Design of Electronic Actuation Control Unit with Ultra Capacitors as the Embedded Energy Back up for Mechatronic Applications

Ramya K R* and Madhu B M**
*PG Student, SIT, Tumakuru
ramyapanish@gmail.com
**Assistant Professor, SIT, Tumakuru
madhukumar.b.m@gmail.com

Abstract: This Paper presents as electronic actuation control unit which will provide an embedded energy of about 450J by connecting four EDLC (Electric Double Layer Capacitor) of 3V and capacitance is of high value 25 F in case of emergency conditions such as during accidents if the main battery fails or if any problems occur in the wiring parasitic of vehicle connectivity network. Ultra capacitor based energy system used in the electric vehicle propulsion and it provides high energy density for the electronic actuation control unit in case of emergency conditions. Ultra capacitor will provide the energy back up if main battery fails in the vehicle and it will provide the necessary voltage and current levels to the ACU to make the system to work in safe condition. Step-up converter (Boost Converter) will provide the voltage and current levels for to the load and it is used in SMPS (Switch Mode Power Supply) because it is having low switching losses and efficiency is high. ACU can be designed on the PCB (personal Computer Board) which is inserted in the vehicle connectivity network. CAN (Controller Area Network) protocol is used in the automotive domain as the connectivity network. ACU will maintain the power level and provide power level of hundred of watts within a short time for the crucial mechatronic applications.

Keywords: Actuation Control Unit (ACU); Boost converter; EDLC capacitor; H Bridge; DSP processor; PIC Microcontroller.

Introduction

Mechanical system is becoming mechatronic system with electric or electronic actuation and it is used in safety critical applications and biomedical devices. To improve the quality of life of elderly people by replacing wounded and disabled people with robotised prosthetic arm or leg. Lithium cells are gaining importance in the market because of their superior energy density and faults can be reduced. As per the reference [1] in real production of vehicle most of the subsystems are still mechanical actuated, electric or electronic actuation is added a supporting function. Reliability of the vehicle can be improved by adding electric or elctronic actuation to the mechanical system. Mechatronic system are used in the brake, steering and door control system to increase comport of the driver with some extra functionalities.

As per the reference [2] Electric actuation reliability problem can be improved by using lithium cells as the energy backup and Lithium ion batteries have high power density and reduced risk of faults. Lithium cells have the reliability problems above 60^{o} C or at zero temperature so reliability of the electric actuation control unit can be increased by using low cost and compact embedded energy storage devices such as ultra capacitor. Local energy backup system will provide the required power for the actuator to work in safe condition. Switching regulator (Boost converter) will provide the necessary voltage and current levels to the load. ACU can be used to maintain the power level and is scalable in terms of voltage or current levels and in terms of input or output channels.

As per the reference [3] Electronic actuation control unit architecture used in many applications such as robotised gearbox for a SAE (society of automotive engineer) race car to improve the reliability of the vehicle and to provide comfortableness to the driver with some extra functionalities, robotised arm is used to increase the quality of life of elderly people and for advanced mechatronic device such as E-latch (Electronic latch) in a car. The Controller Area Network (CAN) is Multi-drop; Multi-master serial bus provides communications between controllers, sensors, and actuators. CAN is the connectivity network in the vehicle sub system. Gear box can be robotized by using electronic control units, sensors and actuators by replacing mechanical link from the shift lever and clutch pedal to increase the comport of the driver with extra functionalities and improve the reliability of the mechanical vehicle. ACU will explode the hundred watts of power in only a few seconds in case of emergency conditions and it is used in robotics, vehicular system and safety critical mechatronic applications.

Architecture of Electronic Actuation Control Unit

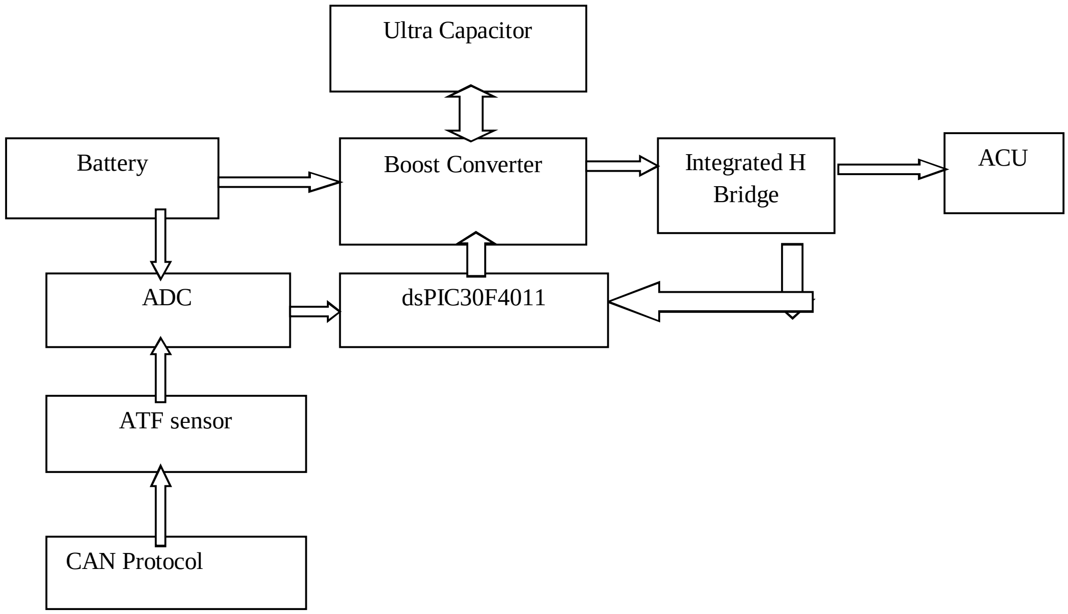


Figure1. Actuation Control Unit Architecture

A low voltage domain having PIC micro controller core which can be enhanced with CAN connectivity towards the computer, PWM output channels are multiplexed with analog to digital converter.PIC micro controller is a 16-bit peripheral interface controller and it consist of read-only memory (ROM) or field programmable EPROM for program storage. Analog to Digital converter will sense the abnormal conditions such as battery failure and it provide message to the DSP controller (dsPIC30F4011) controller will monitor the whole system depending on the requirement. The dsPIC30F4011 is high speed 16- bit PIC microcontroller with nine channel ADC and separate data memory and program memory processor. It consists of six PWM signals and clock frequency around 120MHz. The PWM output channels and analog to digital converter of the ACU architecture reduce the power consumption and improve the performance.

A high voltage domain consists of a power management unit and protection circuitry to interface the low voltage domain of 12 V lithium-ion batteries. Integrated H Bridge will control the speed of the geared DC motor depending upon the switching sequence of the MOSFET (Metal oxide semiconductor field effect transistor). Protection circuitry can be able to operate up to 60 V and the PMU (power management unit) will maintain the power supply, integrates boost converter will provide the required voltage level and current level to the actuation control unit and boost the nominal battery voltage level 12 V to the required voltage level (28V) for the relevant applications.

Integrated H Bridge will control the door latch of the vehicle by using geared DC motor and it will maintain the voltage level of 60V, current level 40A and it can sustain power level of 2 KW. It will maintain the PWM motor control up to 20KHz. Passive device such as ultra capacitors for embedded energy backup and resistors and Hall Effect sensors for current monitoring. Ultra capacitor will maintain the energy backup in case of main battery failure and if any problem occurs in the wiring connectivity network of the vehicle.ACU is working properly even in case of main battery failure by using ultra capacitors as embedded energy storage device.

Hardware Implementation of the Proposed Methodology

The battery voltage in the car is typically 12V for some of the motors and for some of the devices in the car uses higher voltage i.e., 24 V to 28 V. In order to get the higher voltage, boost converter is being used.

Boost converter parameter.

- Input voltage 12V
- Output voltage 24 to 28 V
- Switching frequency 25 KHz

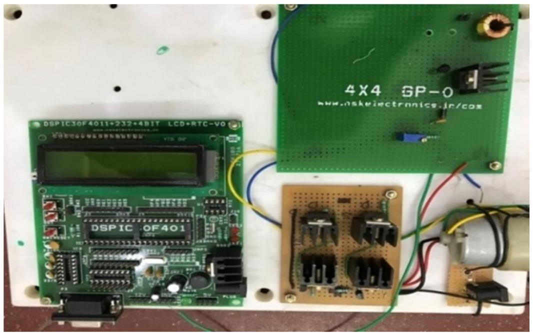


Figure 2. Hardware Implementation of ACU for Door Latch control

Feedback output voltage is scaled down to 0 to 5V using voltage divider circuit. It is assume the feedback voltage will be equal to 0 to 5 V when desired output is available at the output. The feedback voltage is read by ADC the reading will be 2.5V. A compare routine will check the feedback if the feedback is less than 2.5V it will increment the PWM if it is greater than 2.5 V controller loop will decrease the PWM on-time. This process acts like closed loop and will maintain the desired output, it is important to set the voltage divider ratio to give the 2.5 V at the desired voltage. The motors used in the car for window and other applications will be geared DC motor this motor can be operated in both the directions; in order to achieve this H Bridge configuration has been used.

Table1. Look up table for H Bridge Configuration

Input A	Input B	Motor Condition
0	0	Doesn't operate
0	1	Operates in forward direction
1	0	Operates in reverse direction
1	1	Doesn't operate

Local Energy Back-Up for Safety Critical Applications to Increase the Reliability of ACU

As per the reference [4] Embedded energy Backup system for ACU can be charged by the vehicle battery but when the battery fails, ultra capacitors will provide the energy for the ACU to make the system to work in good condition. Actuators will require power of about 100 W to 1 KW. Ultra capacitors will provide minimum voltage of 10 V, current up to 10 A, power less than 100 W and will provide the energy back-up of about 450 J; it should be placed near to the actuator controller. Ultra capacitor based energy storage system is used for electric vehicle propulsion. Lithium batteries are used in automotive domain as energy storage device for vehicles and it provide high energy density.

As per the reference [6] Ultra capacitor will provide high power density compared to lithium ion batteries. Lithium based rechargeable batteries does not covered required temperature range limited at 60^{o}C. There are some lithium based battery (Li-$SOCl_2$) rated for about 3.6 V that can operate up to 150^{o}C, but some of the lithium ion batteries are non-rechargeable and are characterized by high series resistance. Lead acid or nickel based batteries are rarely used due to lower efficiency in terms of energy density and power density.

As per the reference [7] Ultra capacitors can be used as embedded energy storage devices in our applications because it has temperature range and higher power density. The proposed embedded energy back-up system include four electric double layer capacitor of each capacitance 25F and each rated for about 3 V connected in series plus boost converter. The proposed system will provide an embedded energy of 450.

Boost Converter will provide the necessary voltage and current level to meet the ACU requirement with less distortion. Microcontroller will drive actuation control unit by opening the converter switch and driver feedback switch of the figure 2, when the main battery voltage presents. The Boost converter is in off condition, the Ultra capacitors will maintain the energy backup and the converter switch SW1 and driver feedback switch SW2 are integrated to maximize power efficiency. Boost converter will integrate the voltage and current mode controls. The programmability of converter output voltage can be changed by changing the gain of the voltage sensor to meet the ACU requirement. The output of the Boost Converter will feed to the Integrated H Bridge to control the DC geared Motor by providing proper switching sequence to the switch.

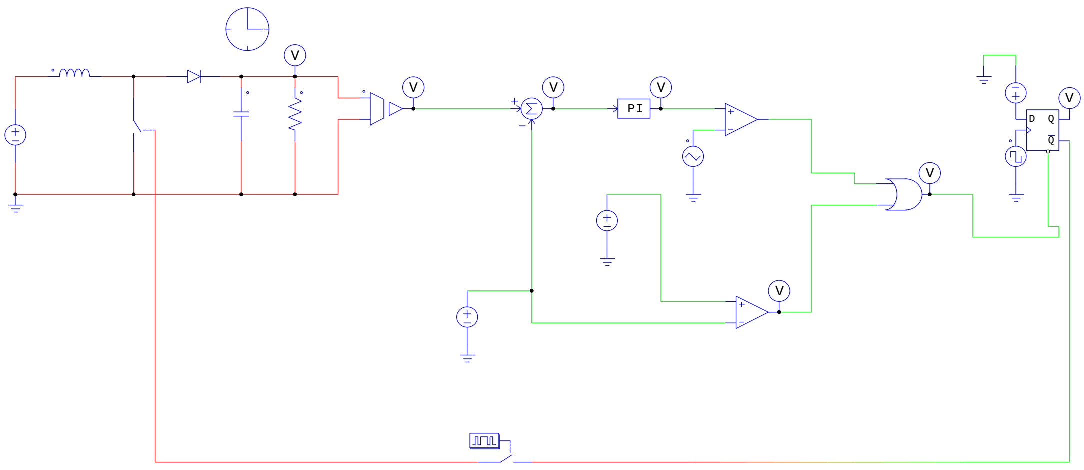


Figure 3 Control Loops of Boost Converter

Boost Converter Design and Simulation Results

Boost Converter is the switching converter that operates by periodically opening and closing an electronic switch. It has low switching loss and can be used as SMPS (switch mode power supply). It will provide the required voltage and current levels for the actuator operation to make the system work in safe condition and step up the voltage as per the requirement.

Parameters Design

- Input Voltage (Vs) = 12V
- Output Voltage (Vo) = 28V
- Output Power = 100W
- Switching frequency = 25000 Hz

Formulae to calculate the parameters of Boost Converter

- Duty ratio D = $(Vo - Vs)/V0$
- Output Current $Io = Po/Vo$
- Resistance $R = (Vo * Vo)/Io$
- Inductor Current1 $I_l = (Vo * Io)/(Vs)$

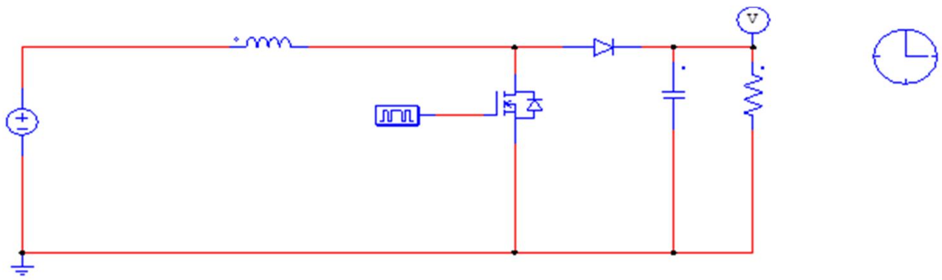
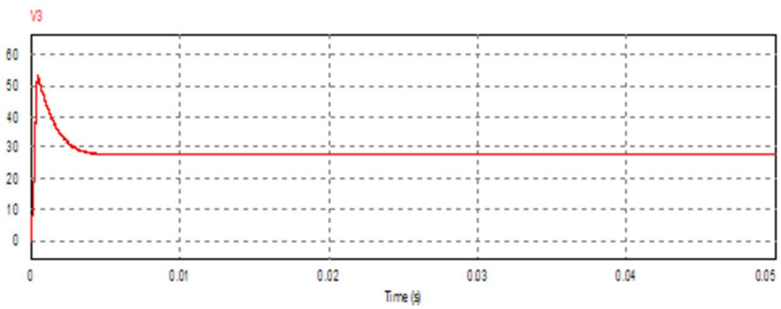


Figure 4. Boost Converter Circuit



Waveform 1. Output Voltage of the Boost Converter

- Change in Inductor Current $\Delta I_{l1} = 0.4 * I_{l1}$
- Inductor $L_1 = D(1-D)(1-D)/2f$
- Capacitor $C = (Vo * D)/(R * \Delta V_{cf})$
- Output voltage ripple is less than 1%

Design Parameters:

Table 3. Input Parameters

Input voltage	Output voltage	Output power	Switching frequency
12V	28V	100W	25000 Hz

Table 4. Output Parameters

Duty Ratio	0.571
Resistance	7.84Ω
Output current	3.571A
Inductor current	8.334A
Maximum inductor current	8.7A
Minimum inductor current	7.996A
Minimum value of inductor	16.5 uH
Capacitance	300 uF

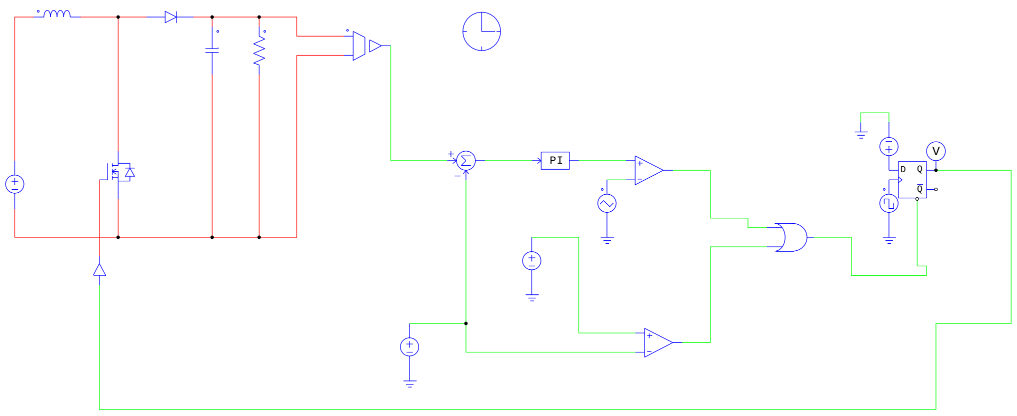
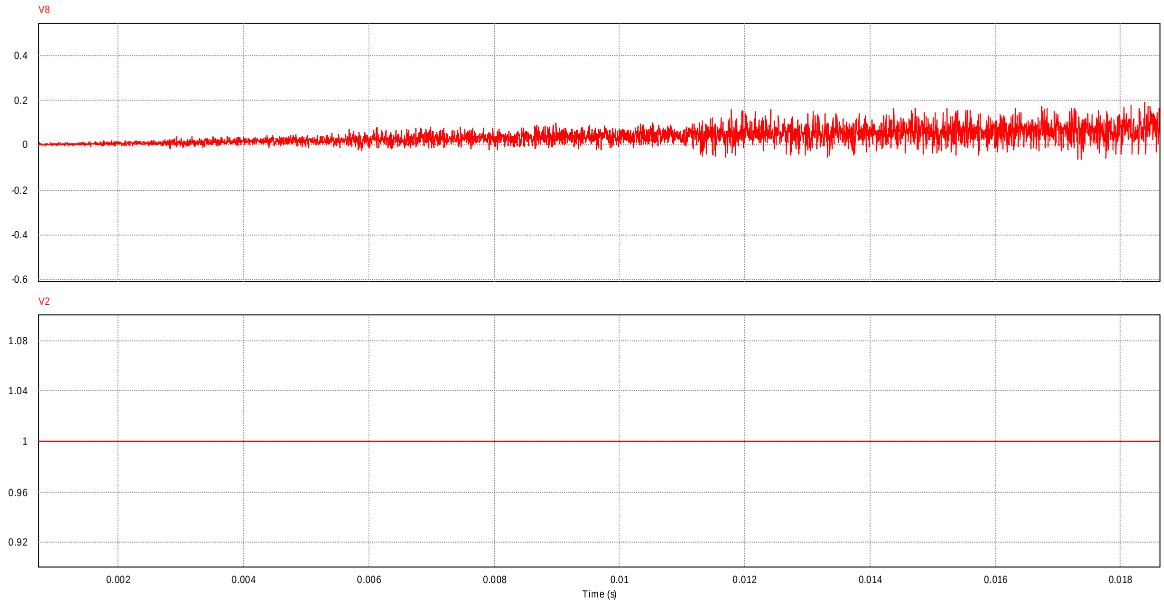


Figure 5. Detailed control loops of Boost Converter

Boost converter will step up the voltage and voltage sensor will sense the output voltage of the converter, compare the output voltage with the reference voltage and given to the D-flip flop. The digital output of the D-flip flop is fed back to drive the MOSFET switch through on-off controller and output voltage changes when the switch triggered from the feedback of the D-flip-flop. D-flip flop is the delay flip-flop and the output of the flip flop is in terms of binary values and the truth table is as follows.

Table 5. D Flip-Flop truth table

Input	Output
0	1
1	0



Waveform 2. Output Voltage of the Boost Converter Control Loop

Conclusion

This paper presented the electronic actuation controller for Electro-Mechanical applications and full operation can be done by using Ultra capacitor as the storage energy system. Ultra capacitor can be used as embedded energy storage back up in case of emergency conditions such as accidents and connection failure in the wiring system of the vehicle connectivity network. Boost Converter circuit will boost up the voltage and provides the necessary voltage and current levels for the operation of the actuator to make the system to work in good condition. Integrated H Bridge will control the door latch of the vehicle by using geared DC motor.The proposed system will provide the embedded energy up to 450J and it is used for vehicle door control, windows control and to make the gearbox robotized for mechatronic applications. Ultra capacitor has the temperature reliability range from -40^{o} to 130^{o}C and life cycle of more than 10000 cycles. Actuation control Unit will provide more power within a short time for mechatronic applications.

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