International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075, Volume-8 Issue-7 May, 2019

# A Multi-Port Bidirectional Dc-Dc Converter for Hybrid Energy Storage System

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***Abstract***: ***A multiport bidirectional dc-dc converter for hybrid energy storage system and dc grid applications is presented. Recently, this has paved a new way for development of many power management systems. This combination reduces cost and improves performance of the system. Designed to transfer power between energy storage system and dc bus and vice versa, thereby balancing power between the both. When power is excess in dc bus side and deficient in energy storage system, power will flow from dc bus( HV side) to energy storage side(LV side) -charging of energy storage system (buck mode). When power is deficient in high voltage side, energy flows from low voltage side-discharging of energy storage system (boost mode).***

***Index Terms***: ***Multi-port bidirectional dc-dc converter, Hybrid energy storage, DC bus microgrid*.**

## I. INTRODUCTION

Renewable sources of energy have an important part in supplying power as it is pollution free available in abundant and will be a promising option in the regions of weak power grid and which don't have access to power grid. But combining renewable energy sources such as photovoltaic systems wind energy systems with power grid is not easy because there will be frequent fluctuations.

In this case, combining renewable energy sources with energy storage system will be a better option. Battery is commonly used for storing energy. Battery has many advantages like long life span, low initial cost, high energy density. But has disadvantages such as slow dynamic response and low power density. So, can't be operated at sudden load or power changes. Supercapacitor can operate at sudden load or power changes. Advantages of supercapacitor are fast charging or discharging time, has long life span and easy maintenance. Hence, hybrid energy storage system comprising battery together with supercapacitor is used for improving of system's performance. Battery stores energy under steady state and supercapacitor stores energy during transient state (i.e) at sudden changes on load or power.

Bidirectional dc-dc converter is used for efficient power transfer between hybrid energy storage system and dc grid. This helps in balancing power between the both. This improves efficiency, system's performance.

Bidirectional dc-dc converter is of two categories: Non-Isolated and Isolated topologies. Non-isolated converters find applications which do not require galvanic isolation and isolated types have transformer for isolation between energy storage system and the load or grid. Isolated topology has advantages over non-isolated topology as it increases reliability, increases safety preventing the spread of fault at one side to the other side.

Bidirectional dc-dc converter finds application in many areas like space, motor drives, micro-grid, electric vehicles, telecommunication, uninterrupted power supplies.

## II. MULTI PORT BIDIRECTIONAL DC-DC CONVERTER

The suggested converter topology is shown in Fig 1. There are three ports – The battery port, Super capacitor port, DC bus port. The low voltage port (i.e) the battery port is on the primary side of the transformer and the high voltage port (i.e) the dc bus port and the super capacitor port on the secondary side.

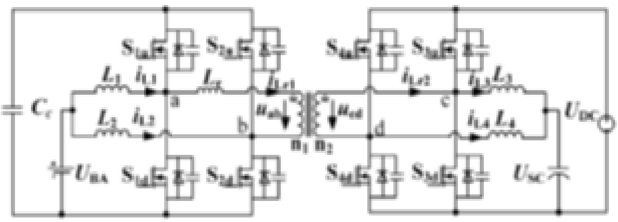

Fig.1 Proposed bidirectional dc- dc converter.

At the primary side of the transformer, the switches $S_{1u}$, $S_{2u}$, $S_{1d}$ and $S_{2d}$ along with parasitic capacitors and body diodes and the inductors $L_1$, $L_2$ form 2 channel interleaved buck/boost topology where battery is connected to the low voltage port ( $U_{ba}$ ). At secondary side, the switches $S_{3u}$, $S_{4u}$, $S_{3d}$ and $S_{4d}$ along body diodes and parasitic capacitors and the inductors $L_3$, $L_4$ form 2 channel interleaved buck/boost topology where DC bus is connected to high voltage port and Supercapacitor to low voltage port. At battery side, filter capacitor $C_c$ which forms high voltage port is not connected to any power input or output. There will be improvement in converter's performance by controlling voltage($U_{Cc}$) of this port.

On the battery side switches $S_{1u}$ and $S_{2d}$ conduct at the same time and after 180°, $S_{2u}$ and $S_{1d}$ conduct. Similarly at the side of DC bus, the switches S3u and S4d conduct at the same time and after 180°, $S_{4u}$ and $S_{3d}$ conduct. D1 and D2 are the duty cycles of the switches at the battery side and DC bus side respectively.

**Revised Manuscript Received on May 06, 2019**
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$U_{cc}$ is the primary side voltage,$U_{dc}$ is the secondary side voltage i.e,dc bus voltage Adjusting D1, this will control $U_{Cc}$. The duty cycle D2 will depend on $U_{dc}$ and $U_{sc}$. The phase shift of the converter $\phi$ ( $-\pi \le \phi \le \pi$ ). The power flow between the DC bus and battery can be controlled by $\Phi$. The maximum power transferred at $\phi = 0.5\ \pi$, D1= D2 =0.5. The power transfer depends on leakage inductor too. So the leakage inductor has to be designed to achieve maximum power transfer.

## A. RMS Current Through Leakage Inductor,Ilr_rms

As the battery side power transfer equal to rated value,Ilr_rms is

$$Ilr\_rms=\sqrt{\left(\frac{1}{2\pi}\right)\left(\int_0^{2\pi}(iLR(\theta))^{\wedge}2\,d\theta\right)} \qquad (1)$$

The capacitor Cc voltage , UCc = 2Uba, will impact the leakage inductor current and transmitted power.

## *B.* Calculation of Active Power and Reactive Power

The leakage inductor's RMS voltage is,

$$Ulr\_rms=\sqrt{\left(\frac{1}{2\pi}\right)\left(\int_0^{2\pi}(Uab(\theta)-Ucd(\theta)^{\wedge}2\,d\theta\right)} \qquad (2)$$

The reactive power is given by

$$Qlr = Ulr\_rms.Ilr\_rms \qquad (3)$$

Reactive power to active power ratio is given by

$$KQP=Qlr / Pba \qquad (4)$$

Decreasing phase shift angle as low as possible will reduce reactive component. Design of leakage inductor should meet the requirement and improve efficiency.

# III. DESIGN OF CONVERTER

## 1) Design of Components of the Converter:

### A. Transformation ratio:

The preferred turns ratio should be of D1 $\le$0.5 if the voltage of battery is at its peak value and followed by minimum voltage value at the DC bus.

### B. Leakage inductance of the transformer:

At the instant $\phi=\pi/2$, the power transfer to dc bus side from battery side is high.Design leakage inductance such that maximum powe r is transferred at every operating point.

### C. Design criteria for dc bus and battery side inductance:

Inductors has to be designed in such a way that the ripple current is minimized for improving the life span of battery. Fluctuations in inductor current can be up to 0.1 to 0.2 times of the maximum inductor current.

## 2) Prototype design:

For testing, considering a hybrid energy storage prototype and 380V dc micro grid experiment system.

(i) DC bus voltage $U_{dc}$=350-420V (380-420v when charging,350-380v when discharging); (ii) the battery voltage $U_{ba}$=42 – 56.4V ; (iii) the rated battery power $P_{ba}$ =1kW; (iv) the supercapacitor voltage $U_{sc}$=152-300V ; (v)the rated super capacitor power $P_{sc}$=10kW and (vi) switching frequency 20kHz.

A) Leakage inductance $L_r$ and Turns ratio of the transformer

Transformer's turns ratio is set as n1:n2=1:3.1. This will be suitable when dc voltage is at minimum value and operating range for D1 will be 0.3≤D1≤0.5 and duty cycle D2 of the dc-bus side between $0.35 \le D2 \le 0.86$ influenced by $U_{dc}$ and $U_{sc}$.As per the requirement, the leakage inductance $L_r$ is modeled to be 0.025 mh

B) Inductors on the dc-bus side:

$U_{dc}$ = 350 Volts, $U_{sc}$ =300 Volts, and $U_{ba}$ = 56.4 Volts. The modelling of Inductors on the dc-bus side likewise $i_{min}$ <−13A, $i_{max}$ >13 A. As per requirement, $L_3 = L_4$ = 45 micro henry.

## D. Inductor Battery Side:

Total ripple current is given by following equations

$$\Delta i0 = \frac{(UCc-2Uba)\,Uba}{f\,L\,UCc}\quad ,\quad 0 < D1 < ½ \qquad (5)$$

$$\Delta i0 = \frac{(2UCc-2\,Uba)\left(\frac{Uba}{UCc}-\frac{1}{2}\right)}{f\,L}\quad ,\ ½ < D2 < 1 \qquad (6)$$

The output ripple current is maximum when UCc = 135.5 Volt and Uba = 40 Volt.The inductor ripple current is placed to be 0.2 times of the inductor's maximum current and battery's maximum current, Iba(max) to 25 A, so ΔImax = 5 A and inductors are rated as L1 = L2 = 164 µH.

# IV. STATES OF OPERATION OF THE CONVERTER

Depending on operating state of battery, there are two stages- energy storage state and energy release state. During normal operation, Supercapacitor voltage Usc has to be maintained at its mid voltage, Usc_mid.

### A) Energy Storage State

When power at dc bus is more than the power required by load, the excess power can be stored. Now the converter will operate in buck mode and in energy storage state. State diagram is shown in Fig 2.

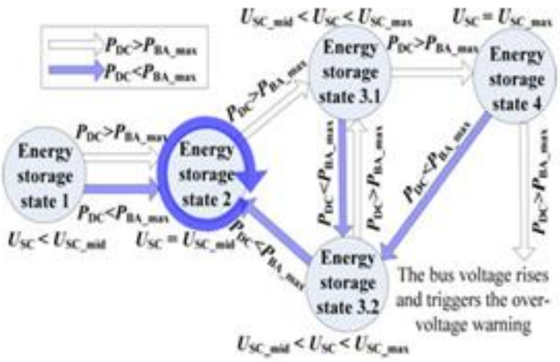


Fig 2 Energy storage state diagram

i) When $U_{sc} < U_{sc\_mid}$, Supercapacitor charges first and battery not charged till $U_{sc} = U_{sc\_mid}$.

ii)When $U_{sc} = U_{sc\_mid}$, battery charges when $P_{dc} < P_{ba\_max}$ and supercapacitor voltage limited to $U_{sc\_mid}$. When $P_{dc} > P_{ba\_max}$, battery


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charges and excess power absorbed by supercapacitor.

iii) When $U_{sc\_mid} < U_{sc} < U_{sc\_max}$, battery will charge and excess power will be absorbed by supercapacitor if $P_{dc} > P_{ba\_max}$ and if $P_{dc} < P_{ba\_max}$, battery will be charged and supercapacitor will discharge to compensate the voltage drop at dc bus.

iv) When $U_{sc} = U_{sc\_max}$, supercapacitor will not charged further if Pdc > Pba_max and there will be warning for overvoltage. If Pdc < Pba_max, battery will charge and supercapacitor will discharge.

### B) Energy Release State

When power at dc bus is less than the power required by load, power is required by bus to supply load. Power can be taken for energy storage system. Now the converter will operate in boost mode and in energy release state. State diagram is shown in Fig 3.

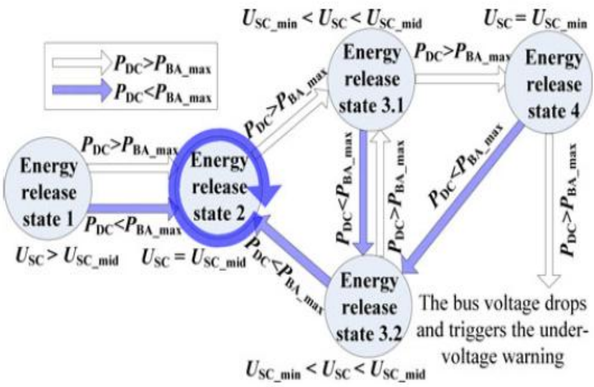



Fig 3 Energy release state diagram.

i) When $U_{sc} > U_{sc\_mid}$, Supercapacitor charges first and battery not charged till $U_{sc} = U_{sc\_mid}$.

ii) When $U_{sc} = U_{sc\_mid}$, battery discharges when $P_{dc} < P_{ba\_max}$ and supercapacitor voltage limited to $U_{sc\_mid}$. When $P_{dc} > P_{ba\_max}$, supercapacitor charges and battery not charged.

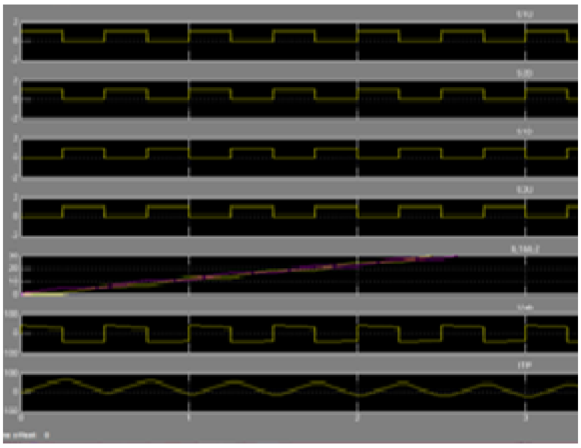
iii) When $U_{sc\_min} < U_{sc} < U_{sc\_mid}$, battery will discharge and supercapacitor discharges till $U_{sc} = U_{sc\_min}$, if $P_{dc} > P_{ba\_max}$ and if $P_{dc} < P_{ba\_max}$, battery will discharge and supercapacitor will be charged by excess power till $U_{sc} = U_{sc\_mid}$ .

iv) When $U_{sc} = U_{sc\_min}$, supercapacitor will not discharge further if $P_{dc} > P_{ba\_max}$ and there will be warning for lowvoltage. If $P_{dc} < P_{ba\_max}$, battery will charge and supercapacitor charged till $U_{sc} = U_{sc\_mid}$.

## V. SIMULATION RESULTS:

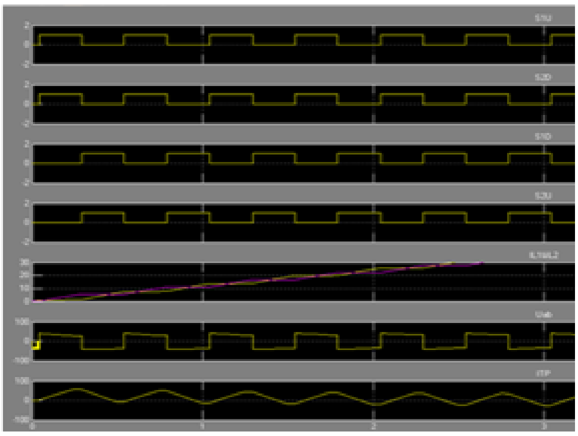
### A) BDC(primary leading secondary)

Pulses ,primary side inductor current, current at primary of transformer, voltage at primary side



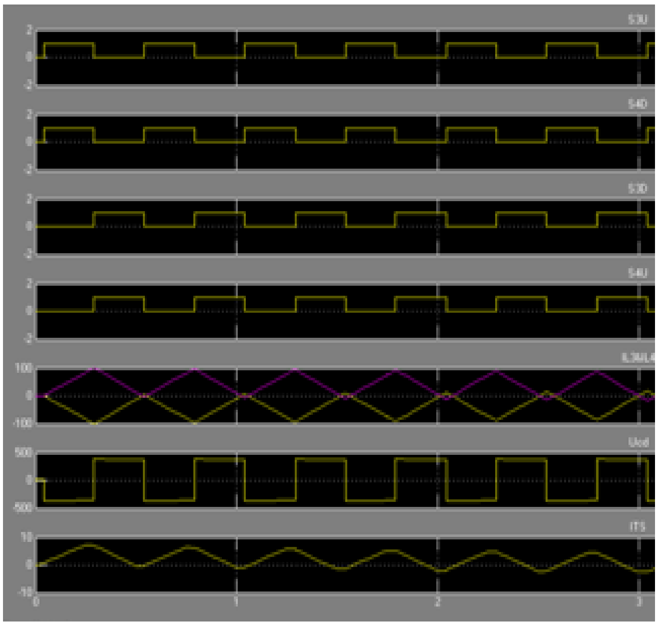
### B) BDC (secondary leading primary)

Pulses ,primary side inductor current, current at primary of transformer, voltage at primary side



### C) BDC(primary leading secondary)

Pulses , secondary side inductor current, current at secondary of transformer, voltage at secondary side





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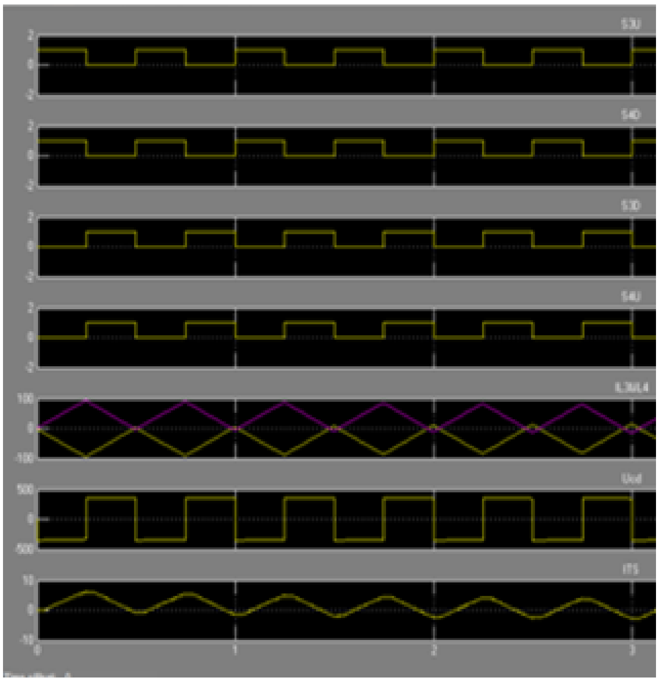
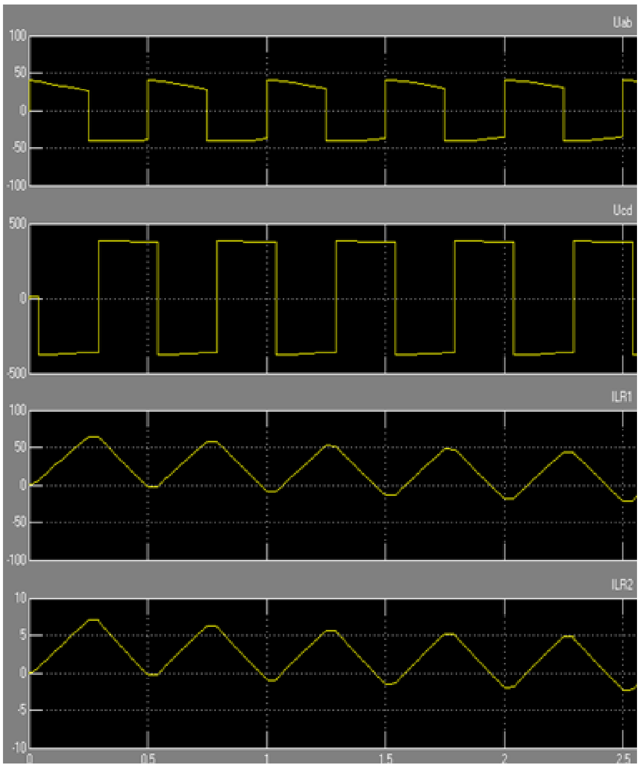
**D) BDC(Secondary leading primary)**

Pulses , secondary side inductor current, current at secondary of transformer, voltage at secondary side



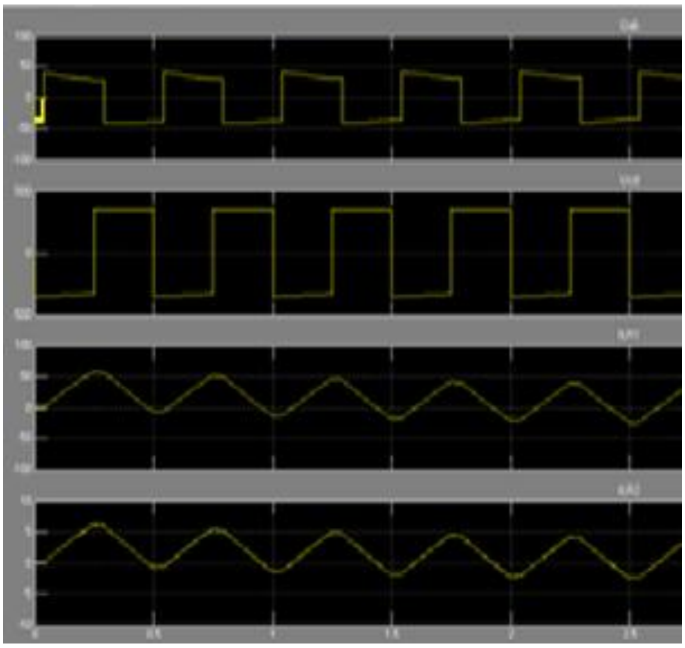
**E)BDC(primary leading secondary)**

VOLTAGE AND CURRENT at primary side and secondary side



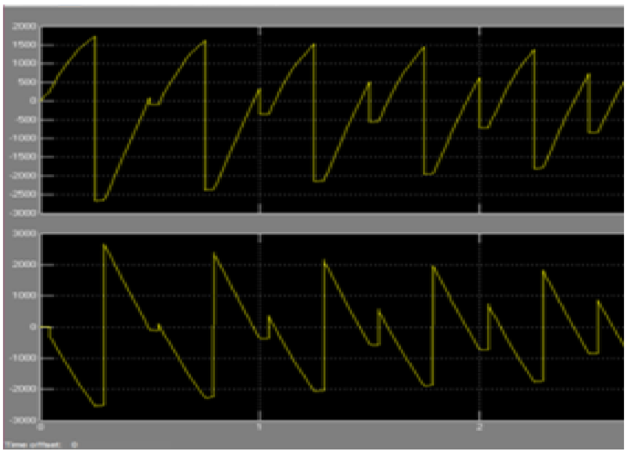

**F)BDC(secondary leading primary)**

VOLTAGE AND CURRENT at primary side and secondary side



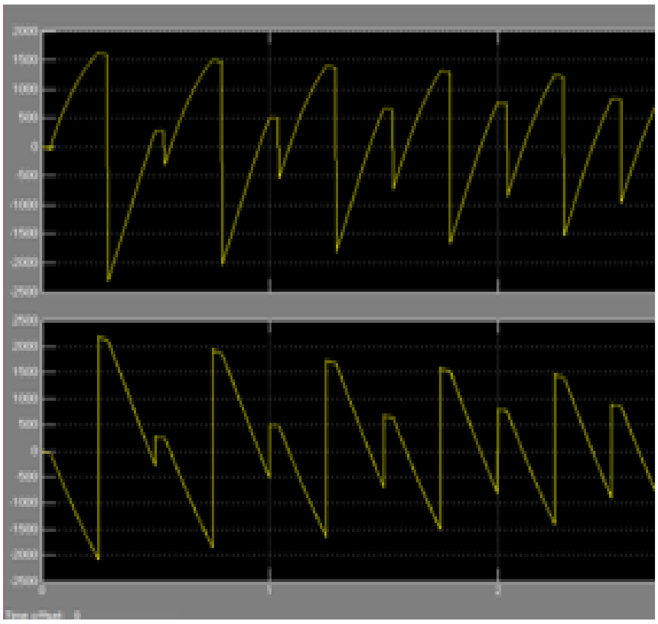
**G) BDC(primary leading secondary)**

POWER at both side



**H) BDC(Secondary leading primary)**

POWER at both side





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## VI CONCLUSION

An isolated bidirectional multiport dc-dc converter for exchange of power between hybrid energy storage system and the dc bus is proposed. The analysis of power transmission between dc bus and battery side has been made in this work.

## REFERENCES

1. Shaojun Xie, Zhihui Ding, Cheng Wang, Chen Yang and Zhao Zhang, , "A Novel Soft-Switching Multiport Bidirectional DC–DC Converter for Hybrid Energy Storage System" , Ieee Transactions On Power Electronics, Vol. 29, No. 4, April 2014 1595.
2. B. Fahimi and W. Jiang, "Multiport power electronic interface—concept, modeling, and design," IEEE Trans. Power Electron., vol. 26, no. 7, pp. 1890–1900, Jul. 2011.
3. M. A. M. Hendrix and J. L. Duarte and H. Tao, "Multiport converters for hybrid power sources," in Proc. IEEE Power Electron. Spec. Conf., 2008, pp. 3412–3418.
4. H. Fan, D.Xu, and C. Zhao, "A PWM plus phase-shift control bidirectional DC-DC converter," IEEE Trans. Power Electron., vol. 19, no. 3, pp. 666– 675, May 2004.
5. Y.Liu, Y.Qing, B. Wu, F. Zhuo, F. Long and W. Gu, "A management strategy for solar panel-battery-super capacitor hybrid energy system in solar car," in Proc. IEEE 8th Int. Conf. Power Electron. ECCE Asia, 2011, pp.1682–1687

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