MAS Journal of Applied Sciences
Uygulamalı Bilimler Dergisi
ISSN: 2757-5675
masjaps.com

OPEN ACCESS

DOI: http://dx.doi.org/10.5281/zenodo.14306946

Araştırma Makalesi / Research Article

Techno-Economic Analysis of Three 1.025 Mw Photovoltaic Power Plants

Turhan KOYUNCU [1], Fuat LÜLE [1*]
[1] Adiyaman University, Vocational School of Technical Sciences, Adiyaman
*Corresponding author: flule@adiyaman.edu.tr

Received: 28.07.2024 **Accepted**: 10.09.2024

Abstract

Techno-economic analysis of three (A, B and C) 1.025 MW solar photovoltaic power plants (SPVPs) has been done and payback periods of these SPVPs has also been determined in this paper. Selected SPVPs were installed in location of Adiyaman City, Turkey (Latitude: 37,45°, Longitude: 38,17° and Altitude: 672 m) in 2017. Date of commencement of operation is November 27, 2017, installed power capacity per SPVP is *1.025 MW*, installation cost per SPVP is *$1000000*, supply method for installation is 100% equity capital and sales price of the electricity to the grid is *0.133 $/kWh*. The results of the work showed us that the first year average electric energy production is *1691642 kWh*, internal consumption is *11513 kWh*, net generation is *1680129 kWh* and average payback period is *6.0 years* for these SPVPs.

Keywords: Solar PV plant, techno-economic analysis, payback period

1.Introduction

Increasing demand and scarcity in conventional sources have triggered the scientist to pave way for the development of research in the field of renewable energy sources especially solar energy (Goura, 2015, Kumar and Sudhakar, 2015).

Renewable energy sources are considered as alternative energy sources due to environmental pollution, global warming and depletion of ozone layer caused by green house effect. *Earth receives about* 3.8×10^{24} *J* of solar energy on an average which *is 6000 times greater than the world consumption.* Solar energy is most readily available source of energy. Solar energy is Non-polluting and maintenance free. Solar energy is becoming more and more attractive especially with the constant fluctuation in supply of grid electricity. Solar power plant is commonly based on the conversion of sunlight into electricity directly using *photovoltaic (PV)* panel (Omar et al., 2007, Shukla et al., 2016).

In current era the use of renewable technology for energy generation is growing at a faster rate. Considering the low stock of conventional fuels and consistent price rise the use of solar energy at places where solar radiations are available throughout the year must be utilized to its maximum. At the same time as the efficiency of the solar systems is low a real time financial analysis must be done to identify the conditions in which it will be most economical. The use of energy for the production and installation of the renewable system must be taken into account to calculate their energy payback time or payback period (Khatri, 2016, Chandel et al., 2014, Kazem et al., 2017). Therefore, *techno-economic analysis of three 1.025 MW solar photovoltaic power plants (SPVPs)* that located in Adiyaman City, Turkey, has been done and payback periods of these SPVPs has also been determined in this paper. The results of the work showed us that the first year average electric energy production is 1691642 kWh, internal consumption is 11513 kWh, net generation is 1680129 kWh and average *payback period is 6.0 years* for these SPVPs.

2.Materials and Methods

Three (A, B and C) 1.025 MW solar photovoltaic power plants (SPVPs) has been selected for this work. These SPVPs were installed in location of Adiyaman City, Turkey (Latitude: 37,45°, Longitude: 38,17° and Altitude: 672 m) in 2017. Date of commencement of operation is November 27, 2017, installed power capacity per SPVP is 1.025 MW, installation cost per SPVP is $1000000, supply method for installation is ***100***% equity capital and sales price of the electricity to the grid is 0.133 $/kWh.

Each selected solar photovoltaic power plant mainly has steel frame constructions for panel placing, *polycrystalline silicon* type solar PV (photovoltaic) panels, combinations of MPPT (maximum power point tracker) + inverter boxes, collecting busbar, transformer boxes, distributor busbar, kWh meter (output counter), underground cable line and mechanical components for external grid connection, control building, lighting and camera monitoring system (Fig. 1).

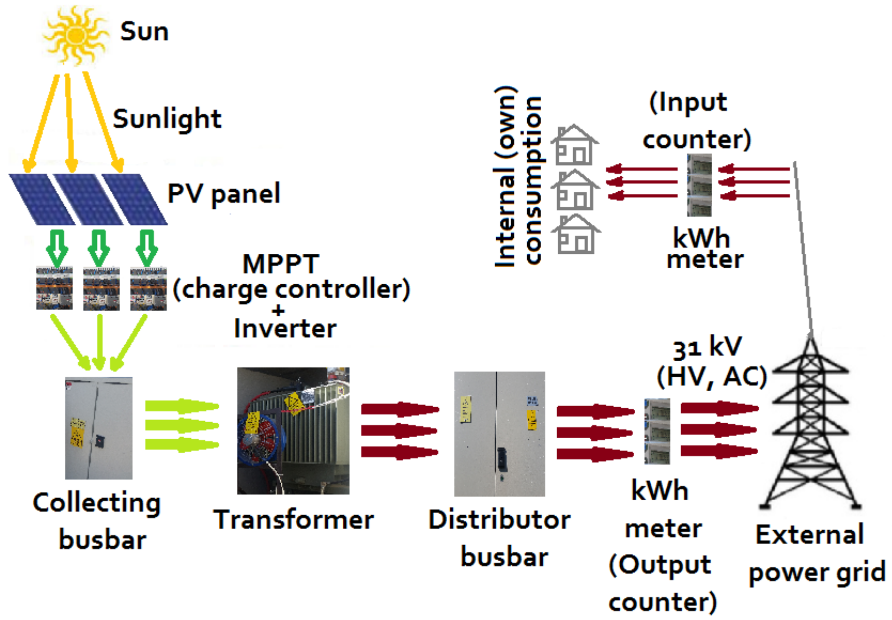

Figure 1. Schematic presentation of working principle of three 1.025 MW SPVPs

Technical specifications of polycrystalline silicon PV module are given in Table 1 and some other technical features regarding the three 1.025 MW solar photovoltaic power plants are also seen in Table 2. As seen from these tables that each PV module has 60 cells, 16.32 % peak efficiency (under STC : Standard Test Conditions : irradiance @ 1000 W/m^2 with an air mass 1.5, module temperature @ 25 °C and @ 0 m s^{-1} wind speed) , 1.6236 m^2 area, 18.5 kg mass, 45 ± 2 °C nominal operating cell temperature and 97.5%, 90.0%, 80.0% of overall efficiency for first year, 10 years and 25 years, respectively. Besides, it should be noted that the efficiency of solar PV panels are affected by environmental and climatic conditions, temperature, dust and using time (Darwish et al., 2015, Maghami et al., 2016, Costa et al., 2016, Ketjoy and Konyu, 2014, Menoufi et al., 2017, Kumar et al., 2013). In addition to this, other components of the SPVPs such as MPPT, inverter, and transformer has also efficiencies that commonly changing between 95 % … 99 % (Koyuncu, 2018a). The maximum possible efficiency of solar panels can also be obtained in first year.

Table 1. Technical specifications of polycrystalline silicon PV module

Type	Polycrystalline silicon
Number of cells	60
Peak efficiency (%)	16.32
97.5% power output warranty period (Year)	First year
90% power output warranty period (Year)	10
80% power output warranty period (Year)	25

Table 2. Some technical features regarding three 1.025 MW solar photovoltaic power plants

PV module type	Polycrystalline silicon
Maximum labeled efficiency of module	16.32 %
Module power output warranty for first years	0.975 x 0.1632 = 0.15912 = 15.912 %
Module power output warranty for 10 years	0.90 x 0.1632 = 0.14688 = 14.688 %
Module power output warranty for 25 years	0.80 x 0.1632 = 0.13056 = 13.056 %
Estimated total efficiency of MPPT, inverter and transformer	0.98 x 0.98 x 0.97 = 0.9316 = 93.160 %
Estimated average losses of power cut	0.274 %
Estimated average losses of dust	0.5 %
Calculated system total efficiency for first year	0.15912x0.9316x0.99726 = 0.14783 = 14.783 %
Measured system total efficiency for first year	A = 15.04 %, B = 15.06 %, C = 14.91 % Average = 15.00 %
Estimated system total efficiency during 10 years	0.14688x0.9316x0.99726x0.9950 = 0.13577 = 13.577 %
Estimated system total efficiency during 25 years	0.13056x0.9316x0.99726x0.9950 = 0.12069 = 12.069 %
Overall cost of operation, maintenance and cleaning (twice a year) per SPVP and per year	2000 $/Year (May, 2019, Turkey)
Sales price of the electricity to the grid	0.133 $/kWh
Annual personal expenses for each SPVP	15350 $/Year (May, 2019, Turkey)
Annual interest income of capital	21000 $/Year (May, 2019, Turkey)

Payback period of a solar photovoltaic power plant can simply be calculated by using Equations 1 - 4. This easiest calculation is the initial (or installation) cost divided by cost displaced per year (CDP). Here, the CDP is equal to the difference between annual net energy income and annual total of operation, maintenance cleaning cost, personnel expenses and interest income of capital per SPVP (Table 3) (Thumann and Mehta, 2008, Foster et al., 2010, Koyuncu, 2018a; 2018b; 2019).

$$\boldsymbol{PBP}\ (Years) = \frac{ICS}{CDP} \tag{1}$$

$$\boldsymbol{CDP}\ (\$/kWh) = EPA\ x\ COE - (AOM + PER + INT) \tag{2}$$

$$\boldsymbol{PBP}\ (Years) = \frac{ICS}{EPA\ x\ COE - (AOM + PER + INT)} \tag{3}$$

$$\boldsymbol{PBP}\ (Years) = \frac{ICS\ (\$)}{EPA(kWh/Year)\ xCOE(\$/kWh) - (AOM(\$/Year) + PER(\$/Year) + INT(\$/Year))} \tag{4}$$

Here :

PBP : Payback period, (Years)

ICS : Initial cost of the system (installation cost per SPVP), (ICS = $ 1000000)

CDP: Cost displaced per year, (kWh/Year)

EPA : Annual net produced or generated energy per SPVP during 10 years, (EPA = 1547758, 1549230, 1529385 kWh/Year)

COE : Sales price of the electricity to the grid, (COE = 0.133 $/kWh)

AOM : Annual operation, maintenance and cleaning cost per SPVP, (AOM = 2000 $/Year)

PER : Annual personal expenses per SPVP, (PER = 15350 $/Year)

INT : Annual interest income of capital per SPVP, (INT = 21000 $/Year)

Besides, in order to estimate the generated electric energy for 10 years and 25 years, Equations 5 – 8 can be used.

$$GEN_{10\,years}\,(kWh/Year) = \frac{GEN_{1.year}\,(kWh/Year)\ x\ \eta_{10\,years}}{\eta_{1.year}} \quad (5)$$

$$GEN_{10\,years}\,(kWh/Year) = \frac{GEN_{1.year}\,(kWh/Year)\ x\ 0.13577}{0.14783} \quad (6)$$

$$GEN_{25\,years}\,(kWh/Year) = \frac{GEN_{1.year}\,(kWh/Year)\ x\ \eta_{25\,years}}{\eta_{1.year}} \quad (7)$$

$$GEN_{25\,years}\,(kWh/Year) = \frac{GEN_{1.year}\,(kWh/Year)\ x\ 0.12069}{0.14783} \quad (8)$$

Where :

$\boldsymbol{GEN_{1.year}}$: Generated annual electric energy for first year per SPVP, ($GEN_{1.year}$ = 1695811, 1698024, 1681092 kWh/Year)

$\boldsymbol{GEN_{10\,year}}$: Estimated annual generated electric energy during 10 years, (kWh/Year)

$\boldsymbol{GEN_{25\,year}}$: Estimated annual generated electric energy during 25 years, (kWh/Year)

$\boldsymbol{\eta_{1.year}}$: Calculated system total efficiency for first year, ($\eta_{1.year}$ = 14.783 %)

$\boldsymbol{\eta_{10\,years}}$: Estimated system total efficiency during 10 years, ($\eta_{10\,years}$ = 13.577 %)

$\boldsymbol{\eta_{25\,years}}$: Estimated system total efficiency during 25 years, ($\eta_{25\,years}$ = 12.069 %)

Table 3. Description and rate of budget distribution of SPPs

DESCRIPTION	
Names of SPPs	A, B, C
Location	Adiyaman City, Turkey (Latitude : 37,45°, Longitude: 38,17° and Altitude : 672 m)
Date of commencement of operation	November 27, 2017
Installed power capacity per SPP	1.025 MW
Installation cost per SPP	$ 1000000
Supply method for installation	100 % Equity capital
Sales price of the electricity to the grid	0.133 $/kWh
BUDGET DISTRIBUTION	
Solar panels (45 %)	$ 450000
MPPTs + Inverters (11 %)	$ 110000
Steel frame constructions for panel placing (11 %)	$ 110000
Solar cables (7 %)	$ 70000
All other underground cable line and mechanical components for external grid connection (13 %)	$ 130000
Transformer boxes (4 %)	$ 40000
Cost of land (or field), control building, project, lighting, camera monitoring system, administrative or governmental permits, licenses and formalities (9 %)	$ 90000

3. Findings and Discussion

Electricity generation of three 1.025 MW solar photovoltaic power plant (SPVPs), their internal electricity consumption and net generated electric energy for sale are given in Table 4 and 5. All these *monthly data are related to first year operation of SPVPs*. As seen from these tables that total generated electric energy is 1695811 kWh, 1698024 kWh and 1681092 kWh for A, B and C SPVPs, respectively. Total intenal consumption is 9708 kWh, 10269 kWh and 14563 kWh for A, B and C SPVPs, respectively. The first year average electric energy production is 1691642 kWh, internal consumption is 11513 kWh and net generation is 1680129 kWh. In addition, the payback period of there SPVPs is given in Fig. 2. As seen from this figure that the payback period of SPVPs are about same and there is very less and negligible differences between them. The average payback period is 6.0 Years.

Table 4. Electricity generation of three 1.025 MW solar photovoltaic power plants

Months	**Monthly Generation For First Year (kWh / Month)**		
	Three 1.025 MW Solar Photovoltaıc Power Plants		
	A	B	C
December 2017	93542	93048	92008
January 2018	83249	82077	81959
February 2018	88937	88891	87885
March 2018	144560	144754	144106
April 2018	174266	175068	172510
May 2018	165791	165709	163447
June 2018	184866	185976	182643
July 2018	198833	200001	196571
August 2018	192605	193404	191383
September 2018	163282	163890	163203
October 2018	117175	117260	117980
November 2018	88706	87946	87397
Measured Value (From kWh Meter) For First Year			
Total Gen. (kWh/Year)	1695811	1698024	1681092
Inter.Con. (kWh/Year)	9708	10269	14563
Net Gen. (kWh/Year)	1686103	1687755	1666529
Estimated Annual Average Value During 10 Years			
Total Gen. (kWh/Year)	1557466	1559499	1543948
Inter.Con. (kWh/Year)	9708	10269	14563
Net Gen. (kWh/Year)	1547758	1549230	1529385
Estimated Annual Average Value During 25 Years			
Total Gen.(kWh/Year)	1384478	1386285	1372462
Inter.Con. (kWh/Year)	9708	10269	14563
Net Gen. (kWh/Year)	1374770	1376016	1357899

Table 5. Internal electricity consumption of three identical solar photovoltaic power plants

MONTHS	MONTHLY INTERNAL CONSUMPTION (kWh / Month)		
	THREE 1.025 MW SOLAR PHOTOVOLTAIC POWER PLANTS		
	A	B	C
December 2017	1298	1423	2027
January 2018	1014	1074	1822
February 2018	830	882	1464
March 2018	815	874	1442
April 2018	667	700	1114
May 2018	657	698	1109
June 2018	518	564	825
July 2018	723	723	714
August 2018	650	682	961
September 2018	743	748	951
October 2018	884	937	1047
November 2018	909	964	1087
TOTAL (kWh/Year)	9708	10269	14563

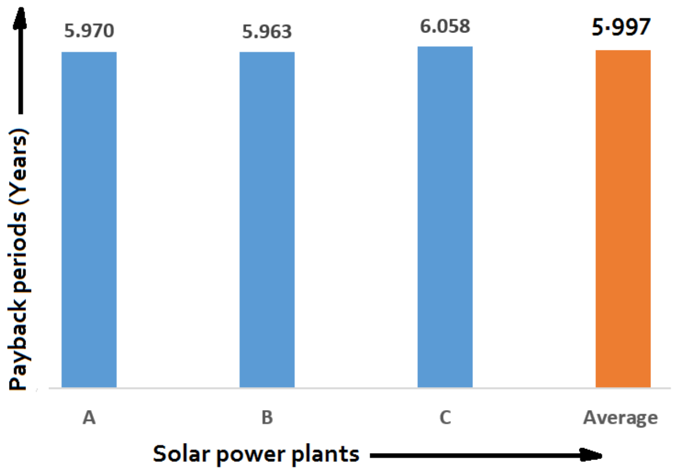

Figure 2. Estimated payback periods of three 1.025 MW solar photovoltaic power plants

4. Results

As a result the average payback period is 6 years (24 %), average profit period is 19 years (76 %), estimated average generated electricity is 35274418 kWh during lifetime, average generated electric energy for payback time is 9252746 kWh (35.55 %) and average generated electricity for profit is 26021672 kWh (64.45 %) for these selected SPVPs.

Declaration of Author Contributions

The authors declare that they have contributed equally to the article. All authors declare that they have seen/read and approved the final version of the article ready for publication.

Declaration of Conflicts of Interest

All authors declare that there is no conflict of interest related to this article.

References

Chandel, M., Agrawal, G.D., Mathur, S., Mathur, A., 2014. Techno-economic analysis of solar photovoltaic power plant for garment zone of jaipur city. *Case Studies in Thermal Engineering*, *2*: 1-7.

Costa, S.C., Diniz, A.S.A., Kazmerski, L.L., 2016. Dust and soiling issues and impacts relating to solar energy systems: literature review update for 2012–2015. *Renewable and Sustainable Energy Reviews*, 63: 33-61.

Darwish, Z.A., Kazem, H.A., Sopian, K., Al-Goul, M.A., Alawadhi, H., 2015. Effect of dust pollutant type on photovoltaic performance. *Renewable and Sustainable Energy Reviews*, 41: 735-744.

Foster, R., Ghassemi, M., Cota, A., 2010. Solar Energy: Renewable Energy and the Environment, first ed. CRC, pp. 231-246.

Goura, R., 2015. Analyzing the on-field performance of a 1-megawatt-grid-tied pv system in South India. *International Journal of Sustainable Energy*, 34(1): 1-9.

Kazem, H.A., Albadi, M.H., Al-Waeli, A.H., Al-Busaidi, A.H., Chaichan, M.T., 2017. Techno-economic feasibility analysis of 1 mw photovoltaic grid connected system in oman. *Case Studies in Thermal Engineering*, 10: 131-141.

Ketjoy, N., Konyu, M., 2014. Study of dust effect on photovoltaic module for photovoltaic power plant. *Energy Procedia*, 52: 431-437.

Khatri, R., 2016. Design and assessment of solar pv plant for girls hostel (GARGI) of MNIT University, Jaipur city: A case study. *Energy Reports*, 2: 89-98.

Koyuncu, T., 2017. Practical efficiency of photovoltaic panel used for solar vehicles. *2nd International Conference on Green Energy Technology (ICGET)*, 18–20, July, Rome, Italy.

Koyuncu, T., 2018a. Fundamentals of Engineering Science and Technology. first ed., Columbia, SC, USA, pp. 461–485.

Koyuncu, T., 2018b. simple payback time of semi-flexible monocrystalline silicon solar panel used for solar vehicles, *3rd International Conference on Green Energy Technology (ICGET)*, 10-12 July, Amsterdam, Netherlands.

Koyuncu, T., 2019. New generation vehicles vs conventional vehicles, first ed., Middletown, DE, USA, pp. 460-468.

Kumar, B.S., Sudhakar, K., 2015. Performance evaluation of 10 mw grid connected solar photovoltaic power plant in India. *Energy Reports*, 1: 184-192.

Kumar, E.S., Sarkar, B., Behera, D.K., 2013. Soiling and dust impact on the efficiency and the maximum power point in the photovoltaic modules. *International Journal of Engineering Research & Technology (IJERT)*, 2(2): 1-8.

Maghami, M.R., Hizam, H., Gomes, C., Radzi, M.A., Rezadad, M.I., Hajighorbani, S., 2016. Power Loss Due to Soiling on Solar Panel: A review. *Renewable and Sustainable Energy Reviews*, 59: 1307-1316.

Menoufi, K., Farghal, H.F., Farghali, A.A., Khedr, M.H., 2017. Dust accumulation on photovoltaic panels: a case study at the east bank of the nile (Beni-Suef, Egypt). *Energy Procedia*, 128: 24-31.

Omar, A., Ismail, D., Muzamir, I., 2007. Simplification of sun tracking mode to gain high concentration solar energy. *American Journal of Applied Sciences*, 4(3): 171-175.

Shukla, A.K., Sudhakar, K., Baredar, P., 2016. Simulation and performance analysis of 110 kWp grid-connected photovoltaic system for residential building in ındia: a comparative analysis of various PV technology. *Energy Reports*, 2: 82-88.

Thumann, A., Mehta, D.P., 2008. Handbook of Energy Engineering, sixth ed. CRC Press, Taylor & Francis, Boca Raton, FL, USA, pp. 271-276.

To Cite: Koyuncu, T., Lüle, F., 2024. Techno-Economic Analysis of Three 1.025 Mw Photovoltaic Power Plants. *MAS Journal of Applied Sciences*, 9(4): 995–1002.
DOI: http://dx.doi.org/10.5281/zenodo.14306946.