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A Simulation Method to Find the Optimal Design of Photovoltaic Home System in Malaysia, Case Study: A Building Integrated Photovoltaic in Putra Jaya

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***Abstract*—**Over recent years, the number of building integrated photovoltaic (BIPV) installations for home systems have been increasing in Malaysia. The paper concerns an analysis - as part of current Research and Development (R&D) efforts - to integrate photovoltaics as an architectural feature of a detached house in the new satellite township of Putrajaya, Malaysia. The analysis was undertaken using calculation and simulation tools to optimize performance of BIPV home system. In this study, a the simulation analysis was undertaken for selected bungalow units based on a long term recorded weather data for city of Kuala Lumpur. The simulation and calculation was done with consideration of a PV panels' tilt and direction, shading effect and economical considerations. A simulation of the performance of a grid connected BIPV house in Kuala Lumpur was undertaken. This case study uses a 60 PV modules with power output of 2.7 kW giving an average of PV electricity output is 255 kWh/month..

***Keywords*—**Building integrated photovoltaic, Malaysia, Simulation, panels' tilt and direction.

I. Introduction

DEVELOPING clean energy resources as alternative to oil become one of the important task assigned to modern science and technology. The reason for this strong motivation is to stop air pollution resulting from the mass consumption of fossil fuels and to keep the ecological cycle of the biosystems on the earth. Among a wide variety of renewable energy project in progress, photovoltaic (PV) cells is the most promising one of as a future energy technology. The direct conversion of solar radiation to electricity by PV cells has a number of significant advantages as an electricity generator. One of the most promising applications of PV power generation is used for residential PV system hooked up to utility grid [1]. This interconnection system permits the excess power produced by the PV system can be sold to the utility. The grid itself constitutes the backup when the PV system's output is not sufficient to satisfy the load, or in the unlikely event the array fails to operate.

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Over recent years, the number of building integrated photovoltaic (BIPV) installations for home systems have been increasing in the world as well as Malaysia. For the optimum design of BIPV systems, it is important to determine their performance at the site installation. Since the amount of power produced by a PV panel depends upon the amount of region's solar irradiation and temperature.

For optimum design of PV system in certain region, the estimation of long term system performance is necessary. One of the approaches to obtain this information is by employing a computer simulation.

The analysis was undertaken using calculation and simulation tools to optimize performance of BIPV home system in the new satellite township of Putrajaya is situated 25 kilometers from city of Kuala Lumpur, Malaysia. In this study, a the simulation analysis was undertaken for selected bungalow units in order to calculate factors which influence the performance of BIPV home system, based on a long term recorded weather data for city of Kuala Lumpur.

Nomenclature

P_s	Total Solar Irradiation [kW/m^2]
P_d	Direct component of Solar Irradiation [kW/m^2]
P_r	Diffuse component of Solar Irradiation [kW/m^2]
H	Sun Elevation
θ	Oblique angle of sun [radian]
α	Azimuth angle of the sun [radian]
δ	Declination of the sun [radian]
ω	Hour angle [degree]
ϕ	North latitude
P_{0d}	Direct (normal) Irradiation [radian]

P_{0r}	Diffuse (horizontal) Irradiation [radian]
P_0	Global Horizontal Irradiation [kW/m^2]
L	Latitude [degree]
D	Declination of the sun [degree]
T	Hour angle [degree]
I_{ph}	Photovoltaic Current [A]
I_{ph0}	Photovoltaic Current at base condition (temperature=25 oC and irradiation 1 kW/m^2)[A]
T_c	Module temperature [K]
T_{air}	Outside air temperature [K]
I_0	Diode Saturation Current [A]
V	PV voltage [V]
I	PV current [A]
R_s	Inner series resistance [Ω]
R_p	Inner parallel resistance [Ω]
q	Electric charge [C]
D_p	Diode factor
k	Boltzman constant
G_0	Generated Power output of PV [W]
V_{OC}	Open-circuit Voltage [V]
I_{SC}	Short-Circuit Current [A]
V_{max}	Maximum Voltage [V]
I_{max}	Maximum Current [A]
P_{max}	Maximum Power [W]

II. Solar Radiation in Kuala Lumpur

Kuala Lumpur is located at North longitude 3.7 and East longitude 101.33, lies entirely in the equation region and the city is at an elevation of about 50 m. The data of solar radiation of Kuala Lumpur is based on The Solar Radiation Research in The Sunshine Project of Japan (1601 points over the world) of New Energy and Industrial Technology Development Organization (NEDO) issued by Japan Weather Association on 1989 [2]. Fig. 1 shows the solar radiation and ambient temperature records summarized by mean monthly. The average monthly of solar irradiation and temperature is 131 kWh/m^2 and 25 ^{o}C respectively. Heavy rainfall, constantly high temperature and relative humidity characterize the Kuala Lumpur as well as Malaysian climate. Generally, the rain falling most in the afternoon or early evening with the monthly average daily sunshine ranging from 4 hr to 8 hr [3].

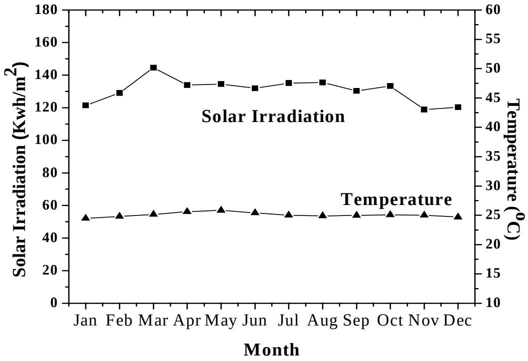


Fig. 1 Summarized monthly the solar radiation and ambient temperature of Kuala Lumpur

III. Simulation Procedure

We use special software such as Solar Pro[2] that contains most items concerned with PV generation. The electricity generated based on longitude, latitude, azimuth angle, oblique angle, and shade on the array from nearby building. In addition, it contains the characteristics of each module as whole circuit, inverter characteristics and reduction ration. Solar radiation is calculated as follows,

$$P_s = P_d + P_r \qquad (1)$$

$$P_d = (H\cos\theta - \sin\theta\cos\alpha\sin\delta\cos\phi + \sin\theta \cos\alpha\cos\delta\sin\phi\cos\omega + \sin\theta\sin\alpha \cos\delta\sin\omega)\times P_{0d} \qquad (2)$$

$$P_r = P_{0r}(1+\cos\theta)/2 + 0.2\times P_0 \times(1-\cos\theta)/2 \qquad (3)$$

Where H is the sun elevation can be expressed by the following equations:

$$H = \sin^{-1}(\cos L\times\cos D\times\cos T + \sin D\times\sin L) \qquad (4)$$

The photovoltaic current (I_{ph}) can be calculated use:

$$I_{ph} = I_{ph0}\left\{1 + 5.1029\times10^{-4}(T_c - 298.16)\right\} \times\left[1.03\times P_r - 0.03\left\{1-\exp(-8\times P_s\right\}\right] \qquad (5)$$

And the I-V characteristics of solar cell module are based on the following equation.

$$I = I_{ph} - I_o[\exp\left\{C(V + I\times R_s)\right\} - 1] - (V + I\times R_s)/R_p \qquad (6)$$

$$C = q/(D_p \times k \times T_c) \quad (7)$$

$$T_c = T_{air} + 45 \times P_s \quad (8)$$

Power system generation is calculated use:

$$G_o = \text{PV power} \times \text{Inverter Efficiency } (0.92) \times \text{Reduction Coefficient } (0.92) \quad (9)$$

IV. Simulation Results

A. The calculation of effective angle and direction of Photovoltaic Module in Kuala Lumpur

Same papers reported that the performance of a photovoltaic panel is affected by its direction and its tilt angle with the horizontal plane [4,5], we calculated the correlation between PV performance and its direction and tilt angles. In this simulation we use a PV module connected to grid, where the PV module specification is shown in Table I.

TABLE I
SPECIFICATION OF PV MODULE WHICH USED IN THIS SIMULATION (BASED ON CONDITION OF TEMPERATURE 25^{o}C AND IRRADIATION IS 1.0 KW/M^2)

Type	KC-40 (Kyocera)
V_{OC}	21.5 [V]
I_{SC}	2.48 [A]
V_{max}	16.90 [A]
I_{max}	2.34 [A]
P_{max}	40 [W]

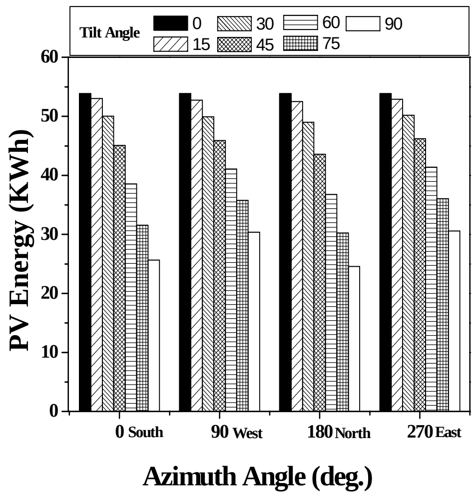


Fig. 2 Summary of simulation results of the annual output of PV energy with variation of azimuth angle and tilt angle

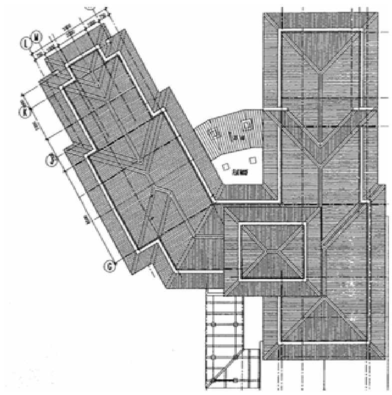
The simulation result shown in Fig. 2. Where the optimum PV module tilt angle (inclination) in Malaysia is between 0° and 15° and orientation of the system facing either North, South, East or West will generate an almost equal energy yield with difference ±1%. The orientation of the PV installation is not so important in Kuala Lumpur.

B. A Case Study: Design of BIPV System for a Bungalow in Putrajaya

A BIPV system will be installed to a selected bungalow in Putrajaya. The architectural diagram of this bungalow described in Fig. 3. The function of PV system in this bungalow is to support electricity and contribute in reducing of electric cost, not as main electric source, the main of electric source for this bungalow is from grid system.

The simulation and calculation was done with consideration of an optimal PV panels' tilt and direction as obtained in Fig. 2.

(a)



(b)

Fig. 3 Architectural diagram of a bungalow in Putrajaya which used as model in this simulation (a) Face View and (b) Top View

We use same PV modules (KC40) as has been done in simulation to determine PV panels' tilt and direction as obtained in Fig. 2. The number of PV modules are 60, with connected (Series x parallel: 10 x 6). We calculated the total power output at standard condition for PV modules network is 2.72 kW. This PV module installed on the roof of water tank as shown in Fig. 4. Direction of PV modules is on South (17 modules), West (13 modules), North (17 modules) and East (13 modules) and tilt of module is fixed 15^o.

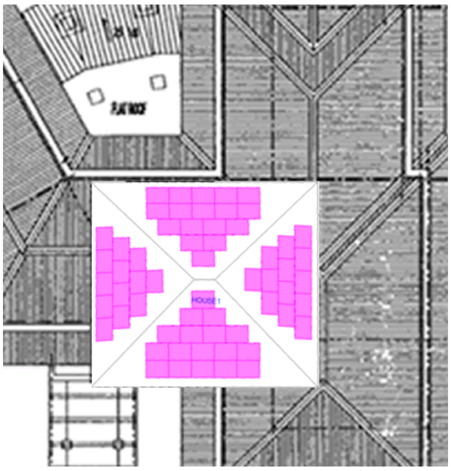


Fig. 4 Position and arrangement of PV modules on Water tank roof

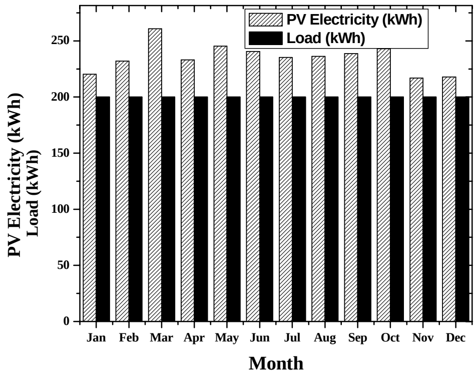


Fig. 5 The calculated energy output and load of BIPV system in a year

The technical configuration of the BIPV system in here is grid connected without use battery as normally the BIPV system in urban area. The load of electricity we assumed as normal electric consumption load for medium house in Malaysia that is 200kWh/month. The cost estimation to build BIPV system in Malaysia currently is RM 25,000/kWp or USD 6867/kW, Total for 2.72 kW for this BIPV system we need USD 18,540. Electric price for buying and selling in Malaysia currently is RM 0.218/kWh or USD 0.06/kWh.

Using these parameters and consideration of a PV panels' tilt and direction, shading effect and economical aspects we did simulation for one year operation based on a long term recorded weather data for city of Kuala Lumpur and results of the simulation described in Fig. 5.

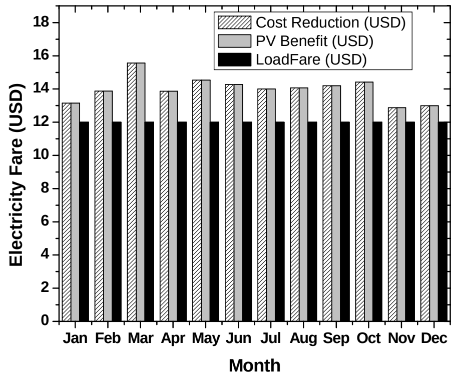


Fig. 6 The calculated cost reduction, PV benefits and Load of BIPV System

Fig. 5 shows the calculated energy output and load of BIPV system in a year, the average energy produced by the BIPV system is 240kWh/month or total in a year is 2800kWh, we compared the result in Fig. 5 and Fig. 1 and we can conclude that PV electricity output is proportional with solar irradiation energy which received by PV modules.

Fig. 6 shows the economical calculation for this BIPV system. Using BIPV system the expenditure cost for electricity can be reduced till USD 15/month or USD 279/year and this is one of benefits which can be yield from the BIPV system.

We also calculated the payback period for this BIPV system, if the cost estimation to build the 2.72 kW BIPV system in Malaysia is USD 18,540 and its benefit is USD 279/year, then the payback period is 72 years as shown in Fig. 7, this is almost three time longer than the lifetime of the PV modules themselves. The break even point about 25 years is possible to be reached if the PV system cost drop about 30% of present value or the energy cost rises to 300% of present value, although the economically still not efficient but the BIPV system contributes to reduce the air pollution.

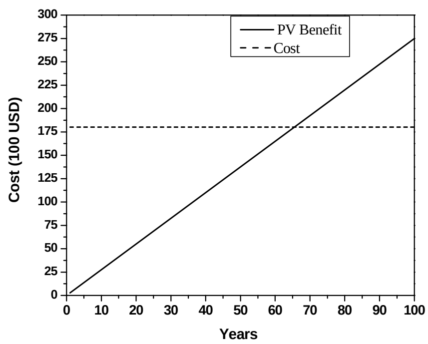


Fig. 7 The calculated payback period for the BIPV system

V. Conclusion

The optimum values of tilt angles and direction of a PV panel in Kuala Lumpur were determined using simulation method. Where the optimum PV module tilt angle (inclination) in Malaysia is between 0° and 15° and any orientation of the system facing either North, South, East or West.

Using this optimum value we calculated the energy output and economy analysis for a bungalow in Putrajaya. The average electric energy produced by the BIPV system is 240kWh/month or total cumulative production energy in a year is 2800 kWh, and it give benefit about USD 279/year.

Break event point for this system still far than our wishes, but this system give a contribution in reducing air pollution and promoting the clean energy.

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