Design & Implementation of Power Bank using Supercapacitor

Bommegowda K. B, Durga Prasad

***Abstract:** Portable power banks are comprised of battery in a case with a circuit to control power flow. Power banks are becoming increasingly popular because the battery life of phones, tablets and portable media players is ex ceeded by the number of time gadgets used in aday. In this paper, the design and implementation of power bank using supercapacitors as a charge storage device is presented. Existing power banks use batteries to store charges and it takes a long time to charge completely. In this work, batteries are replaced with supercapacitors to take advantage of its quick charging and slow discharging feature. Supercapacitors are charged using charging and regulation circuit. An output regulator circuit delivers the necessary power for charging portable devices. A display is also implemented using a PIC microcontroller for monitoring.*

***Keywords**: Supercapacitor, Input regulator, Output regulator, Charging circuit.*

I. INTRODUCTION

Batteries and capacitors do a similar job, storing electricity but in completely different ways. Batteries use chemicals to store energy whereas capacitors use static electricity (electrostatics) rather than chemicals to store energy. The supercapacitor differs in two important ways from an ordinary condenser: its plates have a much larger area and the distance between them is much smaller because the separator between them works differently than a conventional dielectric [1]. Supercapacitors store more energy than ordinary condensers by creating a very thin "double layer" of charge between two plates made of porous materials typically carbon-based, soaked in an electrolyte [2]. A supercapacitor's large benefit is that it can store and discharge energy much faster than a battery almost immediately. This is because a supercapacitor operates by setting up static electric charges on solids, while a battery depends on rapidly producing batteries through chemical reactions that often involve liquids. Batteries have a higher energy density but supercapacitors have a higher power density [3]. That makes supercapacitors particularly suitable for storing and releasing a large amount of power relatively quickly. Although supercapacitors work at relatively low voltages (2 to 3 Volts), they can be connected in series to produce high voltage for the use in more powerful equipment [4]. Since supercapacitors operate electrostatically rather than through reversible chemical reactions, they can be loaded and fired multiple occasions theoretically. They have little or no inner strength, which implies that they store and discharge electricity without a lot of electricity and operate very near to 100% effectiveness [5].

II. SYSTEM OVERVIEW

The block diagram of the complete system is shown in Fig 1. The charging circuit consisting of a step-down transformer and full bridge rectifier is connected to the 230V, 50 Hz main supply. It is then connected to the input regulation circuit which charges the capacitor bank and then it is given to the output regulation circuit which gives 5V, 1A output. A display unit is used to monitor the charging percentage.

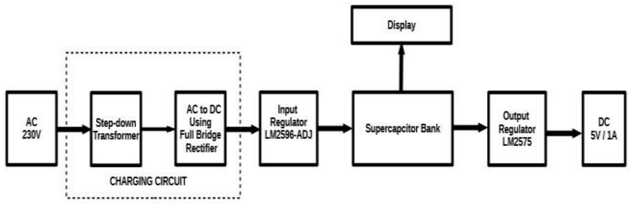

Fig. 1. Block diagram of the system

The Alternating Current (AC) is merely electrical charge mo tion through a medium that periodically shifts direction.
Here the input to the power-bank is taken from the 230V AC supply. This is converted to necessary voltage using the charging circuit.

The charging circuit consists of a step-down transformer and full bridge rectifier as shown in Fig. 2. Here the supply voltage is stepped down to 12V, 3A AC and using a bridge rectifier AC is converted to DC to store the electrical energy. Using the LM2596 voltage regulator IC, the supercapacitor bank is charged at a constant current of about 3A.The input regulator circuit is shown in Fig. 3.
The output voltage of the circuit of the input regulator is des cribed by equation 1.

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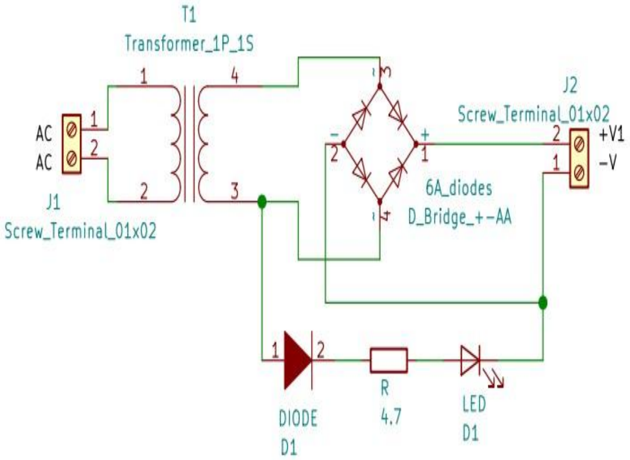

Fig. 2. Charging circuit

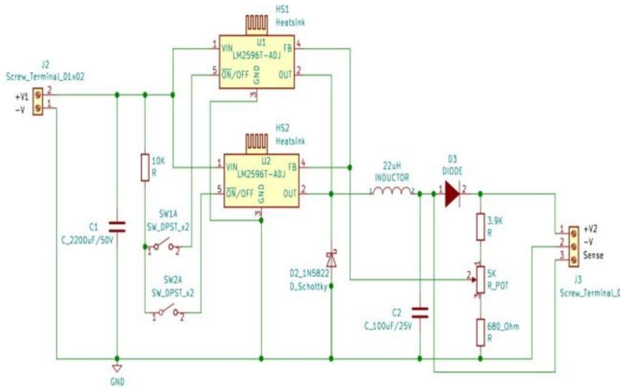

Fig. 3. Input regulator circuit

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) \quad (1)$$

V_{ref} = 3V, V_{out} = 6.8V, R_1 - 3.9kΩ, R_2 - 5kΩ pot, R_3 - 680Ω C_{in} - 2200μF/50V, C_{out} - 100μF/25V, D_1 - 5A/40V Schottky Rectifier, L_1 - 22μH

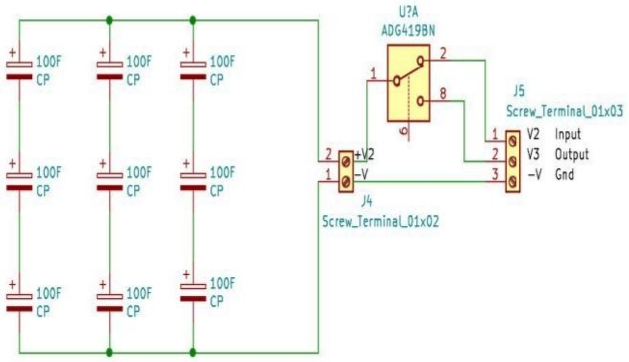

Fig. 4. Supercapacitor bank

The supercapacitor is used for storing electrical charge and its power bank is shown in Fig 4. They are arranged in a 3x3 bank configuration to increase overall bank voltage and capacitance. Three supercapacitors are connected in series and three sets of these are connected in parallel. Effective capacitance in series and parallel combination are

C_{series} = 33.33F and

$C_{parallel}$ = 300F

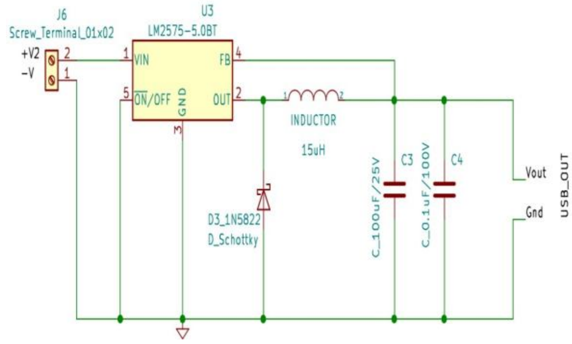

Fig. 5. Output regulator circuit

Using the LM2596 regulator IC, the output from the supercapacitor bank is converted to 5V, 1A DC which is necessary to charge a cell phone. The output regulator circuit is shown in Fig 5. The designed values are as follows:

D2 - 5A/40V Schottky Rectifier

C1 – 100μF/25V

C2 – 0.1μF/100V

L1 – 15μH

III. SYSTEM HARDWARE

(a) LM2596 Regulator

The LM2596 series of controllers are monolithic integrated circuits that provide all the active features for a step down (b uck) switching controller that can drive a 3A load with outst anding line and load regulation.

(b) LM2575 Regulator

The LM2575 device significantly simplifies the design of sw itching power supplies by offering conveniently all the activ e features required in an integrated circuit for a step down (b uck) switching regulator.

(c) *Supercapacitor*

A supercapacitor (also called an ultra-capacitor) is a high capacity capacitor with capacitance values much greater than other condensers (but reduced voltage constraints) that bridges the divide between electrolyte condensers and rechargeable battery. They typically supply 10 to 100 times more energy per cell quantity or mass than electrolytic condensers, can accommodate and produce charging much quicker than batteries, and endure much more periods of charging and release than rechargeable batteries.

Supercapacitors are an important component of this work. They are used to store charges which happen to be the main function of a power bank. In this work supercapacitor of capacitance 100F and voltage rating of 2.7V are used. They are arranged in a 3x3 bank configuration for higher voltage and power rating. Here 3 supercapacitors are in series and 3 sets of these are in parallel forming a 3x3 bank and net output voltage of this bank is 8.1V.

IV. SYSTEM SOFTWARE

(a) PIC Microcontroller

The Peripheral Interface Controller (PIC) microcontroller is the family of specialized microcontroller chips produced by Microchip Technology. It is an 8-bit microcontroller based on CMOS FLASH that combines the strong PIC architecture of Microchip into a bundle of 28 pins.

The PIC16F882 has 128 bytes of EEPROM information storage and much more.

(b) Display Unit

A display unit consisting of PIC microcontroller and 16x2 LCD is designed to display charge status of the power bank. This unit displays the charging percentage while connected to the external power supply and displays charge stored in the supercapacitor bank when external supply is disconnected.

(c) Mikro C PRO

The PIC mikro C PRO is a fully functional ANSI C compiler for Microchip PIC applications. It is one of the compilers commonly used to develop PIC computers software. It functions easy IDE, sophisticated optimization strong compiler, loads of hardware and software libraries, and extra instruments.

(d) PICkit-3

PICkit is a group of Microchip Technology programmers for PIC microcontrollers. They are used for microcontrollers programming and debugging as well as the EEPROM program. It has a quicker PIC24F 16-bit processor and a wider variety of voltage regulations. It has an internal switch-mode voltage regulator. This enables them to produce voltages of 2.5 to 5.5 volts at around 100mA from a 5V USB load.

V. HARDWARE IMPLEMENTATION

Using the LM2596 voltage regulator IC the supercapacitor bank is charged at a constant current of about 3A. The input regulator circuit is shown in Fig. 6.

Fig. 6. Input circuit

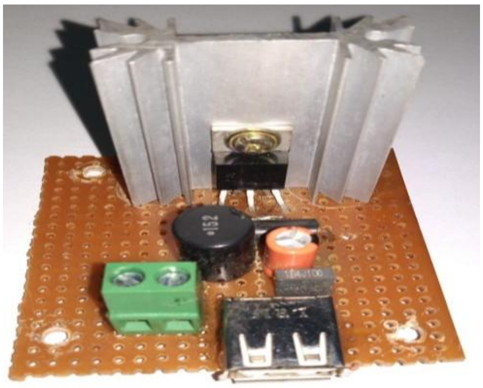

Fig. 7. Output circuit

Using LM2596 IC the output from the supercapacitor bank is converted to 5V, 1A DC which is necessary to charge a cell phone. The output regulator circuit is shown in Fig. 7.

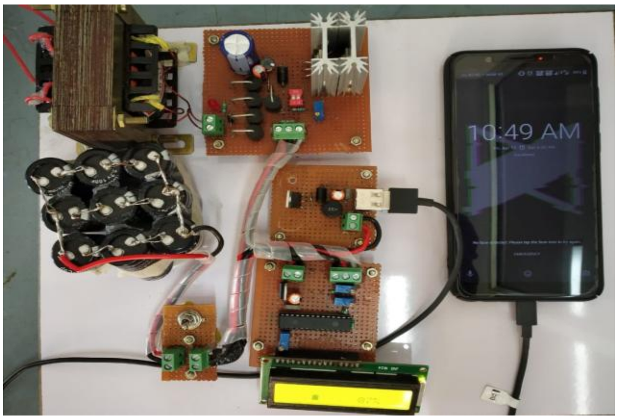

Fig. 8. Assembled regulator circuits with supercapacitor

Fig. 8 shows the complete prototype of the system. Circuit boards are built by assembling components on general-purpose PCB.

VI. RESULTS AND DISCUSSIONS

Software or hardware system testing is performed on a full embedded device to assess the adherence of the scheme with its given specifications. It is done in two steps, first is unit testing and second is integration testing. Several test cases were conducted to note down the performance of the devices. The results of the test cases for different devices are mentioned in this section.

The expected and tested results of the charging circuit, input regulator circuit, supercapacitor bank, and output regulator circuit are tabulated in Table I. The input regulator module waveform is shown in Fig. 9. Theoretically, it is designed to give 6.8V DC at the output but practically it is found to be 7.2V DC. The output regulator module waveform is shown in Fig. 10. Output regulator can deliver 5V DC according to the datasheet but practically it is found to be around 5.6V DC.

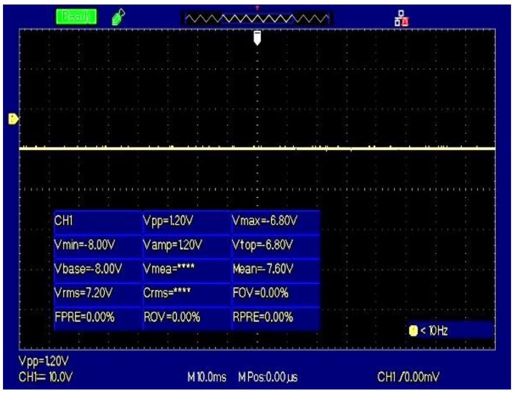

Fig. 9. Input module

Table-I: Testing parameters of the regulator and charging circuits

Sl. No.	Test	Parameter	Expected Result	Tested Result
1	For charging circuit	Output voltage	12V AC	13.2V AC
2	For input regulator circuit		6.8V DC	7.2V DC
3	supercapacitor bank	Charging time	1-2 min	1 min 40sec
		Output voltage	8.1V DC	8V DC
4	Output regulator circuit	Output voltage	5V DC	5.6V DC

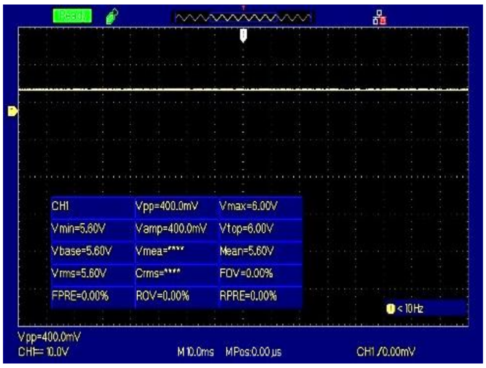

Fig. 10. Output module

The supercapacitor bank output waveform is shown in Fig. 11. The voltage across the supercapacitor bank is calculated to be 8.1V DC and practically it can be charged up to 8V DC by the input regulator circuit.

The transformer output waveform is shown in Fig. 12. Using 0-12V, 3A step down transformer, 230V AC is step down to 12V AC on the entry hand. While 12V AC is expected, 13.2V AC is found at the transformer output. Table II gives a comparative analysis of supercapacitor, electrolytic capacitor, and battery in terms of charging and discharging time, energy and power density and life cycle.

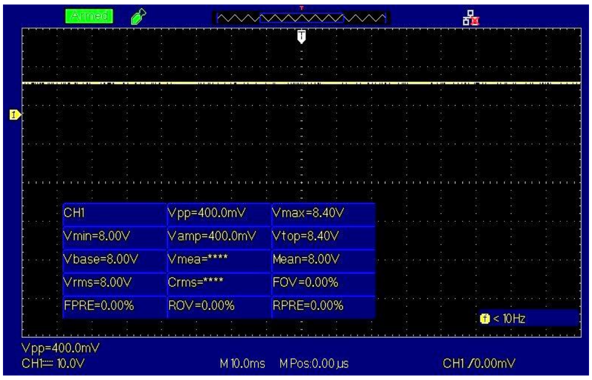

Fig. 11. Supercapacitor bank output

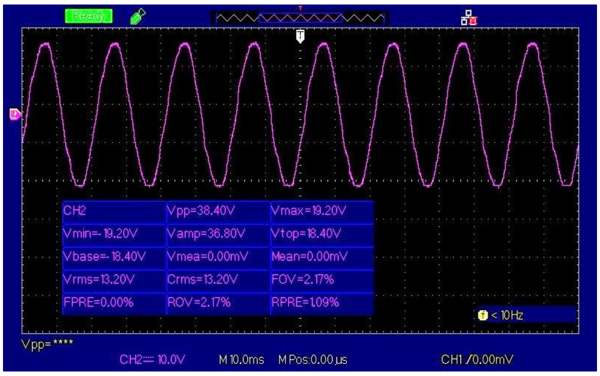

Fig. 12. Transformer output

Table-II: Comparative analysis of storage devices

Storage device characteristics	Super capacitor	Capacitor	Battery
Charging time	1-30 sec	$10^{-2} < t < 10^{-6}$ sec	1< t <5 h
Discharging time	1-30 sec	$10^{-2} < t < 10^{-6}$ sec	t > 0.3 h
Energy density (W h/kg)	1-10 sec	< 0.1 sec	10-100
Lifetime (cycle number)	10^6	10^6	1000
Power density (W/kg)	10,000	>1000000	< 1000
Charge/discharge efficiency	0.85-0.98	> 0.95	0.7-0.85

VII. CONCLUSION

A reliable and portable power bank which can be charged quickly is designed and implemented in this work. From this work, it is evident that the supercapacitor has higher energy density compared to the electrolytic capacitor and also its charge/discharge efficiency is higher compared to the battery and electrolytic capacitor. The supercapacitor has a long life cycle compared to batteries. The drawbacks of the supercapacitors are their linear voltage and current drop. With the development in the field of construction of supercapacitors, we may have compact supercapacitors with high energy density.

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