Investigation of Photovoltaic Panel Topology Performance to Feed Electricity in Rural Area

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***Abstract*—Solar energy as a renewable energy has an important role in meeting energy needs. It provides an energy source which are environmentally friendly, extensive, renewable and sustainable. Those mains reasons make solar energy is interesting to be implemented at rural area. This paper describes the analysis of the photovoltaic-inverter topology engineering design in a rural area at Ngadiprono Village, Temanggung. The application of solar energy can be converted into electrical energy using solar panels or photovoltaic (PV). The right PV topology can produce maximum power with high efficiency because the proper topology reduces losses and mismatches in the system. In this work, the performance of proposed PV topology is analysed and carried out by using PSIM. In this paper, the investigation of photovoltaic was early initiated to conduct for single, series, parallel topology and combination of series-parallel topology with 4 panels. Based on early investigation results and consideration that the demand of electricity for Ngadiprono Village is 11750 Watt, then in this work, the simulated PV topology was continued by taking account 32 panels in series and 30 panels in parallel. The results show that the power generated by PV is influenced by the height and the low of solar radiation and temperature. The higher the solar radiation and the lower the temperature have significant influence to the higher the power generated by PV. By considering the position of solar with a year the maximum PV power yields 65282.96 Watt at 547.008 Voltage as the sun is at the equator.**

Keywords—Inverter, Photovoltaic Array, Photovoltaic-inverter Topology Design, and PSIM.

I. INTRODUCTION

Ngadiprono Village, Temanggung is a rural area with the main agricultural area in Temanggung Regency which is astronomically located between 110023'- 110046'30" East Longitude and 7014'-7032'35" South Latitude. Ngadiprono Village as a tourist village supports homestays and 24-hour production activities which routinely require electrical energy. However, the erratic access to electricity and frequent blackouts has had a significant impact on community activities. Meanwhile, photovoltaic is increasingly being used because of its clean, pollution-free, abundant and inexhaustible nature [1]. Energy source taken from PV has an advantage for decreasing the depletion rate of fossil, as well as supplying energy to remote rural areas, without harm pollution to surrounding environment [2]. According to ESDM, the potential for solar energy in Indonesia is very large, which is around 4.8kWh/m^2 or equivalent to 112,000 GWp, but only 10 MWp has been utilized [3].

Ngadiprono Village has a car park area of ± 1500 m^2 without the shadow of tall trees or other buildings that can be used for PV installation while at the same time realizing Ngadiprono Village as an energy independent village by utilizing renewable energy. Solar radiation and temperature in a place vary according to the local climatic conditions. Location has becoming a major aspect affecting photovoltaic power system design, so PV specifications vary for different places [4], [5]. Therefore, it is necessary to research the engineering design of the photovoltaic-inverter topology that is suitable for these rural areas through proper technical analysis. The work provided in paper is part of performance investigation of the photovoltaic panel topology for electricity supply in the rural area. The topology of the photovoltaic system aims to increase the efficiency of the photovoltaic system in general by reducing losses due to mismatches in the system. Selection of the right configuration can provide good performance in photovoltaic systems with the highest maximum power and relatively low power losses [6]. In addition, the calculation to know the output voltage and power from the photovoltaic topology will help to match the inverter specifications.

II. RURAL AREA PROFILE

Ngadiprono Village, Temanggung is astronomically located between 110023'-110046'30" East Longitude and 7014'-7032'35" South Latitude as shown in Fig. 1. To determine the optimal tilt angle, RETScreen Expert software is used according to geographic location. Village using trial and error method [7], obtained the optimal slope angle at an angle of 11°. The average radiation of this location is about 5.57 kWh/m^2/day and the ambient temperature averages about 25.8° C. Table 1 shows the Monthly average radiation data of the site. The estimated load requirements in this village are shown in Table 2. Energy demand per day is around 11 kWh which consists of household loads, public facilities and public street lighting. The photovoltaic design system in this study is a centralized off grid system as shown in Fig. 2. The burden on the rural area is supplied by the photovoltaic and also the electricity grid from Electric State Company or PT. Perusahaan Listrik Negara.

III. PHOTOVOLTAIC DESIGN SYSTEM METHODOLOGY

The design of a PV system is a process of determining the capacity (in terms of power, voltage and current) of each component of the photovoltaic power system to meet the load requirements in rural areas. The design steps are shown in Fig. 3.

A. Determining Inverter Specifications

The inverter functions to convert DC power into AC power in a photovoltaic system. The inverter power rating should not be less than the total power consumed in different loads. Usually, the inverter capacity is taken from the sum of all loads running simultaneously to get the power that must be sent to the inverter (TP1). Equation 1 can be used. While equation 2 is used to find the energy that enters the inverter and the daily sunshine hour, the average sun hour available per day at the research site was about 5 hours. Inverter specifications are shown in table 3 [4].

$$TP1 = \frac{Energy\ Rating}{Daily\ sunshine\ hour \times Efficiency\ inverter} \quad (1)$$

$$E_{inv} = \frac{Energy\ rating}{Efficiency\ inverter} \quad (2)$$

B. *Determining Capacity Battery*

Batteries are the most important part of Solar PV planning. The battery capacity must store enough energy to operate all loads at night. Battery storage is conventionally measured in Ah (ampere hour). The battery specifications used in this study are listed in table 4. To find the battery capacity, Equation 3 is used [4].

$$B_{AH} = \frac{E_{inv} \times \mathrm{N_{backup}}}{\mathrm{VDC} \times \mathrm{DoD}} \quad (3)$$

$$E_{bat} = \frac{Vdc \times B_{AH}}{\text{efficiency baterry}} \quad (4)$$

C. *Determining Solar Pv Array Specifications and Pv Topology*

The Solar PV array is a major component of a PV system. The PV specifications used are shown in Table 5 [8]. This specification is used to calculate the topological design, equations 5, 6, 7 are used which are shown in Table 6 [4]. The inverter has been equipped with the recommended MPPT voltage range. In this research, the PV array voltage (V_{PV}) was chosen from the recommendations, which was 550 V.

$$I_{PV} = \frac{E_{inv}}{V_{PV} \times \text{daily sunshine hour}} \quad (5)$$

$$S_{PV} = \frac{V_{PV}}{Vm} \quad (6)$$

$$\mathrm{P_{PV}} = \frac{\mathrm{I_{PV}}}{\mathrm{I_m}} \quad (7)$$

D. *Design and Simulation*

An early investigation is initiated by single PV topology, series topology, parallel topology, and series-parallel topology as they are shown in Fig. 5 to Fig. 7. Each of topology gives a basic information about maximum power yields, voltage and currents. As the demand of electricity for Ngadiprono Village is about 11750 Watt, then in this study, the simulated PV topology requires PV panels to be installed are 32 panels in series and 30 panels are in parallel as shown in Fig. 8.

Fig. 1. Map of the research location

TABLE 1. MONTHLY AVERAGE RADIATION DATA OF THE SITE

Month	Irradiance (kWh/m²/day)	Temperature (⁰C)
January	4.035	25.8
February	4.3999	25.8
March	5.402	25.9
April	5.6941	26.0
May	5.8852	25.9
June	5.741	25.6
July	6.223	25.4
August	6.7612	25.7
September	6.8773	26.1
October	6.2249	26.2
November	5.0704	25.9
December	4.3653	25.8

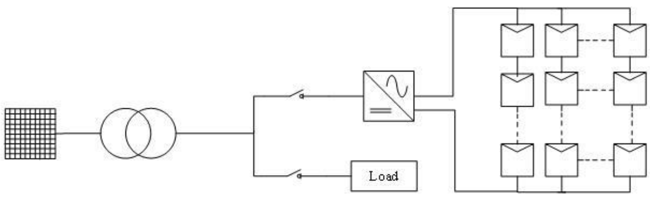

Fig. 2. Photovoltaic design system

TABLE 2. LOAD ESTIMATES

No	Load Type	Power Rating (Watt)	Hours Used (hour)	Energy Rating (Watt-hour/day)
1	Household	10800	24	259200
2	Social Facilities	900	12	10800
3	public street lighting	50	8	400
Total		**11750**	**60**	**270400**

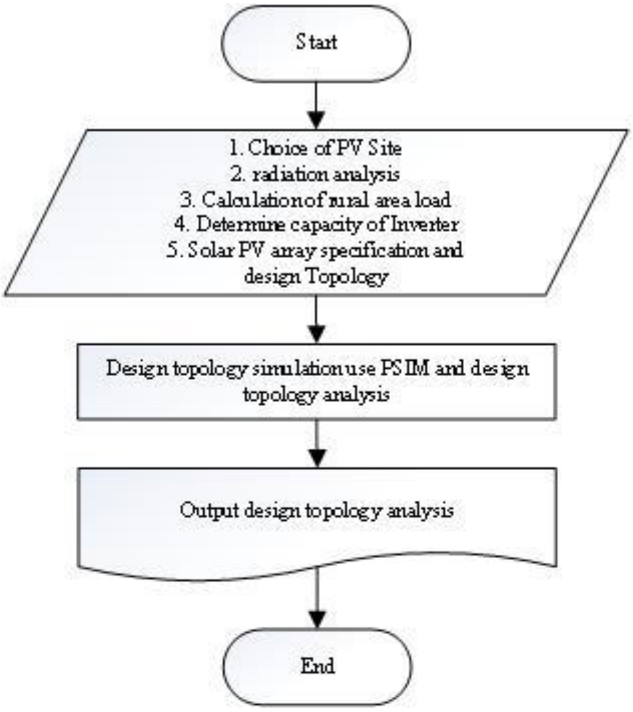

Fig. 3. Flowchart PV design system

TABLE 3. INVERTER SPECIFICATIONS

Parameters	**Calculated Parameter Value**	Remarks
Input power to the inverter (TP1)	60 kW	Equation 1
Max. Input DC voltage (V_{DC})	750 VDC	inverter data sheet [8]
MPPT Voltage Range	450-550 VDC	inverter data sheet [8]
Power Factor	0.8	inverter data sheet [8]
Efficiency	90%	inverter data sheet [8]
Energy input to inverter (E_{inv})	300 kWh	Equation 2

TABLE 4. BATTERY SPECIFICATIONS

Parameters	**Calculated Parameter Value**	Remarks
Usage/day	8 hours	
Autonomy (N_{backup})	3 day	
Depth of Discharge (DoD)	80%	Battery data sheet [9]
Required capacity of battery bank (B_{AH})	3125 Ah	Equation 3
Battery bank operation voltage (V_{dc})	360 VDC	Inverter data sheet [8]
Efficiency battery	85%	Battery data sheet [9]
Energy battery (E_{bat})	1323,5 kWh	Equation 4

TABLE 5. PV SPECIFICATIONS

Electrical Specifications	
Model	KC60
Maximum power (P_m)	60 Watts
Maximum power voltage (V_m)	16.9 Volts
Maximum power current (I_m)	3.55 Amps
Open circuit voltage	21.5 Volts
Short circuit current	3.73 Amps

TABLE 6. SOLAR PV ARRAY TOPOLOGY

Array Voltage Output (V_{PV})	550 V	Refereed Equation
Array Current Output (I_{PV})	109 A	Equation 5
Total module in series (S_{PV})	32	Equation 6
Total module in parallel (P_{PV})	30	Equation 7
Total PV array capacity	57.6 kWp	Total module*wattage rating per module

IV. RESULT AND ANALYSIS

The characteristics of voltage and current for maximum irradiance and ambient temperature is presented in IV curve, while the maximum power yield is presented in PV curve.

The P-V and I-V curve of the simulation results are shown in Fig. 9 to Fig. 16. The results for single PV topology give maximum power up to 67.981 Watt at 17.052 Voltage. The series topology produces 135.532 watt at 34.062 volt and parallel topology generated 135.961 watt at 17.031 volt. Finally, the combination of series-parallel topology with 4 panels installed deliver 271.065 Watt at 34.062 Volt.

The simulation results shown are samples from simulations that were run with maximum solar irradiation and maximum temperature. From the graph, it is known that the greater the number of PVs arranged in series, the greater the voltage generated, while the increasing number of PVs arranged in parallel, the greater the current generated by PV.

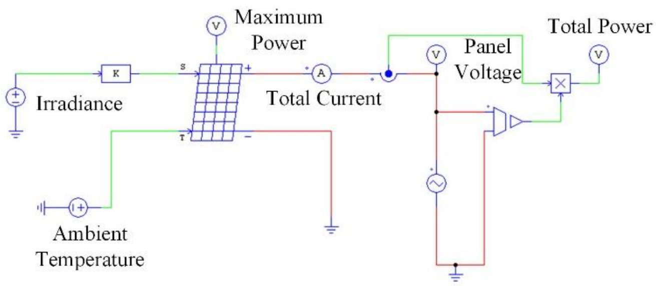

Fig. 4. Single PV topology

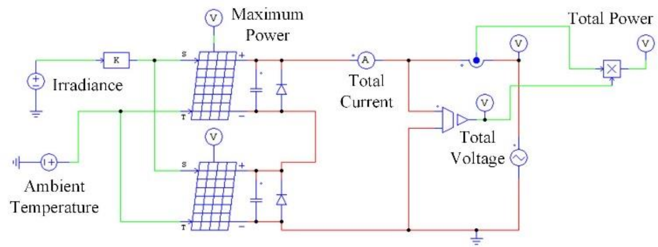

Fig. 5. Two PV in series topology

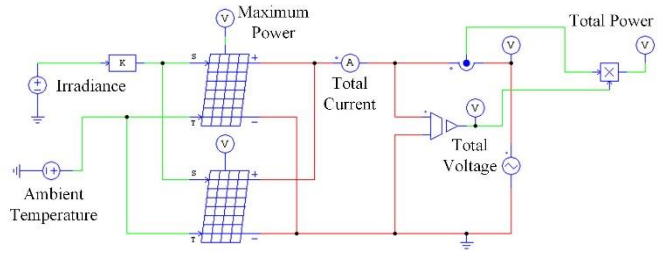

Fig. 6. Two PV in parallel topology

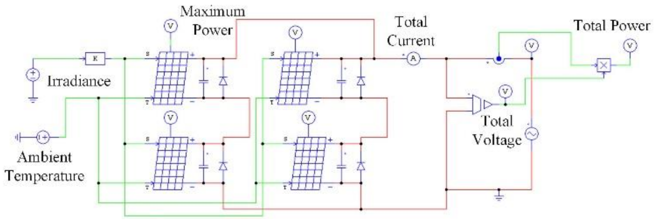

Fig. 7. Four PV in series-parallel topology

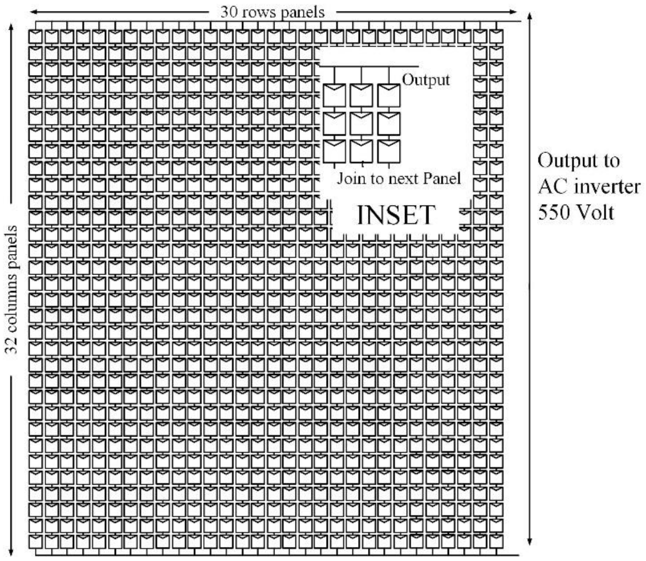

Fig. 8. PV array topology

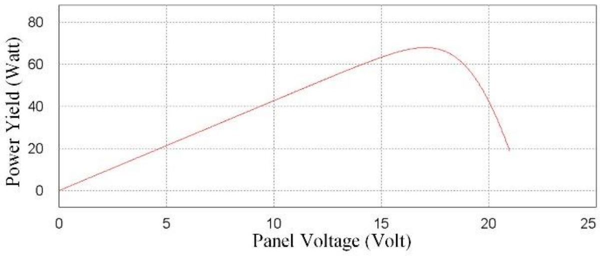

Fig. 9. P-V curve of single PV topology

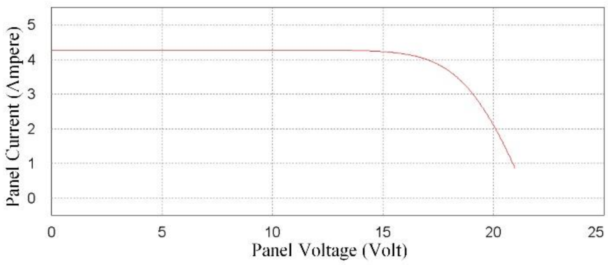

Fig. 10. I-V curve of single PV topology

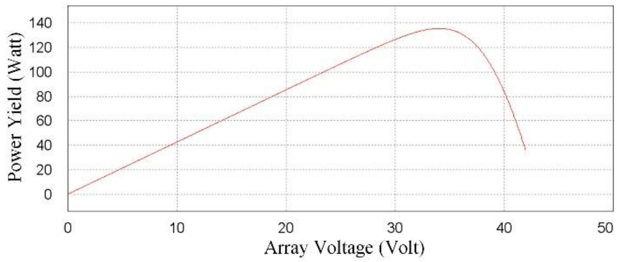

Fig. 11. P-V curve of two PV in series topology

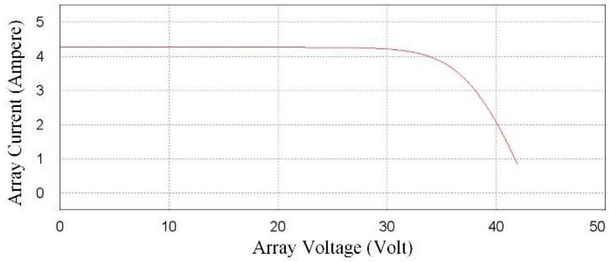

Fig. 12. I-V curve of two PV in series topology

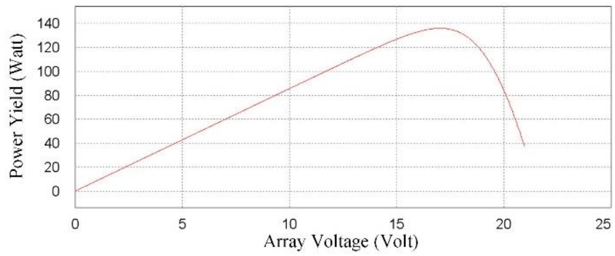

Fig. 13. P-V curve of two PV in parallel topology

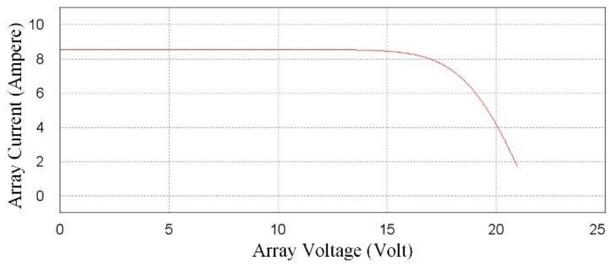

Fig. 14. I-V curve of two PV in parallel topology

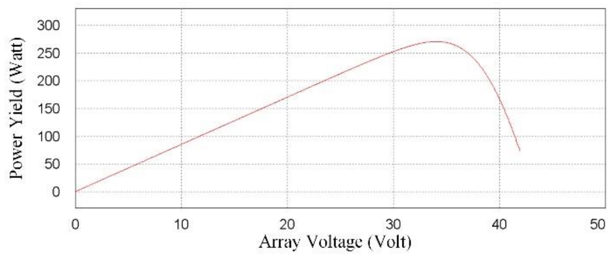

Fig. 15. P-V curve of four PV in series-parallel topology

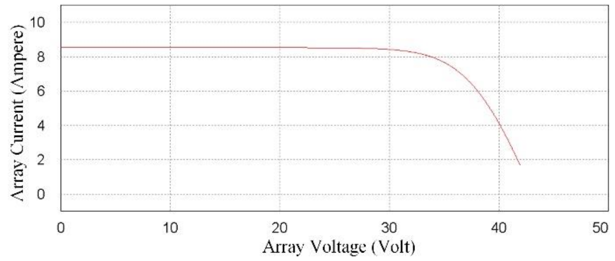

Fig. 16. P-V curve of four PV in series-parallel topology

Fig. 17 to Fig. 19 shows the results of experimental simulation with the proposed topology in Fig. 8. The experimental set was carried out with variable sun position whether the solar is north, equatorial and south latitude to provide a certain amount of irradiance. The experiments also considered the ambient temperature at maximum, minimum, and average values.

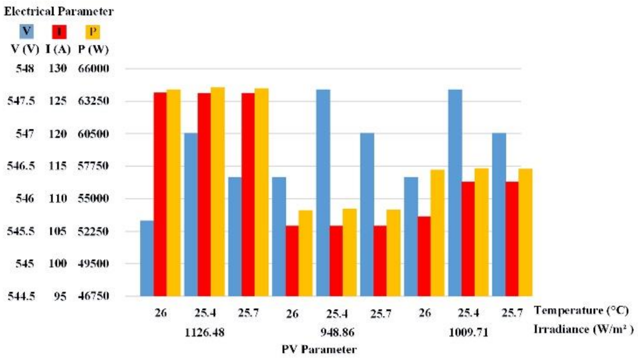

Fig. 17 Simulation results when the sun position at north latitude

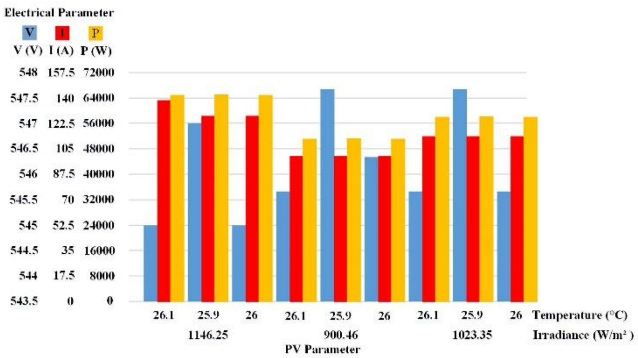

Fig. 18 Simulation results when the sun position at the equator

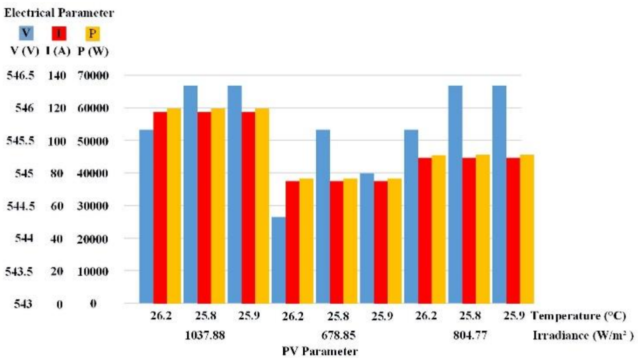

Fig. 19 Simulation results when the sun position in north latitude

To get bigger power harvested from PVs, then the combination of 32 panels in series and 30 panels in parallel were considered in calculation. The results shown in Fig. 8 gives maximum power up to 64427.35 Watt at 547.008 Voltage when the sun's position in northern latitude. When the sun's position is at the equator, then it provides 65282.96 Watt at 547.008 Voltage. While the maximum power is obtained when the sun's position is in the south latitude and the power is 60132.74 Watt at 546.336 Voltage. The lowest PV output power occurred as irradiance is minimum and temperature is maximum. When the sun at south latitude, the yield power is 38527.63 Watt at 544.32 Voltage. The results above agree lead the indication that the power produced by PV is significantly influenced by the height and the level of solar irradiance and temperature.

V. Conclusion

Electrical energy is the main energy for human life. Electrical energy is obtained from renewable energy, one of which is solar energy, which is an environmentally friendly energy future. In producing electrical energy from solar energy, photovoltaic (PV) is needed. The right PV topology aims to maximize the output power of the PV. From the simulations, it can be concluded that the maximum power generated from PV topology is 65282.96 Watt at 547.008 Voltage when the sun is at the equator. This power is obtained from the PV topology which is arranged in combination with 32 panel in series and 30 panels in parallel.

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