Improving the energy efficiency of microsystems with solar PV sources for individual power supply of residential buildings (feasibility study for the regions of Azerbaijan)

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Abstract

In recent years, small, isolated power supply systems have been widely developed, in which the main share of electricity generation is produced based on low-power renewable sources (solar PV converters, wind turbines and other types of RS). At present, schemes of mini and micro-systems of power supply with different composition of renewable sources, differing in parameters depending on geographic and weather conditions of their locations. While there are no universal approaches to choosing the optimal combination used in such systems of renewable sources and traditional sources (diesel generator, batteries) used. This article provides a practical method for the technical feasibility study for the construction of a Stand-Alone Photovoltaic (SAPV) system in Karabakh region of Azerbaijan Republic. Based on the current growing role of the subject region, its energy security and economic development the aim is to build the most efficient and optimal cleaner energy production facilities in this area. Considering the lack of methodology for the measurement of renewable energy potential in Karabakh region, we employed evaluation methods based on mapping techniques, simulation software for solar stand-alone unit and the analytical tools offered by PVSyst Software. Solar module, battery, DC/AC pure sine wave power inverter, and the charge controller are the main components of the suggested PV system design. Choosing optimal capacity and arrangement increase the plant's efficiency and reduces the overall system costs. In this method, according to the geographical location the number of solar modules and their optimal angles are defined. PVSyst software is used for the system analysis, and the simulation results show the performance of the designed system on an individual residential building located in Zangilan city of Karabakh region. The main novelty of this study is related to the integration of the renewable energy potential maps combined with a density of population, are good predictors of locations for the development of renewable energy source-based facilities. The contribution of the proposed method is the provision of technical calculation and feasibility check for remote areas where making local measurements of RES potential is a constrain. The study concludes with recommendations towards the optimal size of stand-alone solar system and its components and use of renewable energy potential to achieve more balanced regional development and clean energy production.

Keywords: stand-alone, clean energy, solar photovoltaic, PV system, PVsyst

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I. INTRODUCTION

The world-wide demand for solar electric power systems has grown steadily over the last 20 years. The need for reliable and low-cost electric power in rural areas of the world is the primary force driving the world-wide photovoltaic (PV) industry today. For a large number of applications, PV technology is simply the least-cost option.

Typical applications of PV in use today include stand-alone power systems for cottages and remote residences, remote telecommunication sites for utilities and the military, water pumping for farmers, and emergency call boxes for highways and college campuses, to name just a few [1, 2, 3]

Significant growth in demand for PV systems is expected to occur in developing countries to help meet the basic electrical needs of the 2 billion people without access to conventional electricity grids. PV modules are integrated into systems designed for specific applications. The components added to the module constitute the "balance of system" or BOS. Balance of system components can be classified into three categories:

• Batteries - store electricity to provide energy on demand at night or on overcast days;

• Inverters - required to convert the DC power produced by the PV module into AC power;

• Controllers - manage the energy storage to the battery and deliver power to the load

Not all systems will require all these components. For example, in systems where no AC loads present an inverter is not required. For on-grid systems, the utility grid acts as the storage medium and batteries are not required [4, 5].

Some stand-alone systems, for example, include a fossil fuel generator that provides electricity when the batteries become depleted; and water pumping systems require a DC or AC pump. This article suggests an off-grid solar power system, for a typical home at Zangilan, Azerbaijan. To computing the off-grid solar system components, as it was requested the design was done for the shortest day of the year which is 21st of December. The solar data is obtained from NASA web site and PVSyst software.

In the Figure 1,2, 3 and 4 it is shown the photovoltaic power potential of the study area for one day, monthly averages and yearly data.

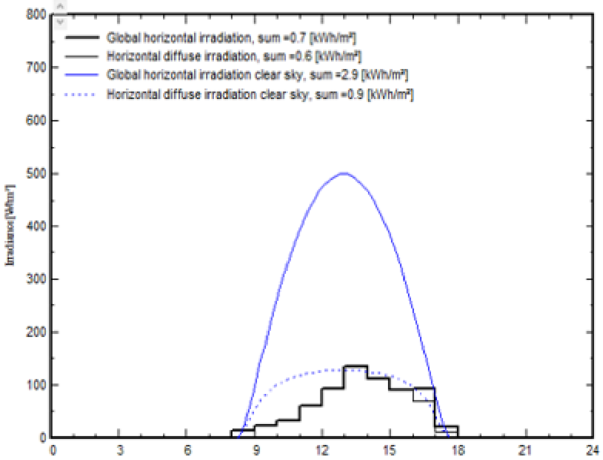

Figure 1. Daily photovoltaic power potential

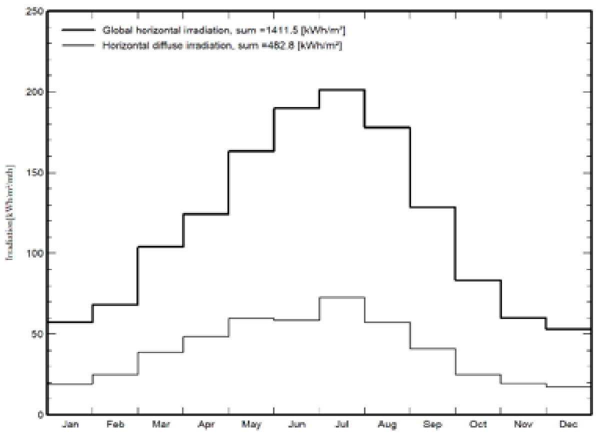

Figure 2. Monthly photovoltaic power potential

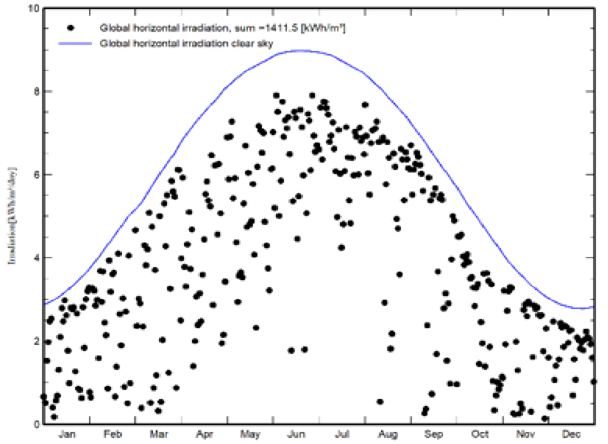

Figure 3. Daily photovoltaic power potential for one year

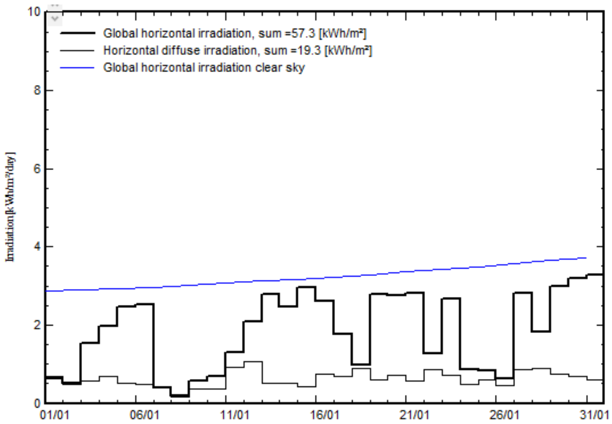

Figure 4. Daily photovoltaic power potential for one month

Obtained results are compared with the data extracted from SolarGIS web software and NASA available data. The data from NASA collected from Surface meteorology and Solar Energy (SSE) Release 6.0 Data Set (Jan 2008), 22-year Monthly & Annual Average (July 1983 - June 2005) and shown on Table 1.

Table 1. Average monthly values and annual amount of Solar radiation

Month	SolarGIS GHI kWh/m²/month	Pvsyst GHI kWh/m²/month	PVSyst kWh/m²/day	NASA kWh/m²/day
Jan	64.0	57.3	1.85	20.3
Feb	79.4	68.3	2.44	2.75
Mar	110.7	104.1	3.36	3.61
Apr	124.5	124.5	4.15	4.44
May	151.7	163.3	5.27	5.37
Jun	179.3	189.8	6.33	6.34
Jul	187.7	201.3	6.49	6.33
Aug	172.8	177.8	5.74	5.59
Sep	121.0	128.5	4.28	4.64
Oct	92.9	83.3	2.69	3.38
Nov	68.2	60.1	2.00	2.27
Dec	57.2	53.3	1.72	1.70
Yearly	1409.4	1411.5	3.87	4.04

There is minor difference between the data, and this considered applicable as the data are collected via satellite. In previous studies it has been identified that the Zangilan city has more solar power potential than the other cities of Karabakh region, Azerbaijan.

II. LOAD MODELING

A typical home is a 120 square meter house located in Zangilan, Azerbaijan, location: latitude: 39.30N, longitude: 46.590E.

A typical home loads are described in Table 2. Hourly distribution and the daily consumption are presented in Figure 5.

Table 2. Household characteristics and energy demand

Loads	Power (watt)	Qty	Hours	Total power (watt)	Energy (Watt.h)
Lamps	10	12	5	120	600
TV/PC/Mobile	100	2	5	200	1000
Domestic Appliances	500	1	4	500	2000
Fridge	33.292	1	24	33.292	799.008
Washing Machine	1000	1	2	1000	2000
Heater (Hot water)	100	1	24	100	2400
Air Conditioning	1000	1	3	1000	3000
Stand-by consumers	6	1	24	6	144
Total Power of Loads	2959.292				
Total Energy Demand	11943.008				

While creating load parameters seasonal demand is considered and identified higher demand during summer season due to air connditioning system. Table 2 shows the summer season load characteristics during June-August.

The calculation is based on the energy demand which is in our case is 11943Wh≈ 12kWh.

It has been identified that the maximum demand of the house is during summer season due to air conditioning unit. Considering the daily household consumers and seasonal modulation, the avarage 12kWh is used for calculation.

III. TYPICAL LAYOUT

Stand-alone systems are always organized around a battery storage:

- A PV Array charges the battery or directly delivers its power to the user

- The user's needs should be well defined, with its daily profile

Figure 6 describes the typical layout of standalone system:

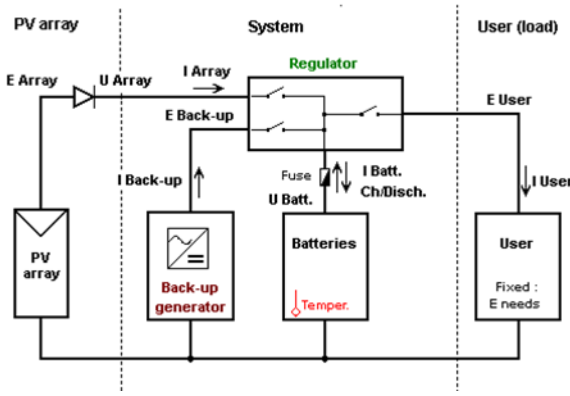

Figure 6. Typical layout of Stand-alone system.

The system performs a balance between the PV production (depending on irradiance) and the users' needs. The difference should be derived in the battery, either Positively(charge) or negatively (discharge) [6, 7, 8].
The energy balance is controlled by the charger controller. The role of the controller is to handle the energy flow, mainly for the protection of the battery:
- When the battery is full, the PV array should be disconnected
- When the battery is empty, the user should be disconnected

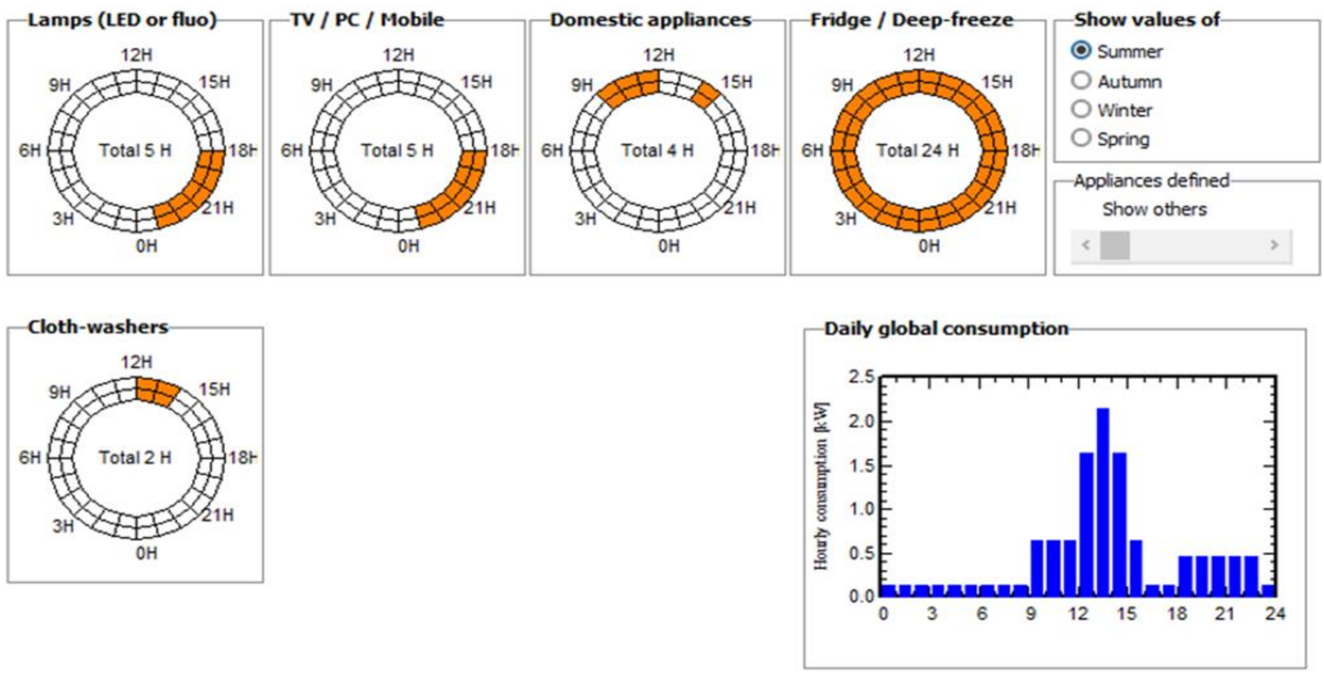

Figure 5. Households' hourly distribution

Moreover, the controller may manage the starting of an eventual back-up generator, when the battery is empty, and the solar gain is not sufficient. However, back-up generator is optional and is not considered in this article [9, 10].

IV. CALCULATION OF SYSTEM COMPONENTS FOR AUTONOMOUS STAND-ALONE POWER SUPPLY OF INIDIVIDUAL RESIDENTIAL HOUSE FIGURES/CAPTIONS

The calculation is starting with defining of declination, elevation and tilt angles based on the selected area coordinates (latitude and longitude). This is required to define the peak sun hours which is the main parameters in correct selection of PV panels [11, 12].

Declination angle determined by using below formula and it is the angle between the universe axis and the earth axis:

$$\delta = 23.5 \sin\left[\frac{360}{365}(284 + d)\right]$$

Where δ – is declination angle, d – is the day number of the year.

Elevation angle is the angle between the sun rays and the horizontal plane and determined as below formula:

$$\alpha = 90 - \emptyset + \delta$$

Here, α – is elevation angle, ∅- is the latitude of the selected area.

The tilt angle is an angle between the solar panel and the horizontal plane. It is defined as per below formula:

$$\beta = 90 - \alpha$$

Where, β- is a tilt angle, α – is an elevation angle.
The calculation is done for each month of the year.

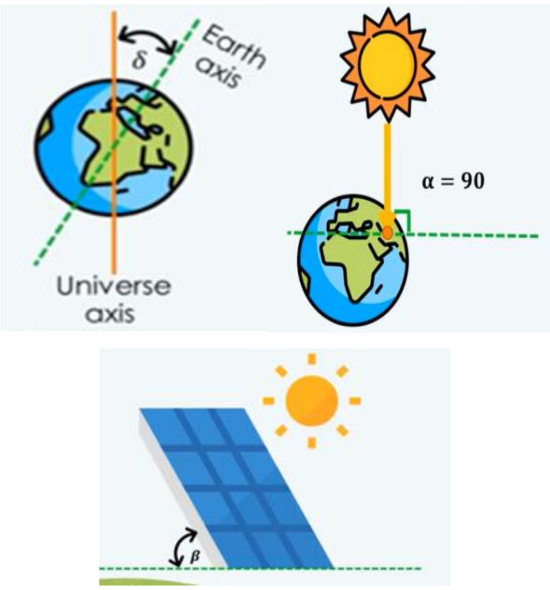

Figure 7. Declination, elevation and tilt angles

Ones the required angles are calculated, the peak sun hours can be defined by using below formula:

$$S_m = \frac{S_H \times \sin(\alpha+\beta)}{\sin\alpha}$$

Where, S_m – is peak sun hour, α and β elevation and declination angles, accordingly.

The results obtained from calculations are presented in Table 3.

Based on the calculated peak sun hour and energy demand the number of required PV panels can be calculated as following:

$$Number\ of\ panels = \frac{P_{in}}{power\ of\ single\ panel}$$

$$P_{in} = \frac{Energy}{\eta \times S_m}$$

Where the P_{in} – is an input power of PV panel, η- is an efficiency of panel. While selecting PV panel NOCT-Nominal operating cell temperature, TCP-Temperature coefficient of panel, efficiency and open circuit voltage are collected from the panel datasheets.

To choose batteries below calculation is done:

$$Total\ Ah = \frac{Energy \times AD}{\eta \times V_{bus} \times DOD}$$

Where the AD – autonomy days, considered to compensate sun absence, DOD – Depth of discharge, V_{bus} – total system voltage, η – battery efficiency.

By taking in to account the inverter nominal voltage, the bus voltage is identified. Thus, the number of parallel branch of batteries are calculated.

$$N.of\ batteries\ in\ each\ branch = \frac{V_{bus}}{V_{battery}}$$

$$V_{bus} = V_{inverter}$$

$$AH\ for\ single\ branch = single\ battery\ AH \times N.of\ bat\ in\ each\ branch$$

$$N.of\ parallel\ branch = \frac{Total\ AH}{AH\ for\ single\ branch}$$

Charger Controller is calculated and selected based on its rated minimum current.

$$I_{charger\ min.} = \frac{N.of\ panel \times P_{single}}{V_{bus}}$$

Table 3. Angles and peak sun hour calculation results

Parameters	Jan	Feb	March	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
S_H	2.03	2.75	3.61	4.44	5.37	6.34	6.33	5.59	4.64	3.38	2.27	1.7
Latitude	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04	39.04
Longitude	46.61	46.61	46.61	46.61	46.61	46.61	46.61	46.61	46.61	46.60	46.61	46.61
Day Number	21	52	80	111	141	172	202	233	264	294	325	355
Declination	-20.155	-11.2	-0.3452	11.66	20.27	23.5	20.47	11.77	-0.291	-11.861	-20.53	-23.50
Elevation	30.804	39.76	50.614	62.62	71.18	74.46	71.40	62.67	50.68	39.10	30.43	27.46
Beta(calc.)	62.54	62.54	62.55	62.54	62.5	62.54	62.56	62.54	62.55	62.54	62.55	62.55
Beta(design)	60	60	60	60	60	60	60	60	60	60	60	60
Sm	3.97	4.24	4.38	4.22	4.277	4.70	5.015	5.302	5.617	5.30	4.484	3.685
Sm(min)	**3.684557**											
Sm(max)	**5.61689907**											
P.S.H	**4.597850573**											

Inverter selection is implemented based on the below formula:

$$P_{inverter} = \frac{P_{load} \times Safety\ Factor}{PF}$$

Where, $Safety\ Factor$ – consider the sudden increase of the loads power, PF – is the power factor.

Ones the panels are selected required area calculation can be done. During this calculation the actual dimensions of each panel and spacing between the panels are considered

V. RESULTS & DISCUSSION

Based on the calculation, the optimal tilt angle of PV panels shall be 60 degrees. At this degree the PV panel calculated is Generic STP-415S-A78-Vfh, Si-Mono type 8 of panels with 415Wp nominal power and 38A open circuit current. The suitable battery is Li-Ion battery, 180Ah, 26V batteries. The calculated inverter power is 5kW. Obtained results are simulated via PVSyst software.

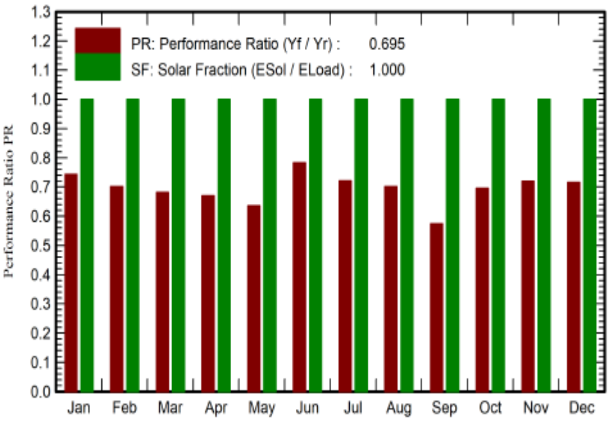

Figure 8. Performance Ratio

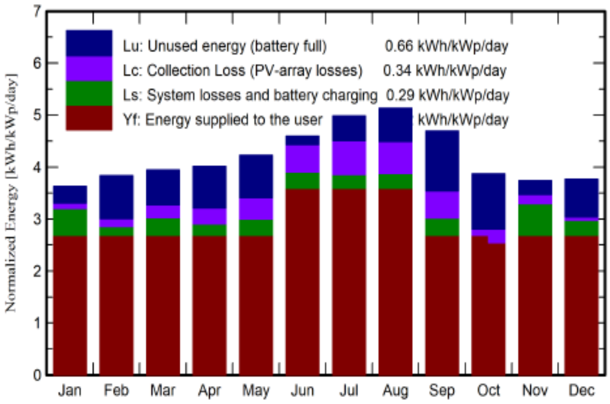

Figure 9. Normalized production (per installed kWp)

Table 4. Balances and Main result

Month	GlibHor kWh/m2	E_Avail kWh/m^2	E_User kWh	E-Load kWh
Jan	57.3	345.2	277.2	277.2
Feb	68.3	328.7	250.4	250.4
Mar	104.1	363.1	277.2	277.2
Apr	124.5	354.9	268.3	268.3
May	163.3	378.3	277.2	277.2
Jun	189.8	385.0	358.3	358.3
Jul	201.3	427.1	370.2	370.2
Aug	177.8	444.8	370.2	370.2
Sep	128.5	399.7	268.3	268.3
Oct	83.3	357.8	277.2	277.2
Nov	60.1	338.0	268.3	268.3
Dec	53.3	367.1	277.2	277.2
Yearly	1411.5	4489.7	3540.3	3540.3

Legend:
GlobHor- Global horizontal Irradiation
E_Avail- Available Solar Energy
E_User- Energy Supplied to the user
E_load - Energy Need of the user

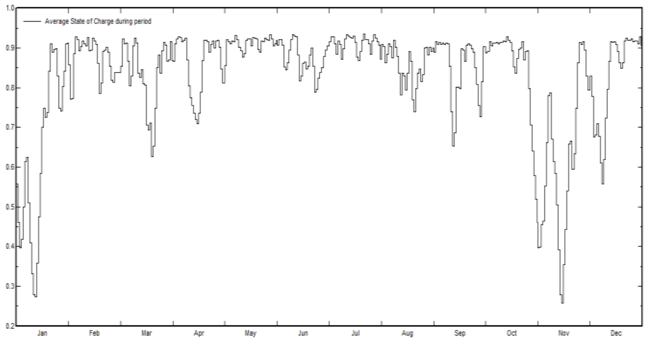

Figure 10. Battery State of Charge Daily Distribution

VI. CONCLUSION

The simulation results are shown for the system that includes 8 of 415Wp PV panels connected in 4 Strings and 2 in series. The NOCT of panel is 450. The selected battery is Li-Ion 26V, 180Ah battery connected 8 in parallel x 2 in series. The nominal capacity of the battery is 1140Ah (C10). The universal type of controller is selected for the simulation.

The Table 4 and Figure 8 and 9 reported by PvSyst software, shows that by using the selected panel the user demand can be fully covered by solar energy. The solar fraction is equal to 1.0 which means that the required energy is provided by solar panel. The performance ratio is almost 70% by taking in to account the system loses. As per Figure 10 the batteries maximum DOD is 0.28 during January and November for only 2-3 days. In all other cases battery DOD remains close to 0.5, which is an effective value for its lifecycle. The dimensions of the panel are taken from the technical datasheet and identified 18m2 location space is required to install the PV panels. The panels are considered to be free mounted type with air circulation for cooling system.

Provision of residential buildings with the individual PV systems will significantly affect the life of the residents, where they can independently regulate their energy demand and usage, learn RES based innovative technologies from operation and maintenance wise and improve their social life.

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