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Design of Induction Cooker Temperature Stabilizer Using Pulse Width Modulation

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Abstract:
Induction heating is a system that has long been used in industries that require metal materials in their production. Previously, induction heating still used a simple system and had quite large dimensions. With the development of advances in power electronics technology, induction heaters can be simplified into small sizes. Even today the use of induction heaters has shifted to conventional needs that can be used at home or daily activities. Unlike other types of stoves that use gas, the heat generated on an induction cooker occurs directly in the pot or cooking medium. For this reason, kitchen utensils must be made of ferromagnetic metal. On an induction cooker, under the pot is placed a coil (coil) of copper. Alternating current (AC) flowing through the coil causes an alternating magnetic field (magnetic flux). The magnetic flux will be induced into the cookware above it. In cookware made of ferromagnetic metal, eddy currents occur which can heat food without causing a fire. This research discusses the design of an induction cooker that can stabilize temperature automatically through programming. The results of the research show that the duty cycle will be zero if it reaches the desired temperature set point. In addition, the higher the duty cycle value used, the higher the current flowing, thus increasing the heating speed. The results of the research are that by utilizing the duty cycle value, a temperature stabilizer using PWM on an induction cooker can be made. This can be proven by the various duty cycle values that are set.

Keywords: *Cooker induction, IoT, Ferromagnetic, Eddy currents, PWM*

Introduction

Energy subsidies put a lot of pressure on the Indonesian state budget. In 2019, spending on energy subsidies totaled IDR 136.9 trillion ($9.7 billion). LPG (Liquid Petrolium Gasses) subsidies worth IDR 54 trillion or around 40 percent of the total energy subsidies in 2019 have continued to increase in recent years. Therefore, the government realizes the need for energy reform, particularly the conversion from LPG to induction cookers. The statement of the Minister of Energy and Mineral Resources in 2021 in the GSI report shows that LPG (Liquid Petrolium Gasses) stoves and induction cooktops have a thermal efficiency of 40 and 85% respectively.[1] This figure is a significant difference in efficiency, considering that the stove is a primary need for society to be able to process food ingredients continuously. Besides energy efficiency, the advantage of using an induction cooktop is its long-term cost.

Induction stoves are proven to be more economical than LPG stoves. This has been tested in the PLN STT journal. From experiments conducted to boil 1 liter of water, an induction cooker costs Rp. 152.56 while an LPG stove costs Rp. 161.25 [2]. This instability is [3]due to the frequency anomaly. Many improvements have been made to induction cookers, such as modifications to the coil [4], increasing the power factor [5], and using the PID method and fuzzy logic to control temperature. [6]

But from these studies, no one has used the PWM method as a temperature stabilizer on an induction cooker. So research to adjust the pulse width to stabilize the temperature is necessary to do.

RESEARCH METHOD

The research methodology was carried out in several stages which included hardware design including electronics design that would use core components such as STM32, temperature sensors, IGBT H15R1203, pancake coil shaped coils until the hardware system worked properly as the system had been designed. After the hardware design is complete, the next step is to design the software by making the planned system into an Arduino IDE program using the C programming language.

1. Blok Diagram

The system block diagram is a chart that explains the overall system work process. This aims to facilitate understanding of the outline of the research to be made. The system block diagram can be seen in Figure 1. Induction Cooker system block diagram

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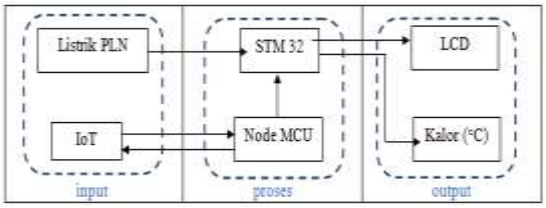


Figure 1 contains an explanation of the overall induction cooker system. The system is divided into 3 parts namely input, process, and output. The system input starts with a 220-volt power supply, then adjustments can be made mechanically. After that, it goes to the processing that occurs in the microcontroller. In processing, there are commands that will determine the output as desired through the duty cycle value using the PWM method and electromagnetic induction events through alternating current flowed coils. The system output can be displayed via the installed LCD and the heat generated due to the skin effect of eddy currents.

2. Electromagnetic Induction

Electromagnetic induction is an EMF (Electric Motive Force) event that occurs in a coil due to a change in magnetic flux. In 1821, Michael Faraday experimented about a changing magnetic field that could induce an electric current [7]. The magnitude of the magnetic flux can be understood as a magnetic field (induction) that occurs in a cross-sectional area and is related to the angle of the direction of magnetic induction and the normal line of the field. Mathematically, this can be written:

$$\Phi = BAcos\theta \qquad (1)$$

Where Φ is the magnetic flux, B is the magnetic induction, A is the area of the field, and θ is the angle between the direction of magnetic induction and the direction of the normal to the field.

3. Eddy Current

When an alternating current flows in a conductor, an alternating magnetic field will arise in the area of the conductor. It also occurs when any conductive material is placed in an alternating magnetic field, there will be a flow of current arising in the material [8]. The current that arises in the conductive material is against the generated magnetic field, this tends to eliminate the magnetic field. Current must pass through a conductive surface before entering, so current flows automatically closer to the surface. The magnitude of a magnetic field used to oppose the current (intensity) will store the current in the conductive material. This is because intensity is a function of frequency [9].

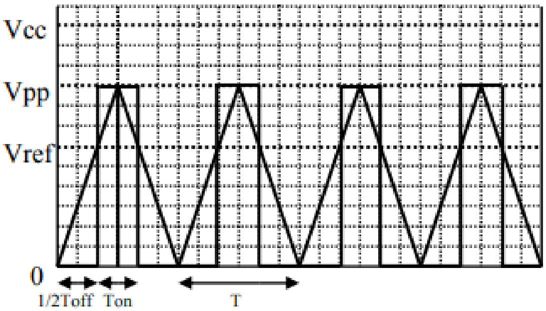
If the frequency is higher (increased) then the current flow becomes more effective in generating all the required magnetic fields. This also occurs in small currents that will flow in the layers below the surface. This event can be known as the skin effect where the skin effect is so useful for producing the concentration or intensity of the current on the surface of a conductive material. The current that comes out on the surface of the conductive material is known as Eddy currents [10]. In an induction machine, the losses we need are usually found in the moving iron (stator), and can be obtained by measuring the input to the machine that is operating without being loaded at a certain frequency or speed. Of course, it must be balanced with the presence of magnetic flux. In the eddy current losses, the magnitude depends on the frequency for the state of the tool in normal conditions, the square of the flux density, and to find out the magnitude of the eddy current losses can be known through the equation below [11]

$$Pc = Kc\ (Bmaks.f)^2 \qquad (2)$$

Where Pc is the eddy current loss, Kc is the eddy constant, Bmax is the maximum flux and f is the frequency.

4. PWM (Pulse Width Modulation)

PWM is a circuit that produces a variety of pulses for different AC or DC inputs. With the PWM method, you will get the amount of duty cycle which consists of time on and time off. The duty cycle value of course varies according to the input current [12]. In principle, this PWM compares triangular and square voltages with a changing on-off period, which is in the form of a reference voltage. The value of this PWM is annotated with a duty cycle. Duty cycle is a representation of high logic conditions in a signal period and is expressed in the form (%) with a range of 0% to 100% [12]. To better understand, it can be observed through Figure 2



Pulse Width Modulation

Based on Figure 2, the equation is obtained:

$$\frac{Vpp}{Vref} = \frac{\frac{1}{2}T}{\frac{1}{2}Toff} \qquad (3)$$

So that

$$\delta = \frac{Ton}{Ton+Toff} \qquad (4)$$

And the equation for the duty cycle value is like equations 5 and 6:

$$Timeperiode = \frac{1}{frekuensi} \qquad (5)$$

$$Duttycycle = \frac{ton}{tperiode} \qquad (6)$$

RESULTS AND DISCUSSION

At this stage testing of the system that has been made. If an error occurs or the system does not work properly, an evaluation is held to correct the error that has occurred. Tests include sensor calibration, duty cycle value, temperature stabilizer, and input power.

1. Sensor Calibration

Calibration is needed to ensure that the results of measurements or checks carried out by the tool are accurate and consistent with other instruments. The electronic component that was calibrated was a type-k thermocouple sensor.

Table 1. Calibration of the K-type thermocouple sensor

Thermocouple Temperature	Thermometer Temperature
70.5°C	70.4°C

In the type K thermocouple sensor table, it is known that the temperature test value is 70.5○C and on the thermometer the test value is 70.4○C. So it can be seen that the type k thermocouple is in good condition and can be used in this study as a temperature detection sensor.

2. Duty cycle measured test

This duty cycle measurement serves to determine the accuracy of the system using an oscilloscope measuring instrument. To find out the ton on and t off time periods in each duty cycle is to use equations 5 and 6. The duty cycle test values can be seen in Table 2:

Table 2. Duty cycle values on the oscilloscope

Time/div	Time on	Duty cycle
5 div	5.2µs	30%
5 div	8 µs	40%
5 div	10 µs	50%

From the table above it can be seen that the PWM method has been running well, this is evidenced by the magnitude of the duty cycle value measured on the oscilloscope and the calculations are the same as equations 5 and 6 as desired, namely 30%, 40%, and 50%.

3. Testing the PWM Method Temperature Stabilizer

An important factor in this study is related to temperature, this is inseparable from the initial objectives of the study, one of which was to determine the work of PWM in stabilizing temperature. So that the temperature set point samples used are starting from 50○C, 80○C, and 110○C. Each temperature is tested using a different duty cycle value. The duty cycle values used include 30%, 40%, and 50%.

Temperature Set Point Testing 50○C DC 30%

NO	Dutty Cycle	Time (s)	Suhu (°C)
1	30%	0	28
2	30%	20	31.25
3	30%	40	46.75
4	30%	58	51.75
5	0%	58	51.75

Temperature Set Point Testing 50○C DC 30%

NO	Duty Cycle	Waktuke (s)	Suhu (°C)
1	40%	0	28.25
2	40%	20	41.25
3	40%	36	51.5
4	0%	37	51.5

Temperature Set Point Testing 50○C DC 30%

NO	Dutty Cycle	Waktuke (s)	Suhu (°C)
1	50%	0	27.75
2	50%	20	44.75
3	50%	34	51.25
4	0%	36	51.25

From Table 3 it can be seen that the greater the power or duty cycle value, the faster the heating time will be. To facilitate observation, it can be seen in the diagram in Figure 3. For duty cycle values of 30%, 40%, and 50%.

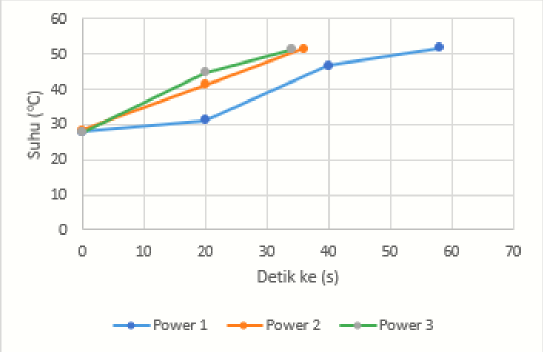


Figure 3. Duty cycle values for temperature

The fastest heating occurs at 50% duty cycle value. At first, the temperature of the medium (oil) was room temperature, namely 27.75○C then when the heating time was 20 seconds, the degree of temperature increase was 44.75. And at the installation time of 34 seconds, the system has reached the specified temperature set point, which is 50○C.

4. Output Power Testing

This test aims to determine the comparison of the amount of output power used for each duty cycle

Testing the output power of the duty cycle

Dutty Cycle	Set point suhu (°C)	Daya input (watt)
30%	50	528.4
30%	80	575.5
30%	110	575.7
40%	50	623.00
40%	80	632.6
40%	110	634.2
50%	50	636.8
50%	80	641.1
50%	110	643.00

From Table 4 of the test above it can be seen that the more the set point duty cycle, the time to heat the oil tends to be faster. So that the greater the duty cycle, the higher the power used where the current flowing into the coil is also getting bigger. This has an impact on the fast heating time by load (pan). In accordance with the electric power formula which reads the higher the power, the greater the required current, because power is directly proportional to current.

In table 4 it can be seen that the greatest power usage is at a 50% duty cycle value when the set point temperature is 110○C. Its power usage is as much as 643 watts.

CONCLUSION

Based on the test results of the Design and Build of an Induction Cooker Temperature Using Stabilizer PWM, it can be concluded that:

1. The pulse width that is set is the amount of current flowing in a coil that can produce eddy currents and is expressed in percent (dutty cycle). It can be seen that the duty cycle will be 0 if the temperature has reached the set point. If the temperature decreases (below the set point) then the duty cycle value will return to the initial setting and will be zero (0) when the temperature has reached the set point.
2. The higher the duty cycle value, the higher the heating speed, this is related to the current flowing in the coil. So that according to the law of electric power, namely the higher the power required, the greater the value of the current flowing.

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