March 28, 2017

Voltage Doubler Rectifier with Switch for High and Low AC Inputs

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Abstract: An alternating current (AC) rectifier can double the voltage for low-voltage AC sources, such as 110 volt AC sources, and maintain the voltage for high-voltage AC sources, such as 220 volt AC sources. The rectifier can therefore provide a consistent high direct current (DC) voltage, such as 220 volts, regardless of whether the rectifier is plugged into a source such as a wall outlet in the United States, where wall outlets typically provide 110 volts AC, or a wall outlet in Europe, where wall outlets typically provide 220 volts AC. The rectifier can be included in an integrated circuit of a power adapter that couples a computing device to the wall outlet. As a safety feature, the rectifier can include a fuse and a switch that short-circuits the rectifier when the rectifier is unable to avoid doubling the voltage in response to a high-voltage AC source, blowing the fuse to prevent a fire or explosion.

A universal alternating current (AC) output voltage ranges from 100 volts to 240 volts. With a ten percent tolerance, the universal AC output voltage range can be between 90 and 264 volts. To narrow this wide AC output voltage range, a voltage doubler can double standardized low voltages to bring the voltage to a standardized high voltage.

AC input voltages of electrical outlets are typically either low line, between 100 and 127 volts, or high line, between 220 and 240 volts. This publication describes doubling the low line (or low) voltage and maintaining the high line (or high) voltage, so that the universal output voltage range will be between 200 and 254 volts. With a ten percent tolerance, this output range is between 180 volts and 280 volts, which is much narrower than the AC output voltage range of between 90 and 264 volts without a voltage doubler.

FIG. 1 shows a pin-out of a voltage doubler rectifier. The voltage doubler rectifier can be packaged as an integrated circuit that is included in a power adapter. The power adapter can plug into both an electrical outlet in a wall and a computing device to provide power to the computing device. The voltage doubler rectifier rectifies alternating current (AC) input voltage into a direct current (DC) output voltage. If the AC voltage is low, such as below a threshold value (such as 165 volts in an example in which the voltage doubler rectifier is designed to accommodate input AC voltages of 110 or 120 volts and 220 or 230 volts), then the voltage doubler rectifier will double the voltage. If the AC voltage is high, such as above the threshold, then the voltage doubler rectifier will not double the voltage.

In the example shown in FIG. 1, the voltage doubler rectifier includes two AC inputs, a line (L) node and a neutral (N) node. The voltage of the line node varies between a maximum positive value of the AC input value (such as 110 volts or 220 volts) and a maximum negative value of the AC input value (such as 110 volts or 220 volts). The voltage doubler rectifier includes three DC outputs, a bus pin V_{BUS} that outputs the high rectified DC voltage value, such as 110 volts or 220 volts, a ground (GND) node that has a voltage of ground or zero, and a neutral node V_N that has a DC voltage between the bus voltage and ground. The voltage doubler rectifier can also include a power-supply pin V_{CC} that provides power for the control circuit that controls whether the voltage doubler rectifier doubles the voltage. The power-supply pin can be an auxiliary power from the auxiliary winding of the or an LDO from the V_{BUS}.

FIG. 2 is a circuit diagram of the voltage doubler rectifier. As shown in FIG. 2, the voltage doubler rectifier includes diodes D1, D2, D3, D4 that prevent current from flowing from the bus to ground and/or from flowing from the line to neutral. The diodes D1, D2, D3, D4 also prevent the bus from experiencing a negative voltage when the line voltage is negative. The voltage doubler rectifier also includes capacitors C1, C2 that maintain a constant voltage level between the bus and ground, causing the output voltage difference between bus and ground to be constant. The two capacitors C1, C2, which can have low voltage ratings, arranged in series reduces bulk capacitor size compared to having a single, larger, high rating capacitor. The voltage doubler rectifier also includes Zener regulators TVS1, TVS2, which regulate the voltage between the bus and the ground to maintain a voltage balance between the capacitors C1, C2.

The voltage doubler rectifier includes a switch S1 connecting a node between the diodes D2, D4 to a node which is between the Zener regulators TVS1, TVS2 and between the capacitors C1, C2. When the switch S1 is open and/or off, the voltage drop between the bus and ground across the two capacitors C1, C2, which is the output voltage of the voltage doubler rectifier, is equal to the voltage of the AC input received at the line and neutral nodes. When the switch S1 is closed and/or on, during the positive half cycle, the AC input current flows from the line through the diode D1, capacitor C1, and switch S1 to neutral, and during the negative half cycle, the AC input current flows from neutral through the switch S1, through the capacitor C2, and diode D3 back to the line, doubling the voltage between the bus and ground when receiving a low line input. When the switch S1 is closed and/or on, the voltage drop between the bus and neutral across one of the capacitors C1 is equal to the voltage of the AC input received at the line and neutral nodes. When the switch S1 is closed and/or on, the voltage drop between the neutral and ground across the second capacitors C2 is equal to the voltage drop between the bus and neutral across the first capacitor C1, for a total voltage drop between the bus and ground across the two capacitors C1, C2 of twice the voltage drop when the switch S1 is open and/or off, doubling the output voltage.

The switch S1 can be implemented as an insulated-gate bipolar transistor (IGBT), a metal-oxide-semiconductor field-effect transistor (MOSFET) with series block diode, or back-to-back MOSFETs (shown in FIG. 3), as a dual *n*-channel MOSFET (NMOS transistor) common drain connection, dual *p*-channel MOSFET (NMOS transistor) common source, or triode for alternating current (TRIAC), any of which can be controlled by a gate that receives input from a voltage doubler controller. The switch S1 is controlled by the voltage doubler controller. The voltage doubler controller opens the switch S1 when the input AC voltage is high (which may be used interchangeably with high line), and closes the switch S1 when the voltage is low (which may be used interchangeably with low line).

FIG. 3 shows the voltage doubler rectifier with the switch implemented as back-to-back MOSFETs, and the voltage doubler controller is implemented as a combination of a low-dropout regulator (LDO), a gate driver, and amplifier comparator. The LDO can either regulate the V_{BUS} to V_{DD} or regulate the V_{CC} to V_{DD}. V_{CC} can be from an auxiliary power supply. The LDO provides a supply voltage V_{DD} to the high side gate driver via the supply voltage when the voltage at the bus is less than a threshold (such as 165 volts). The high side gate driver also receives the gate control signal from the comparator. When the gate signal from the comparator is high, the high side gate driver increases a voltage at gates of the transistors of the switch, activating the transistors to turn the switch on and/or closing the switch, doubling the voltage drop between the bus and ground.

FIG. 4 is a circuit diagram of the voltage doubler rectifier in an example in which the voltage doubler rectifier includes a protection control switch S2 and a fuse to prevent damage from excessive voltage at the bus. In this example, if the line voltage is high, such as above a threshold (such as 165 volts), and the voltage doubler rectifier is unable to open and/or turn off the switch S1, then the protection control switch S2 will close and/or turn on. The closing and/or turning on of the protection control switch S2 will allow current to flow freely from the line to neutral, blowing the fuse and disabling the voltage doubler rectifier. Without the protection control switch S2 and fuse, if the line voltage were high and the switch S1 could not be opened and/or turned off, the voltage would still be doubled, such as from 220 volts to 440 volts, which could result in a fire or explosion in the capacitors C1, C2, and/or damage to the computing device to which the voltage doubler rectifier supplies power. Instead, by blowing the fuse and disabling the voltage doubler rectifier, the protection control switch S2 protects users of the voltage doubler rectifier and the computing device.

FIG. 5 is a circuit diagram of the voltage doubler rectifier in an example in which the voltage doubler rectifier includes the fuse of FIG. 4, a protection control switch S3, and can optionally include the protection control switch S2 of FIG. 4, to prevent damage from excessive voltage at the bus. In this example, the protection control switch S3 can be implemented as a transistor that turns on when the line voltage is high and the switch S1 cannot open and/or turn off, blowing the fuse to prevent further damage.

FIG. 6 is a circuit diagram of the voltage doubler rectifier in an example in which the voltage doubler rectifier includes the fuse of FIGs. 4 and 5, and also includes a fuse F2 in series with the switch S1. In this example, when the voltage doubler rectifier determines that the voltage at the line is high and that the switch S1 cannot be opened, and/or turned off, the voltage doubler rectifier will close and/or turn on a second switch S2, which will blow the fuse F2. The fuse F2 can blow if current is flowing through switch S2. Once the fuse F2 is blown, current cannot flow through either switch S1 or S2. With the fuse F2 blown, the voltage doubler rectifier can still function as a voltage rectifier, but will not double the voltage.

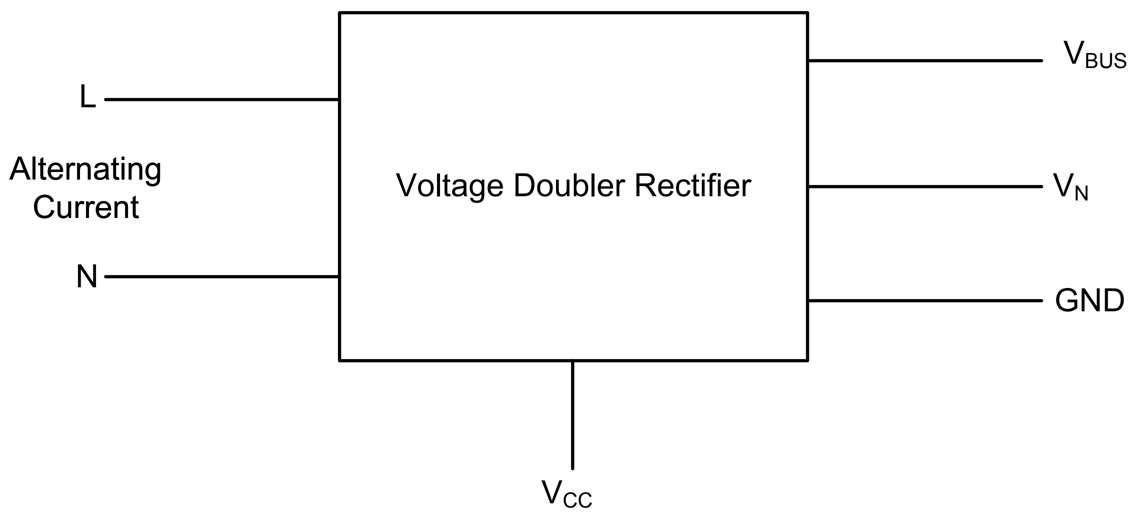
L
Alternating
Current
N
Voltage Doubler Rectifier
VBUS
VN
GND
VCC

FIG. 1

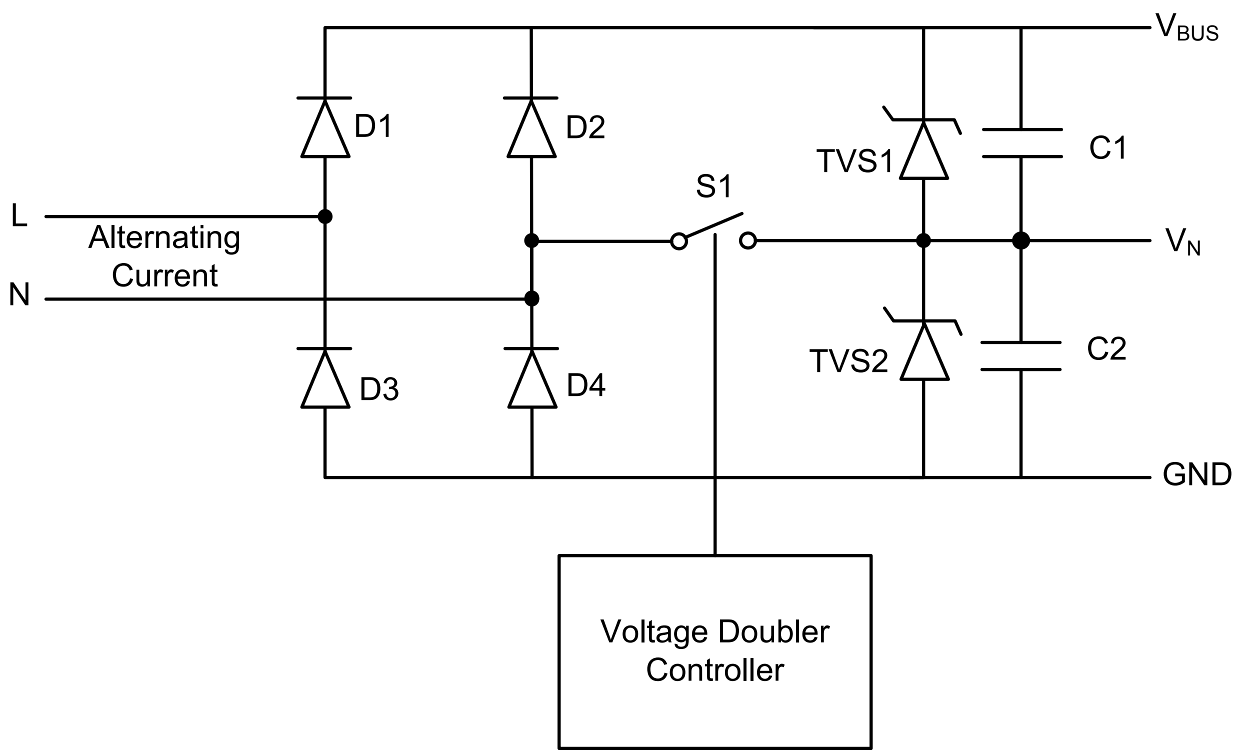
VBUS
D1
D2
TVS1
C1
S1
L
Alternating
Current
N
VN
TVS2
C2
D3
D4
GND
Voltage Doubler
Controller

FIG. 2

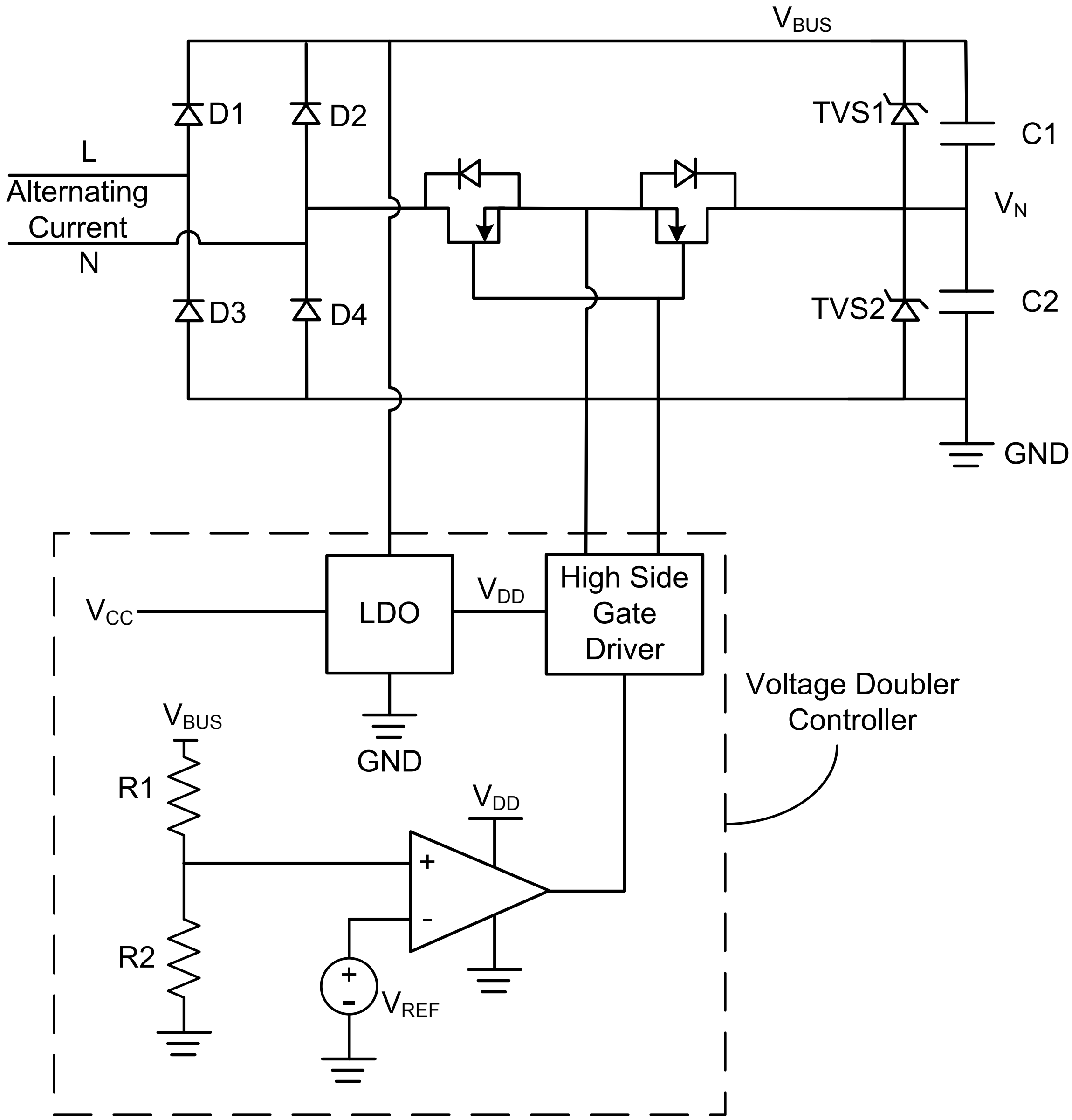
VBUS
D1
D2
TVS1
C1
L
Alternating
Current
N
VN
D3
D4
TVS2
C2
GND
VCC
LDO
VDD
High Side
Gate
Driver
Voltage Doubler
Controller
VBUS
R1
GND
VDD
+
-
R2
+
-
VREF

FIG. 3

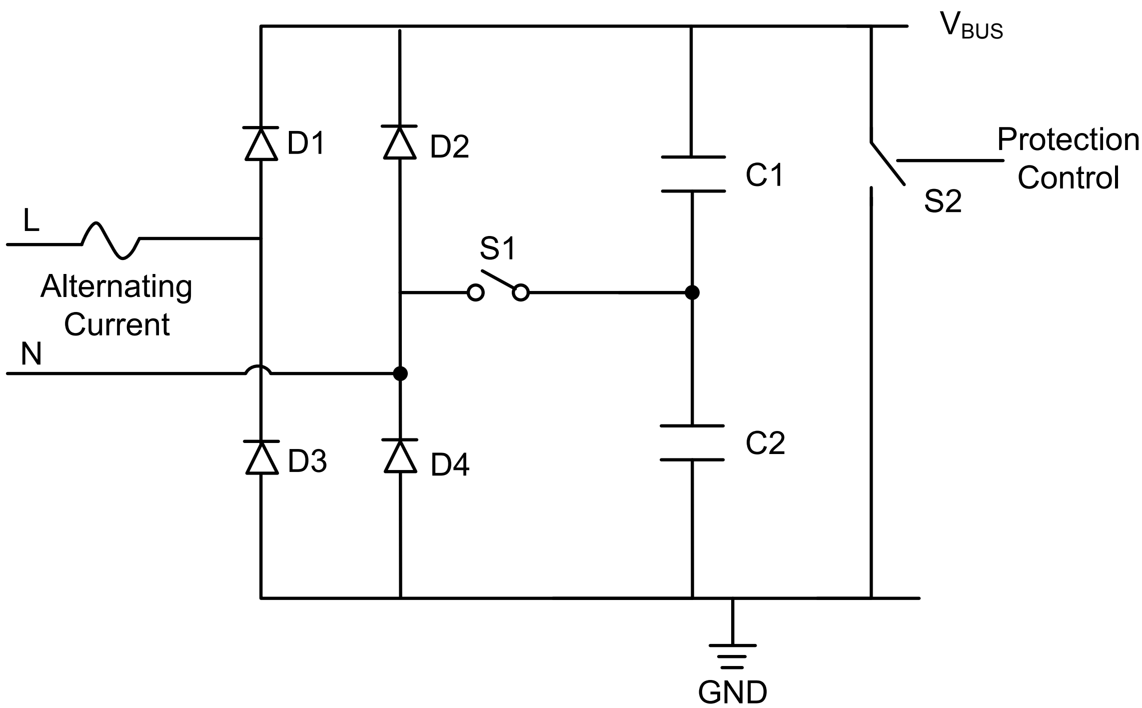
VBUS
D1
D2
C1
Protection
Control
S2
L
S1
Alternating
Current
N
D3
D4
C2
GND

FIG. 4

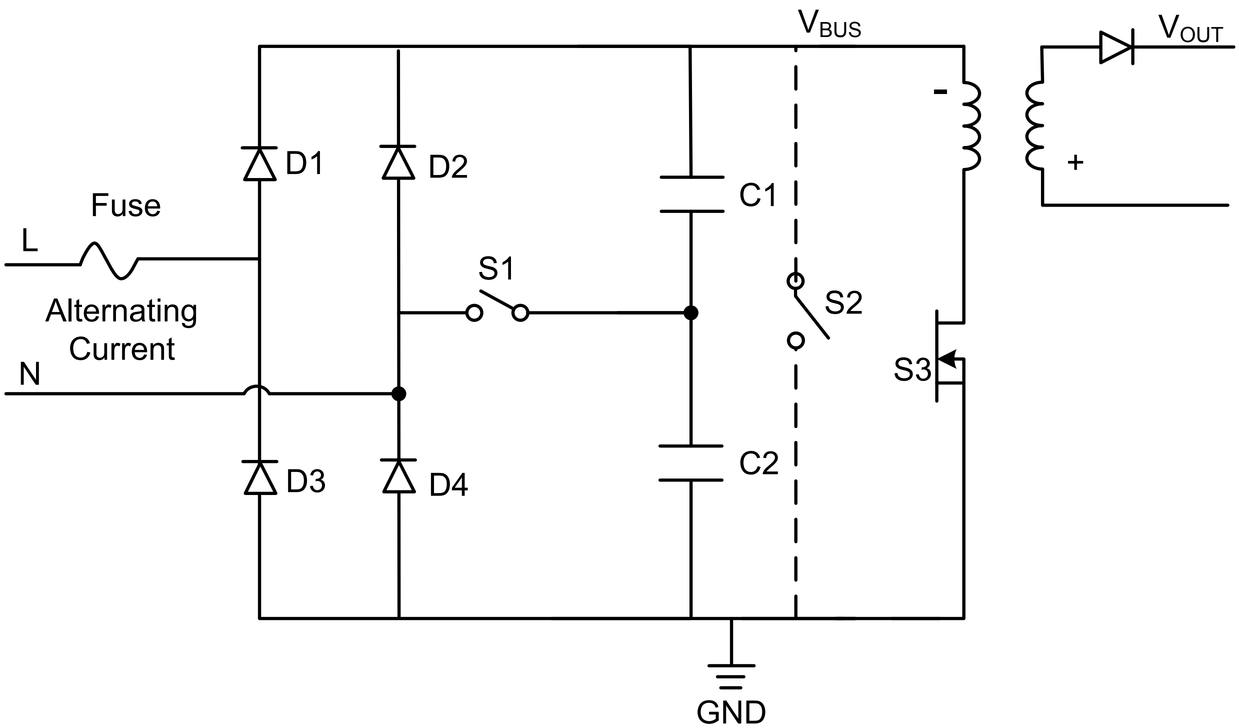
VBUS
VOUT
-
+
D1
D2
C1
Fuse
L
S1
S2
Alternating
Current
S3
N
D3
D4
C2
GND

FIG. 5

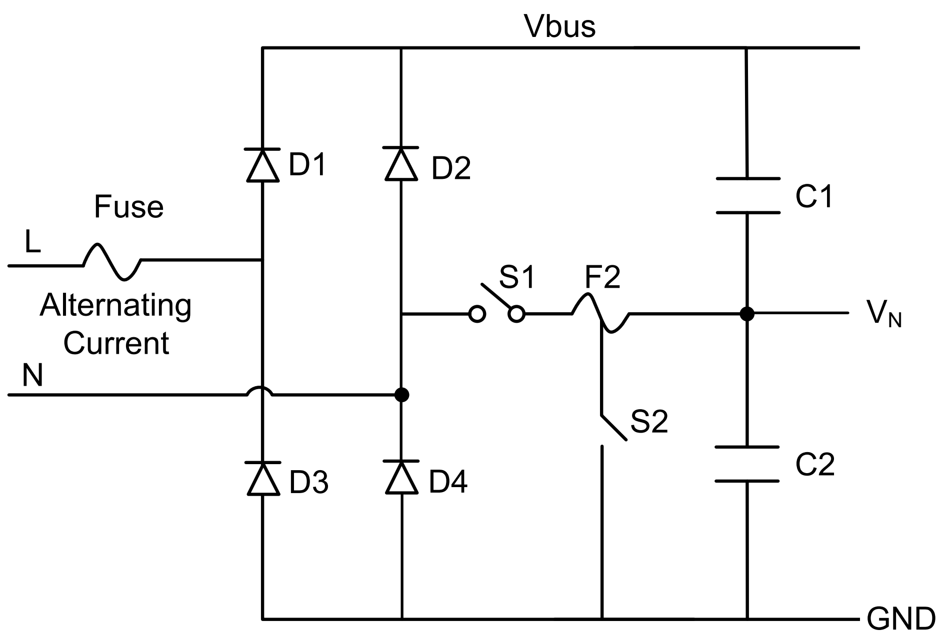
Vbus
D1
D2
C1
Fuse
L
S1
F2
Alternating
Current
V_N
N
S2
D3
D4
C2
GND

FIG. 6