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Design and Construction of a Two Input Power Sources with Three Output Terminals Power Bank

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--***ABSTRACT***--
Recent years have seen a mass manufacturing and production of portable electronic devices and gadgets, such as smart phones, digital notebooks, digital cameras, portable players like DVD player, PDA and MP3 player, Global Positioning System devices, health care devices, and so on. All these products have become necessities to people and required to be powered at all times. But the greatest challenge is the epileptic power supply experienced in this country. In this work, we have designed and constructed a power bank that has two input power sources, a backup battery with three outputs terminals. The two input sources are solar panel (Solar energy) and electrical energy from the Power Holding Company of Nigeria National (PHCN). The three output terminals have current ratings of 0.5 A, 1.0 A and 1.5 A at constant output DC voltage of 5 Volts. Tests and measurements carried out show that the power bank is most effective and efficient when alternating current is used as its input source at the 1.5 A output termina. This power bank is environmental friendly, portable and can be used in cities, towns and even villages.
***KEY WORDS**: Power bank; Solar panel; Alternating current; Backup Battery; Output terminals*

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I. INTRODUCTION

In the present world, portability has become a very important factor; the world constantly looking for new and innovative ways to add comfort to our lives. One of the most frustrating things that can happen anywhere is to discover that one's mobile phone or any digital device has ran out of power at the moment you need it most. Power bank is a portable charging device that a charges some specific electronics devices which are charged through the USB at all times. A Power bank supplies electrical power to electronic gadgets and at the same time stores electrical energy in a battery which is used as a back-up when there is power failure from any of the conventional sources.

The concept of power bank is becoming very popular as it has become the need and also its demand is increasing because of fast growth of digital products. Portable Chargers are convenient because of their size that makes them convenient to carry about. Since the global economy is growing very rapidly, people continued to carry more and more portable electronic products, such as mobile phones, camcorders, laptops, digital cameras, tablets, portable players likeb MP3 player, PDAs, Global Positioning System devices, DVD player, MP4 player, thermal equipment, healthcare equipment, and so on.

People have become so much addicted to the technology that they can hardly live without it. Similarly, digital devices don't have much power that enable them survive for the whole day when used continuously. The solution to this emerging challenge is through continuous research and new technologies such as power bank. Power bank must have protective measures for short circuit, battery overcharge and over discharge, thermal shutdown and other power supply problems. This should be achieved through high-performance power management technology.

Solar panels are simply solar cells lined up together in series and parallel so as get sufficient voltage and are p-n junction semiconductor devices with pure silicon wafer doped with n - type phosphorous on the top, with a p - type boron on the base. If the PV cell is placed in the sun, photons of light strike the electrons in the p-n junction and energize them, knocking them free of their atoms. These electrons are attracted to the positive charge in the n-type silicon and repelled by the negative charge in the p-type silicon. Connecting wires across the junction will generate a current. Solar panels have applications in solar energy harvesting devices to convert incident light into electricity [1].

Energy consumption has always a noticeable impact on the environment. Fast growing world population, increasing prosperity and the hunger for fuel that has developed a consequence, have led to a rapid rise in the need for energy, so to fulfill that need we require renewable resources. Solar energy is a very vital source of renewable energy because it is readily available all year round. This means that if solar energy is adequately utilized, there will be enough energy for every consumer in the nearest future. Solar energy can be stored in solar energy storage system and be used at any time in the day. However, there are some regions of the globe which have limited supply of solar irradiance. In this case, new solar technologies are emerging to ensure adequate usage of limited solar irradiance [2].

Solar energy storage systems have been improved via recent technologies that allow excess solar energy to be collected and saved for longer period. Recently, there are a great number of growing facilities or equipment which uses Seasonal Thermal Energy Storage (STES). STES enables solar energy to be stored in summer for space heating during winter in parts of the polar regions of the world. In rural communities of developing countries, there are fewer energy options (*e.g.* hydro-power, nuclear power, thermal power, *etc.*) to meet its domestic energy requirement. Moreover, energy generation in developing countries is plagued with various fundamental challenges. For example, Nigeria Electricity consumption per capital within 2010 and 2014 is 149 KWh, this is insufficient, and hence makes energy crisis in Nigeria lingered for four decades [2].

The major liability or drawbacks of electronic lines comes because of the distortion of electrical lines or lack of generation of electricity in remote areas, during disaster or natural calamities. These setbacks can be controlled using solar panels and power banks. The solar panels utilize the sun while the power banks store sufficient energy that could be used during electrical energy power failure. The solar panels convert solar energy to electrical energy in charging handsets and other communication gadgets, which are useful during disasters and power outage [3].

In this work, we have designed and Constructed a two input power Sources, backup battery with three output terminals power bank for charging rechargeable electronic gadgets**.** The two input sources are form solar energy generated from the sun, an electrical energy generated from the National grid (PHCN). The anticipated three output current have ratings of 0.5 A (0.49 A Measured), 1.0 A (0.92 A measured) and 1.5A (1.44 A measured) at input DC voltage of 5 Volts.

1.2 Block diagram of the Power Bank

This section presents the various units of the block diagram of the power bank. It consists of three units, and are presented as follows

- The Power Supply Unit: The power supply unit has a two - way automatic power supply systems. It gets inputs from both the ac mains and the solar panel. They are capable of feeding the three outputs directly, and, equally charging the backup battery.
- Charge Control Unit. It consist of three parts; the relay switch, the charge controller for back-up battery and a potential divider.
- Output Unit: The output consists of a boost DC- DC converter that boosts the output voltage received from either the two input power sources or the backup battery before feeding the three outputs.

The Block diagram of the power bank is shown in Fig 1.

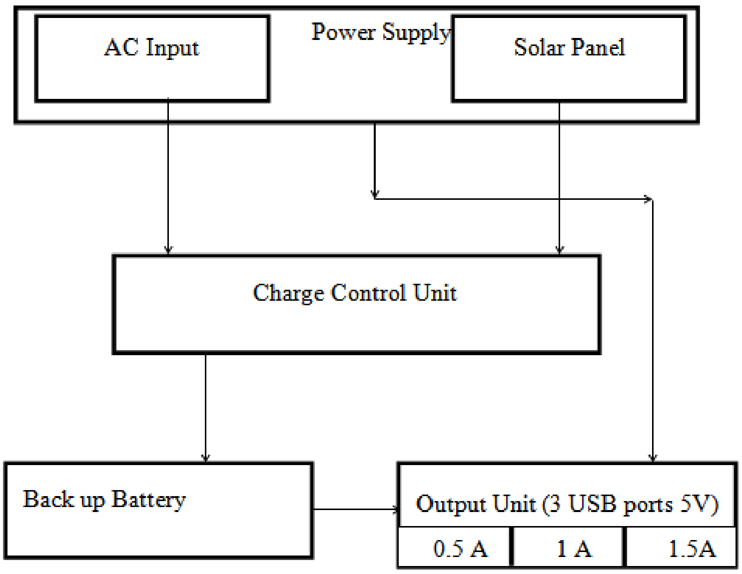

Figure 1: Block diagram of the Power bank

1.3 Circuit Description of the Block Diagram of the Power Bank

The circuit description of the block diagram presents the theories and the relevant equations used in the design process.

1.3.1 The Power Supply Unit

The two independent input power supply systems were connected to the selection device which acts as an automatic change over switch, switching on any of the available input supply to charge the control unit; and also direct to the USBs ports. A 220/12 V transformer was chosen because its rating is capable of meeting the current demand of the circuit, and is protected by a 2 A fuse against excess current. Four diodes were used in the power supply unit to provide a full wave rectification.

- **The A.C mains**

It has a limiting resistor, four zener diodes; LM7812 V voltage regulator and a capacitor. The value of the limiting resistor (R_1), Peak inverse voltage (PIV) and the filter capacitor were calculated using the following equations [4]

- The Limiting Resistor R_1

$$R_1 = \frac{\text{Voltage drop}}{\text{LED current}} \tag{1}$$

$$R_1 = \frac{V_{CC} - V_{LED}}{I_{LED}} \tag{2}$$

where V_{CC} is the supply voltage to the diode (= 6 V), V_{LED} is the voltage across the light emitting diode (LED) (= 2.0 V), I_{LED} is the maximum allowable current across the LED (= 10 mA). The value of R_1 obtained was 400 Ω. However, a preferred value of 500 Ω was used.

- The Peak Inverse Voltage

The peak inverse voltage (PIV) obtainable at the secondary terminal transformer is twice the terminal voltage V_s (=12 V), and can be obtained from equation (3) below

$$\text{PIV} = 2 \times V_S = 24 \text{ V} \tag{3}$$

- The Filter capacitor

The value of the filter capacitors was obtained using equation (4) below

$$C_1 = \frac{1}{2\sqrt{3}\,\omega R_1 y}$$

(4)

For full wave rectifier circuits, ω = 628.32 rad/s; y is the ripple factor = 5% = 0.05. With a constant output voltage of 12 V, V_{LED} voltage of 2 V, and LED current of 10 mA, the following values were obtained; R_1 = 285.71 Ω (a preferred value of 300 Ω was used); PIV = 24 V and C_1 = 20 µF. However, a preferred value of 50 µF capacitor was used.

- The LM137 H Voltage regulator

The LM137 H voltage regulator can provide an output voltage of 12 V to both the rectifier and the backup battery, and, a charging current of 1.5 A to both the backup battery and the output of the device.

- **The Solar Panel**

A solar panel of 12 V; 20 W to provide a short circuit current of 1.67 A was used in this research work. The circuit diagram of the power supply unit that in - cooperates both the a.c source and the solar panel is shown in Fig 2.

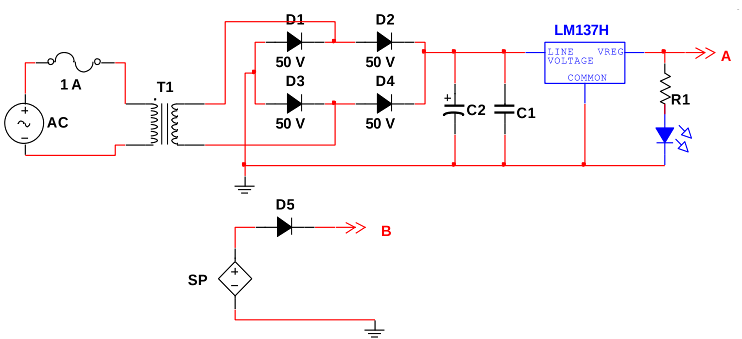

Figure 2: The Circuit of the Power Supply Unit

1.4 Charge Control Unit

The charge control unit contains a relay that switches automatically between the two input sources to charge the backup battery which functions as an input source to the three outputs in the absence of both the a.c and the solar energy. The circuit diagram of the charge control unit is shown in Fig. 3.

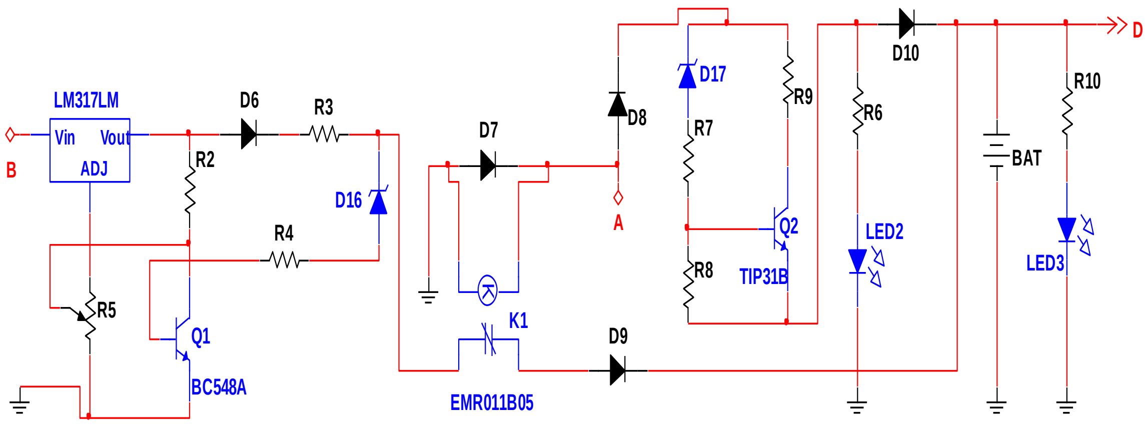

Figure 3: The Circuit of the Charge Control Unit

The Charge Control Unit Consists of three parts

1.4.1 The Relay Switch

Relays are switches that open and close circuits electromechanically or electronically. Relays control one electrical circuit by opening and closing contacts in the other circuit. The relay in the charge control unit is connected across the rectifier output voltage V_{RV} (≈ 12V). The current passing through the relay is given as

$$I_R = \frac{V_{RV}}{R_{relay}} \qquad (6)$$

where R_{relay} is the resistance of the relay.

1.4.2 Charge Controller for Back-Up Battery

A charge controller limits the rate at which electric current is added to or drawn from electric batteries. It also prevents overcharging and can protect the battery against overvoltage. It consists of three resistors, a zener diode and a transistor. The voltage across the diode is given as

$$V_z = V_{ch} - V_{bat}$$

(7)

where V_{ch} (= V_s) is the voltage of the charge controller, and V_{bat} is the potential difference across the standby battery (= 6.0 V). One obtains V_z = 6.0 V.

1.4.3 The Potential Divider –Bias Resistors R_7 & R_8

A potential divider an arrangement of resistors used to obtain a fraction of the potential difference provided by a voltage supply [5]. The internal resistance of the back-up battery (R_{bat}) was assumed to be negligible, while the zener resistance is assumed to be zero (when it is fully conducting). The biasing resistors R_7 and R_8 could be determined from equation (8) below

$$R_7 + R_8 = \frac{V_z}{I_z} - R_{bat} \qquad (8)$$

Using I_z as 30 mA and R_{bat} = 8 Ω, in equation (8) and the value of V_z, one gets $R_7 + R_8$ = 192 Ω. Typical values of R_7 should be around five times R_8, using the rule of thumb. This gives the values of R_8 = 32.00 Ω and R_7 = 160.00 Ω. A preferred value of 30 Ω and 200 Ω were used respectively. Assuming the backup battery may run down to 4.5 V at a charging current of 0.65 A, and R_{bat} = 8 Ω, then the required limiting resistor R_9 was obtained using equation (9) below

$$R_9 + R_{bat} = \frac{V_{CC} - V_{Bat}}{I_{Ch}} \qquad (9)$$

Using the values of the parameters above in equation (9), R_9 = 2.76 V. A preferred value of 3 Ω was used in this work.

1.4.4 The Output Unit

The output consists of a boost DC- DC converter that boosts the output voltage received from either the two sources or the back – up battery before feeding the three adjustable voltage regulators LM317. The regulators adjust the voltages to 5 V each, and supply a current limited at that voltage corresponding to a specified DC current outputs of 0.5 A, 1.0 A and 1.5 A . The second relay in the output units makes an automatic selection between the input sources (AC main and Solar panel) and the back-up battery.

The following information was retrieved from [6].

- **Inductor Selection:** Inductor values were selected based on the recommendations that values for general application circuits are between 1.5 µH to 4.7 µH.
- **Capacitor Selection**: the output capacitor is required to maintain the DC voltage. Hence, equivalent series resistance (ERS) capacitors are required to reduce the output voltage ripple. To this end ceramic capacitors of X5R and X7R were used in this work
- **LM317 voltage regulator** was used to provide an output voltage of 5 V to each of the three outputs.
- **Resistances of the three output terminals**:

(i)For the first output of expected current I_1 = 0.5 A, R_{24} was chosen as 10 Ω

(ii)For the second output of expected current I_2 =1.0 A, R_{25} was chosen as 5 Ω

(i)For the third output of expected current I_3 = 1.5 A, R_{24} was chosen as 3.5 Ω

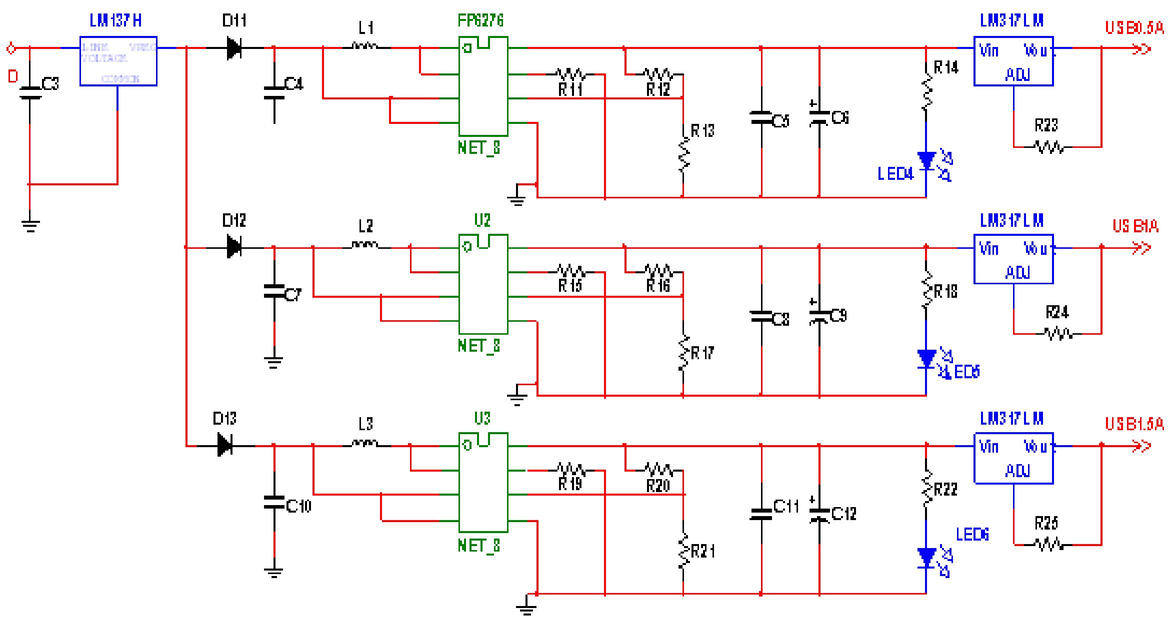

Figure 4. Circuit Diagram of the Output Unit

1.5 Figures of Merit of the Power bank

Two figures of merit were calculated for this power bank, to ascertain its effectiveness relative to other conventional power banks, and, to determine its efficiency when using the two independent sources of inputs.

(i)The Effectiveness of the Power bank: The effectiveness of the constructed power bank was compared with a conventional (i.e. readymade) power bank based on the time to charge a mobile phone to reach 100 %. This is calculated using equation (10) below

$$Effectiveness = \frac{Time\ taken\ to\ charge\ a\ mobile\ phone\ by\ conventinal\ power\ bank\ to\ 100\%}{Time\ taken\ to\ charge\ a\ mobile\ phone\ by\ our\ power\ bank\ to\ 100\%} \times 100\% \quad (10)$$

(ii)The Efficiency of the Power bank, η: The efficiencies of the power bank were calculated using equation (11) with respect to solar panel as the input source, and equation (12) with a.c as the input source, defined as [7]

$$\eta_{Solar} = \frac{V_{mpp} \times I_{mpp}}{P_{in(Solar)}} \times 100\% \quad (11)$$

where V_{mpp} is the voltage measure at maximum power point, I_{mpp} is the current measured at the maximum power point, and P_{in} is the input power of the solar panel used.

$$\eta_{a.c} = \frac{V_{mpp} \times I_{mpp}}{P_{in(a.c)}} \times 100\%$$

(12)

where $P_{in(a.c)} = I_s V_s$. I_s is the current measured from the transformer output of the secondary terminal, while V_s is the voltage measured from the transformer output of the secondary terminal.

1.6 Materials and Methods

This section consists of two parts, the materials/equipments and the method used in the construction work.

1.6.1 Materials and Equipments

- The equipments used in this work are the usual equipments used in electronic construction such as multimeter; Breadboard; Masking tape; Soldering iron; Lead; Screw drivers; and Pliers.
- The materials used are; A step-down transformer (230 V/12V); solar panel;: relays; diodes; resistors; IC adjustable voltage regulators; transistors; USB ports; capacitors; LED; zener diode; boost DC - DC converter (FP6276), Lithium iron backup battery, and adjustable voltage regulator (LM317).

1.6.2 Methodology

The methodology consists of the complete circuit diagram and the construction. The design was based on the fact that the power bank could be used for charging DC rechargeable electronic gadgets with three independent outputs currents of 0.5, 1.0 A and 1.5 A at 5 Volts. The choice of output currents and the voltage were done based on the following information given in Table 1. The complete circuit diagram of the power bank is shown in Fig 5.

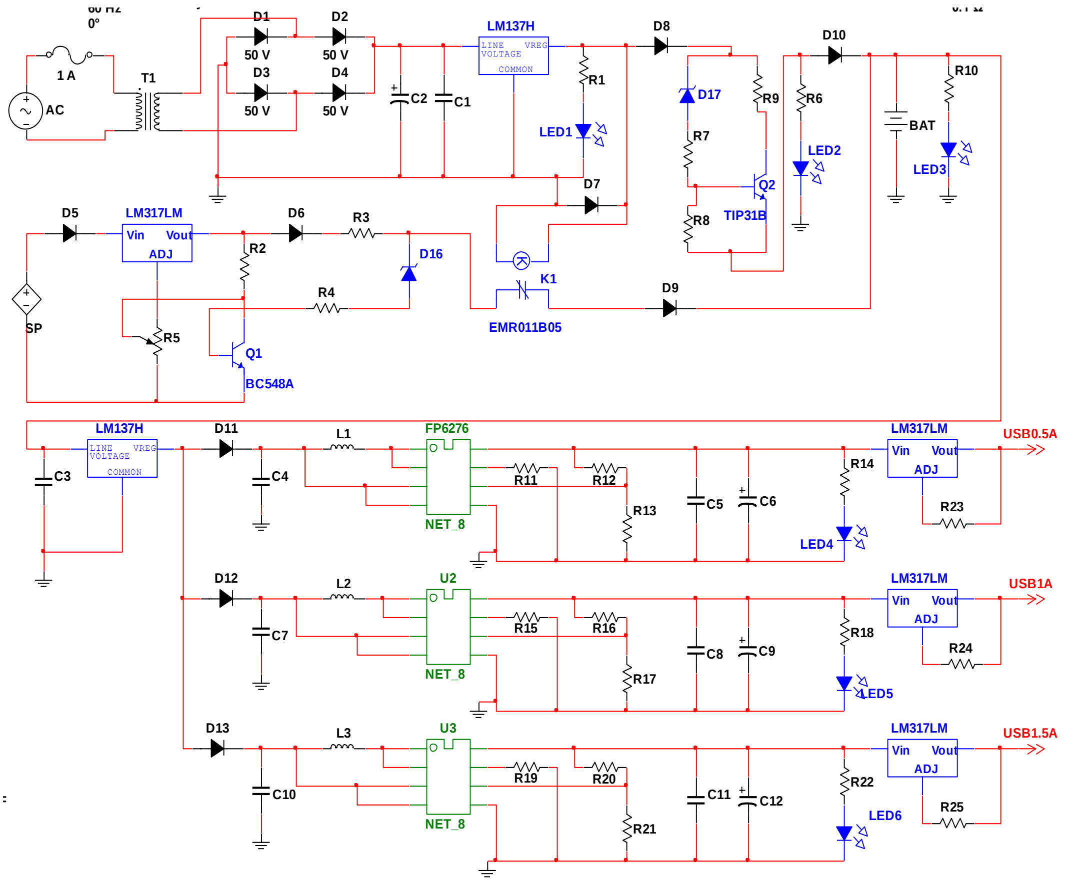

Fig. 5: Complete Circuit Diagram of the Power bank

1.7 Construction, Tests and Measurements

This section of the work consists of construction, testing and the required measurements

1.7.1 Construction

Construction means assembling of circuit components to produce one physical unit. All the circuit components were arranged on a Vero board and soldered using a 60 watt soldering iron. Care was taken when soldering to avoid overheating and subsequent damage. All components were properly polarized and protruding terminals were cut off to prevent bridging of the components. All wire tips and components laid were cleaned and trimmed before and after soldering.

1.7.2. Tests

With the completion of the design and construction of the power bank, the system was tested using multi-meter to see if the actual performance conforms to the design specification. The results of the tests conducted include:

(i) Power Supply Test: After soldering and mounting of components needed to build the power supply units, the following tests were carried out to ascertain that it conforms to the design. The results obtained from the power supply test are presented in Table 1.

(ii)Charge Control Unit Test: The results obtained from the charge control unit test are presented in Table 2.

(iii)Output Unit Tests: The results obtained from the output unit test are shown in Table 3.

1.7.3 Measurements

The parameters measured include; Voltage at maximum power point V_{mpp} and Current at maximum power point I_{mpp} via the backup battery from any of the two input sources; Current from the transformer output of the secondary terminal I_s; Voltage from the transformer output of the secondary terminal V_s; Time taken to charge ItelP12 mobile phone from USB ports 3 and 2, and then, TECNO T40 mobile phone from USB port1 using the conventional power bank, and time taken to measure the same mobile phones using the constructed power bank. The time required to charge Itel P12 using USB port1 was very slow, that was what prompted the use of TECNO T40 at USB port of output current of 0.5 A.

1.8 Results and Discussion

1.8.1 Results

The results obtained from the tests and the measurements are presented as follows:

Table 1: Test from Power Supply Units

S/N	Stages	Voltage (V)
1	a.c input to transformer	220.00 AC
2	Secondary terminal of transformer	24.00 AC
3	Output of bridge rectifier	24.00 DC
4	Output of smoothing capacitor	12.00 DC
5	Output of regulator (LM7812)	12.00 DC
6	Output of the solar panel	10.45 DC

Table 2: Result Tests from Charge Control Unit

S/N	Stages	Theoretical Values	Measured Values
1	Charging current from Solar panel	1.500 A	1.25 A
2	Charging current from AC mains, I_S	1.500 A	1.35 A
3	Maximum Output voltage from solar panel charge control circuit	10.450 V	9.00 V
4	Maximum Output voltage from AC charge control circuit; Vs	12.000 V	10.35 V

Table 3. Efficiency of the Constructed Power Bank

S/N	Designation	Expected Values		Measured Values		Efficiency η_{Solar} (%)	Efficiency $\eta_{a.c}$ (%)
		Voltage (V)	Current (A)	Voltage; V_{mpp} (V)	Current; I_{mpp} (A)		
1	USB port3	5.00	1.50	4.95	1.44	35.64	51.02
2	USB port2	5.00	1.00	4.77	0.92	21.94	31.41
3	USB port1	5.00	0.50	4.69	0.49	11.50	16.45

Table 4: Effectiveness of the Constructed Power Bank

S/NO	Type of Phone	Output ports	Time Taken for our Device to charge a	Time Taken for our Device to charge a phone to 100 % via	Time Taken for Conventional power bank to	Effectiveness relative to a.c Source	Effectiveness relative to Solar

			phone to 100 % via a.c Source (Hrs)	Solar Panel (Hrs)	charge a phone to 100 (Hrs)	(%)	Panel (%)
1	Itel P12	USB port3	1:32	2.05	1.10	83.30	53.66
2	Itel P12	USB port2	3:12	5.21	2.48	79.50	47.60
3	TECNO T410	USB port1	1:24	2.01	1.05	84.70	51.72

1.8.2 Discussion

From Table 1; the measurements carried out provided the required DC voltages that are needed from the two input power sources. The value of the a.c after rectification was 12 V from a.c mains of 220 V, while a voltage value of 10.45 V was obtained from the solar panel from its specification of 12 V; 20 W.

In Table 2, the measured values of the current and the voltage from the charge control unit via the secondary terminal of the transformer were I_S = 1.35 A and V_S = 10.35 V respectively. The product of these two parameters gave the input power of the a.c source that has been rectified. Tables 3 and 4 show the efficiency and the effectiveness of the power bank respectively. From Tables 3 and 4, tests and measurements on USB ports 3 and 2 of the output terminals of 1.5 A (1.44 A measured) and 1.00 A (0.92 A measured) respectively were carried out using Itel P12 mobile phone, while test and measurement on the third USB pot 1 (0.5 A) was conducted using TECNO T410 mobile phone. We discovered that the charging time for Itel P12 was time consuming, and hence, that output terminal was not suitable to charge high version rechargeable gadgets to 100 % capacity. This results show that higher voltage and current values provide short charging period. Result from Table 3 shows that the efficiency of the power bank is maximum at the 1.5 A (1.44 A) output terminal, and the value is higher when the input source is switched to a.c mains. The same outcome is seen in Table 4, when calculating and comparing the effectiveness of the power bank. This could be as a result of the conversion process that first takes place in solar energy conversion to electrical energy.

One interesting result is the efficiency of the solar panel; the values are within the range of values of the efficiency of solar panel in an independent research conducted by [6].

1.9 Conclusion

We have designed and constructed a power bank with two input sources, a backup battery and three output terminals. Results show that the power bank is effective when compared with the conventional power bank. It is equally more effective and efficient at the 1.5 A output terminal with a.c as the input source. One can conclude that higher voltage and current values provide short charging period. This power bank can be used in cities, towns and villages where power supply is epileptic.

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Plate I: Picture of the constructed Power bank

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