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# Design of PFC Smart Charger for Electric Vehicle Application

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**Abstract:** ***In this paper, a new three-phase power-factor correction (PFC) scheme is proposed using two single-phase PFC modules. Two standard single-phase PFC modules are then employed to process the "two" phase power to dc output. Split inductors and diodes are employed to limit interaction between the two PFC stages. The performance of the proposed PFC rectifier was evaluated on an experimental 1.3-kW universal-line PFC prototype. In addition, a detailed analytical model for this topology is presented, enabling the calculation of the converter power losses and efficiency. These study results have been organized and published as several technical papers during the course of this project. In this technical report, the cumulative interleaved coupled inductor DC-DC converter studies are summarized.***

**Keywords:** Uncontrolled rectifier, interleaved buck converter Single phase inverter

## 1. Introduction

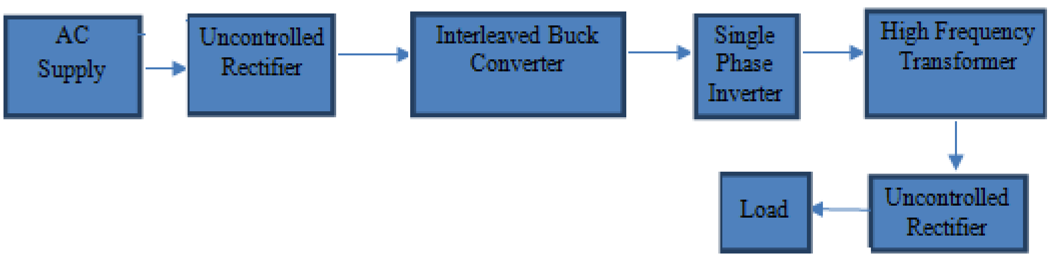
A Plug-in Hybrid Electric Vehicle (PHEV) is a hybrid vehicle which uses rechargeable batteries or another energy storage device that can be restored to full charge by connecting a plug to an external electric power source such as electric wall socket. A PHEV has the characteristics of both a conventional hybrid electric vehicle which is having an electric motor and an internal combustion engine (ICE) of an electric vehicle.

Most PHEVs on the road today are passenger cars. But PHEV vehicles are also available in the form of commercial vehicles such as vans, trucks, buses, motorcycles, scooters, and military vehicles. The common charger that is used in PHEV includes an AC-DC converter with power factor correction (PFC) followed by an isolated DC-DC converter with input and output EMI filters. The front-end ac–dc converter is a key component of the charger system. Proper choice of this topology is essential to meet the regulatory requirements for input current harmonics, output voltage regulation and implementation of power factor correction.

Typical charging infrastructure scenarios include overnight charging at a home garage, overnight charging at an apartment complex, and opportunity charging at commercial facility. The overall transportation system cost can be reduced by providing rich charging infrastructure rather than compensating for lean infrastructure with additional battery size and range.

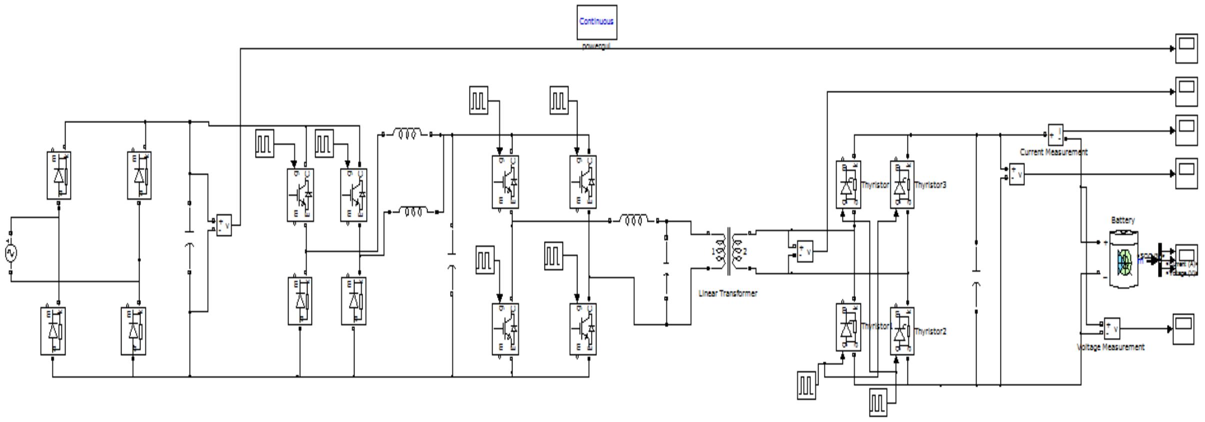
## 2. Methodology

Normally battery is charged using a DC supply. It consists of more harmonic components. To avoid the harmonic components intermediate converters were used to improve the voltage (amplitude and ripple content). Normally buck converters where used to buck the input DC voltage. Since it contained more harmonics, Interleaved buck converters where used. So Interleaved buck converter with high frequency transformers where used to reduce the ripple content and charge the battery effectively. The proposed Battery for charging is "Exide 12V 7AH "

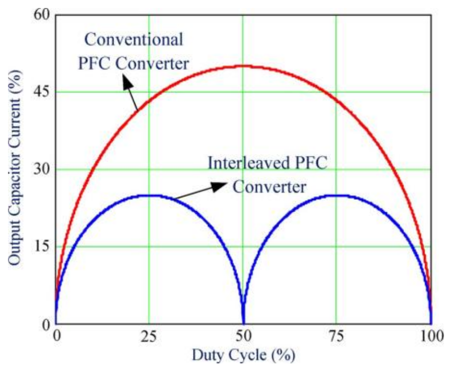



For the subject DC- DC converter project, converters were primarily operated and analyzed in CCM mode so that both inductor currents ($i_1$and $i_2$) were always positive. The primary benefit of CCM over Discontinuous Conduction Mode (DCM) of operation is the minimization of circuit ringing, inductor and input ripple current, and voltage ripple effects and their associated mitigation.

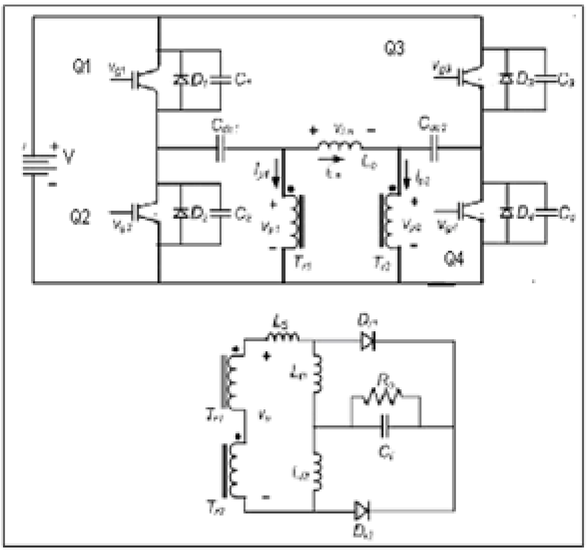
## 3. Result and Discussion




The interleaved PFC consists of two continuous conduction mode (CCM) buck converters in parallel, which operate 180◦out of phase. The input current is the sum of the inductor currents in LB1 and LB2. Since the inductor ripple currents are out of phase, they tend to cancel each other and reduce the input ripple current. The maximum input inductor ripple current cancelation occurs at 50% of the duty cycle. The picture shows the ratio of the input current ripple to the inductor current ripple as a function of duty cycle.




The major limitation of the FBZVS converter has been the limited range of operation over which ZVS can be achieved. When the load current is low, the ZVS of the lagging-leg switches is lost as the energy stored in the leakage inductance of the transformer is insufficient to discharge the switch and transformer capacitances. The loss of ZVS results in increased switching losses and electromagnetic interference (EMI). In the case of high power converters using insulated gate bipolar transistor (IGBT), an external snubber capacitor is connected to reduce the rate of rise of voltage and turn-off losses.




### 3.1 Modeling of Uncontrolled Rectifier

The peak A.C supply of 325V is given to a uncontrolled rectifier or full bridge rectifier it normally consists of 4 diodes and a capacitor to smoothen the ripple contents. The diodes D1 and D3 operates in positive have cycle and the diodes D2 and D4 operates in negative half cycle thus it acts like a full bridge rectifier.

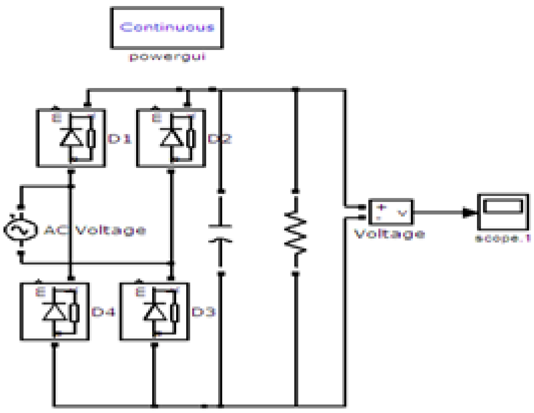



**Figure 3.1:** Uncontrolled rectifier

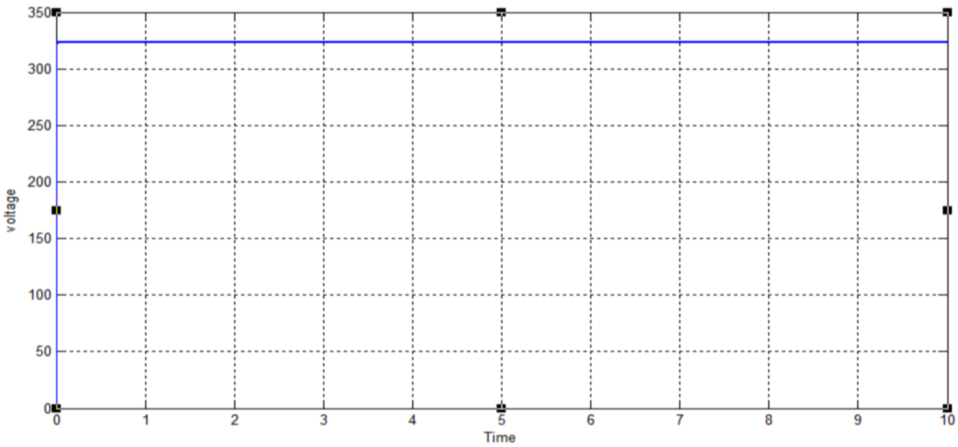



**Figure 3.2:** Simulated voltage -time characteristics of uncontrolled rectifier using Matlab

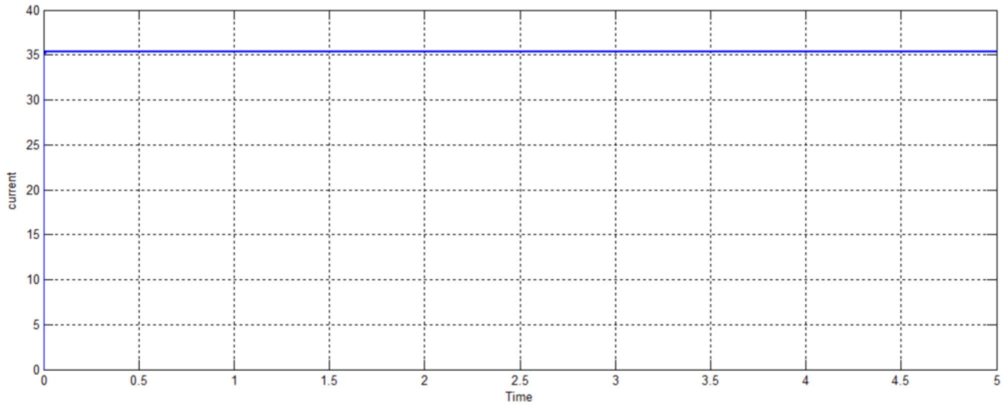



**Figure 3.3:** Simulated current -time characteristics of uncontrolled rectifier using Matlab

### 3.2 Modeling of Interleaved Buck Converter

An interleaved buck converter (step-down converter) is a DC-to-DC power converter which steps down voltage (while stepping up current) from its input (supply) to its output (load). It is a class of switched-mode power supply (SMPS) typically containing at least two semiconductors (a diode and a transistor, although modern buck converters frequently replace the diode with a second transistor used for synchronous rectification) and at least one energy storage element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors (sometimes in combination with inductors) are normally added to such a converter's output (load-side filter) and input (supply-side filter).

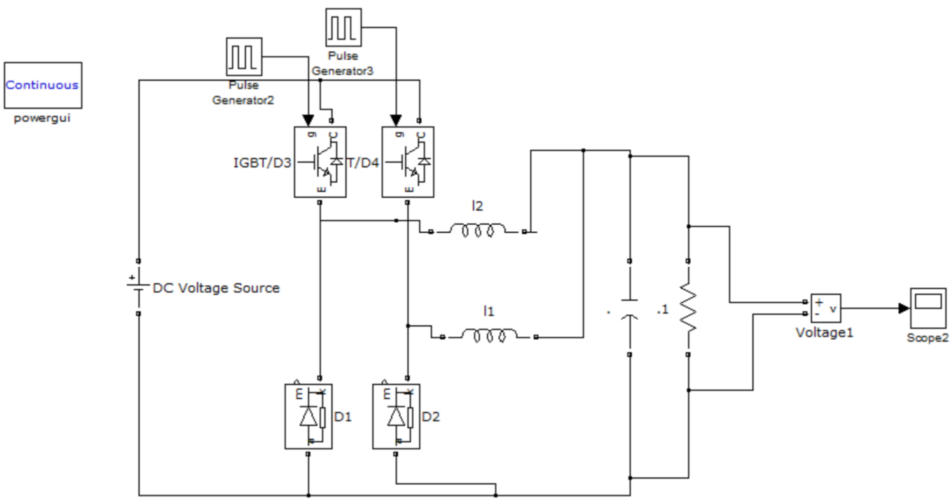



**Figure 3.4:** Interleaved buck converter

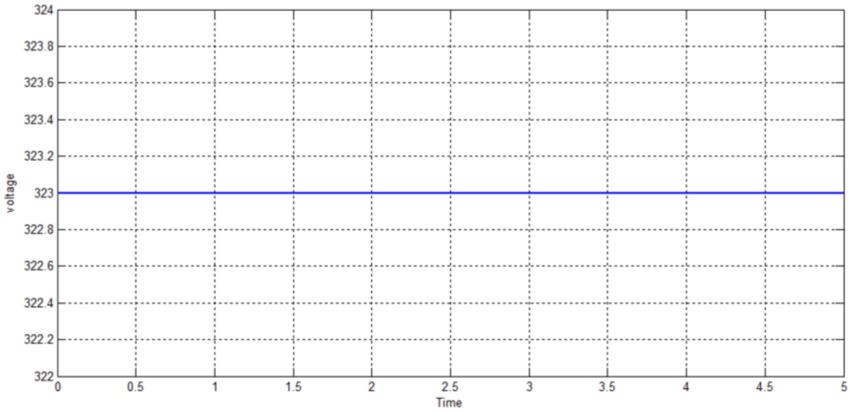



**Figure 3.5:** Voltage-time characteristics input for interleaved buck converter using Matlab.

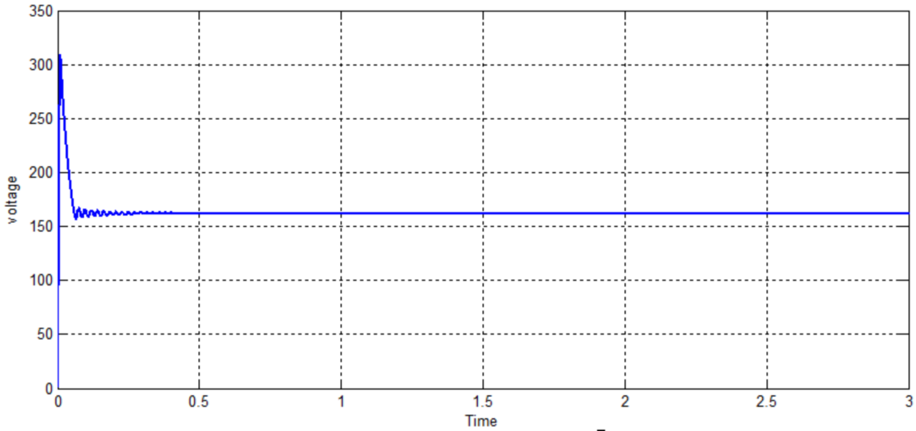



**Figure 3.6:** Simulated voltage -time characteristics for interleaved buck converter using Matlab.

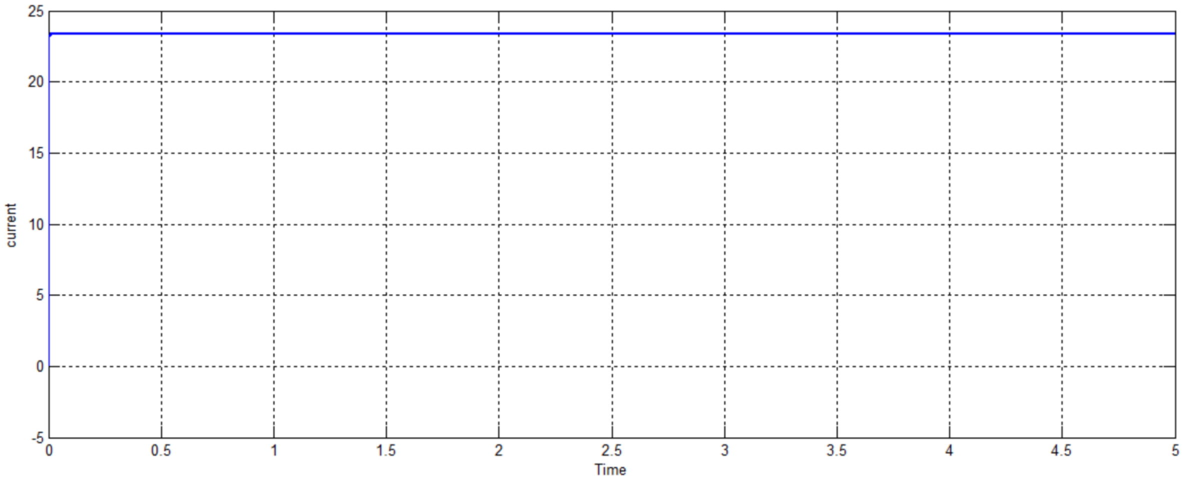



**Figure 3.7:** Simulated current -time characteristics for interleaved buck converter using Matlab.

### 3.3 Modelling of Single Phase Inverter

Full bridge converter is also basic circuit to convert dc to ac. An ac output is synthesized from a dc input by closing and opening switches in an appropriate sequence. There are also four different states depending on which switches are closed. Switches S1 and S4 should not be closed at the same time. S2 and S3 should be be closed in parallel too. Otherwise, a short circuit would exist across the dc source. Real switches do not turn on or off instantaneously. Hence, switching transition times must be accommodated in the control of switches. Overlap of switch "on" will cause short circuit (shoot-through fault) across the dc voltage source. The time allowed for switching is called blanking time.

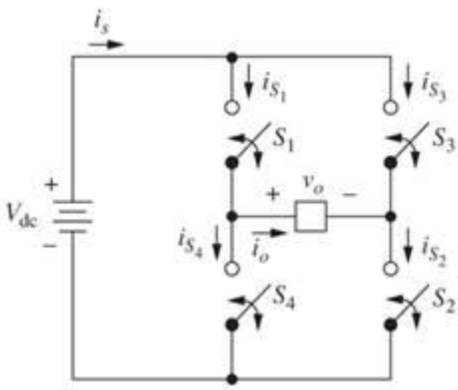
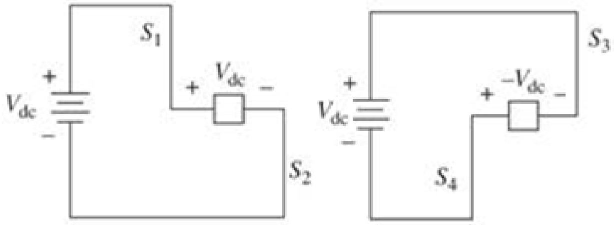
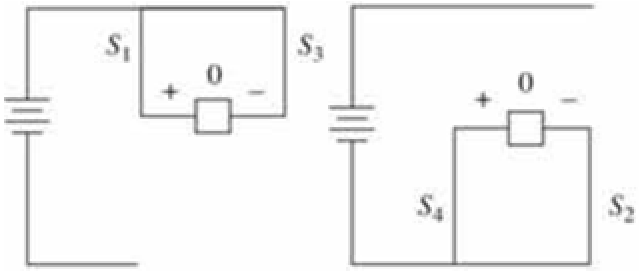



**Figure 3.8:** single phase inverter




**State 1 and State 2**




**State 3 and State 4**

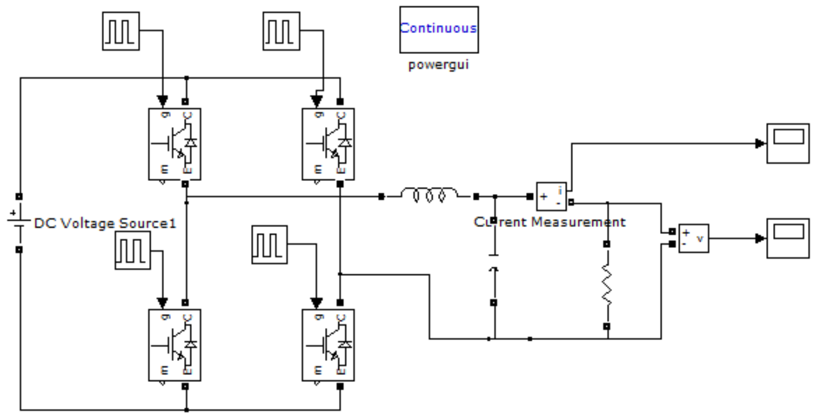



**Figure 3.9:** Single phase inverter

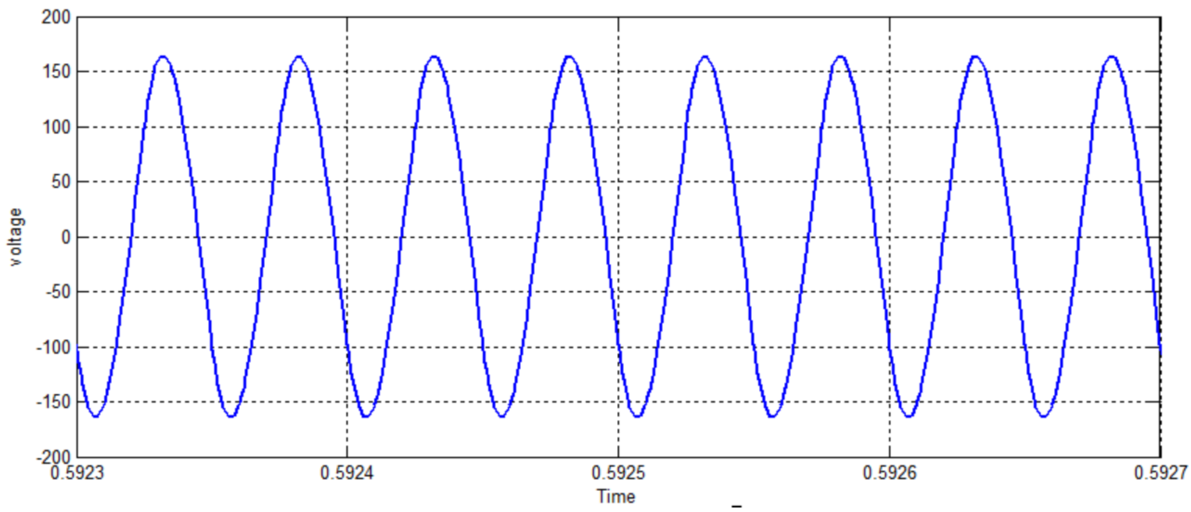



**Figure 3.10:** Simulated voltage -time characteristics for single phase inverter using Matlab.

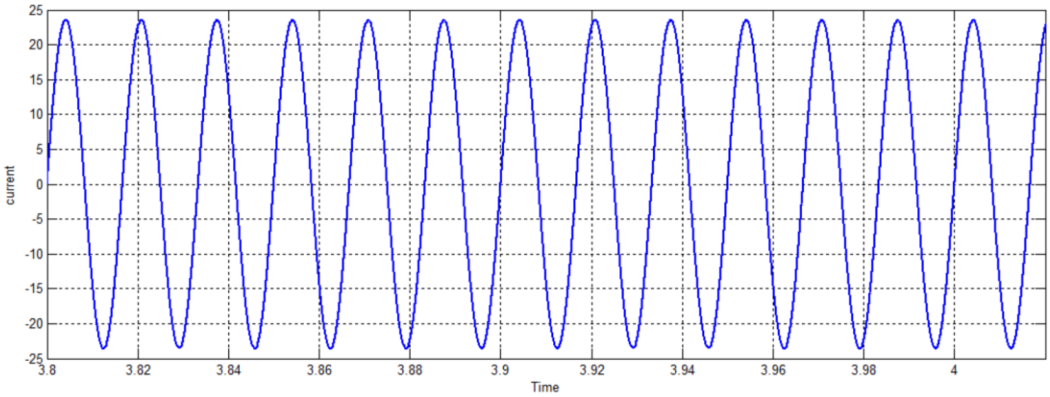



**Figure 3.11:** Simulated current -time characteristics for single phase inverter using Matlab

### 3.4 Modelling of Uncontrolled Rectifier Coupled with Interleaved Buck Converter

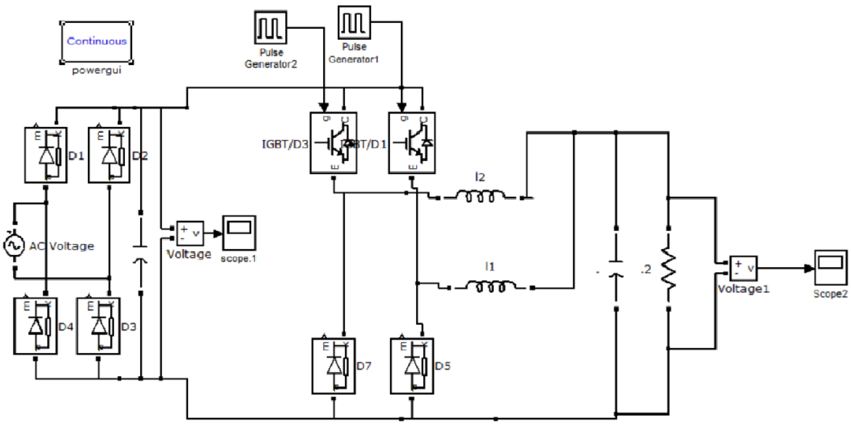



**Figure 3.7:** uncontrolled rectifier coupled with interleaved buck converter

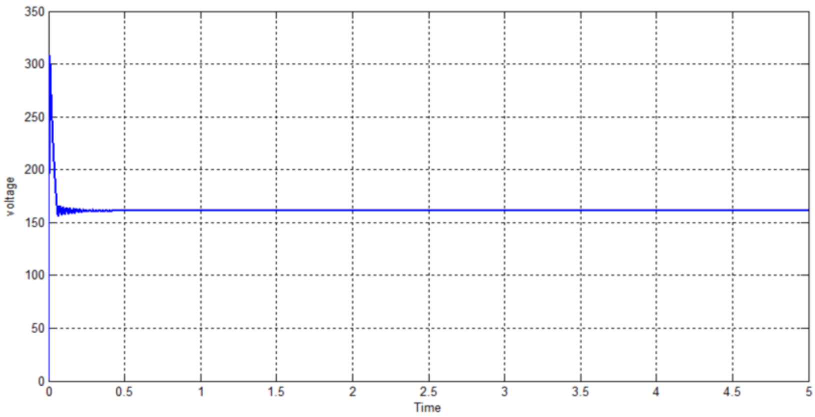



**Figure 3.6:** Simulated voltage -time characteristics for uncontrolled rectifier coupled with interleaved buck converter using Matlab.

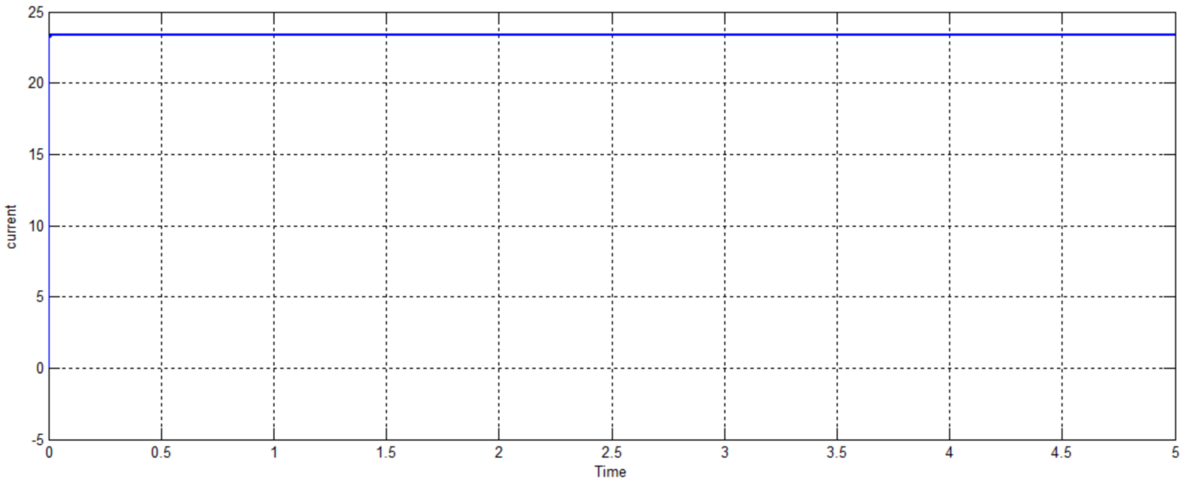


**Figure 3.7:** Simulated current -time characteristics for uncontrolled rectifier coupled with interleaved buck converter using Matlab.

### 3.5 Modelling of Uncontrolled Rectifier Coupled with Interleaved Buck Converter and Single Phase Inverter

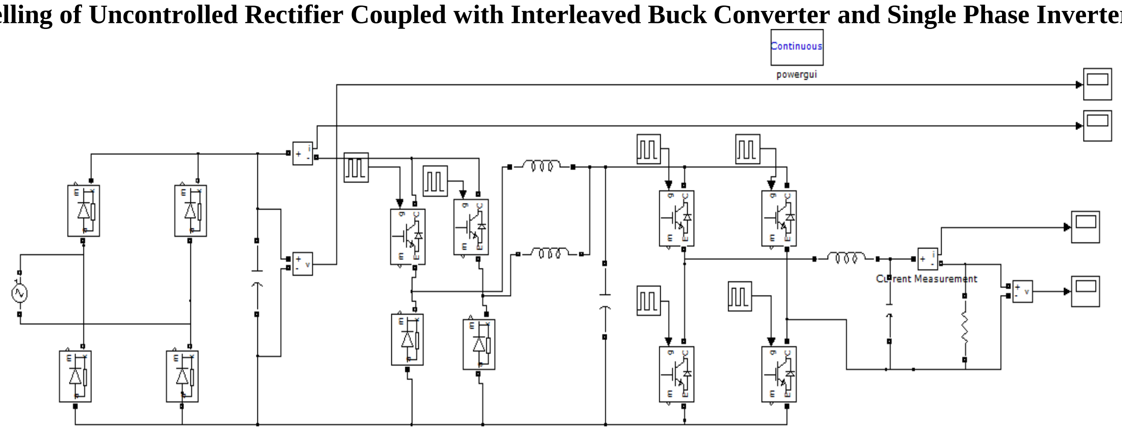



**Figure 3.8:** uncontrolled rectifier coupled with interleaved buck converter and single phase inverter

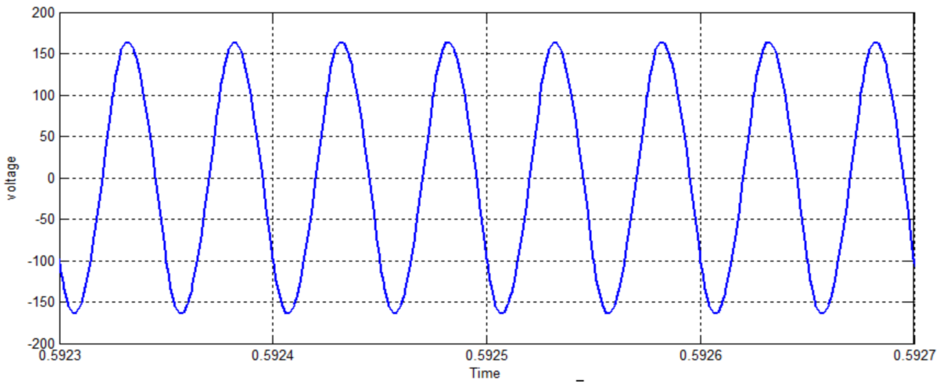


**Figure 3.9:** Simulated voltage -time characteristics for uncontrolled rectifier coupled with interleaved buck converter and single phase inverter using Matlab.

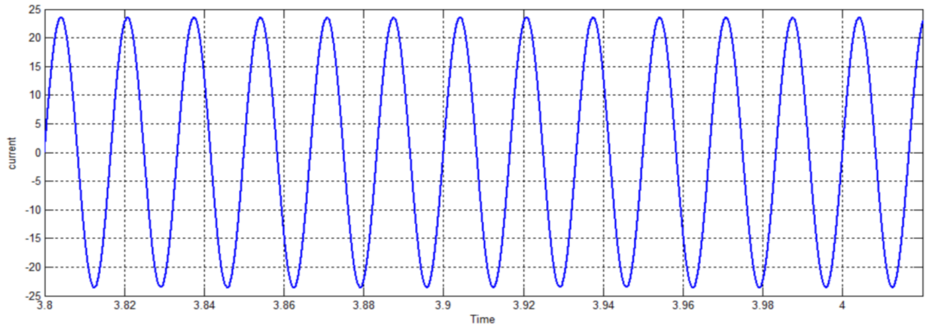


**Figure 3.10:** Simulated current -time characteristics for uncontrolled rectifier coupled with interleaved buck converter and single phase inverter using Matlab.

### 3.6 Modelling of Uncontrolled Rectifier Coupled with Interleaved Buck Converter and Single Phase Inverter and Transformer

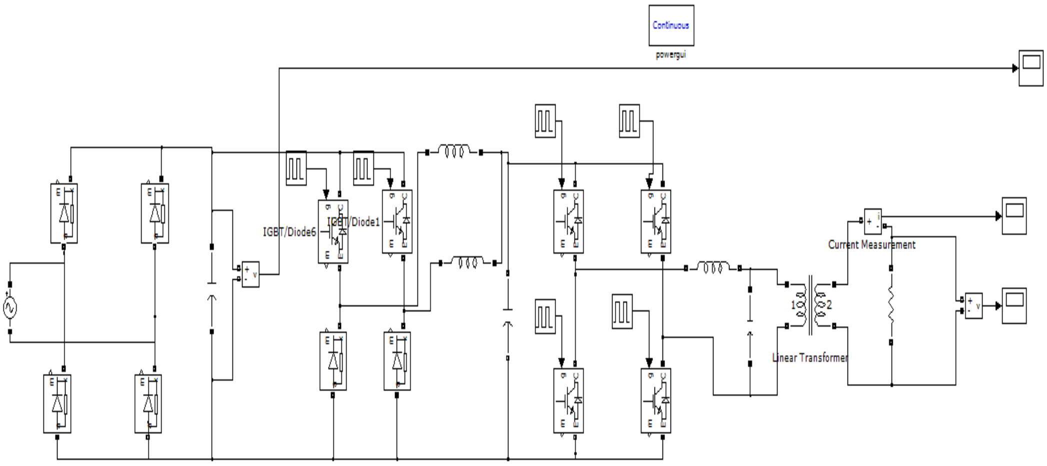



**Figure 3.11:** uncontrolled rectifier coupled with interleaved buck converter and single phase inverter and transformer

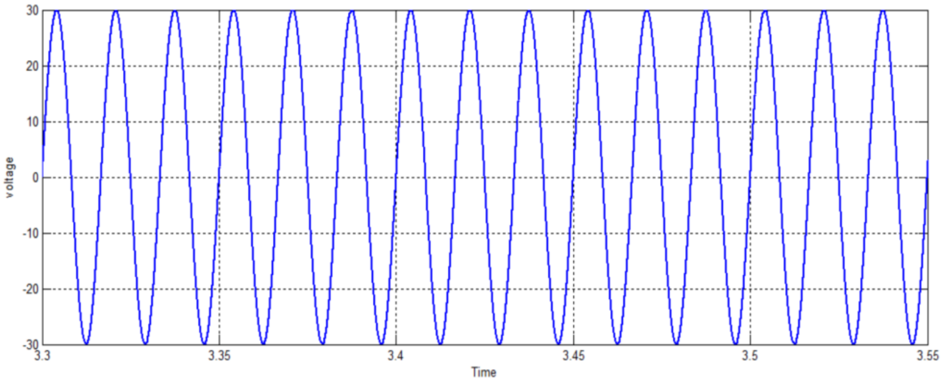



**Figure 3.12:** Simulated voltage-time characteristics for uncontrolled rectifier coupled with interleaved buck converter and single phase inverter and transformer using Matlab.

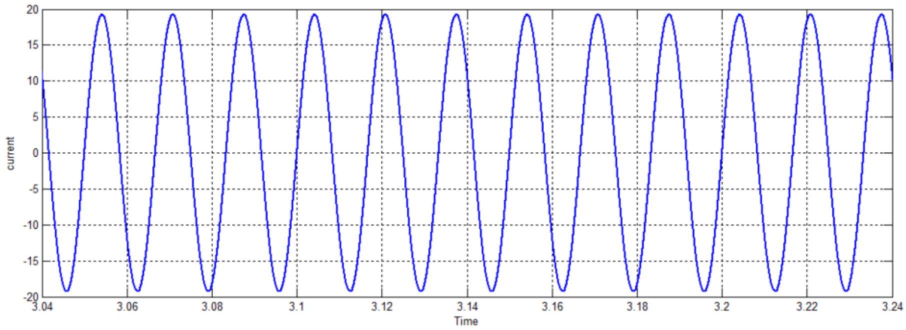



**Figure 3.13:** Simulated current-time characteristics for uncontrolled rectifier coupled with interleaved buck converter and single phase inverter and transformer using Matlab.

### 3.7 Modeling of Full Circuit

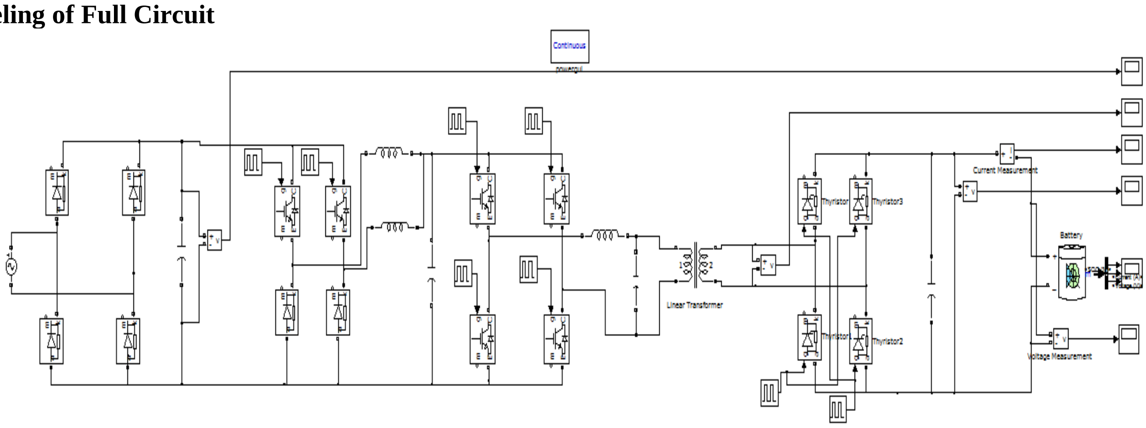



**Figure 3.14:** uncontrolled rectifier coupled with interleaved buck converter and single phase inverter and transformer and controlled rectifier

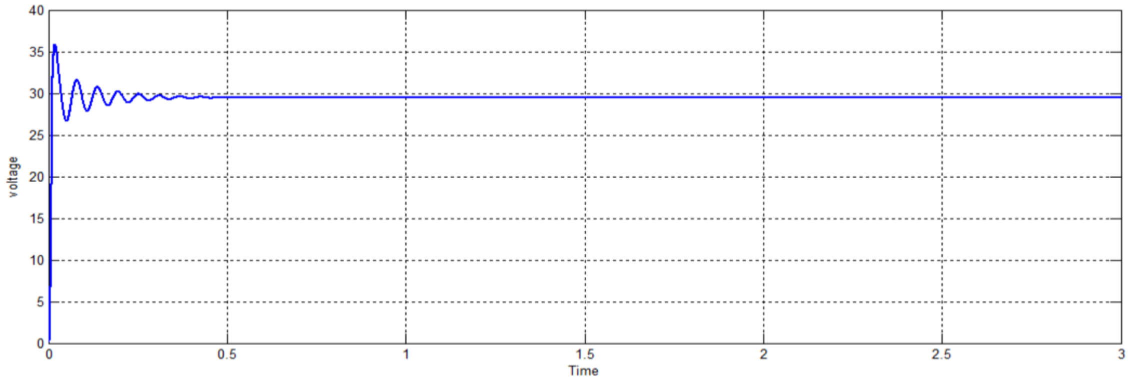



**Figure 3.15:** Simulated current-time characteristics uncontrolled rectifier coupled with interleaved buck converter and single phase inverter and transformer and controlled rectifier using Matlab.

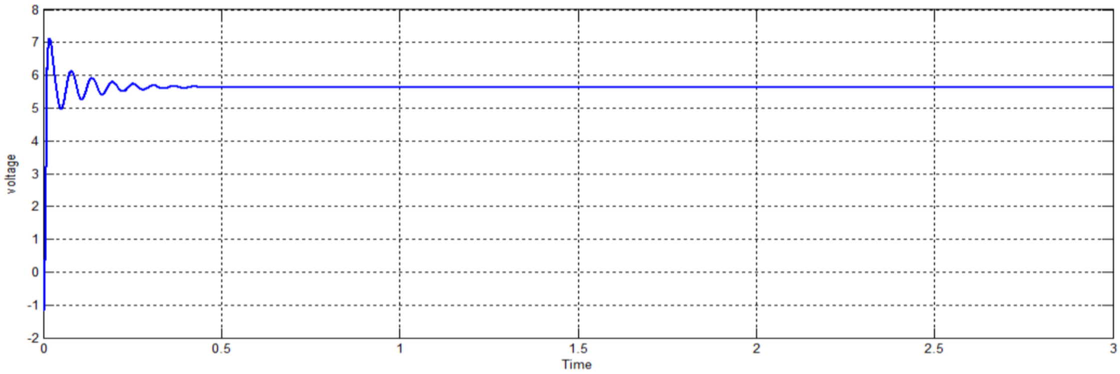



**Figure 3.16:** Simulated current-time characteristics uncontrolled rectifier coupled with interleaved buck converter and single phase inverter and transformer and controlled rectifier using Matlab.

### 3.8 Characteristics of Battery

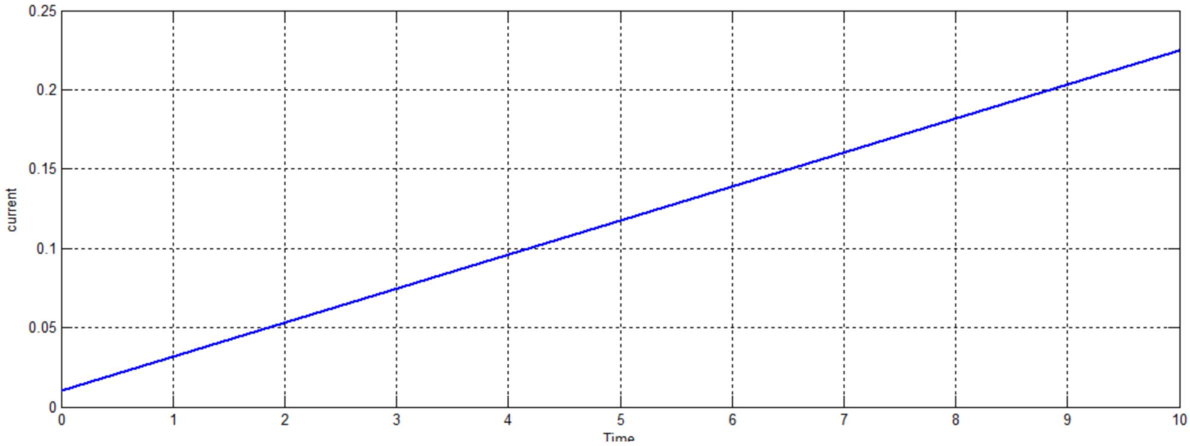



**Figure 3.16:** Battery state of charge

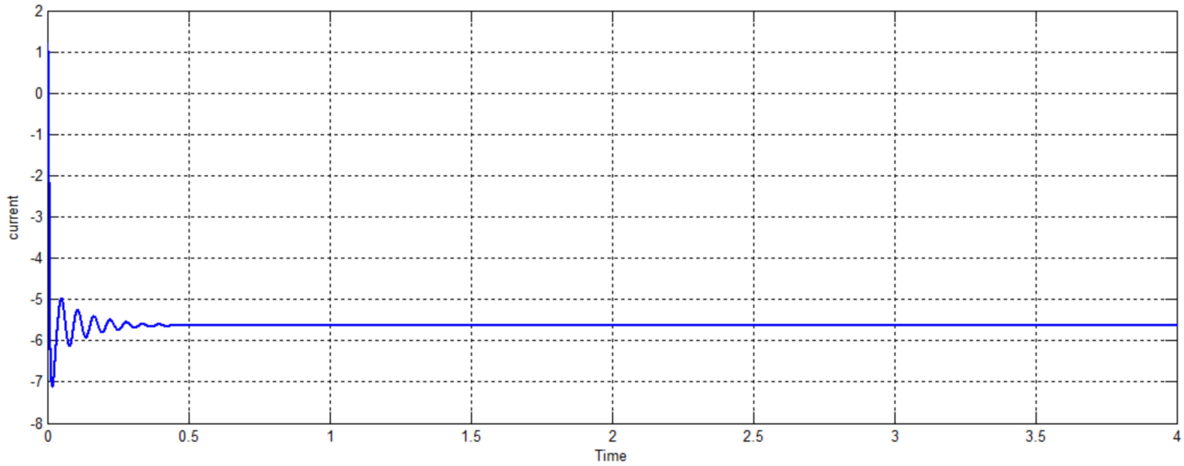



**Figure 3.17:** Battery current

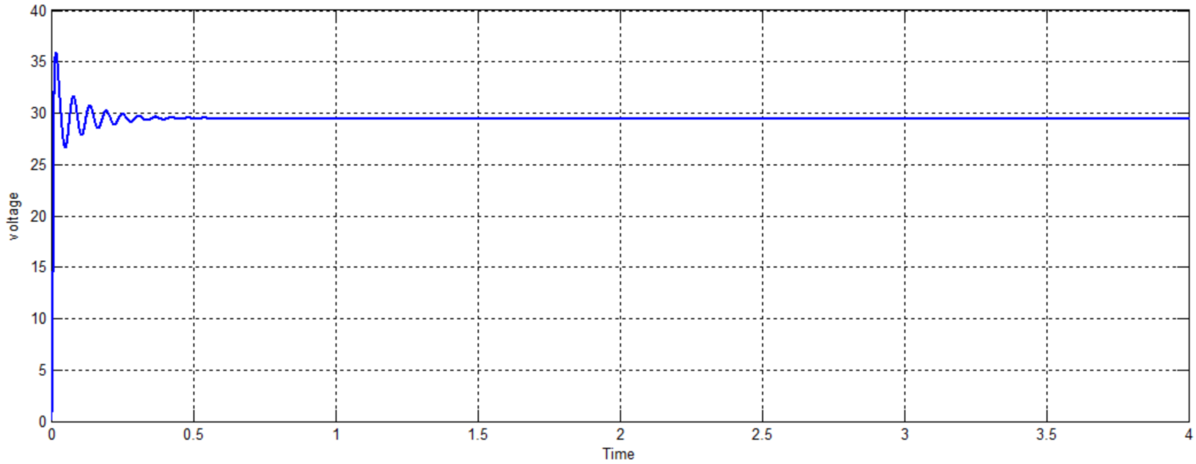



**Figure 3.18:** Battery voltage

## 4. Conclusion

The alternative has been presented to overcome the demerits of traditional buck converter for plug in hybrid electric vehicles. Analysis has shown that a general four –level flying capacitor dc-dc converter reduce the inductance requirement dramatically. Moreover, a variable dc-dc converter has been proposed that was derived from the four-level dc-dc converter to further minimize the inductance to null for hybrid electric vehicle that require three discrete voltage levels. The transient current is well under control with the aid of the duty cycle control. By advantageously utility stray inductance, the variable dc-dc converter achieves high efficiency with high power density. Therefore, it is a promising alternative to the existing boost converter for Hybrid Electric Vehicle.

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