NIGERIA JOURNAL OF PURE AND APPLIED PHYSICS

Nigeria Journal of Pure & Applied Physics, Vol. 9, No. 1, pages 17–22, 2019

Development of Alternating Current (AC) Line Monitoring Device for Power System Management

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Abstract: This work presents a study of the effect of imbalance between the supply of and demand of power from the National grid on electrical appliances. In the study, an alternating current (ac) line monitoring device was developed using arduino microcontroller to carry out the investigation. The device is a single system capable of measuring both the main frequency and nominal voltage of electricity supply. The device consists of seven major components: 12 V step-down transformer, half-wave rectifier, attenuator, wave-shaping circuit, arduino microcontroller, Liquid crystal display and micro SD card. The heart of the device is the arduino microcontroller that reads the period of the pulses from the shaping circuit and the output voltage from the scale resistor connected to the attenuator circuit in order to measure the levels frequency and voltage of the ac main source. By graphically compared the reading of the voltage obtained by the ac monitoring device with that of the standard Mastech voltmeter, it was shown that the device has a good correlation with the standard voltmeter with a deviation of ±0.21%, and this has proven that the device is capable of measuring ac voltage accurately. From the frequency test level results, it was found that the frequency measured by the device closely related to the frequency measured by the standard frequency meter. This shows that the device satisfied the requirement of the overall design. Hence, it can be used in the laboratory for demonstration and research purposes as well as in power plant industries.

Keywords: Mains frequency, nominal voltage, half-wave rectifier, attenuator, wave-shaping circuit, Arduino microcontroller

1. INTRODUCTION

Electricity is set of physical phenomena associated with the presence and motion of matter that has a property of electric charge. It a secondary energy source which can be getting from the conversion of other sources [1]. Electricity is a basic part of nature and one of the most important needs of mankind. From power plants, electricity is generated by series and parallel group of generator (turbine) and transmitted in sinusoidal pattern [2] through a system known as grid. The term grid is an interconnected network for delivering electricity from producers to consumers [3] either 110 V-140 V /60 Hz or 220 V-240 V/50 Hz) [4]. The frequency is the number of times the voltage swings per second. Therefore, it is an important parameter needed to be closely monitored in power system generation and transmission as frequency variation due to imbalance between the supply and demand for electricity will cause voltage and current instability of the power system which may affect the equipment operations.

Many of the industrial and domestic electrical appliances are optimized to run on these frequencies within a tight tolerance, so it is very essential to keep the frequency of power supply stable [5]. Frequency stability is the ability of the power system to maintain steady state frequency, following a severe system upset, resulting in a significant imbalance between generation and load [6]. The basic requirement for the stability of electrical power system is to ensure the system frequency and voltage level close from their steady state limits. So, regardless of the technical reason for individual countries on choosing which frequency level that suits their respective needs, each and every electricity suppliers or power provider companies are obliged to monitor mains frequency constantly as it is very important in managing power grid systems and to analyse the behaviour of the frequency consistently in order to keep it within allow tolerance.

So, any power with a frequency as little as one per cent above or below the standard value risks the damage of equipment. In case of inductive heater, the induced voltages depend on the supply frequency and any rise in the frequency above the allowed value; this may lead to increase in transformer losses and conductor skin effect [7]. While, any fall in the frequency below the allowed value, may lead to drop in transformer magnetizing current [8].

In view of the reasons stated above, it is very important to develop a low cost effective AC monitoring device that will be able to measure both main frequency and nominal voltage of electricity supply to reasonable degree of accuracy and at fast response time. This allow the device to quickly trigger off both indusial and domestic appliance from being get damage.

2. MATERIALS AND METHODS

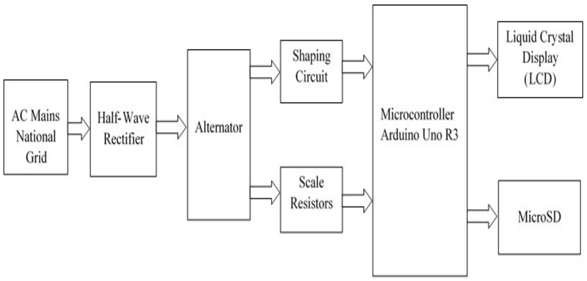

Fig. 1. Block Diagram of the Developed AC Line Monitoring Device.

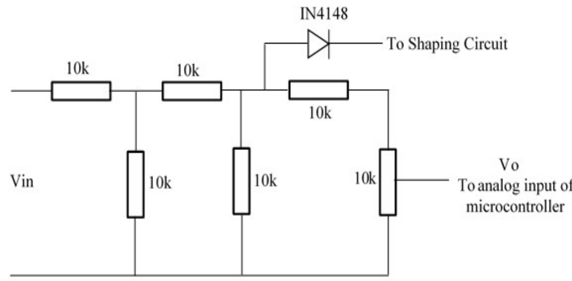

Fig. 4. Attenuator circuit.

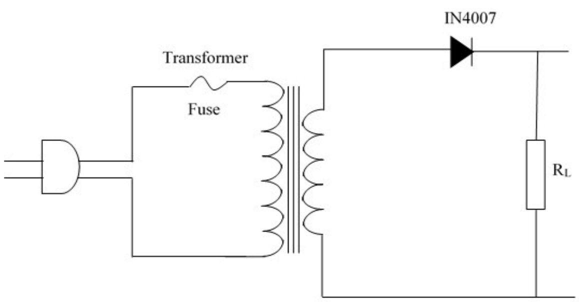

Fig. 2. Half-Wave Rectifier Circuit.

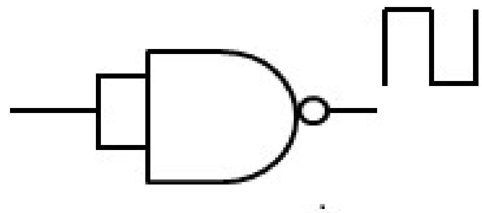

Fig. 5. The shaping circuit.

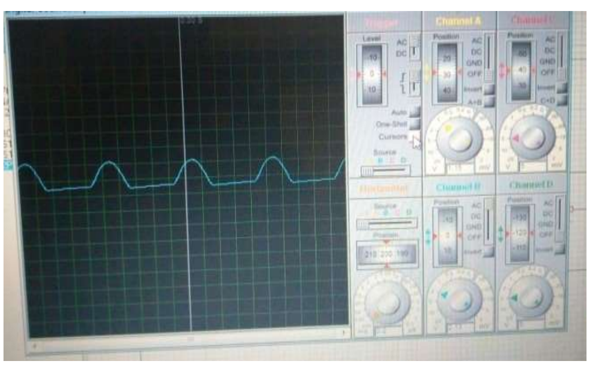

Fig. 3. The Rectifier Output Wave-form of the Rectifier.

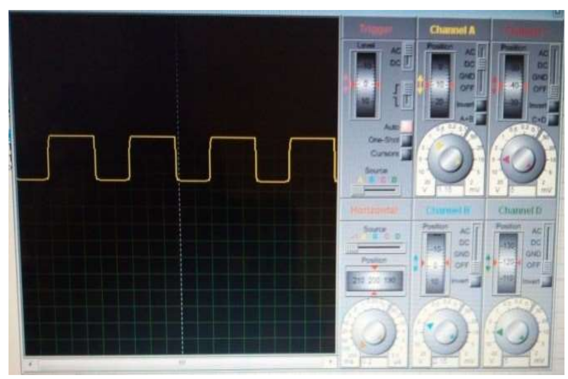

Fig. 6. The Output Wave-form produced by the Shaping Circuit.

The basic block diagram of the ac monitoring device is shown in Figure 1. The device consists of seven major components: 12 V step-down transformer, half-wave rectifier, alternator, shaping circuit, the microcontroller, liquid crystal display and micro SD card shield. The core of the device is the microcontroller. The circuits are designed independently before being coupled into one system. This ensures that if there are any errors, they are independently considered and corrected.

Half-wave rectifier

A half-wave rectifier consists of IN4007 diode was employed to converts the step-down ac voltage from transformer into direct current (dc) voltage. The rectifier only considered the first half cycle of the ac mains input and the output is a dc pulsating voltage. Figures 2 and 3 shows half-wave rectifier circuit and the output waveform produced by the rectifier. This voltage is fed to the input of attenuator circuit shown in Figure 4.

Attenuator circuit

The circuit is constructed with resistive ladder network arranged in Pi form to scale down the peak voltage waveform from the half-wave rectifier output to a voltage level that can be measure by the microcontroller. Fraction of the attenuator output was exploit through a signal diode (IN4148) and fed into a wave-shaping circuit as indicated in Figure 4 in order to be able to measure the frequency of the rectified voltage signal.

https://dx.doi.org/10.4314/njpap.v9i1.4

Fig. 7. Arduino uno microcontroller board.

Fig. 8. 16 x 2 Liquid crystal display (LCD)..

The output of the attenuator is fed into the analog input pin A0 of the microcontroller through a scale resistor formed by a 10k variable resistor. The scale resistor is used in calibrating the voltage and also not to allow the voltage to go beyond the voltage level required by the analog input of the microcontroller. The microcontroller read the voltage and converts into the corresponding digital values by its 10 bits analogue-to-digital converter (ADC) between 0 and 1023. Since the device takes input from 220 V – 240 V ac mains source.

The microcontroller further process the digital values into a readable form by the conversion factor given below:

$$V_{AC} = \text{analogRead (A0)} \tag{1}$$

$$V_{OUT} = \frac{(V_{AC}*240)}{1023} \tag{2}$$

Shaping circuit

For the microcontroller to measure the frequency of the rectified wave signal, a wave shaping circuit using Schmitt trigger NAND gate (CMOS 4093) shown in Figure 5 was employed to reshape the fraction of attenuator output obtained through the signal diode to perfect square wave. The output from alternator is fed into digital Schmitt trigger NAND gate (CMOS 4093) to produce perfect square-wave. Figure 6 show the simulation output of the shaping circuit.

The output of shaping circuit in Figure 5 is fed into the digital input pin 5 of microcontroller to monitor the period of the waveform, that is, the HIGH and LOW of the pulse produced in Figure 5 using "PINGING" in arduino library code in the Sketch library. The sample code uses the simple algorithm.

Time of high pulse = t_H
Time of low pulse = t_L
Time for complete cycle (t) = $t_H + t_L$

The frequency of the pulse output from shaping circuit to digital pin 5 of microcontroller is

$$\text{Frequency} = \frac{1}{t} = \frac{1}{t_H + t_L}\text{(Hz)} \tag{3}$$

The programming code in Arduino platform is shown below

```
pinMode(pingPin, INPUT);
    tH= pulseIn(pingPin, HIGH);
    tL= pulseIn(pingPin, LOW);
    t = tH + tL
```

Control circuit

This section of the device is accomplished using arduino uno microcontroller board, a device that can be programmed for various purposes. The microcontroller is small size computer on a single IC containing processor core, memory and programmable input-output peripheral. Figure 3 shows the picture of the microcontroller board. The board consists of Atmega 328P and is designed for the use of embedded applications, in contrast with microprocessor which are used for personal computers and other general purpose applications. Atmega328 is a low power, high performance; CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. Atmega328 provides 32 K bytes of in-system self-programmable memory with read while write capability and 1Kbyte EPROM [9].

Liquid crystal display

The display unit of the device is achieved using 16 characters x 2 lines Hitachi's HD44780 liquid crystal display (LCD) module. The display is a 16 pins which works with maximum power supply of 5.0 V and the data can be sent in either 4 bit, 2 operations or 8-bit, 1 operation so that it can be interfaced to 8-bit Microcontroller [5]. Here we used 4 bits, 2 operation system. The LCD is used to display the values of the mains frequency and voltage level measure by the device.

Data logger and power unit

The device is integrated with data logger so that the measurements taken by the device over time can be stored for further analysis. The entire system was powered using a 9 V Can battery via pin V_{in} of the microcontroller board, while the other units of the meter were powered with 5 V

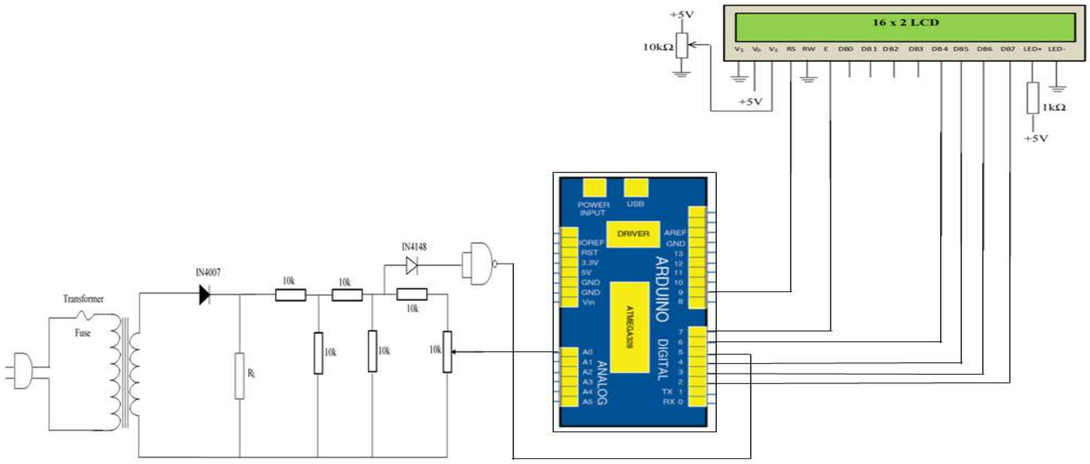

Fig. 9. Complete Circuit Diagram of the Developed AC Line Monitoring Device

Table 1. Readings of Alternating Current (AC) Supply Voltage taken with Standard Digital Voltmeter and the Developed Monitoring Device

Standard Digital AC Voltmeter (V)	Developed AC Device (V)
108.00	109.11
110.00	110.95
122.00	123.04
124.00	125.73
127.00	128.84
131.00	132.13
134.00	134.93
135.00	136.44
137.00	137.21
142.00	144.11
147.00	149.01
151.00	153.32
155.00	156.21
163.00	165.01
168.00	170.13
174.00	175.71
181.00	183.41
183.00	184.69
185.00	187.03
192.00	193.22
197.00	199.21
201.00	202.16
203.00	205.18
205.00	207.08
210.00	212.08
212.00	213.34
215.00	217.02
218.00	219.15
219.00	220.23
219.00	220.23
220.00	221.23
221.00	222.05
225.00	226.18

acquired from the voltage output pin on the

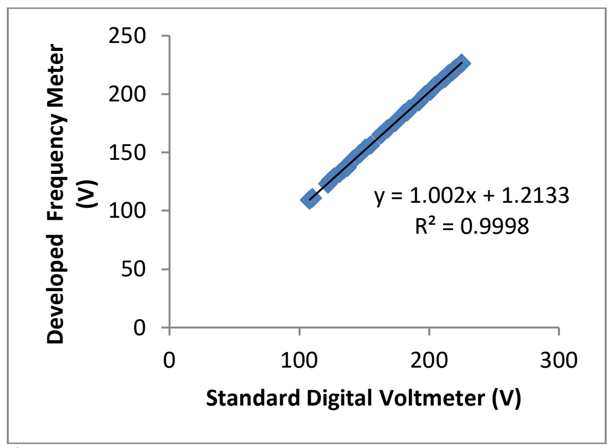

Fig. 10. Graph of Standard Digital Volt meter versus Developed AC Monitoring Device.

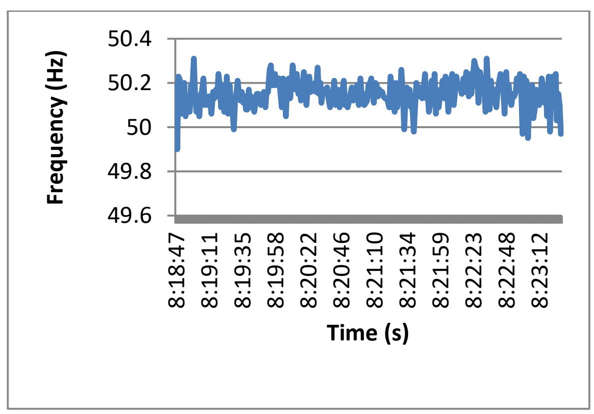

Fig. 11. Spatial Variation of Frequency obtained from National Grid by the Developed Device.

microcontroller board. The complete assembly of the developed ac line monitoring device is shown in Figure 8.

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3. TESTING, CALIBRATION AND PERFORMANCE EVALUATION

Each unit of the developed ac monitoring device shown in Figure 8 was coupled together using flexible cables. The complete arrangement of the developed device was tested by connecting it to an alternating current (ac) source. Also a Mastech digital Multimeter 6205 was used alongside with the developed device to measure ac voltage from mains supply at the Laboratory in the Department of Physics, Federal University of Technology, Akure. The output voltage from the attenuator circuit of the device was adjusted through the scale resistor connected to its output until its value is equivalent to value display on the Mastech meter. The two device were left tested for 5 minutes and readings were recorded at every 30 seconds interval. And the result of the measurement is indicated in Table 1. For the frequency measurement, the frequency unit of the device was also calibrated with a standard ac frequency meter. The two devices were connected to ac voltage supply at the same time to monitor the mains frequency of the power grid to test for the functionality and performance of the developed device. The measurement was taken for 5 minutes and recorded at every 1 second interval. The graphs of the results of the measurements are presented in Figures 11 and 12.

4. RESULTS AND DISCUSSION

The readings from Table 1 clearly show the values of ac supply voltage obtained by the voltage reading unit of the developed ac monitoring device and that of the standard digital voltmeter. The results of the measurement of the supply voltage obtained by the developed device and the standard digital voltmeter were compared in order to determine its reliability.

In this case, the values of the supply voltage obtained from the standard digital voltmeter were plotted in a graph against the values of the supply voltage obtained from the developed ac monitoring device as shown in Figure 10; to check for the instruments correlation.

As in the graph, the slope of the graph was 1.002 and regression R^2 was calculated to be 0.9998; which shows that the correlation between the voltage reading unit of the developed device with that of the standard digital voltmeter was found to be very close to unity, this suggests that the values from the voltage reading unit of the developed device was highly reliable.

Also, from the readings presented in Table 1, the deviation of the voltage reading unit of the developed device from the standard digital voltmeter was found to be ±0.21%, which is still very insignificant. The graphs shown in Figures 11 and 12 indicates the spatial variation of main frequency obtained from the Nigeria power grid as measured by the developed device and the standard frequency meter. From the maximum and minimum value points of the graphs, it was observed that the frequency test level measured by the developed device varies within allowed limits of +0.62% and -0.20% which corresponds to 49.90-50.31 Hz, and the test level from the standard frequency meter shows frequency variation of +0.54% and -0.22% which corresponds to 49.89-50.27 Hz. From these values, it was found that the frequency test level measured by the developed device is closely related to the frequency test level measured by the standard frequency meter. From the frequency test level range measured by the device, it was observed that the device can measure mains frequency within the range of 49.0-51 Hz. Therefore, the result from the device is very reliable.

5. CONCLUSION

This paper has presented the development of a microcontroller based alternating current (ac) monitoring device for power system management. The results demonstrated had proven that the device work satisfactorily with the design circuits and Arduino microcontroller as the heart of the device. The device can measure both frequency and voltage level of power grid, and it is relatively cheaper and proposed a better replacement for the high cost standard frequency meter available in the market as the device was made and assembled from inexpensive materials locally sourced. The results shows that the device satisfied the requirement of the overall design with the voltage reading unit of the device having a deviation of ±0.21% from the standard Mastech voltmeter. Also, from the frequency test level results measured by the device and the standard frequency meter it was observed that the measured frequencies are closely. From the frequency test level range measured by the device show that the device can measure mains frequency within the range of 49.0-51 Hz. Therefore, the meter can be used in the laboratory for demonstration and research purposes as well as in power plant industries. The meter is cost-effective and much more feasible to buy and use because of its simple design.

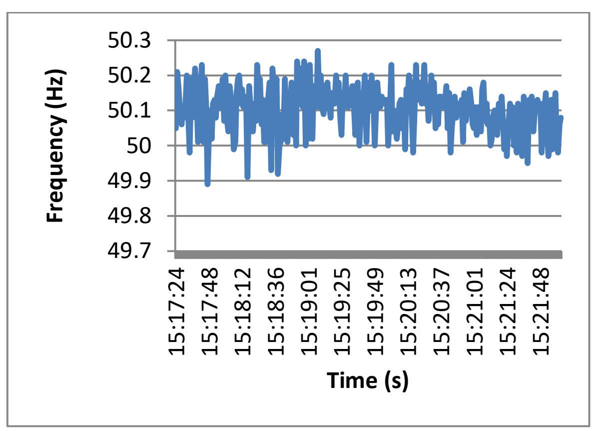

Fig. 12. Spatial Variation of Frequency obtained from National Grid by the Standard Frequency Meter

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