Application Report

SLVAEC4–July 2019

Backplane Power Protection in PLC Systems

Paul Kundmueller

ABSTRACT

As factories become more automated, having a centralized controller becomes even more critical. Programmable Logic Controllers (PLC) can make a factory even more autonomous. In a harsh factory environment, PLCs can face a number of system faults. These faults can cause unwanted downtime. This document analyzes the different design needs for modules requiring backplane power protection, and how TI eFuses help solve these different design needs.

Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 What is a PLC Power Backplane?

A backplane (also known as a base unit) is a common bus shared by many different subsystems. It allows a system to distribute both data and power. This document focuses solely on the power portion of the backplane, known as the “Power Backplane”. The Power Backplane can be viewed as the “heart” of a PLC system. If the Power Backplane fails, the whole system and factory loses its ability to power its “brain,” and, therefore, its automation. Ensuring the backplane remains up and running is crucial.

The power for the backplane is typically generated from a separate power supply module called a DIN power supply. This DIN power supply provides the necessary power for modules connected to the backplane through generic connectors. The typical backplane voltage ranges from 5 V to 24 V based on the PLC system type and manufacturer. Figure 1 shows what a typical backplane looks like.

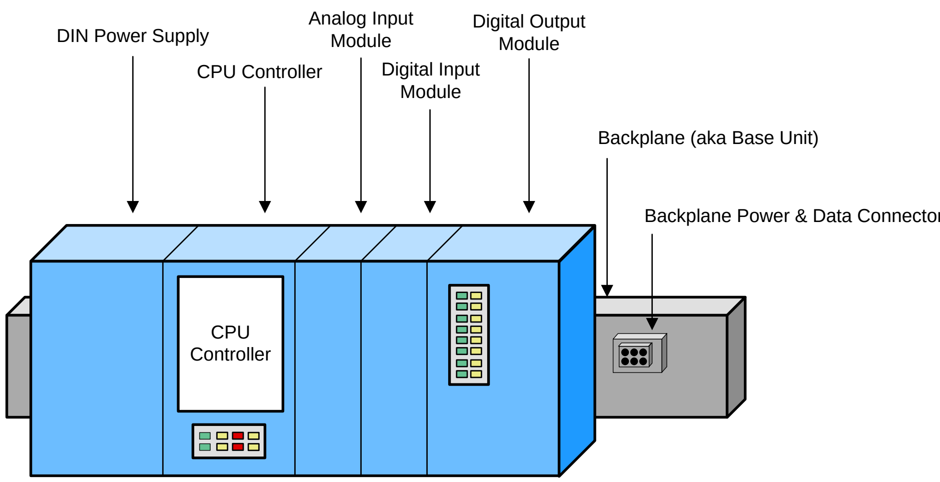


Figure 1. Typical PLC System with a Backplane Interface

2 Design Challenges for Backplane Power Protection

There are many design challenges related to backplane power protection that must be considered when designing a robust PLC system. The following showcases these design needs:

- Current limiting/Short-circuit protection
- Overvoltage protection
- Reverse current blocking for Power Interruptions (IEC 61000-4-29)
- Inrush current control
- Surge protection (IEC 61000-4-5)

As an example, this paper examines the power protection design challenges for a PLC CPU module, and explains the benefits of a TI eFuse in solving these design challenges. Each of these power protection design challenges can be applied to any PLC or DCS module with a backplane power connection. Figure 2 displays a zoom-in of a typical end equipment reference diagram of a PLC CPU module.

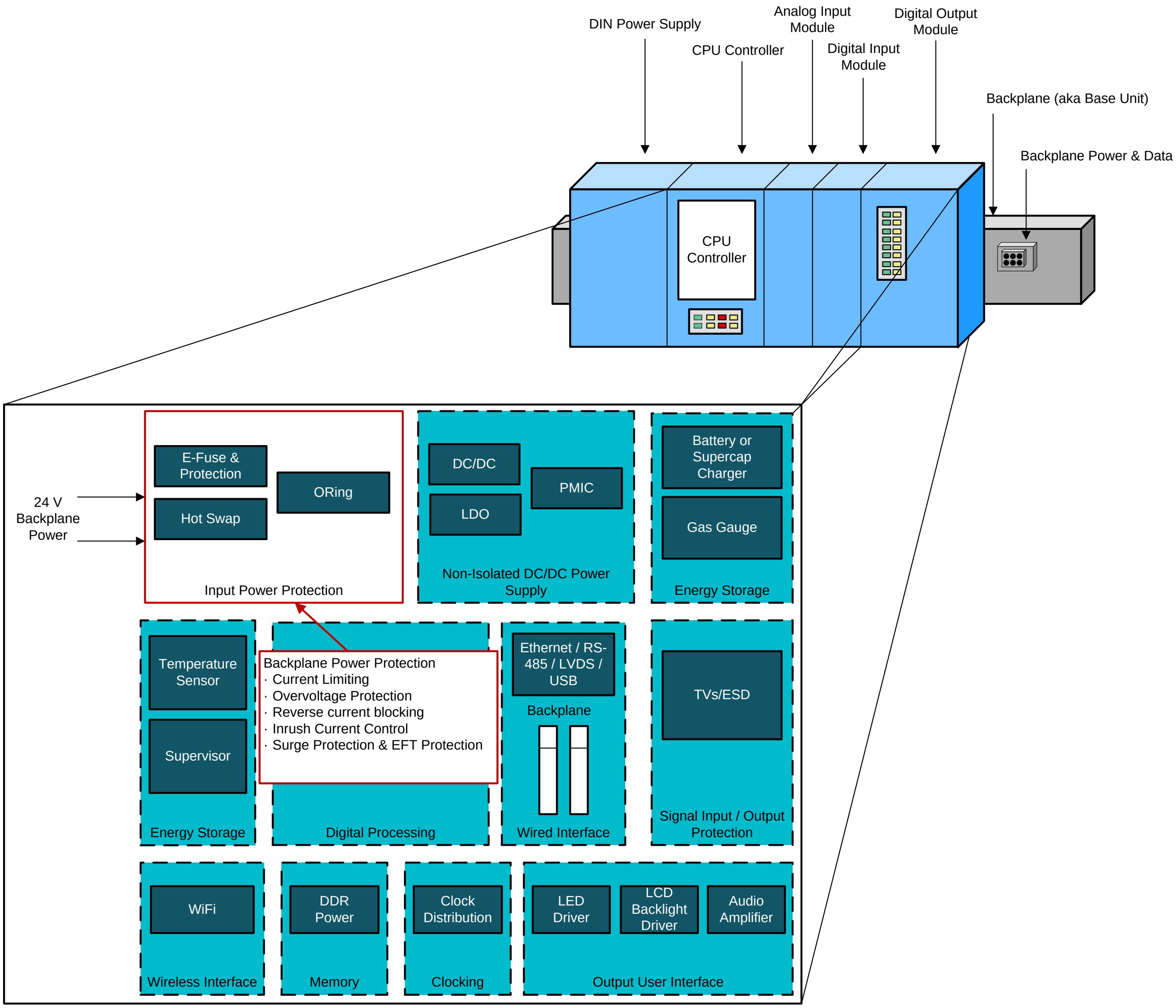


Figure 2. End Equipment Reference Diagram of PLC CPU Module

3 Current Limiting/Short Circuit Protection

Short or overload conditions on the backplane side of certain modules can cause them to fail. It is important to isolate this failure from the rest of the power backplane to avoid bringing down the whole system, and in turn, the factory. Having local current limiting/short-circuit protection in each module is important in achieving this fault isolation.

TI eFuses offer fast short-circuit protection (<1 µs) and current limiting to protect against these hard-short and overload scenarios that can cause total backplane system failure. The following illustration of a short-circuit (Figure 3), simplified schematic (Figure 4), and performance graph (Figure 5) showcase the TPS2660x during a hot-short event.

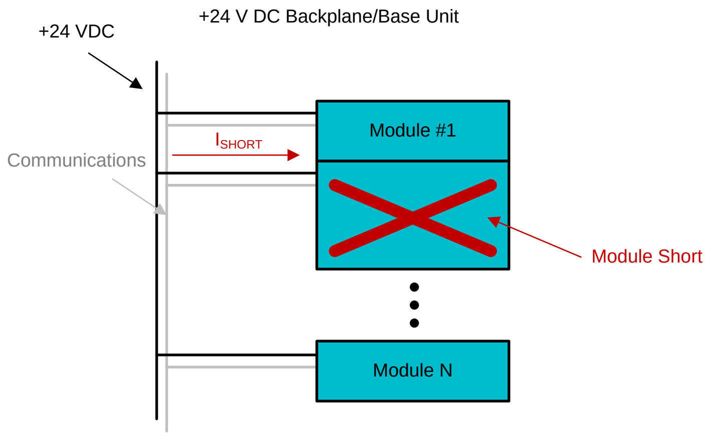


Figure 3. Illustration of Short-Circuit on an Individual Module

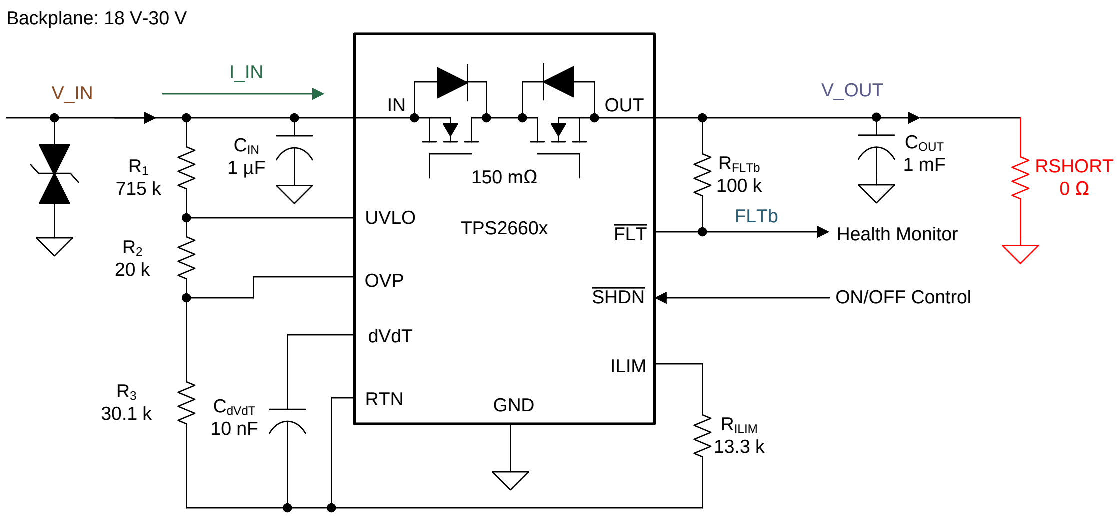
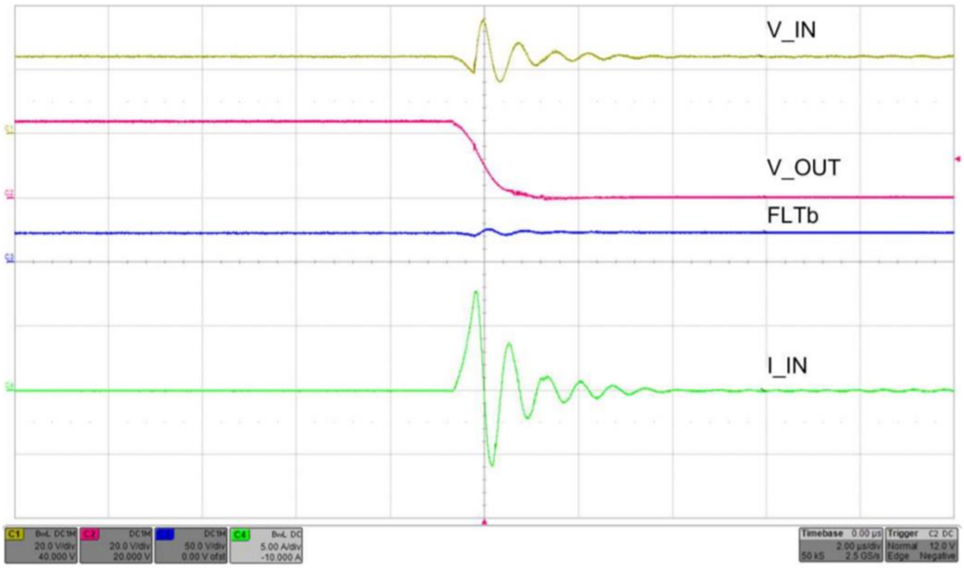


Figure 4. Simplified Schematic of TPS2660



R_{ILIM} = 5.36 kΩ

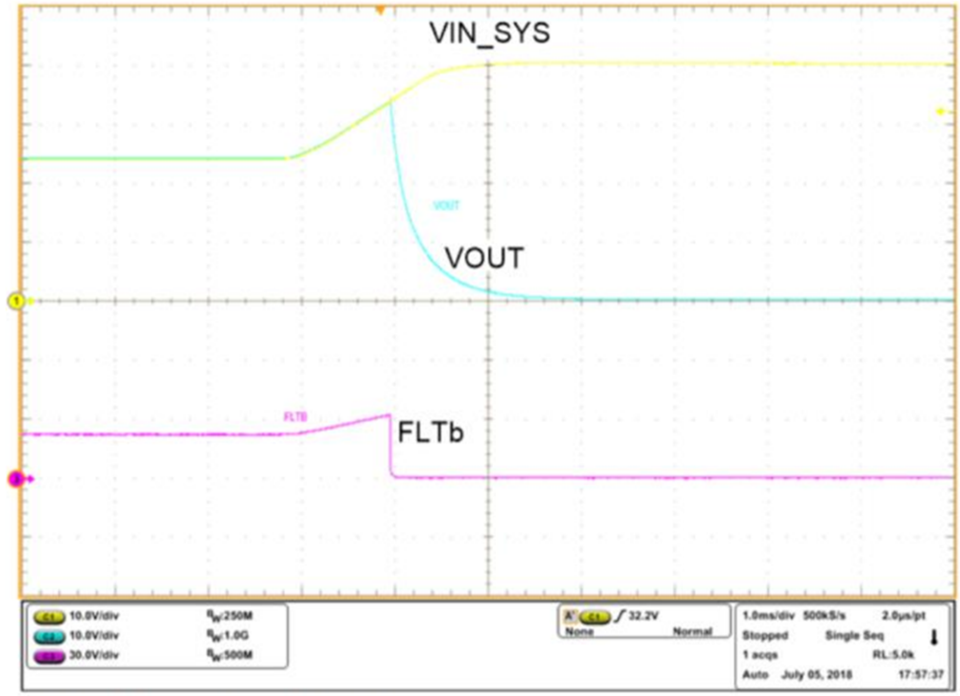
Figure 5. Waveform of TPS2660 Response to an Output Short-Circuit Condition

4 Overvoltage Protection

In addition to limiting the current, another important protection aspect is limiting the voltage to the individual modules. There are a several scenarios where limiting voltage is critical. However, this section will focus on overvoltage protection for Safe Extra Low Voltage (SELV) systems.

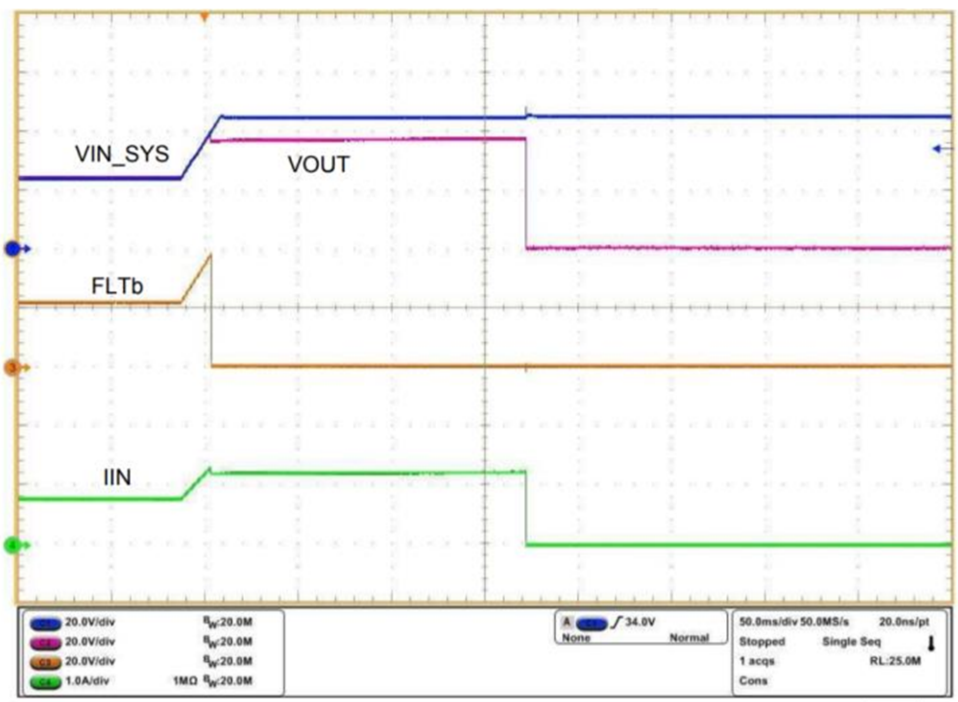
The power supply for the backplane is commonly converted from an AC source to a DC source. Generally the power supplies used to power backplanes are Safe Extra Low Voltage (SELV). One criteria of a SELV power supply is that, if it fails, the output must never exceed 60 V DC. This criteria ensures that the full AC voltage is not exposed to its output, as the output is usually not equipped to handle a voltage that high. Not being exposed to the full AC voltage is good, but the module still needs to be designed to withstand 60 V DC.

In a SELV failure, TI eFuses can withstand the 60 V due to their high voltage rating of 60 V. The overvoltage protection function of a TI eFuse can gate the 60 V from propagating to the rest of the system. Gating the voltage is useful in optimizing the downstream passive component (capacitors and so forth) and converters. This decreases overall solution size and cost. TI eFuses also offer the flexibility to tune the overvoltage protection threshold via external resistor ladder. Depending on the part number, the eFuse has two means to limit an overvoltage event: overvoltage cutoff performance and overvoltage clamping. The overvoltage cutoff feature immediately turns off the device when an overvoltage fault occurs. On the other hand, the overvoltage clamping mode clamps the output to a certain voltage and continues to clamp the voltage until the device reaches its thermal shutdown threshold which then initiates a device shutdown.



TPS26630 and TPS26631

Figure 6. Overvoltage Cut-off Response at 33 V Level



TPS26635

R_{LOAD} = 30Ω, $\overline{FLT}$ connected to VOUT

Figure 7. Overvoltage Clamp Response with the TPS26635

5 Reverse Current Blocking

Systems often need to withstand power interruptions (also known as “brown-outs”) from the backplane power supply, and ride out these interruptions without an operational loss. Typically systems have a holdup capacitance, or a backup source, to supply the necessary power until the backplane power supply recovers. During these brown-out events, the voltage on the backplane power supply can drop to 0 V. Blocking the reverse current is important in avoiding a backup source collapse and a system restart.

A common way to implement reverse current blocking is using a discrete diode. A disadvantage of this method is the poor power dissipation of a diode. This can be problematic for IP67 modules, which have close to zero air flow due to its small plastic enclosure.

TI eFuses integrate a low RDSON blocking FET to achieve this reverse current blocking function without sacrificing power dissipation in the module. Figure 8 and Figure 9 show an illustration and simplified schematic, respectively, of a "brown-out" that occurs on the power backplane. Figure 10 displays a performance graph of the same process. During this power interruption, the input voltage of the eFuse goes to 0 V and reverse current from the output of the eFuse flows to the input of the device. TI eFuses with back-to-back FET topologies have a reverse current comparator to detect this reverse current and quickly shut off the blocking FET to block the reverse current from OUT to IN which ensures that the holdup capacitor on the output does not lose its charge during this power failure scenario.

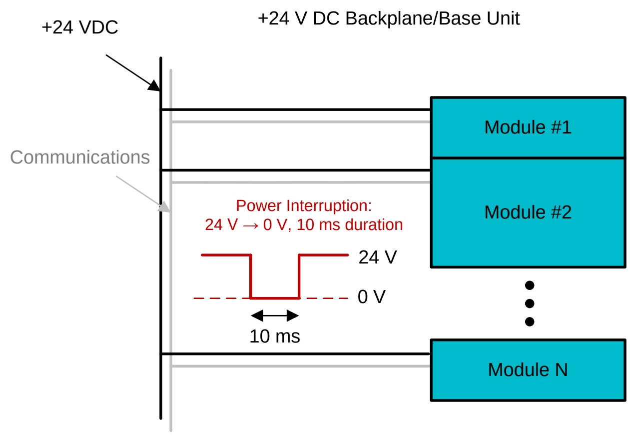


Figure 8. Illustration of Power Interruption Test (IEC 61000-4-29)

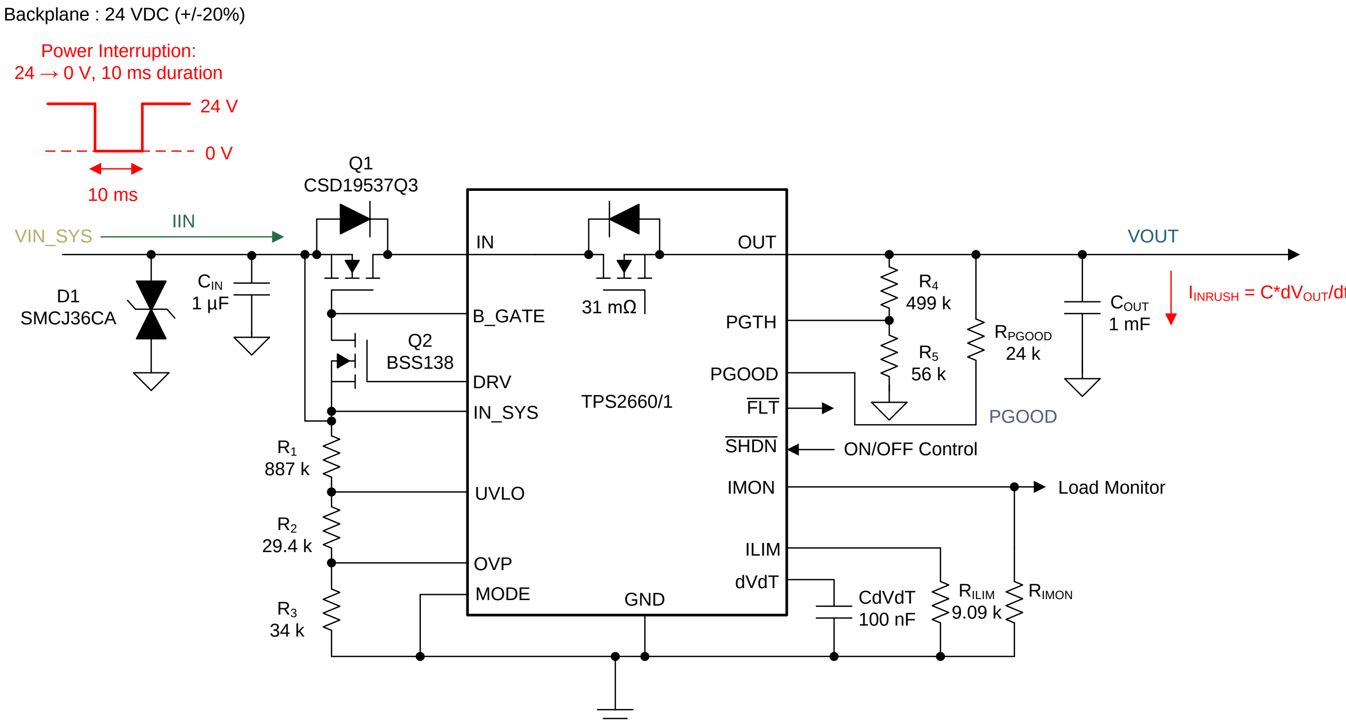


Figure 9. Simplified Schematic of TPS26630/1

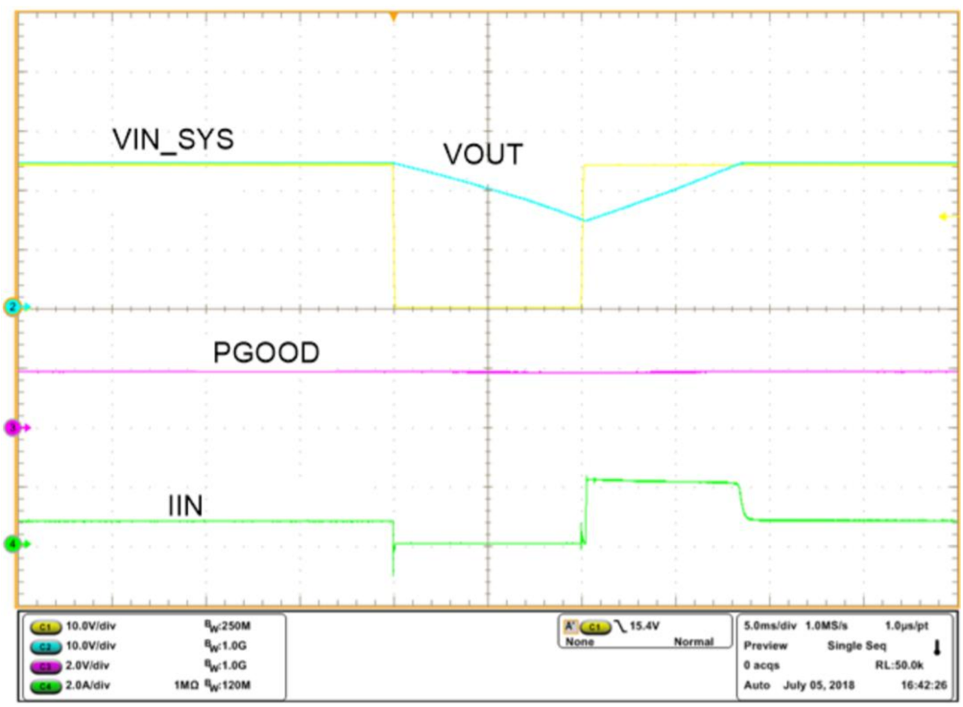


Figure 10. Waveform of TPS2663 in Response to 10 ms Power Interruption Test

6 Inrush Current Control

One advantage of a backplane power supply is that modules can be removed or added without shutting down the system. This is also known as hot-swapping. Hot-swapping capability makes maintenance at 24/7 factories seamless, and allows them to remain fully-functioning.

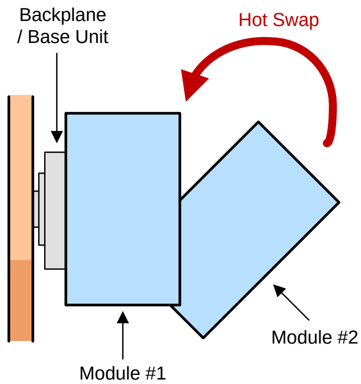


Figure 11. Illustration of a Hot-Swap Event

The very nature of hot-swapping involves placing instantaneous voltage on a system. Many of the modules plugged into a backplane potentially have large input capacitors for DC/DC converters, or large holdup capacitors for passing power interruption tests (IEC61000-4-29), as previously discussed. Placing instantaneous voltage on a capacitor results in a high amount of inrush current (I = Cdv / dt). This often causes the current limiting protection to prematurely trip, or cause the backplane power supply to fail. Either of these problems are even worse issues for a factory.

Having a means to control the rate at which the capacitance on a module is charged is important. Often, a discrete PMOS and RC filter can turn on a capacitive load in a controlled manner. However, this often leads to high peak currents due to the non-linear slew rate of the RC filter.

TI eFuses offer a means to vary the slew rate of its output to linearly control the rate at which the system charges up the output capacitance. This ensures that the backplane power supply does not overload when the system is turned on. TI eFuses include a dvdt pin to adjust the slew rate of the output of the eFuse. A small external capacitor can be placed on the dvdt pin to vary the slew rate of the output. This capacitor can vary the amount of inrush current, charge up the output capacitance ($I_{INRUSH} = C_{OUT} \times dv / dt$). Figure 12 to Figure 15 display the comparison between a discrete circuit and an eFuse when a hot-swap event occurs on a module.

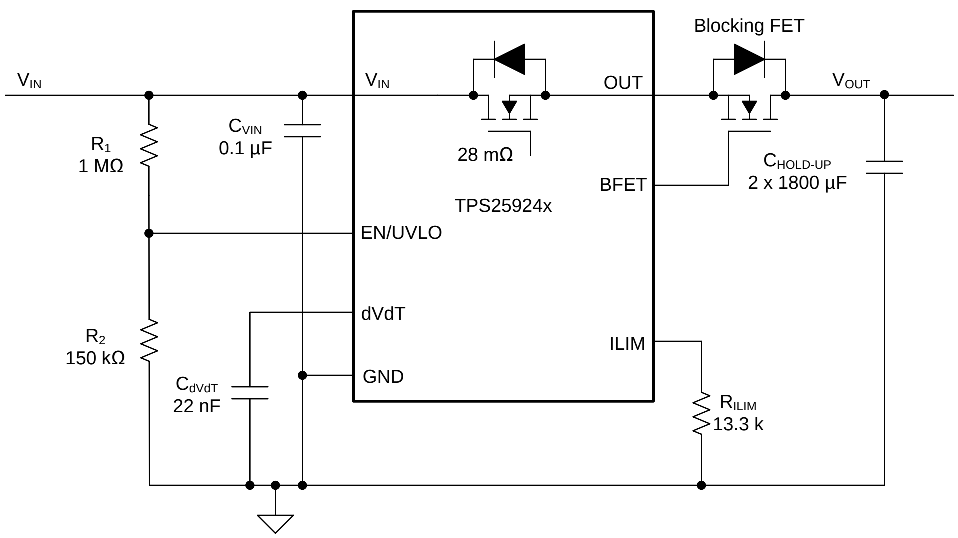
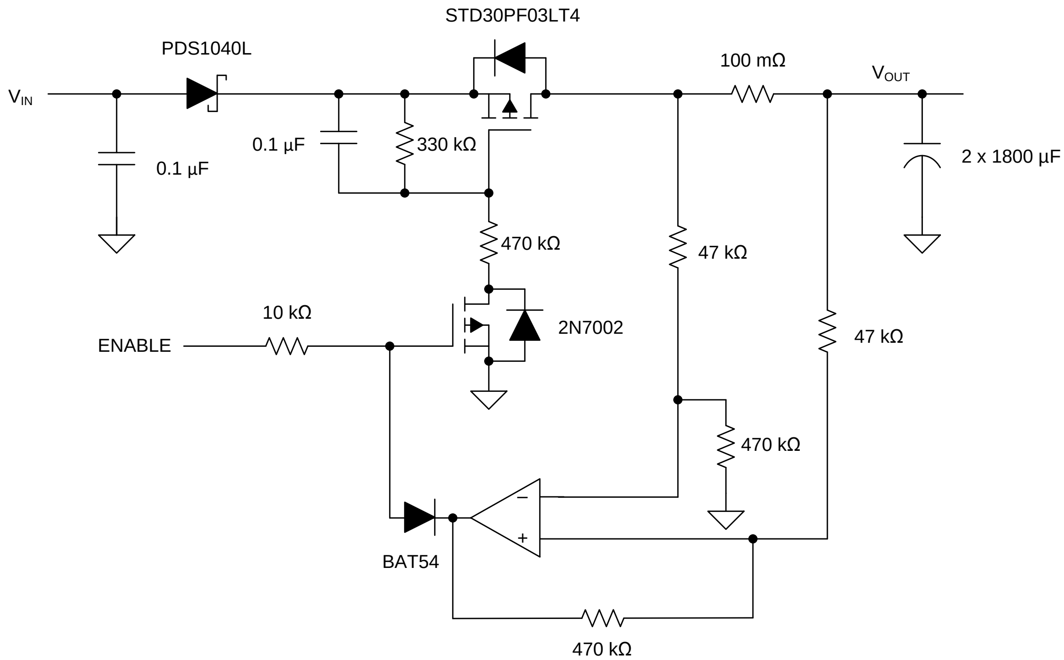


Figure 12. Simplified Schematic of the TPS25924x



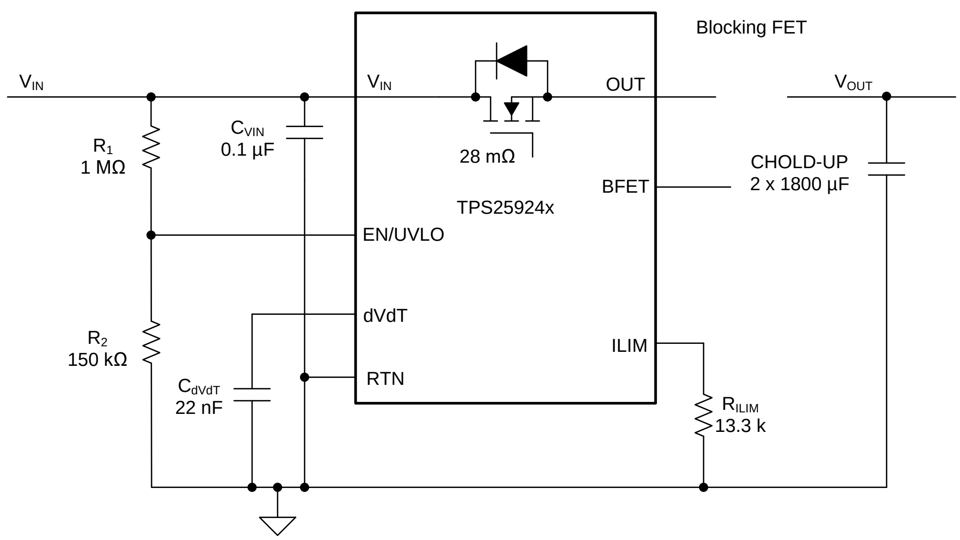


Figure 13. Simplified Schematic of Discrete Solution

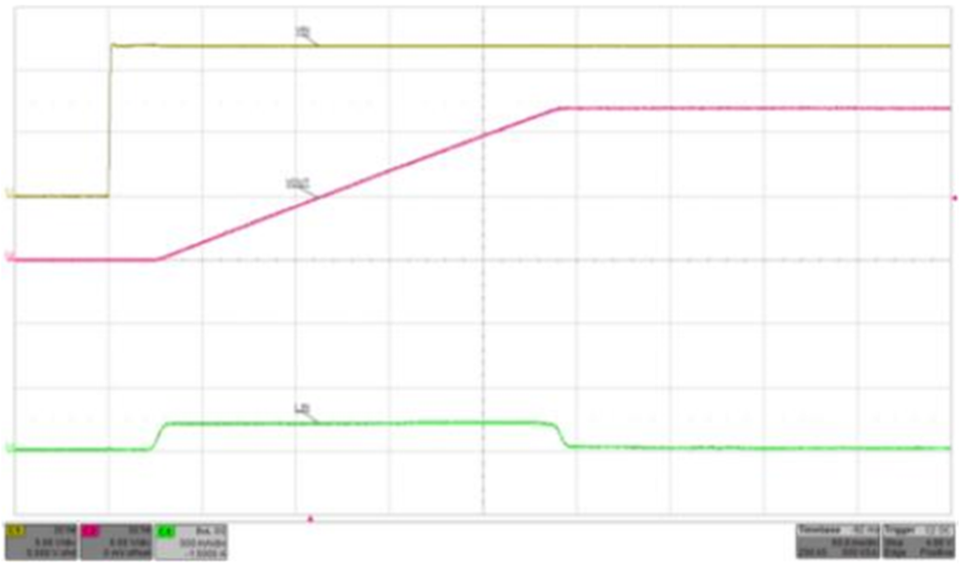


Figure 14. Waveform Showing the Charge Up of 3.6 mF Holdup Capacitor with the TPS25924x

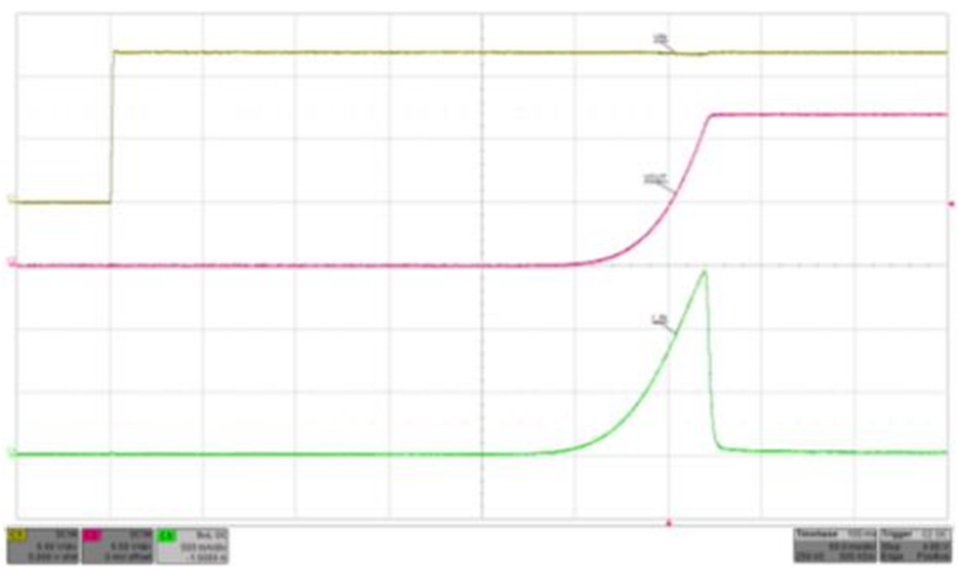


Figure 15. Waveform Showing the Charge Up of 3.6 mF Holdup Capacitor with a Discrete Solution

7 Surge Protection (IEC 61000-4-5)

Many countries with unstable power grids have frequent power surges. These surges can cause the PLC system to continually turn off and on, and reduce an automated factory to a semi-automated factory. The ability to ride through surge events without functionality loss is key to a highly-efficient automated factory. The common PLC system surge immunity testing standard is IEC 61000-4-5. How a system responds to a surge event determines the level of surge immunity it has. Table 1 displays the different surge immunity levels.

Table 1. Surge Immunity Criteria Levels

CRITERIA	DESCRIPTION
A	Normal performance within the limits specified of the manufacturer, requestor, or purchaser
B	Temporary loss of function, or temporary degradation of performance not requiring an operator
C	Temporary loss of function, or degradation of performance that requires operator intervention
D	Loss of function or degradation of performance that is not recoverable, owing to damage of the hardware or software, or loss of data

The most desired surge immunity level is Criteria-A. This means the surge is virtually transparent to the system, and does not interrupt operation. An eFuse provides an optimal, plug-and-play solution to Criteria-A surge performance. The many different functions (reverse current blocking, reverse polarity protection, and so forth) of an eFuse work together to achieve this immunity. Figure 16, Figure 17, and Figure 18 display how the TPS2660 responds to a 500 V / 2 Ω surge event. TI eFuses ensure the output voltage is held up to a certain level to keep the system operational during a surge event.

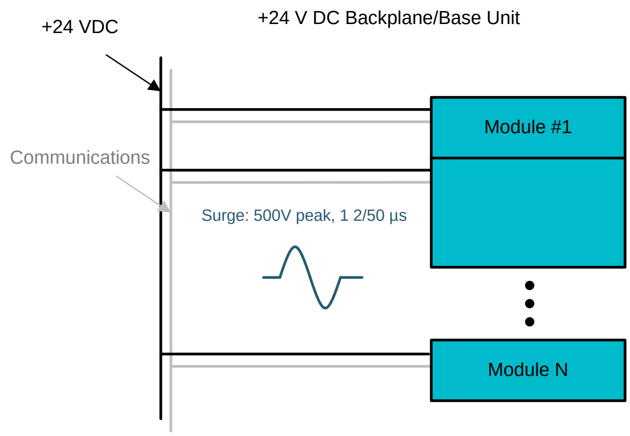


Figure 16. Illustration of a Surge Event on the Backplane

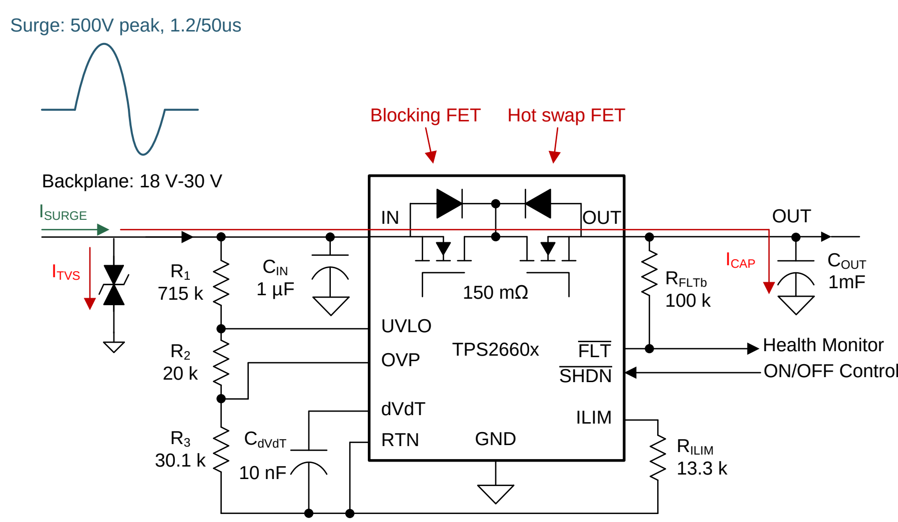


Figure 17. Simplified Schematic for Surge Protection

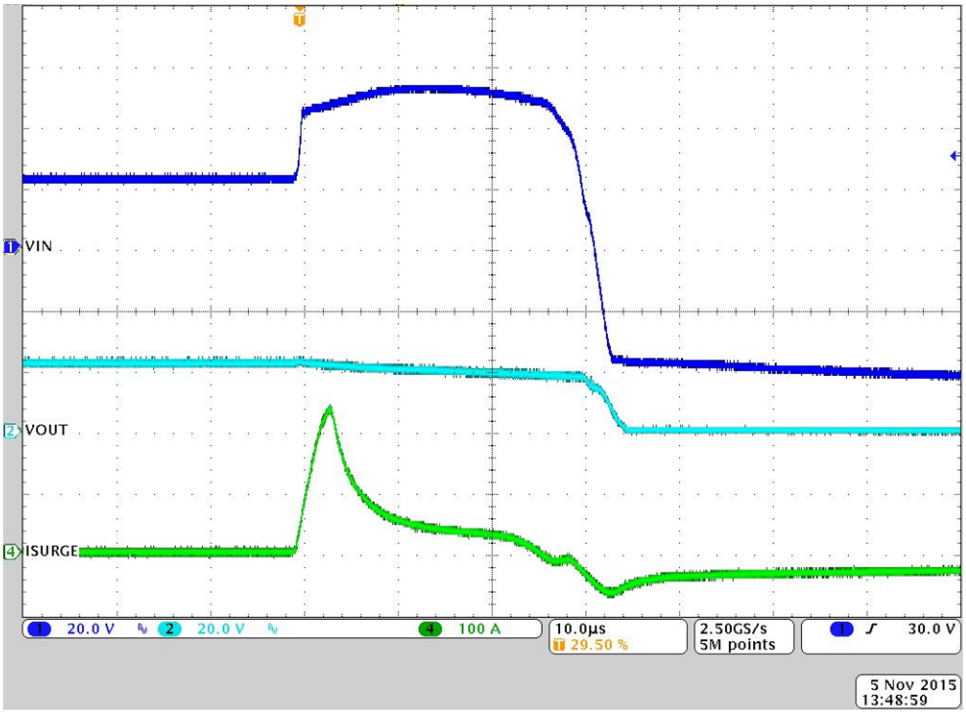


Figure 18. Waveform of TPS2660 During a 500 V / 2 Ω Surge Event

8 Texas Instruments Options for Backplane Power Protection

Among the Power Switches portfolio, Texas Instruments broad eFuse portfolio addresses the different voltage and current level requirements for backplane power protection. Table 2 and Table 3 display a snapshot of TI's offering for 24 V, 5 V, and 12 V backplanes.

Table 2. TI eFuses for 24 V Backplane Power Protection

PARAMETER	TPS2662	TPS2660	TPS2663
FET	Internal	Internal	Internal + External BFET
Vin (Min) (V)	4.5	4.2	4.5
Vin (Max) (V)	57	55	60
ABS MAX (V)	60	60	62
Current limit (Min) (A)	0.025	0.1	0.6
Current limit (Max) (A)	0.88	2.23	6
Ron (Typ.) (mΩ)	500	150	31
Features	• Input reverse polarity protection • Output reverse polarity protection • Overvoltage cutoff • reverse current blocking • Output slew rate control	• Analog current monitor • Input reverse polarity protection • Overvoltage cutoff • Reverse current blocking • Output slew rate control	• Analog current monitor • Input reverse polarity protection • Overvoltage cutoff • Reverse current blocking • Output slew rate control
Package group | # of pins	VSON | 10	HTSSOP | 16 VQFN | 24	VQFN | 24

Table 3. TI eFuses for 5 V and 12 V Backplane Power Protection

PARAMETER	TPS25200	TPS25942
FET	Internal	Internal
Vin (Min) (V)	2.5	2.7
Vin (Max) (V)	6.5	18
ABS MAX (V)	20	20
Current limit (Min) (A)	0.080	0.6
Current limit (Max) (A)	2.9	5.3
Features	• Overvoltage clamping • Reverse current blocking when OFF • Output slew rate control • Input reverse polarity protection with external GND diode	• Analog current monitor • Overvoltage cutoff • Reverse current blocking • Output slew rate control • Input reverse polarity protection with external GND diode
Ron (Typ.) (mΩ)	60	42
Package group	WSON | 6	WQFN | 20

9 Conclusion

As discussed previously, the PLC backplane can be viewed as the "heart" of the system. If the backplane goes down, the whole system is lost. This causes unwanted downtime and higher operating costs. As more intelligence is built into PLC systems, and a drive towards smaller end products continues, compact solutions become even more important. TI's eFuse portfolio offers a wide range of optimized solutions that ensure the PLC system is fully protected without compromising board space. By using an eFuse from Texas instruments, a factory can stay up and operational, even in its unpredictable environment.