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DESIGN AND DEVELOPMENT OF A DUAL POWERED AIR COMPRESSOR FOR TYRE INFLATION

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Abstract: **The development of a dual power air compressor system is the main goal of this work. The dual powered system provides a dependable and sustainable power source by combining solar power, grid supply, and a battery storage system. In order to maximize energy efficiency and save operating costs, the system is automated using sensors and Arduino micro-controllers to monitor and manage the systems' performance. The compressors' energy requirement was assessed and appropriate selection of solar panel capacity, battery capacity and inverter system to integrate with the grid power supply was conducted. Programmable codes were written in C/C++ language and tested using the proteus 8 software. Test results of the system show that the volumetric air flow rate of the system is 0.164 litres/second (i.e., 0.000164 m^3/s) and within 255 seconds, 40 psi of air can be delivered to a 20 liters vessel. The system's performance was seen to be satisfactory and is recommended for car tyre inflation.**

Keywords: **Air compressor, Arduino micro-controller, dual power system, solar powered, tyre inflation.**

1. INTRODUCTION

An air compressor is a mechanical device that increases the pressure of a gas by reducing its volume [1]. This is usually achieved through the conversion of the mechanical power provided either by an electric motor, a diesel engine or a gasoline engine [2]. Several types of air compressors exits, and can be classified under two headings (i) Positive Displacement, which consists of the rotary and reciprocating types of compressor and (ii) Dynamic compressor which consist of the centrifugal and the axial types of compressor [3].

Tyre inflation requires the use of compressors that can deliver high pressure head [4]. While several types of compressors may be used for this purpose, road side vulcanizers usually adopt the positive displacement compressors for their operations because of some of the peculiarities or advantages of the use of this compressor type, which are: easy to operate and maintain, less complex and can deliver high enough pressure to inflate car tyres.

The traditional air compressors typically used for tyre inflation by road side vulcanizers rely on internal combustion engine as prime movers. This power source has significant drawbacks owing to high operating costs (maintenance and fuel cost) and emission of CO_2 (which is hazardous to the human health and the environment).

A critical look at the air compressor system as used by the road side vulcanizers in developing nations (e.g., Nigeria, Ghana, Niger etc.) show that they are not smart (i.e., they are incapable of automatic shut down/cut-off after the delivery of precise amount of the required air to the inflated tyre.) This kind of system poses safety concerns where the operator is not alert or experience to turn off the system when the rated pressure for the car tyre is attained.

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There is a growing interest in the adoption of different concepts and technologies for the design and development of air compressors for tyre inflation. In the work of [5], a solar based portable air compressor system for tyre inflation was designed and constructed for the delivery of 150 psi (rated) air pressure using a 12v 35Ah battery back-up and 12V 50watt Polycrystalline solar panel. Design of a solar based mini air compressor for tyre inflation was developed by [2], they were also able to interface the system with an LCD display to monitor system performance.

In this work, a hybrid-powered air compressor system for tyre inflation by road side vulcanizers is developed. Here, AC power from grid is combined with a stand-alone solar power system for the running of the air compressor system. An Arduino controller is incorporated to allow for an automatic operation of the system such that the air compressor is automatically turn off, when maximum air pressure in the tank is reached, and turns on when air pressure in the tank reaches minimum.

2. MATERIALS AND METHODS

2.1 System Description

An electric motor is used to propel the compressor, causing the motor and the compressor to both rotates simultaneously. This is aided with the help of a fan belt serving as an intermediary between the belt and motor. The rotations of the compressor shaft generate compressed air, which is stored in the compressed air tank for use when needed. A dual power system comprising of solar system and AC supply is incorporated to power the electric motor. An automatic change-over is used to select between the two power sources, (i.e., solar power system or the AC supply) to power the electric motor. At default, the solar power system is the energy source, and an automatic transfer switch (ATS) switches energy source to AC supply when available and vice versa when not available. Pressure sensor is mounted on the compressed air tank, this sensor provides real-time data to the central control system (Arduino-microcontroller), which regulates the compressor system operations and optimizes the energy usage.

The real-time data recorded by the controller is display on an LCD screen, and also used to automate the system. This process provides a safety mechanism to prevent rupture of the storage tank due to overloading beyond its maximum working pressure (MAWP), which could result in a serious explosion, causing severe injuries to the operator. The system automation is done by setting the lowest and highest operating pressures necessary for the particular application (i.e., cut-in and cut-out pressures). The Arduino micro-controller regulates the compressed air pressure in the tank as its reaches the cut-in and cut out pressures. The air compressor system shuts down automatically when the compressed air pressure in the tank reaches the cut-out pressure. An indicator for maximum and minimum tank pressure is provided with a green and red light indicator respectively. Fig. 1 shows a block diagram of the air compressor system.

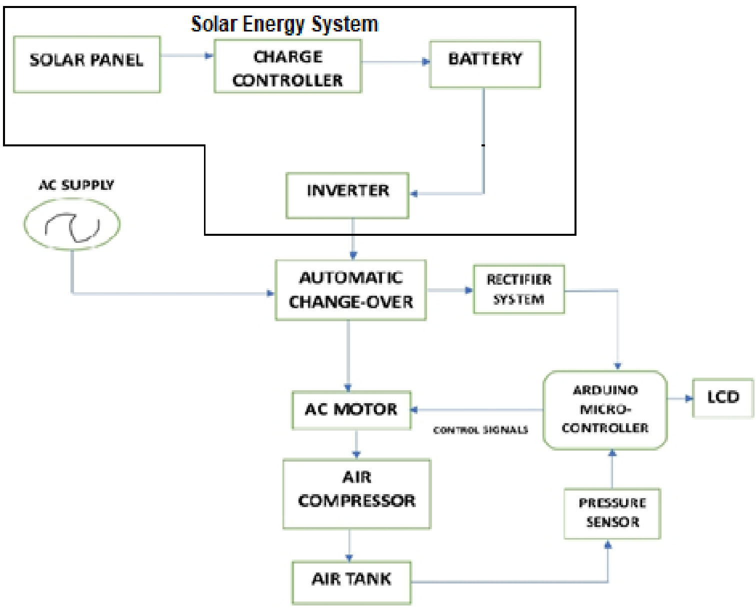

Fig. 1: Block diagram of the air compressor system

Solar Energy System: The solar energy system consists of a photo voltaic (PV) module, a Pulse Width Modulation (PWM) charge controller, a deep cycle lead-acid battery, and a pure sine wave inverter. The PV module is used to convert solar energy into electrical energy, which is used to charge the battery. The battery is used to store the energy generated by the PV module and provide power to the electric motor.

Automatic Change-over: The automatic change-over here is used to select between the solar energy and the AC supply for the proposed system power requirement. Its takes input from the two-power sources as shown in Figure 1, and does the switching automatically. The automatic change-over system is implemented using two contactors. In the design, the solar system is the main power source by default, while the grid supply is the back-up power source when the mains fail.

The Charge Controller: It is used to regulate the flow of current and voltage to the battery. This helps prevent overcharging and undercharging of the battery, which can reduce its lifespan. The charge controller is connected from solar panel to the battery, and it monitors the battery voltage and adjusts the charging current accordingly.

Battery: A deep cycle lead-acid battery is used to store energy generated by both power sources. The battery is connected together with an inverter, to supply power to the electric motor which in turns drives the compressor. The choice for this battery type is due to its relatively low cost, durability, and easy availability.

Inverter: A pure sine wave inverter is used to convert the DC voltage from the battery into AC voltage. This is necessary since the air compressor is driven by an AC motor.

Rectifier: The rectifier system transforms alternating current (220V AC) into a direct current (5V DC) to the Arduino board. To smoothen the DC output, a capacitor is attached.

Compressed Air Tank: The compressed air tank is an essential component of the system as its stores the compressed air produced by the air compressor pump [6]. It is made of steel for strength and durability and to withstand the pressure of the compressed air.

Pressure Sensor: A pressure sensor is mounted on the air tank, which measures the pressure within the tank and provides an electrical output proportional to that pressure. It's a crucial component here as it ensures the safety and efficient operation of systems. The pressure sensor allows for real-time monitoring and control.

Arduino: Arduino micro-controller is utilized to automate air compressor control by monitoring tank pressure using a pressure sensor and a transistor to control the contactor coil. Programming logic is deplored to regulate the compressor's operation based on pressure thresholds.

LCD Screen: A Liquid Crystal Display (LCD) is used to provide real-time information about the pressure readings from the sensors. Its allow for display, the pressure values and other relevant information in a user-friendly manner.

AC Electric Motor: The electric motor used here is a one (1) horse power rated motor. It provides the required drive for the compressor.

2.2 Design Modules

The design of the air compressor system consists of two design modules which are the hardware and software modules. The characterization of the modules is shown in Fig. 2.

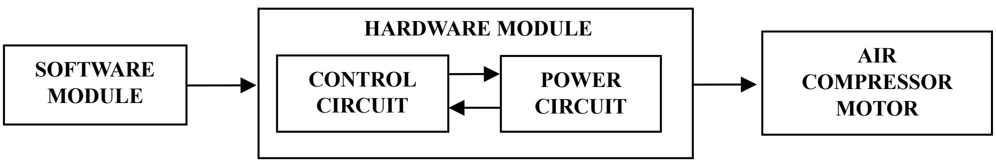

Fig. 2: Design modules of the air compressor system.

2.2.1 Hardware Module

The hardware module refers to the assemblage of the power circuit and control circuit components which synergizes together to form parts of the physical system. A description of the system's power circuit is shown in Fig. 3.

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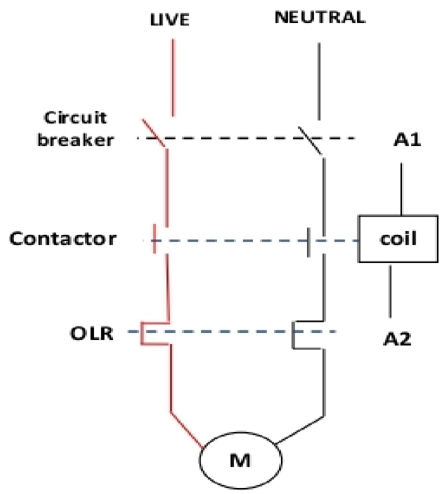

Fig. 3: Power circuit of the air compressor system.

This consist of the circuit breaker, contactor coil, thermal overload relay (OLR) and Power conductors (cables). The control circuit is the brain of the air compressor system. It performs the core function of switching the motor based on the logic from the C/C++program. It also gives visual display of the compressed air pressure in the air tank. Fig. 4 shows the control circuit of the air compressor system.

The sensor translates raw values of pressure in the air tank to electrical signals, this signals are fed to the central control system. The control system compares this pressure at any given time with the set points, which was written in the code, and sends LOW (0V) or HIGH (5V) signal to operate the relay module, which in turns operate the contactor coil to either switch the air compressor motor ON or OFF.

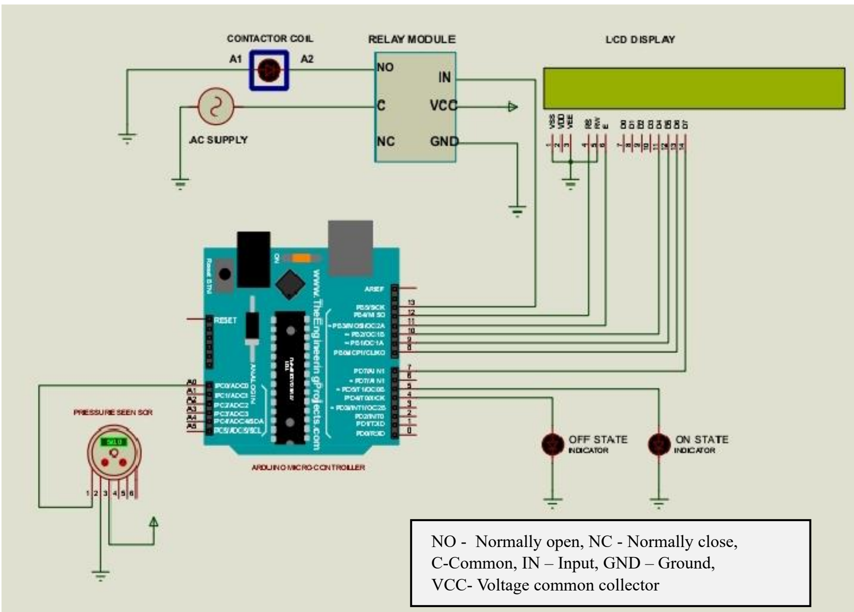

Fig. 4: Control circuit of the air compressor system

2.2.2 Software module

The software module of the system involves the use of C/C++ language to develop logical codes for the micro-controllers to control the system. This codes which are often called "sketch" were written and compiled in Arduino IDE. Fig. 5 shows the flow chart of the system's syntax operations.

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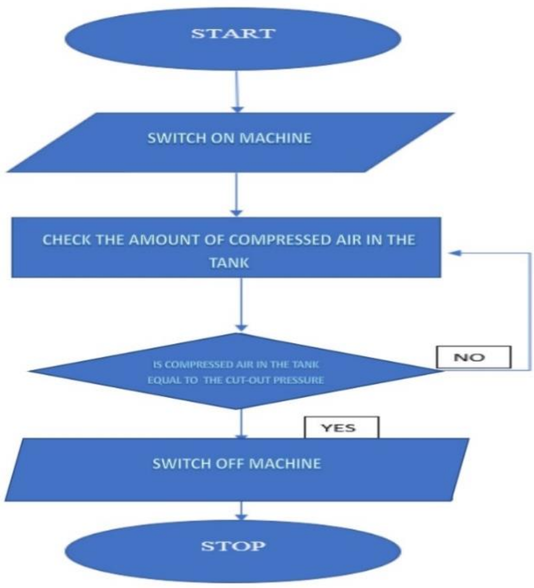

Fig. 5: Flow chart of the system's syntax operations

The codes as written in C/C++ are as follows:

```
// include the library code
#include<LiquidCrystal.h>
#include<Wire.h>

// Set the LCD pins
LiquidCrystal lcd(12, 11, 10, 9, 8, 7);

// the number of the I/0 pin as connected to the controller
constint greenPin = 5;
constint redPin = 4;
constint sensorPin = A0;
constint compressorPin = 13;

voidsetup(){
 lcd.begin(16, 2); // Initialize the LCD with 16 columns and 2 rows
 lcd.setCursor(0, 1);
 pinMode(greenPin, OUTPUT);
 pinMode(redPin, OUTPUT);
 digitalWrite(compressorPin, LOW);
 digitalWrite(greenPin, LOW);
 digitalWrite(redPin, LOW);
 lcd.clear();
}
```

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```
voidloop(){
 int sensorValue = analogRead(sensorPin);
 int pressure = map(sensorValue, 0, 976, 0, 350);
 lcd.print(pressure);
 lcd.print(" psi");

// Turn on the compressor and green indicator when the pressure reaches 150 psi
   if(pressure <= 150){
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("Air tank pressure: ");
   lcd.print(pressure);
   lcd.print(" psi");
   lcd.setCursor(0, 1);
   lcd.print("Compressor turn ON");
   digitalWrite(compressorPin, HIGH);
   digitalWrite(greenPin, HIGH);
   digitalWrite(redPin, LOW);
  }

// Turn off the compressor and green indicator when the pressure reaches 300 psi
  elseif(pressure >= 300){
   lcd.clear();
   lcd.setCursor(0, 0);
   lcd.print("Air tank pressure: ");
   lcd.print(pressure);
   lcd.print(" psi");
   lcd.setCursor(0, 1);
   lcd.print("Compressor turn OFF");
   digitalWrite(redPin, HIGH);
   digitalWrite(greenPin, LOW);
   digitalWrite(compressorPin, LOW);
  }

// Display value of pressure in psi when the pressure reaches is  between 150 and 300psi
  else{
   lcd.clear();
   lcd.setCursor(0, 0);
```

```
    lcd.print("Air tank pressure: ");
    lcd.print(pressure);
    lcd.print(" psi");
  }

// Add some delay to avoid continuous updates and flickering on the LCD
 delay(200);
}
```

2.3 Design specification

Table 1 below shows the system's design specification.

Table 1: Design Specification

S/N	Items	Capacity
1	Air compressor	339.15 W,
2	Electric Motor Power	1Hp, 1450 rpm
3	Electric Motor efficiency	0.85
4	Air tank capacity	20 litres
5	Maximum allowable tank pressure	300 psi
6	Air compressor type	Positive displacement
7	Compressor discharge capacity	0.0001640 m^3/s, 0.164 l/s
8	Cut-in pressure	100 psi
9	Cut-out pressure	300 psi
10	Solar panel number/size	5units x 200W = 1000W
11	MPPT charge controller	50 Amps, 1000W
12	Inverter capacity	1.0 kW
13	Compressor air volume per cycle	0.00000678672 m^3, 0.00678672 litres
14	Ratio of specific heat capacities of the air (n)	1.2

2.4 Design Analysis

Air compressor:

Air compressor power may be expressed as [7] and [8]:

$$P = \frac{(p \times V)}{t} \quad (1)$$

where, p – is the maximum allowable air pressure in the tank, V – volume of air delivered per revolution of the shaft and, t – is the time in seconds.

Since the selected AC electric motor that drives the compressor runs at 1450 rpm, hence the compressor power may be expressed as [12]:

$$P = \frac{(p \times V \times N)}{60} \quad (2)$$

where, N – is the motor revolution per minute.

According to [7], [9] and [10] the volumetric ratio of the compressor may be expressed as:

$$p_1 V_1^n = p_2 V_2^n \qquad \text{or}$$

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n \quad (3)$$

where, p_1 and p_2 are the atmospheric and tank pressure respectively,

V_1 and V_2 are the compressor swept volume and the air tank volume respectively, and

$n -$ ratio of specific heat capacities of air

Hence the delivery temperature T_2 of the air may be expressed as [4], [7] and [11]:

$$T_1 V_1^{n-1} = T_2 V_2^{n-1} \quad \text{or}$$

$$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{n-1} \tag{4}$$

where, T_1 - is the atmospheric air temperature

Based on the power requirement of the compressor, a one (1) horsepower electric motor with an efficiency of 0.85 was selected to drive the compressor.

Hence, actual power available to drive the compressor may be expressed as:

$$\begin{pmatrix}\text{Available power}\\ \text{from}\\ \text{electric motor}\end{pmatrix} = \begin{pmatrix} motor\\ power\end{pmatrix} \times \begin{pmatrix} motor\\ efficiency\end{pmatrix} \tag{5}$$

Hence, the factor of Safety (F.S) for the design (i.e., motor selection design) is expressed as:

$$\text{F.S} = \left(\frac{\text{Available motor power}}{\text{actual motor power used}}\right) \quad \text{or}$$

$$F.S = \left(\frac{\text{Available motor power}}{\text{air compressor power}}\right) \tag{6}$$

Air delivery time per tyre:

Since the system delivers about 0.00000678672 m^3 (i.e., 0.00678672 litres) of air per one shaft-turn or per revolution, which amounts to 0.009841 m^3 (i.e., 9.841 litres) of air in one minute. Hence, the compressor discharge rate and air delivery time of the system can be computed.

Taking the volume of an inflated car tyre at 40psi to be 20 litres, thus the volume of air to be delivered may be expressed using the equation (3):

$$\frac{p_1}{p_2} = \left(\frac{V_2}{V_1}\right)^n$$

where, p_1 is the atmospheric pressure at 1 atm which equals 14.69psi (101.32 kPa) and V_1 is the compressor swept volume at one (1) revolution.

From the computed value of V_1, the volume flow rate, Q of the compressor may be expressed as [9], [13] and [14]:

$$\text{Q} = \left(\frac{V_1 \times N}{60}\right) \tag{7}$$

where, N – is the rpm value of the selected electric motor.

Hence,

$$\text{Q} = \left(\frac{0.00000678672\text{x } 1450}{60}\right) = \quad 0.0001640\ \frac{\text{m}^3}{\text{s}},\ \text{or } 0.164 \text{ litre/s}$$

And, the time, *t* in minute required to inflate an average tyre size of 20 litres at 40 psi (275.72 kPa) is computed as:

$$t = \left(\frac{V_1}{9.841}\right) \tag{8}$$

where, *t* is in minute.

or,

$$t = \left(\frac{V_1}{0.164}\right) \tag{9}$$

where *t* is in seconds

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3. RESULTS AND DISCUSSION

The software design of the air compressor system was tested and simulated on proteus 8 professional v8.6 sp2 software. Figure 6 shows when the air tank pressure is at 300psi. At this pressure (300psi), the compressor is turned off, and is indicated on the LCD displayed screen. When the tank pressure falls to 100 psi, the contactor switches on the air compressor motor and air is filled back to the tank (see Fig. 7). This action causes the green indicator to turn on, showing that the machine is active and in operation.

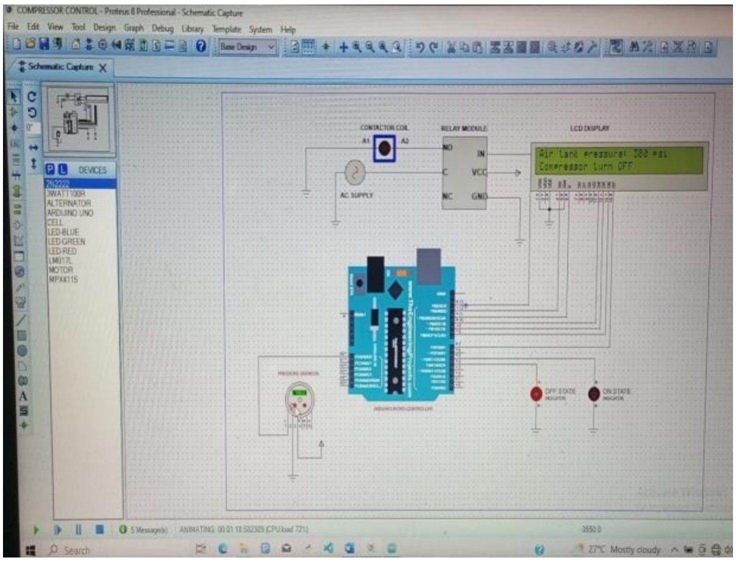

Fig. 6: A snapshot of the simulated system on proteus 8, showing air tank at 300psi.

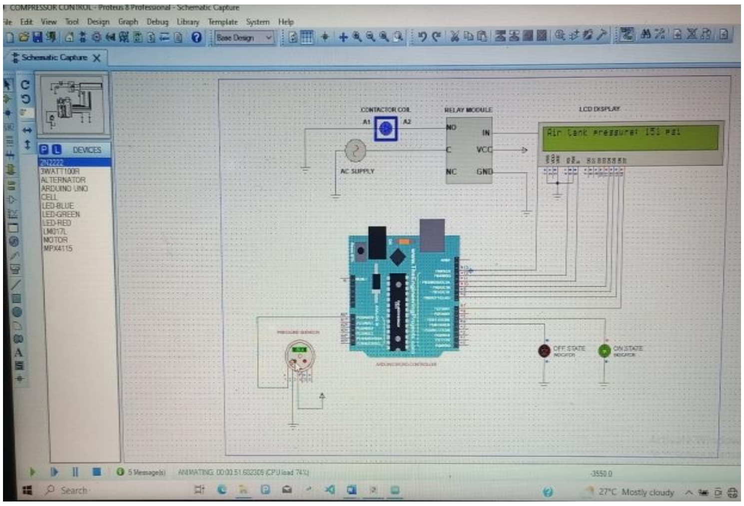

Fig. 7: A snapshot of the simulated system on proteus 8, showing air tank at 151 psi.

Table 2: Computed values of the air compressor system

S/N	Description	Values
1	Air compressor power	339.15 W
2	Volumetric ratio	0116 or 1:8.62
3	Air delivery temperature	492.6 K
4	Available power from electric motor	634.1 W
5	Motor safety factor (F.S)	1.871
6	Volume flow rate (Q)	0.164 ltr/s, 0.0001640 m^3/s
7	Delivery time	250 seconds, 4.2 mins

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Table 3: Test result of the air compressor system

	Using AC power			Using Solar power		
Experimental runs	**Tyre capacity (Litres)**	**Delivery pressure (psi)**	**Time (s)**	**Tyre Capacity (Litres)**	**Delivery pressure (psi)**	**Time (s)**
1st	20	40	252	20	40	255
2nd	20	40	249	20	40	254
3rd	20	40	250	20	40	256
4th	20	40	251	20	40	254
5th	20	40	253	20	40	257
Total	**1000**	**40**	**1255**	**1000**	**40**	**1276**
Average values			**251**			**255.2**

The air compressor system was tested with a car tyre having an average air volume capacity of 20 litres using the AC and solar power sources. The experiment was repeated five (5) times and the result as shown in Table 3 reveals that no significant difference in air delivery time was recorded when using the AC power source and the solar power source.

4. CONCLUSION

In conclusion, a dual powered air compressor system is developed. An Arduino controller is incorporated to allow for automatic operations of the system. Logic codes were written in C/C++ language for the Arduino controllers and the program was simulated using Proteus 8. The test result of the compressor system shows that the machine has a volumetric flow rate of 0.164 l/s (i.e. 0.000164 m^3/s) and can deliver 20liters of air at 40psi within 255 seconds. The result obtained was satisfactory and the machine is recommended for use by road side vulcanizers

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