

## Feasibility Study Of Rooftop Photovoltaic Power System For A Research Institute Towards Green Building In Vietnam

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### Abstract

Use of renewable power technology in urban area can help the buildings to minimize the carbon footprint, meet the electricity needs and achieve the nearly zero-energy building. In this study, the design results of the rooftop grid-tied PV power system with the capacity of 56.7kW for a research institute building in Vietnam are analyzed. The study results have calculated the electricity generation, performance of the rooftop grid-tied PV power system as well as reduction potential of the amount of CO<sub>2</sub> emitted into the environment. The design results of the rooftop grid-tied PV power system for a research institute building will be compared with the actual power generation results of an installed rooftop grid-tied PV power system at a building of General Directorate of Energy - Vietnam Ministry of Industry and Trade in the same city.

**Keywords:** photovoltaic, inverter, rooftop grid-tied PV power system, loss.

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### 1. Introduction

At the present, building sector achieves a large proportion in power consumption all over the world. Construction of building and other related operations in building sector accounted for 36% of global final power usage and about 40% of energy which was related carbon dioxide (CO<sub>2</sub>) emissions [1]. Therefore, governments in the world issued policies towards greener cities and societies by using energy efficiency strategies, renewable energy sources and strategies to fight climate change to decrease the energy consumption of buildings [2-5]. As a kind of sustainable renewable energy source, solar energy can be selected to reduce the pollution and improve energy saving performance of buildings, cities [6-8]. Currently, solar power technology is developing very fast in the world, with a total installed solar power capacity of

509 GW [9]. In 2018, the ground-mounted PV power plant was a major solar market on this type of PV application with the installed capacity of 72.7GW and it was predicted increasing up to 187.4GW in 2023 [9]. Besides, the installed capacity of the rooftop PV power stations was 29.7GW in 2018 and can achieve the target of 76.5GW in 2023 [9] as illustrated in Figure 1.

Construction of rooftop solar power system in urban area can help the buildings, resident homes in general and the institution buildings in particular to reduce carbon footprint, meet the electricity needs and achieve the nearly zero-energy building (ZEB) characterized by a very high-energy performance during the operation and most of the usage energy is produced from renewable energy sources [typically solar thermal and solar power systems] [10]. However, it is noted that when usage of solar power, a part of CO<sub>2</sub> emission also is emitted in the production phase of the photovoltaic modules.

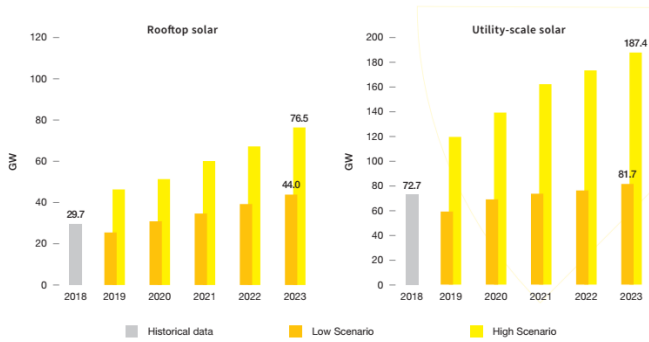


Figure 1. Development of rooftop solar and utility scale solar [1]

Anasuya Gangopadhyay et al [11] studied a 100kW grid-tied rooftop solar PV plant which has been operational since October 2014 at National Institute of Advanced Studies, India to evaluate the performance of grid tied rooftop solar plant from generation, economic and maintenance perspective. Daphne Ngar-yin Mah et al [12] reviewed the usage trends of rooftop solar power in urban area and collected data by conducting 57 interviews with potential rooftop solar PV adopters from the residential, institutional, and commercial sectors in Hong Kong to estimate the perceived barriers and effectiveness of possible government policies for solar power. Adel A. Elbaset, M. S. Hassan [13] researched a new approach for optimum design and implement of rooftop grid connected PV system installation on an institutional building at Minia University, Egypt in order to carry out taking into account PV modules and inverters specifications. Mohammad I et al [14] investigated reduction ways of the electricity demand for Engineering Faculty at Mu'tah University by using the rooftop PV power system with the capacity of 56.7 kW, this plant could generate the electricity of 97.02 MWh per year to the utility grid. Li et al [15] evaluated and compared the techno-economic performance of rooftop grid-connected solar power systems containing 14 families in five climate zones in China. M. MoldovanI, VisaA. Duta [16] presented a nearly zero energy building, solar tracking systems for PV array and solar-thermal convertors, as well as a novel concept for active solar-thermal facades for a sustainable community of the R&D Institute of Transilvania University in Brasov, Romania.

In the case of Vietnam, the electricity demand of administrative and residential buildings increased at an average 9.3 % per annum and achieved an average share of 9.25 % of the whole national power consumption in the period 2010-2016 while energy consumption of commercial buildings have the highest growth rate of about 16.4 % per annum in the same period [17]. Vietnam National Green Growth Strategy [18] was adopted by the government in 2012 with the target for green construction and sustainable urbanization and it was related to the national climate change and economic policy agendas.

Development of green buildings with solar power system is an approach to save energy and plays an important role in cutting greenhouse gas (GHG) emission.

NDP pillars	Energy and GHG	Green production (industry)	Lifestyle
<b>Environmental conservation</b>	<ul style="list-style-type: none"> <li>Target Absolute GHG decoupling</li> <li>Forestry conservation</li> <li>Indirect environmental impact of new energy sources</li> </ul>	<ul style="list-style-type: none"> <li>Actual GHG-GDP decoupling</li> <li>Environmental impact of green industry and modern agriculture</li> </ul>	<ul style="list-style-type: none"> <li>Health and security</li> <li>Indirect GHG emissions of new consumption modes</li> <li>Rebound effect</li> </ul>
<b>Sustainable and equitable socio-economic development</b>	<ul style="list-style-type: none"> <li>Fossil fuels subsidies and Climate finance</li> <li>Investment cycles and energy market uncertainty</li> <li>Energy dependency (coal)</li> <li>Health and security</li> <li>Land-use</li> </ul>	<ul style="list-style-type: none"> <li>Energy pricing</li> <li>Energy efficiency potential</li> <li>Quality of new green jobs</li> </ul>	<ul style="list-style-type: none"> <li>Long-term Energy price for residential sector and citizens</li> <li>Land-use</li> </ul>
<b>Preservation and promotion of culture</b>	<ul style="list-style-type: none"> <li>Population Resettlement</li> <li>"Harmony with nature"</li> </ul>	<ul style="list-style-type: none"> <li>Agriculture modes</li> </ul>	<ul style="list-style-type: none"> <li>Gap between traditional Asian culture and new consumption of emerging middle-class[AASA 2011]</li> </ul>
<b>Good governance</b>	<ul style="list-style-type: none"> <li>Decentralization of energy production sources</li> <li>Reliability and efficiency of GG finance flows</li> </ul>	<ul style="list-style-type: none"> <li>Industry Accountability for energy efficiency</li> <li>Public-private partnerships</li> </ul>	<ul style="list-style-type: none"> <li>Renewable energy production by residential sector or communities</li> </ul>

Figure 2. Main specificities of the Vietnam National Green Growth Strategy tasks [18]

Vietnam has good solar energy potential that could be used to successfully develop the solar power sector. Overall solar energy potential in Vietnam is about 4-5 kWh/m<sup>2</sup>.day in the Southern area, Central area, and partially even Northern area in Vietnam while the average peak irradiation of up to 5.5 kWh/m<sup>2</sup>.day in Central-Southern areas [19]. Solar power has been used in Vietnam since the 1990s but it is mainly used for the remote areas where are far from the national power grid such as mountainous areas, islands, etc.... The small grid-tied solar power plants developed from 2010 and installed for the residential applications. The total installed solar power capacity in Vietnam by 2017 is only about 8MW [20], which is very low in comparison with the potential for solar power in Vietnam because there is no policy of the Government to support the development of solar power.

From April in 2017, the Government of Vietnam announced the policy to support the development of solar power in general and the rooftop PV power system in particular. In which, the surplus electricity produced from the rooftop grid-tied PV power station can be sold to the utility grid with the price of 9.35 centUS/kWh [21]. Therefore, investors are interested in constructing the rooftop PV power station in Vietnam.

Since the 2000s, grid-connected PV power systems have been studied for application of building and resident home in Vietnam. Nguyen Xuan Truong et al [22, 23] designed a grid-connected solar power system with the capacity of 15kW for a building to achieve nearly zero-energy building model, the PV arrays were installed in the area of this building to compensate the energy needed and these authors also researched to improve the power production efficiency of the PV system by using the Solar Tracker system. Baulch et al [24] determined the payback period for the rooftop solar power stations in Ho Chi Minh city. General Directorate of Energy (GDE) - Vietnamese Ministry of Industry and Trade cooperated

with Spanish Agency for International Development Cooperation (AECID) [25] to install and test the effectiveness of the grid-tied PV power station in Hanoi city with the capacity of 22 kW and the off-grid solar power system in Con Dao island with the capacity of 36 kW. German Federal Ministry for Economic Affairs and Energy and GIZ - German Corporation for International Cooperation [26] studied the development potential for solar power rooftop applications in the commercial and industrial sector of Vietnam and to evaluate business opportunities for German solar companies in Vietnam. This report focused on industrial zones and private factories/commercial operations located in Central and Southern Vietnam with the highest solar energy potential.

The rooftop solar power is a new field in the business market in Vietnam. Therefore, this study result will contribute to evaluate the potential of installation of rooftop solar power and reduction of CO<sub>2</sub> for buildings in Vietnam. The simulation results of rooftop grid-tied PV power system with the capacity of 56.7 kW for a research institute building have calculated the solar energy potential in a specialized city, the generation electricity, performance of the rooftop grid-tied PV power system by using PVSYS program as well as reduction amount of CO<sub>2</sub> emitted into the environment. The design results of the rooftop grid-tied PV power system for a research institute building will be compared with the actual power generation results of another installed rooftop grid-tied PV power system at the building of General Directorate of Energy - Vietnam Ministry of Industry and Trade in the same city.

## 2. Rooftop PV power system

The main components and working diagram of the typical grid-tied PV power system in Vietnam are presented in Figure 3. In the favorable weather conditions, the PV modules absorb solar energy and generate the power. The DC/AC inverter is used to convert the direct current (DC) from the PV module to the alternating current (AC) and transmit it into the utility power grid [27, 28]. At any time of the day, a customer's solar power system may produce more or less electricity than their demand for home or business. When the PV system's power production exceeds the customer's demand, the excess energy generation automatically goes through the electric meter into the utility grid. At other times of the day, when the customer's electric demand may be higher than the electricity production of PV power system, the customer buy the additional power to serve the demand from the utility grid. The connection operation between solar system and the utility grid is instantaneous, so the customers never notice any interruption in the flow of power.

Currently, application of grid-tied PV power technology is increasing fastly in Vietnam. The Bi-directional meter can measure the electricity in two

directions and it measures how much energy comes from the power company versus the electricity production from the PV power systems. If more electric energy is produced from the PV system than the customer's demands, the surplus electricity is supplied into the utility's electric system. By which, the surplus electricity produced from grid-tied PV power station can be sold to the utility grid with the price of 9.35 centUS/kWh [21].

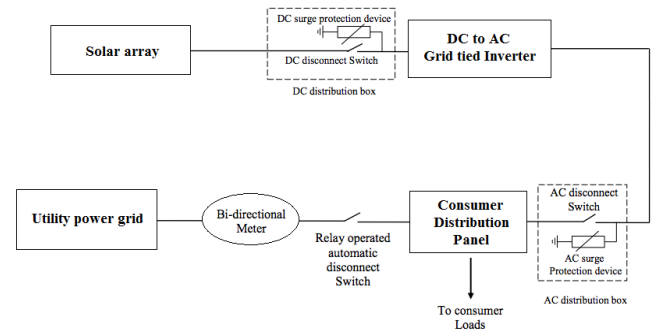


Figure 3. Working diagram of the typical grid-tied PV power system in Vietnam

## 3. Design of PV system at Institute of Geological Science

### 3.1. Site description

The Institute of Geological Science (IGS) under Vietnam Academy of Science and Technology is responsible for scientific research and training on geological and climate change issues. The electricity from grid-tied PV power system will be supplied for buildings, research work and teaching rooms. After the PV power system is completed, IGS will cooperate with other universities and institutions to train environmental geology, geotechnics, energy, environment classes.

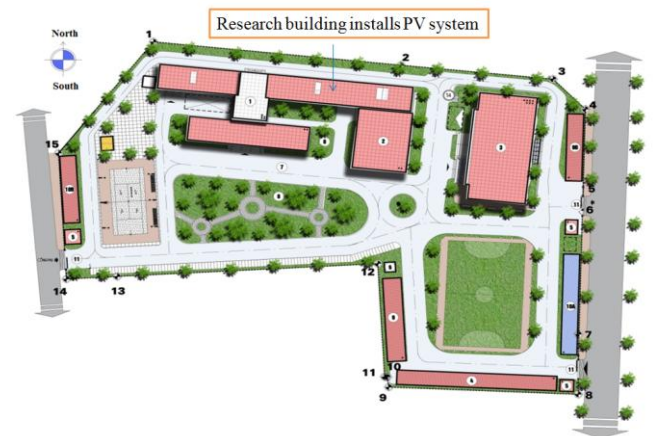


Figure 4. Plan of IGS

The research building in IGS is located at latitude of 21°01'29"N and longitude of 105°48'18"E. The roof of the research building is a concrete roof system and the area of the roof is suitable for constructing the PV power system as shown in Figure 5.



**Figure 5.** Plan of roof on research building at IGS

### 3.2 Performance calculation parameters

In this study, the design of the rooftop grid-tied PV power system with the capacity of 56.7 kW for a research building in IGS was implemented by using specialized software PVSYST [29-34].

In PVSYST program [31, 35-38], the losses, yield factor, performance ratio are determined as below:

*Array Yield (Y<sub>a</sub>):*

$$Y_a = \frac{E_a}{P_0} \quad (1)$$

where, P<sub>0</sub> is power of solar array [kWp]; E<sub>a</sub> is output array yield [kWh]; Y<sub>a</sub> (Array Yield) is the array daily output energy, referred to the nominal power [kWh/kWp/day].

*Reference system Yield (Y<sub>r</sub>):*

$$Y_r = \frac{H_t}{G_0} \quad (2)$$

where, Y<sub>r</sub> (Reference system Yield) is numerically equal to the incident energy in the array plane [kWh/m<sup>2</sup>/day]. H<sub>t</sub> is the total horizontal irradiance on array [kWh/m<sup>2</sup>] and G<sub>0</sub> is the global irradiance at standard condition (STC) (W/m<sup>2</sup>).

*System Yield (Y<sub>f</sub>):*

$$Y_f = \frac{E_{ACout}}{P_{max, STC}} \quad (3)$$

where, Y<sub>f</sub> (System Yield) is the system daily useful energy, referred to the nominal power [kWh/kWp/day]; EACout is the amount of electrical energy generated by the solar power plant; P<sub>max, STC</sub> is the total installed power of solar arrays at standard test condition (STC).

*Performance Ratio (PR):*

$$PR = \frac{Y_f}{Y_r} \quad (4)$$

where, PR (Performance Ratio) is the global system efficiency with respect to the nominal installed power and the incident energy; Y<sub>f</sub> is System Yield; Y<sub>r</sub> is Reference system Yield.

*Collection Loss (L<sub>c</sub>):*

$$L_c = Y_r - Y_a \quad (5)$$

where, L<sub>c</sub> (Collection Loss) is the array losses, including thermal, wiring, module quality, mismatch and IAM losses, shading, dirt, MPP, regulation losses, as well as all other inefficiencies; Y<sub>r</sub> is Reference system Yield; Y<sub>a</sub> is Array Yield.

*System Loss (L<sub>s</sub>):*

$$L_s = Y_a - Y_f \quad (6)$$

where, L<sub>s</sub> (System Loss) is inverter loss in grid-tied solar power system; Y<sub>a</sub> is Array Yield; Y<sub>f</sub> is System Yield.

### 3.3. Design of solar power system

In Vietnam, Hanoi city has the fairly solar energy potential with an average annual solar radiation of 3.85kWh/m<sup>2</sup>.day [39]. The period from January to March and from October to December has the lowest daily average solar radiation value from 2.49kWh/m<sup>2</sup>.day to 3.66kWh/m<sup>2</sup>.day while the daily average solar radiation in the period from April to October has a good value from 3.79 kWh/m<sup>2</sup>.day to 4.67 kWh/m<sup>2</sup>.day.

**Table 1.** Daily solar radiation value in Hanoi city

Month	Solar radiation (kWh/m <sup>2</sup> .day)
1	2.49
2	2.86
3	3.66
4	4.07
5	4.59
6	4.67
7	4.60
8	4.56
9	4.39
10	3.79
11	3.39
12	3.02
Average year	3.85

Solar panels are installed on the roof system of the research building in IGS with the slope angle of 18° and the azimuth angle of 0° in order to achieve the best energy conversion efficiency.

Figure 7 presents the diagram of PV system connection at the research building with the connection structure as below:

The 1<sup>st</sup> inverter of 25kW consists of 4 solar panel strings. Each string consists of 13 mono-crystalline silicon solar panels of 350W that are connected in series. Two

strings are connected to input of a Maximum power point tracking (MPPT) tracker of the grid-tied inverter.

The 2<sup>nd</sup> inverter of 25kW consists of 4 solar panel strings. Each string consists of 14 mono-crystalline silicon solar panels of 350W that are connected in series. Two strings are connected to input of a Maximum power point tracking (MPPT) tracker of the grid-tied inverter.

The 3<sup>rd</sup> inverter of 25kW have 4 solar panel strings. In which, 2 strings consist of 13 mono-crystalline silicon solar panels of 350W in series connection and they are connected to inputs of the first MPPT tracker of the grid-tied inverter. 2 strings include 14 mono-crystalline silicon solar panels of 350W in series connection and this string is connected to the input of the second MPPT tracker of the grid-tied inverter.

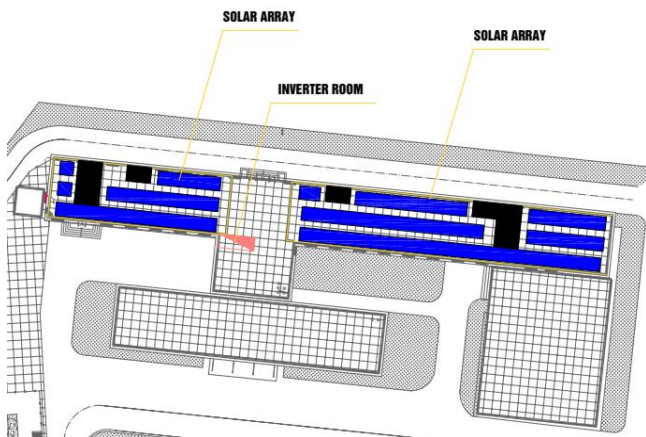


Figure 6. Arrangement of solar panel on the roof of the research building

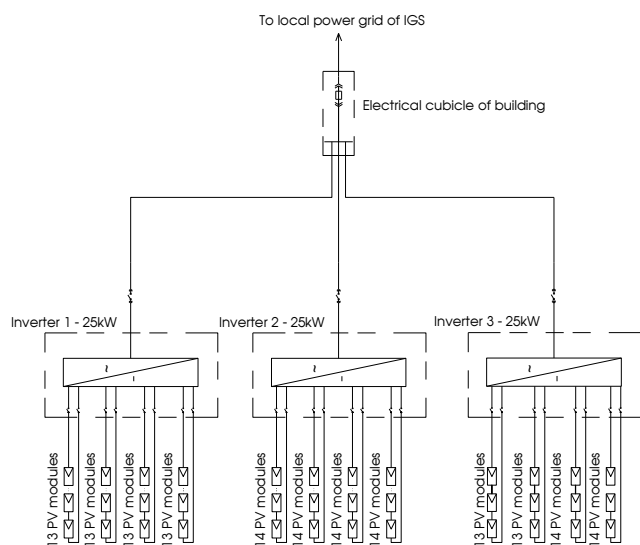


Figure 7. Diagram of PV system connection at the research building

Table 2 shows the main equipments of the the grid-tied PV power station in IGS.

Table 2. Main equipments of the the grid-tied PV power station

No	Equipments	Quantity	Unit
1	Solar panel - SolarWorld 350 W	162	module
	- Maximum power: 350W		
	- Open circuit voltage: 47.3V		
	- MPP voltage: 37.8V		
	- Short circuit current: 9.82A		
2	- MPP current: 9.29A	3	unit
	- Module efficiency: 17.54%		
	Grid-tied Inverter - SMA 25 kW		
	- Max input voltage: 1000V		
	- MPPT voltage range: 390V - 800V		
	- Min input voltage: 150V		
	- Max input current input A/inputB: 33A/33A		
	- Rated power (at 230V, 50Hz): 25kW		
- AC voltage range: 180V - 280V			
- 3 phases			

### 3.4. Study result

PVSYST software is used to calculate the power output, performance as well as the losses of the grid connected PV power station. The types of losses include the Collection loss and the System loss.

Figure 8 presents the loss diagram of the PV power station, it is can be seen that the PV loss due to temperature is the highest value of about 4.8% because Hanoi is in the Northern area of Vietnam. Thus, the temperature difference between four seasons is quite high and not close to the standard working temperature of solar panels of 25<sup>0</sup>C, the temperature in summer can reach 45<sup>0</sup>C while the temperature in winter can be reduced to 8<sup>0</sup>C. On the other hand, the loss of AC wire connecting to the grid power point is the lowest value of 0.3% because the connection distance is only about 22 m. The types of losses will affect the output electricity per kW generated to the power grid and the efficiency of grid connected solar power stations as shown in Figure 10, the generated power by the loss of 13.2 % caused by solar arrays is about 0.53 kWh/kWp/day while the generated power affected by the system loss of 4.4% is about 0.18 kWh/kWp/day, the amount of produced useful electricity at inverter output is only about 3.32 kWh/kWp/day. Hence, the solar power station performance shown in Figure 9 will only reach about 82.4%.

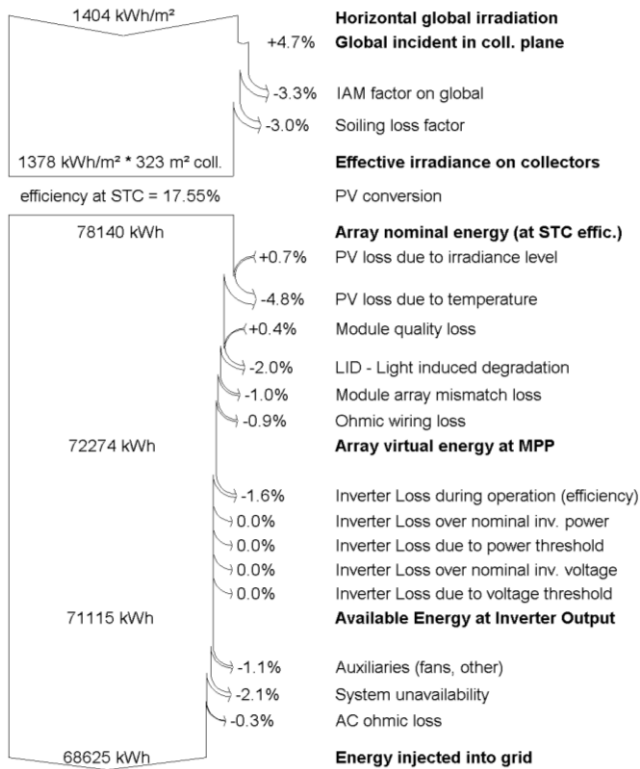


Figure 8. Loss diagram of PV power station

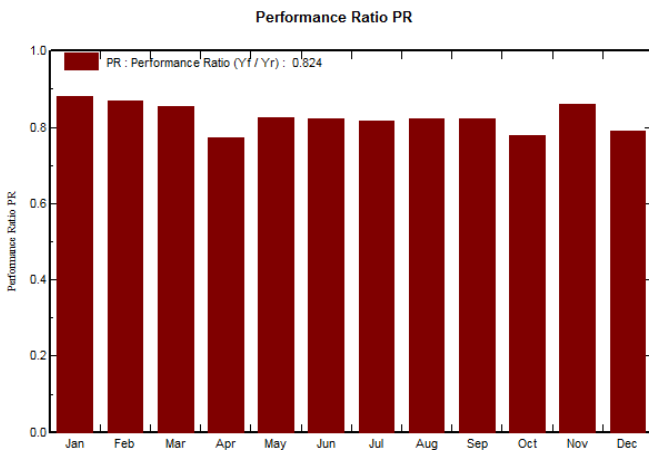


Figure 9. Performance ratio

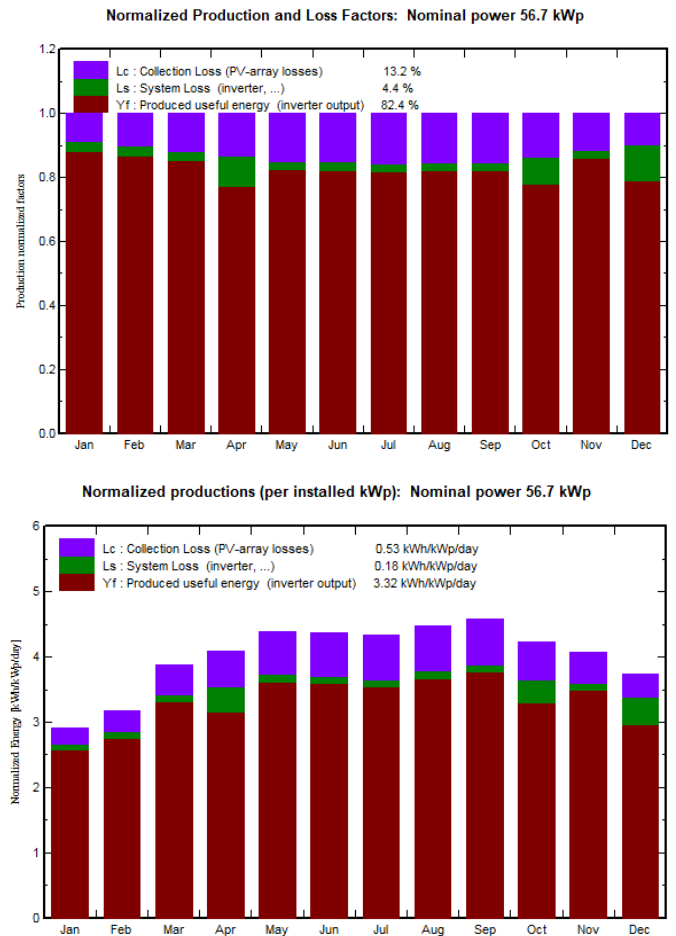


Figure 10. Types of losses versus output power

It can be seen that the generated power from the PV power system in Figure 11 corresponding to the solar radiation value. The time period from May to September has the highest power generation while January and February in the remaining months of the year have the lowest power output. On the other hand, the Global on tilted plane with the solar array slope angle of 18° is about 0.2 kWh/kWp/day higher than the case of GlobHor horizontal as shown in Figure 12. Total annual average electricity from the solar power station transmitting to the utility grid is 68625 kWh per year.

	GlobHor kWh/m <sup>2</sup>	T Amb °C	GlobInc kWh/m <sup>2</sup>	GlobEff kWh/m <sup>2</sup>	EArray kWh	E_Grid kWh	EffArrR %	EffSysR %
January	77.2	11.70	90.3	84.6	4672	4517	16.01	15.48
February	80.1	13.50	88.9	83.5	4528	4379	15.75	15.23
March	113.5	17.20	120.5	113.1	6020	5832	15.46	14.98
April	122.1	21.50	122.5	114.7	6021	5375	15.21	13.58
May	142.3	24.20	136.2	127.5	6563	6368	14.91	14.47
June	140.1	26.10	131.2	122.6	6307	6121	14.88	14.44
July	142.6	26.30	134.4	125.7	6424	6230	14.79	14.34
August	141.4	26.00	138.6	129.8	6654	6460	14.85	14.42
September	131.7	24.30	137.4	129.2	6602	6408	14.87	14.43
October	117.5	21.10	131.0	123.3	6408	5783	15.13	13.66
November	101.7	17.30	122.0	114.8	6129	5951	15.54	15.09
December	93.6	13.29	116.1	109.0	5946	5199	15.84	13.86
Year	1403.8	20.24	1469.2	1377.9	72274	68625	15.22	14.45

Legends: GlobHor Horizontal global irradiation  
 T Amb Ambient Temperature  
 GlobInc Global incident in coll. plane  
 GlobEff Effective Global, corr. for IAM and shadings  
 EArray Effective energy at the output of the array  
 E\_Grid Energy injected into grid  
 EffArrR Effic. Eout array / rough area  
 EffSysR Effic. Eout system / rough area

Figure 11. Total annual average electricity from the solar power station

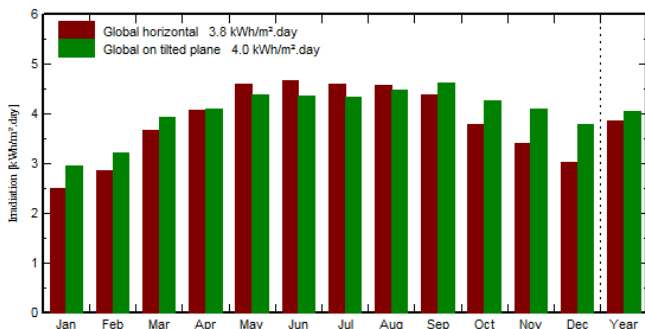


Figure 12. Global on tilted plane versus Global horizontal

### 3.5. Environmental impact

At the present, the investment in construction of grid-connected solar power stations can obtain the economic profit and contribute to environmental protection, combat the phenomenon of climate change by reducing the amount of CO<sub>2</sub> emitted into the environment [40]. The annual average reduction of CO<sub>2</sub> in IGS building is 59.3 ton per year by using the following formula [41]:

$$t_{CO_2e} = E\_Grid \times EF_{grid} \tag{7}$$

where:

E\_Grid - the average annual generation electricity from the solar power station (MWh)

EF<sub>grid</sub> (CO<sub>2</sub> emission factor of Vietnamese power grid) = 0.8649 tCO<sub>2</sub>/MWh [41]

## 4. Comparison of design result with another real work

The results of the design of the grid connected solar power station at the IGS is compared with the actual power generation results of a grid connected solar power station at the General Directorate of Energy building (GDE) [25] as can be seen in table 3 because these projects has the same city location in Vietnam.



Figure 13. GDE building solar PV system [25]

The solar power station using poly-crystalline silicon solar panels and thin film was installed on the roof of the GDE’s building, 23 Ngo Quyen street, Hanoi city at a latitude of 21°01’27”N and longitude of 105°51’18”E. The total capacity of poly-crystalline silicon solar panels in this project was 11kW including 48 modules of 240W of Atersa manufacturer, 01 inverters of 11kW of Ingeteam manufacturer while the total capacity of thin film solar panels was 11kW including 91 modules of 120W of Sharp manufacturer, 01 inverters of 11kW of Ingeteam manufacturer.

Table 3. Comparative parameters of solar power station

Location	Coordinate	Power (kW)	Electricity		Type of solar panel
			kWh/year	kWh/kWp/day	
IGS building	21°01'29"N, 105°48'18"E	56.7	68625	3.31	mono-C
GDE building [25]	21°01'27"N, 105°51'18"E	11	13100	3.26	poly-C
		11	12400	3.08	thin film

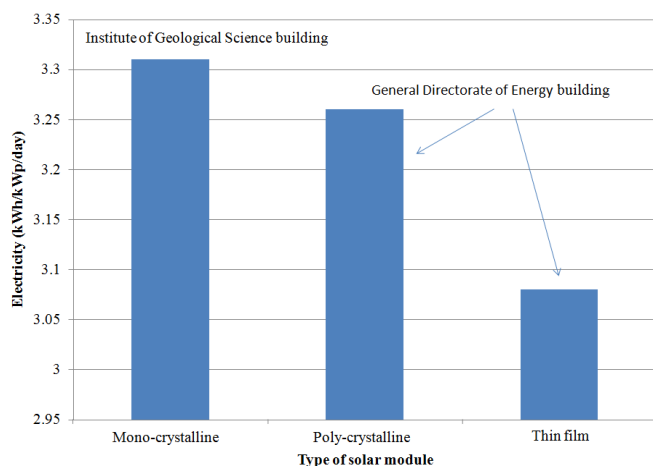


Figure 14. Comparative parameters of solar power stations in Hanoi city

The results of comparing electricity from two solar power stations with the same coordinates in Hanoi and similar solar radiation conditions showed that the electricity of the design results of the solar power station of the IGS building are 0.05 kWh/kWp/day and 0.23 kWh/kWp/day higher than the electricity from the PV power system of GDE building using polycrystalline solar panels and thin film solar panels, respectively, because monocrystalline solar cell performance is higher than performance of polycrystalline solar cell and thin-film solar cell. On the other hand, solar power stations can be more affected by dust losses, climatic conditions in real operation conditions in comparison with the calculations in design stage.

## 5. Conclusion

The power output generated to the utility grid and the performance of grid-connected solar power stations are affected by different types of losses. In which, the loss of solar panels due to temperature has the highest value of about 4.8% because Hanoi city in the Northern region has a high temperature difference between seasons. So the

performance of solar power station at the IGS building is about 82.4%.

The results of comparing electricity from two solar power stations with the same coordinates in Hanoi city and similar solar radiation conditions showed that the electricity of the design results of the solar power station of the IGS building are 0.05 kWh/kWp/day and 0.23 kWh/kWp/day higher than the electricity from PV system of GDE building using polycrystalline solar panels and thin film solar panels, respectively.

Moreover, construction of rooftop grid-tied solar power station at IGS building can help reduce the amount of CO<sub>2</sub> of 59.3 tons per year emitted into the environment, so it will contribute to environmental protection and combat the phenomenon of climate change in the city.

Finally, installation of rooftop PV system in Vietnam can help to save energy for the buildings, reduce greenhouse gas emission in the environment, and contribute to achieve targets of the Vietnam National Green Growth Strategy for green construction and sustainable urbanization.

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