss reduction and lower operation and capital costs. The fitness function is given by:

$$F = \frac{Benefit(A)}{Total\ Cost(X)} \quad (22)$$

Where:

$$Benefit\ (A) = Losses\ avoided\ (in\ kW) \times Cost\ per\ kW \quad (23)$$

$$Total\ Cost\ (X) = Investment\ Cost + Injection\ Cost + Maintenance\ Cost \quad (24)$$

## 4. Methodology

There are twenty-two (132/33) kV substations, forty-four (33/11) kV substations, and nine mobile substations distributed geographically in Erbil city, as shown in Table 1. In this paper, three of the twenty-two substations used as case studies utilize solar photovoltaic system (SPVS) units that are injected and tested in various cases. Rojhalat, Bakoor, and Park, because of these substations, suffer more from low voltage and high power loss among all substations, as reported from the Erbil electricity general directory and also verified by the load flow

results obtained after modeling the systems by ETAP software. Several power system representations are available for design, analysis, simulation, monitoring, control, optimization, and automation applications in the Electrical Transient Analyzer Program (ETAP), the leading integrated database for electrical systems. From modeling to operation, this program provides the most complete and integrated suite of power system networks. For conducting a thorough investigation of electrical networks, ETAP is the finest program for electrical transient analysis. ETAP software is one of the most up-to-date and reliable tools for building, running, and planning an electrical power system. To successfully and accurately perform load flow studies and stability analyses of complex electrical power systems in the shortest amount of time, this paper aims to give a basic understanding of load flow studies and the use of the Electrical Transient Analyzer Program (ETAP) application software. The ETAP program was used to investigate and model the selected radial feeders to analyze the results of the load flow program (Mukherjee et al., 2021).

#### **4.1 Baseline Scenario Without Solar Photovoltaic System (SPVS)**

In this scenario, the ETAP program is used as a simulator modeling Erbil's power substation, without any distributed generation units, such as SPVS. Figures 2, 3, and 4 represent the baseline models for each substation. These results are then used as a baseline to compare with alternative scenarios, such as the addition of SPV models in different locations to ensure the improvement in the voltage profile and the reduction in power losses (PLs) of the distributed power system. Tables 2, 3, and 4 show the total actual and reactive PLs for the baseline case.

#### **4.2 Integration of a 1 MW Solar Photovoltaic System (SPVS)**

In this scenario, the SPVS is being incorporated into a system that will only provide active power or function as a power source with one power factor. This type of SPVS will be installed at various locations along the feeder and monitored for system power losses. Subcases are generated by installing photovoltaic cells operating as DG units with a generating capability of 1 MW each in problem locations. The Kurdistan Region of Iraq's Ministry of Electricity adheres to

international standards, permitting a voltage range of  $\pm 10\%$  for 11 kV networks. The above figure indicates that the allowable voltage range is 9.9 kV to 12.1 kV. Therefore, the standard under the voltage limit is 9.9 kV. The data sheet information was obtained from the Jinko Solar Company, which is a global solar panel leader and has its headquarters in Shanghai, China. 720-watt Jinko monocrystalline photovoltaic panels, each giving a high efficiency of 23.2%. Each panel is 2.4 meters long, 1.3 meters wide, has an average area of 3.12 square meters, and weighs 37.5 kilograms. For a more in-depth discussion, consult Appendix A.

**Firstly**, the problems of the Rojhalat substation, as shown in Figure 2, the transformers 1, 2, and 3 are overloaded (25 MVA), and bus bars numbers 18 and 21 are under voltage. Figure 5, shows the SPVS units connected to bus bars numbers 18 and 21 as a distributed generation unit at the Rojhalat substation. Table 5 shows this substation's actual and reactive power losses after connecting the SPVS.

**Secondly**, as shown in Figure 3, transformer 2 the is overloaded (25 MVA), and the voltage of bus bar numbers 14 and 15 are under standards. Figure 6, shows SPVS units connected to bus bars numbers 14 and 15 as distributed generation units at Bakoor substation. Table 6 shows this substation's actual and reactive power losses after connecting the SPVS.

**Thirdly**, as shown in Figure 4, transformer 3 at Park substation, is overloaded (63 MVA), and bus bar numbers 35, 36, and 38 are under voltage. Figure 7, shows SPVS units connected to bus bar numbers 35, 36, and 38 as distributed generation units. Table 7 shows this substation's actual and reactive power losses after connecting the SPVS.

#### **4.3 Feasibility Analysis of a 1 MW Solar PV Integration using ETAP**

Feasibility analysis forms the core of the evaluation of the integration of renewable energy systems, including solar photovoltaic (PV) systems, into the

existing distribution system. Technical, economic, environmental, and regulatory factors are taken into account to assess the feasibility and viability of these applications. In this work, the feasibility of integrating a 1 MW solar PV system into Erbil's 11 kV distribution grid was investigated, taking into account system stability analysis, voltage profile optimization, land requirements, capital investment, and compliance with regulations, i.e., voltage tolerance limits according to the Ministry of Electricity. This integrated evaluation ensures that the proposed solution, in addition to improving the technical performance of the system, also aligns with economic and environmental objectives, such as reducing power losses and increasing the voltage profile, as shown in Tables 8 and 9, comparing the solar PV system before and after implementation. Detailed feasibility analysis is enclosed in Appendix A. Research such as that conducted by (Prasad et al., 2023) highlights the value of a feasibility study in distributed energy generation planning, as it facilitates informed choices that combine system reliability, economic profits, and long-term sustainability.

#### **4.4 Stability and Sensitivity Analysis for a 1 MW Solar PV Integration using ETAP**

This paper examines the effect of a 5% reduction in solar photovoltaic system (SPVS) efficiency on the operation of an 11 kV Erbil city distribution system. The base case assumes a 1 MW SPVS with an efficiency of 23.2%. A loss of 5% in efficiency results in a decrease of the SPVS output to 950 kW from 1000 kW. This reduction impacts the savings in power loss offered by the SPVS. The power losses were originally reduced by 202 kW (from 3906.8 kW to 3704.8 kW), a percentage reduction of 5.18%. Following the reduction in efficiency, the saving drops to 191.9 kW, which is a 4.91% reduction in loss, as shown in Appendix B. There are similar studies, for example, by (Mahato et al., 2024), which stress the need for sensitivity analysis of distribution generation planning optimization to obtain improved power system performance.

## **5. Results and discussion**

The Rojhalat 132/33/11 kV substation was modeled in ETAP for stability and power flow analysis of the system. The system is comprised of 11 transformers at 22 buses, including large loads like Badawa, Awena City, and Daratoo1. Detailed cable configurations and voltage data were input for higher precision in simulation. ETAP enabled effective analysis for actual performance of the grid. See Appendix C for details.

Electrical voltage drop and power loss are due to thin or long cables, loose connections, overloaded circuits, heavy loads, bad weather, and aging components, all of which raise system resistance. A solar photovoltaic (PV) system minimizes such problems by providing power close to the point of utilization, thereby minimizing transmission loss and grid demand, especially in weak or remote grids. Proper system design, sizing, and quality components are the prerequisites for stable voltage and reliable operation.

### **5.1 Impact of PV on Grid Stability**

The incorporation of a 1 MW solar photovoltaic (PV) system into the 11 kV Erbil city distribution system improved the stability of the grid markedly by improving voltage profiles and minimizing active power losses. Simulation using ETAP software showed that the installation of PV units at voltage weak nodes improved the average voltage from 89.0% to 89.4% and decreased total active power losses by about 5.18%.

These results are consistent with those of (Mahato et al., 2024), who showed that distributed generation, specifically solar PV, successfully reduces power losses and enhances voltage profiles when optimally placed in radial distribution systems.

### **5.2 Voltage Profile Analysis**

Table 8 shows that without a dispersed generating unit (as illustrated in Figures 2, 3, and 4), the line impedance between the source and the load causes a large

voltage drop. However, when a one-MW solar photovoltaic (SPV) system is used to generate power in areas with low voltage (see Figures 5, 6, and 7), the voltage levels get much better, and power losses are reduced, as shown in Table 9.

### **5.3 Power Loss Analysis**

Power loss analysis is the determination of where and how power is lost in an electric circuit. Examples include resistive ( $I^2R$ ) losses, magnetic component core losses, and switching or conduction losses in semiconductor devices. It starts with system definition, then measurement (current, voltage, resistance, etc.), and calculation by formula or simulation to identify losses. This uses instruments such as simulator software and multimeters to facilitate this examination. The result assists in determining the major inefficiencies so that design optimization, such as using more efficient components, better cooling, or using superior materials, is achievable, ultimately resulting in enhanced overall system performance.

### **5.4 Results without connecting a 1 MW solar PV system**

Solar photovoltaic (SPV) systems were not integrated into the grids of Rojalat, Bakoar, and Park substations. Simulated in ETAP software, the basic active losses of power, calculated without the addition of photovoltaic (PV) systems, are: The Rojhalat substation has a loss of 1512.5 kW, the Bakoar substation has a loss of 1252.2 kW, and the Park substation has a loss of 1142.1 kW, as shown in Tables 2, 3, and 4, and the total voltage drop for all substations was 89%. These losses are caused by various factors, including line impedance, connection losses, and additional losses from transformers. This statistic is used as a benchmark for evaluating the results after adding a PV system.

### **5.5 Results with connecting a 1 MW solar PV system**

This case investigated three separate situations, each assessing the impact of injecting the Solar Photovoltaic System (SPVS), functioning as a Distributed Generator (DG), onto various bus bars: In the first case, a solar photovoltaic (SPV) system was installed at the Rojhalat substation, specifically on bus bars 18 and

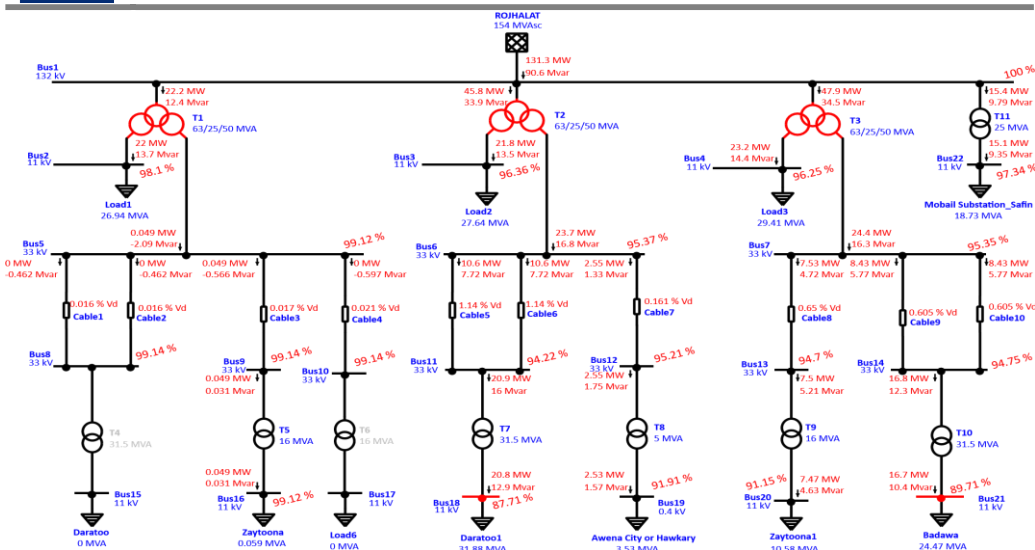
21. The bus bars were selected because their voltage drops were below acceptable levels according to international standards. The affected bus bars are shown in red, as shown in Figure 5, reducing power losses to 1460.2 kW, as shown in Table 5. In the second case, a solar photovoltaic (SPV) system was integrated into the Bakoor substation with connections at bus bars 14 and 15. These bus bars were considered weak points due to their large voltage drops, which significantly violate international standards. To identify them, these bus bars are colored red in Figure 6 to indicate their contribution to system performance, reducing power losses to 1202.1 kW, as shown in Table 6.

**In the third case,** the solar photovoltaic (SPV) system was strategically connected to the park substation, connecting to bus bars 35, 36, and 38. The bus bars were carefully selected following a comprehensive analysis that highlighted any significant voltage fluctuations beyond acceptable limits, according to international standards. Points of visual interest are highlighted in red in Figure 7, highlighting areas of interest for system optimization, which resulted in a reduction of power losses to 1042.5 kW, as shown in Table 7.

Before installing the solar photovoltaic (SPV) system, the average voltage across the three substations, Rojhalat, Bakoor, and Park, was 89.0%, with a total active power loss of 3,906.8 kW. Following the installation of the SPV system, the average voltage increased to 89.4%, marking a 0.4% improvement, while the total active power loss decreased to 3,704.8 kW. This reduction corresponds to an approximate 5.18% decrease in power loss. Notably, the most significant improvements were observed at the substations that had previously experienced voltage drop issues.

**Table (1): Erbil Government Substations (132/33/11 kV)**

| <b>No.</b>   | <b>Name of Substations</b> | <b>Power Grid MVA</b> | <b>No. of 3-W.T. 132/33 kV</b> | <b>No. of 2-W.T. 33/11 kV</b> | <b>No. of 2-W.T. 33/0.4 kV</b> | <b>No. of Cable</b> | <b>No. of OHTL</b> | <b>No. of Bus bars</b> |
|--------------|----------------------------|-----------------------|--------------------------------|-------------------------------|--------------------------------|---------------------|--------------------|------------------------|
| 1            | Azadi                      | 98.24                 | 3                              | 5                             | 1                              | 8                   | 0                  | 18                     |
| 2            | Rozh Halat                 | 154.00                | 3                              | 7                             | 1                              | 10                  | 0                  | 21                     |
| 3            | Salahaddin                 | 81.53                 | 3                              | 12                            | 0                              | 6                   | 0                  | 15                     |
| 4            | Soran                      | 138.71                | 3                              | 10                            | 2                              | 0                   | 5                  | 24                     |
| 5            | Kawrgosk                   | 105.29                | 2                              | 9                             | 0                              | 2                   | 4                  | 19                     |
| 6            | Rezan                      | 65.41                 | 2                              | 8                             | 0                              | 0                   | 4                  | 17                     |
| 7            | Bakoor                     | 158.82                | 3                              | 6                             | 0                              | 9                   | 0                  | 19                     |
| 8            | Park                       | 133.65                | 3                              | 18                            | 0                              | 19                  | 0                  | 38                     |
| 9            | Pirzin                     | 222.94                | 3                              | 6                             | 6                              | 11                  | 0                  | 30                     |
| 10           | Bashur                     | 214.24                | 3                              | 8                             | 1                              | 10                  | 0                  | 23                     |
| 11           | Hawleri Nwe                | 175.65                | 3                              | 2                             | 4                              | 6                   | 0                  | 19                     |
| 12           | Rozh Awa                   | 182.47                | 3                              | 7                             | 1                              | 10                  | 0                  | 22                     |
| 13           | Rosak                      | 69.88                 | 2                              | 4                             | 0                              | 0                   | 4                  | 13                     |
| 14           | Grdmala                    | 140.47                | 3                              | 6                             | 1                              | 1                   | 4                  | 19                     |
| 15           | Bawaji                     | 75.65                 | 2                              | 3                             | 1                              | 0                   | 3                  | 12                     |
| 16           | Koya                       | 48.47                 | 2                              | 2                             | 0                              | 0                   | 2                  | 9                      |
| 17           | Monomenti Shahidan         | 59.06                 | 2                              | 0                             | 0                              | 0                   | 0                  | 5                      |
| 18           | Zanyari                    | 67.76                 | 2                              | 4                             | 0                              | 2                   | 2                  | 13                     |
| 19           | Nishtiman                  | 17.29                 | 2                              | 0                             | 0                              | 0                   | 0                  | 7                      |
| 20           | Nusaran                    | 74.82                 | 3                              | 3                             | 4                              | 7                   | 0                  | 21                     |
| 21           | Karezan                    | 93.76                 | 3                              | 0                             | 1                              | 1                   | 0                  | 9                      |
| 22           | Shawes                     | 63.65                 | 3                              | 2                             | 2                              | 4                   | 0                  | 18                     |
| <b>Total</b> |                            | <b>2441.76</b>        | <b>58</b>                      | <b>122</b>                    | <b>25</b>                      | <b>106</b>          | <b>28</b>          | <b>391</b>             |



W.T.=Winding Transformers, OHTL=Over Head Transmission Line, MVA=Mega Volt Ampere, kV= Kilo Volt.

Figure (2): Rojhalat Substation (132/33/11 kV) without PV, simulated in ETAP

Table (2): Power losses of Rojhalat Substation (132/33/11 kV) without PV, simulated in ETAP

| Branch  | Losses |        |
|---------|--------|--------|
|         | kW     | kvar   |
| Cable1  | 0      | -461.6 |
| Cable2  | 0      | -461.6 |
| Cable3  | 0      | -596.7 |
| Cable4  | 0      | -596.8 |
| Cable5  | 98.8   | -290.1 |
| Cable6  | 98.8   | -290.1 |
| Cable7  | 2.7    | -419   |
| Cable8  | 32.8   | -486.2 |
| Cable9  | 34.3   | -373.9 |
| Cable10 | 34.3   | -373.9 |
| T1      | 77.1   | 847.6  |
| T2      | 331.4  | 3645.4 |
| T3      | 353.4  | 3887.3 |
| T5      | 0      | 0      |

|              |               |                |
|--------------|---------------|----------------|
| T7           | 68.9          | 3101.9         |
| T8           | 13.5          | 175.3          |
| T9           | 29            | 580.5          |
| T10          | 42.5          | 1912           |
| T11          | 295           | 442.5          |
| <b>Total</b> | <b>1512.5</b> | <b>10242.6</b> |

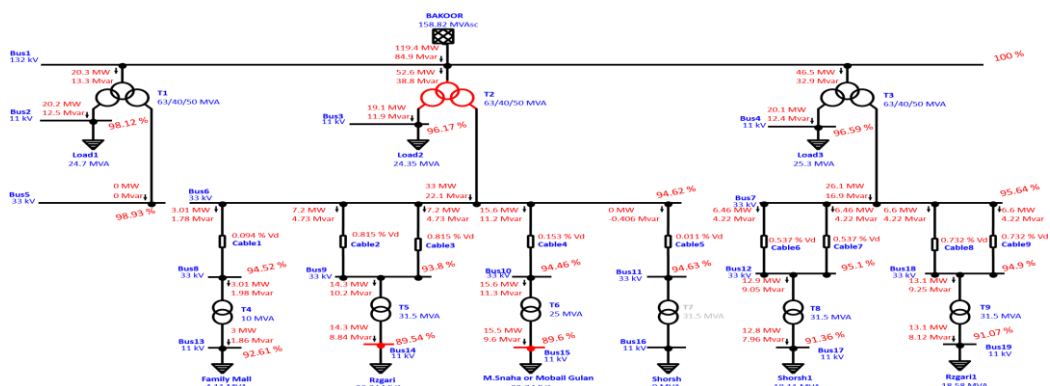


Figure (3): Bakoor Substation (132/33/11 kV) without PV, simulated in ETAP

Table (3): Power losses of Bakoor Substation (132/33/11 kV) without PV, simulated in ETAP

| Branch | Losses |        |
|--------|--------|--------|
|        | kW     | kvar   |
| Cable1 | 1.9    | -197   |
| Cable2 | 47.6   | -388.1 |
| Cable3 | 47.6   | -388.1 |
| Cable4 | 16.2   | -27.7  |
| Cable5 | 0      | -405.7 |
| Cable6 | 27.8   | -308.2 |
| Cable7 | 27.8   | -308.2 |
| Cable8 | 38.7   | -410.3 |
| Cable9 | 38.7   | -410.3 |
| T1     | 67.5   | 742.8  |
| T2     | 442.8  | 4870.6 |
| T3     | 323.4  | 3556.9 |
| T4     | 9.3    | 120.6  |
| T5     | 31     | 1394.6 |

|              |               |                |
|--------------|---------------|----------------|
| T6           | 82.6          | 1652.7         |
| T8           | 24.1          | 1086           |
| T9           | 25.2          | 1136           |
| <b>Total</b> | <b>1252.2</b> | <b>11716.6</b> |

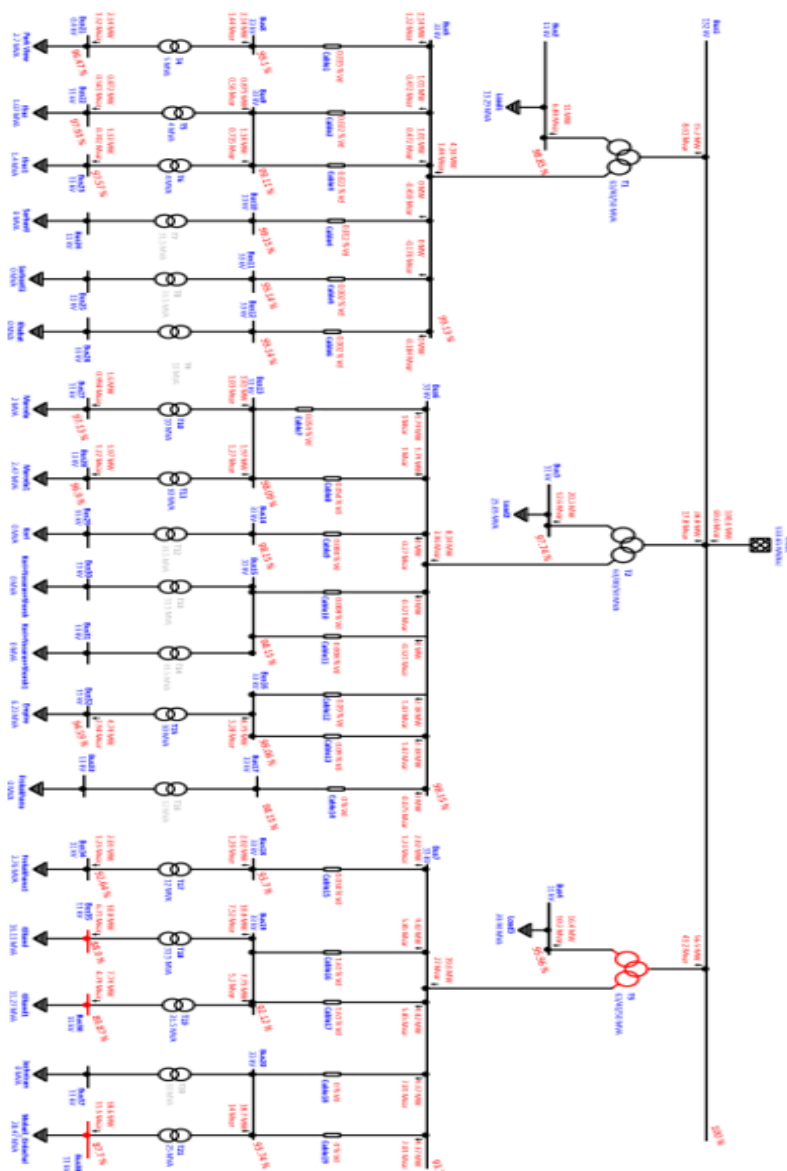


Figure (4): Park Substation (132/33/11 kV) without PV, simulated in ETAP

**Table (4): Power losses of Park Substation (132/33/11 kV) without PV, simulated in ETAP**

| Branch  | Losses |        |
|---------|--------|--------|
|         | kW     | kvar   |
| Cable1  | 0.5    | -118.4 |
| Cable2  | 0.1    | -176   |
| Cable3  | 0.1    | -176   |
| Cable4  | 0      | -459.2 |
| Cable5  | 0      | -176.3 |
| Cable6  | 0      | -183.7 |
| Cable7  | 0.7    | -143.7 |
| Cable8  | 0.7    | -143.7 |
| Cable9  | 0      | -270   |
| Cable10 | 0      | -320.6 |
| Cable11 | 0      | -320.6 |
| Cable12 | 1.7    | -172.1 |
| Cable13 | 1.7    | -172.1 |
| Cable14 | 0      | -75.4  |
| Cable15 | 0.6    | -68    |
| Cable16 | 123.7  | -508.7 |
| Cable17 | 123.7  | -508.7 |
| Cable18 | 0      | -0.1   |
| Cable19 | 0      | -0.1   |
| T1      | 30     | 330.3  |
| T2      | 111.2  | 1223.6 |
| T3      | 554    | 6094.3 |
| T4      | 8.7    | 113    |
| T5      | 2.3    | 19.5   |
| T6      | 3.9    | 33.1   |
| T10     | 2.4    | 31.4   |
| T11     | 3.7    | 47.7   |
| T15     | 17.3   | 346.8  |
| T17     | 3.5    | 45.4   |
| T18     | 18.1   | 813.7  |
| T19     | 9      | 407    |
| T21     | 124.5  | 2490.5 |

|       |        |        |
|-------|--------|--------|
| Total | 1142.1 | 8002.9 |
|-------|--------|--------|

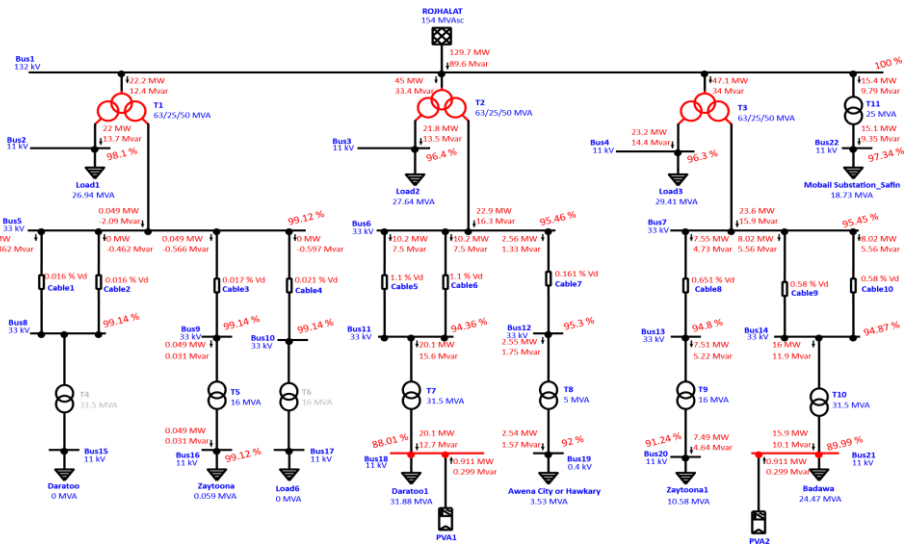


Figure (5): Rojhalat Substation (132/33/11 kV) with PV, simulated in ETAP

Table (5): Power losses of Rojhalat Substation (132/33/11 kV) with PV, simulated in ETAP

| Branch  | Losses |        |
|---------|--------|--------|
|         | kW     | kvar   |
| Cable1  | 0      | -461.6 |
| Cable2  | 0      | -461.6 |
| Cable3  | 0      | -596.7 |
| Cable4  | 0      | -596.8 |
| Cable5  | 92     | -300.2 |
| Cable6  | 92     | -300.2 |
| Cable7  | 2.7    | -419.8 |
| Cable8  | 32.8   | -487.1 |
| Cable9  | 31.3   | -380.5 |
| Cable10 | 31.3   | -380.5 |
| T1      | 77.1   | 847.6  |
| T2      | 319.3  | 3512.1 |

|              |               |               |
|--------------|---------------|---------------|
| T3           | 341           | 3750.5        |
| T5           | 0             | 0             |
| T7           | 64.3          | 2891.8        |
| T8           | 13.5          | 175.6         |
| T9           | 29.1          | 581.6         |
| T10          | 38.8          | 1747.1        |
| T11          | 295           | 442.5         |
| <b>Total</b> | <b>1460.2</b> | <b>9563.8</b> |

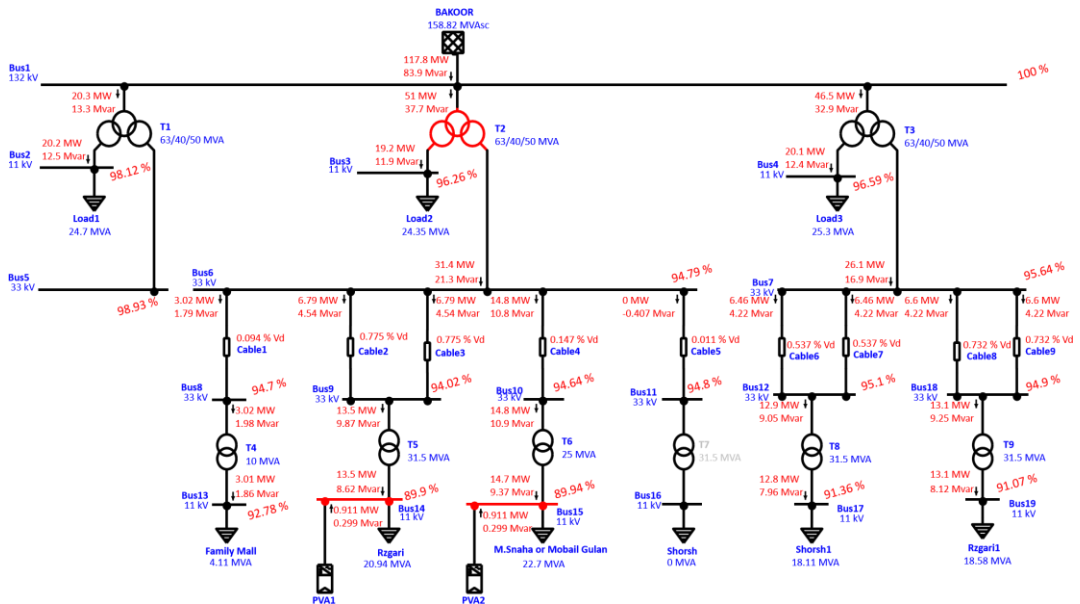


Figure (6): Bakoor Substation (132/33/11 kV) with PV, simulated in ETAP

Table (6): Power losses of Bakoor Substation (132/33/11 kV) without PV, simulated in ETAP

| Branch       | Losses        |              |
|--------------|---------------|--------------|
|              | kW            | kvar         |
| Cable1       | 1.9           | -197.7       |
| Cable2       | 42.8          | -396.4       |
| Cable3       | 42.8          | -396.4       |
| Cable4       | 14.7          | -30.7        |
| Cable5       | 0             | -407.2       |
| Cable6       | 27.8          | -308.2       |
| Cable7       | 27.8          | -308.2       |
| Cable8       | 38.7          | -410.3       |
| Cable9       | 38.7          | -410.3       |
| T1           | 67.5          | 742.8        |
| T2           | 414.5         | 4559.3       |
| T3           | 323.4         | 3556.9       |
| T4           | 9.3           | 121.1        |
| T5           | 27.9          | 1255.5       |
| T6           | 75            | 1500.8       |
| T8           | 24.1          | 1086         |
| T9           | 25.2          | 1136         |
| <b>Total</b> | <b>1202.1</b> | <b>11093</b> |



Table (7): Power losses of Park Substation (132/33/11 kV) with PV, simulated in ETAP

| Branch  | Losses |        |
|---------|--------|--------|
|         | kW     | kvar   |
| Cable1  | 0.5    | -118.4 |
| Cable2  | 0.1    | -176   |
| Cable3  | 0.1    | -176   |
| Cable4  | 0      | -459.2 |
| Cable5  | 0      | -176.3 |
| Cable6  | 0      | -183.7 |
| Cable7  | 0.7    | -143.7 |
| Cable8  | 0.7    | -143.7 |
| Cable9  | 0      | -270   |
| Cable10 | 0      | -320.6 |
| Cable11 | 0      | -320.6 |
| Cable12 | 1.7    | -172.1 |
| Cable13 | 1.7    | -172.1 |
| Cable14 | 0      | -75.4  |
| Cable15 | 0.6    | -68.4  |
| Cable16 | 104.6  | -538.9 |
| Cable17 | 104.6  | -538.9 |
| Cable18 | 0      | -0.1   |
| Cable19 | 0      | -0.1   |
| T1      | 30     | 330.3  |
| T2      | 111.2  | 1223.6 |
| T3      | 505.8  | 5564   |
| T4      | 8.7    | 113    |
| T5      | 2.3    | 19.5   |
| T6      | 3.9    | 33.1   |
| T10     | 2.4    | 31.4   |
| T11     | 3.7    | 47.7   |
| T15     | 17.3   | 346.8  |
| T17     | 3.5    | 45.6   |
| T18     | 15.7   | 708.7  |
| T19     | 7.4    | 332.8  |
| T21     | 115.3  | 2306.9 |

|              |               |               |
|--------------|---------------|---------------|
| <b>Total</b> | <b>1042.5</b> | <b>7049.2</b> |
|--------------|---------------|---------------|

Table (8): Voltage Profile and Power Losses in Substations Before Connecting a 1 MW Solar PV System

| No.     | Name of Substations | Problems with the substations                                  | Under Voltage<br>±10 (%) | Losses |         |
|---------|---------------------|----------------------------------------------------------------|--------------------------|--------|---------|
|         |                     |                                                                |                          | kW     | kvar    |
| 1       | Rozh Halat          | T1,T2 and T3 Overload (25MVA)<br>Bus18 and Bus21 Under Voltage | 87.71                    | 1512.5 | 10242.6 |
|         |                     |                                                                | 89.71                    |        |         |
| 2       | Bakoor              | T2 Overload (25MVA)<br>Bus14 and Bus15 Under Voltage           | 89.54                    | 1252.2 | 11716.6 |
|         |                     |                                                                | 89.6                     |        |         |
| 3       | Park                | T3 Overload (63MVA)<br>Bus35,Bus36 and Bus38 Under Voltage     | 88.9                     | 1142.1 | 8002.9  |
|         |                     |                                                                | 89.87                    |        |         |
|         |                     |                                                                | 87.7                     |        |         |
| Average |                     |                                                                | 89.00                    |        |         |
| Total   |                     |                                                                |                          | 3906.8 | 29962.1 |

Table (9): Voltage Profile and Power Losses in Substations After Connecting a 1 MW Solar PV System

| No.     | Name of Substations | Problems with the substations                                  | Under Voltage<br>±10 (%) | Losses |         |
|---------|---------------------|----------------------------------------------------------------|--------------------------|--------|---------|
|         |                     |                                                                |                          | kW     | kvar    |
| 1       | Rozh Halat          | T1,T2 and T3 Overload (25MVA)<br>Bus18 and Bus21 Under Voltage | 88.01                    | 1460.2 | 9563.8  |
|         |                     |                                                                | 89.99                    |        |         |
| 2       | Bakoor              | T2 Overload (25MVA)<br>Bus14 and Bus15 Under Voltage           | 89.9                     | 1202.1 | 11093   |
|         |                     |                                                                | 89.94                    |        |         |
| 3       | Park                | T3 Overload (63MVA)<br>Bus35,Bus36 and Bus38 Under Voltage     | 89.42                    | 1042.5 | 7049.2  |
|         |                     |                                                                | 90.39                    |        |         |
|         |                     |                                                                | 88.12                    |        |         |
| Average |                     |                                                                | 89.40                    |        |         |
| Total   |                     |                                                                |                          | 3704.8 | 27706.0 |

## 6. Conclusion

The analysis was conducted using ETAP software; voltage drop points were identified on the 11 kV bus bars at selected major substations. A more comprehensive analysis was conducted to identify voltage drop locations on the

11 kV bus bars at selected substations, with a particular focus on Rojhalat, Bakoor, and Park substations. At the Rojhalat substation, transformers 1, 2, and 3 were observed to be operating at a high load per terminal (25 MVA), while bus bar numbers 18 and 21 were operating below the minimum acceptable voltage. Similarly, at the Bakoor substation, transformer 2 was overloaded (25 MVA), and bus bar numbers 14 and 15 were identified as operating under voltage drop conditions. At Park substation, transformer 3 (63 MVA) was significantly overloaded, and all associated bus bar numbers 35, 36, and 38 were found to be operating below their rated voltage levels. Before the installation of the solar photovoltaic (SPV) system, the average voltage level at the three substations was 89.0%, resulting in a total actual power loss of 3906.8 kW. However, the average voltage level increased to 89.4%, **marking a 0.4% improvement**, and the total actual power loss decreased to 3704.8 kW, which represents approximately a 5.18% decrease after the SPVS system was integrated, especially in the substations with voltage drop issues. The system is technically feasible for PV integration.

## **7. Acknowledgment**

I would like to express my gratitude to Salahaddin University—College of Engineering, particularly the Department of Electrical Engineering, for their unwavering support and encouragement throughout my research.

## **References**

- Afzal, M., Huang, Q., Amin, W., Umer, K., Raza, A., & Naeem, M. (2020). Blockchain enabled distributed demand side management in community energy system with smart homes. *IEEE Access*, 8, 37428-37439.
- Ali, M. B., Kazmi, S. A. A., Khan, Z. A., Altamimi, A., Alghassab, M. A., & Alojaiman, B. (2022). Voltage profile improvement by integrating renewable resources with utility grid. *Energies*, 15(22), 8561.
- Aman, M. A., Ahmad, S., Noor, B., & Karam, F. W. (2018). Mitigating the Adverse Impact of Un-Deterministic Distributed Generation on a Distribution System

Considering Voltage Profile. *Engineering, Technology & Applied Science Research*, 8(3).

- Aman, M. A., Ren, X. C., Tareen, W. U. K., Khan, M. A., Anjum, M. R., Hashmi, A. M., Ali, H., Bari, I., Khan, J., & Ahmad, S. (2022a). Optimal siting of distributed generation unit in power distribution system considering voltage profile and power losses. *Mathematical Problems in Engineering*, 2022(1), 5638407.
- Aman, M. A., Ren, X. C., Tareen, W. U. K., Khan, M. A., Anjum, M. R., Hashmi, A. M., Ali, H., Bari, I., Khan, J., & Ahmad, S. (2022b). Research Article Optimal Siting of Distributed Generation Unit in Power Distribution System considering Voltage Profile and Power Losses.
- Berdugo Sarmiento, K. M. (2020). Mejoras en la operación del sistema de transmisión regional de energía eléctrica del Departamento del Atlántico utilizando sistemas flexibles de transmisión de corriente alterna (FACTS)[Corporación Universidad de la Costa]. In: Corporación Universidad de la Costa.
- Bhargava, V., Sinha, S., & Dave, M. (2021). Co-ordinated optimal control of distributed generation in primary distribution system in presence of solar PV for loss reduction and voltage profile improvement. *Energy Systems*, 1-21.
- Bhattacharjee, I. (2021). Optimal Sizing and Placement of Multiple DGs. Second International Conference on Image Processing and Capsule Networks: ICIPCN 2021,
- Biswal, S., Sharma, N. K., & Samantaray, S. R. (2021). Reliability-Based Cost Optimization in Power Distribution Systems Incorporating Distributed Generations and Capacitors. *Electric Power Components and Systems*, 49(8), 792-805.
- Ikram, S., Rehman, K., Altamash, M., & Miraj, J. (2024). Design of Radial Distribution System to Study Load-Flow and Short Circuit Analysis Using ETAP Software. *Pakistan Journal of Engineering and Technology*, 7(01), 42-49.
- Jaleel, A. M., & Abd, M. K. (2023). Reliability Assessment Based on Optimal DGs Planning in the Distribution Systems. *Engineering and Technology Journal*, 41(02), 280-293.
- Kashyap, M., Kansal, S., & Singh, B. P. (2020). Optimal installation of multiple type DGs considering constant, ZIP load and load growth. *International Journal of Ambient Energy*, 41(14), 1561-1569.
- Li, Y., Feng, B., Wang, B., & Sun, S. (2022). Joint planning of distributed generations and energy storage in active distribution networks: A Bi-Level programming approach. *Energy*, 245, 123226.

- Mahato, J. P., Poudel, Y. K., Mandal, R. K., & Chapagain, M. R. (2024). Power loss minimization and voltage profile improvement of radial distribution network through the installation of capacitor and distributed generation (DG). *Archives of Advanced Engineering Science*, 1-9.
- Mansaray, M. O., Diawuo, F. A., & Bantinge, B. (2024). Integration of multiple distributed solar PV (DSP) into the grid: The case of the distribution network in Freetown, Sierra Leone. *Solar Compass*, 10, 100075.
- MORSHED, K. A., & AHMED, A. Optimal Planning of Multiple Renewable Energy-Integrated Distribution System With Uncertainties Using Artificial Hummingbird Algorithm.
- Mukherjee, S., Mandal, R., Ganguly, A., & Paul, A. K. (2021). Analysis on Relay Coordination in IEEE 9 bus PV integrated Hybrid Power System using ETAP software: A case study. IOP Conference Series: Earth and Environmental Science,
- Normanyo, E., & Amankwaa, A. (2020). A Neuro-fuzzy Model for Electric Power Line Losses Reduction in Solar Photovoltaic Integrated Sub-transmission Networks. 2020 6th IEEE International Energy Conference (ENERGYCon),
- Pal, A., Chakraborty, A. K., & Bhowmik, A. R. (2020). Optimal placement and sizing of DG considering power and energy loss minimization in distribution system. *International Journal on Electrical Engineering and Informatics*, 12(3), 624-653.
- Prasad, C. H., Subbaramaiah, K., & Sujatha, P. (2023). Economic Analysis by Optimal Placing of DGs in Distribution Networks by Particle Swarm Optimisation and Gravitational Search Optimisation Algorithm. *Distributed Generation & Alternative Energy Journal*, 923-942.
- Saaklayen, M. A., Shabbir, M. N. S. K., Liang, X., Faried, S. O., & Janbakhsh, M. (2023). A two-stage multi-scenario optimization method for placement and sizing of soft open points in distribution networks. *IEEE Transactions on Industry Applications*, 59(3), 2877-2891.
- Salman, M., Hongsheng, S., Aman, M. A., & Khan, Y. (2022). Enhancing Voltage Profile and Power Loss Reduction Considering Distributed Generation (DG) Resources. *Engineering, Technology & Applied Science Research*, 12(4), 8864-8871.
- Shkrabets, F., Plaksin, S., Ostapchuk, O., Kuznetsov, V., Tymchenko, I., & Muntian, A. (2021). Quick-response protection system against electric shock in distributed generation systems. *Diagnostyka*, 22(3), 59-65.

- Sun, D., & Yu, Y. (2023). Practical steady-state security region of loop-containing active distribution networks. 2023 IEEE Power & Energy Society General Meeting (PESGM),
- Tahir, M., Bakar, B. A., Alam, M., & Mazlihum, M. (2019). Optimal capacitor placement in a distribution system using ETAP software. *Indones. J. Electr. Eng. Comput. Sci*, 15(2), 650-660.
- Wahhab, S. F., & Muhammed, A. A. (2023). Improvement Voltage Profile of Kurdistan Power System By Using SVC/STATCOM. *QALAAI ZANIST JOURNAL*, 8(2), 1232-1252.

## پروفايلي قوالتيه و له دهستداني كارهبا له سيستمه مي كارهباي دابه شكردني شاري ههولير 11 kV به به ستنه وهي له گهل سيستمه مي فو تو قوالتايكي خوړ

پوخته:

گه شه سهندني خپراي خواست له سهر كارهبا له شاري ههولير به هوي فراوانبووني به رفراواني شاره كه بووه ته هوي ته حه داي بهرچاو له سيستمه مي دابه شكردني كارهبادا. ئەم زيادبوونه بووه ته هوي كيشي جوړاو جوړ له ناو سيستمه مي كارهباي دابه شكردنا، له وانه دابه زيني پروفايلي قوالتيه، له دهستداني كارهبا و دابه زيني كواليتي كارهبا. بۆ كه مكردنه وهي زيانه كان و بهر زكردنه وهي قوالتيه بۆ ئاستيكي قبولكراو، ده توانريت سهرچاوهي وزه نو يبووه وه (RES)، به تايبه تي سيستمه مي فو تو قوالتايكي خوړ (PV) له ناو سيستمه مه كه دا له شويني گونجاودا دابريت. له م تو يرينه وهيه دا خاله كيشه داره كان له سيستمه مي 11 كيلو قوالتدا ده ستني شانكران، و سيستمه ميكي فو تو قوالتايكي خوړ به تواناي 1 ميگا وات خرايه ناو پاس باره كان 11 كيلو قوالتيه و بۆ كه مكردنه وهي له دهستداني كارهبا و زيادكردني پروفايلي قوالتيه له و شوينانه ي كه به دهست دابه زيني قوالتيه ده نالين، به به كارهي ناني نهرمه كالاي بهرنامه ي شيكاركه ري راگوزه ري كارهبايي (ETAP). ئەم جي به جيكردنه بووه هوي باشتريووني بهرچاو له ئاستي قوالتيه كه له گهل ستاندارده نيوده وله تيبه كان و ئامانجه كان و وهزاره تي كارهباي ههريمي

كوردستان دهگونجیت، که ریگه به هه لاسانی قۆلتیهی  $\pm 10\%$  ددهات له تۆرپهکانی دابهشکردنی 11 کیلوقۆلتدا. جگه له کهمبوونهوهی لهدهستدانی کارهبا به پێژهی 5.18 % به بهراورد به سیستمهکه به بێ یهکخستنی سیستمی فۆتوقۆلتایکی خۆر. بهلام دانانی سیستمی فۆتوقۆلتایکی خۆر به توانای 1 میگاوات پێویستی به پووبهڕیکی گونجاوی زهوی ههیه. لهو حالهتانهی که ئهو جۆره شوپنه بهردهست نییه، باشتترین بژارده بهکارهینانی ئامپیرهکانی سیستمی گواستنهوهی کارهبا ی گۆراو (FACTS) ه. له کاتیکدا که ئامپیرهکانی سیستمی گواستنهوهی کارهبا ی جیگرهوهی نهرم و نیان تهنها به هێزی کارلیککارانه کاردهکهن، سیستمی فۆتوقۆلتایکی خۆر دهتوانیت ههردوو هێزی چالاک و کارلیککهر کۆنترپۆل بکات، ئهمهش وایکردوو که بژاردیهکی گشتگیرتر بیت کاتیک دهتوانریت.

## **مستوى الجهد وفقدان الطاقة في نظام توزيع الطاقة الكهربائية لمدينة أربيل 11 kV و دمجها مع نظام الطاقة الشمسية**

### **المخلص:**

دى النمو السريع في الطلب على الكهرباء في مدينة أربيل، نتيجةً للتوسع الهائل للمدينة، إلى تحديات كبيرة في نظام توزيع الطاقة. وقد نتج عن هذه الزيادة مشاكل مختلفة في نظام توزيع الطاقة، بما في ذلك انخفاضات في ملف الجهد، وفقدان الطاقة، وتدهور جودة الطاقة. ولتقليل الخسائر ورفع الجهد إلى مستويات مقبولة، يمكن وضع مصادر الطاقة المتجددة (RES)، وخاصةً أنظمة الطاقة الشمسية الكهروضوئية (PV)، داخل النظام في مواقع مثالية. في هذه الورقة، تم تحديد نقاط الإشكال في نظام 11 كيلو فولت، وتم دمج نظام طاقة شمسية كهروضوئية بسعة 1 ميغاوات في قضبان التوصيل 11 كيلو فولت لتقليل فقدان الطاقة وزيادة ملف الجهد في المواقع التي تعاني من انخفاض الجهد، باستخدام برنامج محلل التيارات العابرة الكهربائية (ETAP). وقد أدى هذا التنفيذ إلى تحسن كبير في مستويات الجهد بما يتوافق مع المعايير الدولية وأهداف وزارة الكهرباء في إقليم كردستان، مما يسمح بتذبذب جهد  $\pm 10\%$  في شبكات توزيع 11 كيلو فولت. بالإضافة إلى انخفاض خسائر الطاقة بنسبة 5.18 % مقارنةً بالنظام غير المتكامل مع نظام الطاقة الشمسية الكهروضوئية. مع ذلك، يتطلب تركيب نظام طاقة شمسية كهروضوئية بقدرة 1 ميغاوات مساحات مناسبة من الأراضي. في حال عدم توفر هذه المساحة، يكون الخيار الأمثل هو استخدام أنظمة نقل التيار المتردد المرنة (FACTS). في حين أن أنظمة نقل التيار المتردد المرنة تعمل فقط مع الطاقة التفاعلية، فإن أنظمة الطاقة الشمسية الكهروضوئية قادرة على التحكم في كلٍ من الطاقة الفعالة والتفاعلية، مما يجعلها خيارًا أكثر شمولاً عند الإمكان.

## **Appendix A:**

### **1 MW Solar PV System Design Overview**

#### **1. Basic Information**

Target capacity: 1 MW = 1000 kW

Panel output: 0.72 kW

Number of panels required =  $\frac{1000}{0.72} = 1388.89 \approx \mathbf{1390 \text{ panels}}$

Size of each panel:  $3.12 \text{ m}^2$

Total area required for 1 MW =  $1390 * 3.12 = 4336.8 \text{ m}^2 \approx \mathbf{4350 \text{ m}^2} \approx$

**1.075 acres**

Price per panel: \$60

Total cost of all panels =  $1390 * 60 = \$83400$

Inventor Cost: \$200000

Balance of System (BoS): \$40000

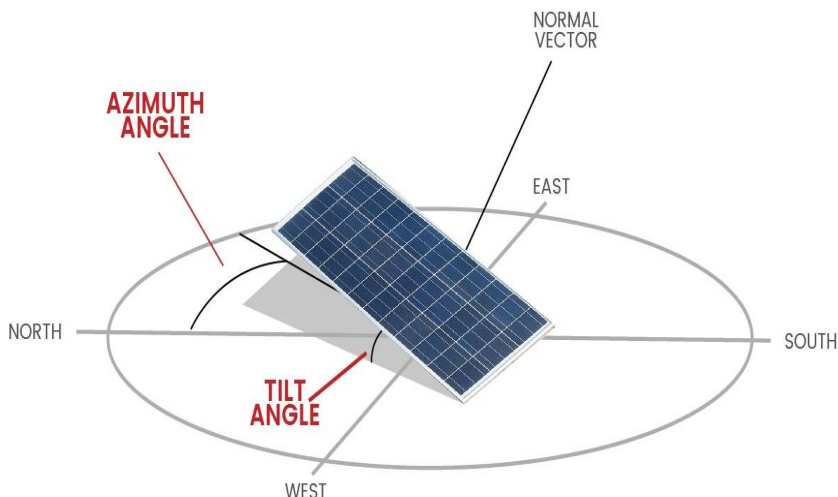
Total investment or Total Estimated Cost =  $\$83400 + \$200000 + \$40000$   
 $= \$323,400 \approx \mathbf{\$323000}$

#### **2. Design steps**

1. Determine daily average electricity consumption (in kWh):

Energy Output per day

$$= \text{Panel Output} * \text{No. of Panels} * \text{Peak Sun Hours} \\ * \text{Inverter Efficiency}$$



2. Calculate optimum azimuth angle  $\alpha_A$  (deg) using:

Visit: <https://footprinthero.com/solar-panel-azimuth-angle-calculator> or

Scan:



Address, City, or Zip Code

Use Your Current Location

Your optimal azimuth angle is true south, which is:  
**5.5° east of magnetic south**

Notes: Your azimuth angle can also be expressed as **94.5° clockwise from magnetic north**.  
 \*Based on 100° clockwise from true north. Your location's current magnetic declination is 5.5°.

Azimuth angle (direction)  $\alpha_A$  (deg) = 5.5°

3. Determine the optimum tilt angle  $\alpha_T$  (deg) using:

Visit: <https://footprinthero.com/solar-panel-tilt-angle-calculator> or

Scan:



Address, City, or Zip Code

Use Your Current Location

Your optimal year-round tilt angle:  
**29.8° from horizontal**

Tilt angle  $\alpha_T$  (deg) = 29.8°  $\approx$  30°

4. Find the average daily peak sun hours  $S_{av-pk}$  (h/day), calculator

Visit: <https://footprinthero.com/peak-sun-hours-calculator> or

Scan:



Peak Sun Hours Calculator

Address, City, or Zip Code

Solar Panel Tilt Angle (degrees from horizontal)  
 (Optional: If left blank, we'll use a default value of 30° (horizontality). You can use our solar panel tilt angle calculator to find the best angle for your solar panels.)

30°

Solar Panel Azimuth Angle (degrees clockwise from north)  
 (Optional: If left blank, we'll use a default value of 100° (parallel to the magnetic north line). You can use our solar panel azimuth angle calculator to find the best direction for your solar panels.)

100°

Calculate Peak Sun Hours

Your annual average:  
**5.86** peak sun hours per day

Peak Sun Hours (PSH) = 5.86 h/day

5. Estimate inverter efficiency ( $\eta_{inv} = 98.5\%$ )

6. Calculate the Photovoltaic system output using the formula:

Energy Output per day

$$= \text{Panel Output} * \text{No. of Panels} * \text{Peak Sun Hours} \\ * \text{Inverter Efficiency}$$

$$E_{\text{daily}} = 0.72 * 1390 * 5.86 * 0.985 = 5776.7 \text{ kWh/day}$$

$$E_{\text{yearly}} = 5776.7 * 365 = 2108495.5 \approx 2108500 \text{ kWh/year}$$

### 3. Financial Evaluation

Energy Cost: \$0.085/kWh

$$\text{Annual Revenue} = 0.085 * 2108495.5 = \$179222.5$$

$$\text{Return On Investment (ROI)} = \left( \frac{\text{Total investment}}{\text{Annual Revenue}} \right) * 100 \\ = \left( \frac{\$179222.5}{\$323000} \right) * 100 = 55.48\%$$

### 4. Economic Feasibility Analysis

a. Energy Loss Reduction (kWh/year)

- Loss Reduction = 202 kW
- Annual Loss Reduction =  $202 \text{ kW} * \frac{24 \text{ hours}}{\text{day}} * 365 \frac{\text{days}}{\text{year}} = 1769520 \text{ kWh/year}$

b. Monetary Savings

Assume the electricity cost in Kurdistan  $\approx$  \$0.085 per kWh

$$\text{Annual Savings} = 1769520 \frac{\text{kWh}}{\text{year}} * \frac{\$0.085}{\text{kWh}} = \$150409.2/\text{year} \\ \approx \$150410/\text{year}$$

c. Payback Period

$$\text{Payback Period} = \frac{\text{Total investment}}{\text{Annual Saving}} = \frac{\$323000}{\$150410} \approx 2.15 \text{ years}$$

Table (10): Technical and Economic Feasibility Analysis of Integrating a 1 MW Solar PV System into an 11 kV Distribution Network

| Parameter           | Before PV Connection | After PV Connection | Improvement/Saving |
|---------------------|----------------------|---------------------|--------------------|
| Average Voltage (%) | 89                   | 89.4                | 0.40%              |

|                               |        |        |             |
|-------------------------------|--------|--------|-------------|
| Total Real Power Loss (kW)    | 3906.8 | 3704.8 | 202.0 kW    |
| Annual Energy Loss (kWh/year) | —      | —      | 1769520 kWh |
| Annual Cost Saving (USD/year) | —      | —      | \$150410    |
| Estimated PV Cost (USD)       | —      | —      | \$323000    |
| Return On Investment (ROI)    | —      | —      | 55.48%      |
| Payback Period (Years)        | —      | —      | 2.15        |

So, technically:

- Voltage profile improved.
- Real and reactive power losses were reduced.

## Appendix B:

### Sensitivity Analysis Calculation: If a 5% Drop in SPVS Efficiency

#### Assumptions from in study:

1. Installed SPVS = 1 MW
2. Panel efficiency (baseline) = 23.2% (Jinko panel)
3. Improvement after SPVS:
  - Voltage rise = 0.4% (from 89% to 89.4%)
  - Power loss reduction = 5.18% (from 3906.8 kW to 3704.8 kW), 202 kW saved.

#### Case: SPVS Efficiency Drop by 5%

New Efficiency:  $\eta_{new} = 23.2\% * (1 - 0.05) = 22.04\%$

New Power Output =  $1 \text{ MW} * \frac{22.04}{23.2} = 0.95 \text{ MW}$

This means the SPVS now delivers 950 kW instead of 1000 kW, a 50 kW decrease.

#### Impact Estimation Using Proportionality

1. Losses Saved at Full Efficiency = 202 kW
2. New Expected Loss Saving:

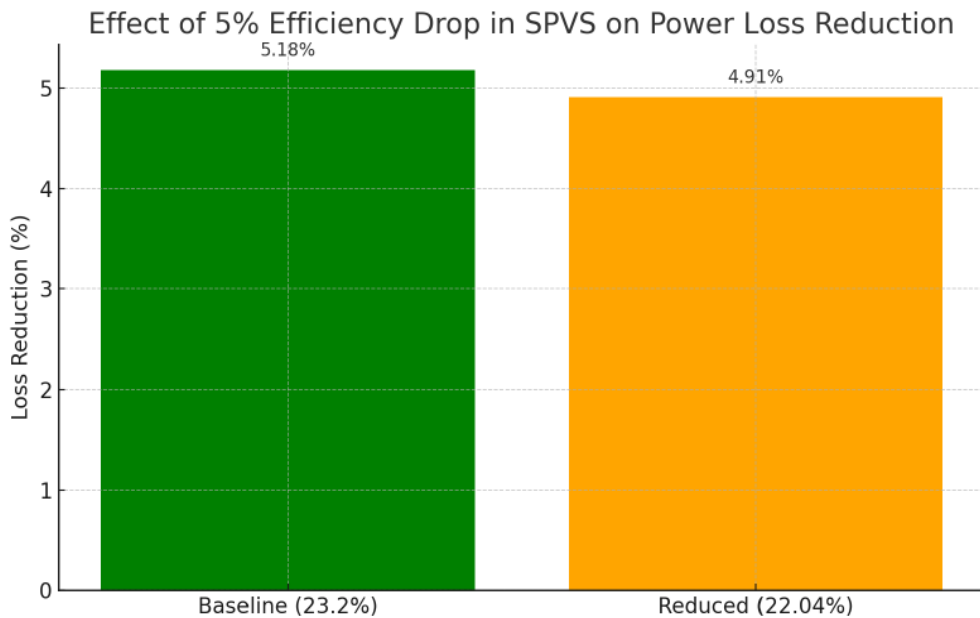
$$\Delta P_{\text{saved,new}} = 202 * \frac{950}{1000} = 191.9 \text{ kW}$$

3. New Power Loss Total

$$\text{Power Loss}_{\text{new}} = 3906.8 - 191.9 = 3714.9 \text{ kW}$$

So, instead of 5.18% savings, the new loss reduction is:

$$\frac{191.9}{3906.8} * 100 = 4.91\%$$



**Figure (8): Comparison of Power Loss Reduction Before and After 5% SPVS Efficiency Drop**

**Table (11): Effect of 5% Efficiency Reduction in SPVS on Output Power and Power Loss Reduction**

| Efficiency | SPVS Output (kW) | Power Losses (kW) | Loss Reduction (%) |
|------------|------------------|-------------------|--------------------|
| 23.20%     | 1000             | 3704.8            | 5.18%              |
| 22.04%     | 950              | 3714.9            | 4.91%              |

### Appendix C:

**ETAP modeling of the Rojhalat 132/33/11 kV Substation presented in table format:**

**Table (12): Generation Parameter of Rojhalat Substation**

| Parameter       | Value    |
|-----------------|----------|
| Substation Name | Rojhalat |

|                        |                                 |
|------------------------|---------------------------------|
| Voltage Levels         | 132 / 33 / 11 kV                |
| Short Circuit Capacity | 154 MVA (at 132 kV)             |
| Software Used          | ETAP                            |
| Main Purpose           | Power Flow & Stability Analysis |

Table (13): Transformer Rating and Loading Data

| Transformer | Rating (MVA) | Voltage Level (kV) | Loading (MW/Mvar) | Connected Bus |
|-------------|--------------|--------------------|-------------------|---------------|
| T1          | 63/25/50     | 132/11/33          | 22 / 13.7         | Bus2          |
| T2          | 63/25/50     | 132/11/33          | 21.8 / 13.5       | Bus3          |
| T3          | 63/25/50     | 132/11/33          | 23.2 / 14.4       | Bus4          |
| T4          | 31.5         | 33/11              | 0/0               | Bus15         |
| T5          | 16           | 33/11              | 0.049/0.031       | Bus16         |
| T6          | 16           | 33/11              | 0/0               | Bus17         |
| T7          | 31.5         | 33/11              | 20.8/12.9         | Bus18         |
| T8          | 5            | 33/11              | 2.53/1.57         | Bus19         |
| T9          | 16           | 33/11              | 7.47/4.63         | Bus20         |
| T10         | 31.5         | 33/11              | 16.7/10.4         | Bus21         |
| T11         | 25           | 132/11             | 15.1/9.35         | Bus22         |

Table (14): Bus Configuration and Connectivity

| Buses   | Voltage Level | Connected Elements                            |
|---------|---------------|-----------------------------------------------|
| Bus1    | 132 kV        | Grid, T1, T2, T3                              |
| Bus2    | 11 kV         | T1, Load1                                     |
| Bus3    | 11 kV         | T2, Load2                                     |
| Bus4    | 11 kV         | T3, Load3                                     |
| Bus5–21 | 33 / 11 kV    | T4–T10, Distribution feeders to various loads |
| Bus 22  | 11 kV         | T11, Distribution feeders to various loads    |

Table (15): Load Distribution and Connection Data

| Load Name | Apparent Power (MVA) | Connected Bus | Voltage Level |
|-----------|----------------------|---------------|---------------|
| Load1     | 26.94                | Bus2          | 11 kV         |
| Load2     | 27.64                | Bus3          | 11 kV         |
| Load3     | 29.41                | Bus4          | 11 kV         |
| Daratoo   | 0                    | Bus 15        | 11 kV         |
| Zaytoona  | 0.059                | Bus 16        | 11 kV         |

|                   |       |        |       |
|-------------------|-------|--------|-------|
| Load6             | 0     | Bus 17 | 11 kV |
| Daratoo1          | 31.88 | Bus18  | 11 kV |
| Awena City        | 3.53  | Bus19  | 11 kV |
| Zaytoona1         | 10.58 | Bus10  | 11 kV |
| Badawa            | 24.47 | Bus21  | 11 kV |
| Mobail Substation | 18.73 | Bus22  | 11 kV |

**Table (16): Power Cable Specifications and Voltage Drops**

| <b>Cable No.</b> | <b>Voltage Drop (%)</b> | <b>Type of Cables</b> | <b>Size of Cables</b> | <b>Length (Km)</b> |
|------------------|-------------------------|-----------------------|-----------------------|--------------------|
| Cable1           | 0.016                   | Cu/XLPE               | 1*240                 | 6                  |
| Cable2           | 0.016                   | Cu/XLPE               | 1*240                 | 6                  |
| Cable3           | 0.017                   | Cu/XLPE               | 1*400                 | 6.5                |
| Cable4           | 0.021                   | Cu/XLPE               | 1*400                 | 6.5                |
| Cable5           | 1.14                    | Cu/XLPE               | 1*240                 | 6                  |
| Cable6           | 1.14                    | Cu/XLPE               | 1*240                 | 6                  |
| Cable7           | 0.161                   | Cu/XLPE               | 1*400                 | 5                  |
| Cable8           | 0.65                    | Cu/XLPE               | 1*400                 | 6.5                |
| Cable9           | 0.605                   | Cu/XLPE               | 1*400                 | 5.2                |
| Cable10          | 0.605                   | Cu/XLPE               | 1*400                 | 5.2                |