Application of inverter input rating method and standard AC voltage drop/over method on automatic transfer switch for hybrid powered e-bike charging station

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ABSTRACT

Automatic transfer switch (ATS) is useful for integrating two different energy sources can be applied to e-bike charging stations. Renewable energy sources from sunlight using 2×100 Wp photovoltaic (PV) modules as the main source in this study, as well as grid energy sources functioned as backup energy. This ATS uses inverter input rating methods and standard AC voltage drop/over, a novelty of this study. The amount of current during testing is up to 14.09 A. The value of the inverter input voltage affects the quality of the inverter output voltage, there is a stability of the inverter output voltage from the AC voltage standard ±5% of the, lowest voltage value of (V_{o_inv}) = 223.9 V and the highest value (V_{o_inv}) = 226.1 V, at the time of (V_{i_inv}) max = 14.15 V and (V_{i_inv}) min = 12.66 V. It can be concluded that the ATS works in the PV position of the supply to the e-bike load, in the PV state it can produce power of a maximum value of 135.9 W at 11:25 am and is at the lowest power of 31 W at 03:31 pm. This ATS device in the switch mode successfully implemented a duration range of 10-21 ms, during the transfer of energy.

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1. INTRODUCTION

The use of e-bikes in Indonesia every year increases in line with the government's role to improve the green energy ecosystem, through government regulation number 79 of 2014 concerning national energy policy that the priority renewable energy to be developed is solar power plants where the government's target in implementing this energy source in 2025 is 23% and in 2050 is 31% [1]. With the increasing use of e-bikes, a charging station is needed, which is specialized in the e-bike sector. Electric vehicles in use increased by the end of this year equivalent to sales from 2.1 million to 7.2 million vehicles globally in 2019, so the percentage increase in electric vehicle use increased by 40% year on year [2]. The e-bike sector first became popular in China, where in 1991, the Chinese Government wanted to have official technology in the development of e-bikes, so that China became the largest country consumer and manufacturer in 2016. Growth and an increasing household income economy are factors increasing demand for e-bikes in China and many Asian countries. Currently, about 90% of the world's e-bikes are sold in China [3].

Growth in e-bike sales in the last decade has increased by 10% per year. Meanwhile, from global e-bike sales estimated at around 90% are in China, where people in daily activities reach 170 million people who use e-bikes. Charging stations for electric vehicles that operate in meeting the needs of daily electric vehicle loads require continuous energy in energy supply to loads, then a microgrid topology where this concept of renewable energy is integrated into the system, with the use of battery energy storage system (BESS) is also applied to this concept as a form of a proposal to meet energy needs in the charging station concept [4], [5], even according to [6] electric vehicle charging stations that are entirely supplied from renewable energy are modes of transportation that apply the concept of zero-emission. On the other hand, [7]-[9], in the eco-friendly e-bike concept, off-grid charging systems are preferred over on-grid systems because they look at the advantages, sustainability, ease of transfer and installation as well as the convenience of the available electrical network. Systems that use microgrids consist of three main elements: energy conversion, energy storage, and energy consumption [6]. In this context, solar power generation from photovoltaic panels becomes the main source to meet the energy needs of the load.

In addition, the battery storage system connected to the solar panel acts as a second energy source that supports the energy needs of the load. To complement energy sources from the public grid, the system also serves as a backup system in anticipation of disruptions to renewable energy sources, the system approach is based on the smart grid concept, which prioritizes system reliability to ensure the fulfillment of energy requirements for loads from charging stations [10], [11]. The study also explained that charging electric vehicles can reduce the price of charging because of the maximum utilization of photovoltaic or PV energy in the concept coupled with a slow charging mode that is more likely to use energy from PV. At the charging station, there are two types of sources used for loads, namely AC and DC sources. If the required power source is an AC source, then the energy source that originally produced the DC source must be equipped with an inverter (DC/AC) to produce an AC source. Conversely, if the available power source is in the form of a DC source, then the energy source that will produce the AC source must have a conversion device in the form of a rectifier (AC/DC) installed [12]. In the study, the author's focus was to use load voltage sourced from AC voltage. This is done to meet the needs of devices used on electric bicycle loads. Therefore, in this study, the main energy source is renewable energy from solar modules that produce DC sources, which then require converters in order to be converted into AC grid sources [12].

According to studies [13]-[16], the concept of charging and discharging electric vehicles can be categorized into several concepts including i) uncontrolled charging, ii) charging is delayed, iii) average charging, iv) smart charging, and v) intelligent discharging. There are two types of the concept of self-control in integrating several energy sources. The first is using a hybrid charger controller device [17], [18] where some of the energy sources produced will be controlled via charge controller/maximum power point tracking (MPPT) for charging mode against storage batteries with voltage using a DC system. The second is using an automatic transfer switch (ATS) [19]-[25] where the installed energy source will be integrated in accordance with the priorities and energy conditions available in the energy source to be supplied. The concept in this control parameter can use an AC or DC voltage system.

In this paper, the main purpose of the study is to maximize the integration of both energy sources derived from PV and the grid with the application of storage batteries to maximize energy from PV. In addition, the research also aims to maintain the quality of the voltage to be supplied to the e-bike load, to meet the voltage required on the e-bike charging device. So the main thoughts that will be discussed in this study include: i) Analysis of the voltage supplied from renewable energy sources, namely PV, during PV energy production, and energy sources from the grid based on the allowable drop/over voltage standards; ii) Analysis of the ability of lead-acid batteries 12 V 100 AH, according to quality standards that need to be maintained along with inverter devices; and iii) Implementation of controls on ATS devices used for hybrid source integration on photovoltaic and grid.

The limitation of the problem of this study is the design of the system used using the load capacity of an e-bike as much as one e-bike with an e-bike specification of 128 Wh in the operation of charging to the e-bike battery and using e-bikes with scooter-style e-bikes or SSEBs. Then the controller used for the operation of the system algorithm is the Arduino uno microcontroller. As well as the hybrid operation of the system on the grid supply source, only the voltage quality is discussed in this study. The application of this system to the needs of the community can be implemented for charging e-bike tires which has been widespread in Indonesian society, because of the lack of charging stations for e-bikes themselves, so the research is focused on meeting these needs, with the application of environmentally friendly energy sources as the basic concept of contributing to the net zero emission (NZE) commitment.

2. METHOD

2.1. Design of e-bike charging station

The e-bike charging station consists of several main components consisting of 2×100 Wp with an open circuit voltage (V_{oc}) of 22.4 V monocrystalline type. Where the number of solar modules is taken from the calculation of daily energy needs of a load of 576 Wh and the average irradiation of sunlight in Malang City of 5.02 kWh/m^2, then the DC/DC converter uses the Powmr MPPT 60 A 13 V device as a device to control the charging of energy from PV to storage batteries. The storage battery with Lead Acid type 12 V 100 AH is installed parallel to Kenika inverter 12 V 1000 W. A System voltage of 12 Vdc is applied to this e-bike charging station concept. The inverter is arranged parallel to the storage battery because when the energy from the PV is below the standard rating on the inverter, the battery will directly support the PV to supply energy to the load through the inverter. Figure 1 shows a block diagram of the system design at the charging station.

The system design on the e-bike charging station is equipped with a monitoring system that includes the value of power, voltage, and current produced by renewable energy sources and the grid, along with energy consumption that has been absorbed by the e-bike load. The charge controller attached to the system operates at a voltage of 13 volts, with the type of MPPT used, the voltage generated by the PV will be stabilized at a voltage rating of 13 volt by the MPPT device to charge energy to the storage battery and will directly supply energy to the e-bike load. The output voltage of the inverter in the form of AC voltage before going to the load will be operated by the ATS system as the main device in the control of energy sources that will supply to the load, where the ATS device is connected to two energy sources from renewable energy and the grid [22]. This ATS device will be the main subject of discussion in this paper. The ATS in this study is to maintain the potential of PV energy supply against e-bike loads, then basically the balance of the energy system in PV in (1), which of the solar irradiance captured by solar modules generates PV power (P_{pv}), then by MPPT directly control the charging of the battery (P_{bat}) dan When the e-bike load is attached (P_L), there will be a large value of power [22]-[27].

$$P_{bat} = P_{pv} - P_L \quad (1)$$

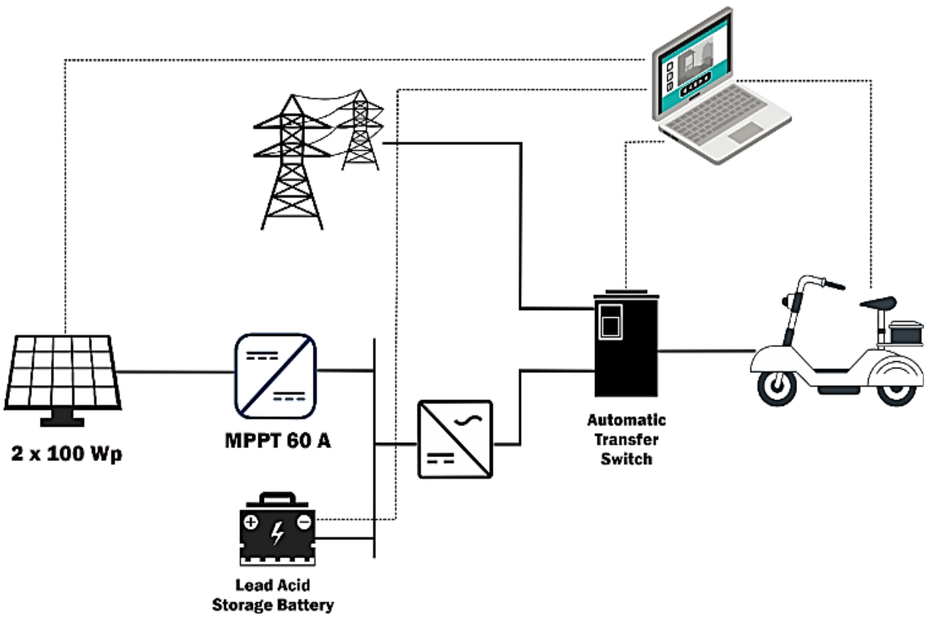

Figure 1. E-bike charging station block diagram

2.2. Battery storage system

Depth of discharge (DoD) of a battery is an important parameter in determining how dept a battery will charge before it is recharged. In this context, the authors have assigned a state of charge (SoC) value that represents the condition of the battery from empty to full based on a specific voltage, which has implications on the DoD of the battery. A limit of SoC at 0% with a voltage of 10.7 volts indicates that the battery is considered completely discharged at that point, while 100% SoC at a voltage of 13.2 volts indicates that the battery has reached its full capacity. The setting of this SoC limit also has direct relevance to the battery charge and discharge cycle. By designing these limits, the authors seek to extend battery life, as less deep charge and discharge cycles tend to increase battery life in the long run. Therefore, knowledge of the battery's DoD value is important because it gives an idea of how much energy can be supplied from the battery before it needs to be recharged, thus affecting the performance and overall life of the lead-acid battery. Figure 2 illustrates the percentage of DoD used at e-bike charging stations, a parameter in determining the maximum limit of energy supply from the battery to the load. There is also an indication of maximum battery discharge which means that the battery is allowed to supply energy to the maximum load at a voltage of 11.2 volts with a DoD percentage of 80%.

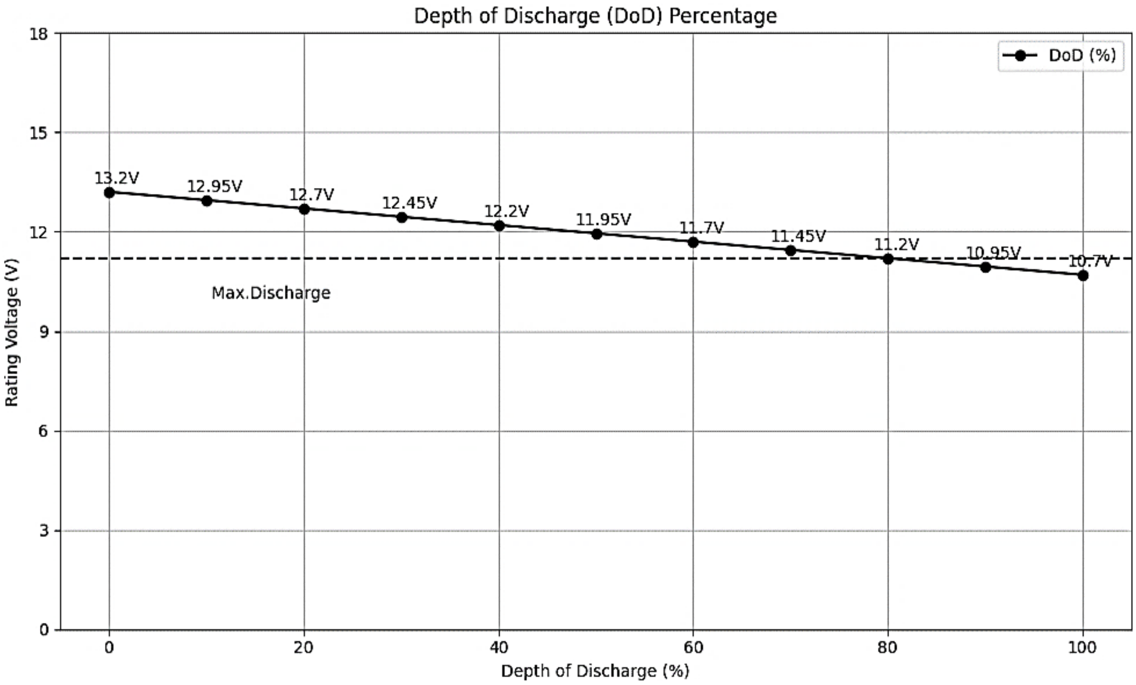

Figure 2. DoD percentage graph of lead acid battery

2.3. Inverter input rating

Figure 3 explains the schematic of the inverter input rating method. This method is a novelty method used for control parameters on ATS. This method summarizes several procedures that include the standard lowering of the DC voltage, the DoD in lead acid batteries, and the minimum/maximum input values required in the inverter specifications. In a system connected to solar panels, the maximum allowable drop in DC voltage is 3% from the solar module furthest to the input of the power converter [28]. For example, 11.64 volts represents 3% of the DC system voltage of 12 volts. Furthermore, the DoD limit of the battery reaches 80% of the 11.2-volt value, and the inverter input specifications range from 10.5 to 15.5 volts. The inverter input voltage range from 11.2 to 15 volts is taken as a parameter, taking into account the permissible DC voltage drop and the battery DoD limit, which still corresponds to the inverter input voltage rating specifications. These parameters are then used to determine whether solar panels can supply power requirements for e-bike loads. Taking into account values such as DC voltage drop and battery DoD limits is an important step in optimizing the efficiency and resilience of renewable energy systems. By ensuring that these parameters remain within adjusted limits, the system can provide stable and reliable power availability to support sustainable energy needs, such as power provision for e-bikes. This emphasizes the importance of proper management of these critical aspects in designing, maintaining, and operating renewable energy systems connected to solar panels for everyday applications [29].

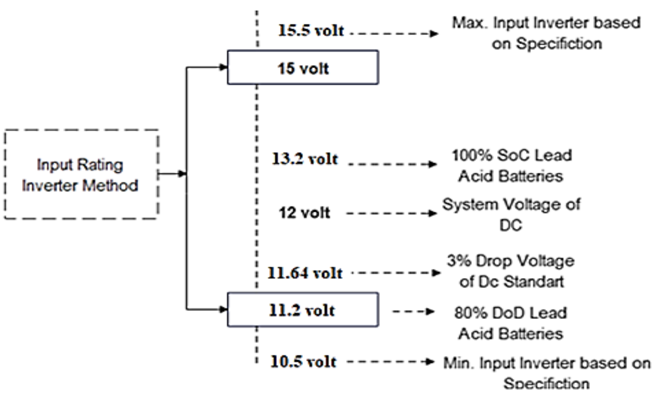

Figure 3. Inverter input rating method

From (2), it will be known the condition of the PV source power when the e-bike load is installed along with the duration, and the last battery power value when the e-bike load is no longer installed. V_{mppt} is the value of the output voltage of the charger controller on the battery, where the P_{bat} will be charging when the P_{bat} value is positive at the same time the value of V_{i_INV}=V_{mppt}. However, P_{bat} will be discharged when the P_{bat} value is negative at the time value of V_{i_INV}=V_{bat}.

V_{i_INV} is the inverter input voltage. The inverter input voltage can come from the PV voltage which has been controlled via SCC or it can also come from the battery voltage when the PV does not get sunlight. V_{bat} is the voltage of the battery when the battery supplies energy to the load or when the PV no longer produces electrical energy. So, the energy that has been charged to the battery will be supplied back by the battery to the load.

$$V_{i\_INV} \approx \begin{cases} V_{mppt}, P_{bat}(+)\ is\ charging \\ V_{mppt}, P_{bat}(-)\ is\ discharging \end{cases} \tag{2}$$

2.4. Standard AC voltage

The allowable AC voltage drop value on the consumer installation side is about ±4-5% of the nominal AC system voltage [28], [30], which is about 220 V. This indicates that the 'drop limit' is about 5% of the nominal system voltage, about 209 volts, with an over-voltage limit ('over voltage limit') in the range of 231 volts, the over/drop voltage value can be found through (3) and (4). These overvoltage limits are adjusted to the voltage specifications on load controls and e-bikes. In some analyses of data collected on grid voltage at night, there were conditions where the voltage exceeded 231 volts. However, on the other hand, the load voltage specification still meets the recommended voltage rating. When overcoming grid voltage conditions that exceed the over-voltage limit at 231 volts, it should be noted that voltage specifications on load control and e-bikes must be carefully observed. Although there are situations where the grid voltage exceeds this upper limit, it is important to ensure that the load control devices as well as the e-bike are able to handle the voltage rise without experiencing damage or malfunction. In these cases, continuous monitoring of system health as well as proper adjustments to control equipment and loads are necessary to maintain safety and optimal performance in the long run.

$$V_{over} = \left(\frac{(Vs - Vn)}{Vn}\right) \times 100\% \tag{3}$$

$$V_{Drop} = \left(\frac{(Vn - Vs)}{Vn}\right) \times 100\% \tag{4}$$

V_{over} is the percentage of voltage value that exceeds of AC voltage value, while V_{Drop} is the voltage drop value at AC voltage. Vn set on 220 V is the nominal voltage standard for AC voltage. Vs is the voltage value detected by the AC voltage sensor. The minimum and maximum limits of the value of V_{over} and V_{drop} become a parameter in the grid system that functions as a backup in automatic transfer switch devices.

2.5. Design of automatic transfer switch

An ATS is an automated device that uses control logic on a controller programmed according to the ATS mechanism. The identifier of this ATS mechanism uses Arduino Uno to implement voltage inputs on each energy source along with outputs connected to e-bike loads. In this study, hybrid energy sources consist of solar panels (200 wp) and grid power sources that are used alternately. ATS gives priority to energy from solar panels, powered by storage batteries (12 V 200 AH), with the grid as a backup in case the solar panels are insufficient load requirements.

Control logic requires input from AC and DC voltage sensors to monitor grid and inverter voltages. The output of the control mechanism uses a relay as a switch that is governed by pre-planned input parameters. This planning requires a switch for each phase conductor and a neutral energy source connected to the load, anticipating a parallel system between the inverter and grid outputs.

Two solar panels of 100 wp each are arranged in parallel to increase the maximum current to 10 A with an open circuit voltage (V_{oc}) value of 22.2 volts. As long as the solar panels produce energy, the storage battery is charged using an MPPT of 60 A. The inverter, which converts DC to AC, is set parallel to the battery so that the battery will provide direct voltage to the inverter when the solar panels are not producing energy. So, the algorithmic process flow of the automatic transfer switch is shown in Figure 4.

In the planning algorithm of this ATS study, apart from considering the fulfillment of energy sources from PV and grid to loads, researchers also consider electronic devices that help with the energy conversion process of PV and devices in switching systems. The energy conversion device from PV researchers maintains the performance of the DC/AC inverter when there is a failure of voltage conversion, then the inverter output becomes an important consideration as an ATS working parameter. Furthermore, the success of the work of the ATS must not be separated from the success of the switching system, the failure of the switching system needs to be considered, therefore the ATS output voltage detected must be considered and must be a parameter in the control mechanism on the ATS.

In Figure 4, V_{i_inv} = input inverter voltage, in this parameter, the system has a limit on the voltage value of 11.2-15 volts in the application of the inverter input rating method. While in other parameters is the output voltage value of the inverter, grid, and ATS, where the AC voltage system is applied, because the voltage system used is an AC voltage system. It is necessary to standardize the voltage applied, in this case the AC voltage drop method is implemented. The limit of AC voltage is 5% over/drop from the nominal voltage (220 V), which is 209-231 V. V_{o_inv} = output inverter voltage, V_{grid} = grid voltage, V_{o_ats} = output ATS voltage.

The controller board used is the Arduino Uno. The use of AC and DC sensors is implemented in this simulation by using an octocoupler as a switch output. The modeling in Figures 5 and 6 is used to assemble controller inputs using AC and DC voltage sensors. The AC sensor is used to read voltage data on the grid system, while the DC sensor is used to read the voltage at the inverter input as a parameter for determining how the photovoltaic system can work. The use of a voltage divider is applied to sensor readings at DC voltage and using (5) for programming on the board controller.

$$V_{DC} = \frac{Vanalog}{\frac{R2}{(R1-R2)}} \quad (5)$$

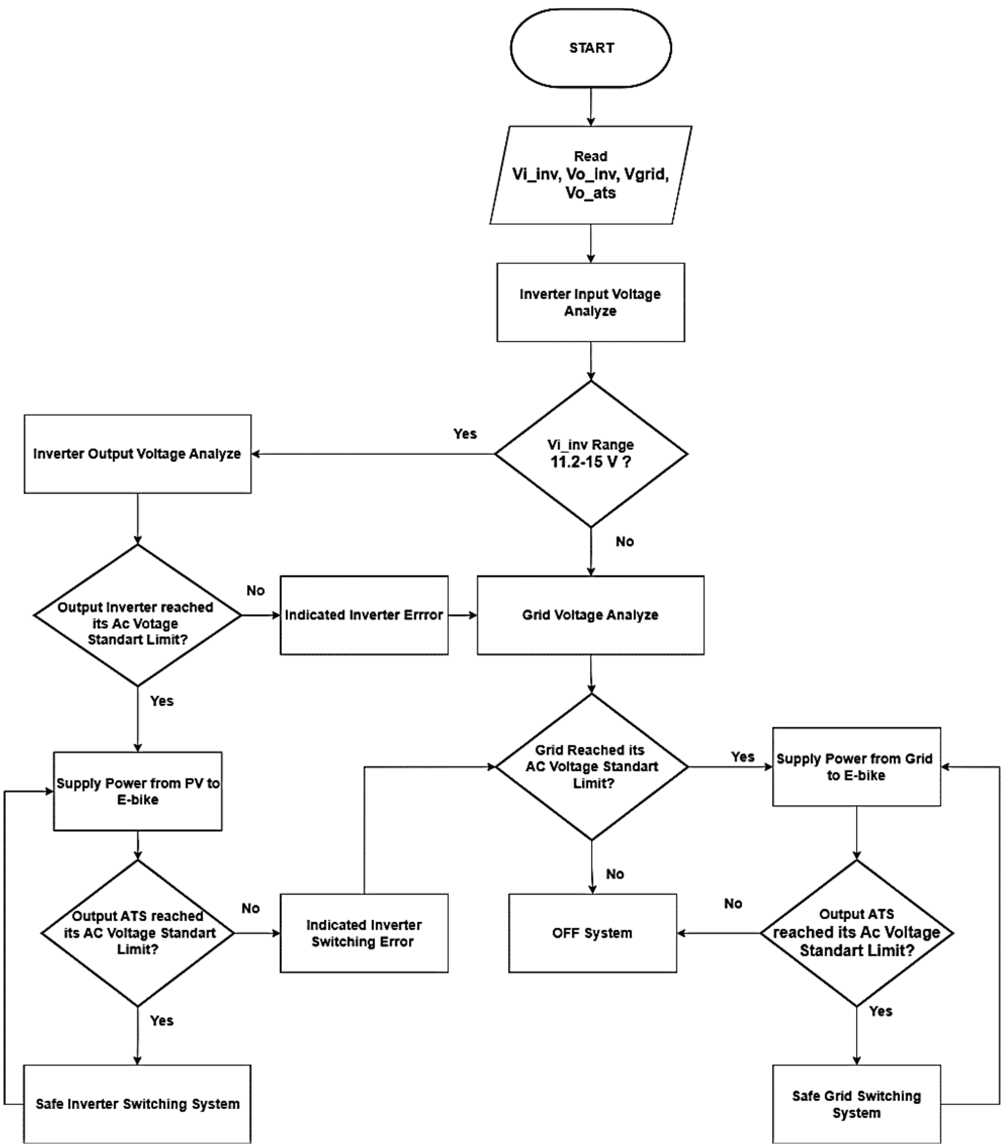

Figure 4. Flowchart of ATS

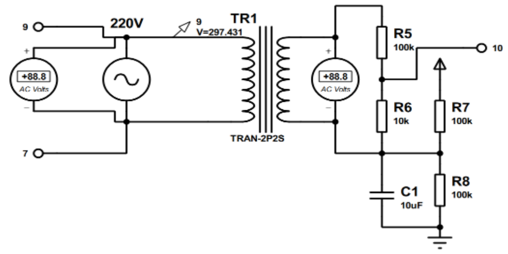

Figure 5. AC voltage sensor reading model on a grid system

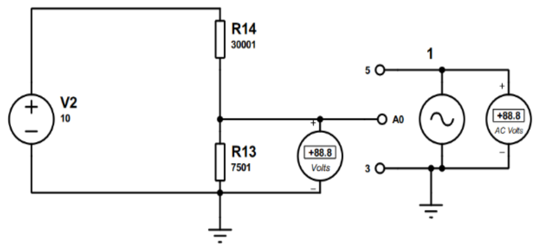

Figure 6. Model for DC voltage sensor

In Figure 7, there is a wiring diagram of an ATS design using the EasyEDA application. This wiring diagram consists of an input system, namely a PZEM sensor (004T) as an AC voltage sensor, a DC voltage sensor for inverter and battery input voltage detection, and then a controller system, namely Arduino Uno as a microcontroller. Finally, an output system, namely a mechanical relay used for automatic switches on loads. The way the whole system works is that the AC voltage sensor (PZEM 004T) and the DC voltage sensor will read the voltage values generated by the PV and the grid. Then the voltage values will be processed by the Arduino Uno controller, with the program that has been uploaded to move (ON/OFF) the relays that have been connected to the PV energy source and the grid. Then, the relay of the four channels in series is connected to the mechanical relay, and the mechanical relay output will be connected in parallel with the load of the e-bike through the outlet for charging the e-bike battery.

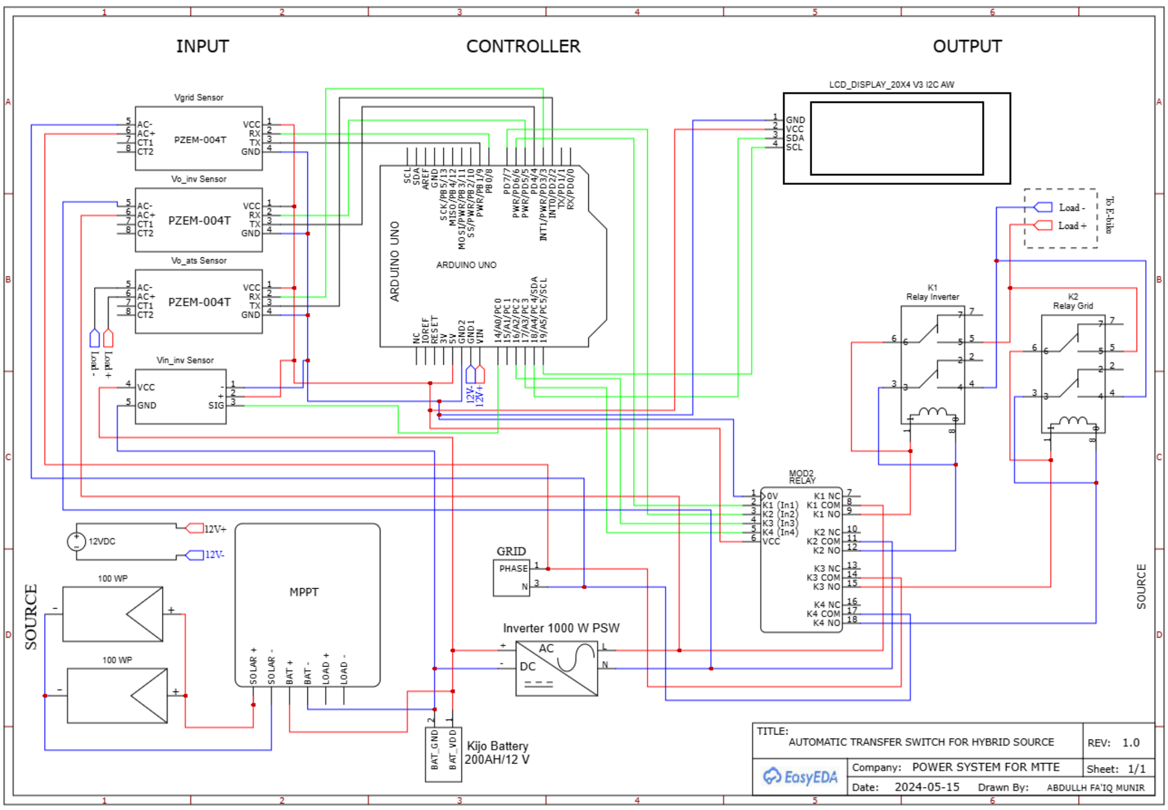

Figure 7. Wiring diagram of ATS

3. RESULTS AND DISCUSSION

The presentation in this section is an explanation of the voltage, current, and power analysis of PV energy sources and grids that are integrated with the use of ATS against loads. The first exposure that will be explained relates to the energy produced by PV where the battery is charging and the e-bike load is on. The use of ATS itself in an algorithm that has been designed for the value of the inverter input voltage to be the main role of PV can supply energy to the load. While the voltage value of the inverter input is based on the value of the power produced by the PV, please also note that the PV will supply to the load at the same time the PV will charge to the storage battery controlled by MPPT. Control programs are applied to implement the ATS algorithm, the mailing list method is used to produce the switching process in a fast time. Analysis of stress on the grid is also presented in the explanation of this section. The analysis that will be explained about the quality of the voltage produced by the grid is related to the percentage value of AC voltage drop/over, where it is a determining parameter ATS can work as a backup to PV.

3.1. PV energy supply to load

In this condition, the PV produces energy in the morning to evening, with a battery storage system scheme installed at the same time, the battery charging condition. Analysis of the power generated by PV is needed to meet its impact on the input voltage of the inverter, so as to determine the maximum PV duration in meeting the control criteria in the ATS and the effectiveness of the PV supplied to the load. The analysis is discussed in the following test results.

3.1.1. PV Power (P_{pv}) analysis of inverter input voltage (V_{in_inv})

Figure 8 displays a graph of research results P_{pv} and V_{in_inv} in the duration of daylight – evening, that the amount of PV power is at a maximum value of 135.9 W at 11.25 am and is at the lowest power of 31 W at 03.31 pm. Looking at the input value of the inverter voltage at the lowest point, which is 12.66 V with the same conditions, the value of PV power in the range of 40 W. Then, when the PV power value is at the lowest point, the value of the inverter input voltage is in the value of the voltage range of 13.25-13.50 V. The analysis provides an understanding that the control scheme of the ATS required in PV as an energy source, PV parameters can supply energy to the load with the duration of day-afternoon, value V_{in_inv} the range of 11.2-15 V can be met at that time because looking at the analysis of the inverter input voltage that occurs large maximum value=14.15 V and minimum value of 12.66 V. Please also note that when PV power is in the range of 40-45 W, the battery storage system will help PV in supplying energy to the load. So that the input voltage of the inverter at the minimum point of 12.66 V will rise to a voltage range of 13.75-13.25 V. These conditions coincide with the PV power at the lowest value.

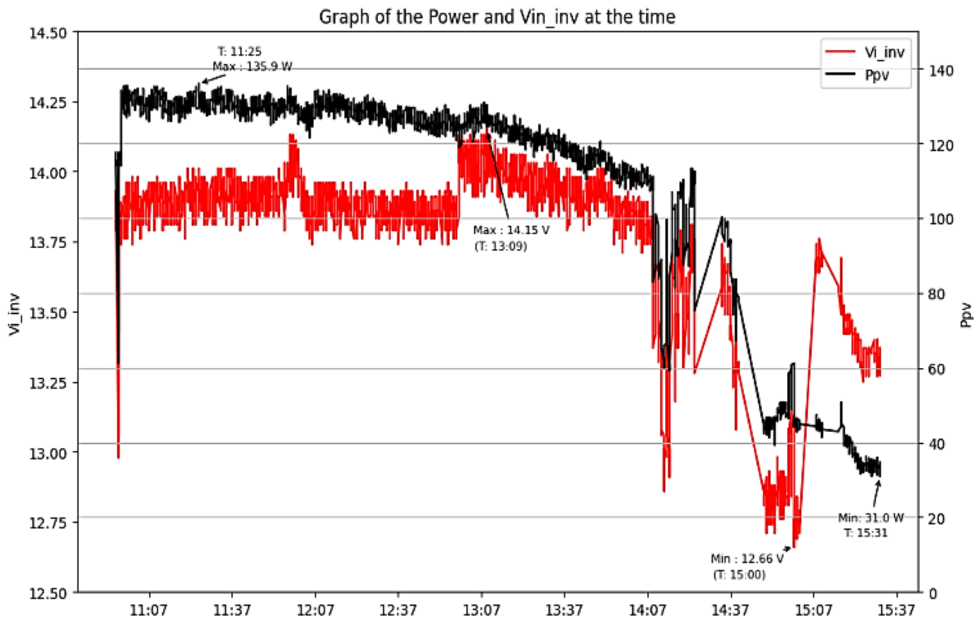

Figure 8. Graphs of P_{pv} and V_{i_inv}

3.1.2. V_{i_inv} against quality V_{o_inv}

ATS in the design described in the previous section, parameters of the inverter output voltage (V_{o_inv}) as a parameter to meet PV can supply energy to the load of the e-bike. Where the standard value of AC voltage is applied in this case which is ±5% of the nominal voltage (220 V). The tests that have been carried out are explained in Figure 9, that V_{i_inv} max=14.15 V and V_{i_inv} min=12.66 V, voltage quality on V_{o_inv} is within the range of the permissible standard value of AC voltage, which is ±5%. Obtained from the lowest voltage value test chart from $V_{o\_inv} = 223.9\ V$ and top marks $V_{o\_inv} = 226{,}1\ V$, this is the main priority of the researcher that the voltage range at the input of the inverter must be in the range 11.2-15 V, in order to meet the voltage quality at the inverter output from the stadium the permissible voltage is ±5%. Then the conclusion during the test takes place with the voltage value V_{i_inv} and V_{o_inv} under the conditions of the range specified in the ATS algorithm. It will maintain the effectiveness of PV supply e-bike loads can maintain the quality of the inverter voltage, and guard against damage to the inverter device itself.

Based on Figure 9, it can be analyzed from the graph readings during the test lasted for nine hours of PV testing, the largest value of ($V_{in_{INV}}\ max$) the inverter input voltage is 14.15 V at 13.09 WIB or Western Indonesia time, then for the lowest value of the inverter input voltage ($V_{in_{INV}}\ min$) at 12.66 V at 15.00 WIB. So, it can be concluded that during the 11 hours of testing the condition of the inverter input is still on the inverter input rating. If analyzed more deeply, the average at a certain hour from the morning to the afternoon of the inverter input voltage value is 13.24 V, meaning that it is 53.7% of the minimum and maximum limit range of the inverter input voltage, the percentage of the quality of the voltage runs for five hours of testing. Then the average usage from 12.00-18.00 WIB the average inverter input voltage produced is 12.78 V, the percentage of inverter input voltage quality during six hours of testing is 41.6% of the minimum limit range, and the maximum inverter input allowed from the ATS system. So, overall, the average voltage read at the inverter input rating is 12.98 V with a percentage of 46% of the minimum and maximum limit range of the inverter input voltage allowed in the ATS system. Thus, the results of the test and analysis of the reading of the inverter voltage input value during the test which lasted 12 hours from morning to night, the analysis is still limited to the inverter input voltage value. A detailed explanation of performance (V_{i_INV}) is available in Table 1 which explains the analysis of test graphs V_{i_INV} for 12 hours of testing.

Based on Table 1, it is known that the value of the inverter input voltage from the large morning-noon range is 53.7%. The average at a certain hour is symbolized by ($V_{i\_INV}\ t, t_1$), while day-night testing obtained a percentage of 41.6%. So that the overall percentage range V_{i_INV} is 46%. With this percentage, it is concluded that the value of the inverter input voltage during the test is in a stable condition than the minimum and maximum allowable voltage limits. Even if you look at the test results based on the average voltage every hour, the highest value of V_{i_INV} is 13.76 V and the lowest value is 11.5 V, the smallest value is at 18.00-19.00. It can be concluded that the PV system planned for e-bike charging needs can supply the battery needs of one e-bike at 07.00-19.00 for 12 hours, with details of full PV mode, PV-battery mode, and full battery mode.

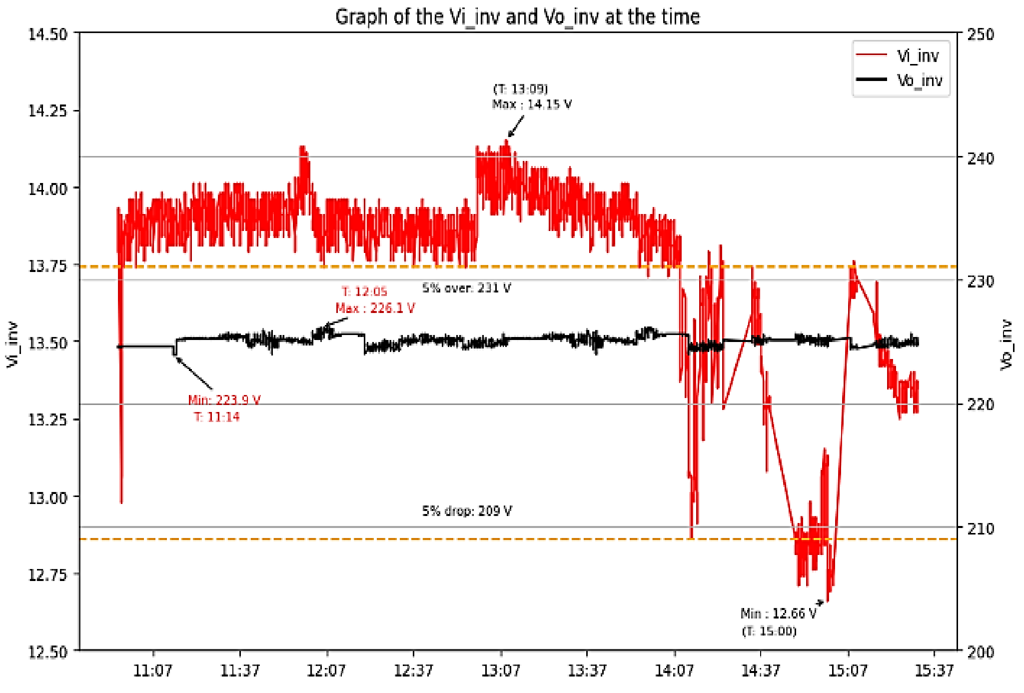

Figure 9. Graphs of V_{0_inv} and V_{i_inv}

Table 1. Performance analysis (V_{i_INV}) during morning-night testing

Min value ($V_{i\_INV}\,min$)	Max value ($V_{i\_INV}\,max$)	Average (07:00-12:00 WIB) ($V_{i\_INV}\ t, t_1$)	Average (12:00-18:00 WIB) ($V_{i\_INV}\ t, t_2$)	Overall average V_{i_INV}	Average $V_{i\_INV}(V)$/h
12.66 V (15:00)	14.15 V (13:09)	13.24 V (07:00-12:00)	12.78 V (12:00-18:00)	12.98 V (07:12-18:42)	12.65 (7:00-8:00) 12.88 (8:00-9:00) 13.21 (9:00-10:00) 13.76 (10:00-11:00) 13.58 (11:00-12:00) 13.72 (12:00-13:00) 13.55 (13:00-14:00) 13.73 (14:00-15:00) 12.72 (15:00-16:00)
Rating percentage V_{i_INV} (%)		53.7%	41.6%	46%	12.05 (16:00-17:00) 11.87 (17:00-18:00) 11.55 (18:00-19:00)

3.2. E-bike loading with PV energy supply

The quality of the inverter output voltage (V_{o_inv}) is stable in the range of ±5% over/drop during the test. Figure 10 explains about the inverter output standby when loading with a PV supply source. The graph on the grid voltage (V_{grid}) shows the value exceeding the 5% over voltage, which is 231.6-235 V. E-bike loading in e-bike battery charging mode is carried out at 00:37-01:57 pm. I_L shows graphs of the highest e-bike loading up to 14.09 A, and the lowest loading 0.23 A. The stability of the inverter output voltage (V_{i_inv}) value at the time of loading affects from the PV's ability to supply energy to the e-bike load up to I_L=14.09 A, during the day-evening hours. We can see from the chart $I_{\_C}$ is the draining current in the storage battery, at 02:37-03:37 pm is in a decreasing position, but the power supply to the load is at the current position 5-10 A. In this case it implies that PV production has decreased in supplying energy to the storage battery for charging, but the energy stored by the storage battery starts in supplying energy to the load of the e-bike.

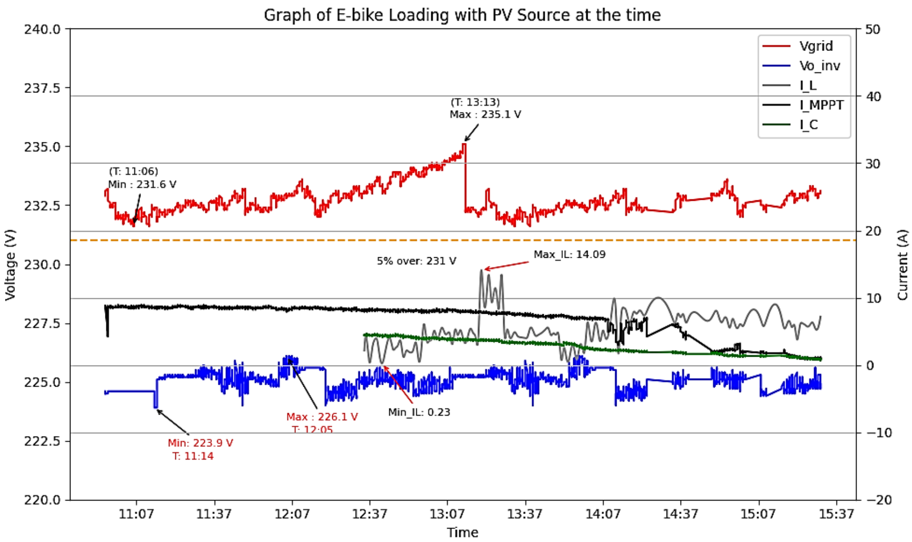

Figure 10. E-bike loading graph with PV source

Figure 11 explains the energy consumption of PV and battery when loading an e-bike. The loading of the e-bike starts during the day, when the PV generates power (P_{pv}) 124.3 W, at the same time the battery is in the charging position. E-bike loading lasts for three hours starting at 00.36 pm–03.26 pm where the conditions (V_{i_INV}) stable in the range of 11.2-15 V, with an average of 13.8 V, while in that condition the battery is stable in the discharging position from 02.10 pm–03-31 pm. From this, it shows that (V_{i_INV}) is an important parameter option in determining the use of PV energy sources in their application to loads, especially in this study to their application to e-bike loads. Therefore, the author uses this inverter rating input method as a simple method in using PV resources as the main energy source in e-bike loads. On the other hand, when (V_{i_INV}) in the range 11.2-15 V the rated voltage (V_{O_INV}) always stable in the range of 209-231 V or ±5% of 220 V. Overall, a hybrid system of PV sources with the grid using ATS devices can maximize the energy sources obtained from PV.

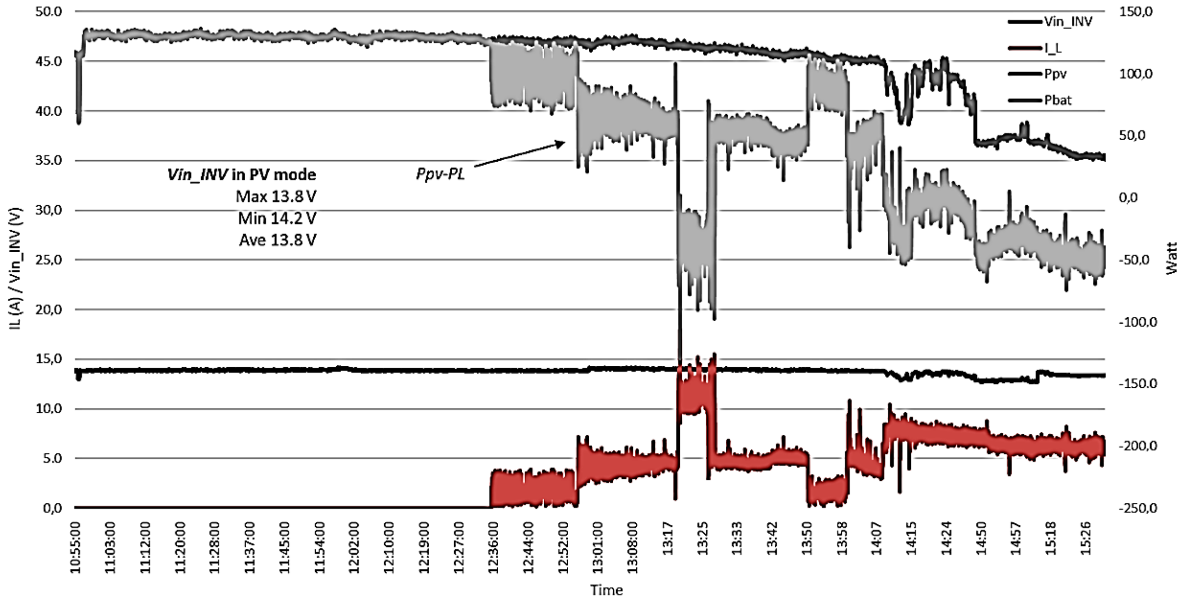

Figure 11. Measured P_{pv}, P_{bat}, I_L and V_{in}_INV

3.3. ATS switching based on source supply

In Table 2, the explanation of the duration of the study using the millis programming language on the ATS resulted in a switching duration in the duration range of 10-21 ms with a variable e-bike load capacity at the time of the experiment. The e-bike's load is as large as $I_L = 7.03\ A$ at 02:20 pm, where the energy source supplied by PV obtained a duration for 18 ms, simultaneously the PV battery at the charging position is P_{bat}=6 W, $P_{pv} = 100.7\ W$. On the next date, an experiment was carried out where the battery was discharged $P_{bat} = 19.1\ W$, $P_{pv} = 111.7$. The load of the installed e-bike is $I_L = 19.1\ A$, on the hour 14:00 with a switching duration of 21 ms. Grid supplies e-bikes at the moment $V_{i\_inv} = 11\ V$ and $V_{grid} = 225\ V$. The percentage of grid voltage over 4% is still within the permissible grid voltage quality range, there is a transfer of energy sources from PV to the grid with a switching duration of 21 ms, where the e-bike load $I_L = 9.66\ A$. In this trial, it can be analyzed that the duration of switching is influenced by the programming language used, namely the millis program, the size of the e-bike load I_L also affects the duration of the switching, which is greater I_L so the longer the switching duration.

Table 2. Switching duration for ats based on source supply

Date	Time	Source supply	Battery mode	P_{pv} / P_{bat} (W)	I_L (A)	V_{i_inv}(V)	$V_{grid}(V)$	Switching duration (ms)	Programming language
16/1/2024	11:08 am	PV	Charging	134.4/134.4	0.1	13.2	223	10	millis
19/1/2024	00:50 pm	PV	Charging	125.6/83.6	3.03	13.3	223	20	millis
19/1/2024	01:34 pm	PV	Charging	122.1/62.9	4.22	13.3	230	20	millis
19/1/2024	02:20 pm	PV	Charging	100.7/ 6.0	7.03	13.3	230	18	millis
23/1/2024	02:00 pm	PV	Discharging	111.7/19.1	9.4	13.5	224	21	millis
23/1/2024	02:13 pm	PV	Discharging	60.4/51.8	8.66	13.5	224	20	millis
23/1/2024	03:28 pm	PV	Discharging	35/61.5	7.25	13.5	225	20	millis
23/1/2024	08:18 pm	Grid	-	-	9.66	11	225	21	millis
24/1/2024	07:17 am	Grid	Charging	36.5/36.5	6.8	11	230	20	millis

4. CONCLUSION

The test results that have been carried out are ATS installed on the e-bike charging station, working on the inverter input voltage rating of 11.2-15 V so that PV can supply to the e-bike load. The amount of current during testing is up to 14.09 A. The value of the inverter input voltage affects the quality of the inverter output voltage, there is a stability of the inverter output voltage from the AC voltage standard ±5%, the lowest voltage value of $V_{o_{inv}} = 223.9\ V$ and top marks $V_{o_{inv}} = 226.1\ V$, at the time of $V_{i_{inv}}$ max = 14.15 V and $V_{i_{inv}}$ min = 12.66 V.

It can be concluded that the ATS works in the PV position of supply to the e-bike load, in the PV state it is able to produce power of a maximum value of 135.9 W at 11:25 am and is at the lowest power of 31 W at

03:31 pm, where the installed e-bike load starts to charge the battery up to I_L max = 14,09 A. At the same time the quality of the inverter output voltage is maintained at its standard and when the e-bike is finished in its charging mode, the inverter input voltage value is still in the range of 13.20-13.25 V. It means that the battery storage system, when 03:31 pm - finished, is still able to supply energy to the e-bike load. Apart from PV's role as a priority source to supply energy to e-bike loads, it is a form of mitigation from grid sources when grid voltage experiences voltage instability. Which is in the ongoing testing V_{grid} max = 235 V and V_{grid} min = 231.6 V. In terms of quality, the voltage is at a percentage over from 5% (231 V) maximum. Finally, this ATS device in the switch mode successfully implemented a duration range of 10-21 ms during the transfer of energy from PV to grid or grid to PV.

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