Jalbrzykowski, Citko, published in Bulletin of the Polish Academy of Technical Sciences Vol. 57, No. 4, 2009. All of these are operated at fixed frequency and controlled by either phase-shifting gate pulses or duty cycle modulation. All of these circuits have the drawback of limited operating ranges for high efficiency operation, such as zero voltage switching (ZVS) of main switches for only a limited load range etc.

The object of the present invention is to provide a method for controlling a series resonant DC/DC converter with improved efficiency. The object is also to provide a method for controlling a series resonant DC/DC converter so that a bidirectional DC/DC converter is achieved. Hence, the series resonant DC/DC converter can be used both for supplying power from the battery to the DC bus during power failures and for supplying power from the DC bus to recharge the battery after a power failure. This reduces the number of components, and hence costs/space can be saved.

SUMMARY OF THE INVENTION

An aspect of t~~T~~he present invention relates to a method for controlling a series resonant DC/DC converter, comprising the steps of:

- defining a switching period TP from time Tstart to time Tend for the series resonant DC/DC converter; where the switching period TP comprises a first half period TA from time Tstart to time Tcenter and a second half period TB from time Tcenter to time Tend, and defining a subsequent switching period TP+1 after the switching period TP;

- controlling a first set of switches of a first switching circuit to be ON from the beginning Tstart of the first half period TA minus a time interval ΔTAE1, where the time interval ΔTAE1 is provided at the end of the first half period TA;

- controlling a second set of switches of the first switching circuit to be ON from the beginning Tcenter of the second half period TB minus a time interval ΔTBE1, where the time interval ΔTBE1 is provided at the end of the second half period TB;

- controlling the first set and the second set of switches of the first switching circuit to be OFF in the time interval ΔTAE1 and the time interval ΔTBE1;

- controlling a first set of switches of a second switching circuit to be ON in the first half period TA minus a time interval ΔTAS1 and minus a time interval ΔTAE2, where the time interval ΔTAS1 is provided at the beginning of the first half period TA and where the time interval ΔTAE2 is provided at the end of the first half period TA;

- controlling a second set of switches of the second switching circuit to be ON in the second half period TB minus time interval ΔTBS1 and minus time interval ΔTBE2, where the time interval ΔTBS1 is provided at the beginning of the second half period TB and where the time interval ΔTBE2 is provided in the end of the second half period TB;

- controlling the first set and the second set of switches of the second switching circuit to be OFF in the time intervals ΔTAS1, ΔTAE2, ΔTBS1 and ΔTBE2;

where the time interval ΔTAE1 forms a first time interval Tsc1off1 wherein the first and second sets of switches of the first switching circuit are OFF, and where the time interval ΔTBE forms a second time interval Tsc1off2 wherein the first and second sets of switches of the first switching circuit are OFF;

where the time intervals ΔTAE2 and ΔTBS1 form a continuous time interval Tsc2off1, where the first and second set of switches of the second switching circuit are OFF; and where the time interval ΔTBE2 and a time interval ΔTAS1(TP+1) of the subsequent switching period TP+1 form a continuous time interval Tsc2off2, where the first and second sets of switches of the second switching circuit are OFF;

where the time interval Tsc1off1 and the time interval Tsc2off1 is overlapping and where the time interval Tsc1off2 and the time interval Tsc2off2 is overlapping.

In the above aspect, the method further comprises the step of controlling the relation between the voltage between first DC terminals of the series resonant DC/DC converter and the voltage between second DC terminals of the series resonant DC/DC converter by varying the length of the switching period TP.

In one embodiment~~aspect~~ the method comprises the step of controlling the centre of interval Tsc1off1 to be close to or equal to the centre of time interval Tsc2off1 and the centre of interval Tsc1off2 to be close to or equal to the centre of time interval Tsc2off2.

~~In one aspect the method comprises the step of controlling the relation between the voltage between first DC terminals of the series resonant DC/DC converter and the voltage between second DC terminals of the series resonant DC/DC converter by varying the length of the switching period TP.~~

In one embodiment~~aspect~~ the method comprises the step of controlling the direction of the power flow through the series resonant DC/DC converter by varying the switching period TP.

In one embodiment~~aspect~~ the method comprises the step of controlling the switches of the first and second switching circuit to provide zero voltage switching at switch turn on and to provide nearly zero current switching at switch turn off by controlling the first and second switching circuit to have a fixed switching frequency close to the series resonant frequency.

In one embodiment~~aspect~~ the switches of the first and second switching circuit are controlled by switching at an operating point at or near the series resonant frequency for all voltages over the first DC terminals which are inside a specified operating range.

In one embodiment~~aspect~~ the switches of the first and second switching circuit are controlled by switching at an operating point at or near the series resonant frequency for all load conditions at the second DC terminals.

An aspect of t~~T~~he present invention also relates to a series resonant DC/DC converter comprising:

- first DC terminals;
- second DC terminals;
- an inductor device;
- a first switching circuit connected between the first DC terminals and the inductor device, where the first switching circuit comprises a first set of switches and a second set of switches;
- a second switching circuit and a resonant circuit connected between the second DC terminals and the inductor device, where the second switching circuit comprises a first set of switches and a second set of switches;
- a control circuit for controlling the set of switches of the first and second switching circuits according to one of the methods above.

DETAILED DESCRIPTION

Embodiments of the present invention will be described in detail in the following with reference to the enclosed drawings, where:

Fig. 1 illustrates a a typical application for bidirectional DC/DC converters;

Fig. 2 illustrates a first embodiment of the DC/DC converter;

Fig. 3 illustrates a second embodiment of the DC/DC converter;

Fig. 4 illustrates a third embodiment of the DC/DC converter;

Fig. 5 illustrates a fourth embodiment of the DC/DC converter;

Fig. 6 illustrates a fifth embodiment of the DC/DC converter;

Fig. 7 illustrates a fifth embodiment of the DC/DC converter; this embodiment does not have a transformer device;

Fig. 8 shows waveforms of voltages and currents of the second embodiment at full load;

Fig. 9 shows details of fig. 9;

CLAIMS

1. Method for controlling a series resonant DC/DC converter, comprising the steps of:

- defining a switching period TP from time Tstart to time Tend for the series resonant DC/DC converter; where the switching period TP comprises a first half period TA from time Tstart to time Tcenter and a second half period TB from time Tcenter to time Tend, and defining a subsequent switching period TP+1 after the switching period TP;

- controlling a first set ~~(S1sc1; S1sc1, S4sc1)~~ of switches of a first switching circuit ~~(SC1)~~ to be ON from the beginning Tstart of the first half period TA minus a time interval ΔTAE1, where the time interval ΔTAE1 is provided at the end of the first half period TA;

- controlling a second set ~~(S2sc1; S2sc1, S3sc1)~~ of switches of the first switching circuit ~~(SC1)~~ to be ON from the beginning Tcenter of the second half period TB minus a time interval ΔTBE1, where the time interval ΔTBE1 is provided at the end of the second half period TB;

- controlling the first set ~~(S1sc1; S1sc1, S4sc1)~~ and the second set ~~(S2sc1; S2sc1, S3sc1)~~ of switches of the first switching circuit ~~(SC1)~~ to be OFF in the time interval ΔTAE1 and the time interval ΔTBE1;

- controlling a first set ~~(S1sc2; S1sc2, S4sc2)~~ of switches of a second switching circuit ~~(SC2)~~ to be ON in the first half period TA minus a time interval ΔTAS1 and minus a time interval ΔTAE2, where the time interval ΔTAS1 is provided at the beginning of the first half period TA and where the time interval ΔTAE2 is provided at the end of the first half period TA;

- controlling a second set ~~(S2sc2; S2sc2, S3sc2)~~ of switches of the second switching circuit ~~(SC2)~~ to be ON in the second half period TB minus time interval ΔTBS1 and minus time interval ΔTBE2, where the time interval ΔTBS1 is provided at the beginning of the second half period TB and where the time interval ΔTBE2 is provided in the end of the second half period TB;

- controlling the first set ~~(S1sc2; S1sc2, S4sc2)~~ and the second set ~~(S2sc2; S2sc2, S3sc2)~~ of switches of the second switching circuit ~~(SC2)~~ to be OFF in the time intervals ΔTAS1, ΔTAE2, ΔTBS1 and ΔTBE2;

where the time interval ΔTAE1 forms a first time interval Tsc1off1 wherein the first and second sets of switches of the first switching circuit ~~(SC1)~~ are OFF, and where the time interval ΔTBE forms a second time interval Tsc1off2 wherein the first and second sets of switches of the first switching circuit ~~(SC1)~~ are OFF;

where the time intervals ΔTAE2 and ΔTBS1 form a continuous time interval Tsc2off1, where the first and second set of switches of the second switching circuit ~~(SC2)~~ are OFF; and where the time interval ΔTBE2 and a time interval ΔTAS1(TP+1) of the subsequent switching period TP+1 form a continuous time interval Tsc2off2, where the first and second sets of switches of the second switching circuit ~~(SC2)~~ are OFF;

where the time interval Tsc1off1 and the time interval Tsc2off1 is overlapping and where the time interval Tsc1off2 and the time interval Tsc2off2 is overlapping

where the method comprises the step of controlling the relation between the voltage between first DC terminals ~~(T1P, T1N)~~ of the series resonant DC/DC converter and the voltage between second DC terminals ~~(T2P, T2N)~~ of the series resonant DC/DC converter by varying the length of the switching period TP.

2. Method according to claim 1, where the method comprises the step of controlling the centre of interval Tsc1off1 to be close to or equal to the centre of time interval Tsc2off1 and the centre of interval Tsc1off2 to be close to or equal to the centre of time interval Tsc2off2.

3. Method according to any one of claims 1 - 2, where the method comprises the step of controlling the direction of the power flow through the series resonant DC/DC converter by varying the switching period TP.

4. Method according to any one of claims 1 - 3, where the method comprises the step of controlling the switches of the first and second switching circuit ~~(SC1, SC2)~~ to provide zero voltage switching (ZVS) at switch turn on and to provide nearly zero current switching (ZCS) at switch turn off by controlling the first and second switching circuit to have a fixed switching frequency close to the series resonant frequency.

5. Method according to claim 4, where the switches of the first and second switching circuit ~~(SC1, SC2)~~ are controlled by switching at an operating point at or near the series resonant frequency for all voltages over the first DC terminals which are inside a specified operating range.

6. Method according to claim 4, where the switches of the first and second switching circuit ~~(SC1, SC2)~~ are controlled by switching at an operating point at or near the series resonant frequency for all load conditions at the second DC terminals.

7. Series resonant DC/DC converter comprising:

- first DC terminals ~~(T1P, T1N)~~;
- second DC terminals ~~(T2P, T2N)~~;
- an inductor device ~~(ID; TD)~~;
- a first switching circuit ~~(SC1)~~ connected between the first DC terminals ~~(T1P, T1N)~~ and the inductor device ~~(ID; TD)~~, where the first switching circuit ~~(SC1)~~ comprises a first set ~~(S1sc1; S1sc1, S4sc1)~~ of switches and a second set ~~(S2sc1; S2sc1, S3sc1)~~ of switches;
- a second switching circuit ~~(SC2)~~ and a resonant circuit ~~(RC)~~ connected between the second DC terminals ~~(T2P, T2N)~~ and the inductor device ~~(ID; TD)~~, where the second switching circuit ~~(SC2)~~ comprises a first set ~~(S1sc2; S1sc2, S4sc2)~~ of switches and a second set ~~(S2sc2; S2sc2, S3sc2)~~ of switches;
- a control circuit for controlling the set of switches of the first and second switching circuits ~~(SC1, SC2)~~ according to the method of any one of claims 1 - 6.