SYSTEM DESIGN AND SIMULATION OF OFF-GRID PHOTOVOLTAIC SYSTEM FOR RURAL ELECTRIFICATION IN MYANMAR

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Abstract: Global environmental concerns, increasing energy demands and developments in renewable energy technologies present a new possibility to implement renewable energy sources. Solar energy is the most prominent among renewable sources, as it is an inexhaustible resource and its exploitation has thus far been ecologically friendly. The potential amount of solar energy is considerably greater than current worldwide energy demands. Solar energy has been developing more rapidly than the other renewable energy sources for the last few decades. In this paper, a proposed area, Bodawtaw village which is located at 22.579N latitude and 95.698E longitude, Shwebo District, Sagaing Region in Myanmar where there is no access the electricity from national grid and it is also very expensive to extend the grid, which is chosen and the renewable energy potential for this region is evaluated to make the system sizing and design of stand-alone photovoltaic (PV) system. Therefore, the detail design of off-grid power system for Bodawtaw village is developed and the performances for the system are analyzed by using MATLAB/Simulink.

Keywords: stand-alone, solar PV, off-grid, renewable energy source, MATLAB

I. INTRODUCTION

Fossil fuels are depreciated in value due to their depletion problem and harmful influence on environment. Thus, people tried to seek new sources of energy, and renewable energy sources, such as photovoltaic and wind energy, have been attracting attention as a clean, environment friendly, and sustainable alternative[1]. In particular, renewable energy sources suffer from the problems of uncertainty and intermittency. Therefore, the system, which combines renewable energy sources, and/or battery energy storage, becomes one of the most promising applications [2], [7].

The solar standalone system can provide a steady community-level electricity service, such as village electrification, offering also the possibility to be upgraded through grid connection in the future[4]. Furthermore, due to their high levels of efficiency, reliability and long term performance, these systems can also be used as an effective backup solution to the public grid in case of blackouts or weak grids, and for professional energy solutions, such as telecommunication stations or emergency rooms at hospitals.

The solar PV system can be also very useful in remote and/or rural areas, where the cost of grid extension is prohibitive and the price of fossil fuels increases drastically with the distance [5,7]. The solar PV systems for rural electrification without the connection to the main grid can be configured in two ways: off-grid with distribution system and off-grid for direct supply [1]. In the first configuration, the PV system is connected to load centers and the power for each household is supplied through the distribution system. In the latter configuration, the system directly serves a few loads without distribution system [1].
Meanwhile, Myanmar is a developing country and around 70% of population lives in the rural area, where electricity from the main grid has not reached yet[9]. Additionally, Myanmar has a lot of renewable energy resources, such as hydropower, biomass, wind, solar and other types of clean energy. Therefore, Myanmar is well suited to apply the renewable energy. For the purpose of the evaluation, we select the Bodawtaw village in Myanmar, which is located far away from the substation in Shwebo District. This village cannot access the electricity until now. Most of the people in this village mainly depend on small petrol engine, batteries and some of people are using candle lamp for lighting, phone charger and other electricity appliances. Between the configurations for PV system, the selected village corresponds to the off-grid with distribution system. Based on this evaluation setup, the daily and monthly load profiles ar calculated from the household data for the village, and get the daily and monthly solar radiation profiles from the climate data.

II. STAND-ALONE PV SYSTEM COMPONENTS

To design a stand-alone photovoltaic system, several components are needed to perform the power generation and conversion function. The proposed PV system in this research consists of solar PV-arrays, battery energy storage, converter, and filter for improving the living standard of life especially in rural areas. The power ratings or size of the systems are determined from the load profile. The configuration of the components in the PV system is shown in Fig. 1.

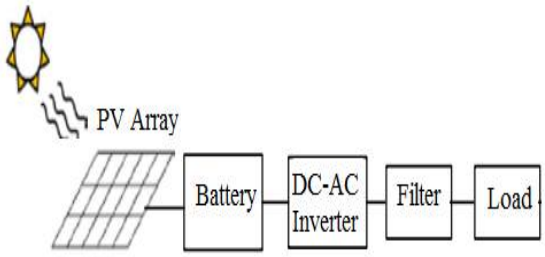

Fig.1. System Components of Stand-alone PV System

2.1. Solar PV Array

Solar energy is a good choice for electric power generation and electromagnetic radiation of solar energy directly converted into electrical energy by solar photovoltaic module. Solar module consists of solar cell. Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The silicon solar cells give output voltage of around 0.7V under open circuit condition [5]. The number of cells in PV module can vary depending on the manufacturer, but mostly a set of 36 or 72 PV cells is used. PV modules are connected in series and parallel configurations for requisite energy[5]. The electric power generated by a solar PV array fluctuates depending on the operating conditions and field factors such as the sun's geometric location, irradiation levels and ambient temperature.

2.2. Battery

Batteries can be used for two independent purposes storage of energy and as a power conditioning mechanism. Batteries are required in many solar electrification systems to supply power at night or when the PV system cannot meet the demand. If batteries are required, they need to be capable of regular deep discharges and should be housed in a weather-resistant box, which is preferably nonmetallic, if non sealed batteries are selected. The selection of battery type and size depends mainly on the load and availability requirements.

2.3. Load Side Inverter

The load side converter, a three phase voltage source inverter, is used as interface between DC- link voltage and the load. Voltage source inverter is the most commonly used type. The input DC voltage may be from an independent source such as a battery or may be the output of a controlled rectifier. The DC-AC inverter is used for many applications including motor drives, uninterruptable power supplies and on renewable energy systems. This type of converter produces a sinusoidal AC output waveform whose magnitude and frequency can be controlled. The load side voltage source inverter control is responsible to regulate the voltage and frequency at the customer load. In the stand-alone solar power systems, there is no grid, the output voltages should be controlled in terms of amplitude and frequency. Pulse Width Modulation (PWM) control strategy is used to control the output load voltage during variation of required load power. The output voltage of the inverter is controlled by varying the pulse width of each cycle of the output voltage.

2.4. Filter

In this paper, the specified load voltage frequency and RMS value of output line voltage are 50 Hz and 400 V, respectively. The voltages Va, Vb, Vc and the currents Ia, Ib, Ic should be measured and transformed from stationary abc reference frame to rotating dq reference frame using chosen electrical load voltage and frequency. When AC power is converted to DC power using rectifiers, or DC power is converted to AC, the output contains undesirable components called ripple. Many rectifier and inverters applications require that the ripple do not exceed a specified value. The more common filters are of L, C and LC.

III. MATHEMATICAL MODEL OF SOLAR CELL

A solar cell is a non-linear device and can be represented as a current source model as shown in Fig. 2. The current source I_{ph} represents the cell photo current, I_d is reverse saturation current of diode, R_{sh} and R_s are the intrinsic shunt and series resistance of the cell respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules, which are further interconnected in a parallel-series configuration to form PV arrays or PV generators [8].

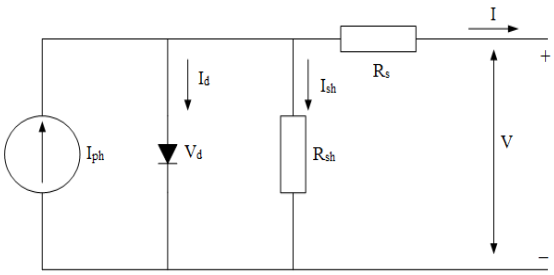

Fig.2. Equivalent circuit of the PV cell one-diode model

The mathematical model of the voltage-current characteristic equations of a solar cell is expressed as follow:

$$I = I_{ph} - I_S\left(\exp\frac{(V + IR_S)}{(nV_tCN_S)} - 1\right) - \frac{V + IR_S}{R_{sh}} \qquad (1)$$

The photocurrent I_{ph} relatively depends on the operating temperature of the cells and solar radiation as expressed in equation 1.

$$I_{ph} = \frac{(I_{sc} + Ki(T_{op} - Tref))\lambda}{1000} \qquad (2)$$

The saturation current I_s of the cell varies with the cell temperature which is represented as:

$$I_s = I_{rs}\left(\frac{T_{op}}{T_{ref}}\right)^3 \exp\left(\frac{qE_g}{nK}\left(\frac{1}{T_{op}} - \frac{1}{T_{ref}}\right)\right) \quad (3)$$

$$I_{rs} = \frac{I_{sc}}{\exp\left[\frac{qV_{oc}}{KCT_{op}n}\right] - 1} \quad (4)$$

$$I_{sh} = \frac{V + IR_S}{R_{sh}} \quad (5)$$

$$I_d = \left(\exp\frac{(V + IR_s)}{(nV_tCN_s)} - 1\right) I_s N_p \quad (6)$$

The PV array circuit model can be used to determine the array current, where the array has N parallel (N_p) and N series (N_s) cells:

$$I = N_p I_{ph} - N_p I_S \left(\exp\frac{\left(\frac{V_{pv}}{N_s} + \frac{IR_S}{N_p}\right)}{KT_{op}m} - 1\right) - \frac{\frac{N_p V_{pv}}{N_s} + IR_S}{R_p} \quad (7)$$

where, m is the ideality zing factor, V_{oc} is the open-circuit voltage of PV, C is the number of cells in a PV panel, N_s & N_p is the number of PV panel in series & parallel, I_{ph} is the photocurrent, I_s is the cell saturation current, T_{op} is cell operation temperature at 25°C, R_{sh} is the shunt resistance, R_s is the series resistance, q is the electron charge (1.6 x 10^{-19} C) and K is the Boltzmann constant (1.38 x 10^{-23} J/K).

The solar cell is characterized by the following parameters [12]:

i. Short circuit current represent the highest current value generated by a cell during the condition where the V=0.

ii. Open circuit voltage is due to the voltage drop across the diode while it is passed through a photocurrent, I_{ph}, where $I_d = I_{ph}$ and the generated current is zero.

iii. The mathematical expression of the cell voltage with no light is:

$$V_{oc} = \frac{mKT_{op}}{q}\ln\left(\frac{I_{ph}}{I_o}\right) \quad (8)$$

$$V_t = \frac{KT_{op}}{q} \quad (9)$$

where, V_t is the thermal voltage.

IV. LOAD AND SOLAR RADIATION PROFILES

4.1. Load Profile

The Bodawtaw village is located at 22.579N latitude and 95.698E longitude in Shwebo District, Sagaing Region, Myanmar. The demand of 350 households has been estimated by calculating the power consumption of a single village in the area.



Fig. 3. Location of Bodawtaw village

Loads are divided into two groups, that is, residence, communal facilities. The residence consists of 350 households in low, medium, and high income levels. Electricity demand in low income level is limited to lighting and TV, phone charger, and the annual growth rate of electricity consumption is small. The households in the medium income level can additionally use the electric fan and CD player, and their annual growth rate of electricity consumption is rapidly increasing. The communal facilities include school, monastery, rural health clinic and street lightings. Detailed components of the load are listed in Table I.

Components		Number	Power Consumption (kWh/day)
Residence	Low income	200	154
	Medium income	100	137
	High income	50	149
Communal facilities	School	1	2.74
	Monastery	1	3.52
	Rural Health Clinic	1	3.18
	Street lighting	600	18
Total power consumption per day			467.44

Table I.: -Load components in the Bodawtaw village.

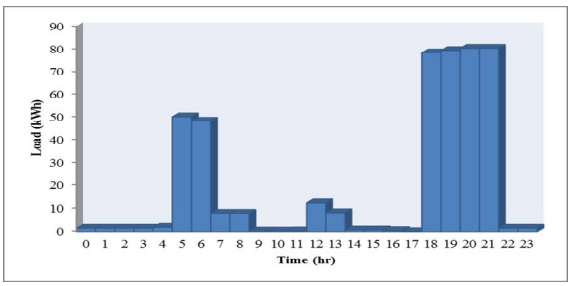

Fig. 4. Daily Load Profile for the proposed village

The power consumption of each component in Table 1 is estimated by assuming the usage pattern in each hour for the appliances which each load component is assumed to use. The daily load profile for proposed village is shown in Fig.4.

4.2. Solar Radiation

The average solar radiation in Myanmar is more than 5 kWh/m^2/day during the dry season [11]. It varies from 2.3 to 3.2 kWh/m^2/day in the extreme north and south regions, while the majority regions in Myanmar including the central area have good solar radiation ranging from 3.6 to 5.2 kWh/m^2/day[11]. Therefore, government and private sector organizations have been promoting and piloting solar PV systems for rural electrification.

The specific monthly solar radiation profile for the selected village is shown in Fig. 5. The annual average is 4.895kWh/m^2/day. The highest and lowest solar radiation occurs in April and September, respectively. In April, the PV array can satisfy the whole load during the daytime and to meet the load in the evening and night with the energy stored in the battery energy storage systems.

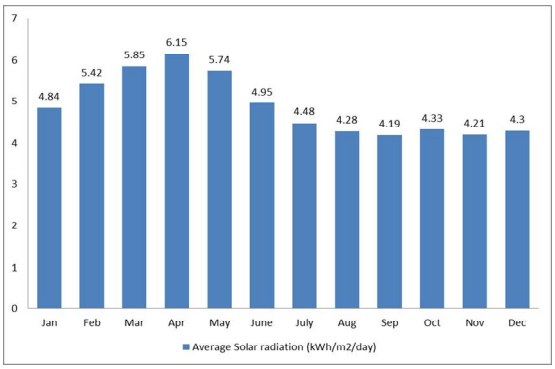

Fig. 5. Monthly Solar Radiation Profile for the Bodawtaw Village

V. DESIGN AND SIMULATION OF PV STAND-ALONE SYSTEM

A stand-alone PV system of 80kW with 400V is required to be feed an inverter. The electrical characteristic of the photovoltaic Mitsubishi electric PV-MLU 250HC PV module specification chosen is described in Table 2. The entire stand-alone PV system was designed in MATLAB/Simulink software by using physical electronic components such as resistors, diodes and a current source to represent the equivalent circuit of solar cell by using equation (1), equation (2), equation (3) and equation (7) as shown in Fig. 6. A larger number of solar cells were then grouped in series and parallel to form a PV array [13]. The radiation is kept constant at 1000 w/m^2 in this simulation.

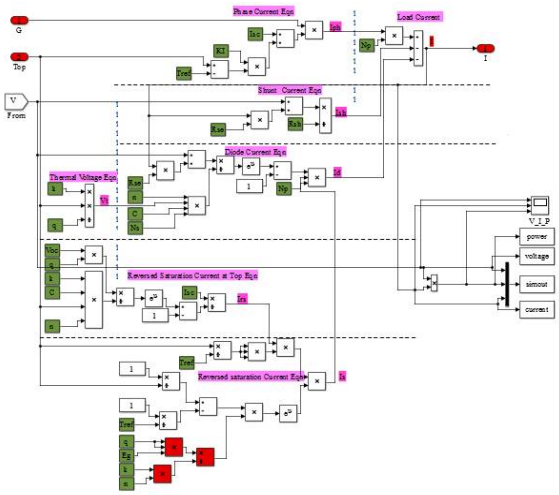

Fig.6 Matlab Simulation of PV Module

The system array size calculation is as follow:

$$\text{Peak Power (Wp)} = \frac{\text{Daily Correct Load}}{\text{Peak Sun hours}} \quad (10)$$

Peak sun hours = 5.8

$$\text{Total number of module} \frac{\text{Peak Power}}{\text{Power for one module}} \quad (11)$$

Power for one module = 250W

Number of modules in series:

$$= \frac{\text{Voltage of DC PV Generator}}{\text{Voltage of one module}} \quad (12)$$

Number of modules in parallel:

$$= \frac{\text{Total number of modules}}{\text{Number of module in series}} \quad (13)$$

Total generated power of modules:

$$= \text{Total number of module} \times \text{module capacity} \quad (14)$$

In the proposed area, off-grid (80kW) PV with battery backup system is installed. There are 330 numbers of poly crystalline PV modules in this system. The array composed of thirty parallel strings with each containing eleven modules in series to obtain a terminal voltage suitable for the purpose system.

The parameter chosen for PV-MLU 250HC module as listed in Table II. The peak value of the product of V and I represent the maximum power point of P_{max} of the solar module. The current and voltage of PV module at the MPP are denoted by I_{mp} and V_{mp}, respectively [12]. The voltage V is considered varying from 0 to open circuit voltage V_{oc} corresponding to the variation in current from short circuit current I_{sc} to 0.

Parameter	value
Number of cells per module	120
Maximum Power (P_{max})	250W
Rated voltage (V_{mp})	31V
Rated current (I_{mp})	8.08A
Open-circuit voltage (V_{oc})	37.6V
Short-circuit current (I_{sc})	8.79A

Temperature coefficient of I_{sc}	0.104%/°C
Temperature coefficient of V_{oc}	-0.38699%/°C
NOCT	45.7°C
Series resistence (R_s)	5.1 Ω
Shunt resistence (R_p)	360.002Ω
Diode ideal factor	1.36

Table II : -PARAMETER OF PV-MLU 250HC SOLAR MODULE

Fig.7 & Fig. 8 show the V-I &P-V characteristics with the variation in solar insolation level at a constant cell temperature of 25 degrees respectively. It can be seen that the short circuit current as well as the power increases with the increases in insolation level, while very little change in the open-circuit voltage.

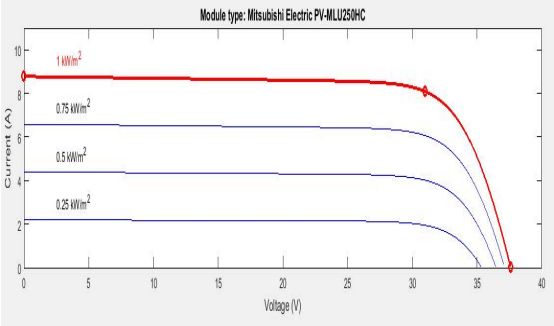

Fig.7 V-I Characteristics for Different Isolation

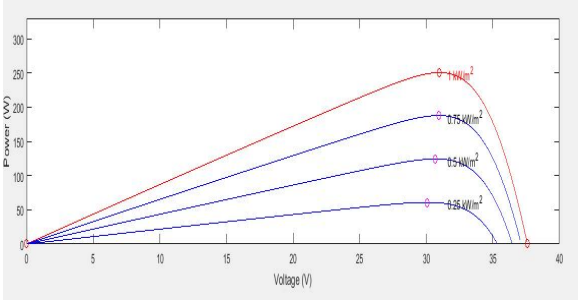

Fig.8 P-V Characteristics for Different Isolation

The overall Simulink model of the 80KW off-grid PV system is depicted in Fig. 9. Fig. 10, Fig. 11 and Fig. 12 below depicts respectively the output power, current and power from the proposed system of PV array at constant solar radiation of 1000W/m^2. The value of output voltage is about 400V after reaching the steady state 250ms, the output current value is 152.6A after reaching the steady state 750ms, and the power value is 94.24kW after reaching the steady state 750ms.

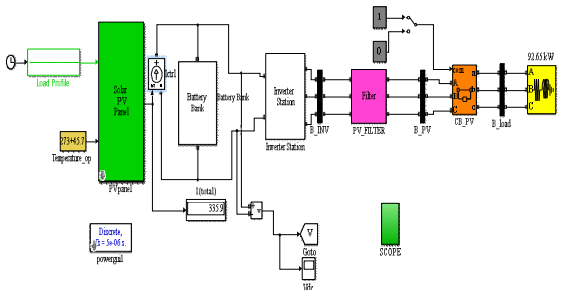

Fig. 9 Simulation Model of Stand-alone PV System

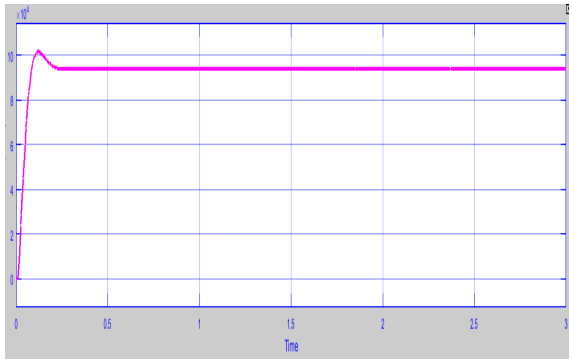

Fig. 10 Output power of proposed System

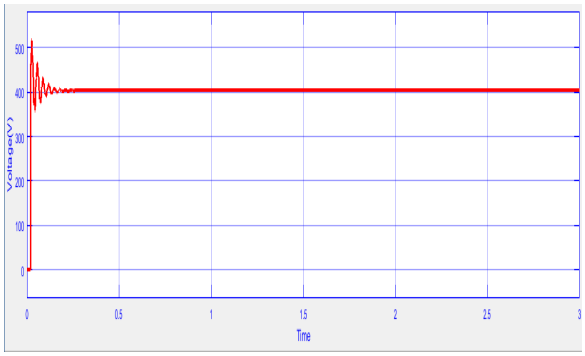

Fig. 11 Output voltage of proposed system

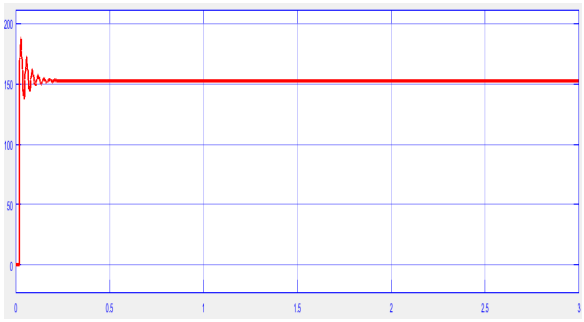

Fig. 12 Output current of stand-alone PV system

The simulation model of stand-alone PV system with three loads condition is shown in Fig. 13. The three variable loads are 0.41kW, 12.43kW and 8.29kW during 11:00 am and 1:00pm.

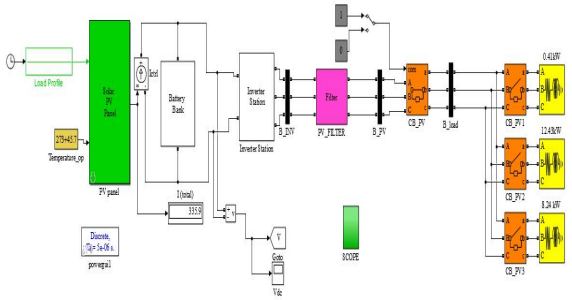

Fig. 13. Simulation Model of Stand-alone PV System during variable load

Fig. 14 illustrates the simulation results of output power of three variable loads condition. The load voltage and current with variable loads is illustrated in Fig. 15 and Fig. 16.

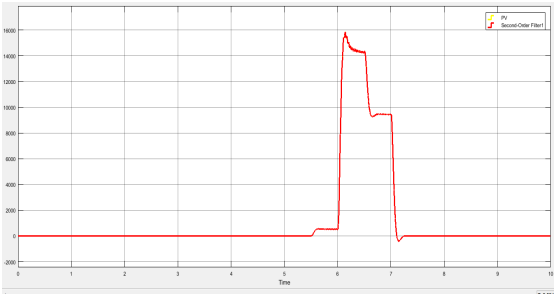

Fig. 14 Output power of system during variable loads

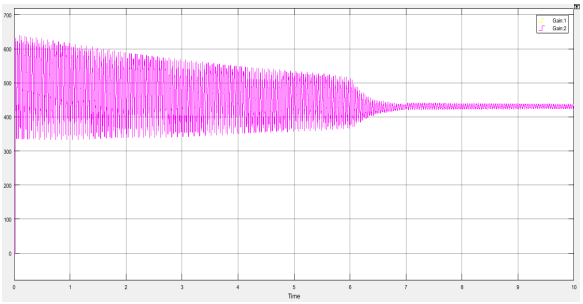

Fig. 15 Output voltage of system during variable loads

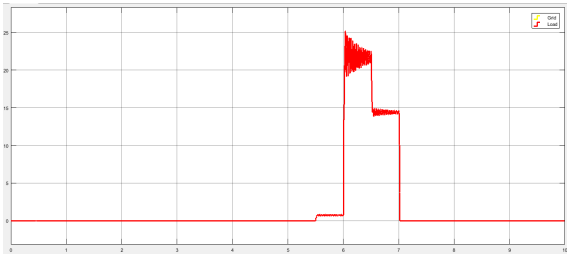

Fig. 16 Output current of system during variable loads

CONCLUSIONS

Myanmar is a country with a lot of renewable energy resources and non-electrified rural villages, which accord with the necessary conditions of the stand-alone system. Thus, in this paper, a village in Myanmar is selected and design the economic feasibility of a stand-alone system considering the specific local conditions and resource availability for the village. Solar energy is a good choice for electric power generation. The proposed PV system in this research intends to improve the living standard of life especially in rural areas.

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