A Hardware Implementation of SEPIC Converter Using ANFIS for Water Flow Control

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Abstract

Water resources are one of the needs for the continuation of life. The majority of people in Indonesia still use a manual water tank filling system, so it requires regular checks. Filling the water tank manually is ineffective because it requires turning on and off the pump first so the use of electrical energy is increasingly wasteful. In this research, a water flow control system was developed to fill water tanks, making it easier to use water both at home and in public facilities. This water flow control system uses a Single Ended Primary Inductor Converter (SEPIC) Converter as a DC motor pump supply voltage regulator. The SEPIC converter has the advantage of being able to increase and decrease the voltage value without changing the polarity. The duty cycle settings on the SEPIC converter are regulated using the Adaptive Neuro-Fuzzy Inference System (ANFIS) control method. The water flow control settings in this system use feedback from the water flow sensor by utilizing the hall effect. Based on simulations and implementation that have been carried out using MATLAB as well as hardware testing, at a set point value of 1.5 liters/minute the output voltage value is 3.9 V, and at a set point value of 3 liters/minute the output voltage value is 6.8 V. Implementation of ANFIS control has proven to be a solution for regulating voltage and has worked more efficiently on loads.

Keywords: *Water resources, Water flow control, SEPIC Converter, Adaptive Neuro-Fuzzy Inference System (ANFIS)*

Abstrak

Sumber daya air termasuk kebutuhan utama dalam berlangsungnya kehidupan. Mayoritas masyarakat di Indonesia masih menggunakan sistem pengisian tangki air secara manual, sehingga memerlukan pengecekan berkala. Pengisian tangki air secara manual sangatlah tidak efektif, karena perlu menyalakan dan mematikan pompa terlebih dahulu sehingga penggunaan energi listrik semakin boros. Pada penelitian ini dibuat sistem kontrol debit air untuk pengisian tangki air, sehingga memudahkan dalam penggunaan air baik di rumah maupun fasilitas umum. Sistem kontrol debit air ini menggunakan *Single Ended Primary Inductor Converter (SEPIC) Converter* sebagai pengatur tegangan *supply* pompa motor DC. SEPIC *converter* mempunyai keunggulan dapat mengatur nilai tegangan tanpa mengubah polaritasnya. Pengaturan *duty cycle* pada SEPIC *converter* diatur menggunakan metode kontrol *Adaptive Neuro-Fuzzy Inference System* (ANFIS). Pengaturan kontrol debit air pada sistem ini menggunakan *feedback* dari *waterflow sensor* dengan memanfaatkan efek *hall*. Berdasarkan simulasi dan implementasi yang telah dilakukan menggunakan MATLAB serta pengujian perangkat keras, pada nilai set point 1,5 liter/menit didapatkan nilai tegangan keluaran sebesar 3,9 V dan pada nilai set point 3 liter/menit didapatkan nilai tegangan keluaran sebesar 6,8 V. Implementasi sistem kontrol ANFIS terbukti dapat menjadi solusi pengaturan tegangan dan mampu berkerja lebih efisien pada beban.
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Kata kunci: *Sumber daya air, Kontrol debit air, SEPIC converter, Adaptive Neuro-Fuzzy Inference System (ANFIS)*

1. Introduction

Water is one of the basic needs for the continuation of life. Looking at the problems faced by the world today, namely the level of atmospheric pollution which has resulted in the depletion of the ozone layer which comes from emissions from burning fossil fuels. To reduce the level of atmospheric pollution, it is necessary to develop energy sources that are more environmentally friendly and sustainable [1]. Most people in Indonesia still use a manual water tank filling system, so it requires regular checks. Filling the water tank manually is not effective, because when the water runs out it needs to turn on the pump first, and when the water is full it can forget to turn it off, making the use of electrical energy even more wasteful. To overcome this problem, it is necessary to fill the water tank automatically, namely by creating a water discharge control system that can minimize the wasteful use of electrical energy.

Solar energy can be converted into electrical energy to be used by humans to meet energy needs that are important in today's times. Moreover, we realize that Indonesia is located in an equatorial region that is rich in solar energy, so we can take advantage of certain conditions to generate electrical energy, one of which is through solar panels [2].

This research presented a water flow control system that uses a water flow sensor which is used to utilize the hall effect. This hall effect worked based on the effect of a magnetic field on moving charged particles. The use of solar panels is used to supply electronic loads via a SEPIC converter to stabilize the source output voltage. SEPIC converter is a step-up and step-down converter. To overcome the weaknesses of the SEPIC converter, a Modified SEPIC converter topology was developed [3]. The selection of a SEPIC converter is based on load requirements, namely the load of a DC motor pump.

The control used in this research is the Adaptive Neuro-Fuzzy Inference System (ANFIS). ANFIS is a method that combines the advantages of Fuzzy Logic and Artificial Neural Networks (ANN). The final step of the fuzzy logic process is defuzzification, namely mapping the fuzzy output values produced at the rule inference stage to quantity output values [4]. After going through the defuzzification process, the data will be trained to become ANFIS. By using ANFIS control, it is hoped that it can be a solution for regulating voltage in this water discharge control system. ANFIS is designed with input in the form of water discharge. Using the ANFIS method because this system uses sources with varying input values, so this adaptive neuro-fuzzy approach is proposed in this research. Thus, neuro-fuzzy systems have all the advantages of fuzzy inference systems and neural network systems. Unstable input data is modeled using fuzzy membership values [5].

Solar panels as a source of renewable electrical energy can be utilized by people who need electrical energy [6]. The SEPIC converter is a combination of a boost converter and an inverted buck-boost converter which can increase or decrease the input voltage value with the output voltage polarity being the same as the input [7]. The advantages of SEPIC converters include low input current ripple, and some capacitors can prevent overheating of components due to working hard [8].

2. Material dan Method

2.1 System Design

In general, this research designed and implemented a SEPIC converter which is used to stabilize the output voltage as a supply to the load. The block diagram of the water flow control system can be seen in Fig. 1.

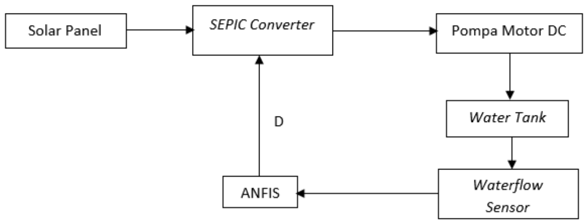

Figure 1. Overview of water flow control system

The block diagram in Fig. 1 shows a system created using solar panels as a source to supply the DC motor pump load. The solar panel output voltage value varies and is then regulated by a SEPIC converter using PWM by a microcontroller to obtain a duty cycle according to load requirements with Adaptive Neuro-Fuzzy Inference System (ANFIS) control.

2.2 Solar Panel Configuration

In this research, the source used is solar panels with the load to be used as a DC motor pump. Then proper solar panel design is needed to meet load requirements. Solar panels with a capacity of 100 Wp were used with specifications that are shown in Table 1.

Table 1. Solar Panel Specification

Parameter	Value	Unit
Model	SP100-18P	-
Peak Power (P_{MAX})	100 W	W
Cell efficiency	16,93%	W
Max power voltage (V_{MP})	17,8 V	%
Max power current (I_{MP})	5,62 A	V
Open circuit voltage (V_{OC})	21,8 V	A
Short circuit current (I_{SC})	6,05	V
Current Temperature	0,03	%/°C

Coefficient α (I_{SC})		
Voltage Temperature Coefficient Q (V_{OC})	-0,32	%/°C

From the specifications shown in Table 1, one solar panel connected in parallel will be needed. The calculation of the maximum power output of solar panels is as follows:

P = 1 × 100

P = 100 Watt

Assuming a decrease in energy due to fluctuations in solar irradiation values of up to 60%, then:

P = 75% × Wp = 75% x 100 = 75 Watt

2.3 SEPIC Converter

SEPIC converter (Single-Ended Primary-Inductor Converter) is a DC-DC converter that can increase or decrease the voltage from the input by setting the duty cycle on the switching component. This SEPIC converter is also called a derivative of the buck-boost converter and has a small input current ripple. The efficiency of the SEPIC converter is the best when compared to other DC converters [9]. The SEPIC Converter image is shown in Fig. 2.

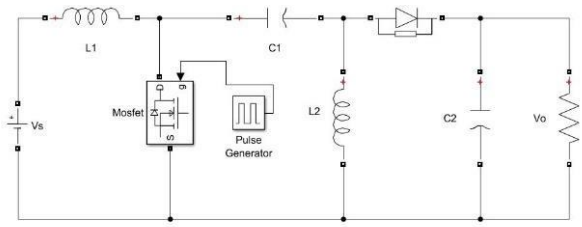

Figure 2. SEPIC converter circuit

There are inductors and capacitors on the output side to reduce output ripple. In the calculation, the inductor current will be operated in Continuous Conduction Mode (CCM). Kirchoff's law of voltage on lines Vs, L1, C1, and L2 is:

$$-Vs + vL1 + vC1 - vL2 = 0 \quad (1)$$

Assuming the average voltage of the inductor is equal to 0, then:

$$-Vs + 0 + vC1 - 0 = 0 \quad (2)$$

So, the average voltage on capacitor C1 is:

$$VC1 = Vs \quad (3)$$

When the switch is closed, the diode is in reverse condition [10]. The SEPIC converter circuit when the switch is closed can be seen in Fig. 3. The voltage flowing through L1 in the time period DT is:

$$vL1 = Vs \quad (4)$$

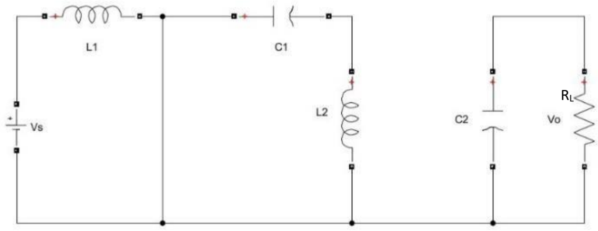

Figure 3. SEPIC converter circuit when the switch is closed

When the switch is open, the diode is in forward condition [11]. The SEPIC converter circuit when the switch is open can be seen in Fig. 4. Kirchoff's law of voltage on the outer part is:

$$-V_s + v_{L_1} + v_{C_1} + V_O = 0 \quad (5)$$

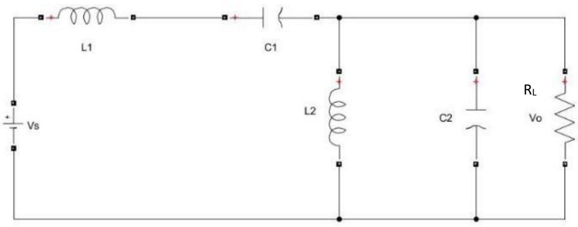

Figure 4. SEPIC converter circuit when the switch is open

Assuming the voltage flowing through C1 is constant at the average voltage Vs

$$-V_s + v_{L_1} + Vs + VO = 0 \quad (6)$$

$$vL1 = -Vo \quad (7)$$

For the interval (1-D)T, because the average voltage flowing through the inductor is for periodic operation, then:

$$v_{L_1} = V_s \text{ dan } v_{L_1} = -V_O \quad (8)$$

Merged into:

$$(v_{L1,sw\ closed})(DT) + (vL1,sw\ open)(1 - D)T = 0 \quad (9)$$

$$VS(DT) - VO\ (1 - D)T = 0 \quad (10)$$

That D is the duty cycle value of the switch component, then from equation 10 it can be simplified to the equation:

$$V_0 = V_S \left(\frac{D}{1-D}\right) \quad (11)$$

SEPIC converter is designed with parameters as in Table 2.

Table 2. SEPIC converter parameter

Parameter	Value	Unit
Vs	32	Volt
Vo	14.4	Volt
Iin	4.64	A
Io	5	A
Fs	100	kHz
RL	2.88	Ω
L1 = L2	99.2	µH
C1 = C2	1.2	µF

2.4 System Calibration

A tank with a capacity of 12 liters was used as a plant experiment. The bottom of the tank was provided with a tap which was used for water use in daily life. An experimental test is carried out using two set points, when the water usage discharge is opened halfway through the tap and the second is when the tap is fully opened. The data taken was read on the flow of water usage when the tap was half opened and released 1.5 liters of water/minute, while when the tap was fully opened it released 3 liters/minute of water.

Figure 5. DC motor pump

The pump used to fill the water tank is according to the specifications when a voltage of 12 V is applied, the resulting water flow has reached the nominal value. The DC motor pump used in this experiment is shown in Fig. 5.

Table 3. Water flow sensor calibration data

Test	Vin (V)	Long (cm)	Wide (cm)	Height (cm)	Vol (cm^3)	*Water flow* (liter/menit)
1	3	31	18	2,2	1262	1,25
2	4,1	31	18	3	1683	1,75
3	5,0	31	18	3,6	2019	2
4	6,1	31	18	4,5	2524	2,5
5	7,1	31	18	5,9	3281	3,25
6	8,1	31	18	6,4	3618	3,75
7	9	31	18	7,2	4039	4
8	10	31	18	8	4459	4,5
9	11	31	18	8,3	4628	4,75
10	12	31	18	8,7	4880	5

Based on Table 3, it can be concluded when the water usage discharge is 1.5 liters/minute, the water tank discharge will also flow 1.5 liters/minute and it is known that after testing DC motor pump requires a voltage of 3.9 V. When the DC motor pump uses a water discharge of 3 liters/minute, the water tank discharge will also flow 3 liters/minute, when testing the DC motor pump requires a voltage of 6.8 V.

2.5 Adaptive Neuro-Fuzzy Inference System (ANFIS)

In this system, ANFIS control is designed with input in the form of water flow usage. Using the ANFIS method because this system uses sources with varying input values, so this adaptive neuro-fuzzy approach is proposed in this research. The adaptive neuro-fuzzy method is an adaptation of neural networks that is functionally equivalent to the Fuzzy Inference System (FIS) system [12]. Thus, neuro-fuzzy systems have all the advantages possessed by fuzzy inference systems and neural network systems. Unstable input data is modeled using fuzzy membership values [13]. Fuzzy membership values are used for description of input data. In particular, this neuro-fuzzy network can eliminate shortcomings in conventional fuzzy system design by training data using trial-error membership functions from fuzzy sets [14].

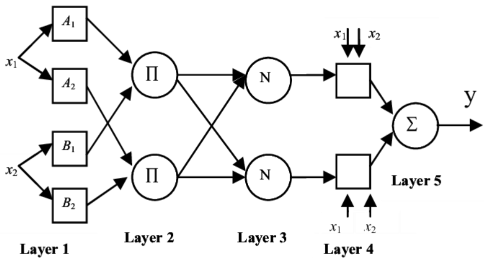

Figure 6. ANFIS Architecture

The ANFIS work process uses a hybrid learning algorithm, which combines the Least Squares Estimator (LSE) and Error Back Propagation (EBP) methods [15]. In the ANFIS structure, the EBP method is carried out in the 1st layer, while the LSE method is carried out in the 4th layer. In layer 1, the parameters are the parameters of the fuzzy set membership function which are non-linear in nature to the system output. The learning process for this parameter uses EBP to update the parameter value. Meanwhile, at layer 4, parameters are linear parameters for the system output, which form the basis of fuzzy rules [16]. The ANFIS method can be adaptive to changes in a given source. So by using the ANFIS method in this research, the system can reach the set point quickly and accurately because the data being compared is error and delta error. In its implementation, ANFIS is fuzzy logic, but the rules and behavior have been learned by Neuro Network [17]. There are two methods for ANFIS learning, namely forward feed and backpropagation. The weight values updated after the learning process are the main factor in shifting input membership and rule changes in ANFIS [18].

The set point value here also depends on the water usage discharge, namely using the set point value when the available water tank is at a certain height with two conditions, meaning that there will be two set points in this system. The first condition is when one of the taps on the tank is fully open and the second condition is when both taps on the tank are half open, so there are two water usage discharges which will later be used as the set point value. The water discharge sensor used is generally used to monitor water use in real-time [19]. The water flow meter sensor used to calculate the flowing water that rotates the rotor. This sensor consists of several parts, including a plastic valve, water rotor, and hall effect sensor [20].

3. Result and Discussion

The results of this research discuss testing the water discharge control system which is integrated with the ANFIS control system. The purpose of this testing and analysis is to determine the success of the system and to find out whether it is by the plans made. The testing method includes partial data collection and continues with integration testing of the entire system. Fig. 7 shows when hardware integration testing is carried out. This test is carried out to see that when the input voltage is maximum, the SEPIC Converter will produce an output voltage according to the set point.

Figure 7. Hardware testing with system integration

3.1 Open Loop Experimental Test

Open loop experimental test on hardware is carried out to test the entire system without proposed control. At input voltage values between 12 V-32 V using a duty cycle of 0.14 and 0.22. When the input voltage value is 32 V produces an output voltage of 3.4 V with a duty cycle of 0.14 and 6.86 V with duty cycle 0.22 as seen in Table 4.

Table 4. Experimental test data for open loop water control system

Duty cycle	Vin (V)	Vout (V)	Flow in (liter/minute)
0.14	12	0,51	0
0.14	16	0,82	0
0.14	20	1,74	0.5
0.14	24	2,33	1
0.14	28	2,89	1,25
0.14	32	3,4	1,5
0.22	12	1,85	0,75
0.22	16	2,89	1,25
0.22	20	3,9	1,5
0.22	24	4,91	2,0
0.22	28	5,91	2,5
0.22	32	6,86	3

Table 4 shows data from open loop integration hardware testing results, consisting of duty cycles of 0.14 and 0.22. Based on the data, the maximum voltage that is set according to design is 32V. The duty cycle setting reached the set point that used is 1.5 liters/minute on a DC motor pump with a voltage of 3.4 V and 3 liters/minute on a DC motor pump with a voltage of 6.86 V. The duty cycle values are 0.14 and 0, 22 is from hardware testing so that the set point reached compliance according to the set value.

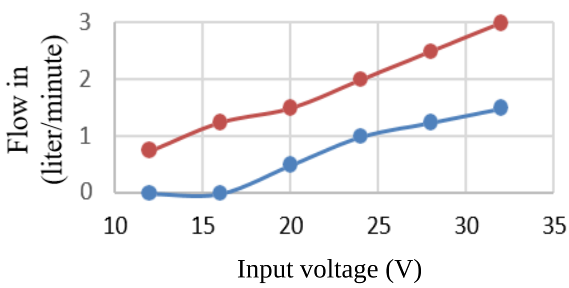

Figure 8. Correlation of input voltage and input flow for open loop experimental test

From the open loop integration hardware test data, it can be seen that the greater the input voltage value. then the input flow value will also be greater. As shown in Fig. 8, the input voltage and water flow values are directly proportional.

3.1 Closed Loop Experimental Test

In closed loop test, the water discharge control method uses ANFIS. Experimental data shows that the output voltage value is stable following the predetermined set point. Fig. 7 shows when testing the closed loop integration hardware. The way the control system that has been created works is by regulating the flow of water coming out of the tap in the water tank by regulating the voltage of the DC motor.

Table 5. Experimental test data for closed loop water control system

Duty cycle	Vin (V)	Vout (V)	Flow in (liter/minute)	Flow out (liter/minute)
0.,034	12	3,92	1,75	1,25
0,2721	16	3,9	1,5	1,5
0,2364	20	3,86	1,5	1,25
0,2029	24	3,83	1,5	1,5
0,1833	28	3,91	1,5	1,5
0,1617	32	3,92	1,5	1,5
0,4475	12	6,81	3,0	3,0
0,3769	16	6,96	3,25	3,0
0,3126	20	6,83	3,0	2,75
0,29	24	6,94	3,25	3,25
0,2527	28	7,0	3,25	3,0
0,2279	32	6,96	3,0	3,0
0	32	0	0	0

Table 6 is data from closed loop integration testing results. In this system there are two set points, namely when the flow out is 1.5 liters/minute and 3 liters/minute. When the system is run with an input voltage value that varies between 12 V - 32 V, the system output voltage will be 3.9V at a flow out set point of 1.5 liters/minute, resulting in a flow in of 1.5 liters/minute. Then the system will run the output voltage at 6.9 V when the flow out is 3 liters/minute, resulting in a flow in of 3 liters/minute.

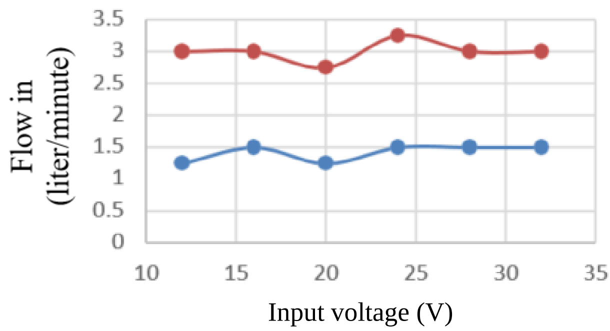

Figure 9. Correlation of input voltage and input flow for closed loop experimental test

From the close loop integration hardware test, it can be seen that the greater the input voltage value, the input flow value will remain relatively stable. As shown in Fig. 9, the states the input voltage and input flow values for the water tank. The test results show that the control system created is capable of working at the specified water flow discharge set point.

4. Conclusion

Based on integration testing without using ANFIS control, the value read on the water flow sensor is directly proportional to the given source. At an input voltage of 12-32 V, the SEPIC converter produces an output voltage of 0.51-6.86 V. In this range, the water flow sensor is able to read water flow of 0-3 liters/minute. Then the set point voltage on the DC motor pump is 3.9 V so that the flowing water discharge is 1.5 liters/minute and 6.8 V so that the flowing water discharge is 3 liters/minute. Meanwhile, for integration testing using ANFIS control, the value read on the water flow sensor will be relatively stable according to the set point even though the source value changes. The use of ANFIS control has proven to be a solution for regulating voltage in the system compared to using a DC power supply source. The control system implemented is proven to be able to work more efficiently on loads.

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