POWER-GATE Single Rectifier (Generation 4.0) Application Sheet

CONDUCTOR SIZING IMPORTANCE

The MOSFET array used in the generation 4.0 POWER-GATE single rectifier has been designed to provide industry-leading, ultra-low on-state resistance. This results in extremely low voltage drops at continuous currents up to 600 A and surge currents up to 3000 A, even at an ambient temperature of over 100 °C (212 °F). In order to maintain a low-voltage drop (and, consequently, low internal power dissipation), it is essential that the cables or bus bars connected to the device are properly sized for the currents expected in the application. Undersized conductors can cause heat to be transferred into the rectifier, which will cause the MOSFET array resistance to increase, negating the low resistance the rectifier was designed to provide. Additionally, when operating at high continuous currents and ambient temperatures, the extra heat from the undersized conductors can raise the internal junction temperatures of the MOSFETs beyond their safe operating area, generating the potential for failure.

Typical applications use cable gauges anywhere from 4 to 4/0 AWG (with insulation ratings of at least +105 °C) depending on the continuous current rating, but other system parameters such as increased cable thermal resistance due to bundling and very high duty cycles at high currents may dictate the use of paralleled cables or large bus bars coupled with forced airflow. Ultimately, it is up to the user to determine the appropriate external conductor to be used in any particular application.

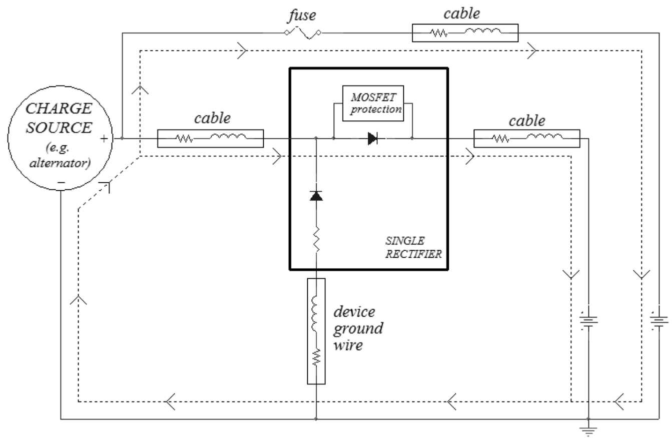
If the device flashes an over-temperature warning (which occurs when the internal device temperature exceeds +135 °C), then, assuming the device is operating within its current limitations outlined in the specification sheet, either the external conductors are undersized for the current flowing through the device, the ambient temperature surrounding the device is in excess of the maximum rating, or a combination of both. The system should then be shut down and the thermal conditions reevaluated so as to ensure the device's continued reliability.

REVERSE CURRENT TURN-OFF AND SYSTEM LOOP INDUCTANCES

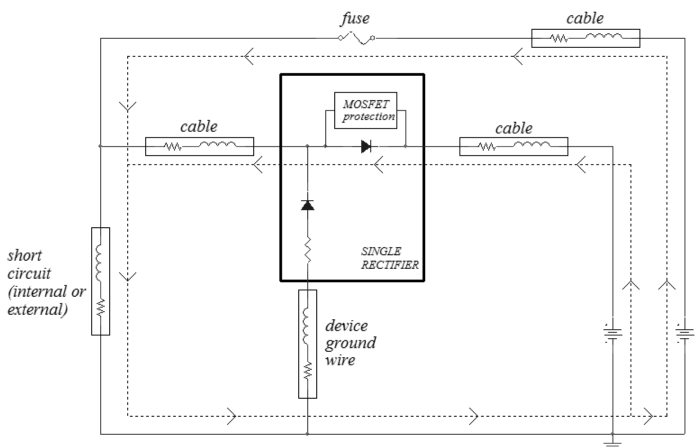
Device reliability is also greatly affected by the system loop inductances during reverse current turn-off conditions. When operating at the high currents the MOSFET array was designed for, the total inductance of the external world it is connected to must be carefully evaluated to ensure that under worst-case conditions, the device will be able to safely dissipate the large amount of energy stored in the inductance's magnetic field.

Reverse current (defined as current flowing from cathode-to-anode) turn-off can occur in one of two ways: 1) The rectifier operating in its standard ideal-diode mode reacting to the reversal in polarity (forward voltage drop going negative), and 2) exiting from combine or alternator excitation modes while reverse current is flowing. Two typical scenarios are depicted in figures 1 and 2.

Figure 1 shows a common use of the single rectifier, which is to allow the charging of two batteries (or banks of batteries) using a single charging source, such as an alternator (although any other DC charging source would be applicable here as well), while



(a)



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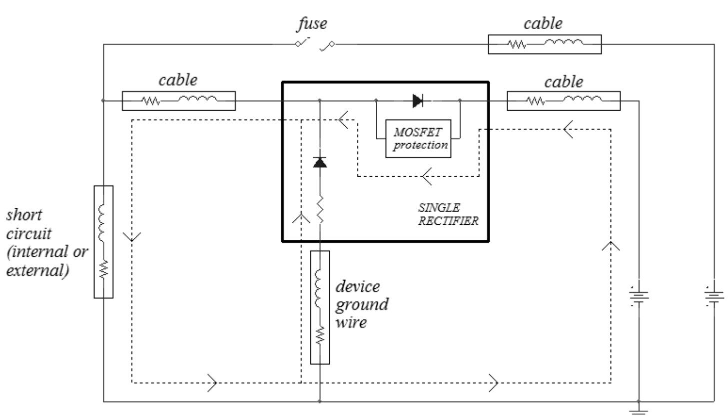


(c)

Figure 1: Reverse current turn-off transient behavior in normal diode mode with system loop inductances. (a) Standard charging with single rectifier passing charging current to one battery with a second battery directly connected to charging source. (b) Reverse current during MOSFET array turn-off after development of a short-circuit at the charging source. (c) Reverse current after MOSFET array turn-off flowing through MOSFET protection circuitry and flyback diode due to system inductances (note blown fuse in path between charging source and directly connected secondary battery).

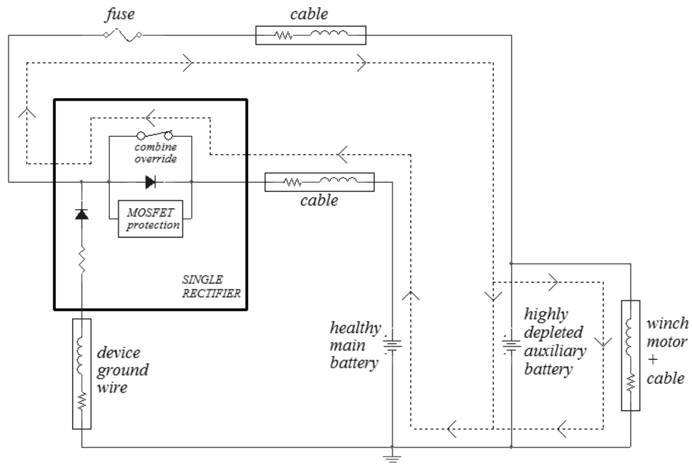
allowing the battery attached to the rectifier anode to be discharged independently from that attached to the cathode. Figure 1a depicts the current flow (as indicated by the dotted line) originating from the charging source, passing through the single rectifier MOSFET array (represented as a diode) to one battery (often a vehicle's starting battery), as well as directly to a second battery (often a vehicle's auxiliary, or "house" battery), and finally returning to the charging source. The inductance of the interconnecting cables is shown, but that of the common ground node has been omitted for simplicity (although they must be considered as well when calculating the system loop inductance).

In Figure 1b, a short circuit has developed at the charging source, either internal to the source, or just external to it. In response to this fault event, the MOSFET array will begin to turn off. Due to the finite turn-off time (reverse recovery time in the specification sheet), reverse current will flow from the battery attached to the cathode, through the MOSFET array to the short circuit, and back to the battery. As the reverse current flows, the inductances will generate significant magnetic fields, especially at the high currents that a short-circuit can generate. Once the MOSFETs have completely turned off, the remaining reverse current will flow through both the MOSFET protection circuitry and the flyback diode until those magnetic fields have decayed; this situation is depicted in Figure 1c.

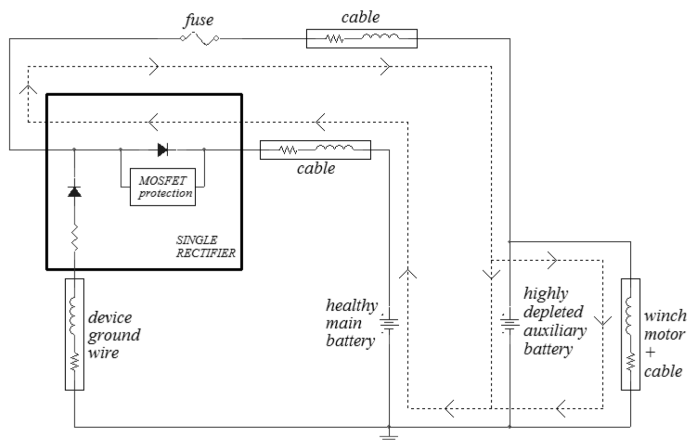
Figure 2 shows another common application of the single rectifier: using the combine mode to supply current to a winch motor attached to a highly depleted auxiliary battery. Figure 2a shows the combine mode overriding the diode functionality of the MOSFET array to allow current to flow from the healthy main battery, through the MOSFET array (from cathode to anode, i.e. in the reverse direction) to the auxiliary battery and winch. In Figure 2b, the combine mode has been switched off. Due to the finite turn-off time (reverse recovery time in the specification sheet), reverse current will flow from the main battery through the MOSFET array to the auxiliary battery and winch. As in the first case explained here, the inductances will generate significant magnetic fields, especially at the high currents that a depleted battery and winch motor can demand. Once the MOSFETs have completely turned off, the remaining reverse current will flow through the MOSFET protection circuitry until those magnetic fields have decayed; this situation is depicted in Figure 2c.

The two cases presented here show that careful attention must be given to the system loop inductances in a variety of reverse current conditions. The protection features are not designed for long conduction periods, as they will quickly overheat due to the large power being dissipated during a reverse shutdown event that is outside the allowable limits. The two key parameters a user needs to evaluate when determining if a dual rectifier will work in any particular application are the worst-case reverse currents flowing through the MOSFET arrays upon turn-off, and the total loop inductance through which those currents are passing. As seen in the first case, there is not always just a single loop to consider, which can make analysis a challenging prospect.

The specification sheet details the maximum reverse current upon turn-off at various loop inductances and temperatures, conditions which should always be adhered to in order to ensure maximum device reliability. If an



(a)



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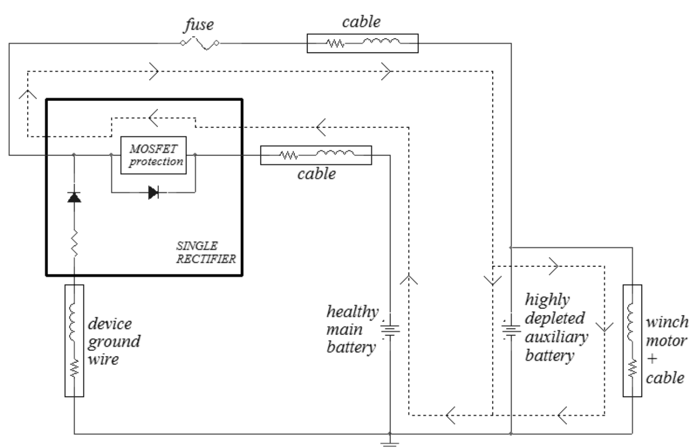

(c)

Figure 2: Reverse current turn-off transient behavior in combine mode with system loop inductance. (a) Main battery supplying current to depleted auxiliary battery and winch motor (diode functionality overridden). (b) Reverse current during MOSFET array turn-off. (c) Reverse current flowing through the MOSFET array protection circuitry due to system inductance.

application has loop inductances that exceed those detailed in the specification sheet, external protection may be required.

ALTERNATOR EXCITATION

In order for an alternator to begin producing output voltage for the charging of batteries and powering of loads, the voltage regulator generally needs to detect battery voltage at its output. In most single rectifier applications an auxiliary battery is always directly connected to the alternator, so no special accommodation is necessary to ensure proper alternator excitation. However, some applications may exist where this is not always the case; e.g. a trailer which houses the auxiliary battery is purposely disconnected from the vehicle for storage. In this situation, the single rectifier presents a barrier to proper alternator excitation, since the inherent purpose of the device is to block current from flowing in the reverse direction. Externally regulated alternators can circumvent this issue by simply moving the sense wire for the regulator directly to the battery side (cathode) of the rectifier. However, many alternators are internally regulated and gaining access to the sensing circuit can be at best an extremely difficult task. POWER-GATE single rectifiers allow for the excitation of any alternator, without the need to access the alternator or modify any wiring to the regulator.

When the alternator excitation function is active, the single rectifier will momentarily override the blocking functionality of the MOSFET array and connect the main battery to the alternator, thus allowing its voltage regulator to properly initiate. This functionality can be triggered in one of two ways: 1) Connecting the device to the starter motor, which is the preferred method, or 2) connecting the device to a keyed-on ignition signal.

Starter Motor Method: Upon application on the starter line of a voltage greater than the trip threshold (~2 V), the device will wake up from its sleep mode (the device’s default state when the anode voltage is less than the cathode, and the alternator excitation and combine functionality are not active) and wait for the disappearance of the starter signal, indicating the starter has been released and, presumably, the cranking process has completed. The device will then wait four seconds before initiating the alternator excitation sequence (the purpose of the delay is to ensure that a highly depleted auxiliary battery cannot instantly drain the main battery to the point where a no-start condition will occur). After the four seconds has elapsed, the MOSFET array will turn on to connect the main battery to the alternator, allowing its regulator to begin operation. The array will remain on for approximately half a second; during this time, the device will be looking for proper alternator charging. If this occurs, the excitation sequence is ended and the device will transition into its standard ideal diode mode. If not, once the half second on-time has elapsed the MOSFET array will turn off. Approximately half a second later, the device will try exciting the alternator once again (with a half-second on-time). This process will occur a maximum of sixty times; if the alternator fails to begin charging after the last attempt, the device will immediately go to sleep and wait for another positive-going starter signal. If at any time during the excitation process the starter voltage rises back above the trip voltage (i.e. another cranking is attempted), the current process will be terminated and the device will wait for the starter voltage to once again disappear before restarting the excitation procedure.

Ignition Method: Upon application on the ignition line of a voltage greater than the turn-on threshold (~2 V), the device will first wait four seconds before initiating the alternator excitation sequence. As with the starter motor method, this allows cranking to occur without a possible depleted auxiliary battery loading down the engine. After the four seconds has elapsed, the MOSFET array will turn on to connect the main battery to the alternator, allowing its regulator to begin operation. The excitation process will then proceed exactly as in the starter motor excitation method; the only difference is if at any time during the process the ignition voltage disappears, the excitation procedure will be terminated and another application of ignition voltage will be required to restart the process.

Word of caution regarding the ignition method: If the vehicle is not started until after the alternator excitation process has completed and there is no auxiliary battery directly connected to the alternator, charging of the main battery will not occur. For example, if the user turns on the ignition, listens to the radio for five minutes, and then cranks the engine, the alternator will not be excited and all vehicle functions will run off the battery. In order to excite the alternator, the vehicle will need to be turned off and restarted. This is the main reason why the starter method of alternator excitation is preferred, as it gives a true indication of the engine running and spinning the alternator.

Never connect both the ignition and starter lines to the vehicle as unpredictable alternator excitation may occur.

COMBINE MODE

The POWER-GATE single rectifiers can be equipped with an optional combine function which allows the user to override the diode functionality of the MOSFET array. When the COMBINE+ and COMBINE- wires are connected together, the device will turn on the MOSFET array, allowing current to flow from the cathode to the anode. This feature can be used to provide extra current from the main battery to accessories attached to an auxiliary battery.

Word of caution: It is highly recommended that a momentary-type switch is used to short the two combine wires together. This ensures that the device will always default to its standard ideal diode state of operation; use of a non-momentary switch leaves open the possibility that the user can accidentally leave the device in an “always-on” state which can drain both batteries. Additionally, COMBINE- is internally tied to the device ground, so care should be taken during installation.

EXTERNAL LEDS

The POWER-GATE single rectifiers also come equipped with a harness for connecting external LEDs for device status monitoring. Every on-board LED is duplicated on the harness so that all functionality, operating states, and fault conditions can be monitored from a remote location, such as a vehicle’s cabin. While not required for operation, the external LEDs are highly recommended so that fault conditions such as over-current, over-temperature, or a blown fuse can be immediately detected and resolved before device health is put at risk.

The outputs are of the open-drain type, with an in-line Schottky diode incorporated to protect the MOSFETs from an accidental reverse voltage condition (see functional block diagram on the specification sheet). Consequently, they can be used not only with external LEDs, but with any other monitoring system that has its own pull-up scheme (e.g. an external computer), as long as the maximum current and voltage as detailed in the specification sheet are adhered to.

FUSE

The POWER-GATE single rectifier uses a fuse in order to protect the flyback diode from a reverse battery condition. If this fuse should blow, the "FUSE OPEN" LED will illuminate. Do not replace the fuse with any other than that specified by the manufacturer.

LOSS OF GROUND

In order to operate properly, the single rectifier requires a good ground connection. If ground is lost, the internal circuit board will not receive power, and thus, will not be able to properly operate the MOSFET array. If the anode voltage is greater than that of the cathode when this occurs, current will pass through the MOSFET body diodes, dramatically increasing the power dissipation and leading to possible array failure. This is another reason why use of the external LEDs is highly recommended, as loss of ground will also cause all LEDs to go dark, immediately indicating to the user that the POWER-GATE requires attention.

OVER-CURRENT INDICATION

If the forward current through the rectifier exceeds approximately 1.2 times the maximum continuous rating ($I_{F,MAX}$), the corresponding red fault LED will blink to make the user aware of the condition. The blink pattern is 0.75 seconds on and 0.25 seconds off and the LED will stop blinking when the forward current has decreased by 10 A from the initiation current (1.2 times $I_{F,MAX}$). While the rectifiers can handle excess current for short periods, the user should avoid this condition whenever possible.

OVER-TEMPERATURE INDICATION

If a rectifier's internal temperature exceeds approximately 135 °C, the red fault LED will begin to blink to indicate to the user that the rectifier's temperature has risen above a point where failure is possible if the condition persists. The blink pattern is 0.25 seconds on and 0.25 seconds off and the LED will stop blinking once the temperature has fallen below 130 °C. Unlike an over-current condition (which can be tolerated for short durations), if an over-temperature condition is present, all current flowing through the device should be immediately removed.

ISOLATION IN DUAL BATTERY APPLICATIONS

In most dual battery applications, a POWER-GATE dual rectifier is the preferred device to ensure the batteries are completely isolated from one another; i.e. each battery can be discharged independently of the other. However, in some applications use of the dual rectifier may be prohibited due to cost or size constraints, in which case the single rectifier can be utilized. When used in dual battery applications, the single rectifier will allow the battery attached to the rectifier's anode (usually an auxiliary battery) to be discharged independently of the battery attached to the rectifier's cathode (usually a vehicle's main battery), but the reverse is not true. Any load attached to the main battery will draw current from both that battery as well as from the one attached to the rectifier's anode. For instance, if a single rectifier is installed in an automotive dual battery application and the user leaves the headlights on, both batteries will be drained.

REVISION HISTORY

Rev 1: Original release (12/14/16)