

Low-Cost HIL Simulation Platform for BMS Multi-Configuration Power Supply

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Abstract—The vast development of new Battery Management System (BMS) circuit models and topologies requires different power supply circuit configuration thus leads to various testing, prototyping and circuit simulations. Given this situation, to avoid high cost, unexpected results and design failure, one kind of simulation has gained high notoriety because of its adaptivity is the well-known Hardware-in-the-Loop Platform (HIL). By using this simulation platform, it allows the comprehensive examination of various possible test-condition cases within the virtual simulation environment. The Power Supply circuit design system and its parameters can be pushed towards the operational limits where potential faults may occur without having any risk in experimental operation thus minimizing the risk in the actual application of the designed circuit. The main contribution of this research work is the development of a low-cost HIL platform that is capable of virtually simulating different Power Supply Circuit Design by utilizing Digital Signal Processor (DSP) thus making it possible to comprehensively validate complex Power Supply Circuit and Power related circuit systems efficiently.

Index Terms—Battery Management System, Hardware-In-The-Loop, DSP, Real-time system, Power Supply

I. INTRODUCTION

The reliability of a vehicle battery has a directly proportional relationship with the vehicles' reliability and performance. Hybrid Electric Vehicle (HEV) and Electric Vehicle (EV) use batteries for operation such as for acceleration and energy regeneration [1] by which the growing population of battery dependent vehicles requires innovation in existing Battery Management Systems circuit designs hence leading to adjustments to each power supply with respect to the BMS circuit topology used. The International Energy Agency (IEA) published its annual publication named Global EV Outlook as of May 2019 which was developed by members of the Electric Vehicles Initiative (EVI) shows that Electric car deployment has been growing rapidly over the past ten years, with the global stock of electric passenger cars passing 5 million in 2018, an increase of 63% from the previous year. Applying HIL in testing a Power supply of a given BMS circuit can give a lot of advantages by which the greatest benefit of a HIL test simulations corresponds to its capacity to perform more realistic tests to validate various control systems, using real hardware and including all runtime effects without having to use the real system [2]. HIL simulation process for specific systems such as BMS are vital in designing by which it's

used in industrial application nowadays and three legal control handbooks namely The Control Handbook, NASA System Engineering handbook and European Cooperation for Space Standardization handbook introduced HIL as the last step of validation of the development process of a system [3]. In this research, HIL platform Simulation for BMS' power supply is developed wherein it can be utilized as an initialization and as a finalization means in different power supply circuits used by distinct battery management systems

The general overview of the typically implemented HIL simulation platform and a comprehensive discussion on its advantages and disadvantages is given in Section II. The proposed HIL implementation of this paper and the MCU that makes this simulation platform low-cost is presented in Section III. The overall implementation flow chart of this research paper is presented in section IV. Software modeling and parameter extraction together with the connection between the circuit model and the controller is given emphasis in section V wherein various extracted parameters are presented. Section VI presents the conclusion followed by acknowledgements and the reference section.

II. CONVENTIONAL HARDWARE-IN-THE-LOOP

A. HIL Platform Architecture Conventional Test Bench Setup

The general architecture of HIL simulation has two sections namely the virtual network which is simulated in a real-time simulator and the other is in the modelled hardware [4] as shown in figure 1. The circuit model used to implement the HIL simulation process in figure 1 is an actual simulation circuit by which it can be implemented both virtually and physically as a prototype which makes this simulation ideal as an initialization and finalization means to any complex circuit designs. The constraints in simulating a real power supply circuit modelled virtually in any circuit simulation software is the time it takes to simulate a single operation whereas physically, the hardware prototype implementation part of a circuit is subjected to risks such as design failures given that the components may be subjected to tests beyond its operating capacity while component degradation may also occur that will result in low component functionality thus resulting to inefficient data acquisition.

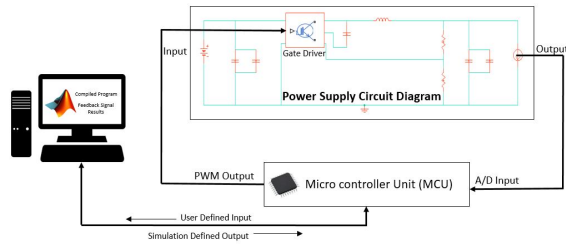


Fig. 1. Widespread HIL Simulation Platform Setup

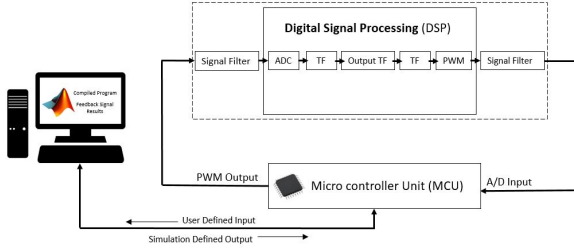


Fig. 2. Digital Signal Processing (DSP) based HIL Simulation Platform Setup

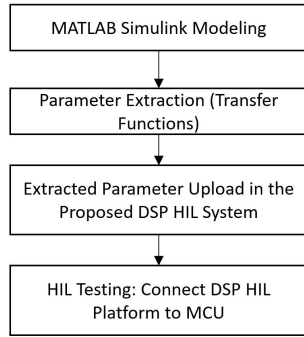


Fig. 3. Flow Chart for the DSP Based HIL Process

III. PROPOSED HIL IMPLEMENTATION

A. HIL Platform Architecture of the Proposed Low-cost Hardware-in-the-Loop Simulation Environment

In figure 2, the proposed low-cost HIL simulation platform is laid out wherein the real circuit is replaced by a DSP. A DSP based HIL requires a circuit model and a controller model as its initialization parameters by which in this paper, both are modelled using MATLAB Simulink. Extraction of required models can be extracted from these initialization parameters such as the transfer function (TF) and the PWM module. The transfer function extracted from the modelled Power Supply circuit will then be uploaded to the DSP based HIL simulation platform wherein the HIL test takes place virtually. For closed-looped feedback testing, the DSP implemented HIL is connected to the MCU by which in this case, the ATMEGA328P of the Arduino Uno is proposed to be utilized.

IV. HIL PROCESS IMPLEMENTATION FLOW CHART

Implementing a DSP based simulation requires a MATLAB Simulink model of the power supply circuit and its controller.

The required parameters will be extracted from the circuit model created and will be uploaded to the HIL system as presented in figure 3.

V. SOFTWARE MODELLING AND PARAMETER EXTRACTION

Hardware-in-the-Loop is a hardware - software collaboration implemented simulation that includes system and circuit models where real hardware components is tested experimentally tested virtually. Overall, circuit simulation of any circuit consumes a lot of time and even a common spice circuit of BMS's power supply converters requires a few minutes per 10 millisecond period of simulation. Paper [5] explained that even though there are some circuit simulation software that are faster than other simulation software, fast and efficient simulation is impossible for conventional SPICE based circuit simulation technologies. With this taken into consideration, paper [6] proves that by using a transfer function, a faster simulation could be implemented given that it's acknowledged as a fast analytical technique

A. Circuit Design Simulation

This research paper used a DC – DC Boost Converter Circuit Model designed in MATLAB Simulink by which an insulated-gate bipolar transistor (IGBT) is used as a switch and is varied with respect to a Pulse Width Modulator (PWM) signal. The goal for this circuit model is to get the PWM duty cycle nominal value to the load voltage.

B. Frequency Response Data Gathering

An interrupt was applied to the PWM duty cycle nominal value in a form of varying sinusoid frequencies to take into account the generated output voltage which will give transition results on how the Circuit Model transformed the magnitude and phase of the injected sinusoids wherein it shows discrete points on the frequency response.

C. Transfer Function Estimation

The resulting frequency response data which was generated by Simulink Control Design is the representation of the modeled system as discrete frequency points hence a transfer function can be integrated with it. To ensure that the estimated transfer function is accurate, the transfer function should coincide with the provided frequency range.

Voltage (V)	Frequency Range (rad/s)	Simulation Time (s)	Transfer Function
12 – 18	200 – 2000	15.5933	$\frac{-2.047e05s + 2.942e08}{s^2 + 6995s + 9.831e06}$
12 – 18	500 - 5000	6.2373	$\frac{-2.052e05s + 9.24e08}{s^2 + 7046s + 9.777e06}$
100 – 160	200 – 2000	15.5933	$\frac{-1.776e06s + 2.469e09}{s^2 + 6995s + 9.834e06}$
100 – 160	500 - 5000	6.2373	$\frac{-1.78e06s + 2.453e09}{s^2 + 7045s + 9.779e06}$

TABLE I
OVERVIEW OF THE TRANSFER FUNCTION EXTRACTED FROM THE DC – DC BOOST CONVERTER POWER SUPPLY CIRCUIT MODEL

Voltage (V)	Frequency Range (rad/s)	Simulation Time (s)	Transfer Function
18 – 6	200 – 2000	15.5933	$\frac{4.695e08}{s^2 + 7108s + 2.509e07}$
18 – 6	500 - 5000	6.2373	$\frac{4.679e08}{s^2 + 7086s + 2.502e07}$
160 – 60	200 – 2000	15.5933	$\frac{4.035e09}{s^2 + 7108s + 2.509e07}$
160 – 60	500 - 5000	6.2373	$\frac{4.021e09}{s^2 + 7086s + 2.502e07}$

TABLE II

OVERVIEW OF THE TRANSFER FUNCTION EXTRACTED FROM THE DC – DC BUCK CONVERTER POWER SUPPLY CIRCUIT MODEL

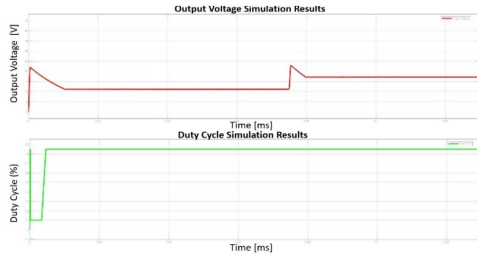


Fig. 4. Output Voltage and Duty Cycle Graph of the Boost Converter Circuit (12V – 18V)

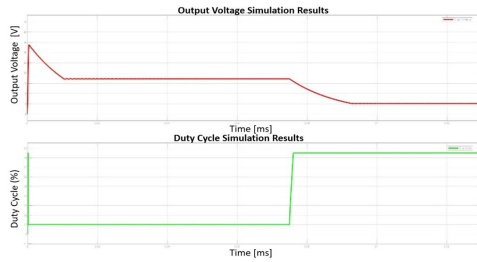


Fig. 5. Output Voltage and Duty Cycle Graph of the buck Converter Circuit (18V – 6V)

Table I and II shows the transfer function of the modelled Power Supply Circuits. Table I shows the transfer function of a 12 – 18 V Power Supply which is usually a typical conversion used in BMS circuits and a 100 – 160 V voltage amplification to show emphasis in the difference of the extracted results. Same conditions is applied on the Buck Converter Circuit Model on Table II. An IGBT controlled by PWM is utilized to vary the circuit simulation parameters e.g. duty cycle and frequency. The table I and II shows the frequency ranges used in the simulation together with its corresponding simulation time.

D. Controller Model for Power Supply Circuit

Figure 4 and 5 shows the corresponding graph of the simulated Power Supply by using a PID controller to vary the IGBT ideal switch gate controlled by a PWM to implement virtual in MATLAB/SIMULINK. The red signal shows the output voltage of the Power Supply while the green signal shows the Duty Cycle of the power supply in the specific simulation sequence in which the total time for this sequence

is 160ms. These signal representation shows the variation of the performance of the power supply given different operating parameters. The signal statistics is then comprehensively analyzed as part of the modelling process for the controller and the power supply.

VI. CONCLUSION

In this paper, a DSP based low-cost HIL for BMS diverse Power Supply Configuration is proposed. The DSP based simulation using Matlab/Simulink will replace the commonly used simulation of real-circuit models making it applicable in simulating different power supply circuit virtually and time-efficiently. The required DSP initialization parameters such as transfer functions for real-time simulation varies directly with respect to the circuit model making it adaptive to any power supply circuit particularly, to any BMS power supply hence together with the proposed low-cost MCU that is responsible for the A/D Input and PWM output of the Virtual HIL simulation system, qualifies this HIL system design cost-effective.

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