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Current Output Estimation of 12 Volts Solar Power Line Source Using Fuzzy Logic-Based Modelling Technique

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ABSTRACT: This study used the fuzzy logic-based system to estimate the output current of a solar panel system at specified amount of power and percentage of cloud cover in the atmosphere. This established the fuzzy rule-based system which was applied from a research study to analyze the behavior of the current output wherein the available solar panels are three 100 watts and two 50 watts making it difficult to measure the current with power of 175 watts and 350 watts. The amount of the produced current was established through the fuzzy rule-based system stated as the following: if the power is low and the atmosphere is almost cloudy then the current produced is very small; if the power is high and the atmosphere is cloudy then the current produced is small; if the power is medium and the atmosphere is partially cloudy then the current produced is average; if the power is high and the atmosphere is clear then the current produced is large. Through defuzzification the fuzzy system was implemented by computing the output value using the centroid method.

KEYWORDS: Current output, solar power, fuzzy system, 12 volts, power, electricity

I. INTRODUCTION

A 12V system is classified as a low-voltage electrical system that uses 12 volts direct current (DC) power. It is usually connected to a battery or multiple batteries. Commonly, this form of electrical system is in off-grid living situations, that was used for appliances lighting of tiny homes incorporating renewable energy sources, such as wind or solar power. In the past few years, renewable energy has greatly spread out in the global energy market (Dafallah, 2018) that in 2016, the number of investments was counted as more than double the amount spent on non-renewable energy sources like cool and gas fire plants [Dafallah et al., 2017]. A sophisticated electrical energy management system is needed to coordinate the power flows within a 12-volt electrical system (Tan et al., 2022). Direct measurements of physical quantities obtained from the network are referred to as "measurements." However, pseudo measurements incorporate any input data to the state estimation that is artificially synthesized to approximate non-measured physical quantities. Due to the lack of adequate measurements in distribution systems, state estimation heavily relies on pseudo measurement (Taczi, 2023). The theory of the pseudo-analysis has shown some important applications in fuzzy logics and fuzzy sets (Pap, 2022). Due to lack of field measurements, the data used in network analysis have various degrees of uncertainties. The use of fuzzy logic-based models can address this issue. To mitigate the negative impact generated by the lack of continuity of the electricity service, models have been developed using fuzzy logic and Artificial Intelligence (AI) techniques to identify faults in distribution systems and take corrective actions (Perez et al., 2018). Accordingly, the application of this approach to the on-line estimation of the field and the armature resistance of DC series motor shows a rapidly converging estimate and the algorithm developed is potentially useful in order to implement a robust closed-loop control (Jabri et al, 2008). The theory of fuzzy sets was used to solve complex problems which considered that an element of the universe can be part of a defined set, based on the knowledge and experience acquired (Castillo et al, 2007). In case study of an electro mechanical system, the structure of a fuzzy system is defined by the number of fuzzy sets of each variable and their distribution in the universe set [Branco et al., 1995). The simulations for the validation of the fuzzy model determined that there is a correspondence between the statistical ranges established for the membership functions of the input variables and the output of the model used by the inference engine (Andrade-Benavides et al, 2022). In the face of future disconnection events, it was used to identify unbalanced radial power distribution system that service restitution times could be shorter and service reliability will increase (Das, 2005).

The development of a fuzzy model is defined according to the characteristics of the system, which can be analyzed through a set of rules that characterize the simple or complex relationships of the model [Branco and Dente, 1998). The implemented model is capable of obtaining an output, which by means of adopted membership functions, allowed to

express in percentage terms the efficient management of the electricity distribution company (Andrade-Benavides et al, 2022). The development of fuzzy logic models requires experience and technical knowledge, which are expressed through membership functions and fuzzy rules (Shirazi & Jadid, 2019). Data ranges are used to design a fuzzy system. These ranges are primarily based on experience and statistical analysis of historical data, which define the membership functions and the decision matrix [Dernoncourt, 2013]. There are several investigations on fuzzy logic and electrical power distribution systems that some models were proposed using fuzzy logic, making it possible to reduce the impact on the continuity of the service considering that failures in an electrical system. (Gururajapathy, 2017). An adaptive protection system is developed based on fuzzy logic models, to perform the adjustment of fault currents in over-current protection relays (Momeso et al, 2019).

Another application that was developed was based on the energy distribution available in charging centers for electric vehicles (Hussain, 2019). Faced with a permanent failure, the network element is severely affected, extending the times for the restitution of the service with corrective actions [Husain, 2018). On this study, the process was employed in a research study to scrutinize the behaviour of the current output, complicated by the presence of three 100-watt solar panels and two 50-watt panels, making it challenging to measure currents of 175 watts and 350 watts.

This study was used to estimate the amount of current produced based from the power of the solar panel and the quantity of cloud cover. The fuzzy rule-based system was established that ultimately was used to estimate the output current of the solar panel with varying amount of power and cloud cover in the atmosphere.

II. METHODOLOGY

The methodology was focused on the materials used, the designed system, and data gathering process.

A. Materials Used

The materials used are the following: solar panels with 3-50 watts and 4-100 hundred watts capacity, electrical wire, electrical tape. A digital multimeter was used to measure current. The main advantage of this device is the exact performance working with an algorithm that is suitable for on-line measurements, without the high computational burden (Petrovic, 2004).

B. The Designed System

The solar panels were connected in parallel connection. The system was designed to produce a total voltage (V_T) of 12 volts and a total power (P_T) of 400 watts. With the designed system, the total current output at certain amount of cloud cover were measured. The diagram is shown in Figure 1.

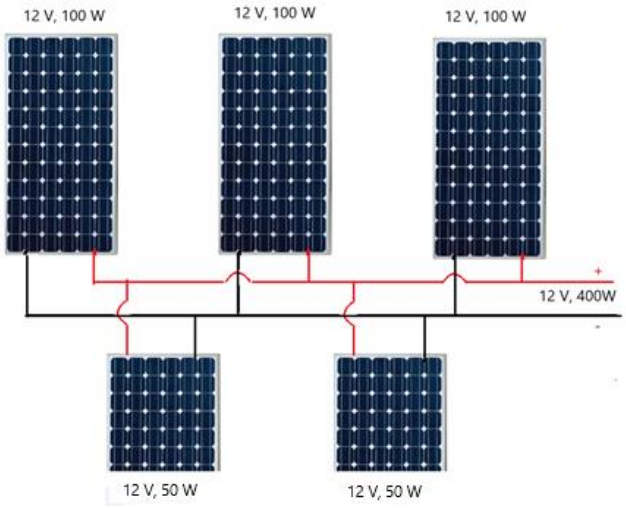

Figure 1. Diagram of the solar panel in parallel connection

Theoretically, the total voltage of the connected panel is equal to the voltage of the individual panel while the total power is the sum of the power of the individual panel and the total current is the sum of the individual current produced by the panel (Mathur, 2009), (Romero, 2023). The equations for total current (I_T), total voltage (V_T) and total power (P_T) are presented as follow:

$$I_T = I_{M_1} + I_{M_2} + I_{M_3} \cdots \quad (1)$$

$$V_T = V_{M_1} = V_{M_2} = V_{M_3} \cdots \quad (2)$$

$$P_T = P_{M_1} + P_{M_2} + P_{M_3} \cdots \quad (3)$$

The real power generated from the solar photovoltaic array is much less than the designed power, so that the loss of load probability increases, however, under complex irradiance conditions, the power generating capability of the photovoltaic system that adopted the parallel configuration of the individual cell level could produce approximately twice that of a conventionally configured series system (Reddy & Reddy, 2016).

C. Data Gathering Process

The first set of data was obtained from the output of a solar panel 12 volts and 50 watts capacity using digital multimeter with current generated at varying amount of cloud cover in the atmosphere. The cloud cover was measured by analysing the pattern of photographic shots which were done at every attempt of measuring the generated current. Photographic shots with clear atmosphere were considered as less than 50% cloud cover while with almost cloudy atmosphere in the image is more than 50% cloud cover. The time of taking the data is from 6:00AM, 9:00AM, 12:00 noon, 1:00PM, 3:00PM and 5:00PM. Another set of data was obtained from 12 volts and 400 watts solar panel. The 12 V, 400 W solar panel is composed of three 12 V, 100W and two 12 V, 50 W solar

panels that were connected in parallel. Careful observation was done in data gathering process. It was revealed that solar collectors in parallel does not decrease the collector's efficiency as the output temperature level through the panel remains relatively lower (Mustapha et al, 2015). There was also statement that if the shading covered the cells partially, then the drop in the power output is proportional to area of the shade in which the current output is equal to the lowest among the cell (Sathyanarayana et al, 2015).

The measurement of current production may encounter challenges due to the varying availability of solar panels within the system. With three panels rated at 100 watts each and two panels rated at 50 watts each, accurately gauging current output becomes complex, especially when dealing with power outputs of 175 watts or multiples thereof like 350 watts, hence, actual measurements were done at the power of 50 watts and 400 watts while the rests were analysed through fuzzy inference systems. The following are the steps included in fuzzy interference system (Knights & Gacosvi, 2023): the first is fuzzification, which maps the crisp input values to degrees of membership in fuzzy subsets. The second is inference, which uses the rules in the rule base to determine the degree to which each rule applies, based on the fuzzy input. The third is defuzzification, which aggregates the results of the inference process to produce a crisp output. The fourth step which is optional is the evaluation of the output, where the results are analysed and compared to the desired results.

III. RESULTS AND DISCUSSION

The fuzzy rule-based system, the statement of the model, and current in relation to power and cloud cover were discussed as follows:

A. The Fuzzy Rule-Based System

The fuzzy logic-based system was used to estimate the current produced by the solar panel system at specific amount of power and percentage of cloud cover. Various parameters, such as the number and the base width of the triangular membership functions used for the fuzzification process are with assigned values in order to optimize the estimation (Asimakopoulou, 2011), however the important parameters that were taken are aggradation and evaluation of rules, fuzzification, and defuzzification process. Aggradation of rules was able to established that if the capacity of the power source is low and the atmosphere is almost cloud covered, then the produced amount of current is small while if the capacity of the power source is high and the atmosphere is less covered with clouds then the produced amount of current is large. In the fuzzification process, the input membership levels are calculated. The graph for power of the solar module was established to calculate the input membership as low, medium and high level shown in figure 2.

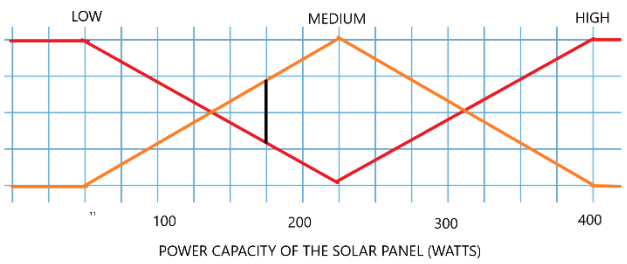

Figure 2. Graphical illustration of the power capacity of the solar panel

The graph for percentage of cloud cover also was established to calculate the input membership level as cloudy, partially cloudy and clear atmosphere shown in figure 3.

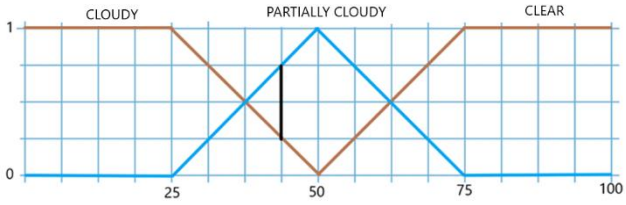

Figure 3. Graphical illustration of the atmospheric cloud cover

The graph for current was established to calculate the input membership as small or large level shown in figure 4.

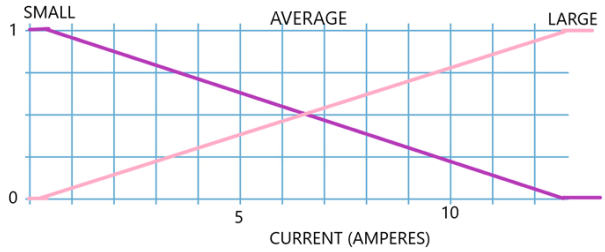

Figure 4. Graphical illustration of the produced current

B. Statement of the fuzzy rule-based model

Based from the established representations regarding power capacity of the solar panel, the cloud cover in the atmosphere and the expected current to be produced, the fuzzy rule-based model was introduced as shown in Table 1.

Table 1. Statement Of The Fuzzy Rule-Based Model

Rule	Statement
1	If the power is low and the atmosphere is almost cloudy then the current produced is very small.
2	If the power is high and the atmosphere is cloudy then the current produced is small.
3	If the power is medium and the atmosphere is partially cloudy then the current produced is average.
4	If the power is high and the atmosphere is clear then the current produced is large.

The presented statements shows that the amount of the current produced in the system varies with the capacity of the solar power system and the amount of cloud cover in the atmosphere.

C. Current in relation to power and cloud cover

Defuzzification plays an important role in the implementation of a fuzzy system since the crisp value generated best represents the possibility distribution of all possible fuzzy control outputs, however the centroid method is usually used to determine the output value by calculating the centroid of gravity of the possibility distribution of the outputs that for continuous values, the output Z is calculated using the equation (Mogharreban & Dilalla, 2006).

$$Z = \frac{\int_{u} \mu(x) x dx}{\int_{\mu} \mu(x) dx} \qquad (4)$$

The relationship between the power (P) of the solar panel, cloud cover (CC) and current (I) are quantified using the centroid method. This action is necessary for it was found from the previous data that both the power output of the solar panel, and the amount of cloud covering give significant effect on the current produced by the solar panel. The result is shown in table 2.

Table 2. Current, Power & Cloud Cover

Parameters			**Data taken**
P(W)	**CC (%)**	**I(A)**	
50	90	0.06	By actual observation
50	0	0.30	By actual observation
			by Fuzzy-Rule Based Model
175	69.75	7.54	P is low with cloudy atmosphere
350	69.75	7.65	P is high with cloudy atmosphere
175	31.25	9.64	P is medium in partial cloudy atmosphere
350	31.25	9.78	power is high in clear atmosphere
400	90	10.18	By actual observation
400	0	12.94	By actual observation

Through the centroid method, several data were computed, particularly the amount of current when the power outputs of the solar panel at 175W and 350 watts with cloud cover of 31.25% and 69.75%. The fuzzy rule based covered are the following: when the power is low with cloudy atmosphere; when the power is low with cloudy atmosphere; when the power is medium with partially cloudy atmosphere, when the power is medium with partially cloudy atmosphere; when power is high with clear atmosphere. Respectively, the then condition are as follows: the current produced is very small; the current produced is small; the current produced is average. the current produced is large. Using the rules and conditions was able to estimate the amount of current produced for a specified amount of power of the solar panel system and the cloud cover. It is necessary that the characteristics of solar panels be understood under partially shading before their installation is carried out under various conditions that modeling have to be applied (Seyedmahmoudian et al, 2013).

CONCLUSIONS

This study was able to estimate the amount of the produced current based from the power of the solar panel system and quantity of cloud cover. That is by establishing fuzzy rule-based system. The fuzzy rule-based model was stated as the following: if the power is low and the atmosphere is almost cloudy then the current produced is very small; if the power is high and the atmosphere is cloudy then the current produced is small; if the power is medium and the atmosphere is partially cloudy then the current produced is average; if the power is high and the atmosphere is clear then the current produced is large. Through defuzzification the fuzzy system was implemented by computing the output value using the centroid method.

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