

# Simulation of Hybrid Boost Fly Back Converter: A Virtual Hardware-in-The-Loop Simulation Approach

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**Abstract:** *Hardware-in-the-loop simulation (HIL) is an efficient way to design and test the power electronic controllers in real-time. Boost converters are incorporated in photovoltaic system applications where the output is dependent on the ambient temperature and irradiation. The hybrid boost fly back converter is used to set-up the low voltage obtained from the photovoltaic system in standalone systems and the voltage from the battery required for EV system architectures. The main objective of this paper is to simulate a hybrid boost fly back converter using a virtual Typhoon Hardware-In-the-Loop (HIL) simulator and compare the results obtained with the simulation carried out using MATLAB/SIMULINK. The steps of the simulation using Typhoon HIL are discussed in brief.*

**Keywords:** *Hybrid boost fly back converter; Hardware-in-the-loop Simulation (HIL); MATLAB/SIMULINK; HIL SCADA; Virtual environment*

## I. INTRODUCTION

Hardware-In-the-Loop Simulation (HILS) plays an important role in the testing of controllers and is an essential part of verification and validation of embedded programming applications, refer [1]. In this simulation technique, the developed program of the controller is simulated using an actual controller with real-time signals of the physical system that is used to control as shown in Fig. 1. The processor replicates the actual signals in of the controller in a defined loop which is intended to control the operation of the controller. The exchange of the signal between the test system and the controller can be observed. This emerging technology is currently used in testing of aviation control systems, traction and railways transportation systems. The merits of Hardware-In-the-Loop testing are four folds; first, the designed controller can be tested even before the actual controller controlling the system (for instance, an electric drive train, engine or transmission) is accessible or fabricated; second, the risk of damaging the controller is reduced which leads to efficient utilization of the resource, reduce expense and hazards.; third, the controllers can be subjected to real-time fault conditions to analyze and study the response of the controller when implemented in real field conditions; fourth, the actual field parameters can be recreated with the

given parameters with which we can analyze the anomalies.

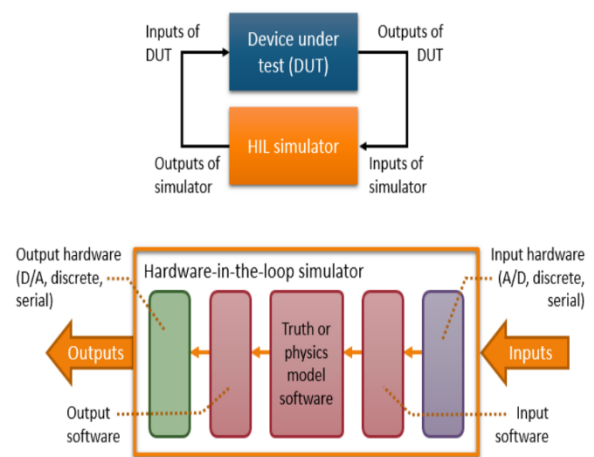


Fig 1. Block diagram of HIL Stimulation

HIL simulation testing is efficiently utilized for testing of electro-mechanical systems that require lower processor power for the desired test rates. On the other hand, testing of controllers for motor drives and power electronics, which are largely utilized in electric vehicles and advance control system architectures for aviation systems need to recreate a lot of dynamic components that involve time-varying elements. These simulations required much higher processing power, dynamic modelling and advanced programming to achieve the desired results with the required test rate. The capability to execute the complex models in time steps starting from the sub-microsecond level to the 10 millisecond level on processor-based system architecture is the basis of the HIL simulation operation.

HIL simulation being the emerging technology has progressed to meet all the requirements by utilizing FPGAs that are commercially available and multi-core central processing units that are interfaced with fast analog and digital channels. The main objective of the Hardware-In-the-Loop simulation (HIL) technique is to use a simulation model of the developed controller and test it with real target hardware field condition parameters. The simulation model gives all the system parameterized signals that are



continuously exchanged over digital to analog modules and provides a voltage to the controller. The delivery of control signals to the controller is carried over analog to digital converter circuits to the simulation model. This is the motivation behind the use of hardware in a loop to carry as intently as possible to replicate the experience of the actual real-time system framework.

The simulation model of the hybrid boost fly back converter is developed in the Typhoon HIL schematic editor and loaded into HIL virtual environment to carry out the testing. The testing is done under an interactive HIL SCADA panel, that can be activated and all the parameterized tests and variety of input voltages can be assigned to check the accuracy of the simulation model in Typhoon HIL. The results are then compared with simulations of SIMULINK modelling.

## II. LITERATURE SURVEY

According to [2], a charger with a buck-boost converter operated with constant current mode to charge a battery is prototyped with the control algorithm being implemented with the use of a microcontroller. The voltage regulation is obtained by the clamping circuit from the forward converter operation to drive the LED display for electronic signboard implementation. The hybrid system has photovoltaic modules as its primary power source and uses an efficient tracking method to maximize the power output of the photovoltaic system. The use of hybrid converters has reduced components, lighter weight, and compact size and has an overall better efficient performance.

As per the work proposed in [3], a simulation is carried out using SIMULINK/MATLAB with power MOSFETs as the power electronic switch for the modelling of the fly back converter. The simulation results obtained are as per the theoretical concept calculations. Fly back converters are effectively used in a hybrid electric vehicle as it possesses the dc-link voltage to support the EV system architecture.

As per [4], a multiphase hybrid boost converter for the photovoltaic system with board conversion ratio as a solution is discussed. With the use of interleaving topology of boost converters, it is possible to operate all the phases with the same switching frequency. A new converter is proposed that can be used to interface the PV system and the inverter/ DC load. The analysis of the simulation results of the converter is discussed to validate the operation of the converter.

According to [5], a new converter topology is discussed which is operated in boost fly back mode. With this topology, low voltage stress due to high voltage gain is minimized in the transformer with an appropriate turn's ratio. The leakage current obtained is back injected into the circuit and the turn-off voltage surge of the main power electronics switch is clamped with the help of a passive snubber circuit. A prototype of the proposed converter is validated with theoretical analysis and the characteristics

of hybrid boost fly back micro-inverter are discussed in detail with boundary conditions.

## III. HYBRID BOOST FLY CONVERTER

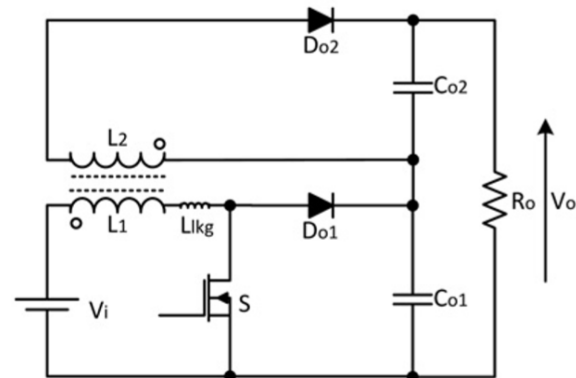


Fig 2. Hybrid boost fly back converter circuit

The fly back converter as shown in Fig. 2 is one of the converter topologies which is broadly used in small scale photovoltaic systems and EV architectures. The coupled inductor provides high voltage gain as a result of the connection between the outputs of fly back and boosts converter, refer [6]. With the turn off state of the switch, the boost converter acts as a clamping circuit. The voltage stress across the power electronic switch is greatly reduced with this hybrid boost fly back converter topology. The voltage stress encountered depends on the turn's ratio of the coupled inductor. The output capacitor clamps the voltage across the switch naturally. The current topology reduces the voltage stress across the output diode also. Whereas the input current is drawn is discontinuous in nature as shown in Fig.7 and Fig.11, and there is a need for input harmonic filters to reduce the EMI levels.

## IV. SIMULINK MODELLING

The hybrid boost fly back converter as represented in Fig. 2 is modelled in SIMULINK with voltage and current measurements at both input and output terminals as shown in Fig. 3. The value of coupled inductor inductance is chosen as per the current and voltage requirement. The load is considered to be a resistive load to simulate a simple load. The PWM signal is obtained from a pulse generator with a suitable duty ratio and switching frequency. The power electronic switch is considered to be an IGBT switch. The leakage inductance is also considered as per the actual circuit to obtain then result as precise and accurate as possible.

## V. HARDWARE-IN-THE-LOOP SIMULATION

The Hardware-in-The-Loop simulation (HIL) is executed in virtual Typhoon HIL which has a virtual environment for testing power electronics controllers in real-time without the need for the actual HIL device connected to it. The virtual environment is available in a limited configurable device model, for this simulation HIL 402 virtual environment is used. HIL 402 can support a

maximum of three power electronic switches and one machine solver.

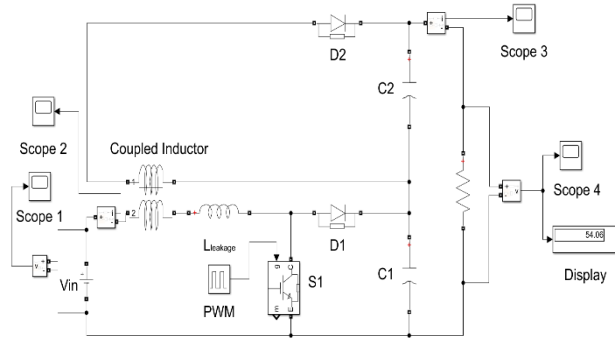


Fig 3. SIMULINK model of the proposed converter

The HIL simulation model consists of an electrical model and a signal processing model. The electrical blocks are coded in the python script and the signal processing model is implemented using C program. The technique of HIL is a “piecewise linear” approach where the entire system is split into subsystems based on the Standard Processing Core (SPC). The capacity of the virtual HIL simulation depends on the processing power of the host system. With the use of fast interface of analog and digital with the processor, it makes the HIL work in sub-micro level time intervals.

The SPC bifurcation depends on the complexity of the simulation model implementation. The semiconductor switches are given the “weight” (value) to be identified by the compiler to validate its processing capacity. For example, boost converter block weights “1”. Likewise, the power semiconductor blocks are assigned the “weight” value. The SPC segregates the sub-circuits based on the semiconductor switches. The entire simulation model is implemented in the HIL schematic editor as shown in Fig. 4 which is validated for the generation of the C code for the implemented simulation model. The C code is then executed and imported to the virtual environment of the Typhoon HIL simulator. The interactive circuit is built with the help of SCADA widgets in the interactive HIL SCADA panel as shown in Fig. 5.

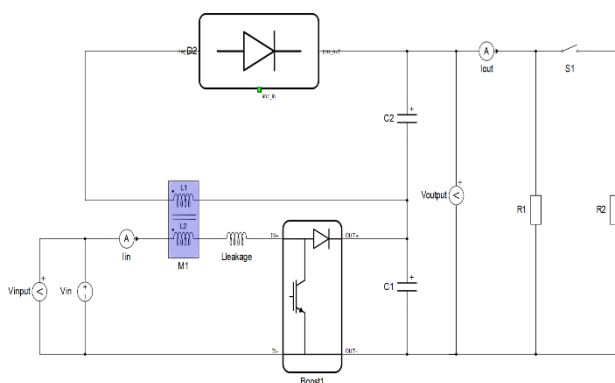


Fig 4. Modelling in HIL schematic editor

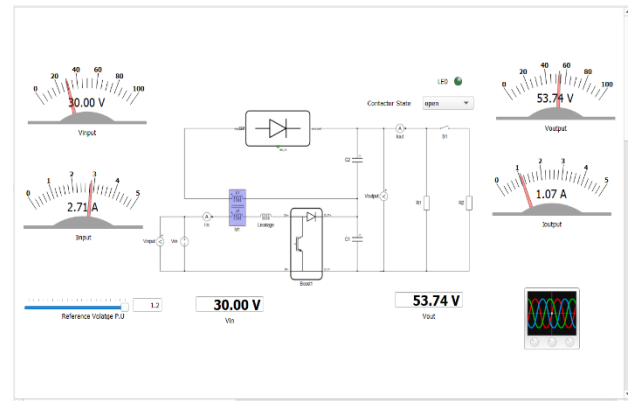


Fig 5. HIL SCADA interactive panel view

The “piecewise linear” linear approach linearizes the circuit parameters. The signals of the linearized circuit are linear time-invariant signals. The linearization process helps to compile state-space model for each power electronic block and passive elements. The number of state-space matrix increases by  $2^N$ , where “N” represents the number of power electronic blocks. As the complexity of the circuit increases, the state-space matrices increase so as the memory consumption. To avoid maximum utilization of memory, sub circuit formation takes place. The sub circuit is processed based on the SPC assigned, which is dependent on the processing core and power available on the computer used for virtual HIL simulation. The sampling rate of the signal depends on the PWM signal frequency. For fast dynamic system response, oversampling is done at a sub-micro level time interval to achieve the desired result.

## VI. SIMULATION RESULTS

### A. SIMULINK Simulation Results

The simulation model is modelled in SIMULINK with the circuit parameters being designed as per the requirement. The following are the parameters of the implemented model.

Leakage = Leakage inductance = 0.1 mH.

fS = Switching frequency = 25kHz

VIN = Input voltage = 30V DC

Ro = Load resistance = 180 Ω

D = Duty cycle = 60%

Fig. 6 represents the input voltage which is at 30V DC and Fig. 7 shows the input current waveform from the source which is about 5.5Amps. The input current is switched current waveform. The output voltage and current obtained are 54.03V which is shown in Fig. 8 and 1.1Amps which is shown in Fig. 9 respectively. The SIMULINK simulation results are obtained with the ordinary differential equation solver. The high gain of the hybrid boost fly back converter is due to the coupled

inductance and the voltage stress on the IGBT switch is significantly reduced. With the variation of duty cycle and PWM signal frequency, the output can be increased further.

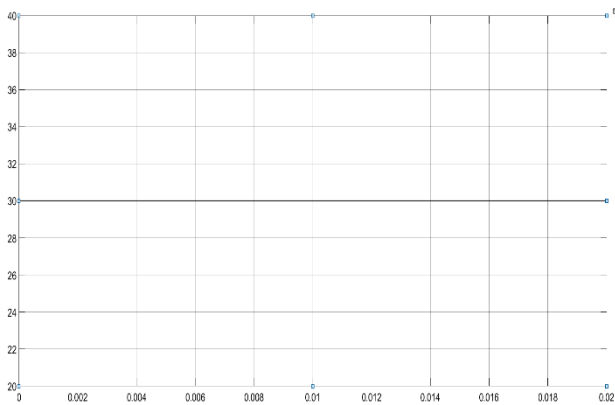


Fig 6. Input voltage (Voltage in V vs Time in sec)

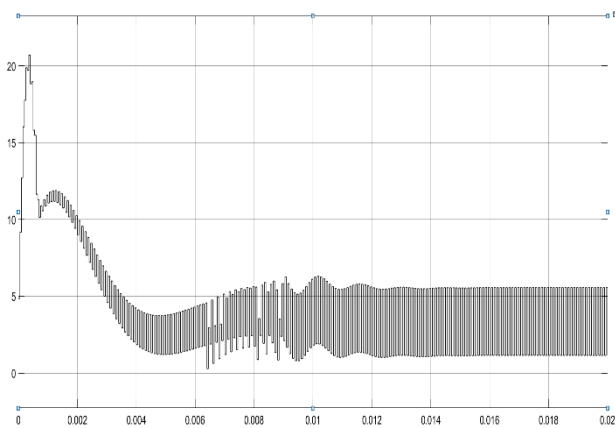


Fig 7. Input current (Current in Amps vs Time in sec)

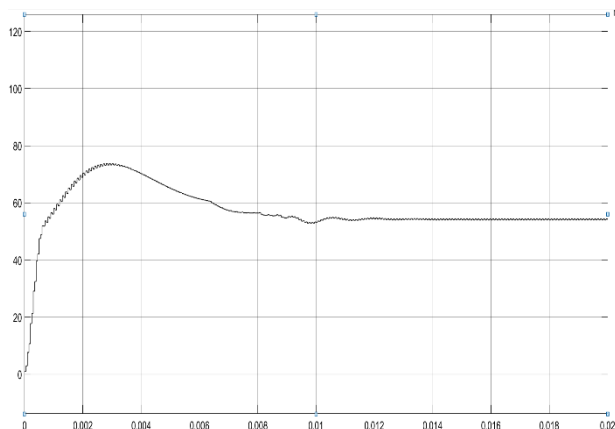


Fig 8. Output voltage (Voltage in V vs Time in sec)

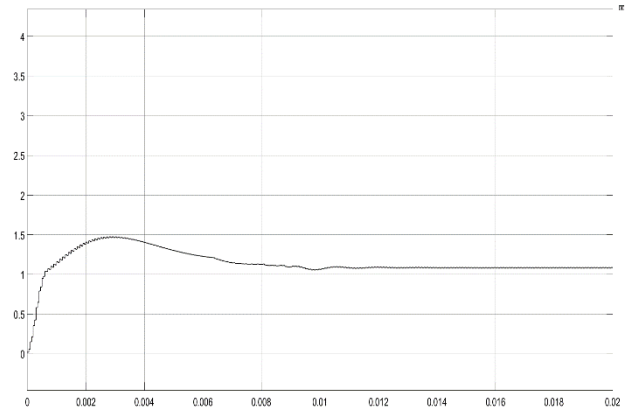


Fig 9. Output current (Current in Amps vs Time in sec)

### B. Typhoon HIL Simulation Results

The hardware product is virtual HIL 402 and configuration is selected to be 4 for the available memory and for the required state space matrices and also the Standard Processing Core (SPC). With a maximum of three power electronic blocks and six contactor switches without the support of non-linear machine. The simulation model is simulated in a virtual Typhoon HIL environment with the same circuit parameters as considered for MATLAB/SIMULINK simulation. The state-space matrices consist of  $2^N=2^2=4$ , because of two power electronic blocks, and  $2^M$  represents the total state space matrix variable, where M represents the sum of passive components. Now,  $M=7$  so,  $2^7=32$  variables. The total state-space matrix variable is  $4+32= 36$  variables for the system computation.

Fig. 10 and Fig. 11 represent the input voltage waveform which is 30V DC and output current with a peak of 12.1 Amps respectively. The output current is discontinuous in nature. The output voltage is shown in Fig. 12 with a peak of 54V DC and output current is represented in Fig. 13 with a peak of 1.01 Amps which is pulsating in nature.

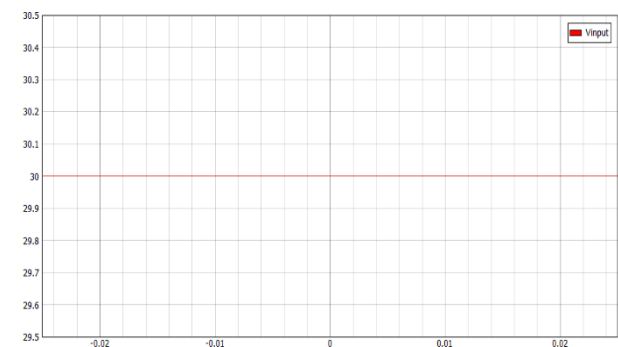


Fig 10. Input voltage (Voltage in V vs Time in sec)



Fig 11. Input current (Current in Amps vs Time in sec)

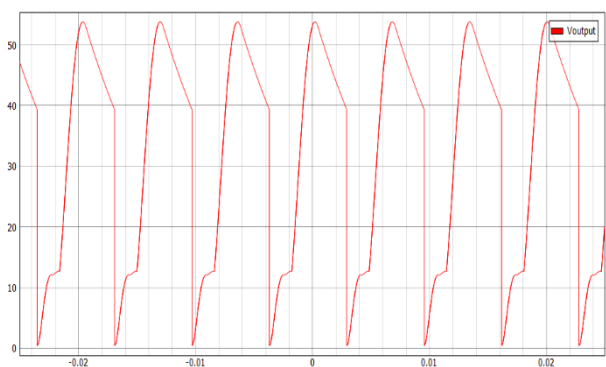


Fig 12. Output voltage (Voltage in V vs Time in sec)

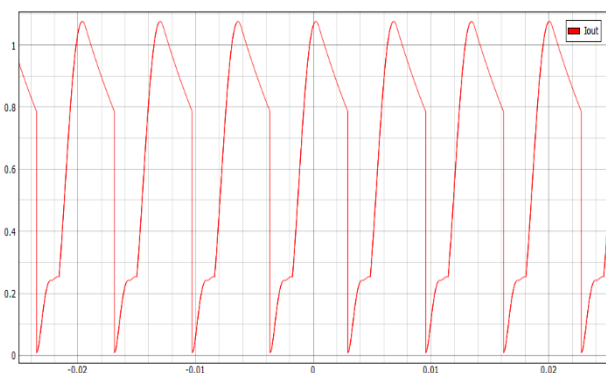


Fig 13. Output current (Current in Amps vs Time in sec)

## VII. CONCLUSION

The Hardware-in-The-Loop simulation was carried out for the simulation model of a hybrid boost fly back converter using a virtual Typhoon HIL simulator. The exact simulation model is simulated in MATLAB/SIMULINK. The obtained results are analyzed and compared to verify the accuracy of the virtual Typhoon HIL simulator. The input current is pulsating in nature for SIMULINK simulation and the output current waveform is discontinuous in HIL simulation and also the output voltage obtained is 54.03V DC in the case of SIMULINK model simulation and 53.74V DC is obtained in virtual

HIL simulation. With better multi-core processor HIL 402, the HIL simulation output would be on par with the SIMULINK simulation results. Typhoon HIL is a very powerful tool for real-time simulation of complex systems and complicated control systems. The virtual Typhoon HIL simulation is very efficient with suitable hardware availability. Moreover, Typhoon HIL is used as a test bench for testing micro-grids which brings revolutionary changes in a real-time simulation platform. Thus, to conclude Typhoon HIL is more flexible and ease of operation makes it a better choice to use in real-time simulations.

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