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A Bidirectional Isolated AC-DC Converter For Hybrid Power Systems

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Abstract

A grid connected bidirectional ac-dc converter along with energy storage has become a promising option for many power systems. With the increasing need for electric power there is an increasing requirement for bi-directional ac-dc converters to transfer energy between different voltage levels. This paper presents a grid connected bidirectional isolated ac-dc converter with a battery energy storage system for use in rural telephony. This topology is based on bidirectional ac-dc converter on the primary side and a current fed push pull on the secondary side of an isolation transformer. When ac mains supplies, it powers the ac load, dc load and bidirectional converter operates in the buck mode to charge the battery to a nominal value of -48V. On the failure of the ac mains, the converter operation is like that of a boost and the battery regulates the voltage and there by provides power to the ac, dc loads. The bidirectional isolated ac-dc converter topology is simulated using MATLAB/SIMULINK and the results are presented.

Key words— Bidirectional isolated ac-dc converter, grid, battery

Nomenclatures	
Ds_1	Duty cycle of switch S_1
Ds_2	Duty cycle of switch S_2
Ds_3	Duty cycle of switch S_3
Ds_4	Duty cycle of switch S_4
V_{batt}	Voltage across the battery
V_{dc}	DC link voltage
F_s	Switching frequency, 100 kHz
L_o	Output inductor
I_{batt}	Current through the battery
$V_{battpeak}$	Peak voltage across the battery
V_{batt}	Nominal voltage across the battery
Greek symbol	
η	Converter efficiency= 80%

1. Introduction

In order to access the grid with battery energy storage system, the power electronic converter is an essential element. It is often employed in a system having two conversion stages along with an inverter/ rectifier [1-2]. It can be divided in to isolated and non-isolated types. A bidirectional non isolated ac-dc converter is proposed for photovoltaic applications with battery storage system [3]. Moreover, to ensure safe operation of the battery, isolated transformers are required to offer galvanic isolation to the battery from the power grid in [4-5]. Galvanic isolation can increase system flexibility by providing voltage matching. Bidirectional isolated ac-dc converters allow transfer of power between two sources in either direction [6]. It has the ability to reverse the direction of flow of current, thereby power and maintains the voltage polarity at either side unchanged. So, they are being increasingly used in applications like battery charger circuits, computer power systems, dc uninterrupted power supplies and telecom power supplies. A bi-directional ac-dc converter has an important role for controlling the power flow between DC bus and AC grid.

Bidirectional converters using resonant [7], soft switching [8] and hard switching PWM [9] has been reported in many literatures. These topologies lead to an increase in component rating, complexity, conduction losses, high current ripple, loss of soft switching at ac loads and lack of isolation in integrated topologies.

Most electrical safety regulations consider dc voltage lower than 50V to be a safe low-voltage circuit. It is also practical, since this voltage can easily be supplied from standard batteries, making it a simple system. Although other voltages are possible, most low telecom loads run on a -48V DC bus. Negative voltage on the line was found to be superior to positive voltage in preventing electrochemical reactions from destroying copper cables if they happen to get wet. Negative voltage also protects against sulphation on battery terminals. Negative voltage is used for powering BTS sites. There are two types of BTS, one is indoor BTS and the other is outdoor BTS. Indoor BTS uses air conditioning load, light load whereas outdoor BTS does not require ac load. The BTS load as well as the air conditioning load is powered by diesel generators and/or grids. So, the proposed converter provides the desired bidirectional flow for powering indoor Base Transceiver Station (BTS) and ac loads. When the grid is not available the battery will be feeding the ac and dc load. When the grid is available ac, dc loads are met along with charging the batteries. This paper utilizes the bidirectional power transfer property of MOSFET. It also include (i) reduced components due to use of the same components in both power flow directions (ii) low stress on switches (iii) galvanic isolation (iv) minimal number of active switches (v) low ripple.

2. Topology and modes of operation

The architecture of grid interactive hybrid system is shown in fig.1.

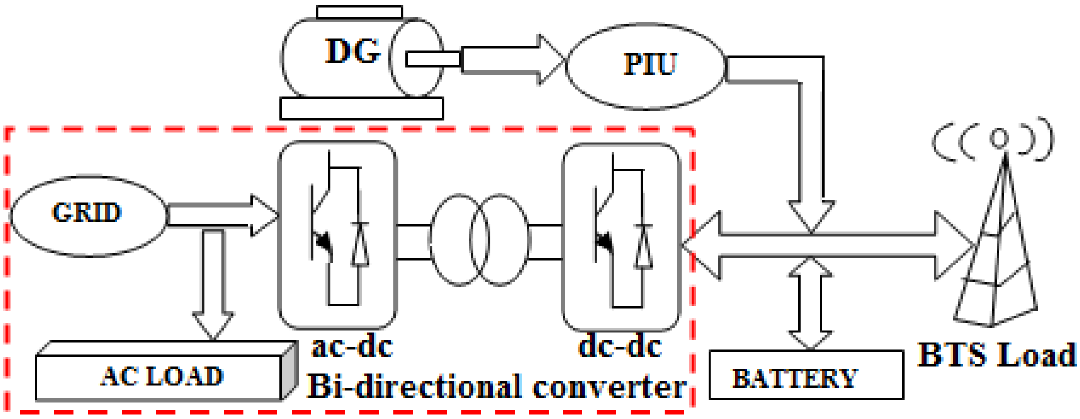

Fig.1 Architecture of grid interactive hybrid system

The PIU fed by DG powers and dc loads of BTS [10-13]. PWM boost rectifier cascaded with bidirectional dc-dc converter. This converter is used for charging the battery from utility grid and supplying AC, DC load.

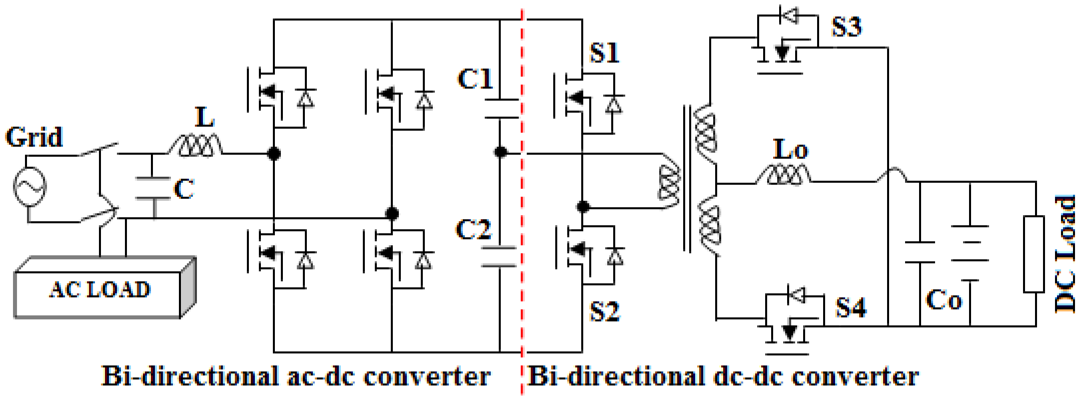

Fig2 Topology of bi-directional ac-dc converter

The basic power circuit topology of bi-directional ac-dc (grid side converter) is shown in fig 2. The transformer provides galvanic isolation between the dc link and the battery. The primary side of the transformer is connected to the ac mains through rectifier. The secondary side of the transformer is connected to the battery forms a current fed push-pull.

When ac main is able to supply the loads, bi-directional dc-dc converter operates in buck mode. Switches S1, S2 are gated and the body diodes of the switches S3, S4 provide battery side rectification. When ac main is insufficient or on the failure mode, the bi-directional dc-dc converter operates in boost mode to supply ac load and the battery regulates the voltage. So, the reversal power flow occurs. Switches S3, S4 are gated and the body diodes of the switches S1, S2 provide rectification at the load side.

So, switches in the OFF state are subject to a voltage stress, equal to the dc input voltage in case of half bridge whereas equal to twice in case of full bridge. Thus in low power applications like powering telecom load, the two switch half bridge is preferred than four switch full bridge topology. This allows low number of primary winding turns, reduction in size and cost.

For the secondary side of the transformer, the current fed push-pull is the most suitable topology. Each division of inductor current reduces the average and rms current in the secondary during the overlap period of the switch. The bidirectional converter has two modes of operation.(i) Forward mode/Charging mode (ii) Reverse mode/current-fed mode. The topology of forward and reverse mode is shown in Fig 3 and Fig 4.

2.1 Forward mode/Charging mode:

This mode is used for charging the battery as and when required. During this mode primary side switches S1, S2 are turned ON. Secondary side switches S3, S4 are turned OFF. So, body diodes of S3, S4 preform the battery side rectification.

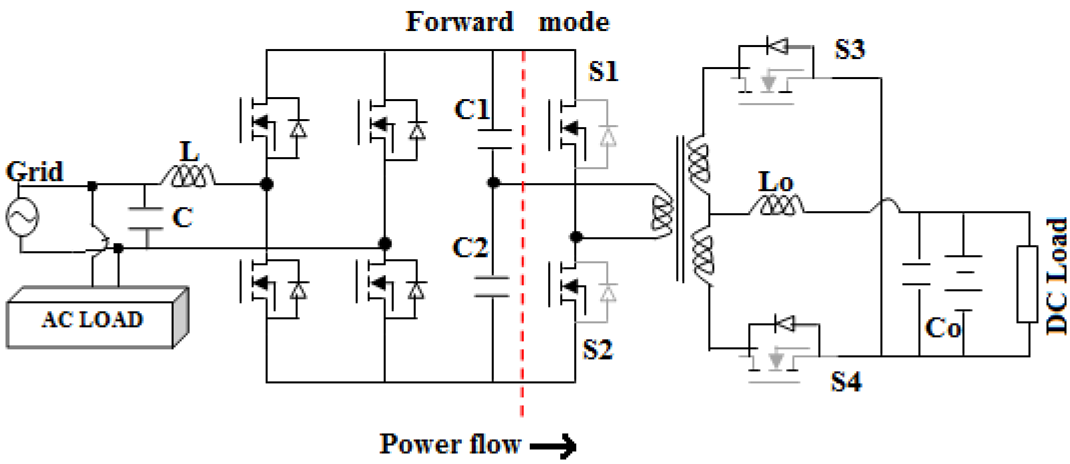

Fig 3 Forward mode/ charging mode

2.2 Reverse mode/Current fed mode:

This mode is used when ac main fails to supply. At that time, battery regulates the voltage. It supplies for ac, dc load. In this mode of operation switches S1, S2 are turned OFF and the switches S3, S4 are turned ON. On the primary side, the body diodes of S1, S2 conduct. Secondary side faces an effective short circuit and current through inductor Lo rises linearly. The duty ratio of all the switches are maintained greater than 50%.

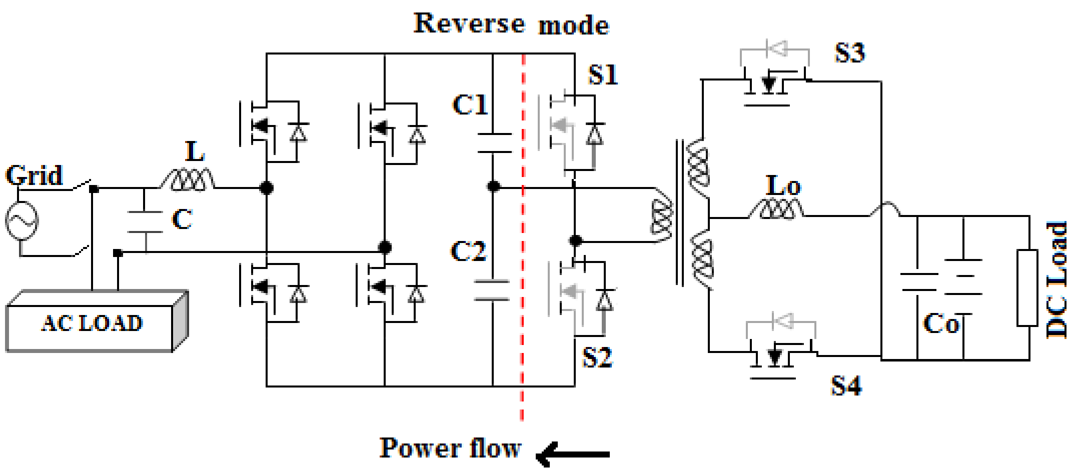

Fig 4 Reverse mode/ current fed mode

The modes of operation can also be explained from the graph shown in fig 5. During mode 1 the gating is given to the switches S1, S2. The topology will be in forward mode which charges the battery as shown in fig 5. During mode 2 the switches S3, S4 are triggered. So, the battery supplies ac and dc load.

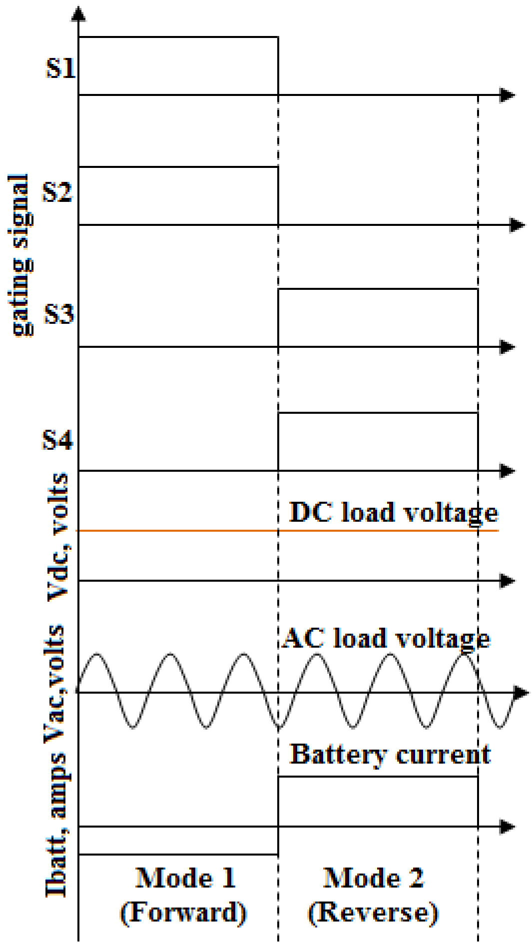

Fig 5 Performance during forward and reverse mode

3. Design of bidirectional converter

This section presents a design of bidirectional ac-dc converter. The duty ratio of S1, S2 in the forward mode are calculated by,

$$Ds_1 = 1- \frac{V_{batt}}{V_{dc}} \quad (1)$$

$$Ds_2 = 1- \frac{V_{batt}}{V_{dc}} \quad (2)$$

The duty ratios of S3, S4 in the reverse mode are calculated by,

$$Ds_3 = \frac{V_{dc}-V_{batt}}{V_{dc}} \quad (3)$$

$$Ds_4 = \frac{V_{dc}-V_{batt}}{V_{dc}} \quad (4)$$

Both the primary and secondary switches depend on the voltage stresses across and the current through them. The maximum reverse voltage across the primary side switches S1, S2 is equal to the maximum dc link voltage.

$$Vs_1= Vs_2= \frac{V_{dc}}{2} \quad (5)$$

The minimum value of output inductor Lo, to maintain continuous inductor current is given by,

$$L_o = \frac{V_{batt} * (1-2* Ds_2)}{4*f_s*I_{batt}} \quad (6)$$

All the capacitors are selected according to the desired output ripple at the dc link.

$$C_o= \frac{L_o *I_{batt}^2}{V_{battpeak}-V_{batt}} \quad (7)$$

$$C_1=C_2= \frac{2* I_{pri} * t_{dis}}{V_{ripple}} \quad (8)$$

$$I_{pri}= \frac{P_{batt} * Ds_2 *100}{V_{batt} * \eta} \quad (9)$$

The input capacitors C1, C2 are equal in value. The capacitors must be large enough to provide sufficient holdup time at the dc bus voltage under ac mains failure, before the converter begins operation in the backup mode.

I_{pri} = Primary current at maximum duty ratio at an expected converter efficiency of η= 80%.

t_{dis}= Capacitor discharge period.

So, for the mode of operation,

DC load power= 1200watts

AC load power= 1800watts

AC input voltage=230V

DC link voltage=110V

Operating frequency= 100 kHz are considered.

A suitable nominal value of the battery voltage is chosen at 48V. The transformer turns ratio is calculated from

$$N= \frac{Vs_{max}}{2* V_{batt}} \quad (10)$$

N= Transformer turns ratio = 2.687

The magnetizing inductance for the transformer was determined to be 360 µH. The specifications for bidirectional ac-dc converter used for the simulation is tabulated as shown in Table.1

Table-1 Components rating

S. NO	COMPONENTS	RATING
1	**Capacitors**	
	C1	0.6f
	C2	0.6f
	Co	1139.32µf
	C	1pf
2	**Inductors**	
	Lo	3.6H
	L	1pH
3	**Switches-Duty ratio**	
	Ds_1	0.75
	Ds_2	0.75
	Ds_3	0.8
	Ds_4	0.8

4. Simulation results and discussion

The switching pulses of switches S1, S2, S3 and S4 are shown in fig 6.

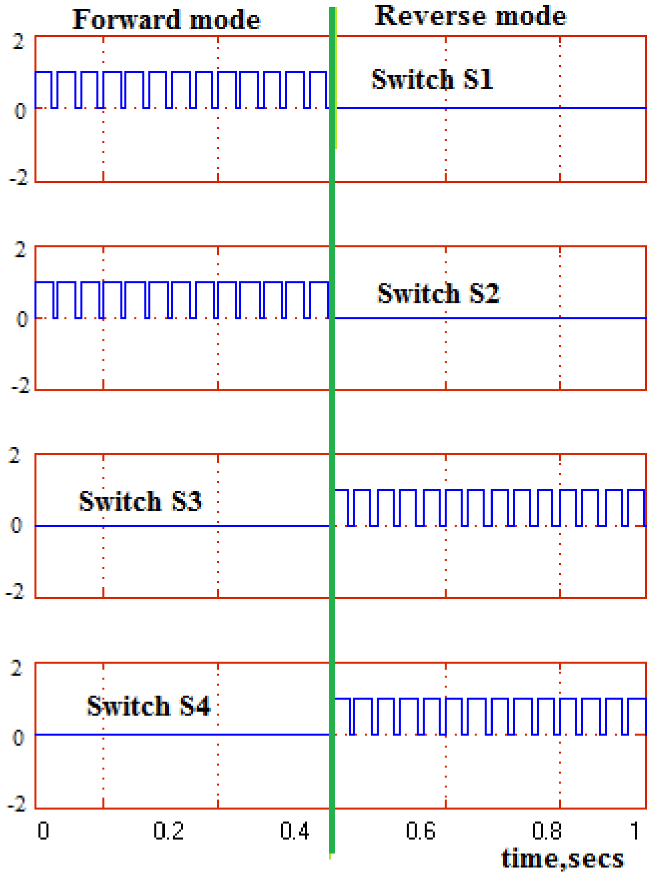

Fig 6 Gating of switches S1-S4

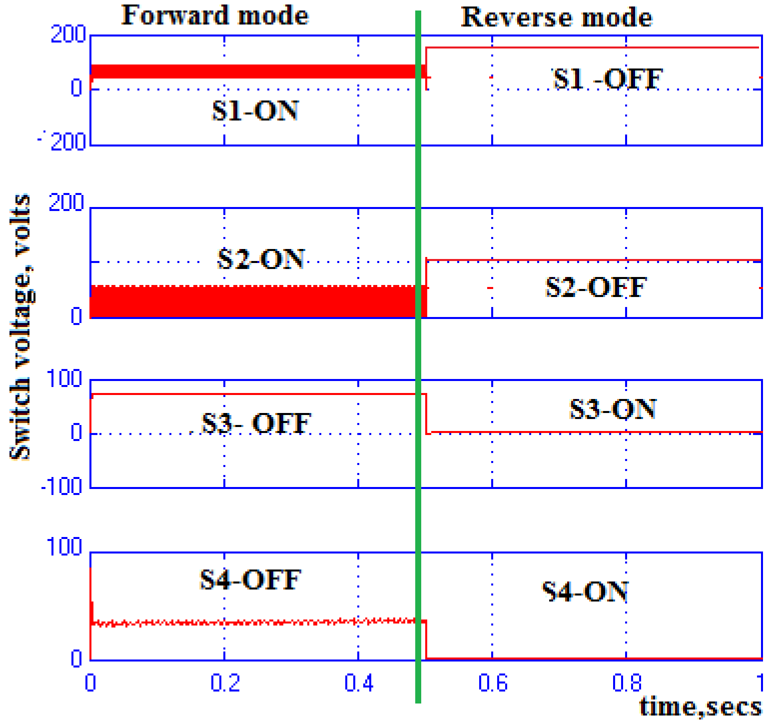

Fig 7a Voltage across switches on both modes

During forward mode switches S1, S2 are turned on and S3, S4 are turned off. During reverse mode switches S1, S2 are turned off and switches S3, S4 are turned on. The voltage across and the current through all the switches are shown in fig 7a and 7b. From fig 7a it has been observed that there is increased voltage drop at the switches when turned off. From fig 7b it is clear that there is increased current when the switches turned on.The dc, ac load voltage, dc link voltage, and the battery current is shown fig 8.

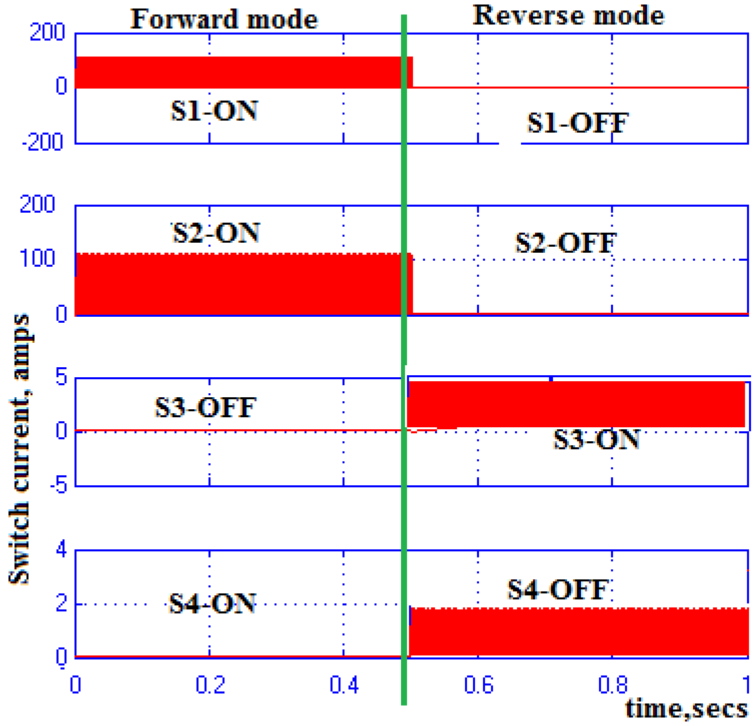

Fig 7b Current through switches both modes

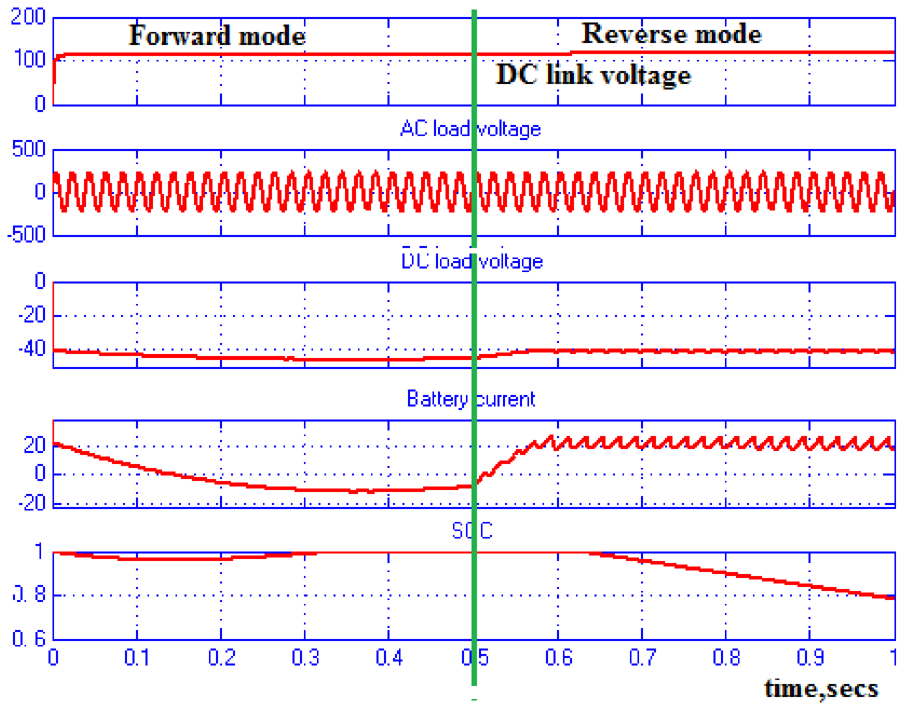

Fig 8 Load voltage, Battery current

The ac load voltage is maintained as 230V during forward and reverse mode. The dc voltage is -48V. DC link voltage is 110V for both the modes of operation. The battery should charge/ discharge when the grid is sufficient/ unavailable.

In fig 8, the battery draws less current during forward mode of operation. During reverse mode of operation the battery current increases which implies the discharging mode of battery.

The efficiency of bi-directional ac-dc converter is calculated as 91% during forward mode of operation and 90% during reverse mode of operation.

5. Conclusion:

Thus bi-directional ac-dc converter has been designed and evaluated for powering rural telecom tower. Whenever grid supply is unavailable, battery is used to power the load. The topology is simulated using MATLAB/ SIMULINK. The results were presented. This can be further extended with renewable side converter to power rural telecom.

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