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DESIGN OF A SOLAR POWERED INDUSTRIAL PRODUCT COUNTER

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Abstract

The aim of the study is to design a solar powered industrial product counter that automatically counts the number of products from a production line.
This study puts into consideration the engineering design approach which involves using required values and manufacturer data sheet. Basically, the design was done in subunit which consist of the power supply unit consisting of the batteries and the solar panel which is used to power the unit, an infrared transmitter and receiver which is senses incoming objects, a PIC microcontroller which controls the action of every part of the circuit, a solar panel which recharges the batteries when the AC supply is out, a motor and a motor driver which drives the conveyor belt to move the product along the process line.
At the end of the design, the individual components/units were coupled together, and the study design was able to count up to 100 products at a time, detect defective product by sensing their height and the whole unit worked with or without AC supply.

Keywords: Counting circuit, PIC microcontroller, seven-segment display, logic systems.

1. INTRODUCTION

The industrial product counter is a machine attached to an industrial process line utilizing a conveyor belt system. As products move along a conveyor belt, a device keep tracks of the products. For medium and large-scale industries producing components, parts and products in large discrete quantities, product counters are very essential as it enables products to be accounted for, aids product packaging and is essential to keep stock of the inventories.

Before electronics became popular, counters where made from mechanical devices [1]. These devices typically consisted of a series of disks mounted on an axle, with the digits zero through nine marked on the edge. Such counters were used as odometers for bicycles and cars and in tape recorders, fuel dispensers etc. Also, hand-held tally counters were mainly used for stock taking and for taking the number of people attending events.

With improvements in electronics components and products, majority of the counters used in the industries are now made up of electronic components, varying from asynchronous counters, synchronous counters, decade counters, ring counters, Johnson counters [2]. Each of these counters is useful for different applications.

Although the use of counters in industrial applications cannot be overemphasized, they also need to be supplied with constant power, because production in largest and medium industries where they are utilized, is a continuous process.

The research [3] designed a circuit that successfully counted objects based on infrared sensing. His circuit made use of a 230 AC supply which was converted into DC, infrared sensors to sense incoming objects, an Oscillator circuit to provide a clock pulses for the micro controller, and a micro controller that reads the sensor output and increments a variable which is displayed on the LCD display.

The research [4] designed and constructed a 4-bit counting system using a PIC microcontroller, a seven-segment LED, a printed circuit board, LEDs, Transistors, a 9 Volt DC power source, and several other passive components. The method adopted for this counter makes use of a microcontroller as the backbone of the design, which holds the command for every action that is to occur during an operation. The output of the circuit was indicated by four Light Emitting Diodes (LEDs) with counts; 0000, 0001, 0010, 0011, 0100, 1010, 0110, 0111, 1000, 1001, 1010, 1011, 1100, 1101, 1110 and 1111.

The research [5] designed an object counter circuit that could automatically count objects. His circuit made use of light dependent resistor, LDR which was the sensor, two IC 555 timers to generate clock signals for the decade counter, and a decade counter which provided a BCD output that was displayed on a 7-segment display.

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The research [2] utilized a design that made use of infrared sensors to sense objects, a micro-controller for detection, a counter circuit, and an LCD to display the number of counts.
The research [6] designed a micro controller-based circuit in which used infrared transmitters and receivers to detect and count objects. The circuit is composed of a TSOP1738 IR detecting device, which is used to count the object and display the result on a 7-segment display.
As seen in the works referenced in this section, most of the previous versions of object counters made use of microcontrollers and infrared sensors, and where powered by an AC supply source that was converted to DC.
Microcontrollers are easy to use, cheap and very fast in operation. Also, infrared sensors are better compared to light dependent resistors (LDR), because of they have greater accuracy coupled with quick response times in the range of 10-100 of milli-seconds. These advantages have informed the use of a micro-controller and an infrared sensor in the construction of the circuit under this study. The power supply for the system will be 240 AC public mains and a 10V back-up solar cell against mains power failure.
This study is relevant to the Nigerian industrial sector because of the production challenges caused mainly by the unreliable state of electric power supply in the country. The solar powered industrial product counter also finds significant applications in the fuel dispensing stations where it can be incorporated into fuel dispensers. Other industrial counters have been introduced, but none of them has incorporated a reliable renewable back-up power supply which is essential for a production line.

2. MATERIALS AND METHODS

The materials used during the construction of the circuit include a soldering iron, soldering lead, a soldering pump, side cutter, digital multi-meter, sandpaper, and electrician knife, as well as plastic Perspex for the casing.
The product counter circuit consists of a power supply (transformer, diodes, voltage regulator, capacitor, resistor, solar panel, battery storage), Infrared transmitter, Infrared receiver module, motor and motor driver, PIC16F887 microcontroller, crystal oscillator, reset circuit, liquid crystal display (LCD)
The main reason for the design of the solar powered industrial counter is to count discrete products automatically even in the absence of power from public supply mains. To make this possible, the major source of power for the entire circuit was provided by a lithium-ion battery. The control unit holds the instructions that dictate all operations of the system. The control unit is implemented with a microcontroller.

3. DESIGN

The research was designed carefully using manual and software design tools for the calculations. The practicality of all the components including integrated circuits, capacitance of the capacitors, resistance of the resistors, infrared transmitters and receivers were verified before they were used in the design.
The research was simulated using Proteus. During prototyping, the infrared receivers were replaced by switches before the actual components were soldered on a circuit board. The infrared transmitter/ receiver was placed on two different circuit boards because they are to be erected on the industrial product counter model while the rest of the circuit were soldered on a PCB which forms main panel board.
The main panel board was constructed by placing and soldering the power components first which include bridge diode, capacitors, voltage regulators which was by soldering of the IC socket for the microcontroller, soldering of the crystal oscillator soldering of all other resistors and capacitors for infrared transmitter and receiver, buttons, LEDS. The button and LEDS were soldered on different but smaller circuit board and attached onto the body of the case. Finally, the transformer, the battery and solar panel was connected to the main panel.
The model is made of wood and is constructed to be able to hold the main panel, the conveying belt, motors and the infrared receiver and transmitter. The infrared receiver and transmitter are mounted on a wooden stand and placed directly opposite each other but at a distance apart.

3.1. Power Supply

The industrial product counter works with 240 AC which is stepped down by a 240/12V transformer and a solar panel with acts as a backup supply for the circuit when the 240 AC is not available. The solar panel used is a polycrystalline panel. Its function is to help recharge the battery when its charge is low. The solar panel specification is listed below:
i Open circuit voltage, I_{sc} = 12V
ii Short circuit voltage, V_{oc} = 0.3 amps
iii Cell technology = polycrystalline
Battery need to be charge at a rate of not greater than one-fifth of the current rating which is 0.2amp per hour.

3.2. Battery Capacity Calculation

The battery used is an 8-cell lithium-ion battery with combine nominal voltage of 10.8 V 1AH. The battery is the main power source of the research and can be charged either by solar, and mains under the control of the microcontroller.

Characteristics of each cell:

$$Nom`inal\ Voltage = 2.7\ V$$

$$Rating = 0.5\ Ampere - Hours$$

The cells are arranged as two parallel sections of 4 series-connected cells:

$$Total\ voltage\ of\ the\ 4\ cells\ connected\ in\ series = (2.7 + 2.7 + 2.7 + 2.7)Volts = 10.8\ Volts$$

$$Total\ voltage\ of\ the\ parrallel\ connection\ of\ the\ two\ groups = \frac{10.8\ \times 10.8}{10.8 + 10.8} = 5.4\ Volts$$

3.3. Step Down, Rectification and Filtering

The step down, rectification and filtering circuit comprises of a transformer to step down the A.C main voltage from 220V to 12V which is further rectified by a bridge diode and filtered by a filtering capacitor microcontroller and the filtered output to switching circuit. The bridge diode is 1N4001 and the filtering capacitor is 1000uF and 50V. ***See figure 1***

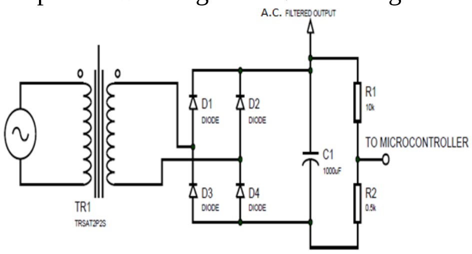

Figure 1: Step down, Rectification and Filtering Circuit

The circuit above equally contain the voltage divider for the A.C sensing of the. The voltage divider was implemented in order to reduce the filtered voltage to a level the microcontroller can measure without damaging the microcontroller pin.

3.4. Transformer Calculations

$$Tranformer\ Turns\ Ratio = \frac{Primary\ Voltage}{Secondary\ Voltage} = \frac{240\ V}{12\ V} = 20$$

$$Tranformer\ Power\ Rating = 24\ Watts$$

$$Power = Current \times Voltage$$

$$Current\ in\ Primary\ Winding = \frac{Power}{Primary\ Voltage} = \frac{24\ Watts}{240\ Volts} = 0.1\ Amperes$$

$$\frac{Primary\ Voltage}{Secondary\ Voltage} = \frac{Secondary\ Current}{Primary\ Current}$$

$$\frac{240\ V}{12\ V} = \frac{Secondary\ Current}{0.1\ Amperes}$$

$$Secondary\ Current = \frac{240\ V\ \times 0.1\ Amperes}{12\ V}$$

$$= 2\ Amperes$$

3.5. Filtering Capacitor Calculations

$$Capacitor\ Charge = C\ \times V$$

$$Capacitor\ Charge = C\ \times (I\ \times R) = I\ \times (R\ \times C) = I\ \times Time\ Constant$$

$$C \times V = I\ \times Time\ Constant$$

$$C = \frac{(I\ \times Time\ Constant)}{V}$$

Given that:

$V\ (Rated\ Output\ Voltage) = 5\ V$
$I\ (Rated\ Output\ Current) = 2\ A$
$Frequency = 50\ Hz$
$Time\ Constant = \frac{1}{2 \times \pi \times f}$

$$Time\ Constant = \frac{1}{2 \times \pi \times f} = \frac{1}{2 \times \pi \times 50}$$
$$= 3.184 \times 10^{-3}$$

$$C = \frac{2\ \times 3.184 \times 10^{-3}}{5}$$
$$= 1270 \times 10^{-6}\ Farads$$

1000µF was chosen due to its availability and the value of its closeness to 1270 µF.
Peak Voltage across capacitor = 9.744V (Bridge diode output voltage)

3.6. Voltage Regulator Calculations

$Peak\ Input\ Voltage = 9.744\ V$
$Nominal\ Voltage\ (Output\ Voltage\ for\ 7805) = 5\ V$
$Nominal\ Voltage\ (Output\ Voltage\ for\ 7812) = 12\ V$
$Maximum\ Current\ Handling\ Capacity = 1.5\ A$
$Input\ Current = 2\ A$
$Frequency = 50\ Hz$

3.7. Voltage Regulator & Switching Circuit

The voltage regulator and switching circuit comprises a set of two voltage regulators (7812 & 7805) and a switching circuit ***figure 2***. Two sets of 7805 & 7812 regulators were made use of to increase the current carrying capacity supplied to the entire circuit. The switching circuit is made up of a relay, diode, transistor, and resistor. The relay is the main switching component in the circuit and the transistor make the relay controllable under the control of the microcontroller. The diode is to prevent back e.m.f emanating from the inductive nature of the relay from affecting the transistor. The resistor R_3 is a current limiting resistor to limit the current going to the base of the transistor from the microcontroller. Below in ***figure 2*** is the circuit diagram of the voltage regulator and switching circuit.

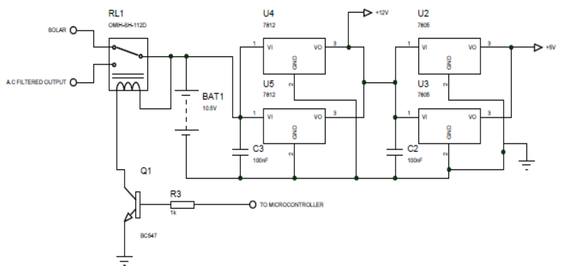

Figure 2: Voltage Regulator and Switching Circuit

3.8. Design of the IR Transmitter Circuit

Infrared (IR) transmitter are light emitters that emit infrared rays. In the circuit design, two sets of infrared emitters or transmitters are made used of, a set consists of five (5) infrared emitters connected in parallel to increase the intensity of infrared rays emitted to the receiver ***as shown in figure 3***. The IR transmitter is connected in series with a resistor directly to the power supply.

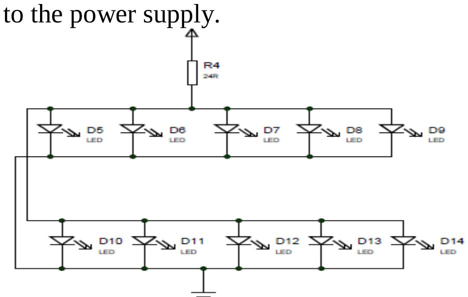

Figure 3: Infrared Transmitter Circuit

3.9. IR Transmitter Current Consumption Calculations

$$Current\ consumption\ of\ the\ one\ infrared\ emitter = 20\ mA$$

$$Total\ current\ consumption\ of\ the\ ten\ infrared\ emitters\ (I_t)\ = 200\ mA$$

$$Infrared\ emitter\ forward\ voltage\ drop\ \ = 1.5\ V$$

$$Source\ Voltage\ (V_s) = 5\ V$$

$$Series\ Resistance\ (R) = \frac{(V_s - V_d)}{(I_t)} = \frac{(5 - 1.5)}{(200 \times 10^{-3})} = 17.5\ \Omega$$

$$Series\ Resistance\ (R)\ available\ for\ use\ = 24\ \Omega$$

3.10. Design of The Infrared Receiver Circuit

Infrared receivers or detector are detectors whose internal resistance increases to about hundreds of kilo ohms when it detects light and act as an open circuit when there are no infrared rays on it. The infrared detector circuit consist of two sets of infrared receivers with each set consisting of four infrared detectors to increase the detecting sensitivity of the receiver at a particular distance. The IR receiver is connected in series with a resistor directly to the power supply and to an analog to digital pin of the microcontroller (PIC16F887). Below in ***figure 4*** is the circuit diagram for the infrared receiver.

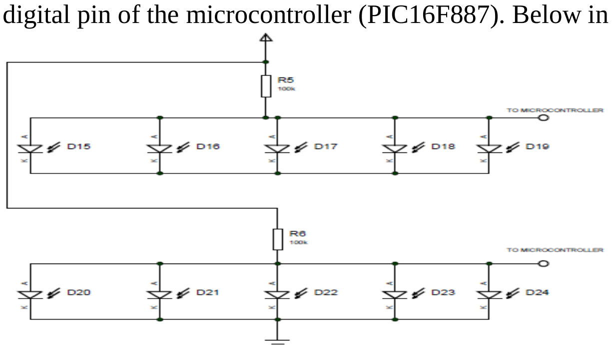

Figure 4: Infrared Receiver

3.11. IR Receiver Series Resistor Calculations

IR resistance when IR is detected = 100K Ohms to 500K Ohms (from datasheet)
IR resistance when IR is not detected = 10M Ohms (from datasheet)
To get a voltage of 3.0 to 4.5 V across the IR detector,
R_3 = R_4 = 100K Ohms (chosen due to availability)

3.12. Control Unit

The control unit comprises the microcontroller (PIC16F887), crystal and the master clear reset circuit which in turn consist of a resistor and a capacitor. The microcontroller is the main control unit which detect voltage drop across the infrared receiver through its internal analog to digital circuitry and in turn control the display of the liquid crystal display. The microcontroller also controls the motion of the two electric motors and respond to the inputs of the buttons. The indicator light emitting diode are also under the control of the microcontroller. The crystal oscillator controls the timing of the microcontroller which means the time at which the microcontroller executes one instruction. The microcontroller frequency is one-fourth of the crystal oscillator frequency. The master clear reset circuit prevents the microcontroller from resetting by connecting the master clear pin to power through a resistor and a capacitor to ground. Below in ***figure 5*** is the circuit diagram of the control unit. C5 and C6 are meant for stabilization of the crystal oscillator.

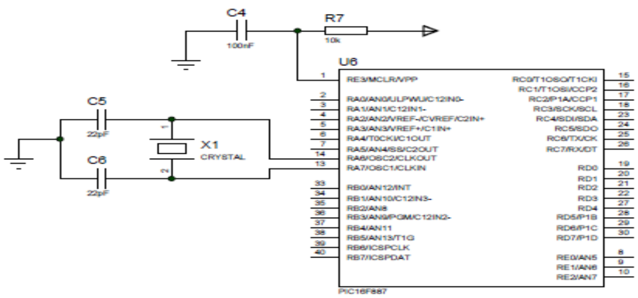

Figure 5: Control Unit

R7 = 10K (Recommended in PIC microcontroller datasheet)
C4 = 100nF (Recommended in PIC microcontroller datasheet)
C5 = C6 = 22pF (Recommended in PIC microcontroller datasheet)

3.13 Button Circuit

The button circuit is a pull-up button circuit which means the buttons are connected to power directly and connected to ground though a 10K resistor. On pressing any of the buttons, the corresponding pin are momentarily connected to power which is sensed by the microcontroller and an action will be carried based on the button pressed and according to the program running in the microcontroller. Below in ***figure 6*** is the button circuit.

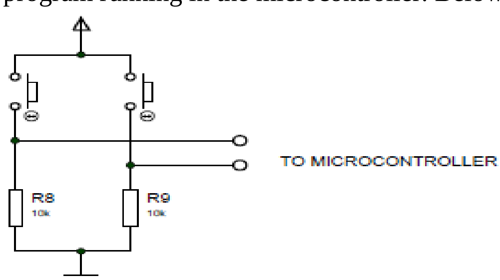

Figure 6: Button Circuit

3.14. Display Circuit

The display circuit consist of the liquid crystal display (LCD) circuit and the indicator circuits which comprises two light emitting diodes each with a series resistor. Below in ***figure 7*** is the display circuit and the potentiometer (RV1) connected to the LCD is meant to control the contrast of the LCD.

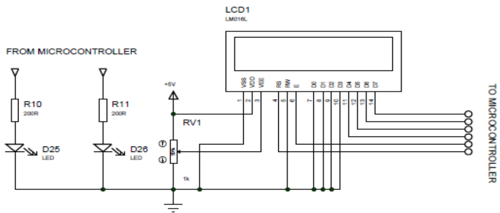

Figure 7: Display Circuit

3.15. LED Series Resistance Calculation

Voltage drop of LED (V_d) = 1.8V
Output of Microcontroller (V_s) = 5V
Forward current of the LED = 20 mA

$$LED\ series\ resistance = \frac{(V_s - V_d) \times 1000}{20} = 160\ \Omega$$

R_{10} = R_{11} = 200 Ω

3.16. Motor and Motor Driver

The motor and motor driver circuit consist of two motors which a corresponding driver circuit. The driver circuit of a MOSFET driver (IR2112) and four MOSFET switches. The MOSFET driver circuit is connected as recommended in the datasheet. The MOSFET driver is needed for the microcontroller to be able to control the MOSFET efficiently such as provision of higher current to drive the MOSFETs and also to enable the microcontroller to be able to drive the high side of the MOSFET. The MOSFETs were connected in H-bridge configuration with one MOSFET driver driving two MOSFETs. Below in ***figure 8*** is the motor and motor driver circuit.

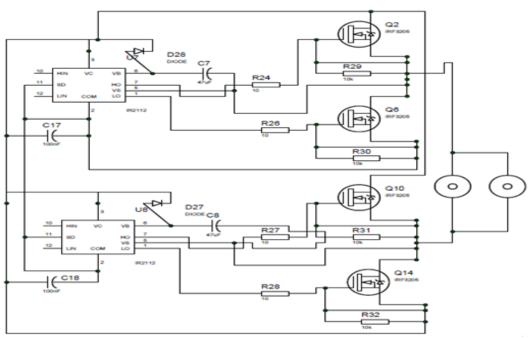

Figure 8: Motor and Motor Driver Circuit

Resistor R_{24}, R_{26}, R_{27} and R_{28} acts as current limiting resistors.
Resistors R_{32}, R_{31},R_{30} and R_{29} are gate-source resistor in order to reduce the switching off time of the MOSFET.
Capacitors C_{17} and C_{18} acts as decoupling capacitors to prevent voltage spike from destroying the MOSFET driver.
Diodes D_{27} and D_{28} coupled with Capacitors C_8 and C_7 form a bootstrap configuration which enable the MOSFET driver to be able to turn on the high-side MOSFET. The connection is recommended in the datasheet of the microcontroller.

4. RESULTS AND DISCUSSIONS

The results of this research are grouped according to the objectives for which the solar powered industrial was to meet which are stated below.

- Counting products on AC supply
- Counting products on DC supply (solar powered)
- Differentiating a quality product from a production lot

4.1. Counting Products on AC Supply

The research was successfully able to count product automatically up to a 100 specimen tested with the system with AC supply. ***See figure 9.***

4.2. Counting Products on Dc Supply (Solar Powered)
In the absence of power from the supply mains, the product counter was still able to count the products automatically relying solely on power from the solar panel connected through the batteries. ***See figure 9***

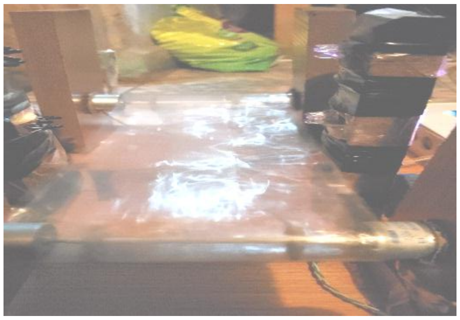

Figure 9: Picture showing the research working on AC/DC supply

4.3. Differentiating a Quality Product from a Production Lot
This using two (2) product specimens, specimen A with 10cm height and specimen B with 5cm height the solar powered industrial product counter based on the height was able to the detect and count specimen A as product and recorded it as a quality product. While specimen B was detected as a product but not as a quality product. ***See figure 10a and 10b, respectively.***

(a) (b)

Figure 10: Picture showing the research working with specimen A and B respectively

4.4. Mode of Operation of the Counter
Figure 11 is a complete diagram of the entire circuit, showing how each unit are connected. The voltage and current requirement for the MOSFET driver is 12v and 2A while the rest of the circuit is 5v 2A respectively. The main power supply unit start with a step-down 240/12 transformer which step down 240 volts AC to 12 volts AC. The 12 volts AC is then rectified by a bridge diode rectifier circuit, the output of the bridge diode is then filter using one 1000micro-farad capacitor. The Output of the rectified is fed to a voltage regulator LM7805 to get a steady 5V DC output to feed most part of the circuit. The output of the filtered 12V DC is also fed directly to the MOSFET driver to power it.
The back-up power supply of the for the system consists of eight of lithium-ion batteries connected to get an output voltage of about 10.8 volts (each cell is 2.7 volts nominal voltage) and a small 12 volts solar-panel connected to charge the battery when no mains is available.
The motor and motor driver circuit consists of two MOSFET drivers, four N-channel MOSFETs. The MOSFET driver acts as an intermediary between the MOSFET and the microcontroller. It enables the microcontroller to be able to turn on and off the MOSFETs. The MOSFETs acts as a channel to connecting the motor power wires to power and ground as also controlling the speed of the motor.

The control unit controls the action of every parts of the circuit. It comprises of the micro controller and a crystal oscillator. The micro controller operates at one fourth of the crystal oscillator frequency. The 22pF capacitor is used to make the crystal oscillator stable, the 0.1micro farad is used to eliminate voltage spikes and 10K ohms is to reduce the amount of current going to the master clear pin 1.
The infrared circuit is connected to power through a series resistor of 24 ohms and the cathode connected to ground, the 24ohms is used to limit the current entering the circuit.
For the receiver circuit, the micro controller detect two different states when the receiver circuit is blocked and when the receiver is not blocked, for that we use a voltage divider rule because the IR receiver act as resistor with two different range of values or between 10mega ohms when blocked and (100-500)K ohms when not blocked. The micro controller detect the two different voltage levels of greater than 4.5V when its blocked and less than 4.5V when it's not blocked, The micro controller increments the display when the sensor is blocked.

4.5. Applications of the Circuit

This research work would be of great use and importance to security personnel in major establishments in Nigeria as it will provide accurate data of the number of people present. It will save enormous amount of time and energy in taking statistics of number present at that point in time and it would also take care of the problem of epileptic power supply because of the integration of the solar panel.

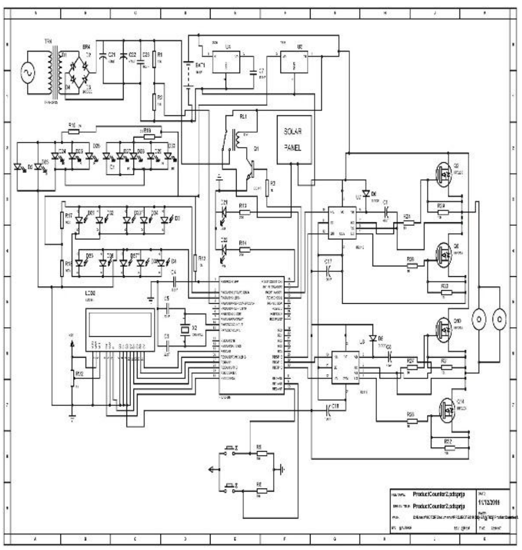

Figure 11: Complete Circuit Diagram

5. CONCLUSION

The need for automation and control in modern day industries cannot be overemphasized. This research gives an insightful picture of this implementation in industries where counting of products is carried out automatically and data logs which help in inventory and accurate stock keeping are taken.
This was successfully able to count product up to 100 products using the height of the product as a criterion for determining a detective product. Another breakthrough was that the research still worked using only power from the solar panel.
The principles of have been highlighted and discussed. The circuit worked satisfactorily as shown pictorially in the indexes although with some limitations and observations.

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