International Journal of Multidisciplinary Approach Research and Science
E-ISSN 2987-226X P-ISSN 2988-0076
Volume 2 Issue 3, September 2024, Pp. 1002-1015
DOI: https://doi.org/10.59653/ijmars.v2i03.828

253 KW Solar PV Power System Design for a Typical 500 Metric Ton Capacity Above Zero Cold Storage in Farah Province

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Received: 10-04-2024 *Reviewed: 20-04-2024* *Accepted: 08-05-2024*

Abstract

This study carries out design of 253 KW PV system for a 500 metric ton cold storage in Farah province. The design includes estimation and calculation of number of solar panel, inverter, batteries, and required land. Farah province located in western part of Afghanistan that has huge solar potential and 300 sunny days. The design of this PV system has calculated carefully. The methodology of this study includes descriptive analysis and formulas. For design o 253 KW PV system is necessary 421 modules, 8 inverters with 326.8 KW, 868 batteries, and 1234 m2 area or land. This will have positive impact on climate change and weather. The design of 253 KW PV system has need to more and careful consideration of different factors such as orientation, capacity of inverter and batteries, number of panels, batteries, and inverter.

Keyword: Solar PV system, Farah province, Sustainable design, Solar potential

Introduction

Farah is one the biggest provinces of Afghanistan in term of area which is located in the western part of Afghanistan, bordered by Nimroz in the south, Herat in the north, Helmand in the east, Ghor in the northeast and Iran in the west. This province covers an area of almost 49,000 kilometers squared with having 1,256 villages and the majority are Pashtun and other ethnic groups include Tajik, Ailat, Moqul, Sadat, Boomdi, Aimaq and Bluch ethnic groups. The province is divided into 11 district Farah Provincial Center, Pushtrud, Khak-e-Safed, Anar Dara, Qala-e-Kah, Shibkoh, Lash-i-Juwayn, Bakwa, Bala Buluk, Gulistan and Pur Chaman. (Council & Farah, September - November 2020) (Satellite , n.d.)

The site of project selected at provincial capital as shown in figure 1 and 2. Farrah City has a population of about 128,047 inhabitants. Farah has a total population of 563,026 which around 266,793 persons (51.0%) are males and 253,481 persons (49.0%) are females as shown in figure 3. 520,274 persons (92.0 %) live in rural areas, 42,752 persons (8.0 %) live in urban areas. (NISA, 2020 & 2021)

Figure 1. Farrah province map. (Satellite , n.d.)

Figure 2. Center of Farrah province, site for design of PV project. (Satellite , n.d.)

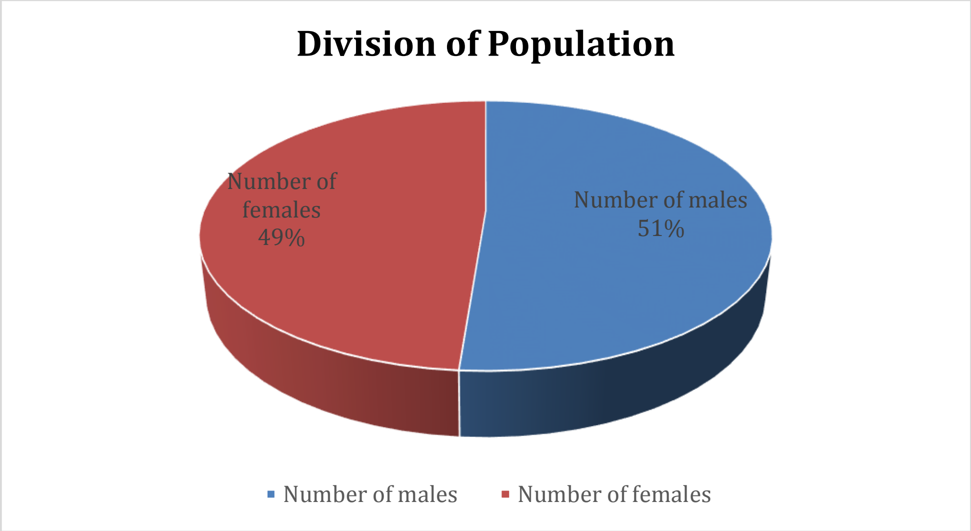

Figure 3. Population of Farah province in term (%).

The weather of Farah province is very suitable for production of fruits, such as jujube and watermelon. At present, the area under the cultivation in Farah province is about 1000-1200 hectares. (Slow Food Foundation for Biodiversity , n.d.) Watermelon make the 50 % of fruits generation in Farah province. About 100 trucks loaded with watermelon come to Kabul City form Farah every year. (Tolo news, n.d.)

The process that produced an electric power by the photovoltaic PV system is called solar PV cooling technology. This energy driven to power a conventional vapor compression refrigeration cycle. (Mouloud.Tizzaoui, et al., 2020) The Sun sends an almost unimaginable amount around 1017W of energy towards Planet Earth, In electrical supply terms this is equivalent to the output of about one hundred million modern fossil fuel or nuclear power stations. (Lynn, 2010) Thus, finiteness of resources is noticeably reflected in the rising prices of oil and gas. At the same time, we are noticing the first effects of burning fossil fuels. The melting of the glaciers, the rise of the ocean levels, and the increase in weather extreme (Mertens, 2019). as cold storages can reduce wastage of agriculture products such as fruits and vegetables, and can increase the value of products in the regional markets by exporting them at the peak time as the local products due to lack of space (not having the facility of cold storage) are being exported with a very low price comparing to the other regional/neighboring countries.

Some of the advantages is highlighted here:

Reduce respiratory activity and degradation by enzymes.

Reduce internal water loss and wilting.

Slow or inhibit the growth of decay-producing microorganisms.

Reduce the production of the natural ripening agent, ethylene.

The vapor-compression uses a circulating liquid refrigerant as the medium (usually R134a) which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. (Krishnakumar, 2017) (Connor, 2019)

The typical vapor-compression system consists of four components:

Compressor

Condenser

Expansion valve (also called a throttle valve)

Evaporator

A vapor compression chiller driven by direct current generated by PV modules is a relatively simple solution, but it requires using a battery. This limits the size and rating of such a system. As a result, this technology is used mainly in small-scale applications. (Mouloud.Tizzaoui, et al., 2020)

To obtain the objectives of this research, we should meet the following research questions.

Research question 1: How many solar panels, inverters, and batteries are necessary for 253 KW solar PV power system design?

Research question 2: How much area is necessary for 253 KW solar PV power system design?

Literature Review

Case studies and best practices in the world

For cooling capacity value of 2.5 kw, the daily energy electric requirement about 27 kwh obtained from a PV supply which estimated to connect 8 modules in series. This system can be draw with inverter, charge-controller and batteries for off-grid situation. Vapor compression cycles driven by PV power solar energy appear to be a good alternative solution in view with the electric consumption in hot season for the case of Saharan environment and for local investment development. The strategy on integrating GPV supply energy is less used regardless their required investments for specific applications in developing country like Algeria. (Mouloud.Tizzaoui, et al., 2020)

From December 2020 up to January 2021 a total of seven cold storages were installed in seven horticulture markets in Northeast Nigeria. We first identified 14 eligible markets across five states (Adamawa, Bauchi, Gombe, Jigawa, and Yobe states). The installed cold storage each powered by 5.6-kilowatt solar panels (18 units of 380-watt photovoltaic panels), each can store up to three tons of common horticulture products. The surplus electricity generated during the day is stored and released at night to enable continued refrigeration.

It has led to net increase in the share (%) of net revenues to gross revenues by 13% and net increase in gross sales revenues and sales volumes by as much as 69 percentage points, which was substantial enough that, even when considering all items sold by market agents, the loss was reduced by 4.7 percentage points at the market-agent level. The declining cost of off-grid solar electricity in recent years has enhanced the potential economic viability of providing such cooling technologies in poor regions like northeast Nigeria, where access to a conventional source of electricity has remained costly. Improved efficiency of solar panels in high-temperature environments has also enhanced the potential for successfully transferring these technologies to tropical countries. However, the knowledge gap is still vast regarding the impacts of certain cooling technologies, such as solar-powered modern cold storage in developing countries. Using these cold storages led to a significant increase in horticulture products sold and profits earned by market agents while significantly reducing the share of products lost or wasted before the sale. (Takeshima, Yamauchi, Edeh, & Hernandez, 2023)

In this study, He analyzed that the thermal analysis (energy and exergy analysis) of a solar assisted cold storage unit was performed experimentally and the following outcomes were concluded.

Cooling Load (Q) was calculated to be in the range of 3–18 kJ/s.

Exergy inflow and outflow rates were found in the ranges of 0.97–3.65 kJ/s and 0.16–1.4 kJ/s, respectively, while exergy destruction was 0.8–2.25 kJ/s, leading to an energetic efficiency of 40–60%.

Energy Utilization Ratio (EUR) was calculated to be 0.37–0.80 with a system Coefficient of Performance (COP) value of 3.95.

Total electrical consumption to attain 4 ◦C in 9 h was 6.179 kWh.

So, it shows that solar energy is a viable solution for running a cold storage unit for the storage of perishable horticultural produce at farm level (Amjad, Akram, Rehman, & Manzoor, 2021).

He makes two scenarios that are based on TRNSYS simulation software. The two scenarios investigated in this study include the photovoltaic system integrated with the grid as well as a thermal storage tank While the second one is to study the supplying an air-cooled chiller using a photovoltaic system integrated with the grid. It was found that the reduction of the consumed energy in the first scenario reduced by 81%. Also, CO2 emissions reduced by 72%. In addition, the payback period equaled nine years and generated $4,350 in total profit along the project life cycle. The second scenario saves 75.6% of the utility energy consumption and decreases CO2 emissions by 68%. Moreover, the payback period becomes 12.4 years with $3,202 in total profit generated. (Sider, Al-Maghalseh, & Alnather, 5)

Solar potential of Farah province

Northern provinces of Afghanistan have the more potential of solar with average irradiance 4.5 kWh per m2 per day as shown in Figure 4. Farah province is one of the highest solar potential in Afghanistan. (Mehrad, Assessment of solar energy potential and development in Afghanistan , 2021)

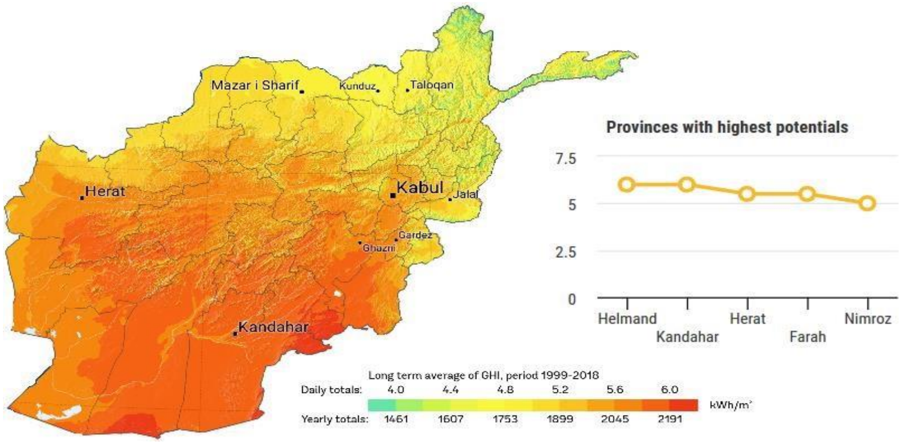

Figure 4. GHI Map of Afghanistan and provinces with the highest values of solar potentials. (Mehrad, Assessment of solar energy potential and development in Afghanistan , 2021)

In Afghanistan, the highest value of GHI is available in April to October. The GHI value from April to October is 6.2 kWh per m2 per day in Farah province and four other provinces as shown in Figure 5. Also, this amount decrease to 3.7 kWh per m^2 per day in other months (Mehrad, Assessment of solar energy potential and development in Afghanistan , 2021).

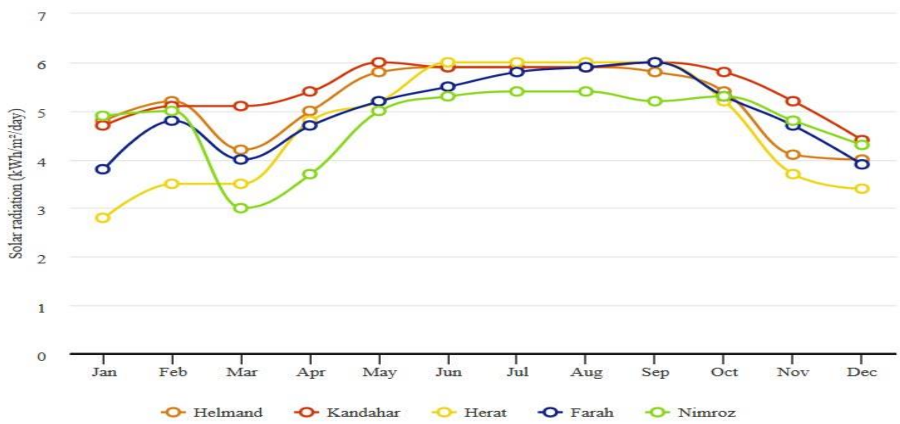

Figure 5. Monthly GHI of Afghanistan's high-value provinces. (Mehrad, Assessment of solar energy potential and development in Afghanistan , 2021)

Afghanistan's total solar potential was estimated about 222,849 MW that Farah province makes 27,000 MW of the total solar potential as shown in Figure 6. Helmand province makes the highest capacity of solar potential and Kapisa makes the lowest. (Mehrad, Assessment of solar energy potential and development in Afghanistan , 2021)

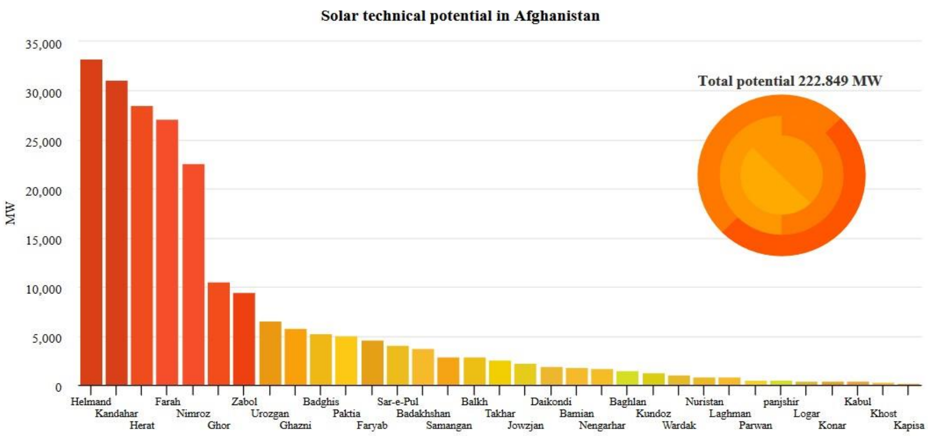

Figure 6. Solar technical potentials in Afghanistan provinces. (Mehrad, Assessment of solar energy potential and development in Afghanistan , 2021)

Site Information

The project site Farah district has an elevation of 726 m from the sea level, along with that it region has a latitude of 32° 14’ 40” in north and longitude of 62° 22’ 88” at east (Morse, 2019).

Research Method

This research is included design of PV system for 253 KW that cover the electricity demand of a cold storage in Farah province.

The analysis of this study includes a comprehensive review of literature review. The data used in this study is secondary data that collected from reliable resources, such as research papers and reports. The secondary data, firstly collected by laboratory test and interview with international organizations.

Analysis of this research has done by descriptive analysis that used from below formula to calculate the research questions for design PV system.

Power Total = Proposed Power demand / (cable Efficiency) * (Inverter Efficiency) * (Sun hour)

Number of Modules = Power Total / Panel rated power

Number of Module in series = System voltage / Module voltage

Number of Strings = Number of Modules / Number of Modules in series

Power Inverter = (Proposed Power demand) * (Safety Factor) / (Inverter Efficiency)

Number of Inverter = Power Inverter / Inverter power

Battery system capacity (Ah) = Energy needed / (Efficiency) ∗ (DOD) ∗ (Batt. Syst. Volt)

Number of batteries in parallel = Battery system capacity (Ah) / Battery Capacity (Ah)

Number of batteries in series = Battery system voltage / Battery voltage

Number of batteries = Number of batteries in parallel * Number of batteries in series

Actual Panel (Length) = (T) * (panel length)

Panel Area = Actual Panel (Length) * (width)

By assuming that 12 rows and 35 strings will be used for PV system, so for finding overall area of PV system,

Distance between each string = (Height panel) * (S)

Length of Plant = (Length of panel + Distance between string) * (Number of Row)

Width of plant = (Width of panel) × (Number of panel in a Row)

Total area = (Width of plant) * (Length of plant)

Result

The first step is to calculate the thermal load calculation of selected cold storage, which recognized a forward step before the design specification of Photovoltaic system. So the required refrigeration capacity may therefore be determined to match up the determined cooling load and thus, enabling a proper selection of refrigeration equipment. The heat load of the cold storage was calculated using the total amount of heat produced from all sources comprising of the transmission heat (h1), infiltration heat (h2), products heat (H\h3), other heat sources (h4), unexpected and unknown heat (h5).

H Total = h1 + h2 + h3 + h4 + h5

Table 1. Summary of Thermal load calculation of the selected Cold storage.

Load (h)	**Results (Whr)**
Total transmission load, h1	25324.5 Whr
Total infiltration load, h1	42500 Whr
Total product load, h3	1736666 Whr
Total other's load, h4	16340 Whr
Total Unexpected and Unknown heat load, h5	0 Whr
Total Thermal load, HTotal	1753000 Whr

The total thermal load of cold storage is calculated 1753 Kwh/day, which product load has the biggest evolvement with 95% from the total thermal load calculation which include the new products enter and be there within cold storage or initially, followed by transmission and infiltration loads with 2% and other's load with 1%.

Designing and solar PV array specification

According to the data above, now we find the energy requirement for peak day of the year (1753kwh). So for determining of the number of solar panels that can generate the amount of power required by the customers from the energy of the sun. The efficiency of the monocrystalline or panel is 15% to 20% and Rated Power of the panel 600W is used.

Table 2. Template of selected Module for Study

PV Module	
Parameter	Specification
Type of module	Mono-Crystalline
Rated Power at STC (Pmax)	600 W
Max. Power Voltage (Vmp)	44 V
Max. Power Current (Imp)	13.63 A
Open Circuit Voltage (Voc)	52.8 V
Short Circuit Current (Isc)	14.99 A
Efficiency	15.3%
Dimension	35.7*23.6*1.9 inch
Weight	27.5 pound

Power Total = Proposed Power demand / (cable Efficiency) * (Inverter Efficiency) * (Sun hour) = 1753 kwh / (0.9) * (0.965) * (8hr) = 252.3 kw

Number of Modules = Power Total / Panel rated power = 252300 w / 600 w = 420.5 Modules

The string voltage system, according to the selected inverter capability, should be 90 V DC. Therefore, the arrangement of the panels in series and parallel is calculated as follows:

Number of Module in series = System voltage / Module voltage

90 V / 44 V = 2

Number of Strings = Number of Modules / Number of Modules in series

421 / 2 = 210.5

Capacity Estimation of inverter

Solar panels convert sunlight directly into DC electricity which is then stored in deep cycle batteries. Therefore, in an off-grid solar system buildings and house appliances work on AC, these inverters convert the DC input from PV and battery to AC for it to be delivered to the load. We know that the maximum power which our system is necessary between 250kw-260kw. Thus we choose an inverter that might be on average 30kw wattage.

Table 3. Template of selected Inverter for Study

Inverter	
Parameters	Specification
Max. DC Power	39,000 W
Max. input voltage	192V / 240V
Mpp voltage range	170 - 500V
Max. input voltage	500V
Max. input current	36A
Output(AC)	30,000 W
Max. apparent AC power	45,000VA
Nominal AC Voltage / range	120V
AC power frequency / range	50Hz, 60Hz
Rated grid frequency / rated grid voltage	50Hz / 230Hz
Max. output current	48A
Efficiency	96.5 %
Max. efficiency	97.5%

Power Inverter = (Proposed Power demand) * (Safety Factor) / (Inverter Efficiency)

(252.3) * (1.25) / (0.965) = 326.8 Kw

Then for finding the numbers of inverter, we chose a 30 Kw Inverter The design process for inverter is easy, an inverter chosen that can handle the maximum electric wattage that must be drawn by all of the electric appliances when they are all turned on at the same time.

Number of Inverter = Power Inverter / Inverter power

(252300 w) / (30000 w) = 7.569 ~ 8 Units

Capacity estimation of Battery

Since PV electricity is precious, especially during long cloudy periods or in winter, the batteries must also display low self - discharge rates and high efficiency. The capacity of a cell or battery is normally quoted in ampere hours (Ah), that is the product of the current supplied and the time for which it flows. The battery selected should be able to store sufficient energy enough for operating loads on rainy or cloudy days and at night times. Here we must note some consideration about our lead acid battery at rated capacity (250 Ah, 48v), which will support needed load (1753 kwh/day) at night.

1. Depth of discharge is given 75%

2. Autonomy days is assumed to be two days

3. Battery Efficiency 90%

4. Inverter Efficiency 85%

Battery system capacity (Ah) = Energy needed / (Efficiency) ∗ (DOD) ∗ (Batt. Syst. Volt)

1753000 Whr / (0.9) * (0.75) * (48) = 54104.9 Ah

Number of batteries in parallel = Battery system capacity (Ah) / Battery Capacity (Ah)

54104.9 Ah / 250 = 216.4

Number of batteries in series = Battery system voltage / Battery voltage

48 / 12 = 4

Number of batteries = Number of batteries in parallel * Number of batteries in series

4 * 217 = 868 Unit

Land requirement and PV module orientation

The orientation of PV modules for tilted or ground-mounted PV systems. This is carried out to avoid potential shading of PV modules. Determining the orientation and inter-row spacing for a system is a bit complicated and troublesome, avoiding which may lead to under performance of the system and reduced efficiency. The first step is to calculate the inter-row spacing. The Average sunlight angle (S) is taken to 44 and Tilt Angle (T) is 34, the Area of the PV panel and the final wiring diagram of the proposed system. The land requirements for this project is also will be calculated by knowing panels area,

Actual Panel (Length) = (T) * (panel length) = Cos (34) * (2.4 m) = 1.98 m

Panel Area = Actual Panel (Length) * (width) = (1.98) * (1.1) = 2.28 m2 (one panel)

By assuming that 12 rows and 35 strings will be used for PV system, so for finding overall area of PV system,

Distance between each string = (Height panel) * (S) = (0.72 m) * (tan (44)) = 0.69 m

Length of Plant = (Length of panel + Distance between string) * (Number of Row) = (1.98 + 0.69) × (12) = 32.04 m

Width of plant = (Width of panel) × (Number of panel in a Row) = (1.1) * (35) = 38.5 m

Total area = (Width of plant) * (Length of plant) = (32.04 m) * (38.5 m) = 1233.5 m2

The overall system can be modified by table below.

Table 4. Show the summary of electrical system and equipment

GPV Parameters description	Value
Power electric energy of the cooling unit	252.3 (kw)
Daily electrical energy requirement	1753 (kWh)
Average global radiation energy of the	6.566 (kWh/m2/day)
Nominal power at STC condition	250 (wc)
Real power of the module Preal, mod	0.585(KWc/da)
Daily Produced Energy of a modules	6.45 (KWc/day)
Number equivalent hours of sunshine	8 (h)
Total number of modules	421
Number of Modules in Series	2
Number of Branches in Parallel	211
Surface area of the GPV Feild SGPV	1233.5 (m2)

Discussion

Design of PV system for a cold storage is comfortable, useful, and economical than other resources and system. Afghanistan has 300 sunny days that it is huge potential for generation of electricity. Response to electricity demand for this cold storage by PV system can reduce the fossil fuel for electricity generation. This will have positive impact on climate change and weather. The design of 253 KW PV system has need to more and careful consideration of different factors such as orientation, capacity of inverter and batteries, number of panels, batteries, and inverter. By design this system for cold storage in Farah province, the efficiency and reliability of energy will be increased. Design of PV system for cold storage in Farah province has some challenges and limitation such as need of reliable power supply to maintain optimal storage conditions, limited space for solar panel installation that need to address.

Conclusion

Farah is one of the biggest and sunny province of Afghanistan that located in the western section of country. The area of Farah province is about 49,000 kilometer square. Afghanistan's northern provinces has 4.5 kwh per m2 per day. In Farah province the high value of GHI is 6.2 kwh per m2 per day in April to October and decease to 3.7 kwh per m2 per day in other months. The project site Farah district has an elevation of 726 m from the sea level, along with that it region has a latitude of 32° 14' 40" in north and longitude of 62° 22' 88" at east. Design of PV system for a cold storage is comfortable, useful, and economical than other resources and system. Afghanistan has 300 sunny days that it is huge potential for generation of electricity. Response to electricity demand for this cold storage by PV system can reduce the fossil fuel for electricity generation. For design o 253 KW PV system is necessary 421 modules, 8 inverters with 326.8 KW, 868 batteries, and 1234 m2 area or land.

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