



Europäisches  
Patentamt  
European  
Patent Office  
Office européen  
des brevets



(11)

EP 2 876 655 A1

(12)

## EUROPEAN PATENT APPLICATION

(43) Date of publication:  
27.05.2015 Bulletin 2015/22

(51) Int Cl.:  
*H01F 7/18 (2006.01)* *H02H 9/04 (2006.01)*

(21) Application number: 13193637.9

(22) Date of filing: 20.11.2013

(84) Designated Contracting States:  
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB  
GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO  
PL PT RO RS SE SI SK SM TR**  
Designated Extension States:  
**BA ME**

(71) Applicant: **Danfoss A/S  
6430 Nordborg (DK)**  
(72) Inventor: **Pastrello, Marco  
31033 Castelfranco Veneto (IT)**

### (54) Circuit and method for recirculating a current

(57) The present invention relates to a circuit for passing AC or DC power from a power source to a connected load, the circuit comprising a main switch for connecting/disconnecting the load to/from the power source, a first current path for recirculating a current in a first

direction when the load is disconnected from the power source, and a second current path for recirculating a current in a second direction when the load is disconnected from the power source. The present invention further relates to an associated method for recirculating a current.

100

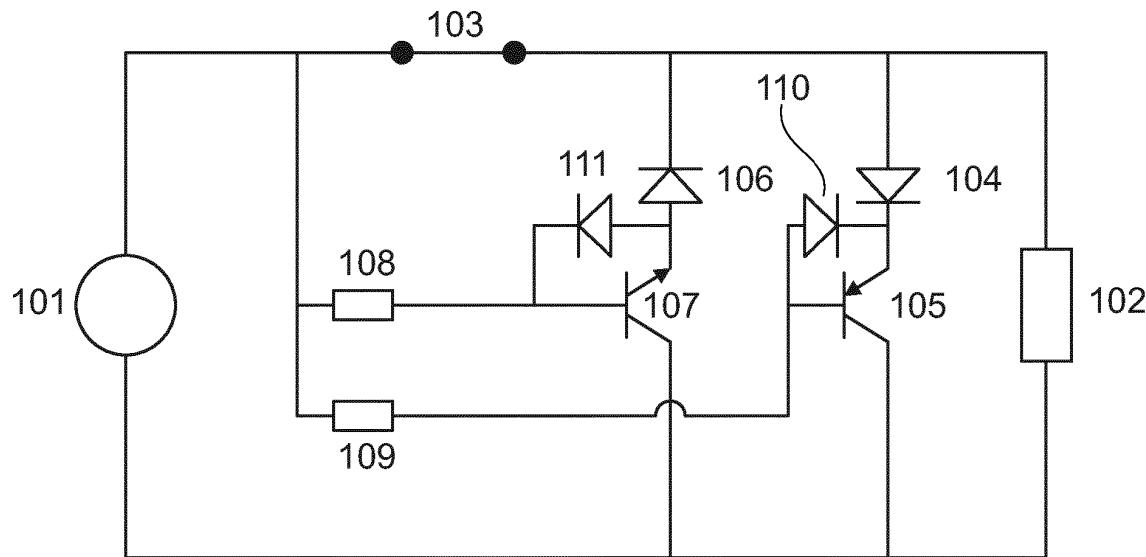


Fig. 1

**Description****FIELD OF THE INVENTION**

**[0001]** The present invention relates to a circuit and an associated method for automatic recirculation of currents within said circuit. In particular the present invention facilitates that pulse width modulated (PWM) currents, DC currents with any polarity as well as AC currents may be recirculated in an automatic manner when the load is disconnected from the power source.

**BACKGROUND OF THE INVENTION**

**[0002]** Recirculation of AC currents in circuits including inductive loads is known to be complicated. In particular, recirculation of AC currents and recirculation of DC currents with both positive and negative polarities is complicated.

**[0003]** US 6,670,792 discloses how a DC current with the help of a traditional diode may be recirculated. However, the arrangement presented in US 6,670,792 only allows that DC currents originating from a voltage of a certain polarity may be recirculated. A current driven by a voltage of the opposite polarity may not be recirculated.

**[0004]** WO 2012/021072 shows an arrangement where AC current may be recirculated by sequentially shunting diodes in the positive and the negative half periods. Controllable switches are applied for shunting the diodes. The arrangement suggested in WO 2012/021072 appears to be a complicated and expensive arrangement.

**[0005]** It may be seen as an object of embodiments of the present invention to provide a circuit and an associated method for recirculating a current within said circuit.

**[0006]** It may be seen as a further object of embodiments of the present invention to provide a circuit and an associated method for recirculation of DC, AC or PWM currents.

**[0007]** It may be seen as an even further object of embodiments of the present invention to provide a circuit and an associated method where recirculation is performed automatically.

**DESCRIPTION OF THE INVENTION**

**[0008]** The above-mentioned objects are complied with by providing, in a first aspect, a circuit for passing AC or DC power from a power source to a connected load, the circuit comprising

- a main switch for connecting/disconnecting the load to/from the power source,
- a first current path for recirculating a current in a first direction when the load is disconnected from the power source, and

- a second current path for recirculating a current in a second direction when the load is disconnected from the power source

5 wherein the first and second current paths are implemented in a manner so that recirculation of a current is performed in an automatic way.

**[0009]** Thus, when the main switch is closed power may be delivered from the power source to the load. Similarly, when the main switch is open the load is disconnected from the power source. The power source may in principle be any kind of power source including all sorts of AC and DC power source. Optionally a PWM circuit may be applied to modulate the output of the power source.

**[0010]** The first current path may comprise a NPN type switch and a diode arranged to conduct in the first direction. Similarly, the second current path may comprise a PNP type switch and a diode arranged to conduct in the 10 second direction. The first and second direction may, at least through the load, be opposite current directions.

**[0011]** It is an advantage of the present invention that either the first or the second current path is activated automatically immediately after the main switch is opened. The direction of the current in the load determines which of the two recirculating current paths to be activated. It is advantageous that no specific and dedicated actions need to be taken in order to activate a given recirculation path. The activation is performed automatically.

**[0012]** The NPN and the PNP switches may be connected to the power source via respective gate resistors.

**[0013]** At least part of the first and second current paths may be arranged in parallel. Thus, the NPN type switch and the PNP type switch may be arranged in parallel to each other, and furthermore they may be arranged in parallel over the load.

**[0014]** In a second aspect, the present invention relates to a power supply unit comprising a circuit according to the first aspect.

**[0015]** In a third aspect the present invention relates to a method for automatic recirculating AC or DC power within a circuit comprising a power source and a load connectable thereto, the method comprising the steps of

- 45 - disconnecting the load from the power source,
- recirculating a current in a first direction along a first current path in case of a first voltage polarity across the load, or
- recirculating a current in a second direction in a second current path in case of a second voltage polarity across the load.

**[0016]** As previously disclosed the load is disconnected from the power source by opening a main switch in the form of a controllable switch.

**[0017]** Again, it is advantageous that either the first or the second current path is activated automatically immediately after the main switch is opened, i.e. immediately after the load has been disconnected from the power source. Thus, it is advantageous that no specific and dedicated actions need to be taken in order to activate a given recirculation path.

**[0018]** The first current path may comprise a NPN type switch and a diode arranged to conduct in the first direction. The second current path may comprise a PNP type switch and a diode arranged to conduct in the second direction. The NPN type switch and the PNP type switch may be arranged in parallel over the load.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0019]** The present invention will now be described in further details with reference to the accompanying figures, where

Fig. 1 shows how power is fed to the load, and

Fig. 2 shows how current is recirculated when the load is disconnected from the power source.

**[0020]** While the invention is susceptible to various modifications and alternative forms, specific embodiments have been shown by way of examples in the drawings and will be described in detail herein. It should be understood, however, that the invention is not intended to be limited to the particular forms disclosed. Rather, the invention is to cover all modifications, equivalents, and alternatives falling within the spirit and scope of the invention as defined by the appended claims.

#### DETAILED DESCRIPTION OF THE INVENTION

**[0021]** In its most general aspect the present invention relates to a circuit and an associated method for recirculating a current within said circuit in an automatic manner. The circuit comprises a power source and a load connectable thereto. The current recirculation is a consequence of the load being abruptly disconnected from the power source.

**[0022]** It is an advantage of the present invention that the circuit is operable with both AC and DC power sources. In case of a DC power source the polarity of the power source voltage is of no importance. Also, pulse width modulated power source voltages may be applied to the load as well.

**[0023]** The load may in principle be any kind of load, such as a resistive, an inductive or a capacitive load. In case of an inductive load the associated inductive current must be recirculated when the load is disconnected from the power source.

**[0024]** Referring now to Fig. 1 a circuit 100 according to an embodiment of the present invention is depicted. As seen in Fig. 1 a power source 101 is connected to a

load 102 via a closed switch 103. The circuit 100 depicted in Fig. 1 is designed to be operated at 24 V AC. However, the power source may deliver AC or DC power having different voltage levels, such as voltage levels up to around 220 V. Moreover, the polarities of DC power sources are arbitrary.

**[0025]** At 24 V AC the power source voltage may, without any complications, be pulse width modulated with a modulation frequency of up to 1 kHz. However, higher modulation frequencies may be applicable as well.

**[0026]** The circuit 100 comprises two oppositely directed recirculation paths. The first path comprises switch 107 and diode 106 whereas the second path comprises switch 105 and diode 104. Diodes 110 and 111 serve as overvoltage protection circuits for the switches 105 and 107, respectively.

**[0027]** The first and second recirculation paths are arranged parallel to each other and parallel to the load 102 as well. The gates of the switches 105 and 107 are connected to the power source 101 via respective gate transistors 109 and 108. The switches 105 and 107 are PNP and NPN type switches, respectively.

**[0028]** It is advantageous that the circuit according to the present invention is capable of biasing the correct switch (105 or 107) automatically without applying additional drive circuits. This automatic biasing of the correct switch (105 or 107) ensures that a current recirculation path is established automatically when the load is disconnected from the power source.

**[0029]** Fig. 2 shows how the load current,  $I$ , is automatically recirculated when the switch 203 is opened. The "plus" shown in Fig. 2 indicates the polarity of the power source voltage. In the scenario depicted in Fig. 2 the current,  $I$ , automatically recirculates in the circuit containing the load 202, the switch 207 and the positively biased diode 206. Similarly, an oppositely directed current may recirculate in the loop comprising the load 202, the switch 205 and the diode 204. Similar to Fig. 1 diodes 210 and 211 serve as overvoltage protection circuits for the switches 205 and 207, respectively.

**[0030]** It is an advantage of the present invention that the current starts recirculating automatically as soon as the switch 103, 203 is opened. Thus, no transistors or other types of switches are to be activated in order to allow recirculation of currents. This automatic recirculation behaviour is completely independent of the polarity and the nature (DC or AC) of the currents. Also, PWM currents may be recirculated automatically.

#### Claims

1. A circuit for passing AC or DC power from a power source to a connected load, the circuit comprising
  - a main switch for connecting/disconnecting the load to/from the power source,
  - a first current path for recirculating a current in

a first direction when the load is disconnected from the power source, and  
 - a second current path for recirculating a current in a second direction when the load is disconnected from the power source,

wherein the first and second current paths are implemented in a manner so that recirculation of a current is performed in an automatic way.

2. A circuit according to claim 1, further comprising means adapted to pulse width modulate power from the power source.

3. A circuit according to claim 1 or 2, wherein the first current path comprises a NPN type switch and a diode arranged to conduct in the first direction.

4. A circuit according to claim 3, wherein the second current path comprises a PNP type switch and a diode arranged to conduct in the second direction.

5. A circuit according to claim 4, wherein the gates of the NPN and the PNP switches are connected to the power source via respective gate resistors.

6. A circuit according to any of the preceding claims, wherein at least part of the first and second current paths are arranged in parallel.

7. A circuit according to claim 6, wherein the NPN type switch and the PNP type switch are arranged in parallel.

8. A circuit according to any of the preceding claims, wherein the NPN type switch and the PNP type switch are arranged in parallel over the load.

9. A circuit according to any of the preceding claims wherein the power source comprises a DC power source.

10. A circuit according to any of claims 1-8, wherein the power source comprises an AC power source.

11. A power supply unit comprising a circuit according to any of the preceding claims.

12. A method for automatic recirculating AC or DC power within a circuit comprising a power source and a load connectable thereto, the method comprising the steps of

- disconnecting the load from the power source,  
 - recirculating a current in a first direction along a first current path in case of a first voltage polarity across the load, or  
 - recirculating a current in a second direction in

a second current path in case of a second voltage polarity across the load.

13. A method according to claim 12, wherein the load is disconnected from power source by opening a controllable switch.

14. A method according to claim 12 or 13, wherein first current path comprises a NPN type switch and a diode arranged to conduct in the first direction, and wherein second current path comprises a PNP type switch and a diode arranged to conduct in the second direction.

15. A method according to claim 14, wherein the NPN type switch and the PNP type switch are arranged in parallel over the load.

5

10

15

20

25

30

35

40

45

50

55

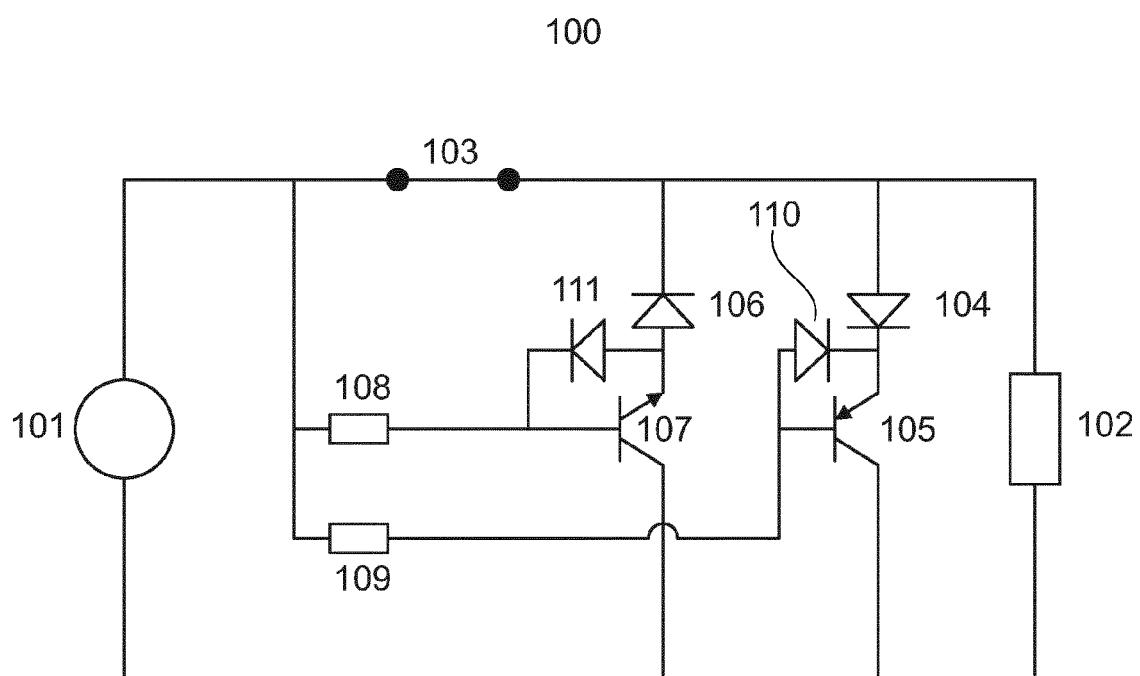


Fig. 1

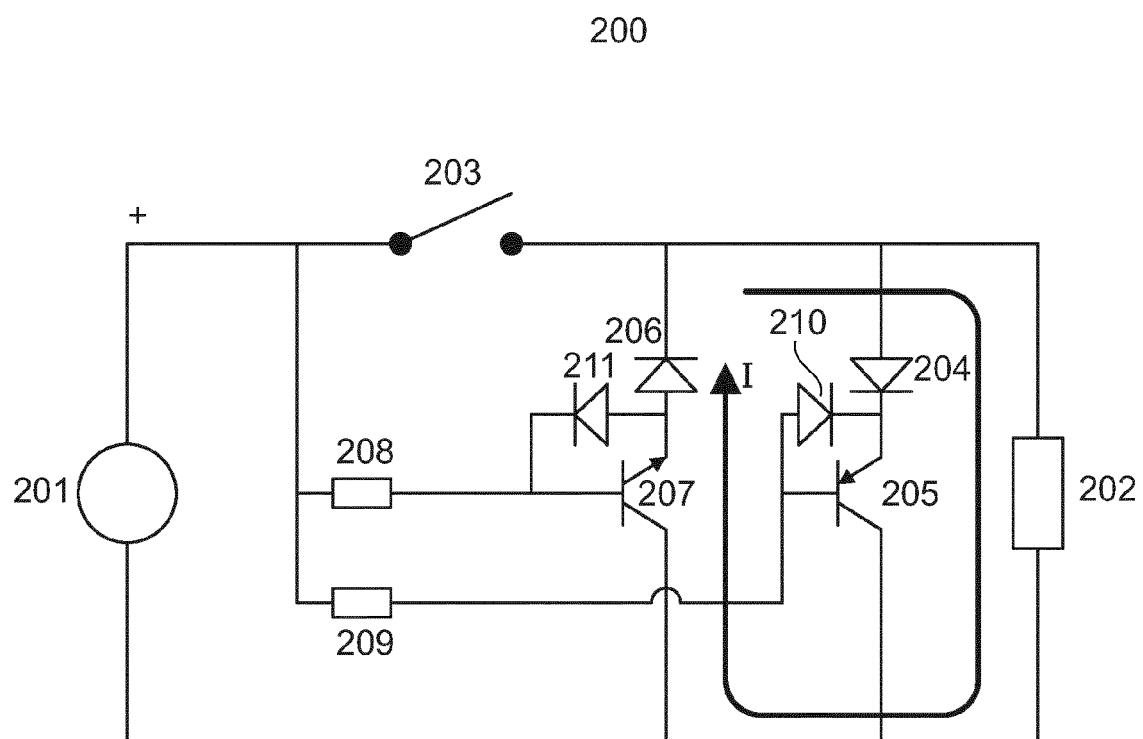


Fig. 2



## EUROPEAN SEARCH REPORT

Application Number  
EP 13 19 3637

5

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
10 X	JP 2000 184783 A (OMRON TATEISI ELECTRONICS CO) 30 June 2000 (2000-06-30) * paragraphs [0002] - [0004], [0023]; figure 5 *	1-8, 10-15	INV. H01F7/18 H02H9/04
15 X	JP 2000 293243 A (MITSUBISHI ELECTRIC CORP) 20 October 2000 (2000-10-20) * paragraph [0002] - paragraph [0007]; figure 11 *	1,3,4, 6-8, 10-15	
20 X	JP 2006 333588 A (NIPPON INTER ELECTRONICS CORP) 7 December 2006 (2006-12-07) * paragraphs [0004] - [0010], [0078]; figures 1,3,11 *	1-8, 10-15	
25 X	US 2011/157942 A1 (BABCOCK PAUL M [US] ET AL) 30 June 2011 (2011-06-30) * paragraphs [0011], [0027] - [0029], [0069] - [0092]; figures 5,6 *	1-4,6-9, 11-15	
30 A	US 6 188 203 B1 (RICE KEVIN E [US] ET AL) 13 February 2001 (2001-02-13) * column 5, line 35 - column 6, line 3; figures 2,3 *	1-15	TECHNICAL FIELDS SEARCHED (IPC)
35			H01F H02H
40			
45			
50 1	The present search report has been drawn up for all claims		
55	Place of search Munich	Date of completion of the search 10 April 2014	Examiner Gatzert, C
CATEGORY OF CITED DOCUMENTS			
X: particularly relevant if taken alone Y: particularly relevant if combined with another document of the same category A: technological background O: non-written disclosure P: intermediate document			
T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document			

ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.

EP 13 19 3637

5

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

10-04-2014

10

	Patent document cited in search report		Publication date	Patent family member(s)		Publication date
	JP 2000184783	A	30-06-2000	NONE		
15	JP 2000293243	A	20-10-2000	NONE		
	JP 2006333588	A	07-12-2006	JP 4726202 B2 JP 2006333588 A	20-07-2011 07-12-2006	
20	US 2011157942	A1	30-06-2011	AU 2010343096 A1 CA 2785715 A1 CN 102859860 A EP 2520014 A1 JP 2013516156 A US 2011157942 A1 WO 2011090732 A1	16-08-2012 28-07-2011 02-01-2013 07-11-2012 09-05-2013 30-06-2011 28-07-2011	
25	US 6188203	B1	13-02-2001	US 5903130 A US 6188203 B1 US 2001009363 A1	11-05-1999 13-02-2001 26-07-2001	
30						
35						
40						
45						
50						
55						

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

**REFERENCES CITED IN THE DESCRIPTION**

*This list of references cited by the applicant is for the reader's convenience only. It does not form part of the European patent document. Even though great care has been taken in compiling the references, errors or omissions cannot be excluded and the EPO disclaims all liability in this regard.*

**Patent documents cited in the description**

- US 6670792 B [0003]
- WO 2012021072 A [0004]