Advanced Engineering Science
http://publish.mersin.edu.tr/index.php/ades
e-ISSN 2791-8580

Optimal design, cost analysis and impact of a tracked bifacial PV plant in distribution system

Andi Hida [*1], **Rajmonda Bualoti** [1], **Pavlina Qosja** [2]

[1] *Polytechnic University of Tirana, Electrical Power Systems Department, Albania, andi.hida@fie.edu.al; r_bualoti@yahoo.com*
[2] *AEG Partners Balkan, Energetic Department, Albania, pavlina.qosja@fie.edu.al*

Cite this study: Hida, A., Bualoti, R., & Qosja, P. (2024). Optimal design, cost analysis and impact of a tracked bifacial PV plant in distribution system. Advanced Engineering Science, 4, 65-75

Keywords
Bifacial PV
Single-axis tracking
Techno-Economic
Distribution System
Technical losses

Research Article
Received: 20.12.2023
Revised: 02.02.2024
Accepted: 20.02.2024
Published: 01.03.2024

check for updates

Abstract

The rapid development in the photovoltaic (PV) sector requires more and more in-depth studies. In this context, this paper presents a techno-economic analysis of a 10 MWp PV plant installed in the south-west of Albania. To increase its performance, a single-axis solar tracking system with bifacial modules has been chosen. Moreover, the optimal design and sizing of the PV plant is determined through software, considering various factors. In this context, the results show that the annual yield of the on-grid PV system will be 1,670 kWh/kWp. In the same vein, the calculations present that the internal rate of return IRR is 20.6%, which indicates that the project will have a positive return on the investment value. Meanwhile the payback period of the investment is 4.8 years, which is considered as an investment that provides high income. These values are quite attractive for investors. On the other hand, the impact of this PV system on the distribution system parameters, for different scenarios, has been studied. While an improvement is seen in the voltage levels of the nodes, some of the lines and transformers show technical losses due to their loading.

1. Introduction

In recent years interest in the use and development of renewable energy sources (RESs) have been increasing, considering growing concerns about global warming, environmental pollution, as well as security of energy supply. For example, according to IEA, compared to 2022, by 2027, it is expected that RESs capacity will grow by almost 2400 GW (or 75%) [1]. Several factors have influenced this increase in RES penetration, such as: market conditions, investment costs, technology diversity, resource availability, proximity to the distribution or transmission network, etc. Another very important factor are government policies such as incentive fees, support schemes, or banking policies (loans) for the support and development of these technologies.

Among RESs, solar photovoltaic (PV) can provide suitable solutions to global climate change and give its impact to the global energy crisis. Moreover, in countries like Albania (energy production in which is based almost entirely on hydropower (99.28%), always questioning its reliability), the increase in installed PV capacities would affect the diversification of sources of electricity production [2-3]. It is worth mentioning that Albania has great potential for the use of solar energy, especially in its western part (for example “Fier” area) where Global Horizontal Irradiation (GHI) reaches a maximum of 1750 kWh/m^2 per year. For this reason, most of the PV plants installed in Albania (29MW) are located in the Fier area, overloading its distribution system.

Thus, determining the most suitable point for connecting PV plants to the power system is a very important issue. For this purpose, their impact on network parameters should be considered, such as: voltage levels, loading of distribution lines and transformers and active power losses.

On the other hand, Law 24/2023 [4] on promoting the use of energy from RESs has increased the demand for the construction of new massive solar PVs in Albania. In particular, solar tracking systems and bifacial modules have been used in some of the PV projects. In this context, detailed techno-economic feasibility studies are required in these cases.

There are numerous literatures on techno-economic analysis of tracked bifacial PVs. The studies show that the performance of PV systems has always been increasing. In particular, this performance depends on the optimal design and sizing of the PV plants [5]. Moreover, it strongly depends on the module temperatures. For this purpose, authors in [6] evaluated the performance of ten different PV module temperature. Meanwhile, the authors in [7] study the combined effect of tilt angle and ambient temperature for maximizing the PV output.

In the same vein, authors in [8] show that the average energy produced by a PV module with single axis tracker was 1.35 times greater than that of a fixed one. This is a consequence of a higher irradiation on the PV modules, considering the solar tracking mechanism. While reference [9] points out that the maximum power point tracking (MPPT) system should be considered, a large number of MPPT techniques have been proposed. Furthermore, authors in [10] argue that bifacial PV produce 9 % to 23 % more power than monofacial PV. However, this improvement depends on the albedo values, the surface types, as well as the tilt angle. For example, reference [11] shows that using a white surface coating, is the best option and will increase the energy production of bifacial modules.

Meanwhile, compared to monofacial, bifacial PV modules cost 10% more [12]. In this context, a detailed economic analysis is necessary. In [13], the authors determined the internal rate of return (IRR) for the bifacial and monofacial rooftop system, 24% and 23%, respectively. These values are quite attractive for investors.

On the other hand, the new PVs can cause problems in the distribution system. In this way, it is important to calculate in advance the network parameters, such as voltages and technical losses [14].

In addition, the authors did not find any research paper for techno-economic analysis of tracked bifacial PVs and their impact in Albanian power system. This paper goals at filling this gap.

In our opinion, this paper can be valuable for further studies in the PV sector. To the best of the author's knowledge, this is the first research paper that presents a detailed techno-economic analysis of a massive tracked bifacial PV in Albania, considering various factors. Furthermore, the novel contributions are the following:

- A techno-economic analysis (for the optimal design) based on a real-world data of a massive tracked bifacial PV, installed in Fieri area.
- The impact of the solar PV system on the Fieri distribution system parameters. In particular, voltage levels, loading of distribution lines & transformers, a well as active power losses has been analysing. In terms of power losses, 2 different scenarios are taken into consideration.
- According to the financial analysis, investments in PVs are quite attractive for investors. Especially using solar tracking systems with bifacial modules.
- The obtained results give important suggestions for different stakeholders (including the solar PV industry), as well as for the future work of the distribution system.

The remainder of the paper is organized as follows. Section 2 introduces the material and methods, including the site location, the methodology employed in this work, as well as the theoretical background on the PV performance parameters. Furthermore, Section 3 deals with the main results and discussion of the paper. Finally, Section 4 provides concluding remarks and future work directions.

2. Material and Method

2.1. Study Area

Considering the great potential of solar radiation, the PV system will be installed in Fieri area (Figure 1). For example, according to Global Solar Atlas (by the World Bank Group), the annual yield in this region could go up to 1607 kWh/kWp [15]. In this context, Figure 2 shows the annual yield (kWh/kWp) for different areas in Albania.

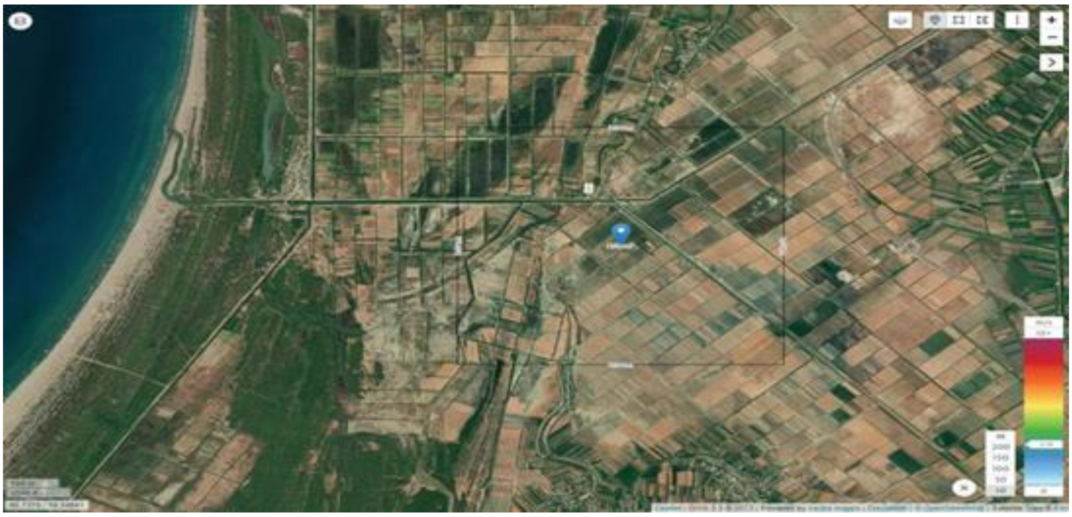

Figure 1. Satellite view of the location of PV the plant.

Figure 2. The annual yield (kWh/kWp) in Albania [15].

Furthermore, in Fieri area there are over 2500 hours and at least 280 days of sunshine in a year. Moreover, peak sun hours reach over 4.3.

Another parameter that must be taken into consideration is the wind speed. From a simulation carried out in the area where the proposed project will be developed (specifically on a 9 km^2), for a height of 10 m above the ground, it results that the average wind speed is 2.98 m/s, varying from a minimum of 2.75 m /s up to a maximum of 3.08 m/s.

2.2. Methodology

The methodology used to carry out this analysis combines the previous experiences undertaken in Albania in the field of feasibility studies and potential investments in RESs, more specifically in the generation of electricity through PV plants as well as forms of good management in the provision of this service. The study is based on solar radiation data averaged and published by SolarGis, as well as based on Global Solar Atlas [15]. These programs are used as a model for simulating and evaluating data and performance, besides to calculate expected yield. For example, according to the simulations in SolarGis Albania, the annual average GHI for the solar PV area is about 1669.4 kWh/m^2.

On the other hand, the financial part has been analysed in relation to the value of the investment, the method of financing, the repayment of the loan, the return of the investment and the incomes from the sales in the HUPX power exchange [16].

All simulation results for the techno-economic analysis are obtained using PV*SOL 2022 version R7 [17]. it's worth mentioning that we used the optimization option of the software to determine the optimal design and sizing of the PV plant. Furthermore, Figure 3 shows the methodology used in this work.

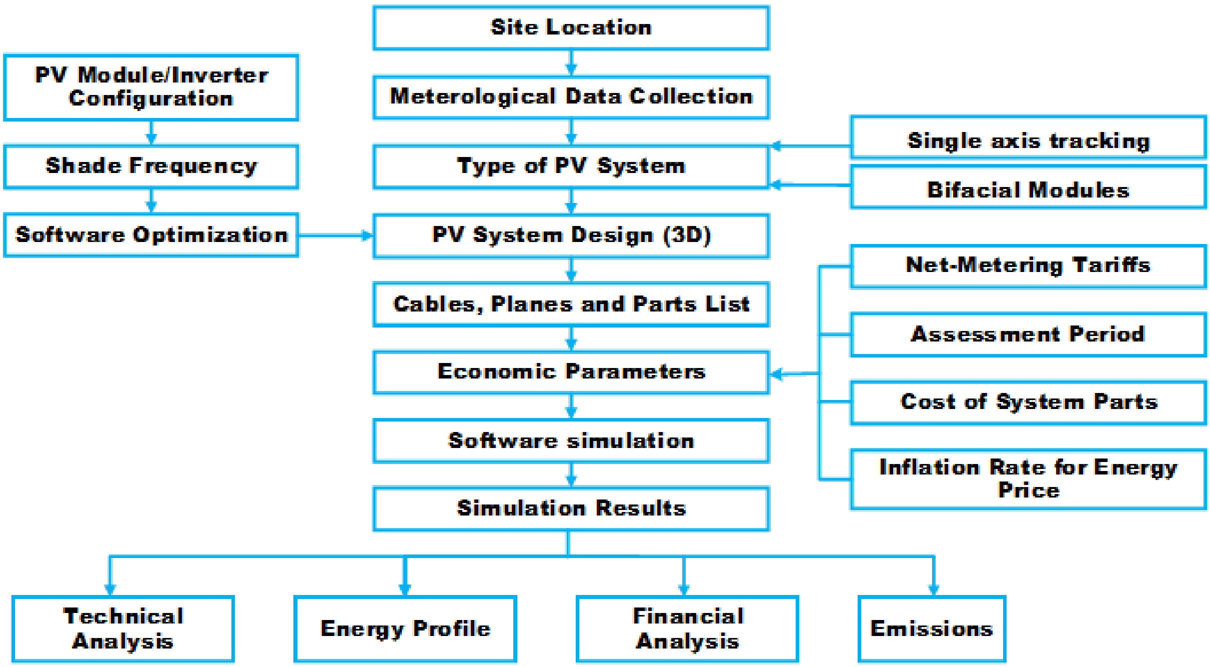

Figure 3. Overall workflow diagram [5].

Meanwhile, AS DAISY Off-Line Bizon software [18] was used to calculate the impact of the photovoltaic system on the parameters of the Fieri distribution system, connected to its most suitable point.

2.3. Performance parameters

The annual energy production from the PV system (through PV modules), is given by Equation 1:

$$E_{AC} = P_{DC} \cdot \eta_{inv} \cdot t \tag{1}$$

where P_{DC} and η_{inv} represent the DC power of PV system and the inverter efficiency, respectively; and t represents the time in hours [5].

Meanwhile, the output DC power of the PV system is influenced by solar incidence angle on the PV modules and is given by Equation 2:

$$P_{DC} = I \cdot S \cdot \cos(\alpha) \tag{2}$$

where I represents the solar irradiance measured in kW/m^2; S and α are the total PVs surface area (m^2) and solar incidence angle, respectively.

Furthermore, the PV inverter convert the electricity from DC to AC, to transport the energy from the source to the loads. Its power can be calculated using Equation 3:

$$P_{inv}(t) = P_L^m(t) \cdot \eta_{inv} \tag{3}$$

where $P_L^m(t)$ is the maximum load demand, which is a key point in inverter sizing [19].

In addition, against to monofacial modules, bifacial ones have several different characteristics. In this case, the Bifacial Factor (FB) serves as a critical factor for comparing the performance of monofacial versus bifacial modules (Equation 4):

$$FB = \frac{P_{bifacial}}{P_{monofacial}} \tag{4}$$

where $P_{bifacial}$ and $P_{monofacial}$ represent the generated power by a bifacial module and by a monofacial ones, respectively [20].

On the other hand, economic analysis can be performed through Net Present Value (NPV). It can be defined by Equation 5 [21]:

$$NPV = \sum_{n=0}^{N} \frac{F_n}{(1+d)^n} \tag{5}$$

where, F_n is the net cash flow in year n, N is the time period, and d is the annual discount rate.

If NPV > 0, it means after the analysis period, the revenues (cash inflow) exceed the cost which indicates that the project is attractive. In particular, when NPV becomes zero at the end of the analysis period, we can measure of discount rate (Equation 6). This value represents Internal Rate of Return (IRR) [21]:

$$NPV = \sum_{n=0}^{N} \frac{F_n}{(1+IRR)^n} = 0 \tag{6}$$

Generally, the higher the IRR, the project is more easily accepted.

Finally, Payback Period measures the amount of time required to recoup the cost of an initial investment. It can be can be expressed as: Payback Period = Initial Investment/Cash Flow Per Year.

3. Results and Discussion

A techno-economic analysis of a tracking PV system with bifacial module, installed in Fieri distribution system is presented in this section. Furthermore, in the last subsection, the impact of this PV system on the distribution network parameters is presented.

3.1. Technical analysis

The optimal design and sizing of the Single-Axis Tracked Bifacial PV Plant is shown in Figure 4. Specifically, the on-grid PV system with a total power of 10 MWp consists of: 17220 Bifacial PV modules (RECOM PANTHER 650 Wp, 20.9%), 96 inverters (SUNNY TRIPOWER CORE2 STP 110-60), 2 Smart Transformation Stations (2x6000kVA), AC and DC cables, and one bidirectional meter.

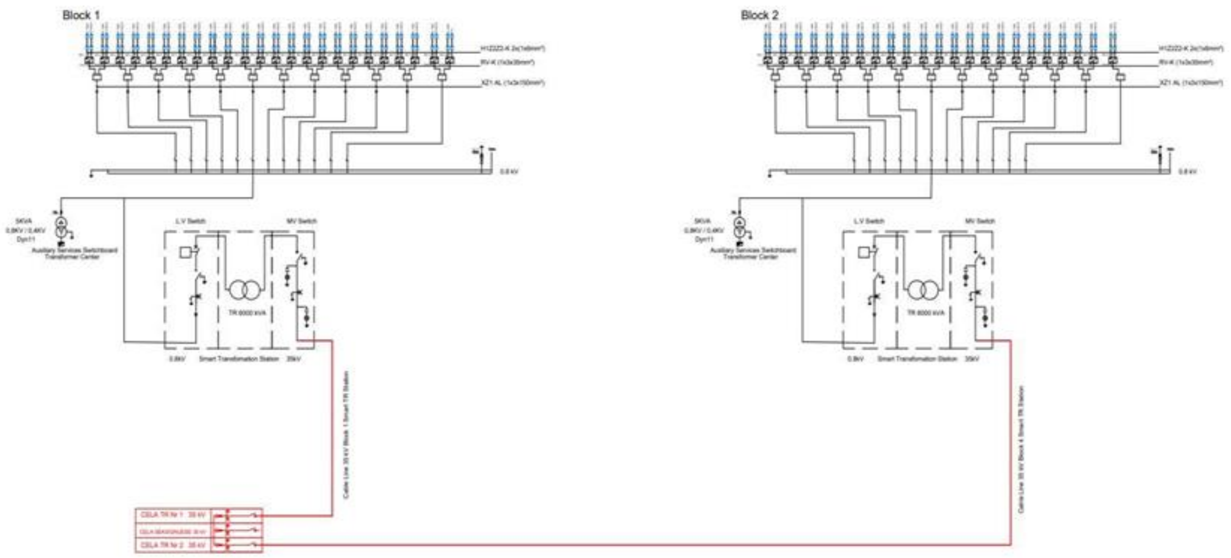

Figure 4. The principal electrical scheme of the PV plant

The on-grid PV system's, with 92% of Performance Ratio (PR), will generate 17949 MWh in the first year (with annual yield 1,670 kWh/kWp). Furthermore, the other main simulation results of the technical analysis are shown in Table 1.

Table 1. Simulation results: Technical analysis.

Items	Value
Installed capacity	11.2 MWp (DC), 10 MW (AC)
PVs area	53492 m^2
Orientation	South (Single Axis Tracker)
CO_2 emissions avoided	8435 ton
Assessment period	25 years
Number of working hours	1,794.94 hours/year

3.2. Energy profile

Considering the degradation of photovoltaic modules, the forecast energy production will decrease during years (Figure 5).

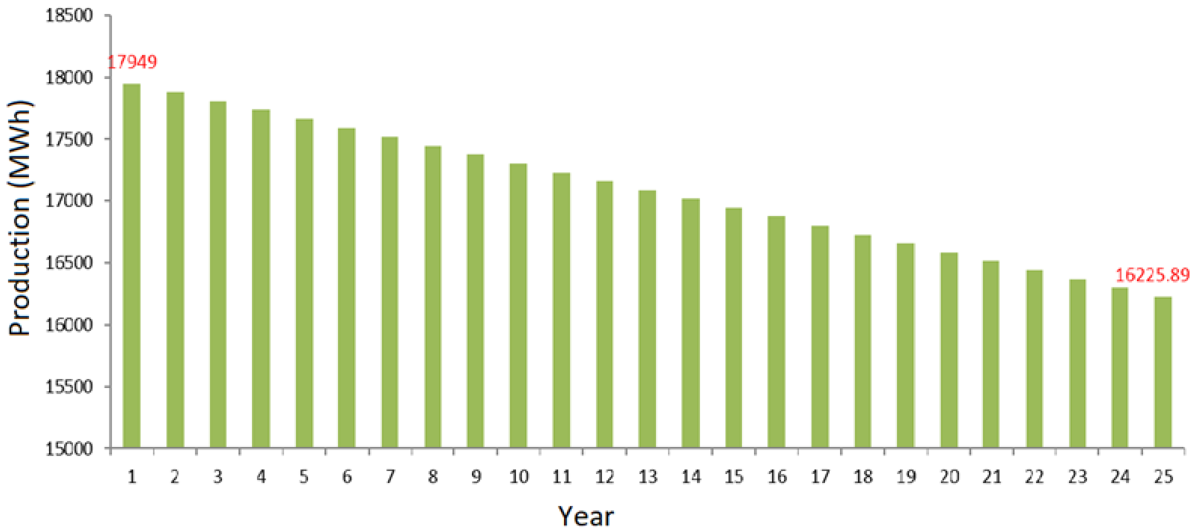

Figure 5. The forecast of yearly energy production.

Photovoltaic module degradation is a gradual process that occurs as a result of various factors, including environmental conditions, temperature, solar radiation, humidity, and pollution. In our case, bifacial PV modules retain 85% productivity after 25 years.

3.3. Financial analysis

While the total investment cost is 7.04 million €, the payback period and the Internal rate of return of the project according to the calculated flows will be respectively 4.8 years and 20.6%. In particular, Figure 6 shows the cost distribution of solar PV system components (in % of total cost).

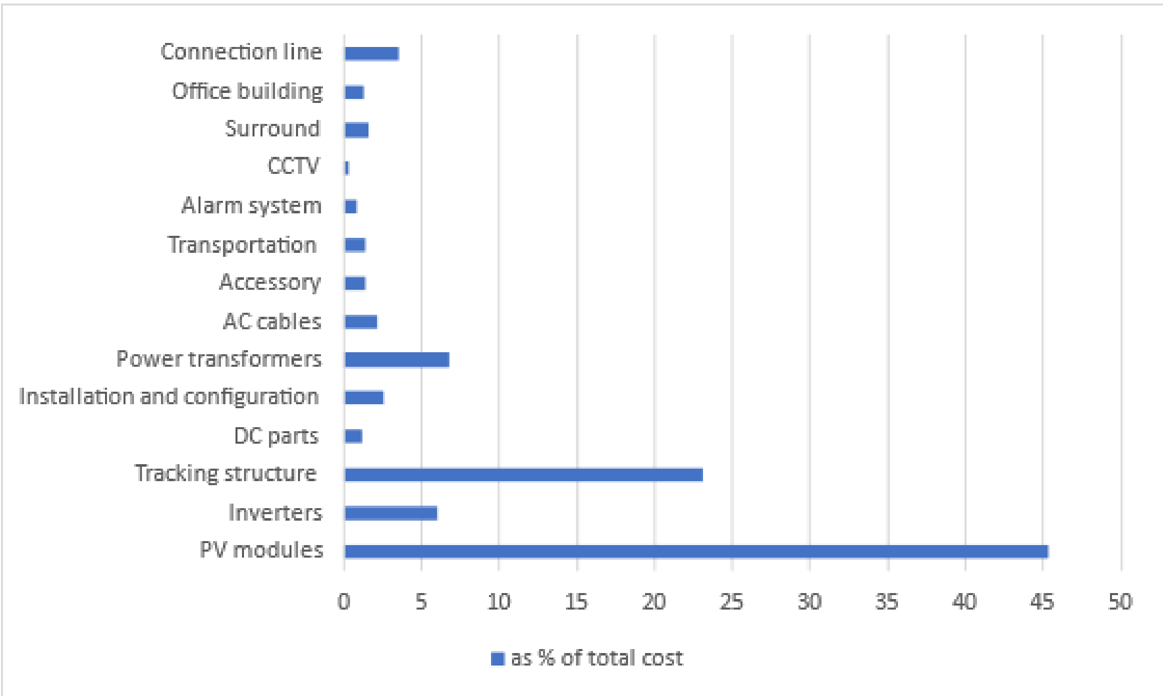

Figure 6. The cost distribution of solar PV system components

Furthermore, in the financial analysis, it is assumed to receive a loan in the value of 80% of the total cost (5.632 million €, with +/-3.5 % annual interest rate for 10 years). In addition, annual loan interest is shown in Figure 6.

These bank interests will be repaid through the revenues collected from the sale of energy in the free market. In this context, the average prices of energy sales in the years 2021 and 2022, for the Hungarian Power Exchange (HUPX) [16], have been taken into consideration. Since the price for 2022 is higher, then the calculation will be made with the 2021 price, since we think that the 2022 price is dictated by the war in Ukraine and the energy crisis. Thus, an average price of 113.58 €/MWh (2021) is provided for the calculation of the revenues from the sale of energy (Figure 7) [16].

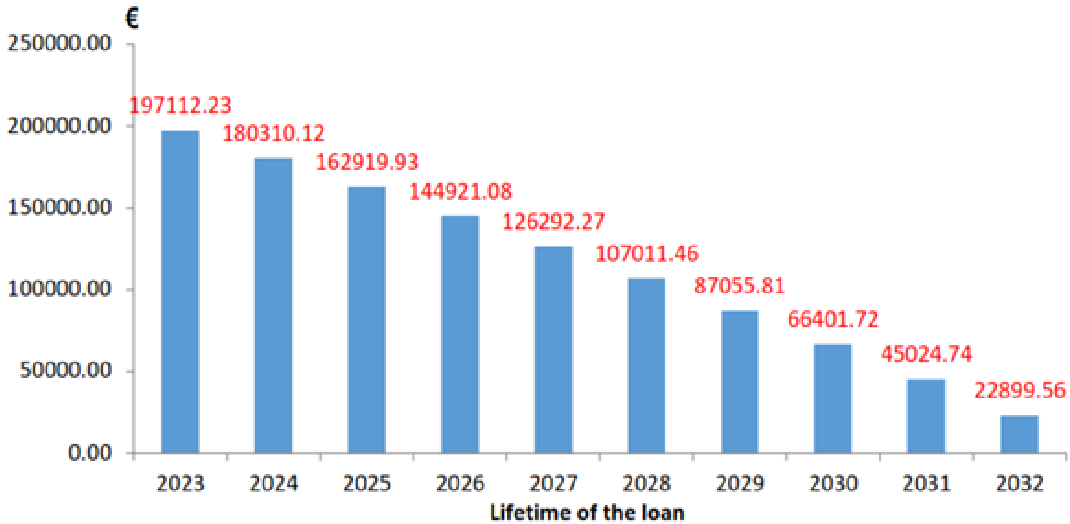

Figure 6. Annual loan interest

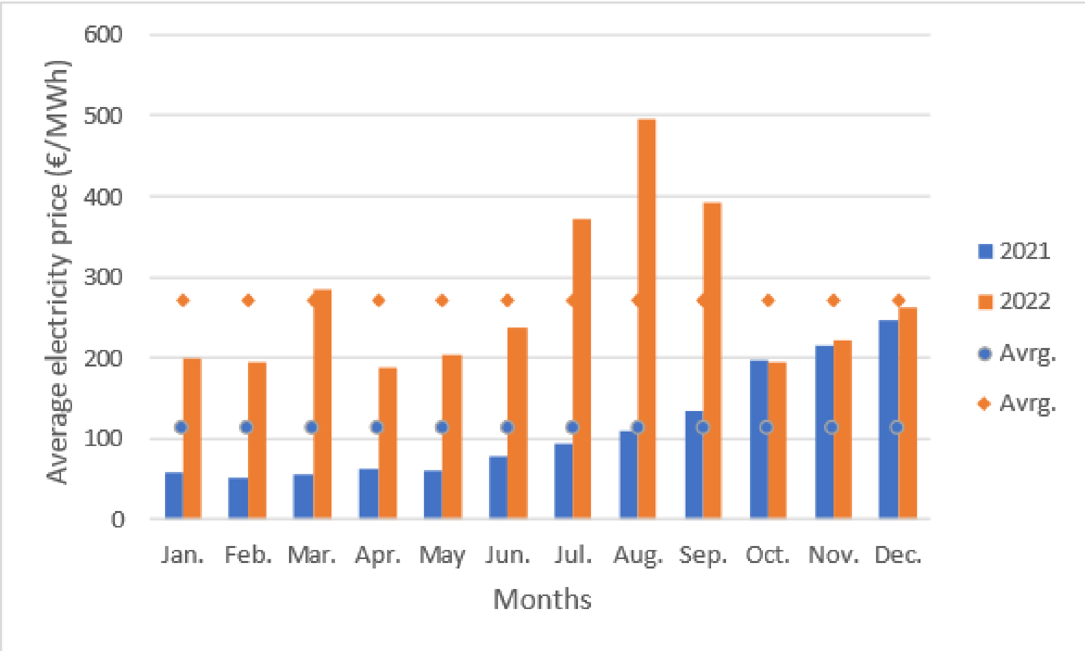

Figure 7. Average energy price, HUPX [16].

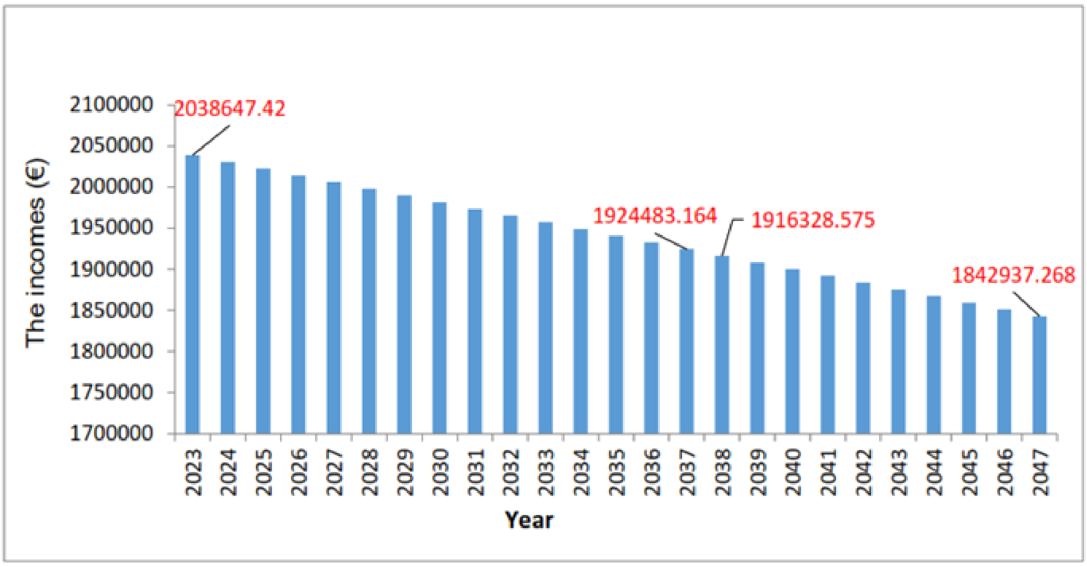

Figure 8. The revenues from the sale of energy.

Based on this average price, the annual revenue from the sale of produced energy, during 25 years, is calculated. Figure 8 presents the income from the PV system in each year.

In the same vein, a more detailed presentation of the cumulative cash flow in years is given in Figure 9. These values are quite attractive for investors.

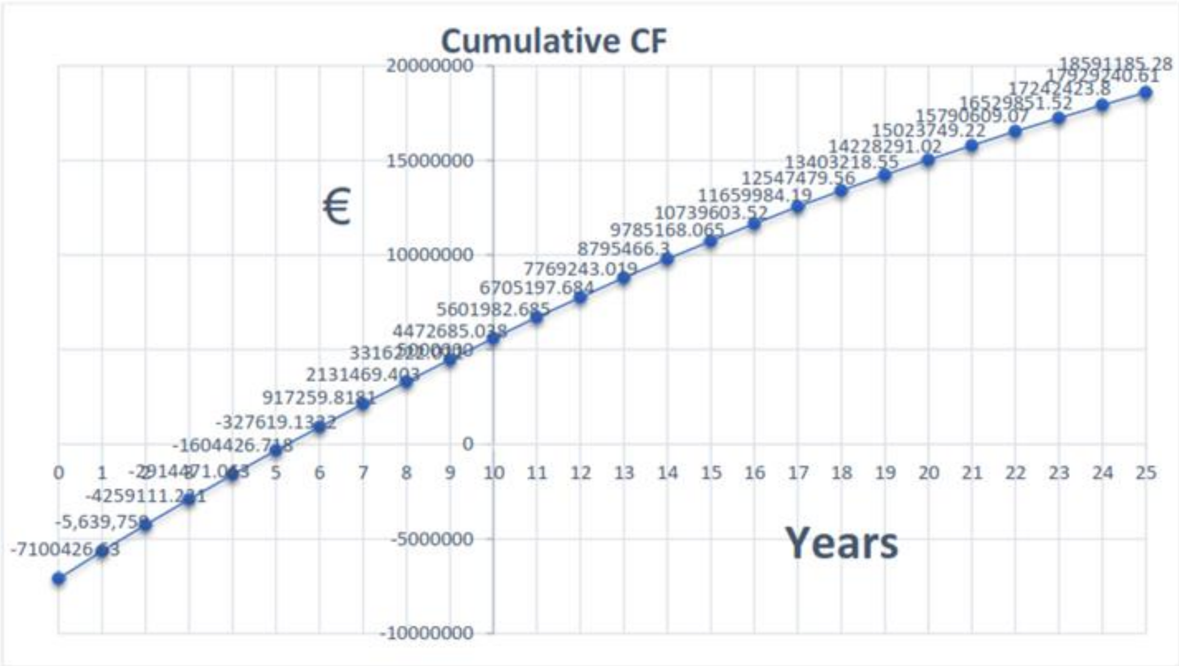

Figure 9. Cumulative Cash Flow

While after 4.8 years (payback period) the values become positive, at the end of 25 years the profits will be around 18.6 million €.

3.4. Connection to the distribution network

In the area where solar PV is located, the existing electrical network, at the 35 kV, 10 kV and 6 kV voltage levels, is owned by the distribution system operator. The connection of a new source to the electrical network must guarantee the maintenance of the technical network parameters within the allowed limits, even for transient states. The loads of lines or substations must not exceed their maximum thermal capacity and the voltage limits must be within the permitted rates. While the connecting infrastructure to the electrical network is associated with significant investments, the most economical variant that guarantees the technical requirements mentioned above, should be evaluated. Meeting the technical requirements and finding a compromise between the level of losses, the technical possibilities and the necessary investments, constitutes the best choice of connection to the electrical network. The connection schemes are modelled and simulated with AS DAISY Off-Line Bizon software, to evaluate some parameters, such as: voltage levels, line and transformer loading as well as power/energy losses.

Figure 10 shows the closest distribution network lines to the PV system. In this context, 2 different scenarios are considered for the connection point: through the "Kafaraj-Povelçe" line (scenario 1) and through the "Pojan-Hoxhare" line (Scenario 2).

For both scenarios, the total power losses are calculated and presented in Table 2. The table shows that the losses for scenarios 1 & 2, are 8.77% and 13.3%, respectively.

Table 2. Total power losses for 2 different connection point scenarios

Scenario	Power losses (kW)	Power losses (%)
1	2279	8.77
2	3458	13.3

It turns out that the best connection point would be on the 35kV Kafaraj-Povelçe line (Scenario 1). This is the closest line to the PV system, as well as the power losses in this case would be lower. For this purpose, from the point of view of the stability of the static parameters of the network and its security, the connection will made through the construction of a 35 kV line with two circuits (0.7 km in total), with 120/20 mm^2 Aluminium Conductor steel-reinforced Cable (ACSR). In this context, Figure 11 shows the construction of 35kV overhead power line.

Considering the modelling of the electric distribution network according to Scenario 1, the voltage levels of different points are calculated (Figure 12). The range of voltage levels in this case varies within the (99-119) limits.

Figure 10. The geographical extent of the distribution network near the PV system.

Figure 11. 35kV overhead power line.

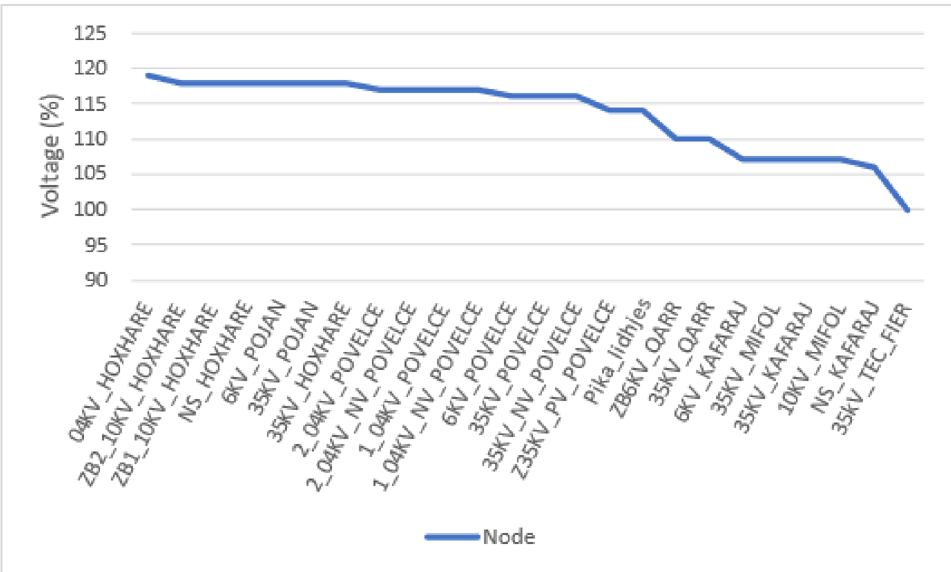

Figure 12. Voltage nodes of distribution system.

On the other hand, Figure 13 shows the impact of the PV plant on lines and transformers losses. For example, the biggest losses appear in "Pojan" and "Kafaraj" transformers.

Figure 13. Lines & transformers losses of the distribution system

While an improvement is seen in the voltage levels of the nodes, some of the lines and transformers show technical losses due to their loading. However, these network parameters are expected.

4. Conclusion

This paper performs techno-economic feasibility analysis of a Single-Axis Tracked Bifacial PV Plant. Optimizing this 10MWp PV system, results in an annual energy production of 17949 MWh/Year. This amount of energy is expected to be sold in the energy exchange. This would bring in an internal rate of return of 20.6% IRR is, as well as a 4.8 years payback period of the investment. These values are quite attractive for investors. On the other hand, this paper analyses the impact of the photovoltaic system on the parameters of the distribution system, connected to its most suitable point. In this context, an improvement is been seen in the voltage levels of the nodes. Meanwhile, some of the lines and transformers show technical losses due to their loading. The future work will perform a comparison between a Single-Axis Tracked Bifacial PV Plant and a static Monofacial PV Plant.

Acknowledgement

This study was partly presented at the 8th Advanced Engineering Days [22].

Funding

This research received no external funding.

Author contributions

Andi Hida: Conceptualization, Writing-Reviewing and Editing, Original draft preparation, Methodology, Software. **Rajmonda Bualoti:** Writing-Reviewing and Editing, Data curation, Validation. **Pavlina Qosja:** Writing, Software, Visualization, Investigation.

Conflicts of interest

The authors declare no conflicts of interest.

References

1. IEA (2022), Renewables 2022, IEA, Paris https://www.iea.org/reports/renewables-2022
2. Energy Regulator Authority (2022). Annual Report. The Situation of the Power Sector and ERE Activity during 2022, https://www.ere.gov.al/en/publications/annual-reports
3. Hida A., Voshtina E., Shaliu D., Bualoti R., & Çelo M. (2023). Integration of PV floating with an existing hydroelectric power plant: An Albanian case study. 12th MAKO CIGRE Conference, C6-006R.
4. KPMG Albania. (2023). New Law on "Promotion of the use of energy from renewable sources. https://kpmg.com/al/en/home/insights/2023/05/new-law-on--promotion-of-the-use-of-energy-from-renewable-source.html
5. Hida, A., Kërçi, T., Bualoti, R., Çelo, M., & Shaliu, D. (2022). A Techno-Economic Analysis of a Photovoltaic Plant: An Albanian Case Study. 1st International Conference on Renewable Energies and Smart Technologies (REST), 28-29, July, 2022, Tirana, Albania
6. Özden, T., Tolgay, D., Yakut, M. S., & Akinoglu, B. G. (2020). An extended analysis of the models to estimate photovoltaic module temperature. Turkish Journal of Engineering, 4(4), 183-196. https://doi.org/10.31127/tuje.639378
7. Hida, A., Bualoti, R., & Çelo, M. (2017). Impact of pollution and tilt angle on solar photovoltaic modules performance. Journal of Electrical Engineering and Information Technologies, 2(2), 97-104. https://doi.org/10.51466/JEEIT172097h
8. Bazyari, S. (2014). A study on the effects of solar tracking systems on the performance of photovoltaic power plants. Journal of Power and Energy Engineering, 2, 718-728. http://dx.doi.org/10.4236/jpee.2014.24096
9. Omar, F. A., Pamuk, N., & Kulaksiz, A. A. (2023). A critical evaluation of maximum power point tracking techniques for PV systems working under partial shading conditions. Turkish Journal of Engineering, 7(1), 73-81. https://doi.org/10.31127/tuje.1032674
10. Alam, M., Gul, M. S., & Muneer, T. (2023). Performance analysis and comparison between bifacial and monofacial solar photovoltaic at various ground albedo conditions. Renewable Energy Focus, 44, 295-316. https://doi.org/10.1016/j.ref.2023.01.005
11. Juaidi, A., Kobari, M., Mallak, A., Titi, A., Abdallah, R., Nassar, M., & Albatayneh, A. (2023). A comparative simulation between monofacial and bifacial PV modules under palestine conditions. Solar Compass, 8, 100059. https://doi.org/10.1016/j.solcom.2023.100059
12. The Complete Guide to Bifacial Solar Panels. (2023). https://www.eco-greenenergy.com/the-complete-guide-to-bifacial-solar-panels/
13. Desai, A., Mukhopadhyay, I., & Ray, A. (2022). Feasibility assessment of bifacial rooftop photovoltaic systems in the state of Gujarat in India. Frontiers in Energy Research, 10, 869890. https://doi.org/10.3389/fenrg.2022.869890
14. Hida, A., Bualoti, R., & Çelo, M. (2023). Impact of the distributed resources on the power quality indicators of the distribution network, A Case Study in Korça, 16th International Scientific Conference on Energy and Climate Change (Promitheas), Athens, October 11-13, 2023
15. World Bank Group. (2020). Global Solar Atlas. https://globalsolaratlas.info/download/albania
16. Hungarian Power Exchange (HUPX). (2010-203). Historical data. https://hupx.hu/en/market-data/dam/historical-data
17. PV*SOL. (2022). PV*SOL, Version 2022. https://pvsol.software/en/
18. As Daisy Off-Line Bizon. (2019). http://www.daisy.cz/daisyeng/1024/index.html
19. Hida, A., Rrotani, V., & Bualoti, R. (2023). Integration of a photovoltaic plant with an electric vehicle charging station. 2nd Conference of National Committee CIGRE Kosovo. November 22-24, 2023.
20. Yakubu, R. O., Mensah, L. D., Quansah, D. A., Adaramola, M. S., & Hammed, Y. (2022). Performance evaluation of bifacial solar PV modules under different climatic regions in Nigeria. E3S Web of Conferences, 354, 02006. https://doi.org/10.1051/e3sconf/202235402006
21. Faruqui, M. F. I., & Jawad, A. (2023). Techno-economic assessment of power generation potential from floating solar photovoltaic systems in Bangladesh. Heliyon, 9(6), e16785. https://doi.org/10.1016/j.heliyon.2023.e16785
22. Hida, A., Bualoti, R., & Qosja, P. (2023). A techno-economic analysis of a single-axis tracked bifacial photovoltaic plant connected in Albanian distribution system. Advanced Engineering Days (AED), 8, 71-74.