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Neuro-Fuzzy based MPPT for Solar PV Panel

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ABSTRACT

Various atmospheric elements like irradiance and temperature, affect the power production and nonlinearity of I-V qualities of solar photovoltaic system. A solution is developed to mitigate the said negative effect, which is the application of maximum power point tracking (MPPT) for charge controllers. MPPT is integrated in buck-boost circuit to instantaneously boost the produced energy of the panel towards the battery by regulating its current or voltage of the panel using pulse width modulated signal (PWM). The proposed algorithm utilized is Adaptive Neuro-Fuzzy Inference System (ANFIS) and inputs are collected with voltage, current, lux and temperature sensors. The neural network trained the data first while the fuzzy logic generated the rules to guide the system to generate the appropriate value of duty cycle as the output. The fuzzy inference system (FIS) training phase showed that the trimf produced the least inaccuracy of 0.0015666%. meanwhile the testing phase showed an average testing error of 0.086933%.

Key words: ANFIS, charge controller, MPPT, solar photovoltaic system

1. INTRODUCTION

Power inefficiency is a common problem when using solar photovoltaic (PV) panels as source of energy. The operation of PV systems is compromised under varying factors of the environment including irradiance and surrounding temperature. Considering this, energy generation is not consistent between through day and night [1].

Multiple studies were performed to increase the efficiency of the PV systems; one solution is MPP tracking by making use of various algorithms [2]. MPP tracking is applied on buck-boost converter circuit so it produces PWM signal that regulates the power output [3]. Many existing methods have been applied to solve the negative effects of temperature. For example, fuzzy logic control (FLC) was utilized in the adjustment of rpm for a water pump [4]. Another method is ANN as applied for a model of MPPT controller [5]. The P and O technique used current, voltage and power cycle as variables [6]. Additionally, the ripple correlation control (RCC) technique was applied in the construction of an analog MPPT controller [7].

This study aims to develop an ANFIS MPPT as battery regulator for PV systems. The study will provide future researchers, the data on how efficient the proposed algorithms in terms of accuracy and error percentage. The study will also help owners of photovoltaic systems for domestic and industry applications.

2. RELATED WORKS

MPPT method is applied into PV system to decrease the effect of lower efficiency of PV panel due to varying I-V values caused by irradiance and temperature [2]. Buck-boost circuit usually use maximum power point tracking to maximize the energy output over rapidly varying change in voltage or current values.

A MATLAB simulation under changing environmental parameters by Lasheen et al. [8] used a constant voltage method for MPPT. A proportional-integrator controller for a feedback control system is used to compare a set value of MPP voltage to the open-circuit voltage (Voc). The duty ratio is produced as a PWM charge and used as input forthe converter circuit through the gate of MOSFET.

FLC-MPPT for a point-tracking controller is developed by Ozdemir et al. [9] The delta PV power and delta PV voltage is used as the input for the FLC controller. Fuzzy logic algorithm automates the set rule and membership functions (MF) to integrate the power cycle value to trigger the gate drive component of the quadratic boost converter. This study concluded a tracking accuracy of 99.10%.

A combined algorithm of P and O (perturb and observe) technique with fractional short-circuit current (FSCC) was proposed by Kollimalla et al. [10] as MPPT algorithm. Short-circuit current and the MPP current is compared to produce the duty cycle value. It is concluded that power fluctuations are reduced and tracking rate of the maximum power point is enhanced.

Enhanced Leader Particle Swarm Optimization (EL-PSO) is a biological based technique imitating bee communication and birds clustering which was developed by R. Jordehi [11] that trains data collected and introduces it to swarm agent. The swarm data go along with the greatest output that varies in each new iteration. The MATLAB simulated process concluded that the EL-PSO technique made the tracking rate of the global maximum power point better compared to standard particle swarm optimization method.

An improved incremental conductance method for MPP tracking is experimented by Loukriz et al. [12] The maximum power point is produced by the formula of change in current over change in voltage compared to the instant current-voltage relationship. The study showed a greater converging rate and less fluctuations of the maximum power point leading to lesser energy inefficiency.

It is proven that using artificial intelligence (AI) technique such as ANFIS, is effective in tracking maximum power in MPPT using irradiance, temperature and current as inputs, and displays greater convergence and lesser oscillations compared to other algorithms [13]. An ANFIS based system designed by Valenzuela et al. [14] used to predict the photosynthetic rate using carbon dioxide, light intensity and temperature as input variables. Through testing of the ANFIS model, an RMSE result of 2.7843e-05 is yielded. A study [15]using fuzzy logic for automation of irrigation schedule and water flow regulation showed an error of 3.86%.Artificial Neural Network is used in intelligent systems to significantly improve the accuracy and prediction rate by means of classifying multiple sets of data e.g., academic placements[16] and GA control system[17].

3. METHODOLOGY

3.1 MPPT Controller

A microcontroller unit (MCU) measures and records the values collected by the temperature, lux, current and voltage sensors connected to the photovoltaic panel. The MPPT covers a DC-DC converter and Arduino MCU which produces the output duty cycle by using ANFIS algorithm. This charges the battery which is also the energy source of the controller and cooling system thus making it standalone. Figure 1 displays the flow of the ANFIS-MPPT Controller.

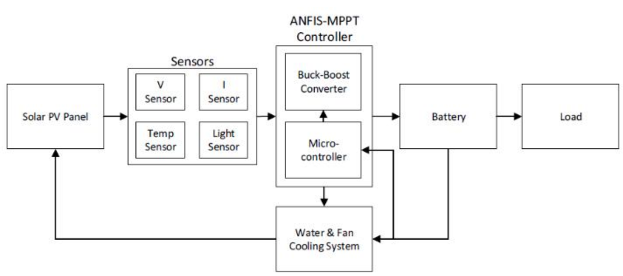


Figure 1: Flow of ANFIS-MPPT Controller

The DC to DC converter produces stable output from the solar panel by either converting it to higher or lower value. The duty cyle controls the MOSFET in the converter circuit hich is calculated by using Equation 1 [18]:

$$Vo = \frac{Vs * D}{1 - D}$$

where Vo denotes the set voltage output of 13.8V as desired while Vs denotes voltage from the panel and duty cycle is represented as D.

Figure 2 shows the DC-DC flow chart. The 150W Solar panel typically generates a voltage value of 0-21 volts varying over changing values of environmental factors [19], then compared to the Vs value of 13.8V to decide whether to buck or boost the voltage that charges the battery (deep cycle).

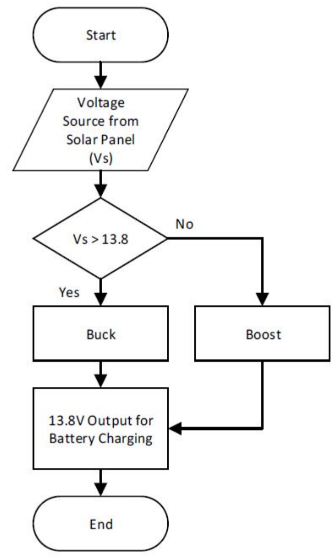


Figure 2: DC-DC Flow Chart

Figure 3 displays the circuit of DC-DC converter which has the gate of the FET component to be operated by the duty cycle converted as PWM signal from the ANFIS implemented on the Atmega 328 Arduino microcontroller. The circuit includes the components: 680uF capacitor, 100 uH inductor, IRF540N N-channel MOSFET, and 1N5408 diode.

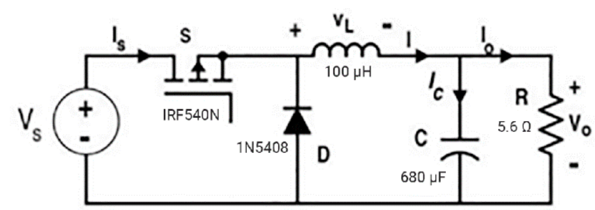


Figure 3: DC-DC Converter Circuit

3.2Neuro-Fuzzy System

The combined fuzzy logic with neural network, ANFIS is a hybrid algorithm. Neuro-Fuzzy MPPT shows an increase of 46.19% in output efficiency matched with a PV system with different algorithm [20]. Amongst various MPPT techniques applied, Neuro-Fuzzy showed the lowest convergence rate of 0.07 seconds with decreased fluctuations and additionally producing the greatest output power [21]. Through ANN, the PV parameters undergoes training to produce the ANFIS model. Every numeral input is clustered into various membership functions by a range of values, then FIS rules is produced. Figure 4 displays the procedures of ANFIS.

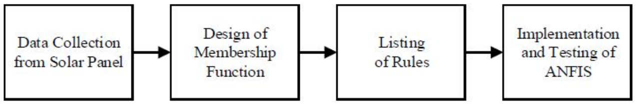
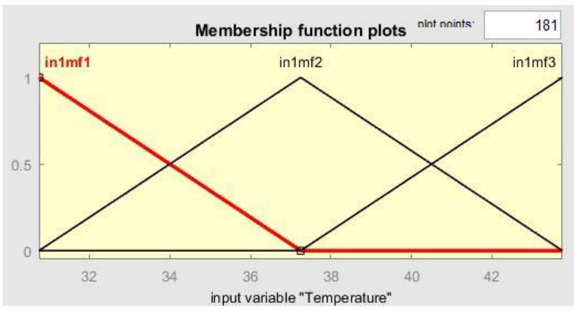
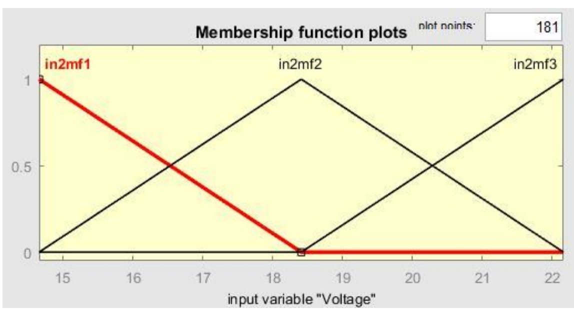


Figure 4: Process Flow of ANFIS

Figure 5a displays the input MFs of temperature identified as:cool, normal, and warm(24.25 30.75 37.25). The membership functions of I-V characteristics are: low, mid and high (10.91 14.66 18.41) and (0.952 1.41 1.868) as displayed by Figure 5b and 5c. Figure 5d displays the MFs of irradiance as: weak, medium and strong (-372.3 773.3 1919).



(5a)



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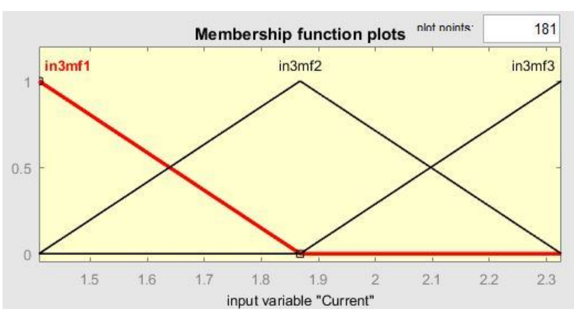

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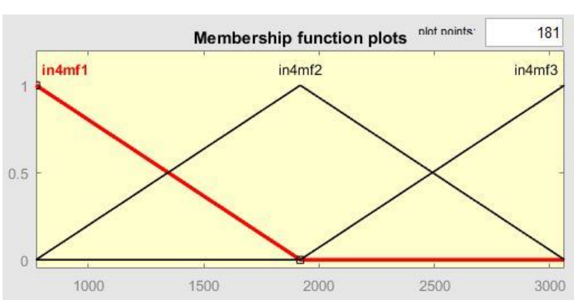

(5d)

Figure 5: MF Plot of Input Variables

The ANFIS network architecture is displayed in Figure 6, showing the 5 stages, namely the input MFs, produced rubrics, output MFs and the corresponding duty cycle. The ANFIS training variables are displayed in Table 1. There are 81 fuzzy rules produced by the ANFIS model, example of 2 rules are as follows:

- Rule Number 1: Duty Cycle is LOW if the following conditions are met: (1) Temperature is HIGH; (2) Voltage is HIGH; (3) Current is LOW; (4) Irradiance is STRONG
- Rule Number 2: Duty Cycle is HIGH if the following conditions are met: (1) Temperature is LOW; (2) Voltage is LOW; (3) Current is HIGH; (4) Irradiance is WEAK

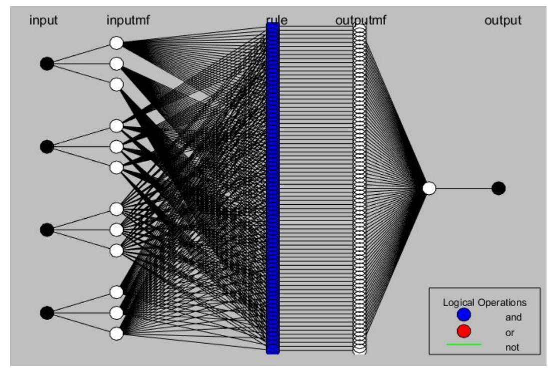

Figure 6: ANFIS Network Architecture

Table 1: ANFIS Training Variables

Item	Description
Number of nodes	193
Number of linear parameters	81
Number of nonlinear parameters	36
Total number of parameters	117
Number of training data pairs	30
Number of checking data pairs	0
Number of fuzzy rules	81
Optimization tool	hybrid

4. RESULTS AND DISCUSSIONS

Deciding the FIS type for fuzzy inference system model is important in producing the least value of error % during the training procedure. Each FIS type with the equivalent inaccuracy % is displayed in Table 2. The trimf type has the least inaccuracy value of 0.0015666% whilst the pimf has the greatest inaccuracy value of 0.27228%.

Table 2: Equivalent Error % of FIS Types

Run	FIS Type	Fuzzy Rules	Training Error (%)
1	trimf	81	0.0015666
2	trapmf	81	0.21363
3	gbellmf	81	0.026759
4	gaussmf	81	0.010623
5	gauss2mf	81	0.06068
6	pimf	81	0.27228
7	dsigmf	81	0.092819
8	psigmf	81	0.092819

Figure 7 and Figure 8 displays the 3D graph of duty cycle with respect input parameters. When irradiance is higher, the voltage is also high while as the temperature level is higher, the current is low.

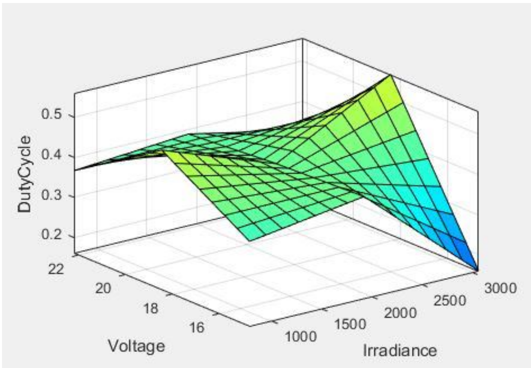

Figure 7: 3D Graph of Power Cycle relative to Irradiance and Voltage

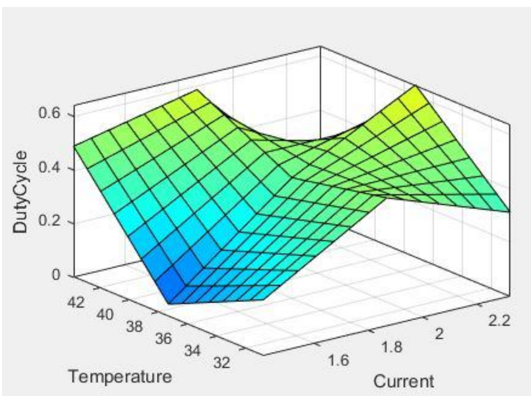

Figure 8: 3D Graph of Power Cycle relative to Temperature and Current

The precision is assessed by the automated duty cycle compared to the fuzzy inference system yield. Figure 9 displays 30 samples during the training phase denoted as circles and the fuzzy inference system output denoted as asterisks. The computed RMSE is 1.5666e-05 which concludes that it is an improved fit. Figure 10 displays 30 samples during the testing phase with an average error of 0.086933%.

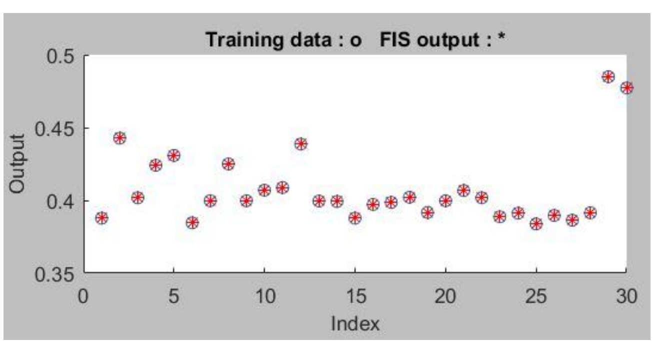

Figure 9: Training Data Plot

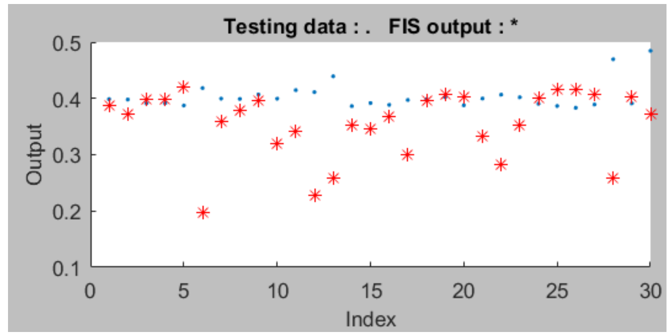

Figure 10: Testing Data Plot

5. CONCLUSION

In conclusion of this study, the applicationof Neuro-Fuzzy algorithm for developingthe AI based model of predication thattracksthe maximum power point of the PV system was shown to have great results. The ANFIS grid partition model produced preciseoutputs, provinggreaterresults than the other prediction models. Through the training phase of trials for different MF shapes, triangular membership function (trimf) showed the least value of error, 1.5666e-05 while through the testing phase of the ANFIS model showed an error of 0.086933%. The experimental output's efficiency was verified through comparison of the data from the ANFIS MPPT charge controller and its standard counterpart.

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