Module trainer of photovoltaic integrated low voltage grid (PV-LV grid) with a variety load

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Abstract. This research is a simulation of the penetration of renewable energy at the primary source. The entire system is a compound system, especially on the load. Load types provide different voltage and current treatment. The simulation is carried out with a mini-grid device consisting of five buses with interface sensors to monitor voltage and current. Photovoltaic grid module (PV) -LV as a trainer, uses two power sources to supply the load to the voltage distribution network module. The loading scenario has two plans, where the difference lies in the type of inductive load (scenario A) and capacitive (scenario B). The types of load consist of incandescent lamps, fluorescent lamps, energy-saving lamps, drilling machines, and soldering tools. Variations in this load to meet predetermined loading scenarios. The PV measurement results show maximum power generation at noon and flowed to the load trainer via a 300W grid-tie inverter of 191.1W. The average load bus voltage increases for scenario A and scenario B by 1.045% and 1.36%, respectively. The result indicates that the integration of PV in low voltage systems positively impacts the voltage profile for both inductive and capacitive loads. The amount of voltage improvement depends on the value of the active power injection of the PV and the load supplied by the system.

1. Introduction
The utilization of the photovoltaic (PV) greatly extends its implementation. The PV energy was a clean energy source that is environmentally friendly and free of emissions is a strong reason to encourage the widespread use of PV. By 2040 the International Energy Agency (IEA) expects 40% of the installed capacity target of renewable energy in ASEAN countries to come from solar PV or 52 GW [1]. The implementation of PV is divided into three models are PV-on grid, PV-off grid, and PV hybrid. The use of PV is still dominated by off-grid PV, where the system works alternately between PV and the primary source. This scheme requires a storage system that has implications for additional cost components. Apart from saving on battery component costs and lowering bill costs [2], the PV-on grid also has a positive technical impact on the distribution system. The integration of PV on the grid will also reduce power losses and voltage drops [3-5]. The series of on-grid courses are connected to the distribution network by optimizing the solar panels' energy to produce as much electricity as possible. Besides that, the on-grid system also applies a load-sharing scheme in which the network and PV are integrated to complete consumers' electricity needs. Electrical equipment includes household, commercial, and industrial markets. The varying load will determine the value of the voltage and current parameters. Load variations from consumers directly affect the voltage's quality, which has implications for the power loss variable [6]. The types of inductive and capacitive loads scenario in
this study provide different injection or absorption of additional reactive data. Research [7] has tested the effect of PV penetration on resident loads, which shows that loads with a fixed impedance or resistance only represent loads with a small voltage drop. This study investigates the effect of variations in the load modeled as residential, industrial, and commercial expenses, which is the scenario as RC load and RL load, which are expected to give different voltage drop variations. This is a representation of consumers who are served on the side of the low voltage distribution. Voltage and current monitoring are carried out using sensors connected to the microcontroller as a data logger. This research contributes to the observation of voltage and current under different load conditions by referring to real loading scenarios experienced by the distribution network. This trainer module is equipped with PV output data recording, main grid output, and external temperature conditions that affect PV [8,9]. This study traced the results in four different sessions, each introduction, material and method, results, and conclusion session.

2. Material and Method
The research conducted for this paper focuses on observing and collecting current. Before and after PV, voltage comparison data is integrated into the primary source on the low voltage (LV) grid trainer module. The steps of this study are illustrated in the flowchart in Figure 1.

![Flowchart](image)

**Figure 1.** The procedure of PV-LV trainer module

2.1. PV-on grid
The solar panel used to generate electrical energy has a total capacity of 240 Wp, a monocrystalline type. This type is because it has actual power generation yield characteristics more than other technology [10,11]. The features and specifications of solar panels are presented in Table 1.

| Table 1. Solar module FL-P-80W specifications |
|-----------------------------------------------|
| Peak power                                    | 80 Wp  |
| Production tolerance                          | 3%     |
Open circuit voltage (VOC) 21.60 A
Maximum power current (IMP) 4.45 A
Maximum power voltage (VMP) 18.00 V
Short circuit current (ISC) 4.74
Maximum system voltage 1000 VDC
Module dimension 1195x540x30 mm

The fabric tested all technical data in Table 1 were in standard condition. The PV panel output is connected directly through the Grid Tie Inverter (GTI) to the low voltage distribution network load without going through storage. This system works synchronously and automatically shares the load between PV and LV grid, as shown in the block diagram in Figure 2. The power meter is installed on bus four, which is the connection point of the PV. PV monitoring consists of current and voltage sensors used as a comparison for the analog measuring instrument installed on the module.

**Figure 2.** Diagram block of PV-LV trainer module

### 2.2. Grid-tie inverter

The GTI used in this study is a type of micro-inverter with soft switching considerations. Soft switching is an advantage because it requires a small power supply, increases inverter efficiency, and reduces heat dissipation. GTI uses a boost converter and an H-bridge inverter [12]. The GTI specifications are shown in Table 2. Boost converter functions to utilize diode components, capacitors, inductors, and MOSFETs.

| Table 2. Technical parameter of GTI |
|-----------------------------|------------------|
| Rated power                | 300 W            |
| DC MAX input               | 360 W            |
| DC input range             | 10.8-28 V        |
| MPPT Voltage               | 15-23VDC         |
| DC max. current            | 20A              |
| AC max output              | 330W             |
| AC output range            | 190-260 VAC      |
| Peak efficiency            | 91%              |

The H-bridge inverter uses a MOSFET with a pulse width modulation (PWM) control system. The LC filter circuit is used to reduce harmonics from the sinusoidal waves generated from the inverter.

### 3. Result and discussion

The Solargis software carried out data retrieval using the trainer module was carried out with a temperature condition of 27.4 °C with the mapping of solar irradiation levels shown in Figure 3 concerning Solargis' record data [13].
Figure 3. Mapping solar data

The explanation of the daily solar radiation map is presented with the following index values:
- Direct normal irradiation (DNI) = 4.075 kWh/kWp per day
- Global horizontal irradiation (GHI) = 5.181 kWh/m² per day
- Diffuse horizontal irradiation (DIF) = 2.316 kWh/m² per day
- Global tilted irradiation at an optimum angle (GTIopta) = 5.193 kWh/m² per day.
- Optimum tilt of PV modules (OPTA) = 4/0°
- Air temperature (TEMP) = 27.4 °C

The results of assembling the PV, GTI, and trainer modules are shown in Figure 4.

Figure 4. PV-LV trainer module
3.1. PV-on grid module trainer performance under load variation

The experiment was carried out using a combination of load models on the free, namely pure resistive, resistive-inductive, resistive-capacitive, and resistive-inductive-capacitive. The variations are carried out using two scenarios called scenarios A and B. In plan A, Bus 2, 3, 4 are given resistive, inductive loads with different inductive loads, while bus 5 uses a resistive load. In scenario B, further treatment is given to bus four by adding a capacitive load. The bus voltage recorded in the monitoring system for each scenario is shown in Figures 5a and 5b.

![Figure 5a. Comparison of changes in voltage bus for scenario A](image1)

![Figure 5b. Comparison of changes in voltage bus for scenario B](image2)

**Figure 5.** Comparison of changes in voltage bus for scenario A and B

The selection of the GTI connection as the output of PV synchronization and the primary grid is based on the enormous load served by the network and the furthest distance from the primary source. The researcher aimed at understanding the benefits of placing PV in an appropriate location [14]. Measurement results and data records show that the highest PV supply occurs from 11 am to 2 pm. The PV-LV supply through the GTI reaches 191.1 W, which can serve a total 360 W load.
3.2. Power quality monitoring

After the integration of PV into the LV system, changes in bus voltage parameters that affect the LV grid's power quality are observed. For scenario A, the most extensive voltage drop occurs on bus five by 4.09%. The integration of PV provides an improved voltage profile so that the voltage drop decreases to 1.55%. In scenario B, which contains a capacitive load, it affects the voltage drop that occurs. The nature of the capacitor gives the most significant reduction in a voltage drop of 2.68%. The integration of PV provides the most significant impact on improving the voltage profile to 2.045%. At the peak of the PV supply, the voltage drop on bus five reached 1.55% and 0.41% for each scenario. The improvement of the voltage profile is a positive impact that PV gives through the active power injection. This causes the change in the total active and reactive power in the power flow to decrease, which indirectly reduces the system's power loss. This will be true if the real power from injected PV is precisely [15]. Excessive injection of PV active power will harm the system.

4. Conclusion

Tests have been carried out using a low voltage distribution network integrated PV trainer module. Synchronization of the primary grid and PV is carried out by the tie grid inverter. The author collected data at seven different times. The most significant power is obtained at noon with the distribution of power from PV of 53.03% from the total load. The resistive-inductive load variable results in a more considerable voltage drop than the resistive-capacitive load variation. The integration of PV in miniature low-voltage systems has a positive impact on improving system voltage. The average voltage improvement obtained is 2.31% and 1.07% in each scenario.

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