Renewable power sharing to grid through novel dual buck interleaved bidirectional converter operating at high frequency

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Abstract—

In this paper a grid interconnected renewable source trough dual buck interleaved bidirectional converter operated at high frequency switching is introduced. The renewable source considered is PVA module along with booster converter and MPPT connected in parallel to the BESS. The dual buck interleaved bidirectional converter has six high frequency operating switches (MOSFET) by which the power transfer is done from renewable to grid and from grid to battery storage. Along with the switches, four energy storage inductors are also used for bucking operation. The grid considered here is a single phase source to which the dual buck interleaved bidirectional converter is connected through LC filter. Different operating conditions are considered for sharing of power from PVA to grid, PVA to battery and grid to battery. The inverter and rectifier stages of the proposed circuit topology are shown with graphical representation using MATLAB Simulink software.

Keywords: PVA (Photo Voltaic Array), MPPT (Maximum Power point tracking), BESS (Battery Energy Storage System), MOSFET (Metal Oxide Semi-conductor Field Effect Transistor), MATLAB (Matrix Laboratory) .

I. INTRODUCTION

Utilization of renewable sources in modern power system has become mandatory so as to decrease environmental pollution and decrease global warming. As the power generation from the renewable sources is not stable and uncertain it is very vital to use efficient circuits to get maximum power at stable voltages during generation. It also very important to store the excess power into energy storage devices [1] so that they can be utilized later during deficit conditions. In previous researches for the energy conversion different and separate circuit topologies are utilized which include booster converter for voltage boosting from PVA [2], bidirectional converter for battery storage system which has the capability to charge and discharge the battery, single or three phase inverter for converting DC to AC voltage [3]. Each circuit is operated separately with its individual control and operates for one condition. This utilization of multiple circuit topologies for the power conversion leads to power loss decreasing the efficiency of the system. A novel topology needs to be adopted in order it operates as multiple types of conversion circuits [4] as per the control given to it.

In this paper a novel bidirectional interleaved dual buck converter is proposed which can operate as inverter and also as rectifier as per the requirement and conditions. The below fig. 1 is the proposed topology connected to single phase grid.

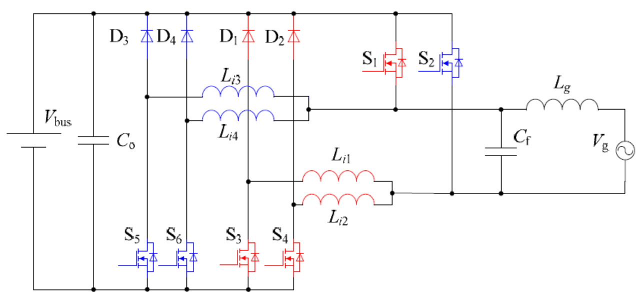

Fig. 1: Proposed bidirectional interleaved dual buck converter

In the above circuit topology all the MOSFET switches S1-S6 are operated at very high frequency [5] which reduced the harmonics generated from the converter. The inductors Li1- Li4 are the energy storage inductors used for bucking operation. The diodes D1-D4 operate as per the switching states of the MOSFET switches. The input Vbus may represent a PVA and boost converter connected in parallel to a battery storage system for power storage. The output of the converter is connected to LC filter for converting the PWM sinusoidal waveform [6] to sinusoidal waveform and injected to the single phase grid. The converter switching states are controlled in synchronization to the grid voltage. The below fig. 2 is the modified circuit [7] with renewable PVA source and battery storage device connected on the DC bus side.

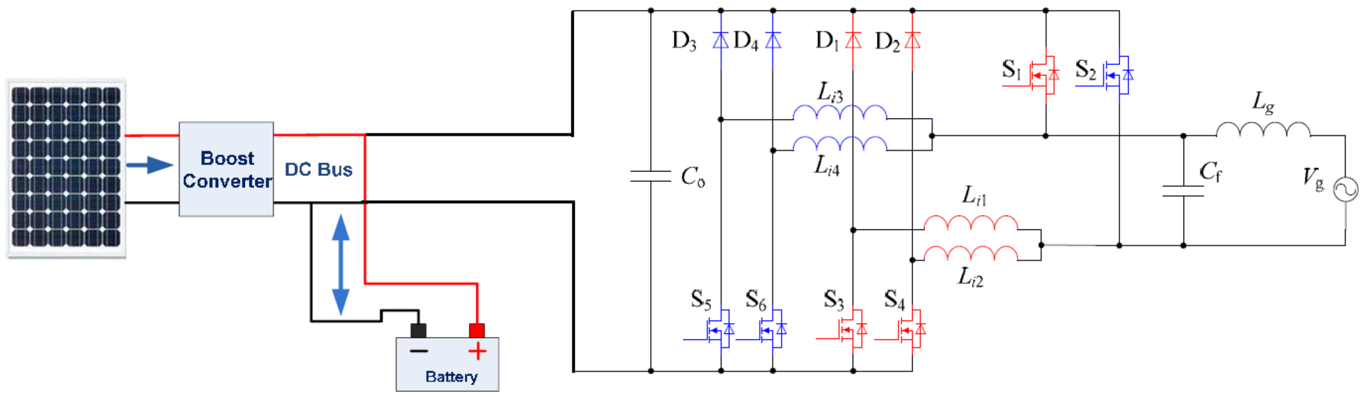

Fig. 2: PVA booster and battery connected bidirectional interleaved dual buck converter

In this paper the section I is included with introduction of the proposed bidirectional interleaved dual buck converter topology followed by section II discussing the operating principle and working modes of the proposed circuit. The section III is included with PVA and Battery storage device modeling and configuration. Simulation results generated by modeling of the proposed circuit in MATLAB software is presented in section IV with all graphs generated with respect to time. The final section V has conclusion to the paper and references cited as per the technology adopted for the modeling of the proposed circuit.

II. PROPOSED DUAL BUCK BIDIRECTIONAL CONVERTER

As seen in fig. 1 the proposed topology is included with six MOSFET switches [8] which are controlled with feedback controller [9] making the same circuit to work as inverter and also rectifier. For the operation of the switches high switching frequency PWM signals are used which are generated by reference signal generation from the feedback loop control. At first the inverter operating mode is discussed with different states [10] of operations.

A. *Inverter mode*

In this mode the circuit has to generate AC voltage at the output terminals of the circuit. In inverter mode the power from DC bus is injected to the Vg grid converting to AC voltage. Considering initially positive voltage generation the below fig. 3 is the first state of switching.

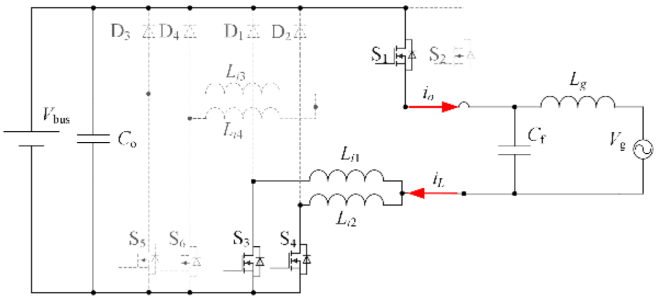

Fig. 3: Inverter Positive mode (inductor charging)

In the above mode of operation the switch S1 is kept ON continuously and switches S3 S4 are fed with PWM pulse. All the remaining switches S2 S5 S6 D1 D2 D3 and D4 are in OFF state. During this mode the current from the DC bus is conducted in positive voltage through the LC filter to the grid and passes through Li1 and Li2 charging them through S3 and S4 respectively. Energy is stored [11] in these inductors Li1 and Li2 until the switches S3 S4 are in ON state. The freewheeling mode in positive voltage condition is shown in fig. 4 below.

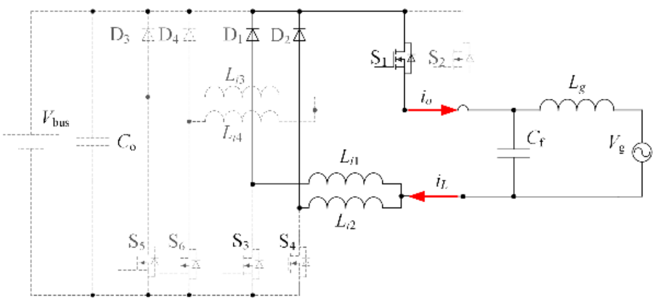

Fig. 4: Inverter Positive mode (inductor discharging)

In the above state all the switches are turned OFF with only S1 switch maintained in ON condition. During this state the diodes D1 D2 go into freewheeling [12] making the inductors Li1 and Li2 to discharge through D1 D2 and S1 to the output terminals. This state ends after the positive voltage cycle and the negative cycle conduction is started. In the negative voltage cycle the switches S5 and S6 are fed with PWM along with switch S1 to be maintained in ON state throughout the negative cycle. The below fig. 5 is the negative cycle switching state.

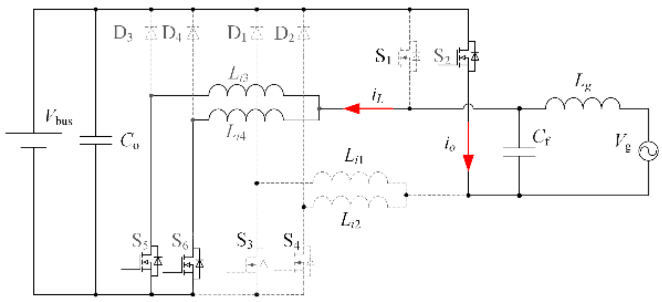

Fig. 5: Inverter Negative mode (inductor charging)

As seen similar to positive state the inductors Li3 and Li4 are charged through the switches S5 and S6 from the DC bus source in negative direction at the output terminals. Now when the switches S5 and S6 are turned OFF the inductors Li3 Li4 are discharged [13] making the diodes D3 D4 into freewheeling. The below fig. 6 is the freewheeling operating state of negative cycle. The below cycle ends when negative voltage conduction is complete.

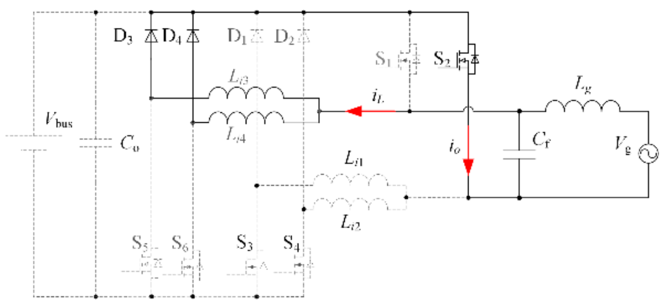

Fig. 6: Inverter Negative mode (inductor discharging)

B. *Rectifier mode*

In this operating mode the power from the grid Vg is injected to the DC bus side which can be stored into a battery storage unit. Considering positive conduction mode [12] at initial stage the below fig. 7 is the first mode of operation in rectifier mode.

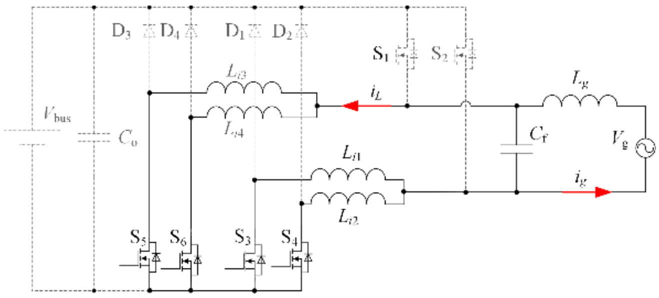

Fig. 7: Rectifier positive mode (inductor charging)

As observed in the above schematic S5 S6 are fed with PWM pulses and S3 S4 are maintained ON continuously for complete positive cycle, charging the inductors Li1 Li2 Li3 and Li4 from the grid voltage Vg. When the pulse is LOW for switches S5 S6 maintaining S3 S4 in ON state the inductors discharge [13] through freewheeling of diodes D3 D4. The below fig. 8 is the freewheeling state during positive cycle.

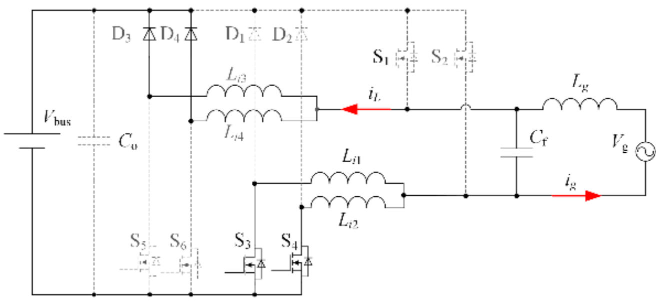

Fig. 8: Rectifier positive mode (inductor discharging)

The above state ends with positive voltage cycle and the negative mode starts. In the negative mode the switches S5 S6 are maintained ON continuously with PWM pulses fed to S3 S4. The inductors are charged in negative direction by the grid voltage Vg. The below fig. 9 is the negative cycle charging mode.

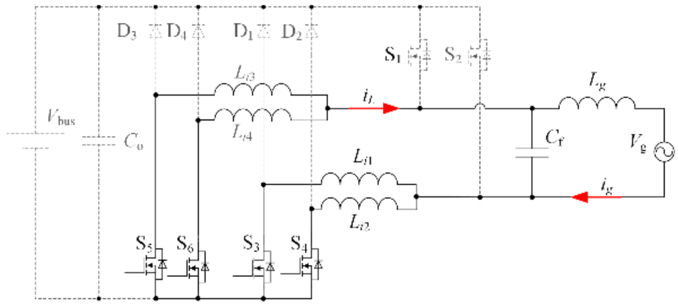

Fig. 9: Rectifier negative mode (inductor charging)

Once the inductors are charged the switches S3 S4 are turned OFF with low signal maintaining the switches S5 S6 in ON state. The negative cycle inductor discharging mode is shown below in fig. 10.

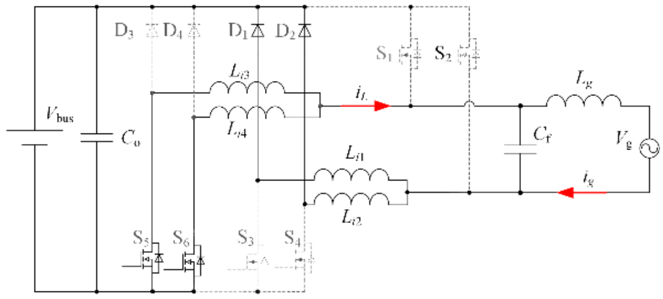

Fig. 10: Rectifier negative mode (inductor discharging)

The inductors are discharged through freewheeling operation of diodes D1 D2 to the DC bus side. The energy is stored into the battery storage in negative cycle also. This mode ends when the negative cycle is complete.

III. PVA AND BESS MODULE

As seen in fig. 2 the DC bus is updated with PVA booster converter connected with battery storage unit for storing excess power generated from PVA or [5] from the grid. The booster converter is operated by MPPT technique. The MPPT algorithm adopted for maximum power extraction from PVA is P&O technique. The P&O MPPT algorithm flow chart can be seen in the below fig. 11.

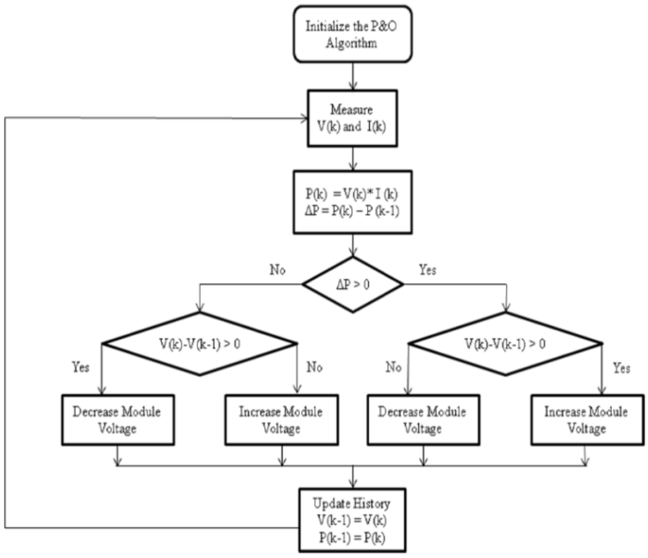

Fig. 11: P&O MPPT flowchart

As observed above in the flowchart PVA voltage and current are considered for the duty ratio generation of the booster converter. From the present values of the voltage V(k) and current I(k) of the PVA past values V(k-1) and I(k-1) are generated using a delay. The change in power and change in voltage are considered by these present and past values which is given as

$$\Delta V = V(k) - V(k-1) \quad \text{.........................(1)}$$

$$\Delta P = P(k) - P(k-1) \quad \text{.........................(2)}$$

The duty ratio increase or decreases depending on these values change. The change in power and voltage change according to the solar irradiation and temperature change. Maximum power will be extracted from the PVA to be either injected to grid or to the battery storage unit connected in parallel to the booster converter [5]. In the next section the simulation results of the proposed topology during excess power generation mode (inverter mode) and deficit power generation mode (rectifier mode) are shown.

IV. SIMULATION RESULTS

The below is the modeling of the proposed test system with input connected with PVA and battery sources. The circuit is operated in two modes, inverter mode and rectifier mode with simulation time of 0.3sec in both conditions. The obtained results are shown followed to the modeling.

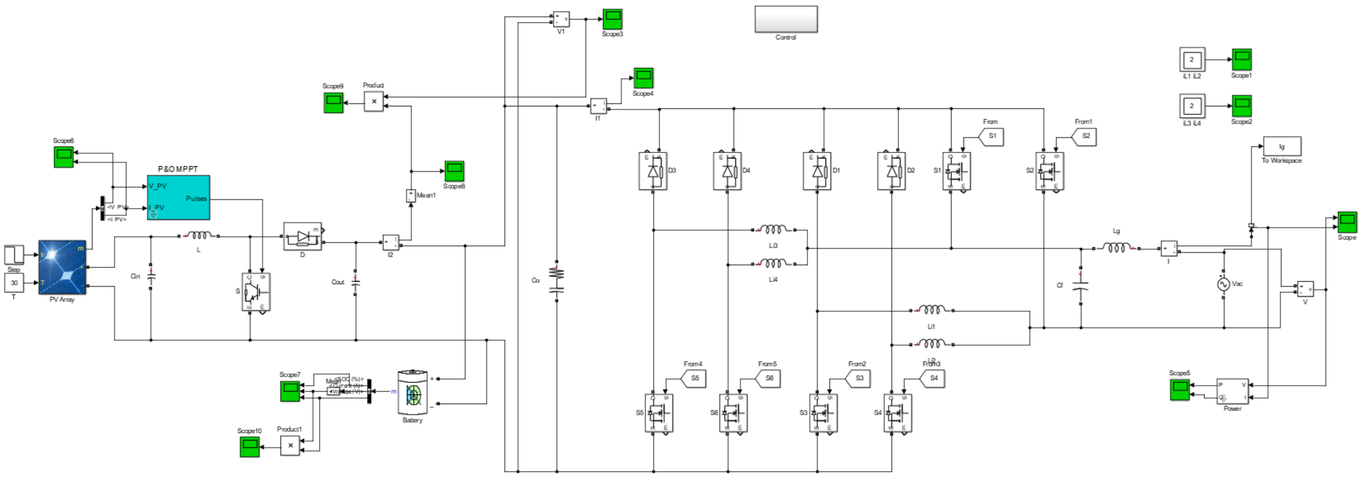

Fig. 12: Modeling of propose test system with PVA and battery module

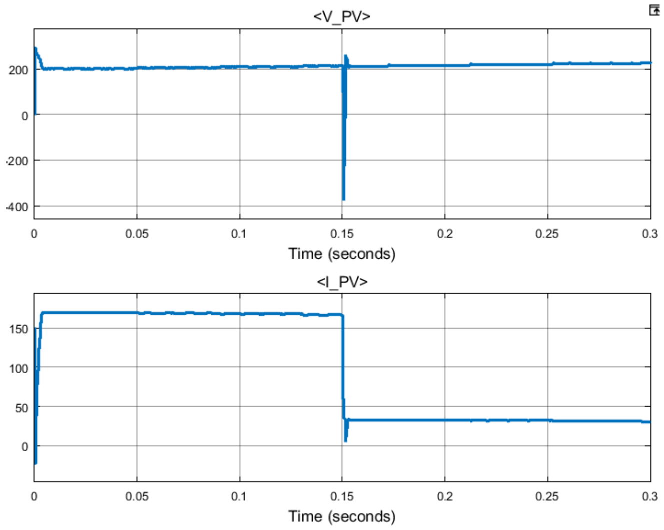

Fig. 13: PVA characteristics in inverter mode

The above are the PVA module voltage and current with change in solar irradiation set at 0.15sec. From 0 to 0.15sec the solar irradiation available is 1000W/mt2 and from 0.15sec to 0.3sec the solar irradiation is reduced to 200W/mt2. As seen the PVA current drops immediately when the solar irradiation is dropped at 0.15sec. The below fig. 14 is the complete power generated by the PVA at different time intervals as per the solar irradiation change.

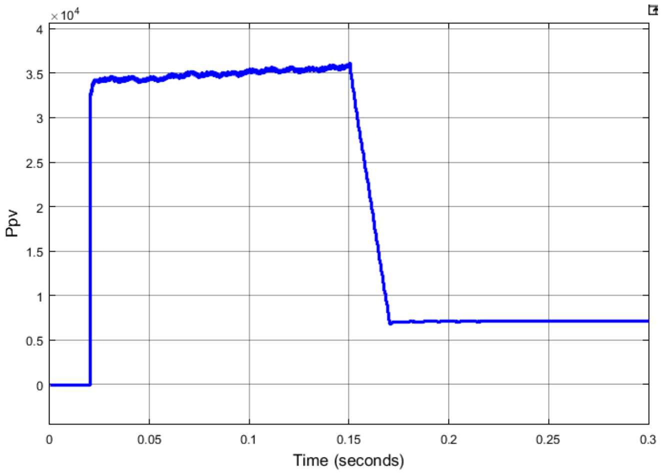

Fig. 14: PVA power generated inverter mode

The below is the battery characteristics during inverter mode with change in solar irradiation. Until 0.15sec the battery current is in negative direction and hence it is considered as charging mode and the SOC is rising. After 0.15sec as the irradiation is dropped the power is insufficient to inject into the grid, therefore the current of the battery is changed to positive direction and the SOC is dripping discharging the battery feeding the grid.

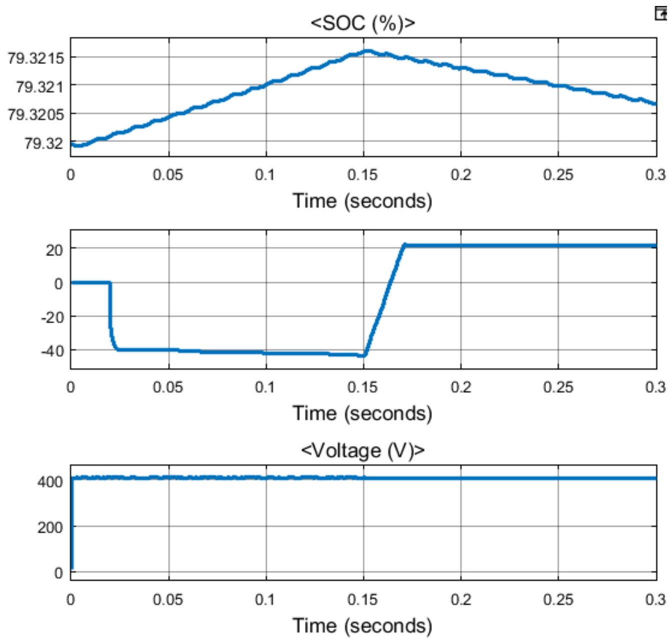

Fig. 15: Battery characteristics inverter mode

The below fig. 16 are the grid voltage and current during inverter mode followed by fig. 17 showing active and reactive powers injected to the grid.

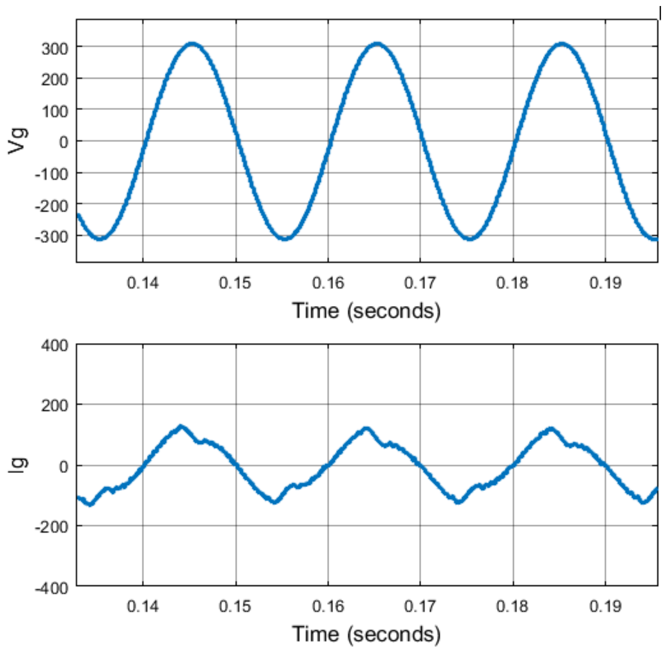

Fig. 16: Grid voltage and current inverter mode

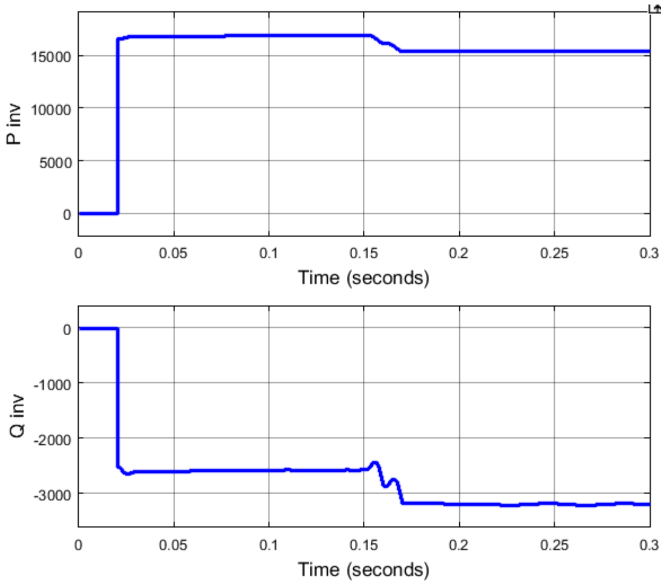

Fig. 17: Injected active and reactive power to grid inverter mode

Now the converter is changed to rectification operation where the switching sequence is changed for the grid power to be stored into battery. The below are the battery characteristics during rectifier mode which is charging from PVA power and grid power too. The current magnitude changes as the solar irradiation drops to lower level. However, the battery is always charging in rectifier mode.

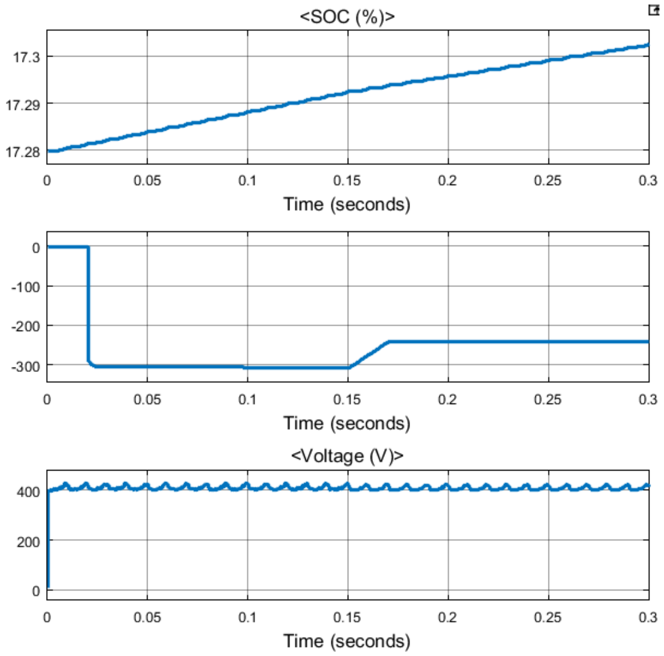

Fig. 18: Battery characteristics in rectifier mode

The below fig. 19 are the active and reactive powers of the grid drawn by the battery for storage followed by fig. 20 grid voltages and currents during rectifier mode.

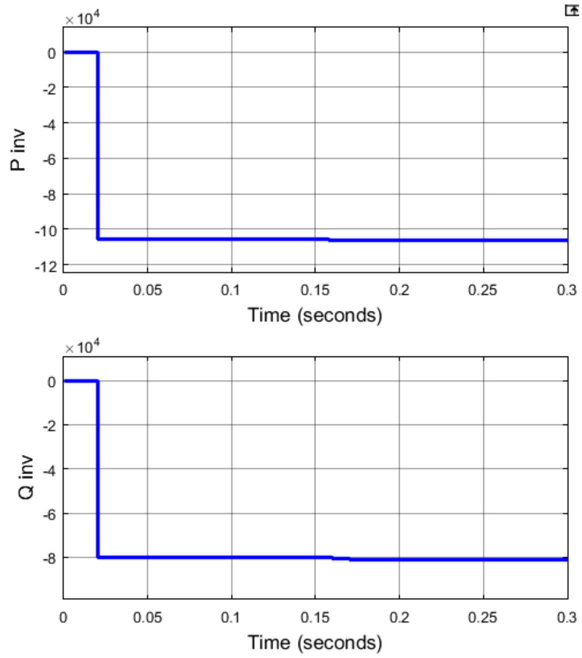

Fig. 19: Active and reactive power drained from grid to battery in rectifier mode

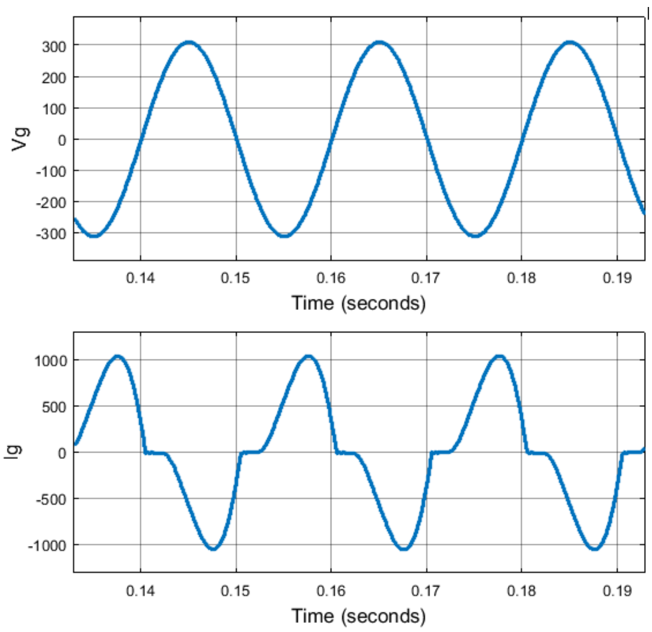

Fig. 20: Grid voltage and current in rectifier mode

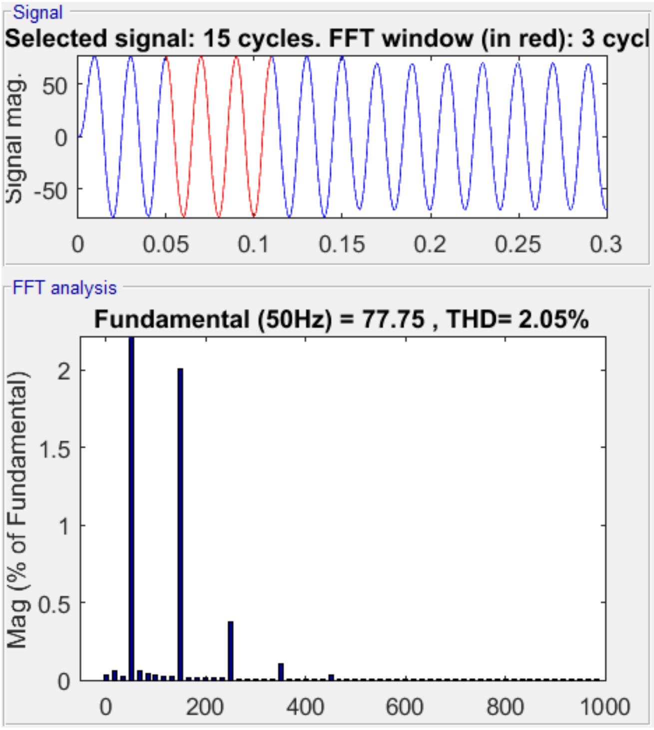

Fig. 21: THD of the grid current

The above is the grid current FFT analysis to determine the THD (Total Harmonic Distortion) of the current in any mode.

V. CONCLUSION

As per the results a successful implementation of proposed topology is done with inverter and rectification modes. The input is integrated with PVA and battery modules for utilization of renewable power and injected to the grid through the proposed bidirectional interleaved dual buck converter. Different operating conditions are considered with variable solar irradiation at different intervals of time observing the change in characteristics of the modules. In any condition the THD of the grid current is maintained below 5% as per IEEE standard. The THD of the current is analyzed using FFT analysis tool available in 'powergui' toolbox which is at 2.05%. The powers injected and drained from the grid in inverter and rectification modes are also represented satisfying bidirectional operation of the proposed bidirectional interleaved dual buck converter.

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