ASSET EVALUATION OF PHOTOVOLTAIC SYSTEMS IN RESIDENTIAL APPLICATIONS IN VIETNAM

Bui Huy Binh[1], Nguyen Trong Giap[1], Nguyen Minh Y[1*]

[1] Dept. of Electrical and Computer Engineering, Faculty of International Training, Thai Nguyen University of Technology, Thai Nguyen, Vietnam, Rm. #111, Bldg. A2, 3-2 Str. Tich Luong, Thai Nguyen, Vietnam.
Email: minhy@tnut.edu.vn; Tel: +842803847288.

Abstract - *Although lots of advancement in Photovoltaics (PVs) technology has been achieved, the cost of producing electricity is still high compared to the conventional sources, e.g., coal, gas, etc. In this paper, we provide a comprehensive evaluation of the economics of PV systems in residences. This is done by comparing the electricity obtained, the construction and maintenance cost in the whole lifetime of PV systems, in accordance with the price of electricity supplied by the utility grid; these all are reflected in the so-called Net Present Value (NPV). The evaluation can also be considered as recommendations to the government the subsidy it should create to encourage the use of PVs in households. Finally, a case study in Vietnam is provided showing the NPV of PV systems at the different levels of the retail price of electricity.*

Key Words: Photovoltaics, Solar energy, Net present value, Renewable subsidy

1. INTRODUCTION

Renewable energy is the energy produced from a source that is not permanently depleted, e.g., sunlight, wind, flowing water, geothermal and plants, etc. The use of Renewable Energy Sources (RESs) in electric power industry can be thought as one of the means for achieving the Greenhouse Gases (GHGs) emission target set in the Kyoto Protocol agreement [1]. A significant increase of renewable markets in the last decade of 20th century is mainly due to many public policies that are made worldwide: Renewable Electricity Standard in the U.S. [2], [3] and Renewable Obligation in UK [4], [5] which requires electric supply companies to produce a specified fraction of their electricity from RESs; the feed-in tariff in Nordic countries [6], [7], which assures electricity from RESs is purchased at a special price according to the production cost of the various technologies which is much higher than the spot market price.

Vietnam, a tropical country located near the Equator, is greatly potential of solar energy. The average solar radiation is estimated about 5kW/m^2/day in the Sourth, and 4kW/m^2/day in the North of Vietnam; in addition, it is stable during the year, the variant is less than 20% between the dry and rainy season. More importantly, in many rural areas, the utility grid is not available; the cost of building transmission line is extremely high due to the long distance but low load. In this case, solar energy seems to be the best choice with an isolated electric grid supplied by PV panels. Therefore, to promote the use of PVs, there is a need to evaluate the economics of PV systems: Whether or not a PV system should be built under a certain circumstance, compared to other options, i.e., building connections to the utility grid; in the other case where the utility grid is available, how is subsidy the government should give to make PVs attractive and competitive compared to the conventional sources, e.g., coal-fired power plants.

Addressing those questions, the remainder of the paper is organized as follows. Section 2 provides the background of the relative position between the Earth and the Sun during the year; the theoretical estimation of solar radiation in a given place (latitude and longitude) on the Earth. Section 3 presents the different kinds of sun tracking used in PV systems and the solar energy they may collect. Section 4 is for the economic evaluation of PV systems; the associated costs are considered and taken into the formulation of NPV. Section 5 gives a case study where the problem is applied to evaluate the NPV of PV systems in residence both with and without the utility grid. Finally, the remarkable points are summarized in the Conclusion.

2. BACKGROUND

The Earth is rotating around the Sun; therefore, their relative position is changing over time. To evaluate the total energy received by the Earth's surface, we must consider the position of the Earth according to the day number called *n* of the year (all parameters in this study depend directly or indirectly on the day number) [7].

2.1 Air Mass Ratio, m

The length of the path h_2 taken by the Sun's rays as they pass through the Earth's atmosphere, divided by the minimum possible path length h_1, which occurs when the sun is directly overhead, is called the *air mass ratio*, *m*.

$$m = \frac{1}{\sin \beta} \quad (1)$$

where β is the angle between the sunlight and Earth's surface [rad].

2.2 Optical Depth, k

Optical depth is the natural logarithm of the ratio of incident to transmitted fluxes.

$$k = \ln\left(\frac{\Phi_e^i}{\Phi_e^t}\right) = -\ln T \qquad (2)$$

where Φ_e^t is the radiant flux transmitted by that material, [W]; Φ_e^i is the radiant flux received by that material, [W]; and T is the transmittance of that material. The optical depth can be calculated by the empirical equation as follows.

$$k = 0.174 + 0.035\sin\left[\frac{360}{365}(n-100)\right] \qquad (3)$$

where n is the day numbers

2.3 Apparent Extraterrestrial Flux, A

The "apparent" extraterrestrial flux, A, [W], is given by

$$A = 1160 + 75\sin\left[\frac{360}{365}(n-275)\right] \qquad (4)$$

2.4 Sky Diffuse Factor, C

The sky diffuse factor, C, becomes larger when the sky is clear

$$C = 0.095 + 0.04\sin\left[\frac{360}{365}(n-100)\right] \qquad (5)$$

2.5 Solar Declination, δ

Solar declination is the angle formed between the plane of the Equator and the line drawn from the center of the sun to the center of the Earth. We know that the Earth is rotating around the Sun and around its own axis. Since the change of its axis's angle is so small that we can assume the tilt angle of the Earth is constant in a day. The Sun is relatively fixed. Thus, the solar declination is changing with respect to the day number n.

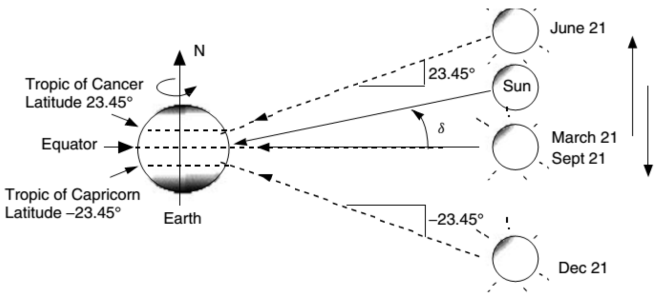

Fig -1: Solar declination.

The calculation for solar declination is given as follows.

$$\delta = 23.45\sin\left[\frac{360}{365}(n-81)\right] \qquad (6)$$

2.6 Altitude Angle of the Sun, β

The Sun's position relative to the Earth is always changing in a day, by calculating the altitude angle of the Sun, the angle between solar beam and the Earth's surface, we can easily calculate the energy from the Sun at any moment in a day.

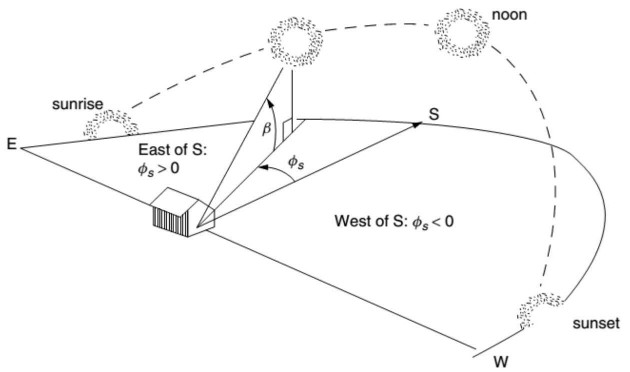

Fig -2: Altitude angle of the Sun at any time in a day.

$$\beta = \sin^{-1}(\cos L\cos\delta\cos H + \sin L\sin\delta) \qquad (7)$$

where L is the latitude, [rad]; δ is the solar declination, [rad]; and H is the hour angle before solar noon, [rad].

$$H = \frac{15°}{hour} \qquad (8)$$

2.7 Hour Angle at Sunrise/Sunset

The hour angles at sunset and sunrise, H_{SR}, H_{SS}, give information about the time of the Sun shining on Earth. At sunset and sunrise, the altitude angle β is zero, so we can write

$$\sin\beta = (\cos L\cos\delta\cos H + \sin L\sin\delta) = 0 \qquad (9)$$

Solving for the hour angle at sunrise gives

$$H_{SR} = \cos^{-1}(-\tan L\tan\delta) \qquad (10)$$

and at sunset

$$H_{SS} = -\cos^{-1}(-\tan L\tan\delta) \qquad (11)$$

2.8 Solar Azimuth Angle, ϕ_S

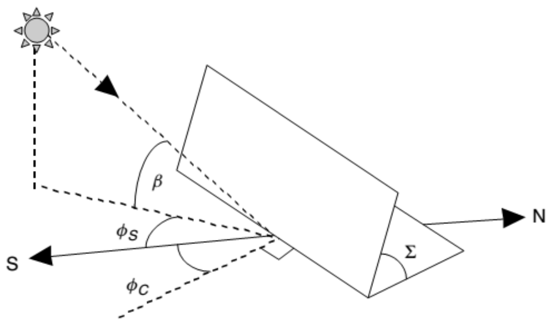

Fig -3: Solar azimuth angle ϕ_S, collector azimuth angle ϕ_C, solar declination β, and collector tilt angle Σ.

The incidence angle is dependent on the solar azimuth angle ϕ_S. Before solar noon, the value of ϕ_S is positive, and negative after solar noon.

$$\sin\phi_S = \frac{\cos\delta\sin H}{\cos\beta} \quad (12)$$

2.9 Incidence Angle, θ

It is useful to calculate the direct radiation if we know the incidence angle which is the angle between the collector surface and the incoming solar beam radiation.

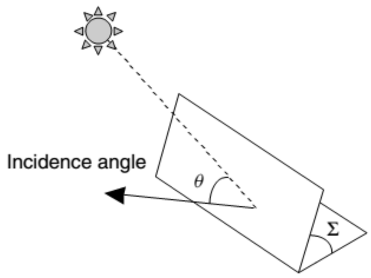

Fig -4: Incidence angle.

The incidence angle can be derived from

$$\cos\theta = \cos\beta\cos(\phi_S - \phi_C)\sin\Sigma + \sin\beta\cos\Sigma \quad (13)$$

2.10 Direct Beam Radiation, I_{BC}

The total radiation from the Sun to the Earth can be divided into three components: Direct beam radiation, diffuse radiation and reflected radiation [Fig -5]. Among these three components, the direct beam radiation is the most important which carries greatest amount of energy.

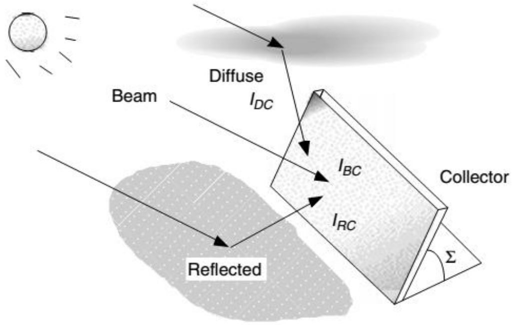

Fig -5: Three components of solar radiation.

The direct beam radiation is given by

$$I_{BC} = Ae^{-km}(\cos\beta\cos(\phi_S - \phi_C)\sin\Sigma + \sin\beta\cos\Sigma) \quad (14)$$

2.11 Diffuse Radiation, I_{DC}

The diffuse radiation, [W], is mainly caused by the diffusion of direct beam through cloud, tree or dust.

$$I_{DC} = CI_B\left(\frac{1+\cos\Sigma}{2}\right) \quad (15)$$

where C is the sky diffuse factor, I_B is direct-beam radiation given by

$$I_B = Ae^{-km} \quad (16)$$

2.12 Reflected Radiation, I_{RC}

When some parts of the diffuse or direct beam radiation strike a surface, for example, the Earth's surface, the reflected radiation appears as the result.

$$I_{RC} = \rho(I_{BH} + I_{DH})\left(\frac{1-\cos\Sigma}{2}\right) \quad (17)$$

where I_{BH} is the beam insolation on a horizontal surface, [W]; I_{DH} is the diffuse insolation on a horizontal surface, [W]; and ρ is the reflectance. I_{RC} is calculated in [W]

3. SOLAR TRACKING SYSTEMS

The purpose of solar tracking systems is to increase the amount of energy received by a PV panel, i.e., make the sunlight projects orthogonally on the collector. PVs can be used with or without solar tracking systems; depending on the number of rotating axes, they are categorized as fixed-axis, one-axis and two-axis collectors. Each kind of tracking systems would result in different amounts of energy that the collector can receive.

3.1 Fixed-axis Collector

This kind of collectors is set fixed on the ground with that the orientation is unchangeable. The disadvantage of fixed-axis collectors is low capacity factor since the Sun light is rarely perpendicular to its surface; however, it is cheap and easy to build. To receive the maximum energy, the azimuth angle should be 0^0, i.e., the collector faces South direction; the tilt angle equals the Latitude, means $\phi_C = 0°$ and $\Sigma = L$, [Fig -6].

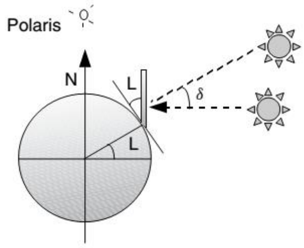

Fig –6: Fixed-axis collector.

Since the collector is set to face South direction, the direct beam radiation, I_{BC}, reaches maximum at noon and decrease at H_{SR} and H_{SS}.

$$I_{BC} = Ae^{-km}\cos\theta \quad (18)$$

or

$$I_{BC} = Ae^{-km}(\cos\beta\cos\phi_S\sin\Sigma + \sin\beta\cos\Sigma) \quad (19)$$

The diffuse radiation, I_{DC}, is given by

$$I_{DC} = CI_B\left(\frac{1+\cos\Sigma}{2}\right) \quad (20)$$

The reflected radiation, I_{RC}, is given by

$$I_{RC} = \rho(I_{BH} + I_{DH})\left(\frac{1-\cos\Sigma}{2}\right) \quad (21)$$

3.2 One-axis Collector

For a better capacity factor, the collector can be controlled rotating arround one axis. To achieve maximum energy, the rotating axis is facing sourth and tilt angle equals the Latitude, means $\phi_C = 0°$ and $\Sigma = L$, [Fig -7].

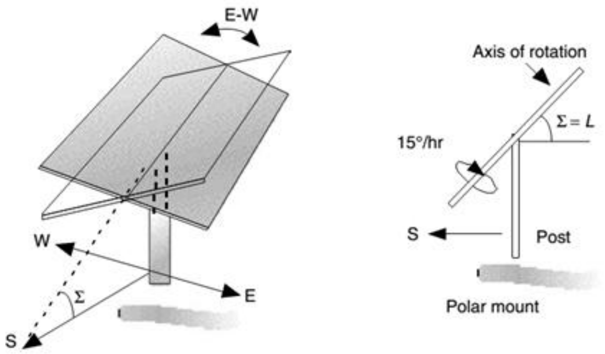

Fig -7: An one-axis east-west tracking system.

In this case, the angle θ equal the solar declination δ, therefore, the direct beam radiation is given by

$$I_{BC} = I_B \cos\delta \qquad (22)$$

For an one-axis tracking system, the collector's tilt angle, Σ, equals the latitude, L, therefore, the diffused radiation for a fixed axis collector given by

$$I_{DC} = CI_B\left(\frac{1+\cos L}{2}\right) \qquad (23)$$

The reflected radiation, I_{RC}, is

$$I_{RC} = \rho\left(I_{BH} + I_{DH}\right)\left(\frac{1-\cos L}{2}\right) \qquad (24)$$

3.3 Two-axis Collector

The collector can be controlled in two directions, both azimuth angle and tilt angle.

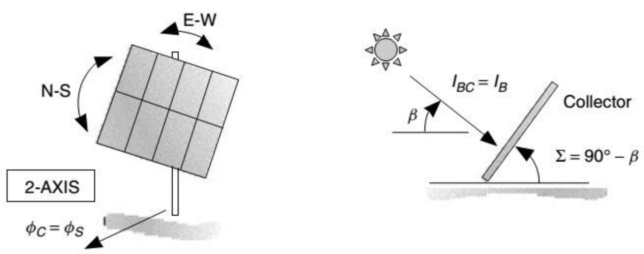

Fig -8: Two-axis tracking angular relationship.

In this case, the direct radiation is the same as direct beam radiation because the collector is always perpendicular to the sunlight.

$$I_B = I_{BC} = Ae^{-km} \qquad (25)$$

For a two-axis collector, the collector's tilt angle, Σ, equals 90 – β, therefore, the diffuse radiation is

$$I_{DC} = CI_B\left[\frac{1+\cos(90-\beta)}{2}\right] \qquad (26)$$

The reflected radiation I_{RC} is then given by

$$I_{RC} = \rho\left(I_{BH} + I_{DH}\right)\left[\frac{1-\cos(90-\beta)}{2}\right] \qquad (27)$$

3.4 Estimate the Solar Energy Received by a Collector

The solar energy received by a collector depends on many factors such as location, diffusion, reflection, and more importantly, the type of tracking systems used. In the following, we will estimate the solar energy in a given place: Thai Nguyen University of Technology, Thai Nguyen, Vietnam with the longitude and latitude are 21.55º N and 105.85º E; with different types of tracking the collector may receive. The amounts of direct- beam, diffuse and reflected radiations are shown in Fig -9, 10 and 11.

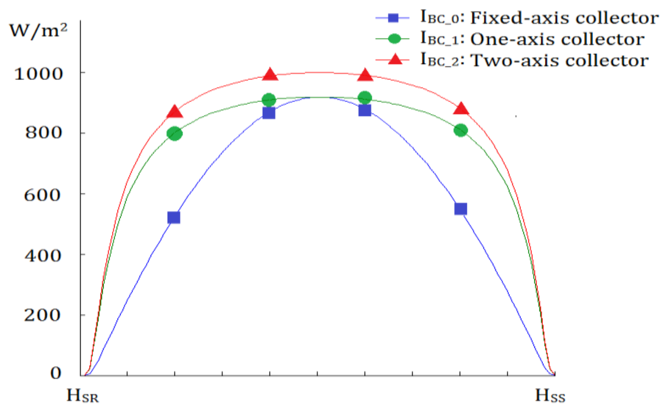

Fig -9: The direct beam radiation, W/m².

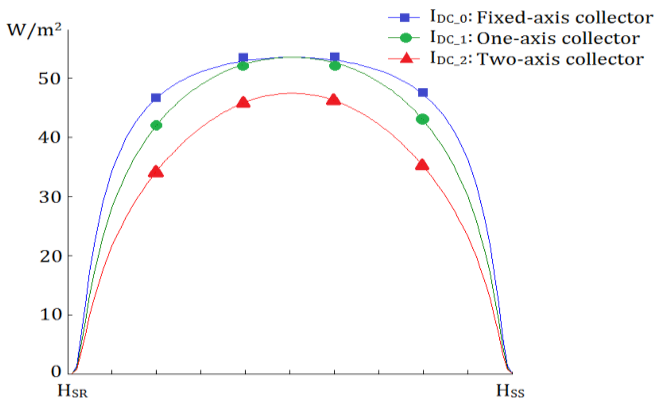

Fig -10: The diffuse radiation, W/m².

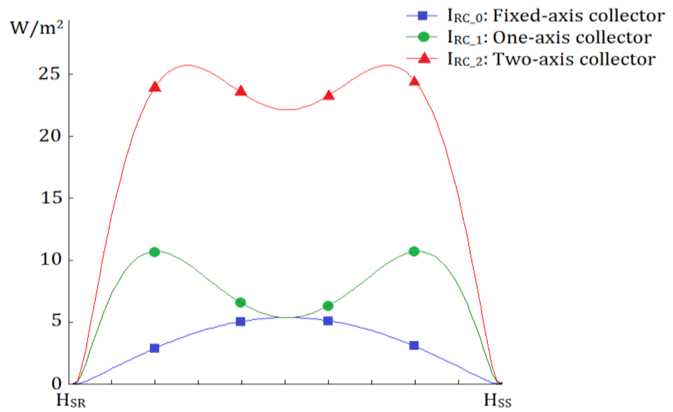

Fig -11: The reflected radiation, W/m².

The total insolation the collector receives is the sum of direct beam, diffuse and reflected radiation [Fig -12].

$$I_C = I_{BC} + I_{DC} + I_{RC} \quad (29)$$

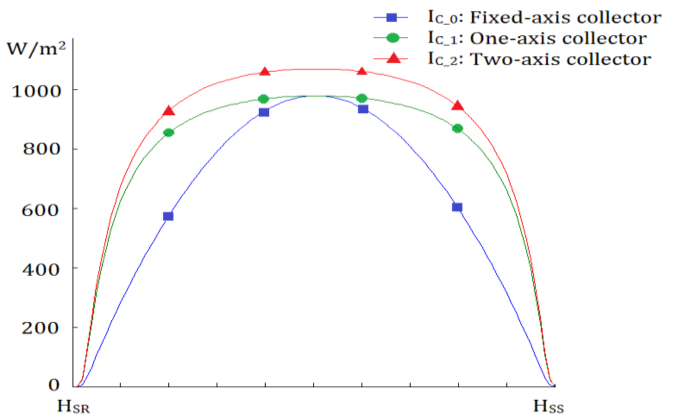

Fig -12: Comparison of total insolation received by fixed axis, one-axis, two-axis collector in a day.

It is obvious that the two-axis collector receives the largest amout of energy while the fixed-axis collect gives the lowest amount. The solar energy each day in one year and the accumulated amount of direct beam, difuse and reflected radiations are shown in Fig -13 and Table 1.

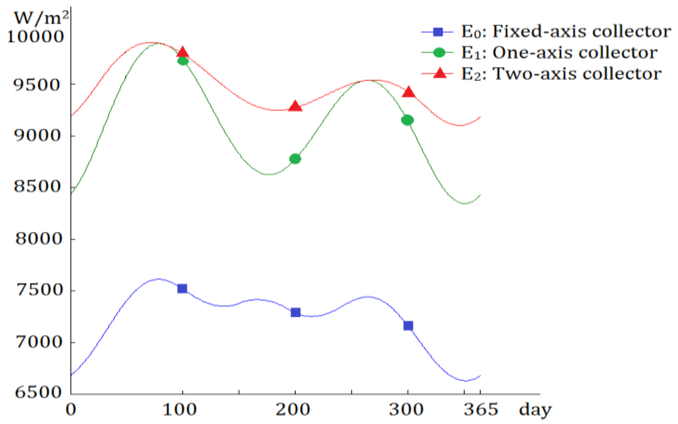

Fig -13: Total energy received by an 1-m² collector in a year, Wh/m².

Table -1: Total energy received in one year (MWh).

Components	Types of tracking systems, (MWh).		
	Fixed-axis	One-axis	Two-axis
Direct radiation	2.34	3.01	3.14
Diffuse radiation	0.29	0.25	0.25
Reflected radiation	0.02	0.07	0.06
Total	2.65	3.33	3.45

4. ECONOMIC EVALUATION OF RESIDENTIAL PV SYSTEMS

4.1 Cost of PV Systems

4.1.1 Capital Cost

Capital cost is the cost used to build the PV systems initially, including the cost for PV panels, batteries (if needed), inverters, and control systems.

$$C_{Cap} = C_{PV} + C_{Bat} + C_{Inv} + C_{Con} \quad (30)$$

where C_{Cap} is the capital cost, [VND]; C_{PV} is the PV cost, [VND]; C_{Bat} is the battery cost, [VND]; C_{Inv} is the inverter cost, [VND]; and C_{Con} is the controller cost, [VND].

4.1.2 Operation and Maintenance Cost

This cost is the expense related to the operation of PV systems, including the cost of fuels, maintenance and the replacement of equipments during the project lifetime. For residential PV systems, there is no fuel cost; the operation and maintenance cost, $C_{O\&M}$, is mainly concerned with the replace of batteries, converters and controller since their lifetimes are shorter than PV panels.

4.2 Revenue

Revenue can be thought as the saving of electricity charge when a portion of loads is provided by PV systems. Therefore, the revenue is closely related to the price of electricity.

$$R = \rho_e \cdot E_{PV} \quad (31)$$

where ρ is the market price, [VND/kWh]; and E_{PV} is the energy received by PV systems, [kWh].

4.3 Net Present Value

Net Present Value (NPV) of a project is defined as the present value of the stream of expected net cash flows from the project minus the project's net investment. The following is the formula for calculating NPV, [8].

$$NPV = \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \quad (32)$$

where C_t is net cash inflow during the period, [VND]; r is discount rate; and t is number of time periods, [year]. The case inflow is given by

$$C_t = R_t - C_{Cap} - C_{O\&M,t} \quad (33)$$

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NPV is a useful tool to determine whether a project or investment will result in a profit or a loss because of its simplicity. A positive NPV means profitable, while a negative NPV means losing [8].

4. CASE STUDY

4.1. Residential PV Systems

A typical PV system in residence is shown in Fig -14; the system consists of a PV panel to transform solar energy to electricity in DC; a DC/DC converter and/or DC/AC inverter to convert DC electricity at low voltage into AC electricity at desired voltage. There are two control mechanism for this PV system: (1) solar tracking and (2) maximum power point tracking which ensures the largest amount of electricity the system can provide.

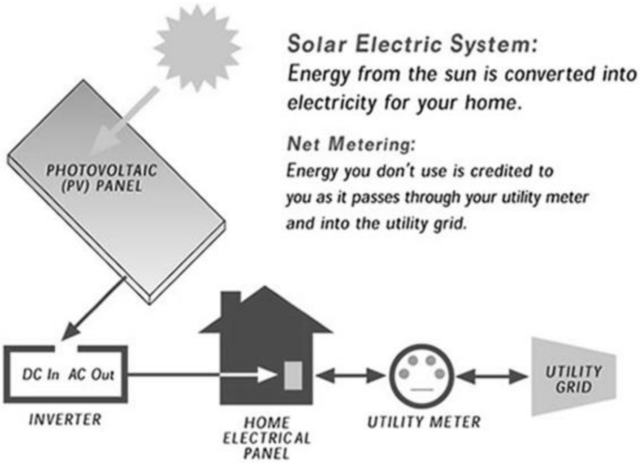

Fig -14: The PV system in residence.

4.2 Net Present Value

4.2.1 Capital cost

PV panel

- The 1-m^2 PV panel
- Efficiency of 15%
- Lifetime 20 – 30 years
- Cost: 3,500,000 VND/m^2

From the previous section, we have found that the total energy the collector receive is about 7kWh/m^2/day

Energy from collector is 15%x7 = 1,050kWh/day/m^2

Battery

- A 12V/100Ah battery
- Efficiency of 80%
- Lifetime: 3 years
- Cost: 1,900,000 VND

The capability of the battery needed is

$$\frac{1050}{0.8\times 12}\times 1.5 = 165Ah$$

The required capability of battery should be greater than 165Ah so we choose 2 batteries of 12V/100Ah. The total cost for battery is 1,900,000 x 2 = 3,800,000 VND.

Inverter

We use an *inverter* to convert the DC into AC electricity.

- An 500W-inverter
- Lifetime of 4 years.
- Cost: 1,000,000 VND

Solar charge controller

We need a solar charge controller to control the charging for battery.

- A 20A/12V controller
- Lifetime: 4 years
- Cost: 1,000,000VND

Table -2: Total capital cost of a PV system.

Components	Cost (VND)
PV Panel	3,500,000
Battery	3,800,000
Inverter	1,000,000
Solar Charge Controller	1,000,000

4.2.2 Operation and Maintenance Cost

As about-discussed, this cost is related to the replacement of batteries, inverter and controller after a certain period of time, i.e., the lifetime of batteries is 3 years, inverters and controllers is about 4 years.

4.2.3 Revenue

The revenue is dependent on the price of electricity bought from the utility grid. In Vietnam, the retail price is in stair-block form, the larger electricity usage; the higher price customer must charge [9].

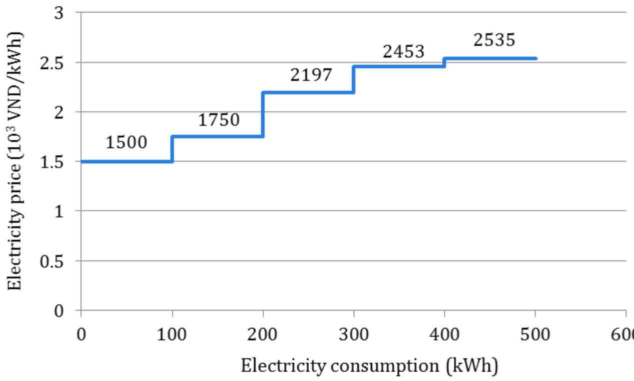

Fig -15: Electricity price for household consumer applied from 16/03/2015 in Vietnam [10].

As calculated before in Table -1, in one year, on 1-m^2 panel, with two-axis tracker, people can get 3.45MWh, the collector's efficiency is 15%. The total energy that collector can produce is $3.45MWh \times 15\% \approx 520$ kWh/year

Therefore, the total revenue is

$$520\times 1,750 = 910,000 \text{ VND/year}$$

Note that we assume the family is using electricity from 1-m² collector.

4.3 With the Utility Grid

In the grid-tied PV system, the expense of battery can be avoided; the difference between generation and loads will be compensated by the utility grid. The revenue is dependent on the price charged for the amount of electricity if the PV system is not used. For example, if the customer's monthly consumption is less than 100kWh, the price charged is 1,500 VND/kWh. Therefore, the revenue can be estimated as 520 x 1,500 = 780,000 VND. Let the discount rate to be 10% as widely accepted in Vietnam, the NPV of the project is shown in Fig -16.

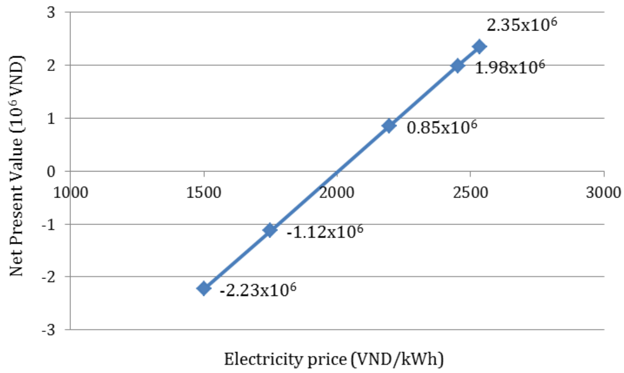

Fig -16: Net present value of the grid-tie PV systems at different price levels.

The result shows that the project is losing when the electricity price is low (1,500 and 1750 VND/kWh), but profitable when the price is at higher levels (2,197; 2,453 and 2,535 VND/kWh). This means, if the monthly consumption of customers is less than 200 kWh, they should not use PVs since the cost of generating electricity is higher than buying from the utility grid. On the other hand, if their consumption is greater than 200 kWh, i.e., the price charged for exceeded electricity is higher (from 2,197 to 2,535 VND/kWh), the customer should build a PV system to self-provide this additional consumption. It is profitable with the positive NPV. The customer is indifferent when the price is about 2,000 VND/kWh because NPV at this price is nearly zero.

4.4 Without the Utility Grid

In the case without the utility grid, a battery bank is needed, storing electricity in the day time for the consumption at night. Assume that in this rural area, the demand is low, thus, the price of 1,500 VND is applied here. The cash inflow and its present value are shown in Table -3.

Table -3. Net present value of the project without the utility grid.

Year	Net cash inflow (10^3 VND)	Present value (10^3 VND)	Year	Net cash inflow (10^3 VND)	Present value (10^3 VND)
0	-9,300	-9,300	11	780	273.385
1	780	709.090	12	-5,020	-1,599.526
2	780	644.628	13	780	225.938
3	-3,020	-2,268.970	14	780	205.398
4	-1,220	-833.276	15	-3,020	-722.963
5	780	484.318	16	-1,220	-265.507
6	-3,020	-1,704.711	17	780	154.318
7	780	400.263	18	-3,020	-543.173
8	-1,220	-569.139	19	780	127.536
9	-3,020	-1,280.774	20	780	115.942
10	780	300.723	NPV		-15,446.5

In this case, NPV is dramatically negative. The main reason is that without the utility grid, a battery bank is required to match the generation and load which usually take place in different time of the day. This equipment is not only expensive but also short in lifetime; and it needs replacement frequently. This, in turn, dramatically raises the cost of producing electricity, makes the project unprofitable. The other reason is that the residential demand in rural areas is low; this makes the scope of the project not reaching the economical scope of PV systems. In addition, a very important factor is not considered in the calculation of NPV in this case: The cost to build electric connection to the utility grid. It should be referred as the revenue of the project, i.e., the saving of the PV system. Therefore, as long as this cost greater than the NPV in Table -3, the project is profitable; otherwise, it is not.

5. CONCLUSIONS

In this paper, we have presented the estimation of the theoretical amount of solar energy in a certain place on the Earth. This is based on the analysis of the relative position between the Earth and Sun during the year as the Earth rotates around the Sun and itself. It is then used to evaluate the economics of PV projects in residence. The revenue in term of electricity received and the cost of PV system's components are considered in the whole project lifetime and taken into account the NPV. The project is said to be profitable if NPV is positive; otherwise, it is losing. The case study shows that, with the availability of the utility grid, the project is profitable for large residential customers (the consumption is greater than 200 kWh per month), but not for small electric users (less than 200 kWh). These results also mean that, to encourage the use of PVs, the government should give incentives to residential customers, making the electricity generated by PV systems worth at least 2,000 VND/kWh (the price at which customers are indifferent in implementing the project). In case without the utility grid, NPV is critically negative. This is mainly due the expensiveness of the battery needed to match generation and loads. However, it is hard to say the project is losing or not when comparing with other options, i.e., building the connection to the utility grid, it is also costly.

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BIOGRAPHIES

Bui Huy Binh is current a senior student at Dept. of Electrical and Computer Engineering, Faculty of International Training, Thai Nguyen University of Technology. His research interest includes renewable energy, integrations of alternative energy resources in power systems.

Nguyen Trong Giap is a junior student at Dept. of Electrical and Computer Engineering, Faculty of International Training, Thai Nguyen University of Technology. His research interest includes renewable energy, controls in power systems.

Nguyen Minh Y received the B.Sc. in electrical engineering from Ha Noi University of Science Technology, Vietnam in 2006, M.Sc. and Ph.D. in electrical engineering from Seoul National University, Seoul, Korea in 2009 and 2013, respectively. He is currently a full-time lecturer with Dept. of Electrical Engineering, Faculty of International Training, Thai Nguyen University of Technology, Vietnam. His research interests are power system operation, integration of alternative sources, distributed generation and microgrid.

