High Efficient Hybrid Cascaded Multilevel Inverter for Battery Energy Management

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Abstract: ***In electric vehicle energy storage systems, a large number of battery cells are usually connected in series to enhance the output voltage for motor driving. In our project, a hybrid cascaded multilevel converter with H-bridge inverter is designed. In the proposed system, eveif any one of the battery cell is damaged, the backup battery which is added in the circuit comes into action at the event of fault which enhances the life of the battery. Where-in in the existing system when any one of battery cell is damaged, the whole battery cell has to be replaced. Each battery cell can be controlled to be connected into the circuit or to be bypassed by a half-bridge converter. The H-bridge inverter is used to control voltage balance of the battery cell. Each half bridge can make the battery cell to be involved into the voltage producing or to be operated in bypassed mode. All half-bridges are cascaded to output a staircase shape dc voltage and an H-bridge converter is used to change the direction of the dc bus voltages to make up ac voltages. Here space vector pulse width modulation technique is used to generate pulse to the thyristors. The proposed design reduces switching loss and Total Harmonic Distortion (THD) compared to the existing system.***

Keywords: EV-ElectricVehicle,THD-TotalHarmonic Distortion

1. Introduction

Energy storage system plays an important role in electric vehicles (EV). Batteries, such as lead-acid or lithium batteries, are the most popular units because of their appropriate energy density and cost. Since the voltages of these kinds of battery cells are relatively low, a large number of battery cells need to be connected in series to meet the voltage requirement of the motor drive. In a traditional method, all the battery cells are directly connected in series and are charged or discharged by the same current, the terminal voltage and state-of-charge (SOC) will be different because of the electrochemical characteristic differences between the battery cells. Multilevel converters are widely used in medium or high voltage motor drives. If their flying capacitors or isolated dc sources are replaced by the battery cells, the battery cells can be cascaded in series combining with the converters instead of connection in series directly. A hybrid cascaded multilevel converter is proposed in this paper which can realize the terminal voltage or SOC balance between the battery cells. The converter can also realize the charge and discharge control of the battery cells. A desired ac voltage can be output at the H-bridge sides to drive the electric motor or to connect to the power grid, So additional battery chargers or motor drive inverters are not necessary any more under this situation. The ac output of the converter is multilevel voltage, while the number of voltage levels is proportional to the number of cascaded battery cells. So in the applications of EV or power grid with a larger number of battery cells, the output ac voltage is approximately ideal sine waves. The harmonics and dv/dt can be greatly reduced than the traditional two-level converters. The proposed converter with modular design can realize the fault redundancy and high reliability easily. And by using proper control technique the harmonics and dv/dt are greatly reduced. In the sinusoidal pulse width modulation, the reference wave is the sine wave. That is compared with the carrier triangular wave, the pulses are produced. That is given to the inverter.

2. Conventional System

There is a half-bridge arm and an Inductance between every two nearby battery cells.

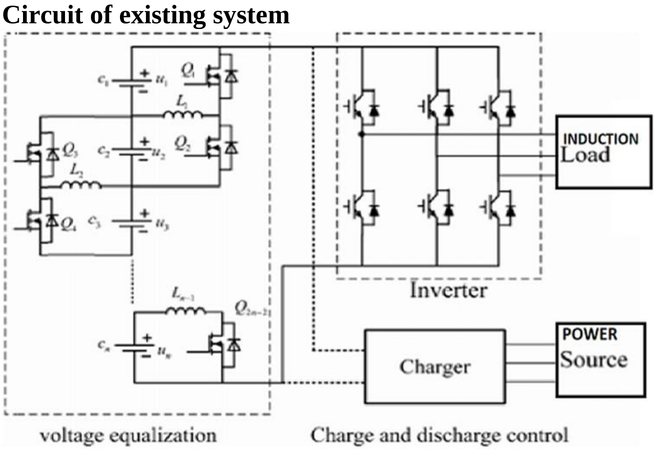
The number of switching devices in the balance circuit is $2*n-2$ and the number of inductance is $n-1$, where n is the number of the battery cells.

The recharging current and voltage can be adjusted by the closed-loop voltage or power control of the rectifier.

Disadvantage

- An additional inverter is needed for the motor drive and a charger is usually needed for the battery recharge.

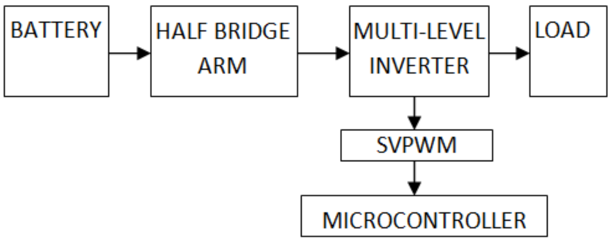
Circuit of existing system



3. Proposed System

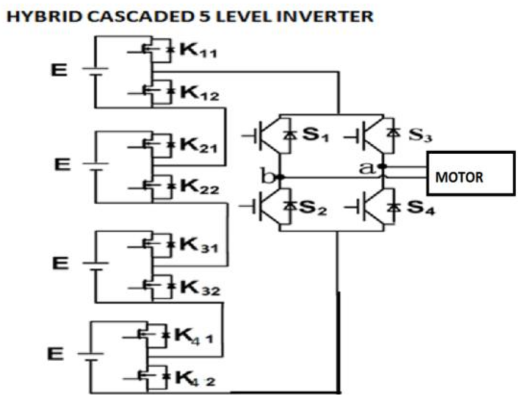
Each battery is connected with two half cells and a Multi-level inverter, the inductance in the conventional model is removed reducing harmonics and no need for a charger or a battery storage, it can be directly used reducing cost. In fact, if the output of the inverter is connected with the three-phase ac source by some filter inductances, the battery recharge can also be realized by an additional control block which is similar with the PWM rectifier.

A. Block diagram of multilevel inverter



The recharging current and voltage can be adjusted by the closed-loop voltage or power control of the rectifier. Each half-bridge can make the battery cell to be involved into the voltage producing or to be bypassed. Therefore, by control of the cascaded half-bridges, the number of battery cells connected in the circuit will be changed, that leads to a variable voltage to be produced at the dc bus. The H-bridge is just used to alternate the direction of the dc voltage to produce ac waveforms. Hence, the switching frequency of devices in the H-bridge equals to the base frequency of the desired ac voltage.

B. Circuit Diagram For Proposed System:



The more of the cascaded cells, the more voltage levels at the output side, and the output voltage is closer to the ideal sinusoidal. The dv/dt and the harmonics are very little. So it is a suitable topology for the energy storage system in electric vehicles and power grid

C. Switching table for proposed system

The switching Table or the pattern in which they turn On is given below by means of Switching table

K11	K12	K21	K22	K31	K32	K41	K42	STATE(IN VOLTS)
0	1	0	1	0	1	0	1	0
1	0	0	1	0	1	0	1	50
1	0	1	0	0	1	0	1	100
1	0	1	0	1	0	0	1	150
1	0	1	0	1	0	1	0	200

- Be aware of the different meanings of the homophones "affect" and "effect," "complement" and "compliment," "discreet" and "discrete," "principal" and "principle."

D. Multi Level Inverters (MLI)

In recent years, industry has begun to demand high power equipment, which now reaches the megawatt level. Controlled AC drives in the mega watt range are usually connected to the medium-voltage network. Today it is hard to connect a single power semi-conductor switch directly to medium voltage grids .For these reasons a new family of multilevel inverters has emerged as the solution for working with high voltage levels.

Multilevel inverters include an array of power semiconductors and capacitor voltage sources, the output of which generates voltages with stepped waveforms with less distortion, less switching frequency, higher efficiency, lower voltage devices and better electro-magnetic compatibility. The commutation of the switches permits the addition of the capacitor voltages, which reach high voltages at the output, while the power semiconductors must withstand only reduced voltages. Multilevel inverter structures have been developed to overcome shortcomings in solid-state switching device ratings so they can be applied to higher voltage systems. The multilevel voltage source inverters unique structure allows them to reach high voltages with low harmonics without the use of transformers. The general function of the multilevel inverter is to synthesize a desired AC voltage from several levels of DC voltages. The advent of the transform less multilevel inverters topology has brought forth various pulse width modulation (PWM) schemes as a means to control the switching of the active devices in each of the multiple voltage levels in the inverter. Multilevel power conversion technology is a very rapidly growing area of power electronics with good potential for further development. The most attractive application of this technology is in the medium-to-high-voltage range, and includes motor drives, power distribution, and power conditioning applications. In general multilevel inverter can be viewed as voltage synthesizers, in which the high output voltage is synthesized from many discrete smaller voltage levels.

Advantages

The main advantages of this approach are summarized as follows:

1) They can generate output voltages with extremely low distortion and lower dv/dt.
2) They draw input current with very low distortion.
3) They can operate with a lower switching frequency.
4) Their efficiency is high (>98%) because of the minimum switching frequency.
5) They are suitable for medium to high power applications.
6) Multilevel waveform naturally limits the problem of large voltage transients.

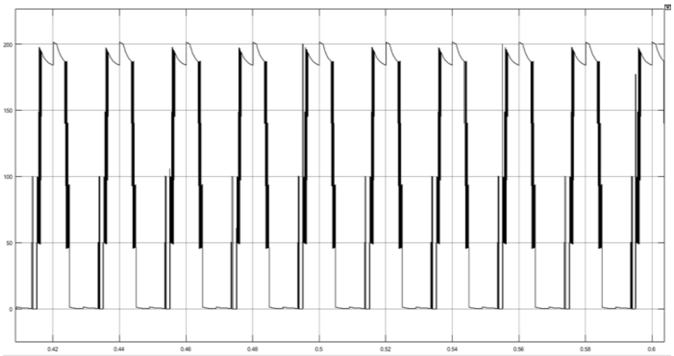
Applications

1) High Power Applications.
2) Where ever need sinusoidal supply, this type of inverter circuit can be implemented.

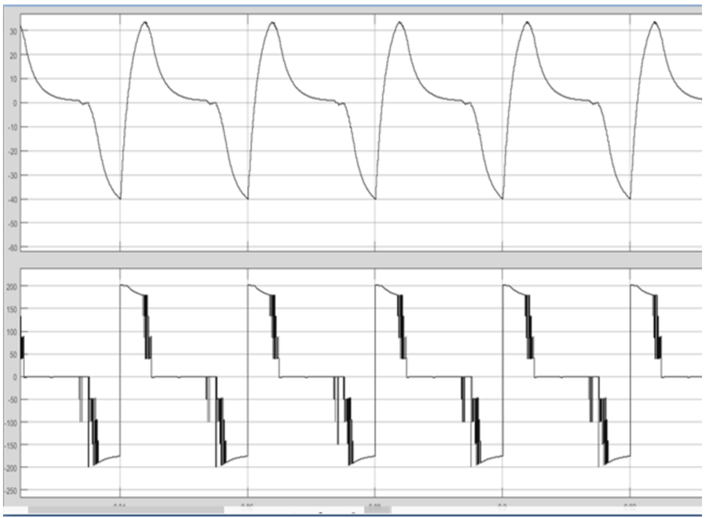
3) To improve the harmonic characteristics, a seven-level inverter could be modulated by a multilevel carrier technique such as five-level carrier modulation.

4. Simulation

A. Cascaded half bridge output



B. Converter AC Output



C. Matlab program

```
function [tshigh,tslow] =svpwm(t)

teta=mod(2*pi*50*t,2*pi);
s=1+fix(teta/(pi/3+1*10^-30));
vdc=400;
m=0.8;
vref=(2/3)*m*vdc;

ts=1/10e3;
fu=sqrt(3)*ts*(vref/vdc);


t1 = fu*(sin(s*pi/3)*cos(teta)-cos(s*pi/3)*sin(teta));
t2 =fu*(cos((s-1)*(pi/3))*sin(teta)-sin((s-1)*(pi/3))*cos(teta));
t0=ts-(t1+t2);


if s==1
tah=(t1+t2+t0/2);
tbh=(t2+t0/2);
tch=(t0/2);
tal=(t1+t2+t0/2);
tbl=(t2+t0/2);
tcl=(t0/2);

elseif s==2
tah=(t1+t0/2);
tbh=(t2+t1+t0/2);
tch=(t0/2);

tal=(t1+t0/2);
tbl=(t2+t1+t0/2);
tcl=(t0/2);

elseif s==3
tah=(t0/2);
tbh=(t2+t1+t0/2);
tch=(t2+t0/2);

tal=(t0/2);
tbl=(t2+t1+t0/2);
tcl=(t2+t0/2);

elseif s==4
tah=(t0/2);
tbh=(t1+t0/2);
tch=(t1+t2+t0/2);

tal=(t0/2);
tbl=(t1+t0/2);
tcl=(t2+t1+t0/2);

elseif s==5
tah=(t2+t0/2);
tbh=(t0/2);
tch=(t1+t2+t0/2);

tal=(t0/2+t2);
tbl=(t0/2);
tcl=(t2+t1+t0/2);
else
tah=(t1+t2+t0/2);
tbh=(t0/2);
tch=(t1+t0/2);

tal=(t0/2+t2+t1);
tbl=(t0/2);
tcl=(t1+t0/2);

end
tsh=[tah tbh tch]*1e5;
tsl=[-tal -tbl -tcl]*1e5;
 tshigh = tsh-5;
tslow = tsl+5;
```

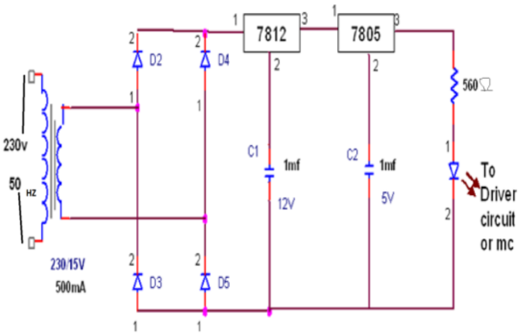
5. Hardware

Hardware Implementation

For the hardware implementation we use different components. They are listed below as

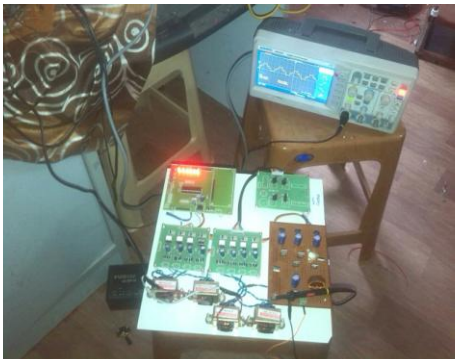
1. Voltage Regulators
• 7812 voltage regulator
• 7805 voltage regulator
2. IC IR TLP250 for the amplification of the pulses given by dsPIC30F2010.

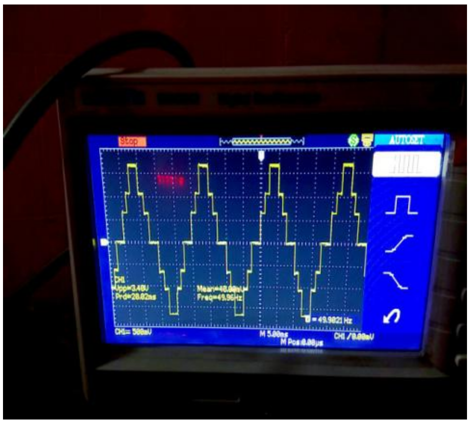
Power supply circuit:
1) A step-down transformer (230/15) V is used to give input supply to the power circuit.
2) The 15V AC input is rectified into 15V pulsating DC with the help of full bridge rectifier circuit.
3) The ripples in the pulsating DC are removed and pure DC is obtained by using a capacitor filter.
4) The positive terminal of the capacitor is connected to the input pin of the7812 regulator for voltage regulation.
5) An output voltage of 12V obtained from the output pin of 7812 is fed as the supply to the pulse amplifier.
6) An output voltage of 5V obtained from the output pin of 7805 is fed as the supply to the micro controller.
7) From the same output pin of the 7805, a LED is connected in series with the resistor to indicate that the power is ON.



Hardware Circuit


Hardware Image


DC Input to Circuit


Staircase Output

6. Acknowledgment

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