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Simulation of Grid-Connected and Off-Grid Solar Power Plants for a Two-Story Office Building in Tehran Using PVsyst Softwar

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ABSTRACT

Given the declining trend in fossil fuel resources and the long time required for their regeneration, the utilization of renewable energy has been increasing. This type of energy, commonly referred to as clean energy, reduces carbon dioxide emissions into the environment and helps prevent environmental pollution. In this paper, grid-connected (on-grid) and stand-alone (off-grid) solar power plants are simulated for a two-story office building in the city of Tehran using PVsyst software. The building is analyzed in terms of the number of infrastructural components, system performance, implementation cost, and the total area of the power plant. The results show that the off-grid solar power plant requires a larger area and is more expensive than the on-grid plant. However, in terms of performance, considering energy storage even on cloudy and rainy days, the on-grid power plant provides a more suitable quality of supply for this office building compared with the off-grid system.
Keywords: Solar energy, solar power plant, PVsyst, grid-connected power plant (On-Grid), stand-alone (off-grid) power plant (Off-Grid)

1. INTRODUCTION

The implementation of solar power plants in regions with favorable solar irradiance is highly important and widely applied, to the extent that it can eliminate the need for fossil fuels and conventional electricity generation methods. Iran is geographically a very suitable country in this regard, where the solar irradiance in different regions, based on the STC standard, ranges between 400 and 500 W/m². From the perspective of constructing solar power plants, Iran enjoys highly suitable conditions with good economic feasibility. Over the past decade, the country has experienced remarkable progress in the development of solar power plants, and several large-scale plants have been constructed in various cities and connected to the electricity distribution grid.

These power plants, in addition to preventing environmental pollution, reducing carbon dioxide emissions, and protecting the ozone layer, also offer a relatively short investment payback period of approximately 3 to 7 years. Therefore, given the long service life of solar equipment, which exceeds 20 years, the use of solar power plants is highly beneficial and cost-effective.

Marcel Sigal and his colleagues (2024) compared a simulated system with an actual off-grid solar power plant in Indonesia using PVsyst software. The results show that the simulation performed with the software exhibits very low error compared with the real system [1]. Sujit Kesharoni and co-authors (2024) designed and simulated a grid-connected solar power plant in Mathura, India. In their study, 100 MW of electrical power was injected into the distribution grid, and the plant efficiency was reported to be around 75% [2]. Randall Espina and his team (2022) simulated a 48 kW off-grid solar power plant in the Philippines using PVsyst [3]. Adel Swalmiya and co-workers (2016) simulated a 15 kW grid-connected solar power plant using PVsyst software [4].

Sam Moeini and colleagues (2010) estimated solar irradiance in Iran using an optimized model, in which solar radiation and shading effects were analyzed [5]. Mohammad Ahmed and his co-authors investigated the selection of an optimal type of solar panel using PVsyst software and concluded that the optimal tilt angle for Tehran is 32 degrees [6]. Pouria Alamdari and colleagues (2013) studied the solar potential in Iran and its various cities; their results indicate that the city of Mahshahr, with an irradiance of 766 W/m², is the most suitable location from both economic and energy perspectives for the construction of a solar power plant [7].

In this paper, we simulate grid-connected and off-grid solar power plants for a two-story office building in Tehran using PVsyst software.

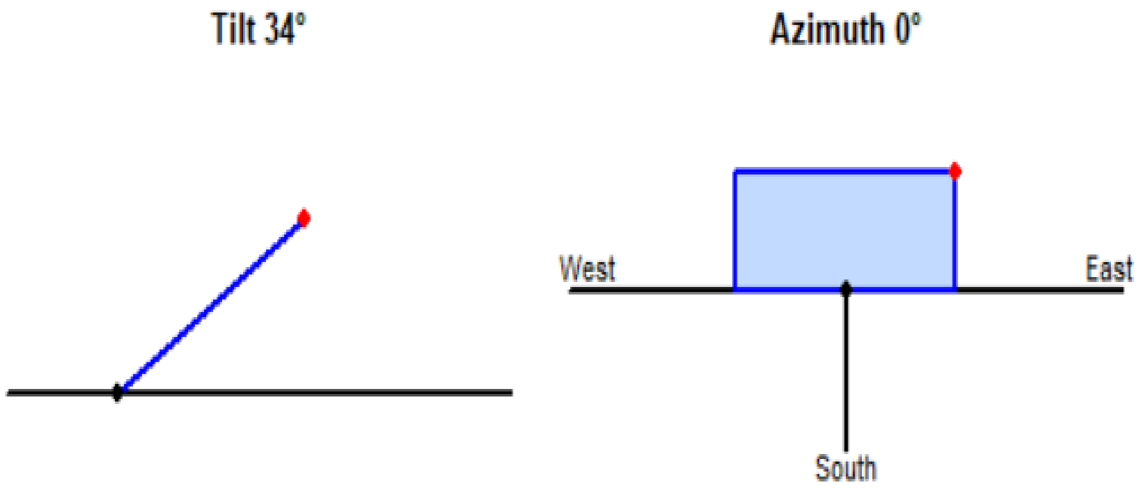
2. Problem Statement

The first step in performing the simulation is to collect detailed information about the electrical appliances used in the office building. Essential data include the type of appliances, their rated power consumption, the number of units, and their daily operating hours. Without this information, conducting an accurate simulation is not possible. Table 1 presents the number of appliances, their power ratings, and their corresponding operating hours in the building.

Table 1. Electrical load data of appliances in the office building

Electrical Appliances in the Building	Rated Power (W)	Quantity	Operating hours per day (h)	Total power demand (W)
Lamp	10	30	9	300
Television and digital receiver	120	2	9	240
evaporative air cooler 5500	550	2	9	1100
air conditioner (18000 BTU)	1400	4	9	5600
Laptop	100	6	9	600
Computer (PC)	150	6	9	900
hotel minibar refrigerator	1200	2	8	2400
Total hourly power demand (W)				11140

Considering the total power demand of the electrical appliances, which amounts to 11,140 W, a 12 kW grid-connected photovoltaic power plant must be designed to supply the



required power for these loads during the operating hours of 8:00 a.m. to 5:00 p.m., as specified in Table 1.

2-1. Grid-Connected (On-Grid) Power Plant

Given the geographical location of the site and its solar irradiance conditions, the optimal tilt angle for installing the photovoltaic panels, according to the software data, is 34 degrees.

Fig. 1. Panel Arrangement and Tilt Angle

Given the rated capacity of 12 kW for the proposed power plant, the system was simulated using PVsyst software. The results of this simulation are presented in Fig. 2.

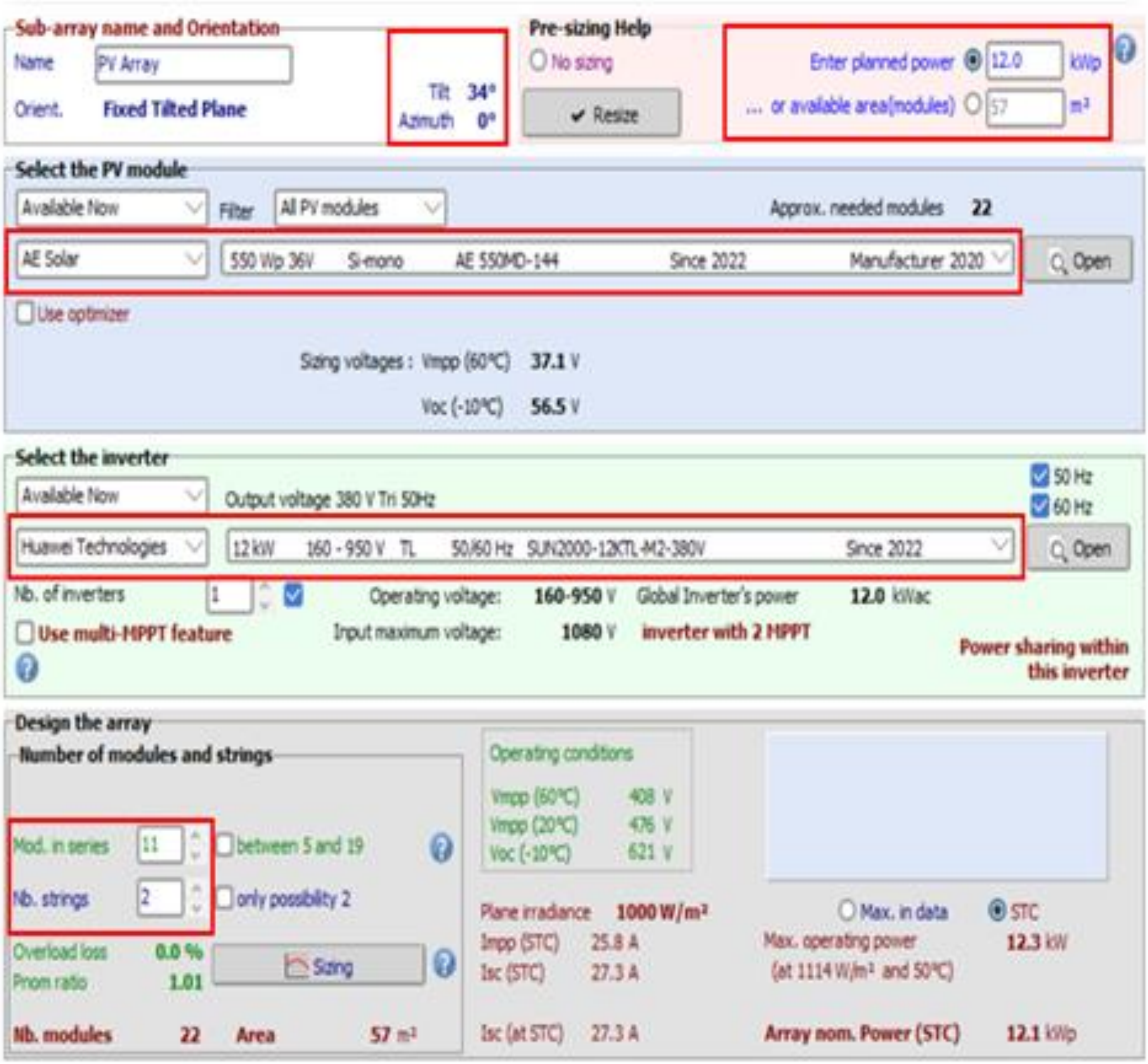


Fig. 2. Simulation of Equipment for the 12 kW Grid-Connected Power Plant

The 12 kW photovoltaic power plant consists of 22 panels rated at 550 W each and a 12 kW grid-connected inverter. The cost estimation of the equipment, including the mounting structure, panels, and inverter, was carried out using PVsyst software and is presented in Fig. 3.

Description	Quantity	Unit price	Total	
PV modules			3,127.74	USD
AE 550MD-144	22.00	110.94	2,440.68	USD
Supports for modules	22.00	31.23	687.06	USD
Inverters			2,089.00	USD
SUN2000-12KTL-M2-380V	1.00	2,089.00	2,089.00	USD
Other components			0.00	USD
Studies and analysis			0.00	USD
Installation			0.00	USD
Insurance			0.00	USD
Land costs			0.00	USD
Loan bank charges	0.00	0.00	0.00	USD
Taxes			0.00	USD
		Total installation cost	**5,216.74**	**USD**

Fig. 3. Cost Estimation of the Power Plant Including Only the Panel Mounting Structure, Panels,

The implementation cost of this power plant is 5,216.74 USD. In addition to this amount, other expenses such as electrical accessories, including cables, connectors, and junction boxes, may also be considered; however, in this study, only the main components of the power plant have been included in the cost analysis. Based on the determined number of components and the configuration of the panels, the layout and appearance of the building are illustrated in Fig. 4.

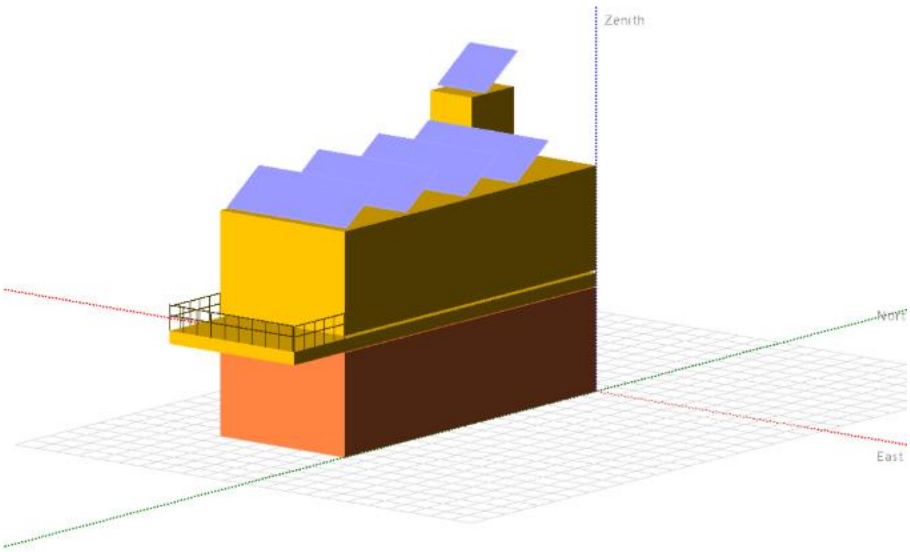


Fig. 4. Building Façade Analysis After Panel Installation

The sun path is shown in Fig. 5.

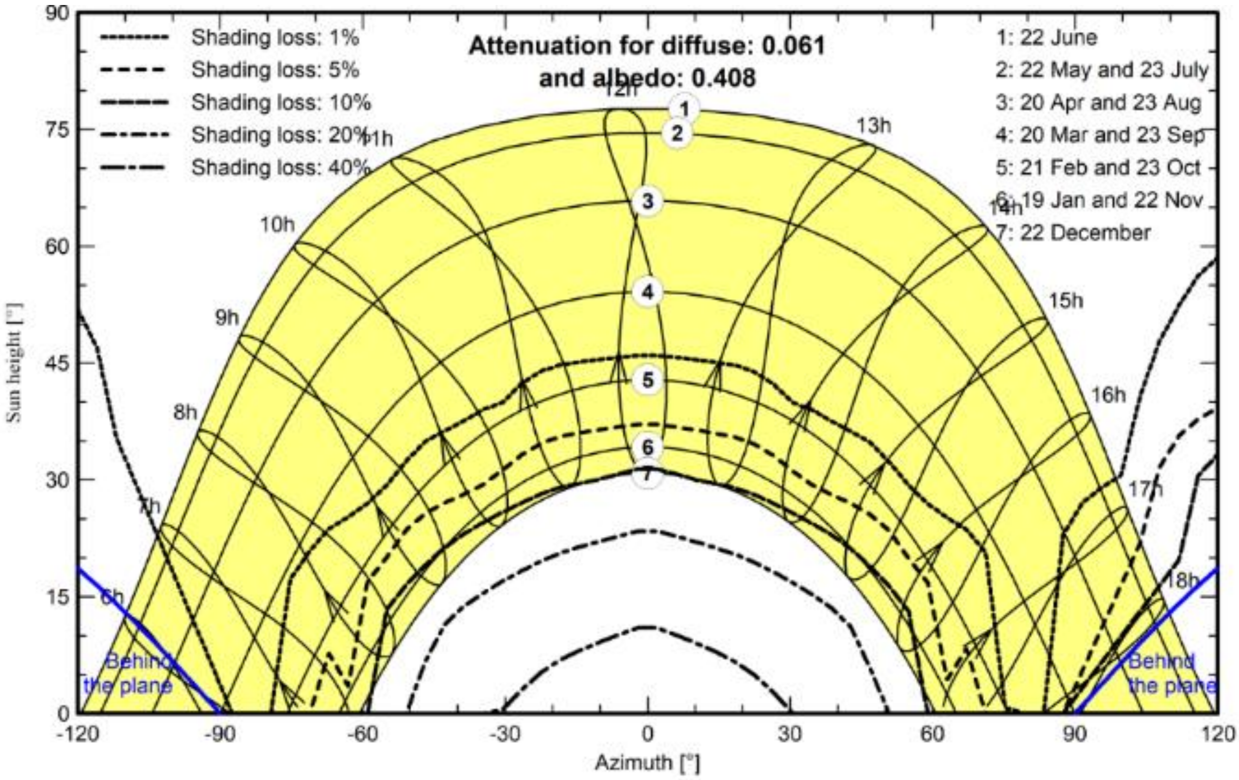


Fig. 5. Annual Sun Path Trajectory

The results, expressed in terms of various parameters for different months of the year, are presented in Table 2. These results have been obtained using PVsyst software.

Table .2. Energy Balance and Main Results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	81.4	32.93	4.76	130.5	117.0	1354	1321	0.837
February	97.8	33.00	6.98	139.3	132.0	1496	1460	0.866
March	141.9	53.22	12.56	170.9	164.3	1809	1766	0.854
April	173.7	65.23	17.47	184.5	176.8	1917	1872	0.839
May	209.0	78.61	23.61	199.6	190.7	2021	1971	0.816
June	223.4	74.01	28.58	201.7	192.5	1998	1949	0.798
July	221.5	75.48	31.46	205.5	196.4	2009	1959	0.788
August	209.3	69.83	30.48	213.5	205.0	2103	2052	0.794
September	173.8	46.87	26.01	204.8	197.5	2047	2000	0.807
October	131.4	35.98	19.86	179.2	172.0	1829	1785	0.823
November	91.4	33.32	11.11	143.0	130.7	1471	1436	0.830
December	75.2	27.30	6.13	126.7	111.7	1288	1256	0.819
Year	1829.9	625.77	18.31	2099.2	1986.7	21341	20827	0.820

PR denotes the performance ratio of the system, which has an annual average value of 0.82. E_{Grid} represents the energy injected into the grid, amounting to 20,827 kWh over one year. E_{Array} refers to the energy generated by the photovoltaic array, with a total annual production of 21,341 kWh. Moreover, GlobHor indicates the total global horizontal irradiance on the plane of the array, which is equal to 1,829.9 kWh/m² per year.

2-2. Off-Grid Power Plant

To determine the required capacity of an off-grid power plant, the number of appliances, the rated power of each appliance, and their respective operating hours must be specified. The total capacity of the power plant is then obtained using Eq. (1):

$$\sum_{i=1}^{\infty}(n_i \times W_i \times h_i) \quad (1)$$

In Eq. (1), n denotes the number of appliances, W is the rated power consumption of each appliance, and h represents the operating time of each appliance in hours.

Based on the data provided in Table 1, the total daily energy demand for the off-grid power plant is calculated to be 97,884 Wh/day.

Table .3. Daily Electricity Consumption of the Appliances

	Nb.	Power	Use	Energy
		W	Hour/day	Wh/day
Lamps (LED or fluo)	30	10/lamp	9.0	2700
TV / PC / Mobile	2	120/app	9.0	2160
water cooler	2	550/app	9.0	9900
Fridge / Deep-freeze	2		24	19200
pc	6		9	8100
air condition	4	1400 tot	9.0	50400
laptop	6	100 tot	9.0	5400
Stand-by consumers			24.0	24
Total daily energy				97884

Based on the data presented in Table 3, the off-grid solar power plant has a rated capacity of 23.1 kW and requires 42 photovoltaic modules of 550 W each, as well as 100 batteries rated at 100 Ah and 12 V. The number of batteries has been determined considering a depth of discharge (DOD) of 80%. The simulation results obtained from PVsyst are shown in Fig. 6.

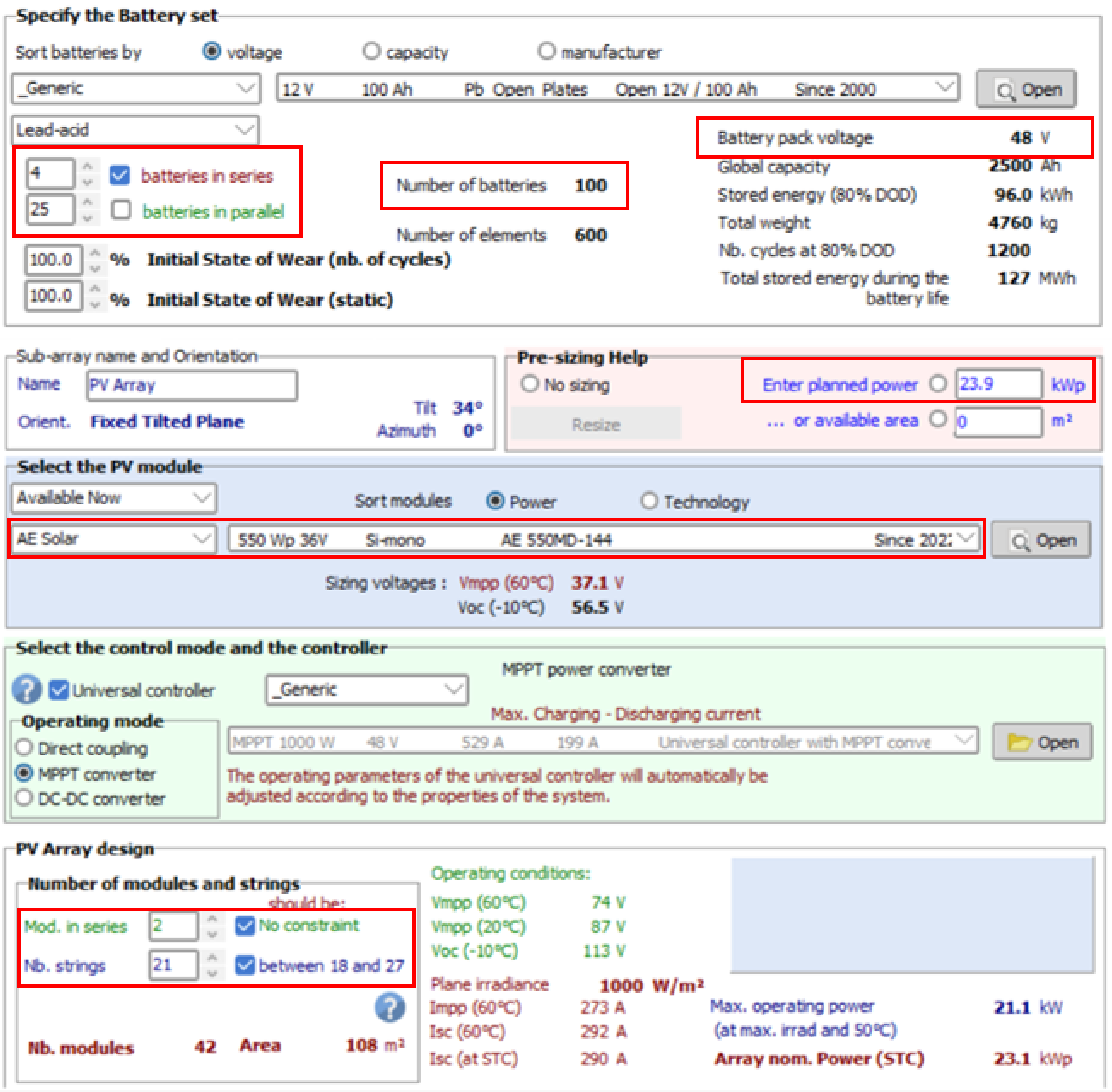


Fig. 6. Simulation Results for the Off-Grid Power Plant

This power plant also includes an inverter and a charge controller; however, in order to reduce costs, two 8 kW Sunverter units (48 V – 150 A) are used.

The installation cost of the off-grid (Off-Grid) power plant is given in Table 4. The cost of the main components of the system—including the mounting structure for the PV modules, the solar panels, the batteries, and the Sunverter units—amounts to 26,930 USD.

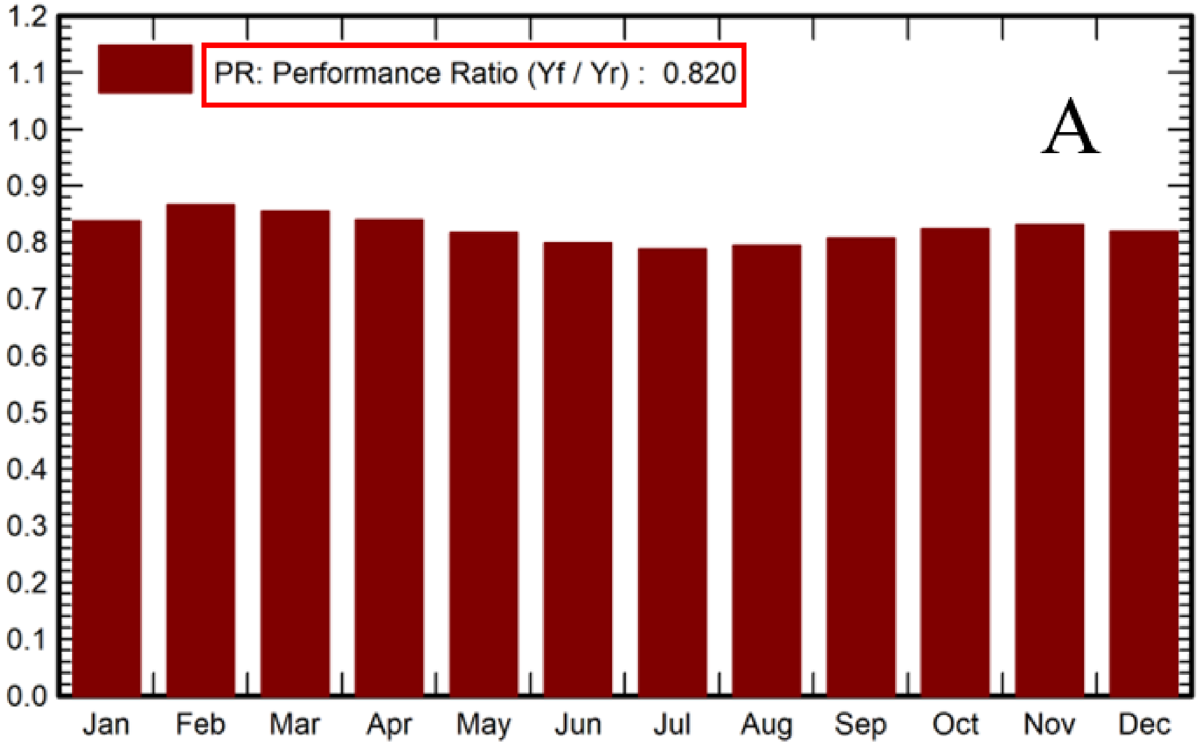
Table .4. Cost of Constructing the Off-Grid Power Plant

Item	Quantity units	Cost USD	Total USD
PV modules			
AE 550MD-144	42	110.94	4,659.48
Supports for modules	42	31.23	1,311.66
Batteries	100	174.09	17,409.00
Controllers			3,550.09
		Total	26,930.23
		Depreciable asset	26,930.23

3. Results and Discussion:

Based on the results obtained from the software, it can be concluded that the optimal tilt angle of the panels for both power plants is 34°, which has been selected as the best possible configuration in both cases. However, according to practical results reported in the literature, the optimal tilt angle for Tehran under ideal conditions is 32°.

The area occupied by the photovoltaic panels is 57 m² for the grid-connected power plant and 107 m² for the off-grid power plant. The performance ratio of both systems, according to the simulation results, is presented in Fig. 7.



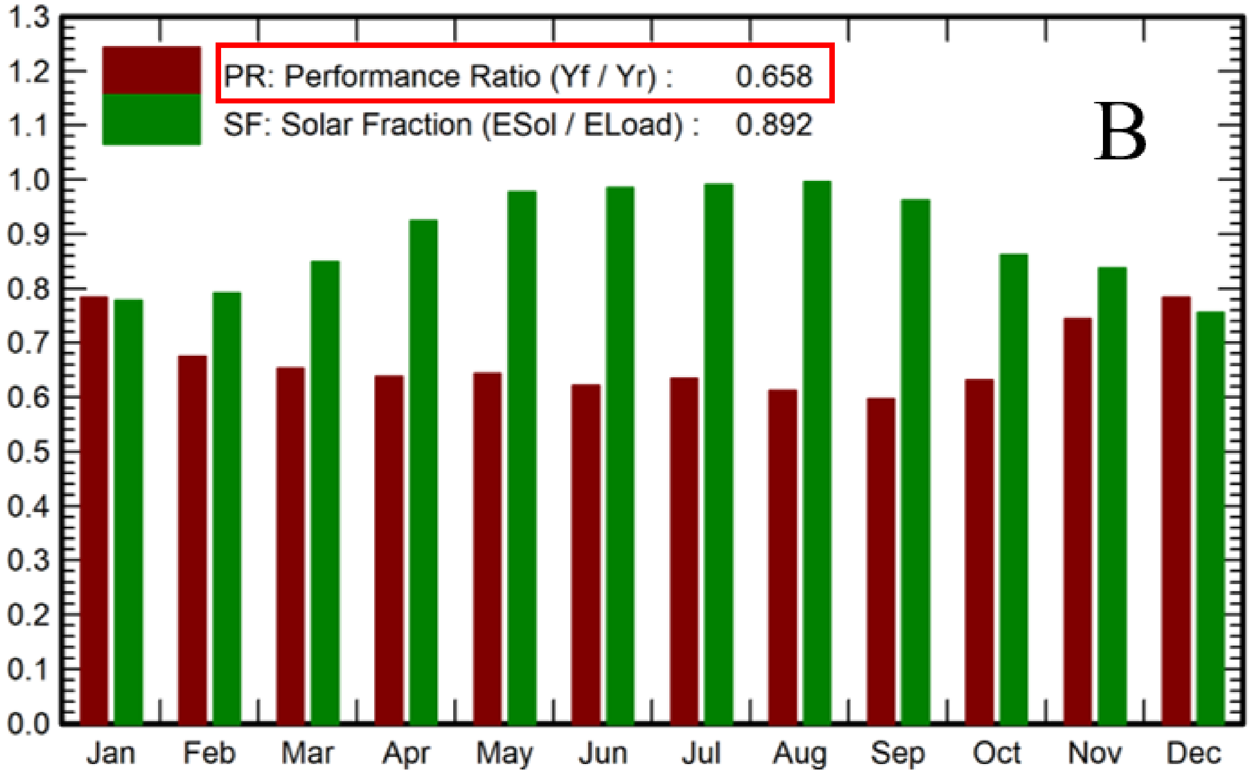


Fig. 7. (A) Grid-connected (On-Grid) power plant and (B) stand-alone (Off-Grid) power plant

In the grid-connected power plant, the performance ratio (PR) of the system is 0.82, whereas in the off-grid solar power plant it is 0.658, indicating that the grid-connected system operates more efficiently in this region. Furthermore, according to the PVsyst software calculations, the implementation cost of the grid-connected power plant is 5,216.74 USD, while the cost of the off-grid power plant is 26,930 USD. From an economic perspective, the installation and implementation cost of the off-grid solar power plant is approximately 5.16 times higher than that of the on-grid system. This cost difference is mainly due to the use of solar batteries, Sunverter units, and the larger number of 550 W panels required in the off-grid configuration.

The energy loss diagrams for both power plants are presented in Fig. 8, which show that the energy losses in the grid-connected system are lower than those in the off-grid system.

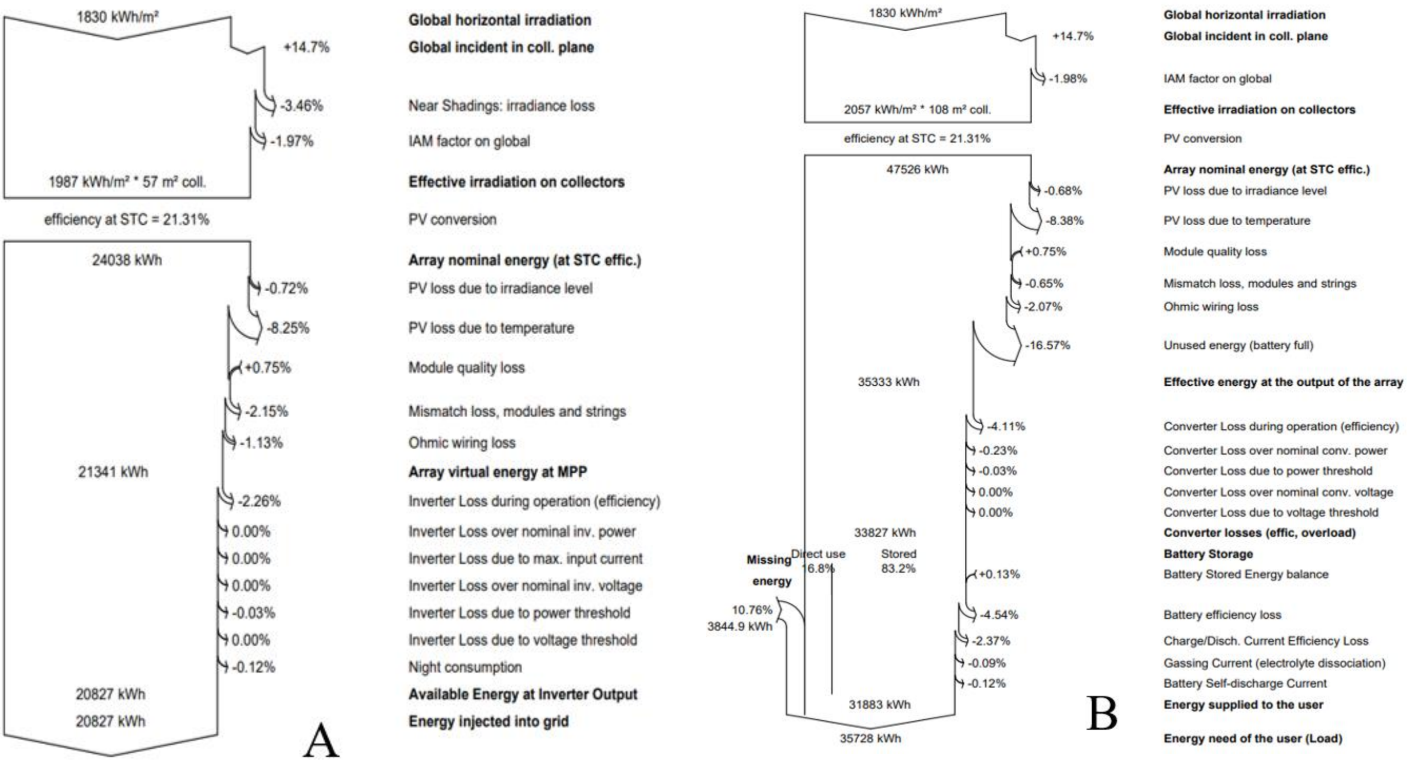


Fig. 8. Energy loss diagram: (A) On-grid power plant / (B) Off-grid power plant

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