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DESIGN AND CONTROL OF NOVEL MULTI LEVEL BI-DIRECTIONAL GRID CONNECTED INVERTER

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ABSTRACT

The main aim of this paper is to Design and Control a Novel Multi Level bidirectional grid-connected inverter for the battery energy storage applications. The proposed grid connected bidirectional multi-level inverter consists of several bidirectional buck boost DC to DC converter and a DC to AC inverter. Advantages of the proposed Novel Multi Level bidirectional grid-connected inverter includes single stage power conversion, low DC bus voltage, pulsating charging and discharging battery currents and separate power control for every battery module. Therefore capacity extension of the battery energy storage system can be attained. It do not require input current sensor to control the power flow for the battery energy storage system. Output current ripple also reduced. To verify the effectiveness of the proposed Novel Multi Level bidirectional grid-connected inverter, hardware experimental results are shown.

KEYWORDS: *Multi Level Inverter (MLI), Discontinuous Conduction Mode (DCM), Battery Management System (BMS)*

Article History

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INTRODUCTION

Renewable energy sources such as Photovoltaic power are more popular now-a-days. However it causes negative impact to the grid voltage and frequency stabilization. Therefore battery energy storage system is essential for controlling the generating units in order to maintain the stability of the power system and also to protect the load from grid fault conditions. Conventional system has battery array which are connected in series or in parallel and a bidirectional grid connected DC to AC inverter as a full bridge inverter. However to maximize the energy storage the voltage of series connected battery array must be equalized. The balancing circuit increase the cost and also reduce the efficiency. The proposed Novel Multi Level bidirectional grid-connected inverter offers higher efficiency, reliability and low cost. The major drawback of battery energy storage system is the lifetime of the battery. The sinusoidal current improves the charging efficiency of lithium ion battery. Normally battery energy storage system requires a two stage converter to get DC to AC output for grid-connected applications and also to produce pulsating current for charging and discharging the battery. It requires current sensors to compute the output power in order to control the power flow. Two stage converter configurations are therefore expensive. Therefore the Novel Multi Level Bi-Directional Grid Connected Inverter is proposed.

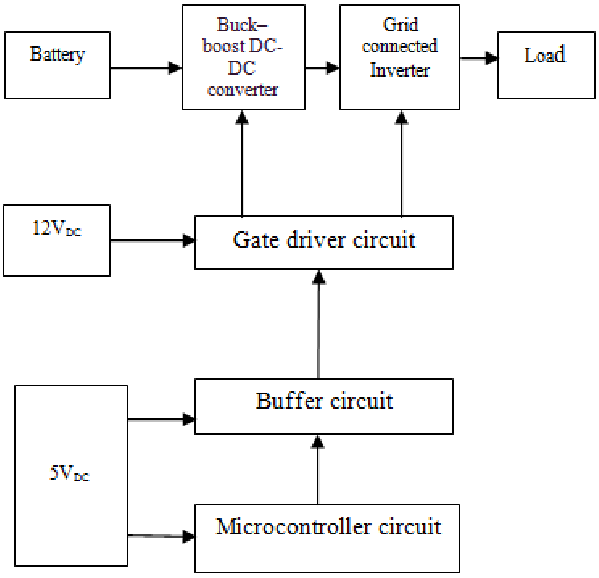

Figure 1: Block Diagram of the Proposed System for Single Battery Modul.

Figure.1 shows separate DC to DC Converter is used for each battery module to control the power output. Pulsating DC current at high frequency were produced at the output of the DC to DC Converter. Therefore low DC bus voltage is obtained. The pulsating current for charging and discharging the battery increases the lifetime of the battery. Multilevel inverter converts this pulsating DC current of high frequency produced by the DC to DC Converter two sinusoidal outputs at line frequency. Multilevel inverter switches are operated at zero voltage and zero current switching in order to reduce the switching loss. Does energy stored in the battery module is effectively transferred to the supply mains through this single power conversion stage. Due to this single power conversion stage power conversion efficiency is improved. The proposed novel multilevel bi-directional inverter is easy to control the power flow without the current sensors. Output inductor sizes also reduced. Control circuit used here is simple and easy to maximize the capacity of the battery energy storage system. In this paper the operation of the proposed Novel Multi Level bidirectional grid-connected inverter is explained. Hardware results show the effectiveness of the proposed system.

PROPOSED NOVEL MULTI LEVEL BIDIRECTIONAL GRID-CONNECTED INVERTER

The circuit diagram of the proposed Novel Multi Level bidirectional grid-connected inverter has 'n' number of buck boost DC to DC Converter and a single Multi Level Inverter (MLI) as shown in Figure.2. Each buck boost DC to DC converter consists of two power switches, 2 power diodes and one inductor. It is used to convert the DC current produced from the battery into pulsating DC current of high frequency. This pulsating DC current of high frequency is converted into sinusoidal output at low frequency by the Multi Level Inverter which has only four active power switches. The switches are operated at low frequency. It also consists of a LC filter at the output. The battery management system (BMS) sends command to charge or discharge the battery.

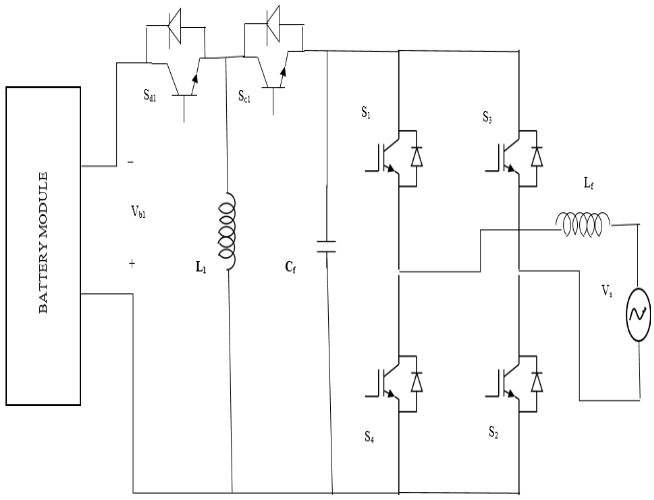

Figure 2: Circuit Diagram of the Proposed Novel Multi Level Bidirectional Grid-Connected Inverter.

The inverter will operate accordingly. The power flow from the battery module to the supply mains is through single stage of power conversion. The buck boost DC to DC Converter can be interleaved to reduce the current Ripple.

MODES OF OPERATION

Discharging

The Switch S_{C1} is turned off. Gate pulse is given to Switch S_{D1}. It is produced by comparing the rectified sinusoidal waveform V_{sin} with the carrier signal. Saw tooth carrier signal V_{saw} is used. The converter operated in discontinuous current mode (DCM).

Inductor current I_{L1} waveform is a rectified AC waveform. For half cycle off the grid supply, the total number of switching N is $f_s/2f$, where $f_s$is the switching frequency and f is the frequency of the grid.

For Discontinuous Conduction Mode (DCM) operation, during the battery discharging the following condition must be satisfied.

D_{m1}→ maximum duty ratio for half cycle off the grid.

$$D_{m1} < \frac{\sqrt{2V_{ac}}}{V_{b1} + \sqrt{2V_{ac}}} \tag{1}$$

V_{ac}→ RMS value of the grid line voltage.

V_{b1}→ Battery voltage.

D_{m1} can be controlled and desired value can be obtained by controlling the amplitude of the rectified sinusoidal signal V_{sin}. Battery discharging power can be given as

$$P_{b1} = \frac{f}{L_1 f_s^2} \sum_{K=1}^{N} \left(V_{b1} D_{M1} \sin\left(\frac{K\pi}{N}\right)\right)^2 \tag{2}$$

The average battery discharging power depends mainly on V_{b1} and D_{m1}. The parameters f, f_s, L_1 and N are design carefully. Battery discharging power is calculated without sensing the battery current. Only by measuring the battery voltage V_{b1} suitable maximum duty ratio D_{m1} is determined.

Charging

The Switch S_{d1} is turned off. Gate signal is given to the switch S_{c1}.

This signal is generated by comparing the reference signal V_{ref} with the carrier signal. The sawtooth signal V_{saw} is used as a carrier signal for the DCM operation.

For DCM operation during the battery charging, the following condition must be satisfied.

$$D_{c1} < \frac{V_{b1}}{V_{b1} + \sqrt{2V_{ac}}} \tag{3}$$

Average battery charging power can be given as

$$P_{b1} = \frac{f D_{C1}^2}{L_1 f_s^2} \sum_{K=1}^{N} (V_C[K])^2 \tag{4}$$

K → Switching period.

V_C → Capacitor voltage.

The Average battery charging power depends mainly on V_C and D_{c1}, The parameters f_s, N, L_1 are designed carefully.

CONTROL STRATEGY

Figure.3 shows the Battery Management System (BMS) which generates charging C, discharging D and power commands (P_{b1}) and this command to the controller of the proposed novel multilevel bi-directional grid connected inverter. The inverter along with an LC filter converts the pulsating DC current of high frequency generated by the buck boost DC to DC Converter into sinusoidal AC supply at line frequency.

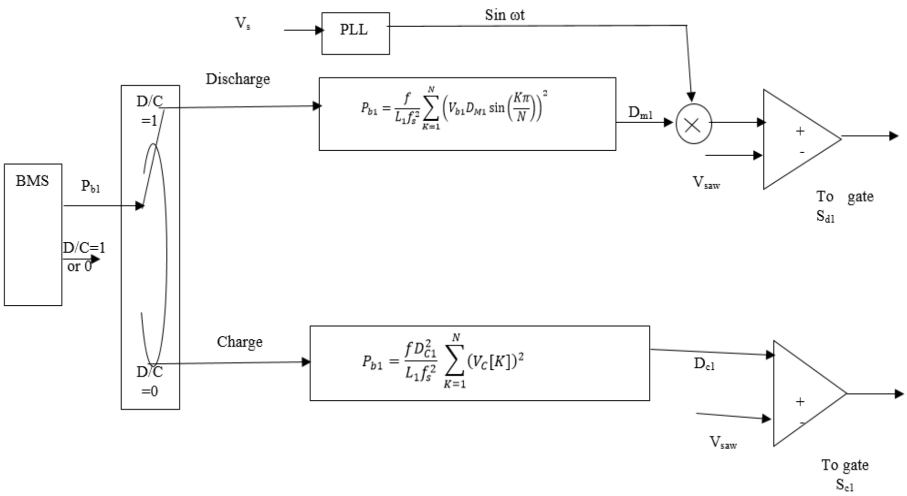

Figure 3: Control Block Diagram.

During the positive half cycles switches S_1 and $S_{2\ are}$ turned ON and during negative half cycle switches S_3 and S_4 or turned ON. The switches are operated at zero voltage and zero current switching to maximize the switching loss. Interleaving buck-boost DC to DC Converter operation, duty cycles of the adjacent converter is shifted 360^0/m. The total current ripple is greatly reduced.

EXPERIMENTAL RESULTS

The prototype of the novel multilevel bi-directional grid connected inverter tablet and it is tested. The maximum duty ratio in charging mode is said to be 0.8 and charging mode is said to be 0.2.

Table 1: Battery Module Specification

1.	Nominal Capacity(0.2C)	7 Ah
2.	Rated Voltage	51.2 V
3.	Maximum Charging Voltage	58 V
4.	Cut-Off Voltage	40 V

Table 2: Specifications of the Prototype

1.	Input inductor $L_1 = L_2 = 180\ \mu H$
2.	Battery module rating voltage $V_{b1} = 50$ V
3.	AC mains = 110 V_{rms}/60Hz
4.	Switching frequency $f_s = 20$ kHz
5.	Output capacitor $C_f = 2\ \mu F$
6.	Output inductor $L_f = 1.5$ mH

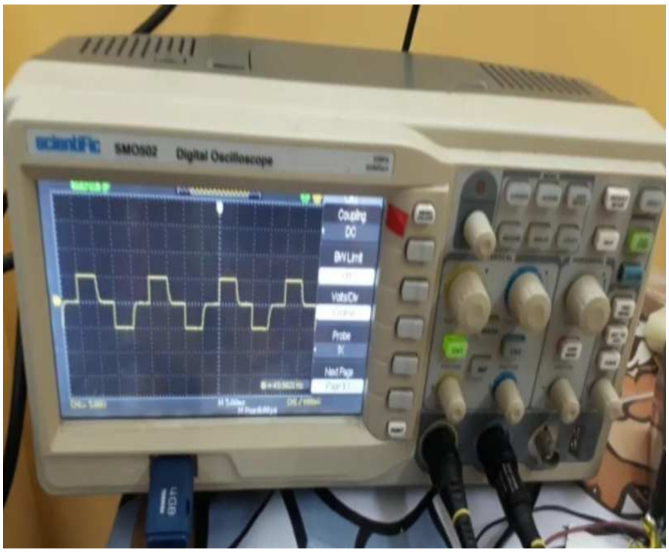

Figure 4.Output Voltage Waveform during Battery Discharging Operation.

The output of the multilevel inverter has peak value of 1.5 A in battery discharging mode. The output of the multilevel inverter has peak value of 1.5 A in reverse direction for battery charging mode. The RMS value of the AC voltage is V_{ac} = 110V.

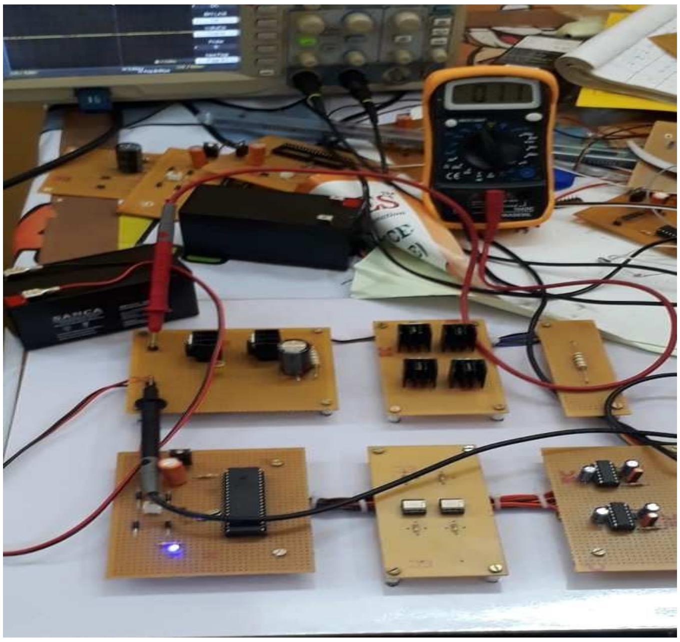

Figure 5: Prototype of the Proposed Novel Multilevel Bi-Directional Grid Connected Inverter.

Hardware prototype is shown in the figure 5. Here TMS320F2808 controller is used. The Total Harmonic Distortion (THD) during Discharging mode is 4.2% and The Total Harmonic Distortion (THD) during charging mode is 4.1%.

CONCLUSIONS

The novel multilevel bi-directional grid connected inverter proposed in this paper. The proposed system has advantages such as high power efficiency long life time, no need of current sensors, simple control, low cost and flexible to increase the capacity e of the battery energy storage system. The prototype design and the output waveforms are presented in order to validate the effectiveness of the proposed system.

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