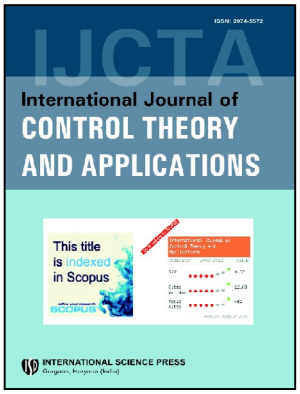

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DC-DC Converter Design with Automated Supercapacitor Backup System

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Abstract: Many industrial applications employ supercapacitor module for back power storage. Interleaved Dc-Dc converter systems are employed for high current drawing industrial applications. In this work a buck converter system is used to supply and industrial system carrying current in the range of 2A to 3A. The buck converter system is designed to yield a constant output voltage of 5V for any fluctuation in input voltage. In order to yield a constant output voltage a control loop has been designed that varies the duty ratio for the buck circuit proportionately with changes or fluctuations in input voltage. In the event the input voltage drops below the require output voltage, the input voltage supply is cut off and a fully charge supercapacitor module gets connected to the industrial application via a boost converter system to provide backup power till the main input power source is fully operational or the voltage of the main input power source becomes higher than the required voltage. For the boost converter system to supply a constant output irrespective of the decaying voltage across the supercapacitor module a PWM control loop is designed to vary the duty ratio proportionately with decay in input voltage. The supercapacitor module has a voltage of 2.85V and a high capacitance is achieved by parallel combination of supercapacitors to form a module. Each unit of this supercapacitor module has a specification of 2.85V and 3400F. The alternate switching of input voltage source supplying the desired load and supercapacitor module supplying the desired load is achieved by using CMOS logic gate circuits. The CMOS inverters are fabricated to our requirement as a result of which different threshold voltages are set for different inverters that decides their on and off state. The system design has been shown for a frequency of 1MHz and a output current draw of 2.5A.

Keywords: Supercapacitor, Buck, Boost, Switching, CMOS.

I. INTRODUCTION

Supercapacitors are energy storing devices [1] with high energy density. A number of circuits have been devised for efficient charging of supercapacitors [2]. Supercapacitors are environment friendly as well as have a greater life cycle compared to batteries. Apart from this supercapacitors are capable of pumping high current at low voltages due to which it is being used in a wide range of industrial applications. Dc-Dc converters also have a wide range of industrial applications owing to the property that it can be used to supply a constant voltage at a constant current and also to step up to step down dc voltages to the desired level. Supercapacitors have high power density due to which supercapacitors can be used to pump high power that too at lower voltages. The only problem with supercapacitors is that supercapacitors with high capacitance have low working voltage as a result of which boost converters need to be used in cascade with supercapacitors in order to power industrial applications. Now a days batteries and supercapacitors are used as hybrid system for industrial applications like in hybrid vehicle [4].

In this work a dc-dc buck converter system is being used to supply an industrial automotive application. So the output has current draw of 2A to 3A at 5V. A control loop [3] has been designed for this buck converter that varies the duty ratio proportionately with changes in input voltage in order to yield a constant output. If the input voltage falls below the desired output voltage, the input voltage is cut off and the output load gets supplied by a supercapacitor module via a boost converter circuit. This boost converter circuit also has a control loop that yields a constant voltage irrespective of the decaying voltage across the supercapacitor module. The supercapacitor module is created by parallel combination of supercapacitors of 2.85V and 3400F in order to store higher energy.

II. CONCEPT OF WORK

In this paper the designing of a closed loop dc-dc converter system [5] having feed-forward [6] path has been discussed. The feed forward path varies the peak of triangular wave [7] or saw-tooth wave [8] with the fluctuation in input voltage. As a result of which the duty ratio of the switching pulse adjusts accordingly in order to yield a constant or regulated output. The dc-dc converter system comprises of a primary power source powered buck converter system supplying constant power to an application at a constant voltage, and a secondary or back -up boost converter system powered by supercapacitor module for proving back up power to the application in case of failure of primary power source. A logic circuit has been designed to switch the power source from primary buck system to the supercapacitor module powered boost converter system in case of primary system failure. Many control strategies for buck converter has been reviewed [9, 10, 11] for varying the duty ratio proportionately with the fluctuations in input and output. The PWM control loop needs a saw-tooth wave generator [6] which will vary the peak of triangular wave with fluctuations in input and a way to increase the reference voltage for PWM with increase in load current beyond the desired limit. The generation of triangular or saw-tooth wave could be rather cumbersome for a wide range of input voltage fluctuations. These repeating periodic triangular wave could generated using ICs but not for a wide range of voltage or voltages exceeding 5V. Another control strategy involves comparing the inductor current of the dc-dc converter [12] with a constant current at some point say at the output or through the output filter capacitor [13]. In CCM [14, 15] the inductor current waveform is triangular in nature whose peak and slope would vary with changes in input voltage. But this system is not feasible for a wide range of voltage fluctuations and due to issues like converter operating in DCM [16].

III. PROPOSED SYSTEM CIRCUIT DIAGRAM

In fig.1 a dc-dc converter system has been shown that is designed to supply load drawing a current of 2.5A at 5V. This is the specification of industrial automotive load. The circuit system shown in fig.1 comprises of three parts. The part of the circuit bordered by green is the main muck converter system supplying the load. The part of the circuit bordered by blue is the supercapacitor powered boost converter system providing back up power to the load in case of failure of the main buck converter system. And the part of the circuit bordered by red is the sequential switching circuit responsible for cutting off the main power source and the buck converter system in case of failure and simultaneously connecting the supercapacitor module powered boost converter system with the load so that the load can function without interruption. The part of the circuit bordered by red is a digital circuit and is responsible for sequential switching. ‘N1’ and ‘N2’ are NOT gates, ‘AN1’ and ‘AN2’ are AND gates and OR is an OR gate. In this circuit 'N1' has been designed to handle a maximum voltage of 2.85V gate while 'N2' is designed to handle a maximum voltage of 5.7. These NOT gates operate in off condition if input is below half of their maximum operating voltage and has been shown in table I. In fig.1 'V_i' is the input voltage of the main power source 'S1', 'M1', 'M2', 'S3', 'M3', 'M4', 'S6' and 'S9' are MOSFETS, out of which 'M1', 'M2', 'M3' and 'M4'are controlled by the sequential circuit bordered by red for switching between the main power source and back-up power source with the load. S2, S4, S7 and S8 are schottky diodes. Schottky are preferred to general purpose diodes due to lower voltage drop and fast recovery. 'L' and 'C' are the inductance and capacitance of the buck converter and 'R_L' and 'R_C' are their equivalent series resistances. 'L1' and 'C1' are the inductance and capacitance of the boost converter and 'R_{L1}' and 'R_{C1}' are their equivalent series resistances. All the 'R' are resistances of same value, 'R_T' and 'R_{T1}' are also resistances of same value. The 'Z' 'Z1' and 'Z3' in figure.1 represent zener diodes that are used for voltage regulation. Their main purpose is to rid the circuit of any unwanted overshoot in the output voltage. 'V_{CS}' denotes the voltage of the supercapacitor module. 'V_o' denotes the output voltage of the entire circuit system while 'I_o' is the current drawn by industrial application. The value of 'V_t' is chosen to be twice the output voltage 'V_o'. 'A1', 'A2', 'A3' and 'A4' in the circuit are op-amps out of which 'A1' and 'A4' in the circuit behaving as comparator.

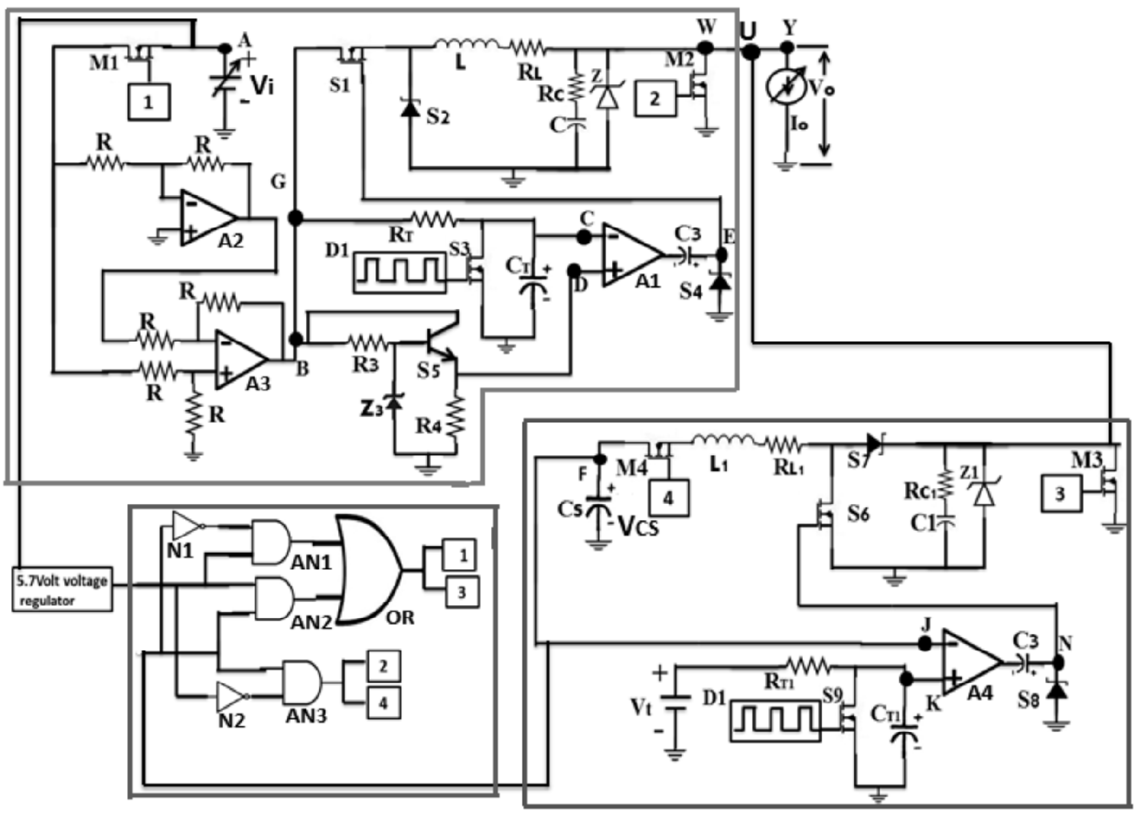


Figure 1: Buck converter system with automated supercapacitor backup system

Table I

NOT Gate	*ON condition*	*OFF condition*
N1	Input voltage>=2.85	Input voltage<2.85
N2	**Input voltage>=1.43**	**Input voltage<1.43**

Till the input voltage 'V_i' remains above the output voltage any change in 'V_i' will lead to change in the peak of saw-tooth wave at point 'C' which in turn will adjust the duty ratio proportionately thereby keeping the output voltage constant. Similarly, when 'V_i' falls below 'V_o', 'V_{CS}' acts as the power source for the load, the duty ratio of boost converter changes accordingly to keep the output constant. The circuit operation has been shown in table II.

Table II

Condition	*M1*	*M2*	*M3*	*M4*	*Input*
$V_i >= V_o$	ON	OFF	ON	OFF	V_i
$V_i < V_o$	**OFF**	**ON**	**OFF**	**ON**	**V_{sc}**

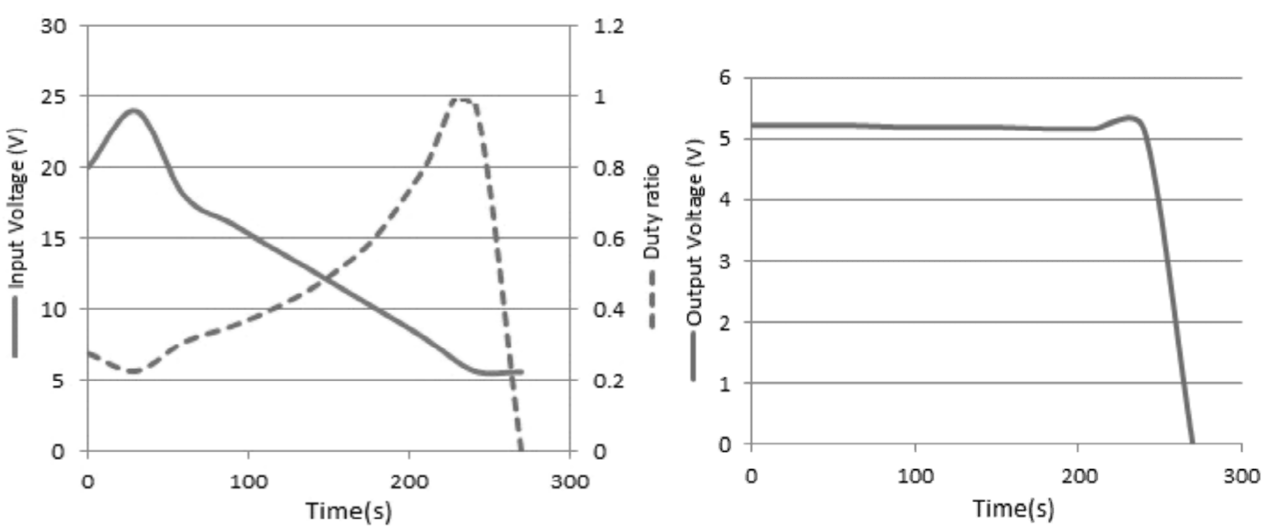
IV. SIMULATION RESULT

Table III

COMPONENT	*COMPONENT NO / SPEC*
MOSFETS 'S1', 'M4'	Si2308BDS
MOSFETS 'M1', 'M2', 'S3', 'M3', 'S6', 'S9'	**2N7000**
Op-amps A1, A4	LT1360
A2	LM358P
A3	OPA37
S5	BC547
S2, S4,S7,S8	1N5819
Z, Z1, Z3	**IN4732A**

The components used for simulation are listed in table III. All the results are shown for a output current draw of 2.5A, although the design can sustain up to a current draw of 7A.

4.1. Simulation results for 270 seconds

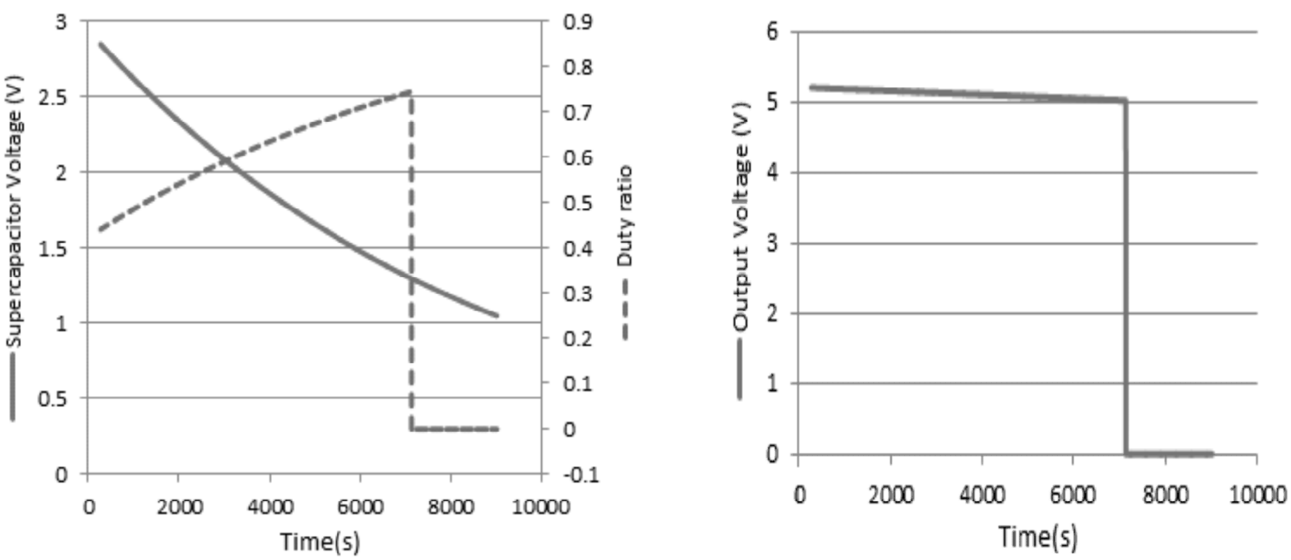


(a) (b)

Figure 2. (a) Buck converter input voltage source till 270 seconds (b) output voltage source till 270 seconds

In fig. 2(a) the blue curve represents the piecewise linear voltage or fluctuating input voltage obtained at node ‘A’ of fig.1 and the red dashed curve is the duty ratio that changing proportionately with changing input voltage in order to yield a constant output voltage which is shown in fig.2(b). The duty ratio curve of fig.2(a) is obtained at node ‘E’ and the output voltage waveform shown in fig.2(b) is obtained at node ‘Y’ of fig.1. The waveforms shown in fig.2(a) and (b) are for the first 270s till Vi>=Vo.

4.2. Simulation results 270 seconds onwards



(c) (d)

Figure 3: (a) input voltage across supercapacitor 270s onwards b) output voltage source 270 onwards

In fig. 3(a) the blue curve represents the piecewise linear voltage or fluctuating input voltage obtained at node ‘F’ of fig.1 and the red dashed curve is the duty ratio that is changing proportionately with the changing input voltage in order to yield a constant output voltage and this output voltage has been shown in fig.3(b). The duty ratio curve of fig.3(a) is obtained at node ‘N’ and the output voltage waveform shown in fig.3(b) is obtained at node ‘Y’ of fig.1. The waveforms shown in fig.3 (a) and (b) are the waveforms obtained 270s onwards i.e. when Vi<Vo.

V. CONCLUSION

An innovative method is developed, which consists of an Analog Buck Circuit and a Digital circuit. The objective of the digital circuit is to make sure that whenever the input voltage drops below a certain voltage then the bank of supercapacitors or supercapacitor module kicks in to maintain the constant output voltage, which in our design is about 5V with an output current draw of 2.5A. This is evident from simulation results or waveforms shown in fig. 2(b) and fig. 3(b). This module can supply from 12.5 Watt to 35 Watt power for the load maintain the constant voltage at the output. This circuit is unique because it can handle high output current (2 to 5 Amp) at constant output voltage, which is 5V. The digital design was an innovative in our case to switch the input power supply from wall power or any power module like battery to the charged supercapacitor bank. This part is mostly done using logic gates, comparators and reference signals, which are normally difficult is practical applications when all the voltages are fluctuation. We have also tested the circuit through simulation and found that switching occurs when the voltage drops below 5 Volts.

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