April 11, 1967 R. L. WHITE 3,313,985

SOLID STATE D.C. CIRCUIT BREAKER

Filed April 3, 1964

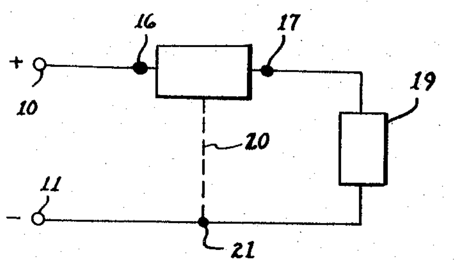

fig. 1

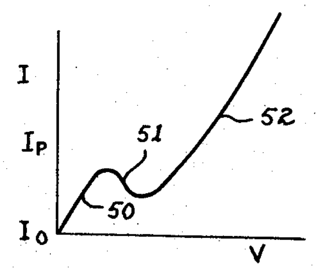

fig. 3

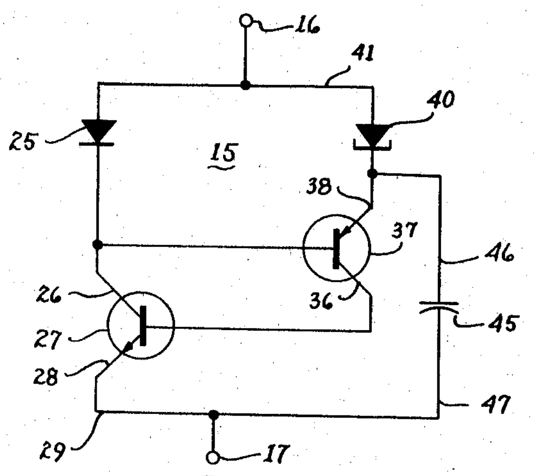

fig. 2

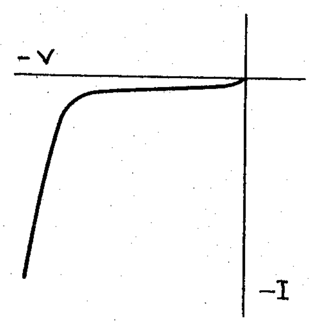

fig. 5

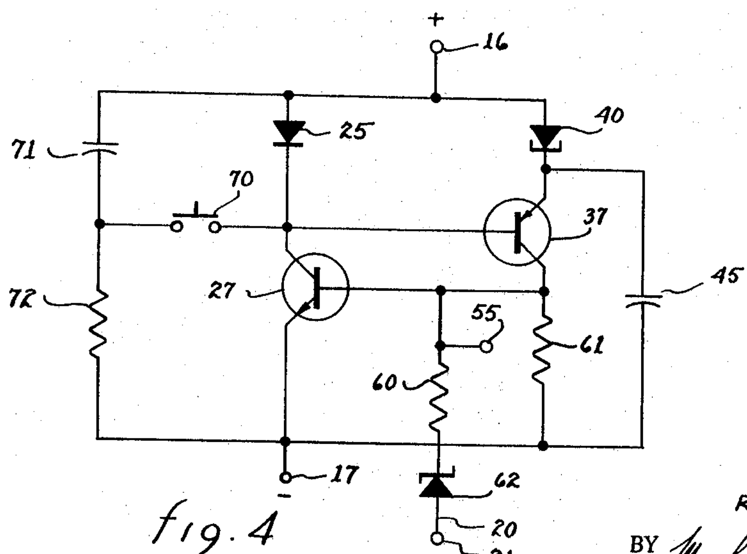

fig. 4

INVENTOR.
RICHARD L. WHITE

BY McLaughlin & Cahill

ATTORNEYS

United States Patent Office 3,313,985
Patented Apr. 11, 1967

1

3,313,985
SOLID STATE D.C. CIRCUIT BREAKER
Richard L. White, Glendora, Calif., assignor to Dickson Electronics Corporation
Filed Apr. 3, 1964, Ser. No. 357,253
6 Claims. (Cl. 317—33)

The present invention pertains to circuit breakers, and more specifically, to circuit breakers of the type for interrupting a direct current when a predetermined circuit condition exists.

The complexities of modern electronic systems have placed a burden upon circuit breakers for effectively interrupting current flowing to the delicate components of the electronic system. Fast acting, direct current circuit breakers are required that present a low voltage drop when inserted in series with a load and which are compatibly sized in relation to the rest of the electronic components. The small physical size of present systems therefore dictates that a circuit breaker shall be compact; further, the interrelationship and the small spacing involved in modern systems requires that the circuit breaker present no radio frequency interference during circuit breaker operation. Reliability and long life are also requirements, particularly in those applications where the circuit breaker is to be located at an inaccessible location.

Accordingly, it is an object of the present invention to provide a direct current circuit breaker that is physically small while nevertheless being reliable and having a long life.

It is another object of the present invention to provide a direct current circuit breaker utilizing the advantages to be gained through the use of solid state devices and inexpensively providing trip speeds faster than those available in circuit breakers of the prior art.

It is a further object of the present invention to provide a direct current circuit breaker that is not inductive and will not produce any radio frequency interference when interrupting the circuit in which it is connected.

It is still another object of the present invention to provide a direct current circuit breaker that is electronically resettable and that has a low voltage drop and power dissipation in operation.

Further objects and advantages of the present invention may become apparent to those skilled in the art as the description thereof proceeds. The invention, and the operation thereof, may more readily be described by reference to the accompanying drawings in which:

FIGURE 1 is a block diagram of a direct current circuit using the circuit breaker of the present invention.

FIGURE 2 is a schematic circuit diagram of a circuit breaker constructed in accordance with the teachings of the present invention.

FIGURE 3 is a volt-ampere curve of a typical tunnel diode useful for describing the operation of the circuit of FIGURE 2.

FIGURE 4 is a schematic circuit diagram of another circuit breaker constructed in accordance with the teachings of the present invention.

FIGURE 5 is a volt-ampere characteristic curve of a typical zener diode useful for describing the operation of the circuit of FIGURE 4.

Referring to FIGURE 1, a source of D.C. potential (not shown) is connected to terminals **10** and **11**. Terminal **10** is indicated in FIGURE 1 as being the positive terminal and is connected to a circuit breaker **15** by connecting the terminal **10** to the circuit breaker terminal **16**. The opposite side of the circuit breaker **15** is connected by terminal **17** to a load indicated generally in FIGURE 1 at **19**. The opposite side of the load **19** is connected to the terminal **11** thereby completing the circuit. The circuit breaker **15** may provide overload pro-

2

tection for the load **19** by detecting an excessive current (and opening the circuit) or by detecting an over-voltage (and opening the circuit). To facilitate the detection of an over-voltage, the circuit breaker **15** may be connected as indicated by the dotted line **20** to the node **21**.

Referring to FIGURE 2, the circuit breaker **15** of FIGURE 1 is shown in greater detail. The circuit breaker **15** includes terminals **16** and **17** for connection to the positive line terminal and to the positive side of the load. The anode of a diode **25** is connected to the terminal **16** and has the cathode electrode thereof connected to the collector electrode **26** of a transistor **27**. The emitter electrode **28** of the transistor is connected via line **29** to the terminal **17**. The base electrode of the transistor **27** is connected by conductor **36** to the collector electrode **36** of a second transistor **37**. The emitter electrode **38** of the second transistor is connected through a tunnel diode **40** and a conductor **41** to the terminal **16**. The base electrode of the transistor **37** is connected through conductor **43** to the collector electrode **26** of the transistor **27**. A capacitor **45** is connected by conductor **46** to the emitter electrode **38** of transistor **37** and is connected by conductor **47** to the terminal **17**.

The operation of the circuit of FIGURE 2 may best be described by first referring to the curve shown in FIGURE 3. The tunnel diode **40** is a non-linear device that exhibits a negative resistance along a portion of its volt-ampere characteristic. The characteristic of FIGURE 3 is intended to be illustrative of a typical tunnel diode. The portion **50** of the curve of FIGURE 3 represents the positive resistance of the tunnel diode for currents initially passing through the diode having a magnitude somewhere between I_o and I_p. If the current exceeds the peak current I_p, the tunnel diode exhibits a negative resistance as indicated by the portion **51** of the curve of FIGURE 3. Thus, if current passes through the tunnel diode and exceeds I_p, the voltage drop across the tunnel diode will jump from the positive resistance portion **50**, to the second positive resistance portion **52**, or in other words will switch from a low to a high voltage state. Referring now to FIGURE 2, it will be assumed that current is flowing from the terminal **16** to the terminal **17** and that the load connected to the terminal **17** is behaving properly. Current will thus flow from the terminal **16** through the tunnel diode **40** to the complementary transistors **27** and **37**. Current will also flow from the terminal **16** through the diode **25** to the two transistors. The current carried by the circuit breaker from terminal **16** to terminal **17** thus passes through the two transistors and is carried from the base of transistor **37** to the collector of transistor **27** and from the collector of transistor **37** to the base of transistor **27**. The circuit will continue to operate in this manner and the bias provided to the transistor **37** by the diode **25** and tunnel diode **40** will assure the "closed" condition of the circuit breaker. The voltage drop exhibited by the circuit breaker is only the forward voltage drop of the diodes and the saturation voltage of the transistors; further, the components described will provide very low power dissipation. If the load circuit connected to the terminal **17** should fail and become short-circuited, the current surge caused by the load failure will be transmitted from the terminal **17** through the capacitor **45** to the cathode of the tunnel diode **40**. The sudden current increase will cause the tunnel diode to switch from the low voltage to the high voltage state thereby removing the forward bias on the transistor **37**. Transistor **37** begins to shut off thereby decreasing the biasing provided to the base electrode of transistor **27**. The "feed-back" provided by transistor **27** to the base electrode of the transistor **37** through the collector electrode **26** further tends to shut transistor **37** off. The total effects of the current surge are cumulative until both transistors **27** and **37** are rapidly cut off. The circuit breaker has thus "opened" and the circuit between terminals **16** and **17** has been interrupted. The circuit breaker of FIGURE 2 may be reset in several ways, and the circuit of FIGURE 4 is intended to illustrate two such methods.

Referring to FIGURE 4, the circuit of FIGURE 2 has been incorporated therein and like elements are referenced by like numerals. When the circuit breaker is in its "open" condition, the transistors **27** and **37** may appropriately be gated to their conducting state (that is, reset) by applying an appropriately poled electronic pulse to the terminal **55** which is transmitted to the base of transistor **27** and the collector of transistor **37**. To mechanically reset the circuit breaker of FIGURE 4, a push-button switch **70** is connected to the base electrode of the transistor **37** and to the terminal **16** through a capacitor **71**. A resistor **72** connects the switch **70** to the terminal **17**. The operation of the manual reset of FIGURE 4 may be described as follows. When the circuit breaker is "open," the capacitor **71** charges to approximately line voltage. When the switch **70** is closed, the capacitor charge provides an appropriate bias to gate the transistor **37** on. As transistor **37** begins to conduct, the cumulative action of the complementary pair (transistors **27** and **37**) quickly gate both transistors to their full "on" condition thereby closing the circuit breaker and establishing a low resistance direct current circuit between terminals **16** and **17**.

A resistor **61** connects the base electrode of the transistor **27** and the collector electrode of the transistor **37** to the terminal **17**; a resistor **60** connects the same node to the cathode of a zener diode **62**. The anode of the zener diode **62** is connected by the conductor **20** to node **21**. The operation of the circuit breaker of FIGURE 4 to detect an over-voltage in the load may be described after reference is made to FIGURE 5. Referring to FIGURE 5, the volt ampere characteristic of a typical zener diode is illustrated. Zener diodes are well known in the art and a detailed description is unnecessary; however, the basic feature utilized in the system of the present invention is the fact that the zener diode appears as a substantial open circuit in the reverse bias direction until a predetermined zener voltage is obtained. At that instant, the diode no longer presents a current block and incremental resistance drops to a very low value. Referring once again to FIGURE 4, the node **21** will be recognized as the node **21** of FIGURE 1. It may therefore be recognized that the voltage existing between terminals **17** and node **21** is, in fact, the load voltage. If the supply voltage should increase, or a transient voltage superimposed on the supply voltage should occur, the voltage increase resulting therefrom will impress a rapid voltage increase between points **17** and **21**. This voltage surge is a negative voltage impressed on the zener diode **62** that exceeds the zener voltage thus permitting current to flow through the diode from terminal **17**. This instantaneous current flow results in a triggering of the circuit breaker through the capacitor **45** in a manner similar to the triggering that occurred from a sudden current increase. The sudden current transient triggers tunnel diode **40** to its high voltage state and initiates the cumulative cut-off procedure for the circuit breaker. Thus, the circuit breaker of FIGURE 4 will rapidly open in the event of a current overload (such as that occurring in the case of a short-circuit) or in the event of an overvoltage. The tunnel diode **40** of FIGURES 2 and 4 may be replaced by any voltage dropping device such as a resistor; however, the tunnel diode presents unique advantages in that the trip point of the circuit breaker may more readily be predicted and reproduced without the otherwise necessity of careful calibration of transistors **27** and **37**. The zener diode **62** may also be replaced by other voltage sensitive devices; however, as in the case with the tunnel diode, the zener diode is particularly advantageous and dependable for the present application. The transistors **27** and **37** are shown in FIGURES 2 and 4 as NPN and PNP transistors respectively, it being understood that the transistors may be reversed as long as they remain complementary. It may thus be seen that the D.C. solid state circuit breaker of the present invention provides a circuit breaker having no inductive component, that is physically small, reliable, does not present any radio frequency interference problems, has a trip speed limited only by the ability of the transistors **27** and **37** to be cut off, is electronically or manually resettable, and exhibits a low voltage drop and power dissipation when in the closed position. It will be apparent to those skilled in the art that many modifications may be made of the present invention without departing from the spirit and scope thereof.

I claim:

1. In a solid state D.C. circuit breaker the combination comprising:

(a) a first and a second transistor each having a collector electrode, an emitter electrode, and a base electrode, said transistors being of complementary types;

(b) means connecting the collector electrode of each transistor to the base electrode of the other transistor;

(c) a capacitor connected between the emitter electrodes of said transistors;

(d) a first and a second terminal;

(e) a device exhibiting a negative resistance along only a portion of its volt-ampere characteristic connected in series between said first terminal and the emitter electrode of said first transistor;

(f) a voltage dropping device connected in series between said first terminal and the base electrode of said first transistor, and

(g) means connecting the emitter electrode of said second transistor to said second terminal.

2. In a solid state D.C. circuit breaker the combination comprising:

(a) a first and a second transistor each having a collector electrode, an emitter electrode, and a base electrode, said transistors being of complementary types;

(b) means connecting the collector electrode of each transistor to the base electrode of the other transistor;

(c) a capacitor connected between the emitter electrodes of said transistors;

(d) a first and a second terminal;

(e) a tunnel diode connected in series between said first terminal and the emitter electrode of said first transistor;

(f) a voltage dropping device connected in series between said first terminal and the base electrode of said first transistor, and

(g) means connecting the emitter electrode of said second transistor to said second terminal.

3. In a solid state D.C. circuit breaker the combination comprising:

(a) a first and a second transistor each having a collector electrode, an emitter electrode, and a base electrode, said transistors being of complementary types;

(b) means connecting the collector electrode of each transistor to the base electrode of the other transistor;

(c) a first and a second terminal;

(d) a device exhibiting a negative resistance along only a portion of its volt-ampere characteristic connected in series between said first terminal and the emitter electrode of said first transistor;

(e) a diode connected in series between said first terminal and the base electrode of said first transistor, and

(f) means connecting the emitter electrode of said second transistor to said second terminal.

4. In a solid state D.C. circuit breaker the combination comprising:

(a) a first and a second transistor each having a collector electrode, an emitter electrode, and a base electrode, said transistors being of complementary types;

(b) means connecting the collector electrode of each transistor to the base electrode of the other transistor;

(c) a capacitor connected between the emitter electrodes of said transistors;

(d) a first and a second terminal;

(e) a tunnel diode connected in series between said first terminal and the emitter electrode of said first transistor;

(f) a diode connected in series between said first terminal and the base electrode of said first transistor, and

(g) means connecting the emitter electrode of said second transistor to said second terminal.

5. In a solid state D.C. circuit breaker the combination comprising:

(a) a first and a second transistor each having a collector electrode, an emitter electrode, and a base electrode, said transistors being of complementary types;

(b) means connecting the collector electrode of each transistor to the base electrode of the other transistor;

(c) a capacitor connected between the emitter electrodes of said transistors;

(d) a first and a second terminal;

(e) a tunnel diode connected in series between said first terminal and the emitter electrode of said first transistor;

(f) a diode connected in series between said first terminal and the base electrode of said first transistor;

(g) means connecting the emitter electrode of said second transistor to said second terminal, and

(h) resetting means connected to said transistors to gate them to conduction when they are in a non-conducting state.

6. In a solid state D.C. circuit breaker the combination comprising:

(a) a first and a second transistor each having a collector electrode, an emitter electrode, and a base electrode, said transistors being of complementary types;

(b) means connecting the collector electrode of each transistor to the base electrode of the other transistor;

(c) a capacitor connected between the emitter electrodes of said transistors;

(d) a first and a second terminal;

(e) a tunnel diode connected in series between said first terminal and the emitter electrode of said first transistor;

(f) a diode connected in series between said first terminal and the base electrode of said first transistor;

(g) means connecting the emitter electrode of said second transistor to said second terminal;

(h) a load having an input terminal and an output terminal;

(i) means connecting the input terminal of said load to said second terminal, and

(j) a zener diode connected between the emitter electrode of said first transistor and the output terminal of said load.

References Cited by the Examiner

UNITED STATES PATENTS

2,864,904	12/1958	Jensen.	
2,962,603	11/1960	Bright ------------	317—33 X
3,176,163	3/1965	Tiemann.	
3,181,032	4/1965	Myers --------------	317—33
3,204,175	8/1965	Kuriger -----------	317—22 X

MILTON O. HIRSHFIELD, *Primary Examiner.*

R. V. LUPO, *Assistant Examiner.*