

## TIC-Driven Optimization of Energy Storage for Enhanced Hybrid Renewable Energy Performance

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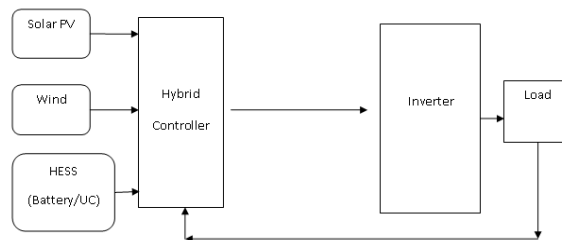
### ABSTRACT

To optimize the performance of energy storage system triple input converter is proposed, the topology is simulated in MATLAB/ Simulink environment. The simulation work is performed with three different input sources, one is solar photo voltaic source and another is battery storage system and yet another is UC bank. The converter is operated with continuous conduction first in buck mode, then in boost mode and finally in buck-boost mode and entire results are analyzed under steady state conditions. Independent switching scheme is used for the generation of the gate pulses to the converter switches. The simulation results of switching pulses, voltage appearing across inductor, current through inductor, voltage appearing across load, and current through load for converter operation in buck mode, then in boost mode and finally, buck- boost mode of operations with converter are presented.

**Keywords:** UC (ultra Capacitor); TIC (Triple Input Converter); Buck Boost converter.

### I. INTRODUCTION

The persistent rise in energy consumption, the accelerating price, the effect of inducing contamination in the environment due to the usage of fossil fuels and the global warming concern motivated the researchers towards making renewable energy sources more efficient. The technologies working in the field of renewable energy have increased reliability level, and proved to be competitive as compared to conventional power generating systems (Dai et al., 2008). The renewable energy sources, as a stand-alone unit, have potential to provide sustainable electricity to the remote regions where conventional power grid fails to serve. The increasing demand for renewable energy has resulted in the development of proper energy storage system with appropriate energy dispensing mechanism. The interest in utilizing Solar PV technology is also spreading very fast. PV systems can be used as a stand-alone system or it can be part of a hybrid system. Nevertheless, the question of availability of solar energy systems has not been satisfactorily addressed by currently available technological schemes. Therefore, battery integrated solar systems have higher availability as compared to battery-less solar systems. (Denholm et al., 2013; Appen et al., 2013; Ogimoto et al., 2013). Still the currently available battery integration systems with solar is not able to meet the power requirements of dynamic loads. Consequently, in this work the improvement in availability of a hybrid solar system with battery and UC is analyzed. The functional block diagram of renewable energy system with HES system is shown in figure 1. The work presented is aimed towards proving the potential of ultra- capacitors to cater sudden power demand placed by inductive loads particularly at the time of starting. The specialty of UC lies in the fact that is capable of charging and discharging at very high rate. Therefore, UC is employed for a number of high power applications. Owing to its high charge and discharge rate UC can be employed to the places where high chunk of power is required at frequent intervals. The potency of UC is realized in this work by connecting it with the battery to a PV based power supply system.



**Figure-1: Functional Block Diagram of Hybrid Renewable energy with HES system**

Today, the storage technology is essential to various energy solutions. The complexity of storing energy has always been inhibitive' still, the development of new demands and applications is requiring deployment of energy storage devices. In many such applications, like hybrid electric vehicles, micro-grid deployment, rural electrification, etc. hybrid storage systems have become more important than ever owing to ensure efficiency, reliability, and economic savings. The hybrid energy solutions are scalable in multiple ways one of which is that it can be a constant source of energy ranging from few seconds to many hours to be a constant source of supply without intervention of grid ever. Moreover, it can also supply various spurts of power as required by various loads thereby ensuring the technical viability of the Solar PV systems catering to the base-load requirements. Hence, all such energy solutions can be designed with hybrid sources to ensure power reliability and economic viability. (Zhao et al., 2016; Fernandes et al., 2008; Burke 1996)

There are various storage technologies available today. Some of them are Solid state batteries, Ultra-capacitors, Flywheels, Pumped hydroelectric storage dams, Rail energy storage, Compressed Air storage etc. Still, many of them are not able to meet the different requirements in terms of the specific energy / power, longevity, operative range, system availability at various duration / location, safety, and cost viability. Recently, consistent technological research and innovation has led to cost reduction in many storage systems so that they can be exploited on a need-basis. (Guo et al., 2017; Ayad et al., 2004). The proposed work focuses on optimizing the performance of battery-ultra-capacitor storage device.

## II. PROPOSED CONVERTER SYSTEM

The TIC (triple input converter) is proposed for HESS. The input sources are the PV, Batter and Ultra capacitors. Figure 2 presents the simulation model of the proposed TIC which is developed in the MATLAB/SIMULINK environment. On observing the model, it is apparent that the left side of the network forms a switch source network in which Sources are PV, BATT and UC switches are S1 to S4 four bidirectional conducting bidirectional blocking switches and two bridging switches SS1 and SS2, which are unidirectional conducting bidirectional blocking switches.

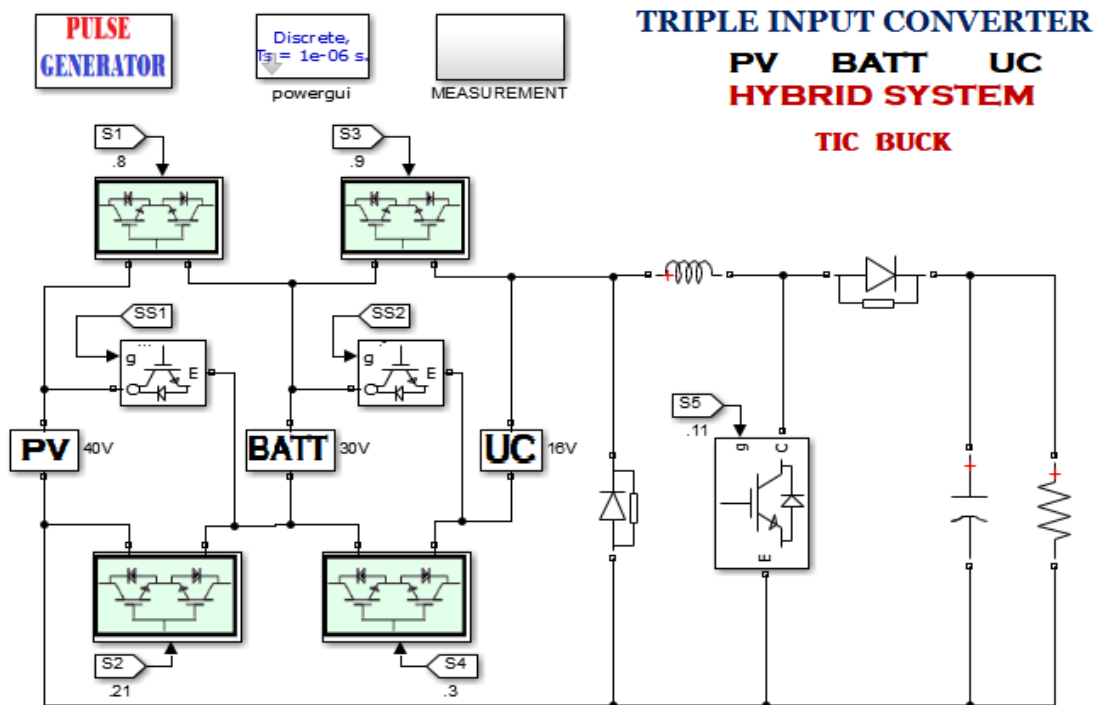
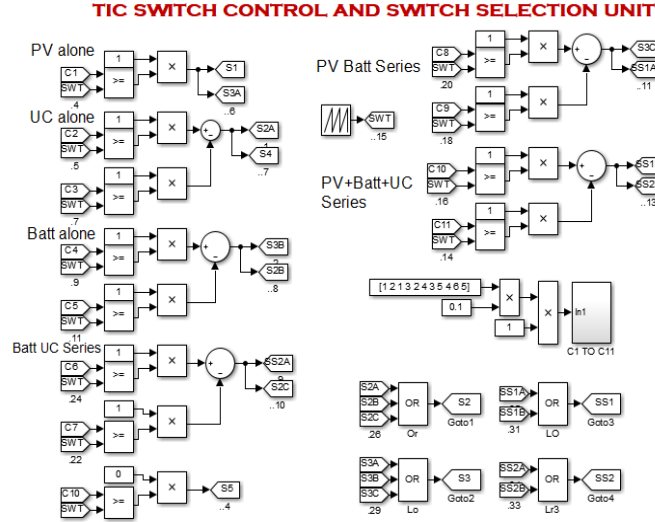


Figure 2: Simulation model of the proposed TIC

In place of bidirectional conducting bidirectional blocking switches, unidirectional conducting bidirectional blocking switches can also be applied. The right side of the network comprises of two diodes, an inductor, a capacitor, a load resistor and a unidirectional conducting bidirectional blocking switch. Source PV is realized from

solar photovoltaic model and BATT is realized from a battery model and source UC is realized from an ultra-capacitor model. S1 to S5 and SS1 SS2 are the driving pulses obtained from the Pulse generating unit. The simulation time is kept as 1e-6 sec. which equals 100kHz, which can be seen in the power GUI block. The measurement subsystem block holds all the scopes for measurement of different quantities for analysis of performance of TIC.



**Figure 3: Pulse Generating Unit for TIC**

Figure 3 represents the development of pulses for the converter switches particularly for the converter operation in buck boost mode. For the generation of pulses, a saw tooth wave with unity magnitude is compared with a constant signal and the required pulse width is generated at the output for different switches of the converter. Furthermore, the switch selection for forming a combination of switches to achieve a particular voltage at the output is done by employing a logical OR operation blocks as shown in the figure.

### III. RESULTS & DISCUSSIONS

The simulation results of switching pulses, voltage appearing across inductor, current through inductor, voltage appearing across load, and current through load for converter operation in buck mode, then in boost mode and finally, buck- boost mode of operations with converter on time  $T_{ON} > 0.5$  (voltage boost) and  $T_{ON} < 0.5$  (voltage buck) are presented respectively in Figures 4 - 5. The respective inductor current waveform indicates that for every level change in voltage, there is a corresponding change in slope of current waveform. The slope of current waveform increases with the increase in magnitude of voltage pulse and has a positive slope for positive voltage. For negative voltage the slope of inductor current becomes negative. It can also be observed that during complete switching cycle the inductor current attains the same level from where it started. The voltage across the load and hence the load current can be varied through suitable adjustments in the duty ratios  $D_1$  to  $D_6$ . The proposed converter is also equally capable to be used as buck converter or boost converter. Furthermore, it can also be used for bidirectional power flow operation for particular application. The non-idealistic behavior of converter components causes trivial deviations from idealistic results owing to the presence of conduction and switching losses and the drop in voltage allied with the same. Table 1 gives the detail of the values of parameters employed for simulation.

**Table 1: Simulation Parameters TIC**

| Mode                  | $V_{PV}$ | $V_{BT}$ | $V_{UC}$ | $T_{ON}$ | $T_{OFF}$ | L   | C           | $f_s$ | $V_0$ | R           |
|-----------------------|----------|----------|----------|----------|-----------|-----|-------------|-------|-------|-------------|
| Buck(b)/Boost(B)      |          |          |          |          |           |     |             |       |       |             |
| $T_{ON} > 0.5T_s$ (B) | 40V      | 30V      | 16V      | $0.6T_s$ | $0.4T_s$  | 7mH | 470 $\mu$ F | 20kHz | 77.5V | 10 $\Omega$ |
| $T_{ON} < 0.5T_s$ (b) | 40V      | 30V      | 16V      | $0.4T_s$ | $0.6T_s$  | 7mH | 470 $\mu$ F | 20kHz | 21V   | 10 $\Omega$ |

### 3.1.1. Simulation Results of Proposed TIC in Buck Mode

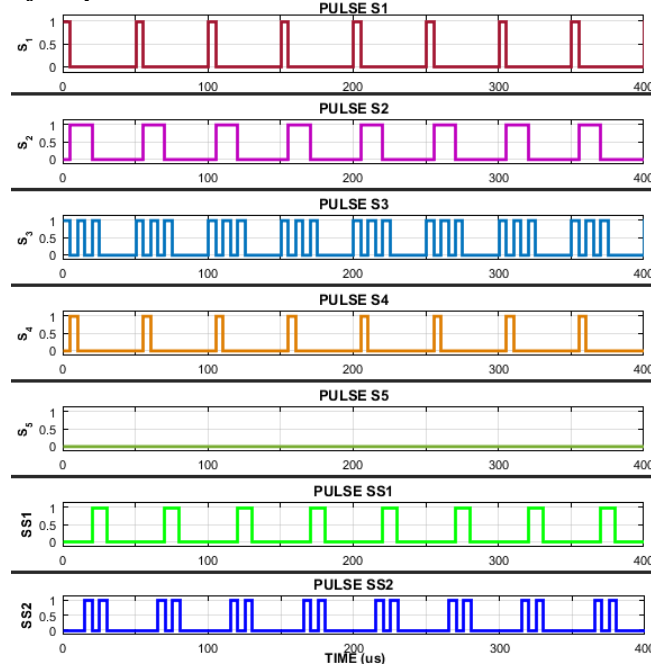


Figure 4: Pulses applied to different switches in buck mode of operation

Figure 4 shows the pulses applied to different switches S1-S5, SS1 and SS2 for converter operation in buck mode. The pulse duration or the pulse width and the repetitiveness of the pulses and their off duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 5 and figure 6 shows the voltage across inductor, current through inductor and voltage across load and current through load respectively for converter operation in buck mode. Figure 4.26 presents the combined voltage, current and power of PV, Battery, UC and load for ease of evaluation of power sharing, current sharing amongst the sources and its match with the load for buck mode of operation.

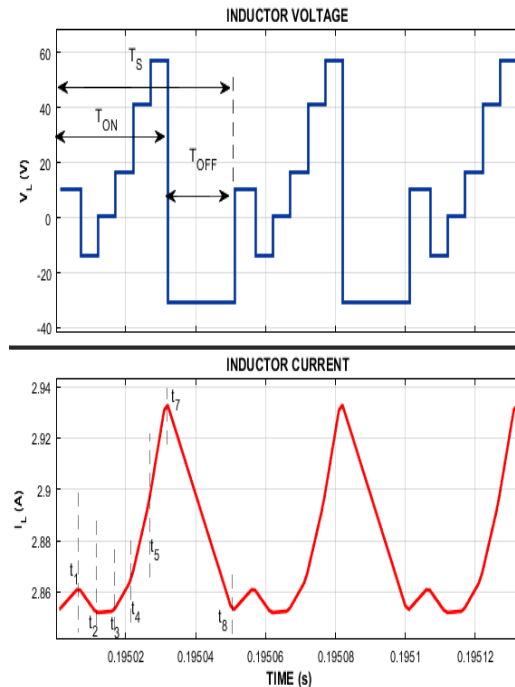


Figure 5: Voltage across inductor and current through inductor for converter operation in Buck mode

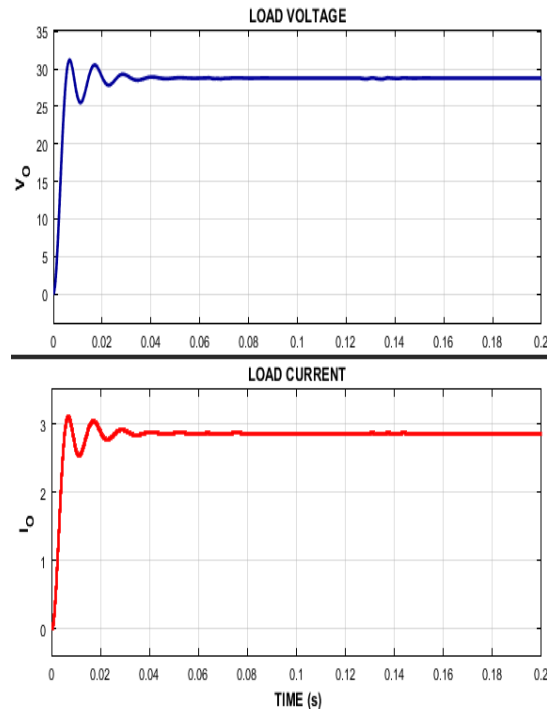


Figure 6: Voltage across load and current through load for converter operation in Buck mode

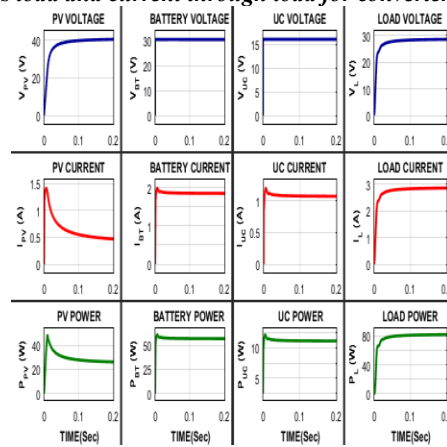


Figure 7 : RMS values of voltages, current, power of PV, Battery, UC and Load

### 3.1.2. Simulation Results of Proposed TIC in Boost Mode

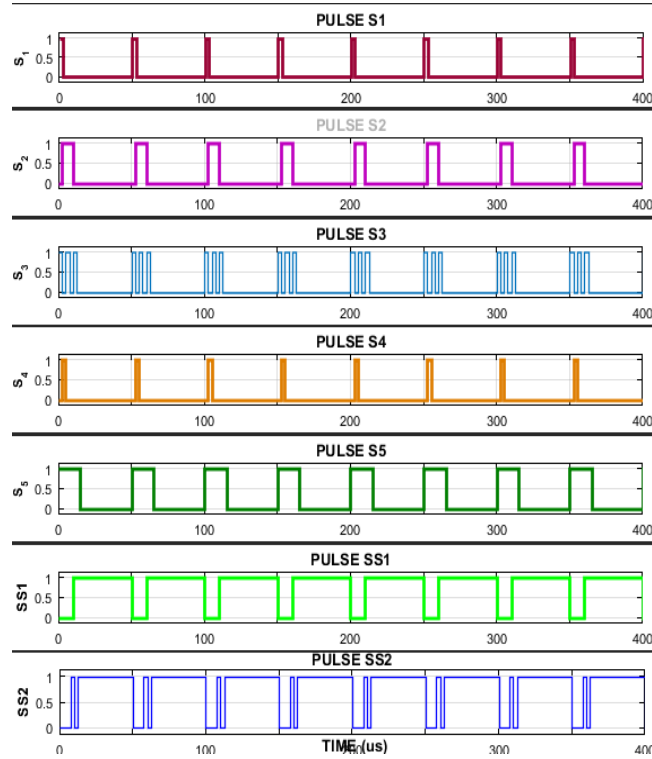


Figure 8: Pulses applied to different switches for converter operation in boost mode

Figure 8 shows the pulses applied to different switches  $S_1$ - $S_5$ ,  $SS1$  and  $SS2$  for converter operation in boost mode. The duration of the pulses and the pulse frequency with their duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. figure 9 and figure 10 shows the Voltage across inductor and current through inductor and Voltage across Load and current through load respectively for converter operation in boost mode. Figure 4.30 presents the combined voltage, current and power of PV, Battery, UC and load for ease of evaluation of power sharing, current sharing amongst the sources and its match with the load

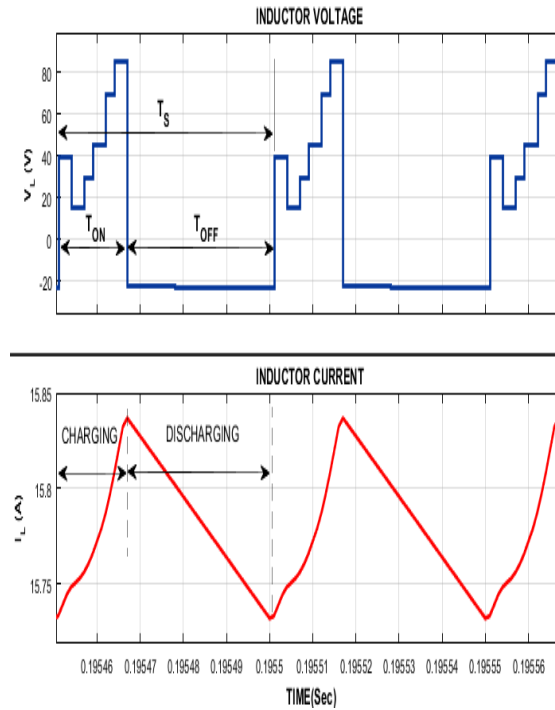


Figure 9: Voltage across Inductor and current through inductor for converter operation in boost mode

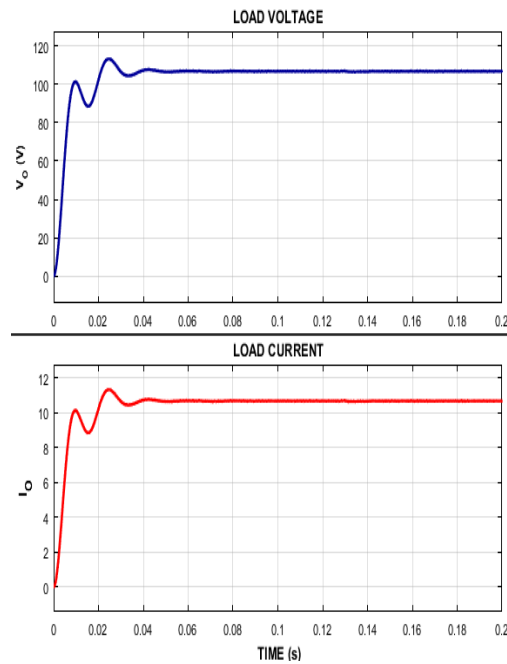


Figure 10: Voltage across load and current through load for converter operation in boost mode

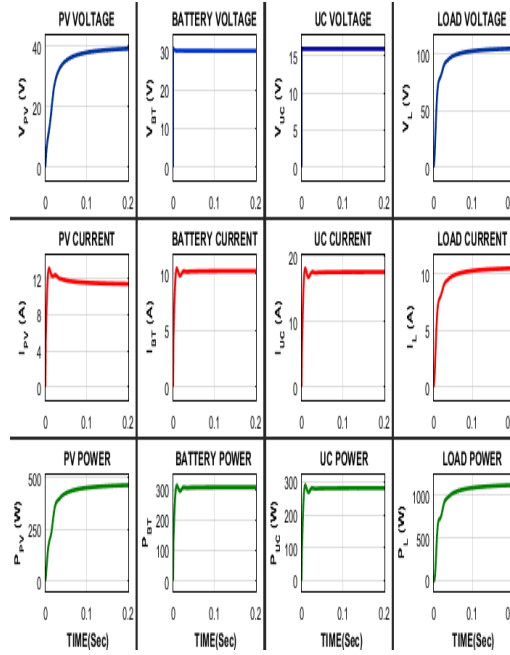


Figure 11: RMS values of voltages, current, power of PV, Battery, UC and Load

### 3.1.3. Simulation Results of Proposed TIC in Buck-Boost Mode

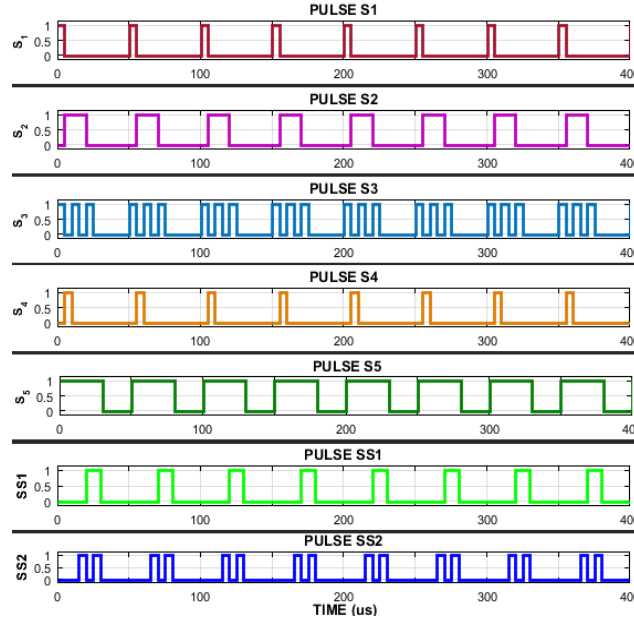


Figure 12: Pulses applied to different switches in buck-boost mode of operation ( $T_{ON} > 0.5T_s$ )

Figure 12 shows the pulses applied to different switches S1-S5, SS1 and SS2 in buck-boost mode of operation for  $T_{ON} > 0.5T_s$ . The duration of the pulse or the pulse width and the repetitiveness of the pulses and their off duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 13 and figure 14 shows Voltage across inductor and current through inductor and Voltage across Load and current through load for converter operation in buck-boost mode respectively. Figure 4.34 presents the combined voltage, current and power of PV, Battery, UC and load for ease of evaluation of power sharing, current sharing amongst the sources and its match with the load.



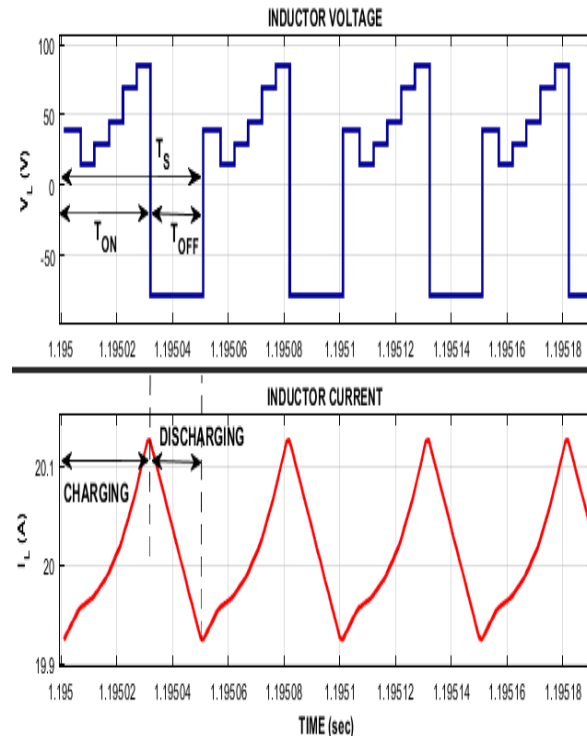


Figure 13: Voltage across Inductor and Current through Inductor for converter operation in buck-boost mode( $T_{ON} > 0.5T_S$ )

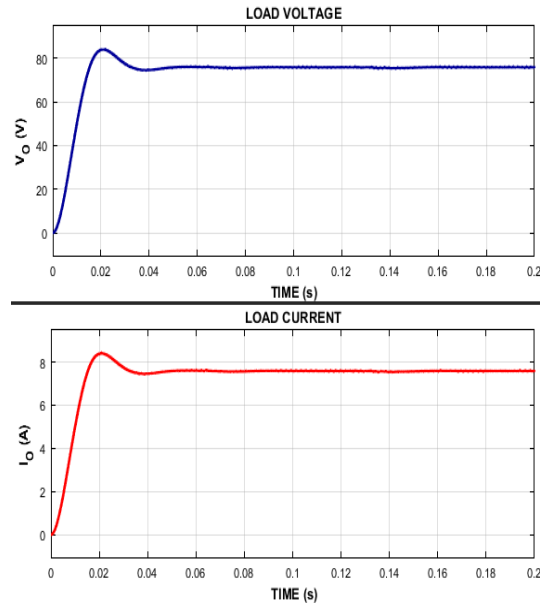


Figure 14: Voltage across Load and Current through Load for converter operation in buck-boost mode ( $T_{ON} > 0.5T_S$ )

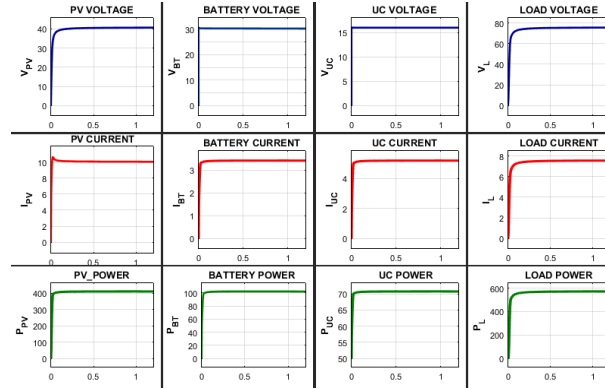


Figure 15: RMS values of voltages, current, power of PV, Battery, UC and Load ( $T_{ON} > 0.5T_s$ )

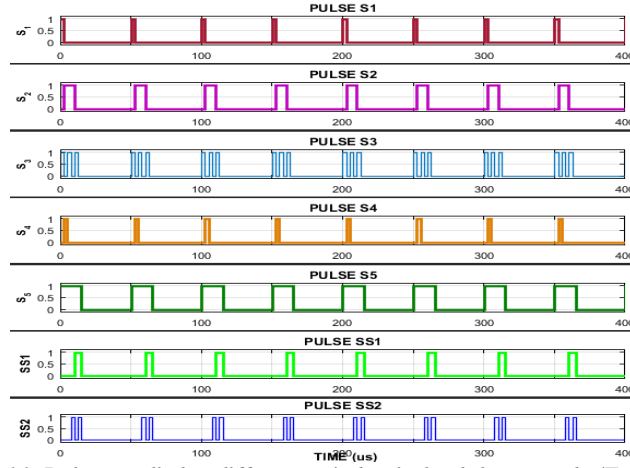


Figure 16: Pulses applied to different switches in buck-boost mode ( $T_{ON} < 0.5T_s$ )

Figure 16 shows the pulses applied to different switches S1-S5, SS1 and SS2 for converter operation in buck-boost mode with  $T_{ON} < T_s$ . The duration of the pulse or the pulse width and the repetitiveness of the pulses and their off duty is decided by the output voltage and the switching strategy adopted to meet the load voltage. Figure 17 and figure 18 shows the voltage across inductor and current through inductor and the voltage across Load and current through load for converter operation in buck-boost mode respectively. Figure 7.38 presents the combined voltage, current and power of PV, Battery, UC and load for ease of evaluation of power sharing, current sharing amongst the sources and its match with the load.

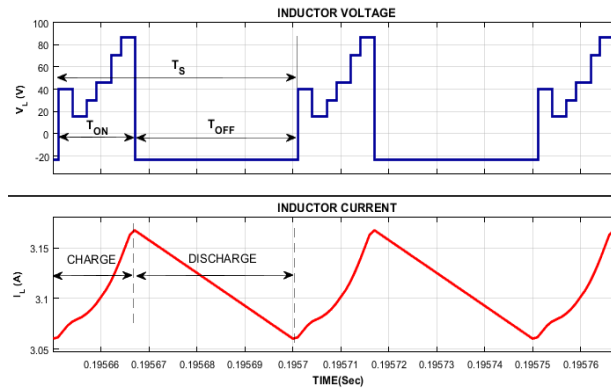


Figure 17: Voltage across Inductor and Current through Inductor for converter operation buck-boost mode ( $T_{ON} < 0.5T_s$ )

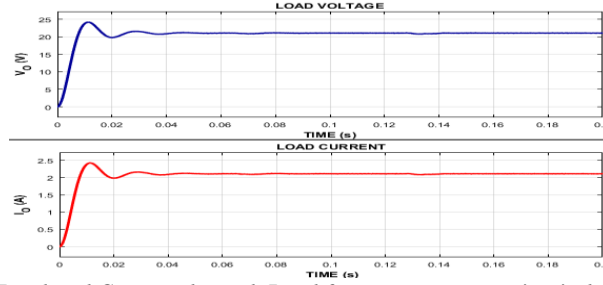


Figure18: Voltage across Load and Current through Load for converter operation in buck-boost mode ( $T_{ON} < 0.5T_s$ )

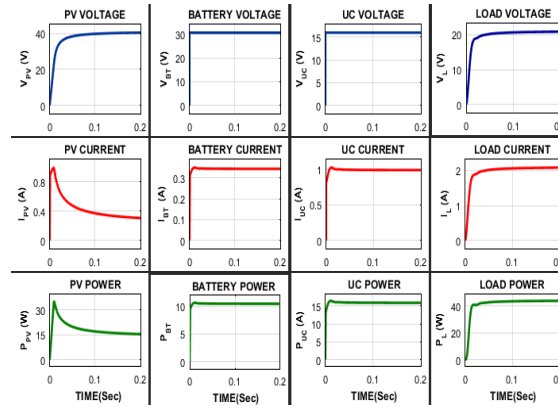


Figure 19: RMS values of voltages, current, power of PV, Battery, UC and Load  $T_{ON} < 0.5T_s$

It is observed that the voltage at output terminals is maintained constant at present value. In this condition also the proposed converter acts as single input converter and ensures stability and reliability.

#### IV. CONCLUSION

The TIC (triple input converter) is proposed for HESS. The input sources are the PV, Batter and Ultra capacitors. The proposed converter is tested for the buck mode, boost mode and buck boost mode separately from the simulation results it is clear that the proposed converter will maintain a constant output voltage and current which makes the system operation more reliable. Also at the time dynamic loads are introduced the stored energy in ultra capacitors plays a major role as it stops the sudden discharge of battery. The topology presented is tested and verified in MATLAB software for the three different modes of operations.

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