POWER-GATE Non-Programmable OR'ING (Generation 4.0) Application Sheet

CONDUCTOR SIZING IMPORTANCE

The MOSFET arrays used in the generation 4.0 POWER-GATE non-programmable OR'ing (hereafter referred to as an NP-OR'ing device) have 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 device, 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.

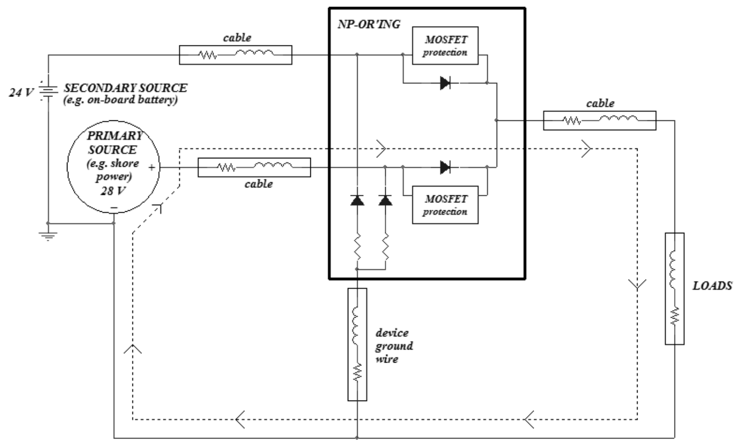
If the device flashes an over-temperature warning (which occurs when the internal device temperature exceeds +135 °C), then, assuming the device is operating within its current limitations outlined in the specification sheet, either the external conductors are undersized for the current flowing through 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

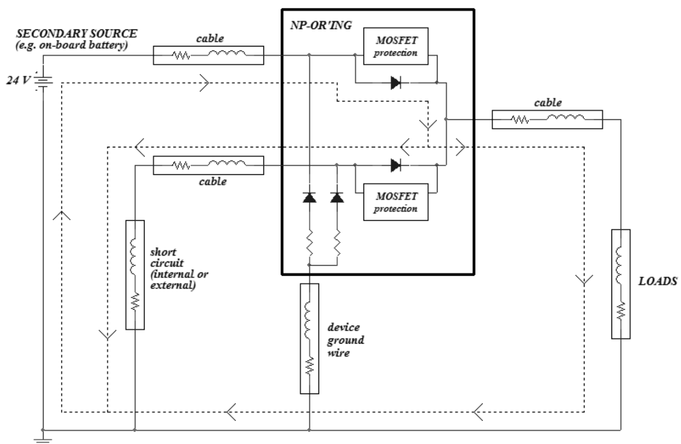
Device reliability is also greatly affected by the system loop inductances during reverse current turn-off conditions. When operating at the high currents the MOSFET arrays were designed for, the total inductance of the external world it is connected to must be carefully evaluated to ensure that under 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 rectifiers operating in their standard ideal-diode mode reacting to the reversal in polarity (forward voltage drop going negative), and 2) exiting from combine mode while reverse current is flowing. Two typical scenarios are depicted in Figures 1 and 2.

Figure 1 shows a common use of the NP-OR'ing device, which is to allow the



(a)



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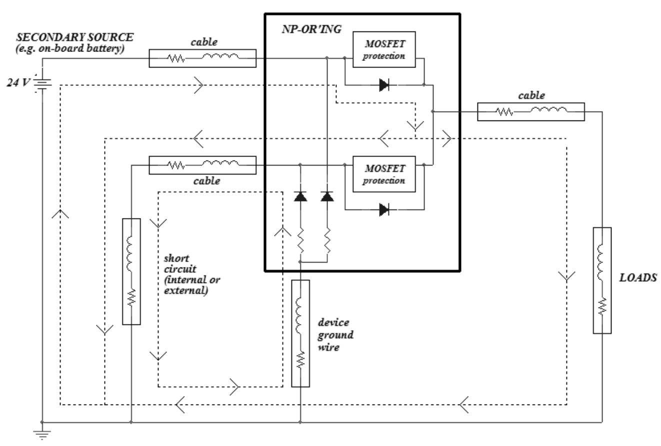

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Figure 1: Reverse current turn-off transient behavior in normal diode mode with system loop inductances. (a) Powering the common load through the higher of two input sources (shore power). (b) Reverse current during MOSFET array turn-off after development of a short-circuit at the shore power source. (c) Reverse current after MOSFET array turn-off flowing through MOSFET protection circuitry and flyback diode due to system inductances.

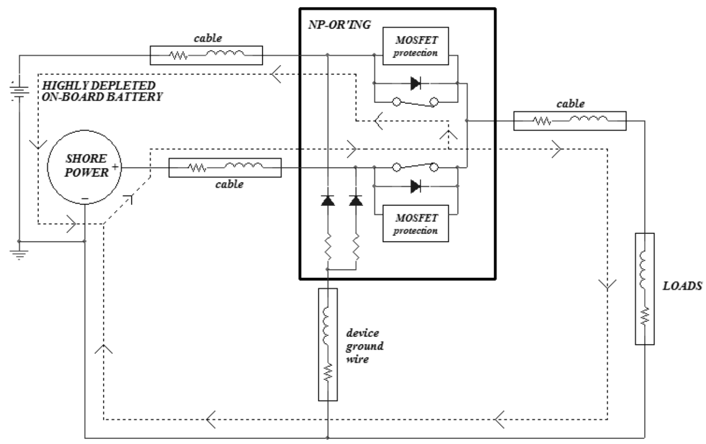
higher of the two input source voltages to power a common load. While the nature of the sources can take many forms, Figure 1 depicts a situation where a vehicle powers arbitrary loads from an on-board battery when mobile (probably coupled with some charging component), but can run off of shore power when docked. Figure 1a depicts the current flow (as indicated by the dotted line) originating from the shore power supply (which is 4 V higher than that of the on-board battery), flowing through its corresponding MOSFET array (represented as a diode) to the common load, and finally returning to the shore power supply. 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 shore power source, either internal, or just external to it. In response to this fault event, its MOSFET array will begin to turn off. Due to the finite turn-off time (reverse recovery time in the specification sheet), short-circuit current will not immediately cease, but will instead flow from the on-board battery, through its MOSFET array, back through the closing MOSFETs to the short circuit, and finally back to the on-board battery. As the fault 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 fault 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 use of the NP-OR'ing device: utilizing the combine mode to supply current from shore power to not only the vehicle loads, but also to the on-board battery in the case where its charging source has failed. Figure 2a shows the combine mode overriding the diode functionality of both MOSFET arrays to allow charging current for a highly depleted on-board battery to flow from the shore power supply, while also continuing to power the vehicle loads.

In Figure 2b, the combine mode has been switched off while a very large charging current is present. Due to the finite turn-off time (reverse recovery time in the specification sheet), the charging current will continue to flow for a short period, and, as in the first case explained here, the inductances will generate significant magnetic fields, especially at the high currents that a depleted battery can demand. Once the MOSFETs have completely turned off, the remaining charging current will flow through the shore power MOSFET array and the on-board battery MOSFET array 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. The two key parameters a user needs to evaluate when determining if a NP-OR'ing device 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.



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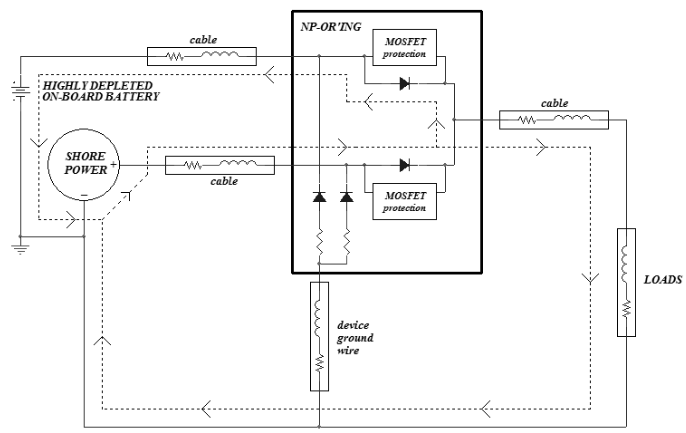

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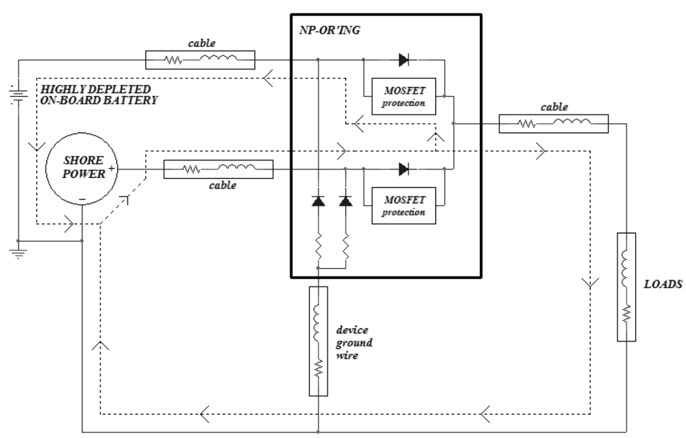

(c)

Figure 2: Reverse current turn-off transient behavior in combine mode with system loop inductance. (a) Shore power providing current to both the vehicle loads as well as the highly depleted on-board battery (both diode functionalities overridden). (b) Reverse current through the on-board battery MOSFET array during turn-off. (c) Forward current flowing through the shore power MOSFET array and reverse current flow through the on-board battery MOSFET array protection circuitry due to system inductance.

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

COMBINE MODE

The POWER-GATE NP-OR'ing device can be equipped with an optional combine function which allows the user to override the diode functionality of the MOSFET arrays. When the COMBINE+ and COMBINE- wires are connected together, the device will turn on both MOSFET arrays, allowing current to flow from one source to the other, and vice-a-versa. This feature can be used for a variety of reasons, such as the scenario described in the previous section where a highly depleted on-board battery requires charging by the other input source.

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. Additionally, COMBINE- is internally tied to device ground, so care should be taken during installation.

EXTERNAL LEDS

The POWER-GATE NP-OR'ing devices 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 NP-OR'ing device uses a fuse in order to protect the two flyback diodes from a reverse voltage 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 NP-OR'ing 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 arrays. If one or more sources are connected 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 a 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 corresponding 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.

NON-PROGRAMMABLE VS. PROGRAMMABLE OR'ING DEVICE

The non-programmable OR'ing consists essentially of two POWER-GATE single rectifiers with their cathodes tied together in a single package. It behaves exactly as one would expect when two diodes are configured in that manner, by passing current from the higher of the two sources to the common load. The primary advantage of the non-programmable OR'ing device is that it allows for nearly instantaneous switching of the load between the two sources; if the higher source suddenly experiences a decrease in voltage below that of the other, the device will immediately switch the load so that there is no deadtime, or period when neither source is providing power. The major difference between the non-programmable OR'ing device and two standard discrete diodes is apparent when the two sources are close in voltage to one another. With discrete diodes, both sources may provide power to the load depending on the voltage difference between them and the level of matching between the two diode's I-V characteristics. Because POWER-GATE rectifiers are MOSFET-based, there is no ability to share the current load in an equivalent manner; one side is on and one side is off. As a result of system dynamics, there is the possibility of rapid switching of the load between the two sources; an example best explains this behavior.

Using the configuration shown in Figures 1 and 2, say, for arguments sake, the shore power source is at 26.5 V and the on-board battery is sitting at 26.4 V. These sources are connected to the inputs of the non-programmable OR'ing, and the shore power source will be providing power to the loads (since it is 0.1 V higher than the on-board battery). Then say that a large load is turned on which causes the shore power source to experience a dip in voltage to 26.3 V. At this point, the non-programmable OR'ing will automatically switch the load to the backup battery. When this occurs, the unloading of the shore power source will cause its voltage to jump back up to 26.5 V (and the on-board battery voltage may sag in response as well); the shore power voltage is now higher than the on-board battery voltage and so the non-programmable OR'ing will switch the load back to the shore power source. That source will again experience a dip, causing the OR'ing to switch the loads back to the on-board battery source. This process will continue indefinitely until the load is sufficiently small as to allow one source to always be higher in voltage than the other. Because of this behavior, Perfect Switch generally recommends that the two sources be separated by at least 0.5 V so as to avoid rapid switching between them.

The programmable OR'ing avoids the oscillatory behavior of the non-programmable OR'ing by using two POWER-GATE bi-directional relays in place of the rectifiers. One relay is connected to a “primary” source and constantly monitors its voltage. The second relay is connected to a “backup” source and receives commands from the primary relay. If the primary source voltage falls below a user-specified trip voltage, the primary relay will disconnect the primary source from the loads and command the other relay to connect the backup battery to the loads. After this, the primary relay will continue to monitor the primary source voltage; if and when that voltage rises back above a user-specified reset voltage for a given period of time, the primary relay will command the other relay to disconnect the backup battery from the loads and will reconnect the primary source to the loads. This configuration allows the user to have great flexibility in deciding within what voltage range the primary source should be allowed to power the loads, as opposed to the non-programmable OR'ing configuration which simply powers the loads from the higher of the two sources.
However, unlike the non-programmable OR'ing device, the programmable version has an associated deadtime during the switching process. Utilizing our current generation 3.0 relays, under worst-case conditions, the deadtime can be as long as 10 ms (the configuration using the upcoming generation 4.0 POWER-GATE relays will have a much shorter deadtime). Some applications utilizing the programmable OR'ing may require the use of a "hold-up" capacitor to provide power to the loads during this deadtime, but the need to do so is completely dependent upon the nature of the attached loads.

Summarizing, the non-programmable OR'ing will allow for switching with essentially no loss of power to the loads, but will only pass the higher of the two sources to the loads, and is prone to rapid switching of the loads between the two sources when they are close in voltage. The programmable OR'ing allows for greater flexibility in determining which source provides power to the loads, but has an inherent deadtime that must be accommodated for.

REVISION HISTORY

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