Design of Adaptive Neuro-Fuzzy Inference Control Based One-Axis Solar Tracker on Battery Charging System

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Abstract. The photovoltaic (PV) panel can produce electrical energy that is very environmentally friendly and easy to use. The use of PV panels is suitable for supplying peak loads or at night using batteries as energy storage. However, the battery needs to manage for control, and the battery can last long. The solution to battery management problems is through research about the battery charging system. The DC-DC converter used is the Single Ended Primary Inductance Converter (SEPIC) type. Voltage Control of the battery charging using Adaptive Neuro-Fuzzy Inference System (ANFIS). In the simulation of bright conditions, ANFIS controls can track the charging point set point and obtain a voltage response with a rise time of 0.0028 s, a maximum overshoot of 0.027 %, a peak time of 0.008 s, and a settling time of 0.0193 s. When charging a solar tracker, PV battery gets a 0.25 % increase compared to a fixed PV panel. PV solar tracker can follow the direction of the sun's position. The irradiation value and maximum temperature affect the input voltage and input current that enters the converter.

Keywords: Battery management, electrical energy, photovoltaic, renewable energy, solar tracker.

1 Introduction

Electrical energy is the energy needed in supporting human life, especially in meeting primary needs. There are food, residence, and clothing needs. The use of electricity is mostly from fossils. The rest comes from renewable energy sources. The use of fossil fuels has caused many problems that are environmental, health, economic. One of the renewable energy sources is solar energy. Solar energy is energy in the form of heat and light emitted

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by the sun. The sun is a source of energy that emits energy that enormous to the earth's surface. The surface of the earth receives up to 1 000 W m^{-2} of solar energy. About 30 % of this energy reflected in space, and the rest is by clouds, oceans, and land. The amount of energy absorbed by the atmosphere, oceans, and the earth's land is around 3 850 000 EJ yr^{-1} [1].

Efforts to maximize the use of solar energy require a transducer that can convert solar energy into electrical energy. This transducer is usually called a solar cell. The solar cell is a device that can produce electricity from light energy. However, in the process of energy conversion in the solar cell, this is influenced by many factors that can reduce the maximum work of energy conversion [2]. These factors include orientation factors towards the position of the ever-changing sun. A solar tracker with a single axis can improve performance than PV fixed [3].

The Lead-acid batteries or lead batteries are one that widely used as a chemical device for storing electrical energy. Many parameters need consideration in battery charging. These parameters are voltage and current. Management also needed for optimal battery charging and using, and maintenance and durability of batteries. The function of battery charging management is to a regulator of the circuit so that the battery optimally can be charged [4]. All the energy produced by PV stored in the battery. This research focused on the charging system for batteries. Their aim to regulate the consumption of the results of the conversion of electrical energy in PV [5].

Referring to the problems above, this research, Adaptive Neuro-Fuzzy Inference System (ANFIS), controls the charging system. This research can regulate the charging process and ensure the use of long-lasting battery life. Adaptive Neuro-Fuzzy Inference System (ANFIS) is a combination of a fuzzy inference system mechanism. It described in neural network architecture so that battery charging is more optimal and makes battery life a long life. Besides, the charging system function is to avoid overcharge by PV panels [5]. In this study, the research will be conducted on the Design of Battery Charging Controls Using Adaptive Neuro-Fuzzy Inference System (ANFIS) in Solar-Based One Tracker PV using MATLAB / SIMULINK software.

2 Research methodology

2.1 Research flow diagram

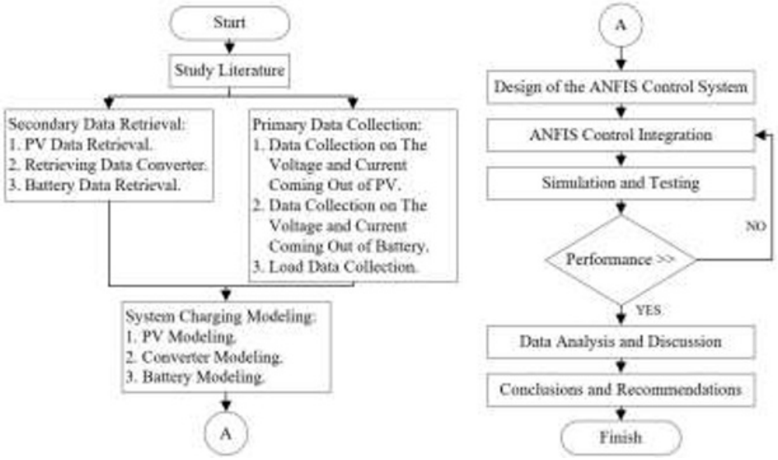


Fig. 1. Research flow diagram

2.2 Study of literature

At the beginning of the study, a literature study was conducted to build a preliminary understanding. It builds detail of theoretical and practice with proper internal reference searches. Journals and papers relate to materials that support this research. There are the solar tracker system and its specifications, ANFIS control methods, and system modeling.

2.3 Solar panel data collection

This stage obtained each parameter from the secondary data of TN-250M type photovoltaic specifications. Data on photovoltaic specifications are as follows,

Table 1. TN-250M type photovoltaic module specifications

Photovoltaic Variable	Value
Maximum Power at STC (Pmp)	250 W
Optimum Operating Voltage (Vmp)	30 V
Optimum Operating Current (Imp)	8.34 A
Open Circuit Voltage (Voc)	36.8 V
Short Circuit Current (Isc)	9 A
Nominal Operating Cell Temperature	45 ± 2°C
Temperature Coefficient of Pm (%)	-0.47 $°C^{-1}$
Temperature Coefficient of Voc (%)	-0.36 $°C^{-1}$
Temperature Coefficient of Isc (%)	0.05 % K
Operating Temperature	-40 °C to 85 °C
Maximum System Voltage	1 000 V DC
Power Tolerance	± 5 %
Surface Maximum Load Capacity	1 / 1 600

The data in Table 1 can be used to calculate the parameters in photovoltaic modeling.

2.4 Data converter retrieval

The DC-DC converter used is a SEPIC converter that can produce an output voltage that greater or smaller than the input voltage. This SEPIC converter will act as an interface between photovoltaic modules and loads. Determination of SEPIC converter specification influenced by several parameters including voltage and input current, voltage and current output, switching frequency, and nominal resistive load [6]. The SEPIC converter specifications used shown in Table 2.

Table 2. SEPIC Converter Specifications

Parameter	Value
Vin	10 V to 15 V
Vout Nominal	14 V
Iout	1.5 A
Switching Frequency	30 kHz
Inductor	0.008 μH
Output Capacitor	3300 μF, 50V
Nominal Resistive Load	4.7 Ω

2.5 Battery data retrieval

The specification of the battery used in this study is as follows.

Table 3. Battery Specifications

Battery brand that used	Luminous
Battery Type	Aki Lead Acid
Battery Nominal Voltage	12 V
Battery Capacity	70 Ah
Dimension	42 cm × 19 cm × 23 cm

2.6 Battery data retrieval

Data collected on voltage and current coming out of photovoltaic by using a multimeter. Retrieval of irradiation and temperature data carried out with the period of taking data is 30 min. Retrieving temperature, solar irradiation, current and voltage data is taken from (06:00) West Indonesian Time / GMT+7 until (17:30) GMT+7.

Table 4. Voltage and current data of PV fixed

O'clock Time	Temperature (°C)	Irradiation (W m^{-2})	Current (A)	Voltage (V)
06:00	28.2	32.7	0.52	28.78
06:30	28.8	60.3	0.62	28.83
07:00	34.2	133.5	1.02	28.94
07:30	40	248.2	1.82	29.02
08:00	40.2	251.5	2.40	29.21
08:30	47	558.2	3.73	29.49
09:00	46.4	635.9	5.57	29.54
09:30	46.6	644.2	5.90	29.48
10:00	48.8	538	5.51	29.59
10:30	59.2	876.2	6.36	29.79
11:00	59.2	819.5	7.80	29.81
11:30	58.4	912.5	7.90	29.81
12:00	60.2	789.4	7.88	29.69
12:30	56.4	749.4	7.12	29.60
13:00	54.8	620.2	6.53	29.50
13:30	53.8	592.4	5.81	29.45
14:00	52.2	583.2	5.47	29.38
14:30	47.2	470.9	4.97	29.18
15:00	46.6	271.6	3.61	29.03
15:30	37.2	194.7	2.52	28.92
16:00	34.2	65.6	1.62	28.78
16:30	33	42.2	0.67	28.75
17:00	30.6	18.4	0.47	28.72
17:30	28.8	3.1	0.27	28.72

Table 5. Voltage and current data on PV tracking

O'clock Time	Temperature (°C)	Irradiation (W m^{-2})	Current (A)	Voltage (V)
06:00	28.4	70.1	0.78	28.81
06:30	30.4	172.5	0.78	28.81
07:00	36.4	409.8	1.71	28.95
07:30	39.6	365.4	3.81	29.25
08:00	40.6	539.8	3.43	29.18
08:30	50.2	712.7	5.00	29.42
09:00	46	705.3	6.55	29.63
09:30	48.6	848.1	6.48	29.82
10:00	48.2	830.2	7.72	29.82
10:30	59	920.6	7.57	29.80
11:00	60.6	895.4	8.40	29.89
11:30	59	922.4	8.19	29.85
12:00	59.4	801.5	8.43	29.89
12:30	57.7	767.4	7.30	29.71
13:00	52.4	778.4	6.92	29.66
13:30	52.2	673.9	6.94	29.68
14:00	56.2	662.4	6.02	29.54
14:30	47.6	612.8	5.98	29.52
15:00	47	374.2	5.61	29.49
15:30	39.2	283.1	3.51	29.17
16:00	32.6	79.6	2.71	29.07
16:30	32.6	94.4	0.87	28.81
17:00	32.2	47	0.97	28.82
17:30	28.6	3.7	0.57	28.76

2.7 Retrieving voltage data and current from the battery

Data collected on the voltage and current coming out of the battery by using a multimeter in the charging process. The period of taking data is 30 m.

2.8 Photovoltaic modeling

Photovoltaic single modeling diode uses Kirchoff's Law principle to obtain current output from the Photovoltaic module.

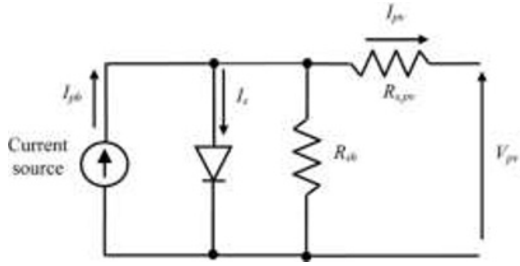


Fig. 2. Single diode electric circuit

2.9 Converter modeling

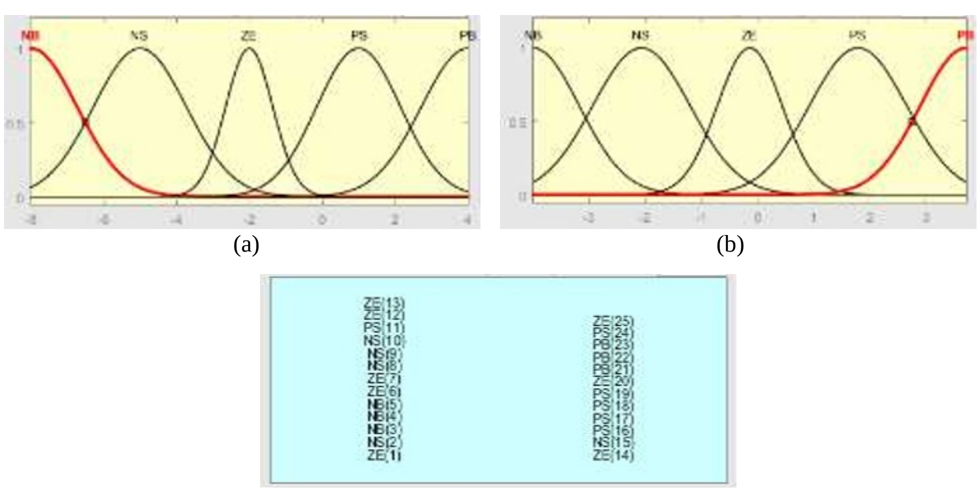
Modeling and simulation of DC-DC converters are done to determine the characteristics of the converter to changes in the duty cycle. The change in duty cycle also influenced by Pulse Width Modulation (PWM). The PWM, in general, is a way of manipulating the signal width expressed by pulses in one period, to obtain a different average voltage. Duty Cycle is a representation of logic high conditions in a signal period and expressed in terms of (%) in the range of 0 % to 100 % [7].

Table 6. Simulation results of testing the SEPIC converter characteristics.

Duty Cycle	V_{in} (Volt)	V_{out} (Volt)
0.1	28	5.964
0.2	28	8.584
0.3	28	14.59
0.4	28	17.1
0.5	28	20.07
0.6	28	26.71
0.7	28	27.51

2.10 Design of the ANFIS control system

In this study, ANFIS is used as voltage control, so that the output voltage of the SEPIC converter produces a setpoint value of approximately 14.55 V. The input used in ANFIS consists of 2 pieces, namely errors and delta errors. The resulting output is the value of the duty cycle difference. ANFIS needs to be trained firstly using pairs of input-output data like Artificial Neural Network. Training needs to done so that ANFIS can learn information about these data sets. During the training process, the premise and consequent parameters adjusted so that ANFIS can form a model that matches the given training data set [8]. In this study, the design of ANFIS was carried out with the help of the ANFIS Editor GUI in MATLAB software.



(a) (b)

(c)

Fig. 3. Membership function : (a) Input error, (b) Input delta error, and (c) Output of training results

3 Results and discussions

3.1 Simulation test of MPPT tracking based on fuzzy logic type-2

Tracking simulation is carried out to know the comparison of MPPT controller output power based on fuzzy logic type 2 that previously design with variations in climatic conditions. The comparison makes between the output of a fixed PV system and the active dual-axis solar tracker system. Primary data that uses as input include PV module surface temperature data, solar irradiation data, and wind speed data. Primary data is taken every 30 min intervals on April 25, 2018, from 06:00 to 17:00 with data collection routes starting from the Institut Teknologi Sepuluh Nopember towards Jembatan Merah Plaza and back again to Institut Teknologi Sepuluh Nopember. Temperature data and solar irradiation from each system plotted for comparison.

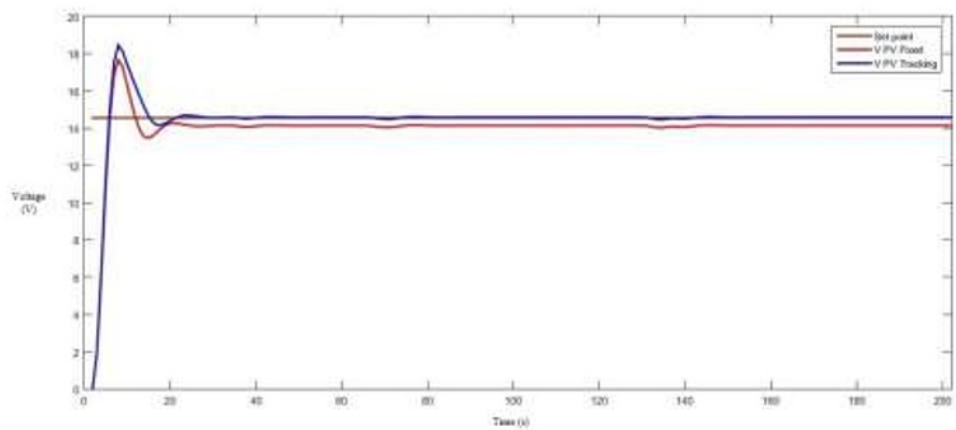


Fig. 4. Voltage tracking of PV fixed and PV tracker

In this simulation, the ANFIS control performance will be known to control stress in a variety of climatic conditions. The voltage coming out of the converter is ≥ 14.55 V, so that the voltage output can charge the battery. The battery charging method used is a constant voltage charging method.

Figure 4 shows the results of a voltage test simulation using ANFIS controls. Simulation results are obtained from data retrieval with bright conditions on April 25 with data collection starting at 06:00. From the results of the response, it can see the value of rising time, peak time, maximum overshoot, and settling time. Where rise time is a measure of time measured from the response t = 0 to the response cuts the first steady-state axis. Peak time is the time needed to reach the first peak, or maximum. Maximum overshoot is a relative value from the comparison between the maximum value response (overshoot) that exceeds the steady-state value and the steady-state value. Settling time is the amount of time required by transient damped oscillations ± 2 % of the final value. The x-axis states the time (seconds). The y-axis states the voltage (V). The brown line is a set point, which is a constant voltage of 14.55 V, while the red line is the result of a stress control response from the ANFIS control design using PV fixed. The blue line is the result of the stress control response from the ANFIS control design using a photovoltaic solar tracker.

The ANFIS control test results of PV tracker show can control the voltage coming out of the converter so that it is not less than 14.55 V. The voltage tracking response of PV fixed is the rise time value of 0.0028 s, and the peak time value is 0.008 s. The settling time value is 0.0173 s, the maximum overshoot value is 0.023 %, and for steady-state error's value is 3.065 %. On the voltage tracking response of PV tracker, the rise time value is 0.0028 s, and the peak time value is 0.008 s. The settling time value is 0.0193 s for the maximum overshoot value of 0.027 % and the steady-state error's value 0.204 %. Based on the experiments above, it shows that the ANFIS control design is quite successful in controlling the voltage in climatic conditions to charge the battery then.

3.2 Charging simulation of ANFIS control with climatic condition variations

This simulation was conducted to determine the performance of ANFIS controllers that have been designed to perform voltage control with variations in climatic conditions. It is bright and cloudy, slightly cloudy.

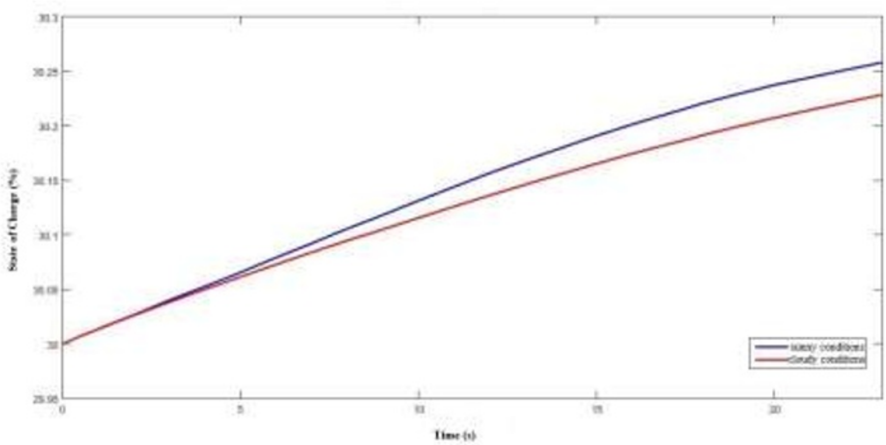


Fig. 5. Simulation results of battery charging with variations in climatic conditions

Figure 5 shows the simulation results of ANFIS control battery charging with variations in climatic conditions. The x-axis states the time (seconds). The y-axis is the state of charge (the ratio capacity of the total energy that can be used by a battery with the total battery capacity). The blue line states charging the battery with sunny weather conditions, while the red line says it is charging the battery with cloudy weather conditions. Visible battery charging response in bright conditions is higher than in overcast conditions. It is possible to output voltage generated by PV on lower overcast conditions, which also affects the battery charging process [9]. Charging the battery in bright conditions reaches 30.26 % while charging the battery in overcast conditions reaches 30.23 % with a battery condition of initially 30 %.

3.3 Simulation of charging process testing ANFIS controls on fixed and tracking conditions

This test was carried out to know how much potential the solar energy used for the 7 Ah capacity charging process using 250 Wp solar panels. Testing had done by using two PV panels that have the same specifications. One panel configuration treated by tracking. The PV module is directed to follow the direction of the arrival of sunlight, while the other panel is in a fixed condition.

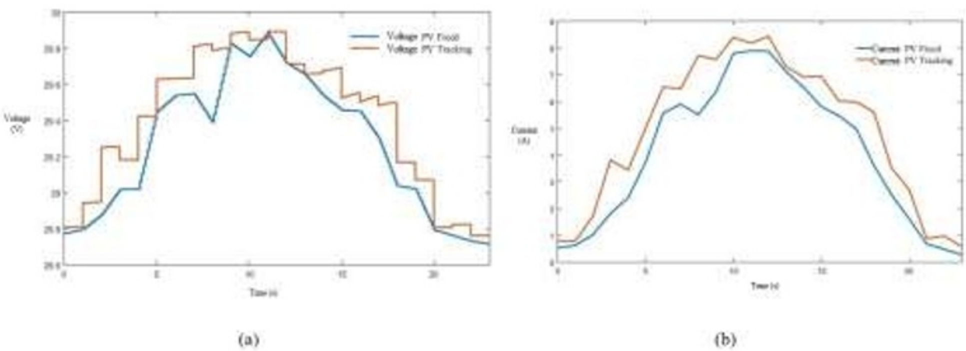


Fig. 6. (a) Voltage dan (b) Current PV fixed dan tracking

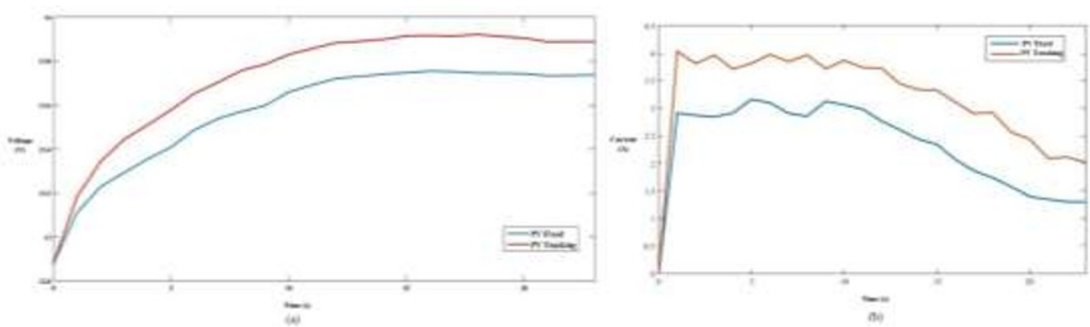


Fig. 7. Comparison of (a) Voltage and (b) Current when charging

Figure 6 shows the voltage and current generated from photovoltaic between PV fixed and PV tracker with bright conditions. Total 7(a) for charging voltage on a PV tracker is higher than PV fixed because PV solar tracker is more maximum in tracking the position of the sun so that the resulting voltage is higher than fixed PV. Figure 7(b) can show that the greater the current during the charging process, then the faster the battery charged. This is happening because the electrical energy supplied with the electric currents that large is more and faster than the small current.

Figure 8 shows the battery charging profile of a fixed PV panel and tracking PV panel with sunny weather and not cloudy conditions. There is an increase filling value produced by each control with variations in climatic conditions and a charging method for constant voltage charging. The condition of the PV panel tracking chart has increased when charging from a fixed PV panel graph. The simulation test results seen for the PV SOC tracking panel amounted to 30.26 %, while the fixed PV panel SOC was only 30.18 %, with the battery condition initially 30 %.

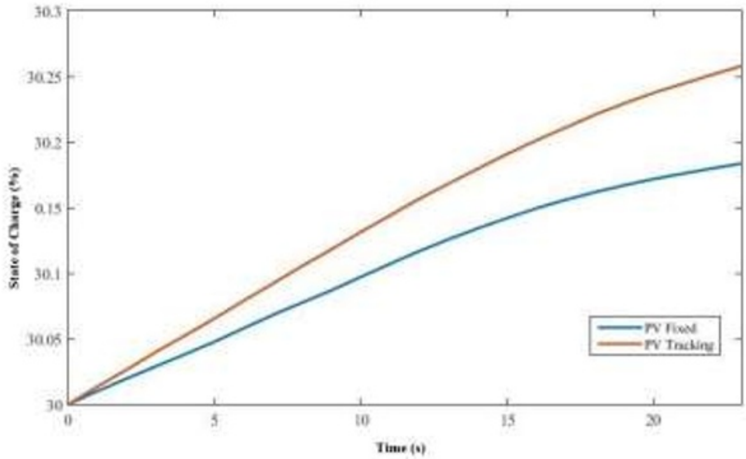


Fig. 8. Comparison of Batteries Charging PV fixed and PV Tracker

3.4 Control and Non-Control Test Simulation

This simulation test was conducted to determine influence in the process of charging to the battery by using controls and without using controls on a PV panel. The controller used remains the same that is ANFIS control. Tests are carried out using four PV panels with the same specifications with a capacity of 250 Wp. The configuration is to complete two panels with ANFIS controllers, while the other two panels not equipped with ANFIS controllers (non-control). PV panels used in fixed and tracking conditions. The results of this simulation are as follows,

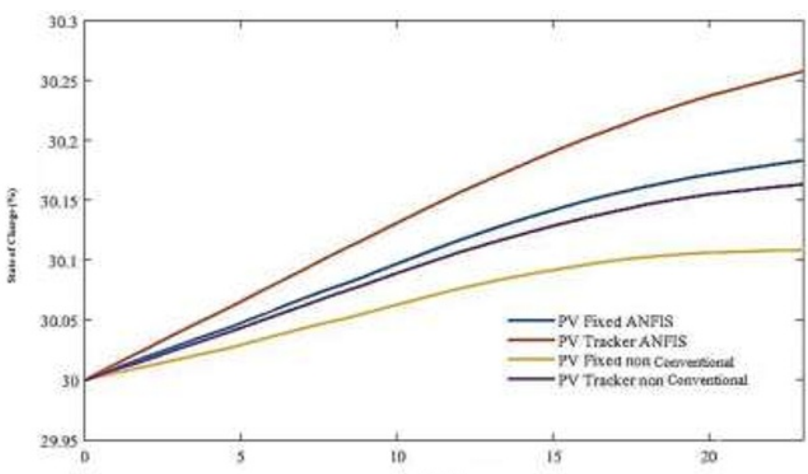


Fig. 9. Comparison of Filling ANFIS and Non-Conventional Controls

Figure 9 shows the simulation results using ANFIS controls and without controls. A system equipped with controls produces a state of charge that is greater than a non-control system. It can have seen that the state of charge in the PV tracking panel always is higher than the fixed PV panel. Based on the above experiment, it proves that the PV panel tracking system always moves to the sun's position, so that makes the current obtained will be higher than the fixed PV. However, overall, ANFIS controls obtain increased when charging that non-control system. This fact shows that the ANFIS controller is better at controlling the voltage coming out of the converter to remain in the range of ± 14.5 V for the battery charging process and more accurate [10].

4 Conclusions

The influential parameters in photovoltaic modeling are the intensity of solar radiation that reaches solar panels and the temperature on the surface of solar panels. The solar irradiation obtained 895.4 W m^{-2} and the temperature 60.6 °C so that the PV voltage obtained at 29.89 V. The parameters that influence the converter modeling are changes in the duty cycle, where changes in the duty cycle range from 0.3. The parameters that influence the battery modeling are current at charging that is 3.978 A. The constant voltage output of the converter is 14.89 V. The parameters that influence the ANFIS control design on the charging system are the membership function with the Gaussian type and the input and output pairs during training data. The voltage error of the Input pair is the difference between the voltage converter and the Vconstant setpoint (± 14.55). The error input is 0.61. The voltage delta error is the difference between the current and previous voltage error 0.024. Single-axis solar tracker PV using ANFIS control can improve the performance of battery charging by 0.25 % compared to fixed PV panels. Obtained a single axis solar tracker SOC PV panel that is equal to 30.26 % and fixed panel PV SOC, which is only 30.18 %.

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