Low-cost transformer tester for laboratory module

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Abstract. This paper presents a low-cost transformer tester for experiment module in electric machine laboratory. Unlikely the expensive transformer tester on the market, this module is built by using Arduino Uno in the hardware side, and LabView in the software side to make it less expensive. Three voltage sensors and one current sensor are used in this equipment for making some several test on transformer such as, short circuit test, open circuit test, polarity test and winding resistance test. The results of all tests can be presenting in LabView as a data and graph. The calculations are also processed in LabView using some functions on it. By using this strategy, the student will be able to learn the transformer test procedures and to compare the results of their calculations by hand with the software's results. This module has been testing by comparing the results with the standard measuring equipment with the error for voltage and current measurements are at 0.81% and 15.29%, respectively.

1. Introduction

A transformer is one of the electrical components that are widely used both in household electrical appliances and in the electricity grid network. The transformer is used to transfer energy from one electric circuit to another without changing its frequency. Two type of transformers are a set-up transformer where the voltage can be increased and step-down transformer for lowering the voltage. The condition of the transformer needs to be known by conducting several tests to find out the parameters of the transformer. A test in detection for transformer winding insulation defects was performed based on applied voltage test [1]. In order to test a current transformer (CT) on site, a new portable intelligent accuracy tester using the microprocessor ARM (S3C2440A the embedded Linux operation system are performed [2]. A good anti-interference performance of selective filtering characteristics also has been proposed for transformer winding deformation tester [3]. In its operation, the transformer will have losses both due to leaky fields and current flow that cause core losses and copper losses. These losses will certainly affect the performance of the transformer and subsequently will affect the performance of the electrical system in it. For this reason, it is necessary to know the value of the transformer parameters by using a no-load test or open circuit test and a short circuit test. In addition, the polarity of the transformer needs to be known for eliminating the reversible connection to the transformer.

In conducting transformer testing generally used a transformer tester that can provide the output of the transformer parameters tested. But the price of this transformer tester is very expensive that can reach tens of millions of rupiah, even for the upper class can reach 100-300 million rupiahs. Another way is to use a separate wattmeter, voltmeter and ammeter to determine the amount of power, voltage and current according to the tests conducted. Experience in the field, especially at the Electrical Machines Laboratory in the Department of Electrical Engineering, Bali State Polytechnic shows that the measuring instruments used by students in carrying out the experiments are easily damaged, even though they use good quality measuring instruments. The replacement requires a long waiting time because it is an imported product and must be ordered from a distributor at a high price. For this reason, it is necessary to build a transformer test equipment that is cheap, reliable, and can be quickly replaced if damage occurs

2. Literature review

Transformer testing.
To find out some parameters of a transformer such as its efficiency, the ratio of primary and secondary coils, the resistance of a transformer coil, the polarity of a single-phase transformer, and the losses contained in the transformer, several tests are used. These tests include an open circuit test or no-load and short circuit test [4] and a polarity test [5].

Open circuit and short circuit test.
Open circuit and short circuit testing are performed to find several parameters of transformers such as efficiency, voltage regulation, circuit constants, etc. This test is done without using the actual load so that in its implementation the power used is not large. These open circuit and short circuit test results provide accurate results as well as tests at full load.

2.1. Open circuit test

The purpose of this open circuit test is to determine the current at no-load conditions and losses from the transformers obtained from the parameters of the no-load test results. This test is carried out on the transformer primary coil. A wattmeter, ammeter, and voltmeter are connected to this primary coil. The nominal voltage applied to this output is sourced from the ac power supply.

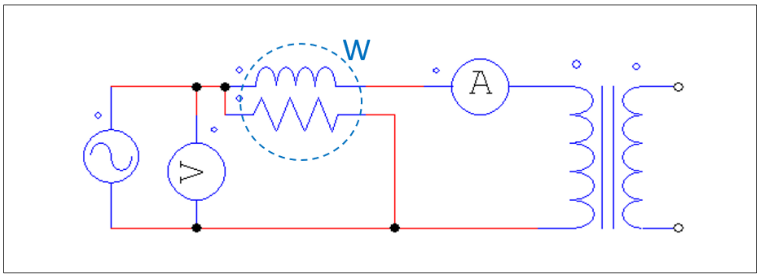

Figure 1. Open circuit test circuit diagram on transformers.

2.2. Open circuit test calculation

If W_0 is a Wattmeter reading, V_1 is a voltmeter reading, and I_0 is the ammeter reading, the copper loss at full transformer condition $P_1 = W_0$ can be stated as:

$$W_0 = V_1 I_0 \, Cos \, \varphi_0 \quad (1)$$

With the value of the power factor in the no-load state:

$$\text{Cos } \varphi_0 = \frac{W_0}{V_1 I_0} \quad (2)$$

The value of I_w current component is:

$$I_w = \frac{W_0}{V_0} \quad (3)$$

By taking the value of W_0 from equation (1) and including it in equation (2), a working component value of:

$$I_w = I_0 \text{ Cos } \varphi_0 \tag{4}$$

and as a component of magnetization:

$$I_m = \sqrt{I_0^2 + I_w^2} \tag{5}$$

For the no load, equivalent exciting resistance is

$$\boldsymbol{R_0} = \frac{\boldsymbol{V_1}}{\boldsymbol{I_w}} \tag{6}$$

And equivalent exciting reactance is

$$X_0 = \frac{V_1}{I_m} \tag{7}$$

At no load or when the open circuit test is performed, the phasor diagram of the transformer can be shown in Figure 2. Iron losses are measured by conducting an open circuit test to calculate transformer efficiency.

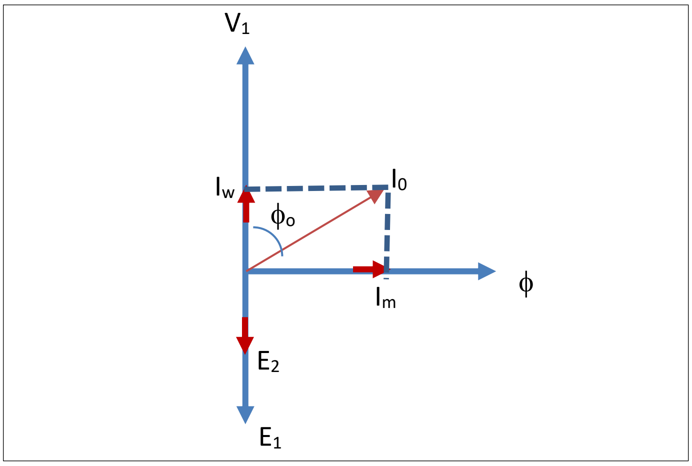

Figure 2. Phasor diagram for open circuit test.

2.3. Short circuit test

Short circuit tests are carried out on the transformer to find out the copper losses that occur when full load. This copper loss is used to determine the efficiency of the transformer. It also to find equivalent resistance, impedance and leakage reactance can be determined from this short circuit test.

Short circuit tests are performed on the transformer secondary or on the high voltage coil of the transformer. Measuring instruments used are wattmeter, voltmeter, and ammeter connected to the high voltage coil. The transformer primary coil is short-circuited using a cable or using an ammeter connected to both terminals.

The low voltage source is connected to the secondary coil because the full load current flows from both coils, both the primary and secondary transformer coils. The circuit diagram for this short circuit test can be seen as shown in Figure 3.

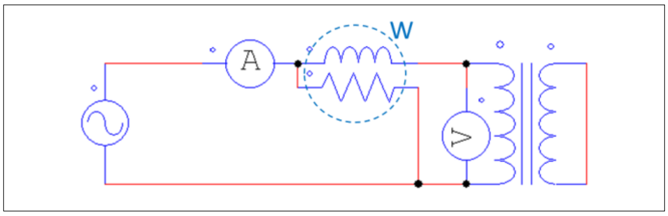

Figure 3. Circuit diagram for short circuit test.

A low voltage source is injected into the secondary coil with a value of about 5 to 10% of its rated normal voltage. Flux will occur in the transformer core but the value is very small compared to normal fluxes. Iron loss in the transformer depends on the flux. The value will be very small in this short circuit test because of the small value of the flux. The measurement results of the wattmeter will only show the copper losses that occur in the coil. A voltmeter will measure the voltage applied to a high voltage coil. The secondary current induces the transformer due to the voltage applied to the transformer.

2.4. Calculations on the short circuit test

For short circuit test calculations can be explained as follows:

If W_c is a Wattmeter reading, V_{2sc} is a voltmeter reading, and I_{2sc} is the ammeter reading, the copper loss at the transformer full load condition can be stated as:

$$P_c = \left(\frac{I_{2\mathrm{fl}}}{I_{2\mathrm{sc}}}\right)^2 W_c \quad \text{dan} \quad I_{2\mathrm{sc}}^2 R_{\mathrm{es}} = W_c \tag{8}$$

Equivalent resistance refers to the secondary part:

The phasor diagram for the short circuit test can be seen in Figure 4 below.

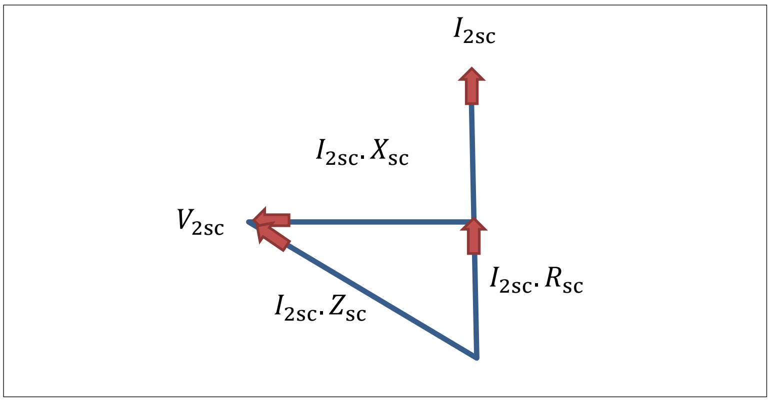

Figure 4. Phasor Diagram of Short Circuit Test.

From the phasor diagram

$$I_{2\mathrm{sc}}^2 Z_{\mathrm{es}} = V_{2\mathrm{sc}} \tag{9}$$

The equivalent impedance referring to the secondary portion is:

$$Z_{\mathrm{es}} = \frac{V_{2\mathrm{sc}}}{I_{2\mathrm{sc}}^2} \tag{10}$$

The equivalent reactance referring to the secondary portion is:

$$X_{\mathrm{es}} = \sqrt{(Z_{\mathrm{es}})^2 - (R_{\mathrm{es}})^2} \tag{11}$$

Voltage regulation voltage of transformers can be obtained at various loads and various power factors after knowing the value of Z_{es} and R_{es}.

In the short circuit test, the wattmeter records total losses including core losses but the value of these core losses is very small compared to copper losses, so that core losses can be ignored.

2.5. Transformer polarity testing

The direction of the induced voltage on the transformer primary and secondary coils is known as a polarity of the transformer. The polarity needs to be determined especially when two transformers are connected in parallel. There are 2 types of polarity, the first one is additive polarity, the same terminals on the primary and secondary coils are connected and the second one is subtractive polarity where terminals that are different from primary and secondary coils are connected. The polarity testing step can be carried out in accordance with Figure 5.

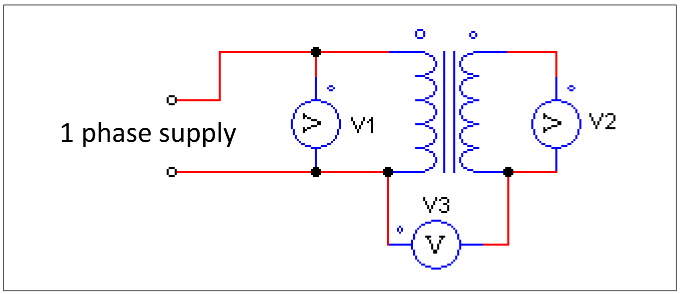

Figure 5. Transformer polarity testing.

2.6. DC resistance testing

DC coil resistance testing per manufacturer recommendation is generally carried out during periodic maintenance and after the internal faults occur [6]. This test can test the performance of the transformer coil, tap changer, and also the connection inside the transformer. The 3 main methods for conducting this test [5] can be described as the voltmeter-ammeter method, the bridge method, and the micro-ohmmeter method. The most commonly used method is the voltmeter-ammeter method, which uses a dc source injected into the transformer coil. In this method, current and voltage are measured for finding the resistance of the coil of a transformer. The tolerance value is 5% when comparing to the transformer manufacture specifications [6]. This test can be seen in Figure 6.

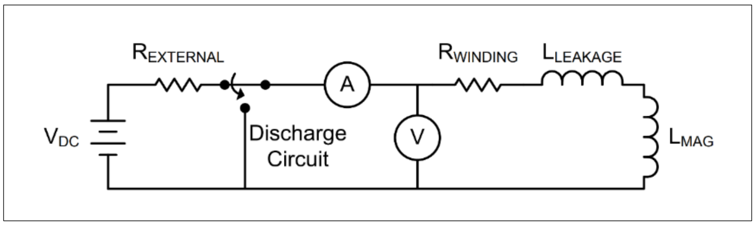

Figure 6. Testing DC resistance.

It should be noted several things in testing the DC transformer coil resistance, including the configuration of coil connections, allowable current and voltage, temperature and safety [6-8].

Calculation of coil resistance is very important to know the possibility of damage to the transformer. This damage can occur due to inadequate design, improper assembly, handling both during shipping and installation, unfavourable environmental influences, and overloaded or inadequate maintenance.

In this test, we will look for gross differences between the coils and the open terminal part. By calculating the transformer coil resistance, bias can be used to ensure each circuit is well connected and strong. The resistance of the transformer coil from time to time will experience changes that include the result of a short circuit on the coil, loose connections, or the occurrence of erosion on the tap changer. Calculation of the transformer coil resistance is carried out according to Ohm's Law, bypassing the DC current to the tested coil and calculating the voltage drop at each terminal.

3. Methodology

This research was conducted at the electrical machine laboratory at the Department of Electrical Engineering, Bali State Polytechnic. An initial survey was conducted to find out how the measurements were previously carried out as well as the quantities measured and the tools used. Furthermore, after knowing the amount you want to know, the design of measuring devices is done using an Arduino microcontroller and its supporting components. Furthermore, the finished tool is tested by comparing the measurement results with standard measuring tools owned by the Department of Electrical Engineering.

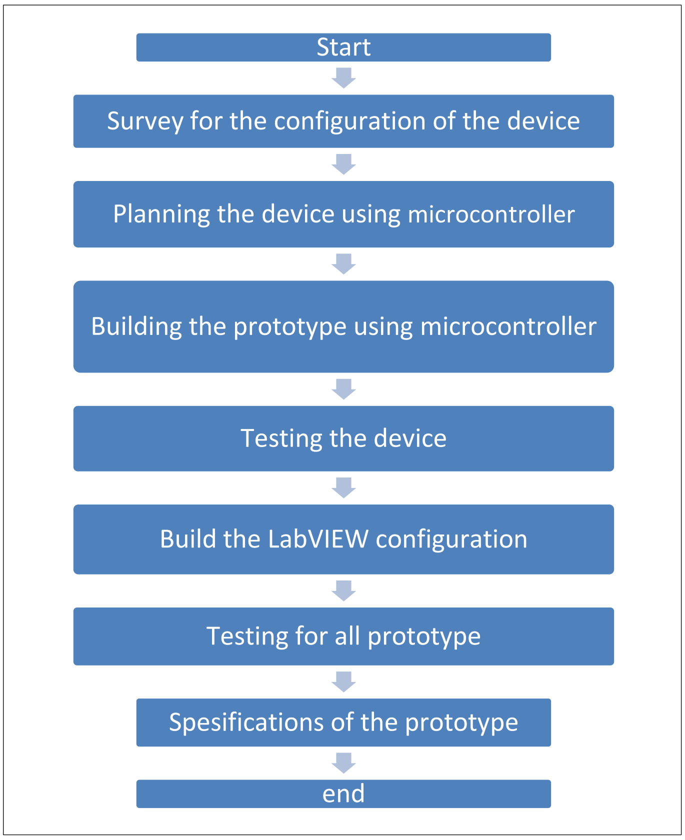

Figure 7. Research flow chart.

The next step is to build a system that can record data (data loggers) to the computer. This operation can be performed using LabVIEW software. From the results of this data recording, then the data can be plotted or carried out the necessary calculations such as to look for power losses.

The entire system, both the measuring device that uses a microcontroller and the program that has been built using LabVIEW will be tested so that later the specifications of the tool that has been built will be obtained.

4. Results and discussions

4.1. Design and manufacture of measuring instruments

To build this Transformer Tester, a number of measuring devices are needed where each test will require a slightly different measuring instrument. For open and close circuit tests, a current and power voltage gauge is required, while the dc resistance test is sufficient to use a current and voltage measuring device only. Unlike the other measurements, the transformer polarity test is enough to use a voltmeter but there are 3 of them. DC source voltage is also required with additional switches and external resistors. The front panel design of this test tool can be seen as in Figure 8.

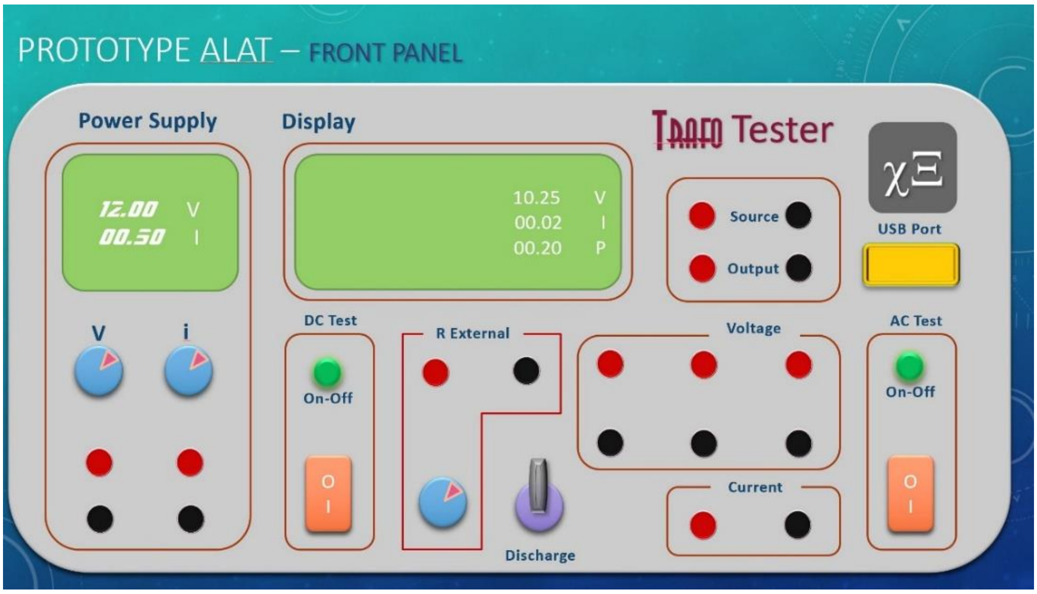

Figure 8. Front panel of prototype transformer tester.

4.2. The series and layout of the transformer test equipment

The transformer tester circuit can be seen as shown in Figure 9 to 12. The sensor circuit using the current transformer and the voltage sensor circuit using a voltage transformer can be seen as in Figure 9. While for the display and Arduino Uno used, the circuit can be seen as in Figure 10 with the supply source as in Figure 11. For the layout of the circuit on the PCB can be seen in Figure 12.

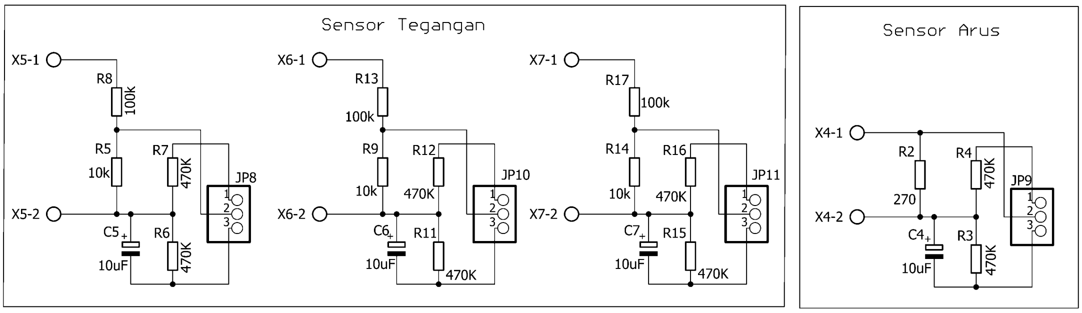

Figure 9. Voltage and current sensor.

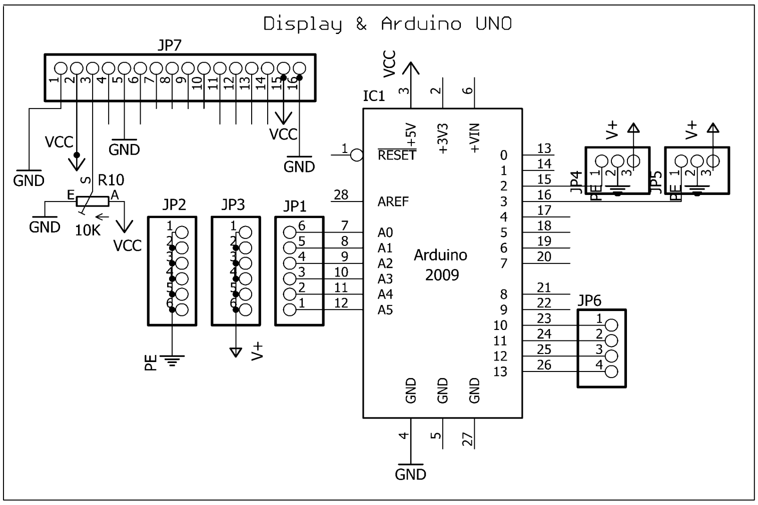

Figure 10. Display using Arduino Uno

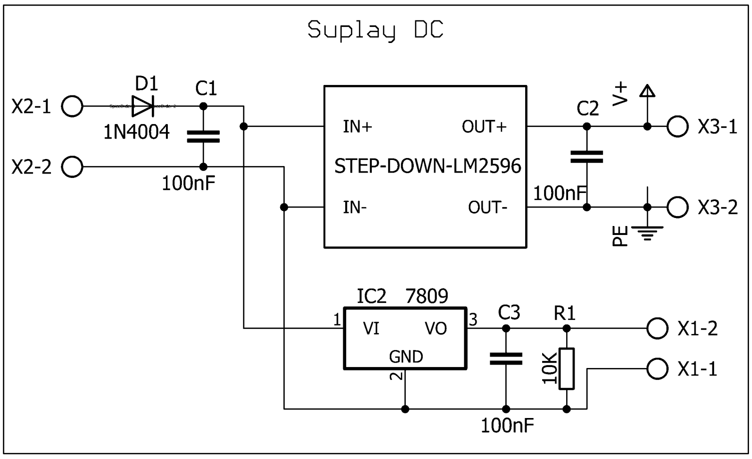

Figure 11. Power supply

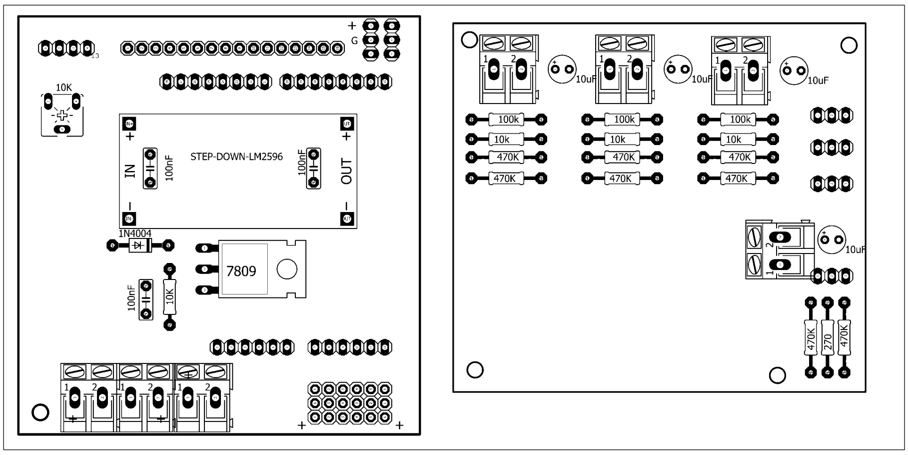

Figure 12. Layout of PCB

4.3. Analysis and testing of transformer test equipment

The testing of this transformer test is carried out by comparing the results of current and voltage measurements from a device made against a multi meter measuring instrument. The results can be seen in Table 1.

Table 1. Result of the voltage test.

No	Voltage source	Standard meter	Voltage - Using Module			Error (%)		
			V1	V2	V3	R	S	T
1	30	30	30.1	30.2	30.1	0.33%	0.67%	0.33%
2	40	40	40.3	40.5	40.3	0.75%	1.25%	0.75%
3	50	50	50.9	50.5	50.2	1.80%	1.00%	0.40%
4	60	60	60.6	60.6	60.4	1.00%	1.00%	0.67%
5	70	70	71.0	71.1	70.5	1.43%	1.57%	0.71%
6	80	80	81.0	81.1	81.1	1.25%	1.37%	1.37%
7	90	90	90.6	91.6	90.9	0.67%	1.78%	1.00%
8	100	100	100.2	100.1	101.5	0.20%	0.10%	1.50%
9	110	110	111.3	111.1	111.1	1.18%	1.00%	1.00%
10	120	120	121.1	120.7	121.5	0.92%	0.58%	1.25%
11	130	130	130.1	130.2	130.1	0.08%	0.15%	0.08%
12	140	140	141.3	141.1	141.2	0.93%	0.79%	0.86%
13	150	150	151.1	150.2	151.3	0.73%	0.13%	0.87%
14	160	160	161.2	161.2	161.1	0.75%	0.75%	0.69%
15	170	170	171.1	170.3	171.5	0.65%	0.18%	0.88%
16	180	180	181.2	181.0	180.2	0.67%	0.56%	0.11%
17	190	190	192.1	192.2	192.0	1.11%	1.16%	1.05%
18	200	200	201.1	201.1	200.5	0.55%	0.55%	0.25%
19	210	210	212.1	212.2	212.0	1.00%	1.05%	0.95%
20	220	220	221.5	221.2	221.4	0.68%	0.55%	0.64%
				Average error:		**0.88%**	**0.85%**	**0.81%**

From the test results of this transformer test equipment, it was found that the voltage test showed a very small error rate of 0.81% as in Table 1. For currents, a large enough error was tested in the amount of 15.29% as shown in Table 2.

Table 2. Result for Current measurement.

No	Input	Current - Standard Meter	Current - Using Module	Error (%)
	(A)	(A)	(A)	(A)
1	0.50	0.50	0.70	40.00%
2	1.00	1.00	1.20	20.00%
3	1.50	1.50	1.70	13.33%
4	2.00	2.00	2.20	10.00%
5	2.50	2.50	2.70	8.00%
6	3.00	3.00	3.30	10.00%
7	3.50	3.50	3.70	5.71%
				15.29%

Figure 13. Transformer tester module.

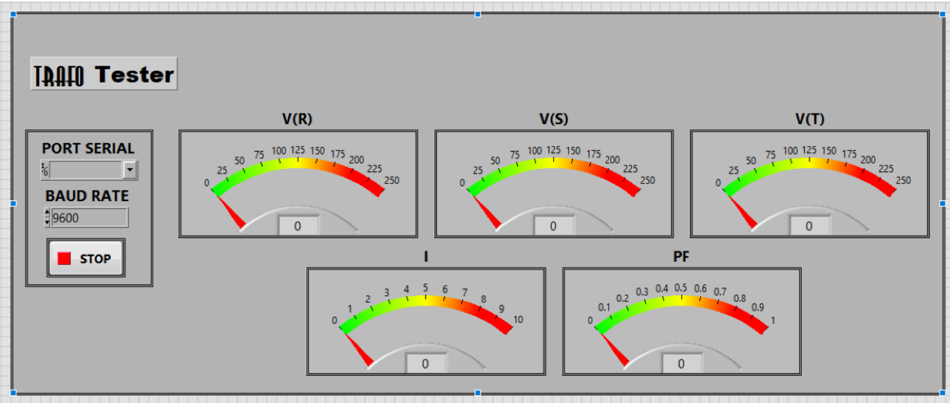

Figure 14. LabVIEW front panel for transformer tester.

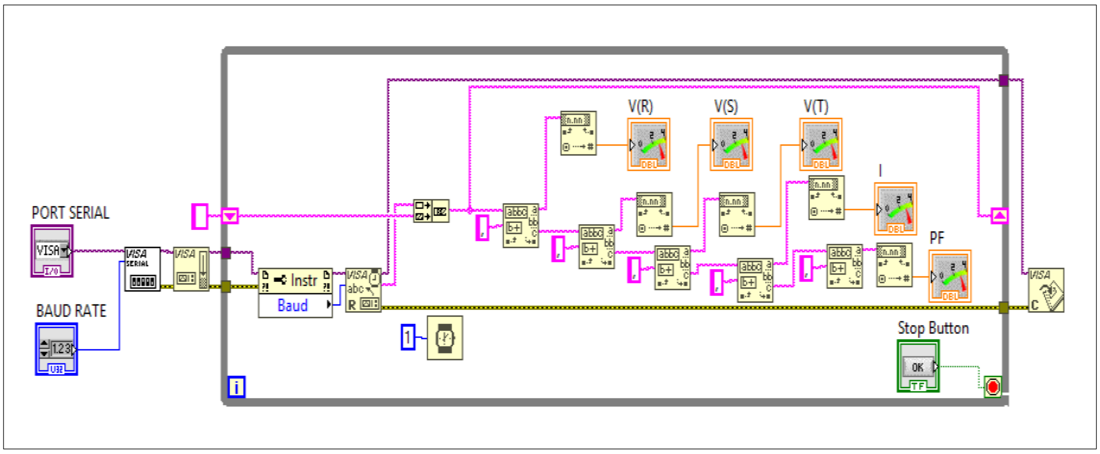

Figure 15. LabVIEW block diagram for transformer tester.

5. Conclusions

This research makes a simple transformer test tool using Arduino and LabVIEW. This test tool can be used to carry out open circuit test, close circuit, polarity, and DC resistance. Errors that occur when voltage and current measurements are 0.81% and 15.29%, respectively.

6. References

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