Solving The Problem of Excess Energy from PV Renewable Energy Sources in AAUP

Ghaydaa Bani Owda
Department of Electrical Engineering
Arab American University
Jenin, Palestine

Razan Bshara
Department of Electrical Engineering
Arab American University
Jenin, Palestine

Yazan Husain
Department of Electrical Engineering
Arab American University
Jenin, Palestine

Ahlam Abu Zahew
Department of Electrical Engineering
Arab American University
Jenin, Palestine
ahlam.zahew@aaup.edu

Samer Alsadi
Department of Electrical Engineering
Palestine Technical University-Kadoorie
Tulkarm, Palestine
s.alsadi@ptuk.edu.ps

Tareq Foqha
Department of Electrical Engineering
Arab American University
Jenin, Palestine
tareq.fuqaha@aaup.edu

Ali Elrashidi
Department of Electrical Engineering,
College of Engineering,
University of Business and Technology
Jeddah, Saudi Arabia
a.elrashidi@ubt.edu.sa

Mohammad Kanan
College of Engineering,
University of Business and Technology
Jeddah, Saudi Arabia
College of Engineering,
Zarqa University
Zarqa, Jordan
m.kanan@ubt.edu.sa

***Abstract*— This study addresses the challenge of surplus solar energy production at Tubas Electricity Company (TDECO), driven by a substantial increase in solar power station capacity. With this surge in production, the possibility of excess electrical energy entering the grid becomes a concern, potentially leading to penalties or disconnection of electricity supply. To tackle this issue, the research employs ETAP software to conduct a comprehensive electrical network simulation in Tubas City. This simulation ensures result accuracy and evaluates the impact of new PV systems in 2023. During the project, an innovative approach was explored, involving the modification of load curves. A 5.9% reduction in the tariff for PV solar energy during peak hours incentivized customers to shift their energy consumption. This strategic load-shifting initiative aimed to align peak demand with peak generation times. Additionally, the study explores the feasibility of deploying battery storage systems to absorb excess energy. The analysis indicates that 664 batteries, each with a capacity of 200 Ah, along with 130 charge controllers rated at 250 volts and 120 amperes, would be required for this purpose. Throughout the project, a critical emphasis was placed on identifying solutions that combine cost-effectiveness with high efficiency. The findings demonstrate that both load shifting and battery storage are viable options to address the excess solar energy issue. However, the study ultimately concludes that load shifting presents a more economical and environmentally friendly choice compared to battery storage. Moreover, the ETAP simulation closely aligns with real-time data, reaffirming the applicability of these solutions in practical scenarios.**

Keywords*— *PV, ETAP, TDECO, AutoCAD.

I. Introduction

The industrial revolution and the rise of large factories and plants have led to an increase in global energy demand. This has prompted a shift towards renewable energy sources, such as solar panels [1], [2].

The Palestinian government recognizes the importance of renewable energy in meeting the country's residential, commercial, and industrial energy needs. It recently launched a national strategy to expand the use of renewable energy, with a goal of producing 120 MW of electricity from alternative energy sources [3]–[5].

The city of Tubas is a leader in implementing solar energy projects. At the end of 2022, its total PV system production reached 19.120 MWp. The company's engineers expect a surplus in solar production compared to total consumption due to the increasing capacity of solar systems [6]–[9].

The Tubas District Electricity Company (TDECO) is a public limited company that was established in Tubas, Palestine in 2006. The company began by supplying electricity to its 23 member shareholders, which included municipal and village councils. In 2011, the company expanded to include electricity departments in municipalities and local authorities, with 15,000 customers [10], [11].

The company is supplied with electricity through two connection points with the Israeli electricity company. It supplies 20,000 customers with a daily consumption rate of 25 mega-volt amperes [12], [13].

Due to the difficult conditions faced by the residents of Tubas, resulting from the occupation and a severe shortage in many aspects, especially in traditional energy sources, the Electricity Company of the Tubas Region turned to using alternative sources such as solar energy [14]–[16].

Tubas governorate was the first in Palestine to start solar energy projects. By the end of 2015, the total solar systems production was 4.475 MWp. As the number of solar systems increased over time, at the end of 2022, the total production of PV systems reached 19.120 MWp. Therefore, the company’s engineers expect a surplus in solar production compared with the total consumption due to the increase in solar systems capacities. The following figure show the production of total PV solar systems in Tubas in 2022 [17].

Our objectives are summarized as follows:

- Analyze consumption and production data of PV solar systems at TDECO in 2022.
- Study the electrical network of Tubas District Electricity Company.
- Propose solutions for managing excess PV solar energy.
- Evaluate solutions based on financial criteria.
- Select the most cost-effective solution for implementation.

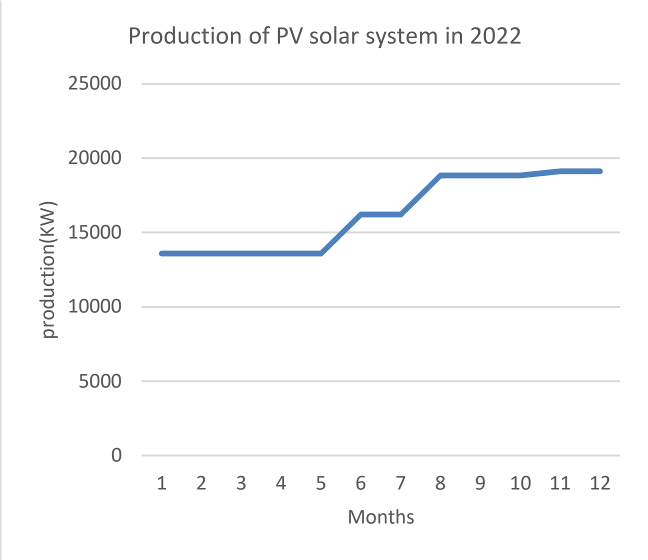

Fig. 1. Production of solar systems in 2022 of TDECO.

II. METHODOLOGY

The Tubas electrical network comprises 674 buses, 267 transformers, and 408 cables and transmission wires, including 33 underground cables. An AutoCAD-generated single line diagram obtained from TDECO served as the basis for building the network in ETAP software. The following figure shows the single line diagram of the Tubas network drawn in ETAP.

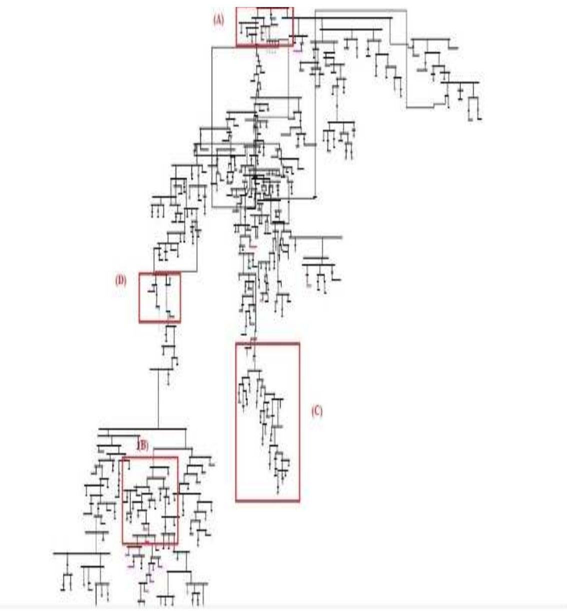

Fig. 2. Single line diagram of Tubas network.

The process of calculating the expected production involves multiple steps. Initially, the generated current in amperes, corresponding to the kilowatt peak production of the Al-Maslamani solar station, is multiplied by the projected number of stations intended for installation. This multiplication yields a preliminary estimation of the production capacity. Subsequently, this estimation is converted into power, providing a quantitative measure of the expected production.

Simultaneously, the expected consumption for 2023 was calculated. This estimation was derived by multiplying the consumption value from the previous year (2022) by a growth factor of 1.05, indicating a 5% annual increase. This growth factor accounts for the anticipated rise in energy demand based on past trends and current economic factors.

In addition to these calculations, detailed analyses were conducted using daily load curves for each month in 2022. These curves were compared with the PV solar system's production data from 2022 and the projected production figures by the end of 2023. This comparison allowed for a comprehensive understanding of the energy consumption patterns throughout the year, enabling the identification of peak demand periods and potential surplus energy generation periods.

Furthermore, the analysis considered both the minimum and maximum load consumption scenarios. By examining these fluctuations, the study aimed to optimize solutions for utilizing excess PV solar energy effectively. These assessments, grounded in real-time data and future projections, form the basis for decision-making regarding the management of solar energy surplus in Tubas District. The following figure

The following figures depict daily load patterns for each month, showcasing the 2022 PV solar system performance, alongside the anticipated production levels by the close of 2023. Additionally, they outline the range of minimum to maximum load consumption.

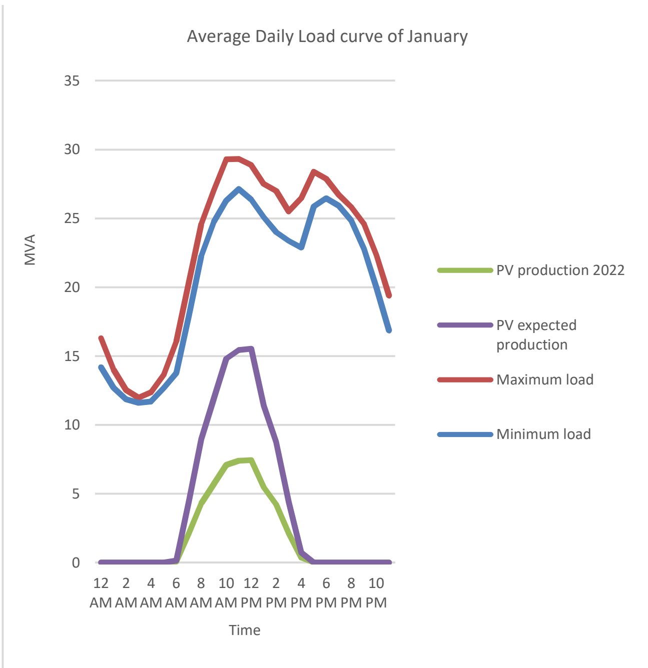

Fig. 3. Average Daily Load curve of January.

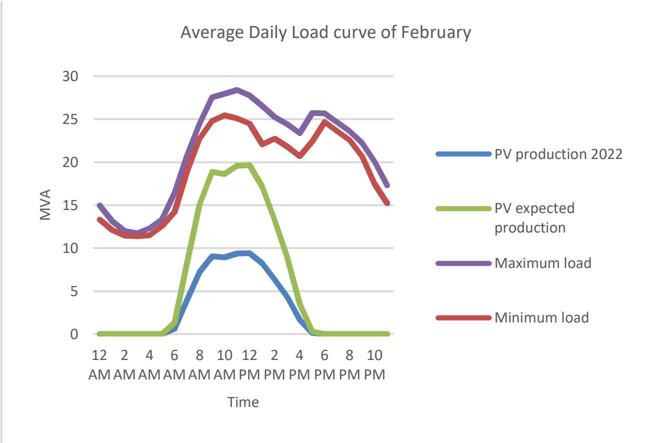

Fig. 4. Average Daily Load curve of Fenruary.

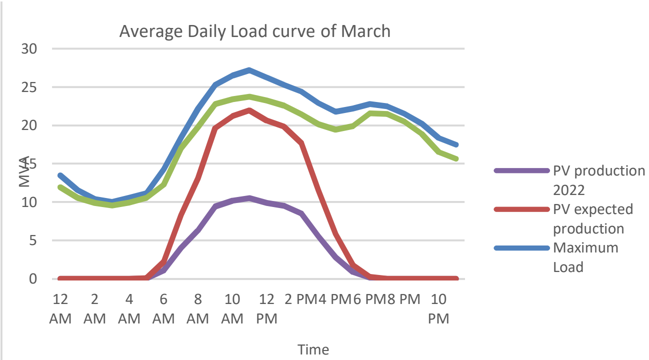

Fig. 5. Average Daily Load curve of March.

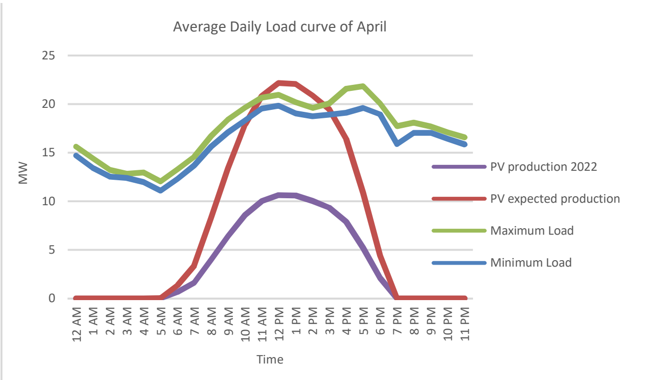

Fig. 6. Average Daily Load curve of April.

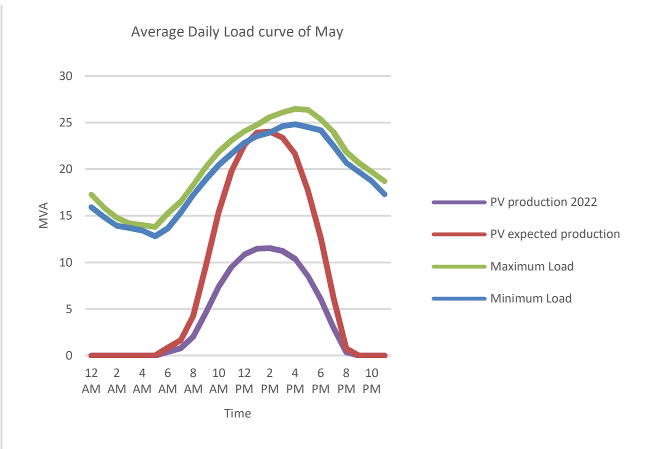

Fig. 7. Average Daily Load curve of May.

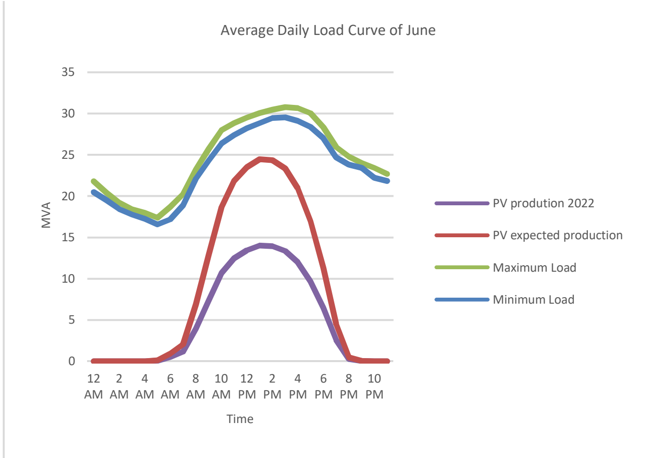

Fig. 8. Average Daily Load curve of June.

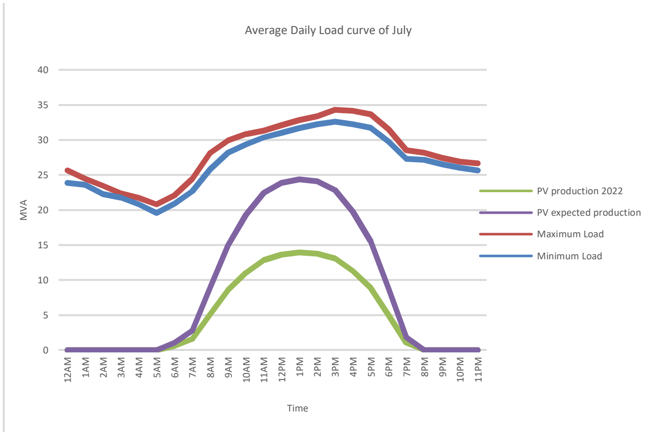

Fig. 9. Average Daily Load curve of July.

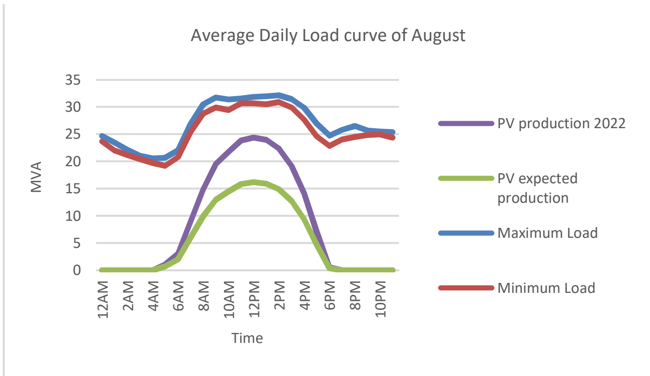

Fig. 10. Average Daily Load curve of Augest.

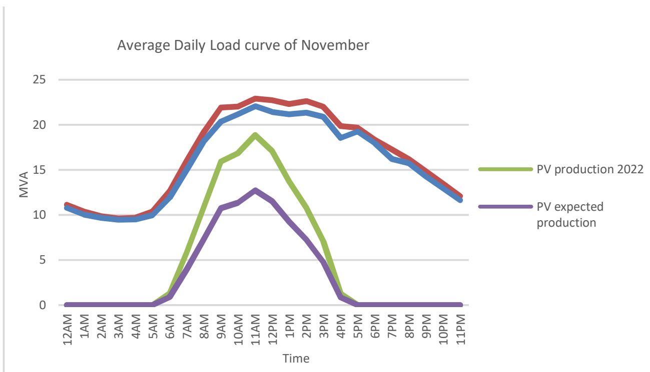

Fig. 11. Average Daily Load curve of November.

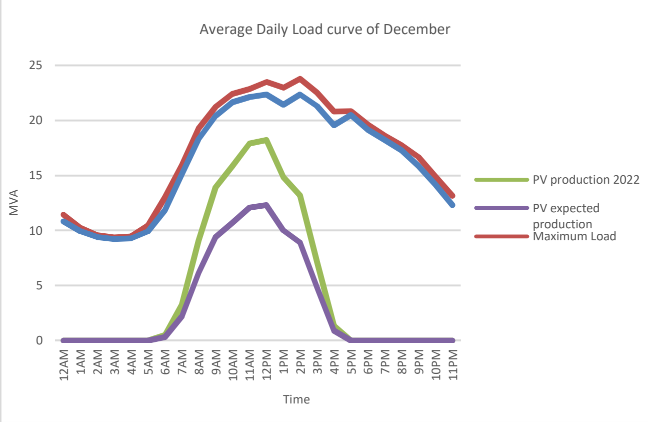

Fig. 12. Average Daily Load curve of December.

III. Results

After comparing the anticipated daily consumption patterns in Tubas with the expected PV solar station production, set to reach 28337Wp by the end of 2023, it's clear that solar generation exceeds consumer needs in April as shown on Fig. 13. This excess energy, totaling 5.1 MWh, necessitated an exploration of solutions. This study explores two primary approaches: load shifting strategies and excess energy storage methods.

To address the surplus in solar production, the Tubas District Electricity Company first applied a load shifting approach. Load shifting involves moving electricity consumption from one time period to another. In this case, the company focused on residential loads, which constitute 45% of the total loads.

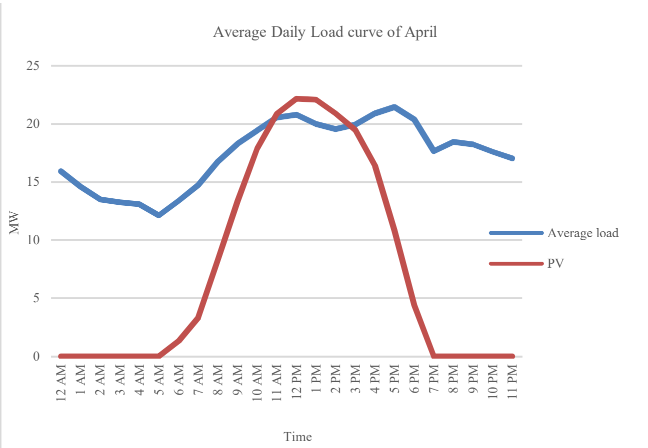

Fig. 13. Average Daily Load curve of April 2022.

The company conducted an online questionnaire to gauge the willingness of customers to shift their household loads from the evening period (5:00 PM to 8:00 PM) to the morning period (11:00 AM to 2:00 PM), which is the peak production time with excess energy beyond consumption.

The response rate to the online questionnaire was low, with only 141 responses participating. This suggests that people had difficulty comprehending the idea from the online questionnaire. To address this, the company conducted a paper-based survey with verbal explanations.

The results of the survey showed that 52% of customers, approximately 10,000 customers, were capable of shifting their household loads from non-peak hours to peak hours. This is a significant number of customers, and it suggests that load shifting has the potential to reduce peak demand and improve the efficiency of the power grid.

The average consumption rate for each household is 1.93. This means that each household consumes an average of 1.93 megawatt-hours of electricity during peak hours. Overall, the results of the survey are positive and suggest that load shifting is a viable way to address the surplus in solar production in Tubas. However, it is important to note that the survey was conducted on a relatively small sample size, so further research is needed to confirm the results.

Distributing 0.5 kilowatt-hours to 10,000 consumers from 11 AM to 2 PM resulted in the following load curve:

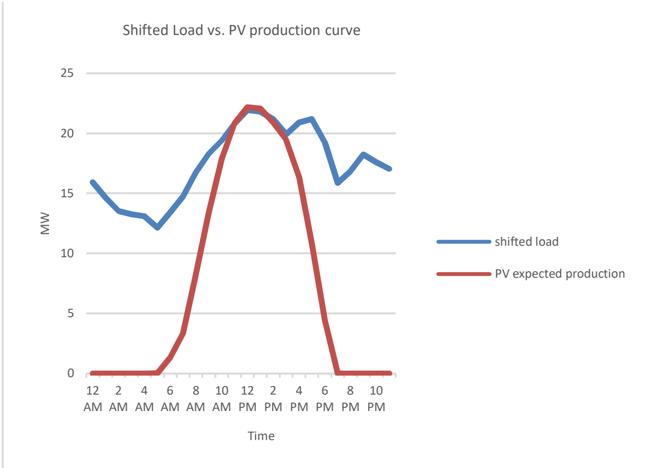

Fig. 14. Shifted Load vs. PV production curve after load shifting.

The Tubas District Electricity Company attempted to sell its excess solar energy to consumers at a new tariff, which was half of the old tariff during peak production hours. However, the response from consumers was not encouraging, as the savings were only 17.8 shekels per month. Therefore, the company decided to conduct a study on distributing the excess energy for free.

To benefit from the distributed energy for free, each subscriber needs to increase their consumption above the original rate of 1.93 kilowatt-hours per month, and then receiving half a kilowatt-hour for free.

During the questionnaire survey, it became apparent that some employees are unable to shift their loads on workdays but can do so on holidays. Consequently, the company divided the month into three scenarios to accommodate all categories: government employees, private sector employees, housewives, and others.

- Scenario 1: Housewives or individuals who can shift their loads on all days of the week.
- Scenario 2: Private and government sector employees who are off from work on Friday.
- Scenario 3: Private sector employees who are going to their business on Saturday.

The above-mentioned scenarios are being implemented where the results are expected to be monitored shortly, consequently, if positive results obtained, the program will be expanded to all customers.

In scenario 1, applicable to individuals who can shift their loads throughout the week, cost calculations during official working days (Sunday to Thursday) and company losses were conducted based on the electric tariff obtained from TEDCO's Engineering (refer to the attached appendices for the tariff photo). The extra energy purchased from PV solar stations was priced at 0.385 shekels per kilowatt-hour, amounting to 1973 shekels for 5.1 megawatt-hours of excess energy purchased.

The company procured 73 megawatt-hours between 5:00 PM to 8:00 PM. This included 53.3 megawatt-hours from the Jalamah point at a tariff of 0.328 shekels/kilowatt-hour, costing 17,482 shekels (accounting for 73% of the total withdrawal from connection points), and 19.7 megawatt-hours from the TYASEER point at a tariff of 0.453 shekels/kilowatt-hour, amounting to 8,930 shekels (27% of the total withdrawal).

The total purchase from both points summed up to 26,412 shekels (17,482 shekels from Jalamah point + 8,930 shekels from TYASEER point).

The distributed energy was sold to different sectors, with specific proportions based on the type of load. For the residential sector, comprising 45% of the total loads, 32.8 megawatt-hours were sold at a tariff of 0.58 shekels/kilowatt-hour, yielding 19,056 shekels.

Prior to the shift, the company purchased 77.9 megawatt-hours for 28,192 shekels and sold 45,674 megawatt-hours. The total profits before the shift were 17,482 shekels, with losses from the profits amounting to 1,103 shekels. Considering the losses from profits and the cost of extra energy purchased from PV solar systems (1103 shekels + 1973 shekels), the total daily losses from the PV solar systems and profits equaled 3,076 shekels.

In Scenario 2, on Fridays, when private and government sector employees are off from work, it is anticipated that 16,000 consumers benefit from the offer. Their consumption is expected to be 38.96 MWh at peak time, while the consumption of the remaining 2800 customers is 5.418 MWh.

After implementing the Friday shift, the company purchased energy for 70.1 megawatt-hours from 5:00 PM to 8:00 PM at a cost of 25,327 shekels and sold it for 41,033 shekels, resulting in a profit of 15,706 shekels. However, the money loss due to the shift, calculated as 17,482 shekels (before the shift) minus 15,706 shekels (after the shift), equals 1,776 shekels. Additionally, there was a loss from the purchase of 2.7 megawatt-hours from Jalamah and TYASEER for 1,010 shekels. The total losses amounted to 4,759 shekels, including the 1,973 shekels for the extra energy purchased.

In Scenario 3, on Saturdays, 13,000 consumers with a consumption of 30.65 MWh and 5,800 customers with 11.22 MWh benefit from the offer. Before the shift, the company made a profit of 17,482 shekels. After the Saturday shift, the company bought 71.5 megawatt-hours for 25,870 shekels and sold them for 41,912 shekels, resulting in a profit of 16,042 shekels. This led to a loss in profits of 1,439 shekels. Additionally, there was a loss from the purchase of 1.6 megawatt-hours from Jalamah and TYASEER for 578 shekels. The total losses in April amounted to 102,540 shekels, calculated based on the losses on Saturdays, Fridays, and regular days.

Implementing the solution of storing excess energy in batteries involves using 664 lithium-ion batteries with a voltage of 48 and a capacity of 200 ampere-hours, totaling 5.1 megawatt-hours. Each battery has a capacity of 7680 watt-hours after considering the depth of discharge (DOD) factor of 0.80. Using charge controllers rated at 250 volts and a maximum current of 120 amperes, 5 batteries can be connected in series to a single charge controller, requiring 130 charge controllers in total. The cost of this solution, including batteries and charge controllers, is $1,499,800 or 5,249,300 shekels. However, considering the revenue from selling the discharged energy to the grid during the night (2344 shekels per day or 70,000 shekels annually), it would take an impractical 75 years just to recover the costs of the batteries and charge controllers, without accounting for additional expenses such as land costs, maintenance, installation, operation, and component replacements in case of damage.

The initial consumption curves drawn from connection points were compared with the expected production from PV solar systems, but it was later realized that these curves didn't account for the total company consumption. Additional consumption was withdrawn from the PV solar systems but wasn't included in the initial curves. This discrepancy was particularly evident in April, with confirmation from the Jalamah connection point data on 21/4/2023, which will be studied further. However, the methodology used to address this presumed issue, including analyzing the problem, applying the load shift solution, calculating its costs, and considering battery storage, was correct based on research and guidance from the project supervisor. The only distinction is that the data used for these solutions is hypothetical and doesn't reflect the actual data for the Tubas company. For instance, it assumes that all residential sector subscribers have increased their consumption during specific hours.

In December, the excess energy was calculated at 9.30 megawatt-hours from 11:00 AM to 1:00 PM. Distributing 9.58 megawatt-hours among 18,800 customers resulted in losses, including a profit difference loss at night of 1548.68 shekels, a loss from excess withdrawal beyond production at connection points of 120 shekels, and the cost of energy purchased from PV solar systems at 3582.958 shekels. The total loss amounted to 5250 shekels. Despite implementing load shifting and reducing excess from 13.1 to 3.45 megawatt-hours, the problem persisted. In May, the excess energy quantity was 26.12 megawatt-hours, leading to a total loss of 6252.923 shekels. Due to practical limitations in increasing residential consumption and the remaining excess energy, load shifting became impractical. Storing excess energy for sale at night emerged as a viable solution, requiring 5699 batteries and 1120 charge controllers, costing 44,287,760.4 shekels. Selling the stored energy at night would yield a daily profit of 20,162.47 shekels, totaling 7,359,300 shekels annually, enabling cost recovery within 6 years.

IV. Conclusions and Recommendations

This study successfully studied and analyzed the electrical network of Tubas District Electricity Company and generated financial returns by selecting the optimal solution to address surplus energy production. ETAP software was used to build the network and perform load flow analysis. They also studied the production and consumption curves to determine the months with surplus energy. Load shifting was applied and a battery field for energy storage was designed, calculating the costs of each solution. They then compared the two solutions and provided recommendations to the company.

Based on the research findings, the following recommendations are made to Tubas District Electricity Company:

- Sell excess electricity back to the main source. If possible, this is the most suitable solution to implement. However, further research is needed to understand the existing agreements and regulations concerning the feed-in of electricity to the grid.
- Implement load shifting. Load shifting is the most suitable approach when energy production exceeds consumption during specific periods, such as one or two months per year. The company should educate customers about load shifting and provide them with incentives to shift their loads to off-peak hours.
- Implement energy storage. If the surplus energy from PV solar systems production consistently exceeds consumption for most of the year, it is preferable to implement an energy storage solution using batteries and discharge it into the grid during the evening hours of the same day. The company should conduct further research to determine the most effective way to implement energy storage solutions.
- Conduct further research on battery storage. Simulating batteries on ETAP is a relatively new subject, and there is a lack of experience and information in this area. The company should conduct a more comprehensive study of the network to determine the voltage profile and identify suitable locations for the batteries. Charging and discharging processes also need to be modeled accurately. The company may also want to consider using specialized software like "dig silent" to facilitate energy storage solutions.

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