

Power Module Start-Up With External Voltage On Output



Abstract

The power conversion industry's adoption of power MOSFETs for output rectification on DC/DC converters and point of load (POL) DC/DC regulators, referred to as synchronous rectification, has significant benefits to the user because of greatly enhanced efficiency and packaging density.

The user must, however, be aware of possible limitations of this approach in certain system situations. Because a MOSFET can conduct current in either direction, a reverse current flow is sometimes possible when attempting to start a DC/DC power module into a partially charged or "pre-biased" output capacitor bank.

This design note defines the situations in which this condition should be considered, explains how potential problems may be avoided, and summarizes how each of the Flex Power Module product offerings perform when starting up into a pre-biased environment.

General Discussion

It is generally assumed that DC/DC power modules will always power up into a load with no voltage on the output, and indeed this is normally the case. There are situations, however, where the voltage on the output of a DC/DC converter or point of load (POL) DC/DC regulator can be other than zero when it attempts to start up. One of these scenarios occurs when using large values of decoupling capacitance on the output of a DC/DC power module without an adequately low bleed resistance. If the time constant of the output capacitor discharge is large, and the power module is powered down and then restarted before the output voltage has decayed, then a pre-biased condition exists. The other most common cause for pre-biasing occurs when using load circuitry powered from two or more voltage sources. If one voltage level is powered down, current from the other voltage source(s) sometimes can flow out of the load and into the converter or regulator that is powered down. This can happen either during a fault condition or if inappropriate power sequencing is used. The severity of this condition (the amount of current capable of being sourced into the output of the power module) depends upon the characteristics of the load circuitry being used. Depending upon the configuration and impedance of the output capacitor network, the characteristics of the load circuitry, the rectification devices employed and design of the power conversion circuitry, potentially large currents can flow into the power module during start up.

Some power converters use diodes as rectification devices. Since the diodes will only conduct in one direction, reverse current flow back into the converter is not possible, and pre-bias situations are of no concern. Most high performance low voltage converters and regulators now use synchronous rectification techniques implemented with power MOSFETs as the conducting and blocking element. This is an appropriate design decision due to their lower forward voltage drop compared to diodes and the ability to precisely control the conduction period from the gate terminal. Both of these characteristics result in substantially improved efficiency and power density relative to diode rectifiers, advantages that have led to the widespread acceptance of synchronous rectification for applications demanding high efficiency. One of the trade-offs for these benefits is that the power system designer needs to be aware of the situation when restarting with pre-biased conditions.

The first cause of pre-biasing, stored energy in the output decoupling network, is the easiest to analyze and correct. Consider a power converter design with no pre-bias protection with a large, low impedance output capacitor bank without provision for discharging the capacitors when powering down. If the converter is turned off and then immediately powered up again, the voltage level and stored energy of the output capacitor bank could be larger than that available from the initial converter switching

cycles. When the synchronous rectifier MOSFETs are turned on under these conditions, current would flow in the reverse direction back into the converter and through the MOSFETs and possibly result in excessive stress and potential for damage. This type of condition is easy to avoid with proper care in the power system design.

The power system designer should be knowledgeable about the discharge rate of each decoupling capacitor network. The rate of discharge can be controlled by using bleed resistance so that the capacitor networks discharge within a reasonable amount of time. To guarantee a normal restart, a power module should generally not be restarted until the output capacitors are discharged to below 0.2 volt. The system designer thus has two ways to avoid this possible pre-bias condition. The capacitors can be discharged more quickly by reducing the value of the bleed resistance. The restart of the DC/DC power module may also be delayed by appropriate control system timing so that the output capacitance has adequate time to discharge to a safe voltage level.

Figure 1 shows how the bleeder resistor is connected in parallel with the load decoupling capacitance. In actual systems, the decoupling capacitance is composed of many smaller value capacitors distributed on the load board to be in close proximity to the load circuit devices for maximum effectiveness. The capacitor shown in the figure represents the summation of all the capacitor values used in the decoupling network. Allowance should be made for the tolerances of the capacitors, which could add substantially to their marked values. Even though the total capacitance is distributed across several physical capacitors, the bleed resistor can be a single component. Its physical location in the decoupling network is not critical. The discharge of the capacitor bank follows the expected exponential curve as a function of the RC time constant as shown in Figure 2. Given the initial value of voltage (the operational output voltage of the DC/DC power module) and the desired pre-bias

voltage before attempting a restart of the converter or regulator, the value of bleeder resistance can be calculated for any desired time delay prior to restart by using the following equation:

$$R = \frac{t}{C \times \ln(v_0 / v_1)}$$

where:

- R = Required bleeder resistance in ohms
- t = Elapsed time prior to restart in seconds
- C = Total decoupling capacitance in farads
- v₀ = Normal output voltage of DC/DC power module in volts
- v₁ = Desired output pre-bias voltage in volts

As an example, assume a 3.3 V DC/DC converter with an output

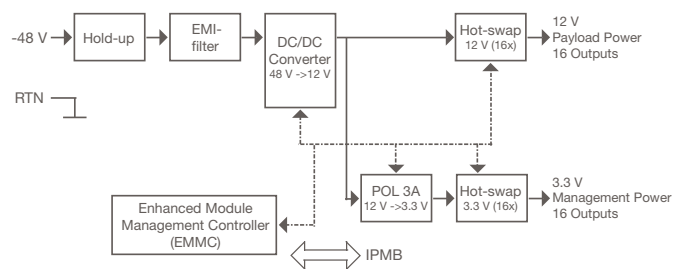


Figure 2

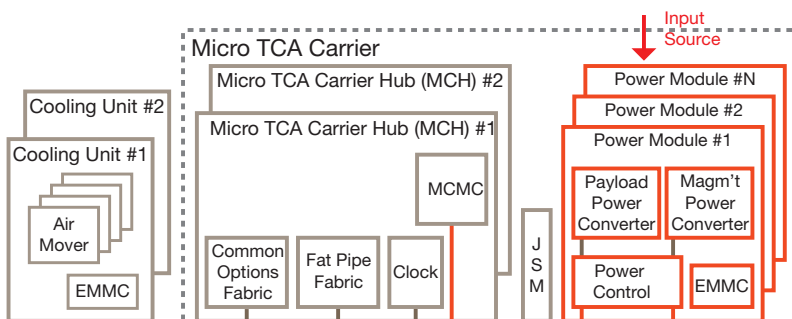


Figure 1

current rating of 20 A. Also assume that the system designer wishes to be able to attempt a restart of the converter after a delay of 0.4 second from when it was turned off.

A widely used rule-of-thumb for the maximum amount of capacitance across the output of a power converter is 100 μF per ampere of output current.

Assuming that this maximum recommended amount was used, the total capacitance on the output of this converter would then be 2000 μF . Assume that the system designer wants to assure that the capacitor bank discharges to a value of 0.15 volts prior to a restart. Using the above formula, the required bleeder resistor value can be calculated as:

$$R = \frac{0.4}{2000 \times 10^{-6} \times \ln(3.3 / 0.15)} = 64.7 \text{ ohms}$$

This amount of resistance will result in a power loss of only a fraction of a watt during normal operation and can be implemented quite easily. By using similar calculations, it can be shown that even smaller delays before the restart can also be easily accommodated by appropriate sizing of the resistor. Note that in actual applications the load circuitry will also help in discharging the decoupling capacitance during the initial part of the discharge curve, so that the above analysis errs on the side of conservatism.

The second cause of pre-biasing, feedback of other voltage sources through the load circuitry, is more difficult to analyze since both the voltage and currents presented to the powered down DC/DC converter or POL regulator will be highly dependent upon the characteristics of the load circuitry. In practical terms, the best way to characterize and understand the potential for a problem is to do actual measurement during the system prototyping. Replacing the DC/DC converter or POL regulator with a resistor to ground will allow for measurement of the voltage and current levels that are being fed back into the power module. The results of these tests can then be used to determine if there is a potential problem, and if so, help with the solution. In general, the same resistive bleed technique used with the first scenario will often work. However in this case, depending upon the current sourcing capability of the load circuits, smaller

value resistors may be needed. In other cases, modest amounts of bleed current will suffice. Each situation will need to be analyzed individually.

It should be understood that the situation discussed here is a general one and applies to power conversion products on an industry-wide basis rather than just to Flex's DC/DC power modules. Nevertheless, it will be helpful to look at each of the Flex offerings in terms of their susceptibility to possible reverse current concerns during startup into a pre-biased output.

Considerations by Product Family

In terms of starting up into a pre-biased load, Flex's DC/DC power modules fall into three categories. Some products use diode rectifiers rather than synchronous rectification implemented with MOSFETs. The outputs of these products will not conduct current in the reverse direction from the load into the power module, so pre-biased conditions are not a consideration.

The second group consists of DC/DC power modules with synchronous MOSFET rectifiers which have been designed to tolerate pre-biased conditions. This is typically done by means of specialized control circuitry that uses the MOSFET intrinsic diode rather than gate-driven operation during the startup period. The user should be aware of some additional considerations for this group of products. First, the input voltage must always be greater than the output voltage throughout the power-up and power-down sequence. This is normally the case and usually will require no specialized design. Some of the product series in this group are POL (point of load) regulators that contain the Auto-Track™ function. This allows the output voltage of two or more POL regulators to track each other, either in a master-slave arrangement or by control from an external source. The immunity from problems with a pre-biased output will not apply if the Auto-Track™ function is being used. This can be solved in one of two ways. The Auto-Track™ can be disabled during the startup period. Alternatively, the inhibit pin can be used to delay the activation of the POL regulator's output for a minimum of 50 ms. The Auto-Track™ operation can then resume.

The third group consists of products that utilize synchronous MOSFET rectification without specialized startup circuitry. With these DC/DC power modules, the techniques described in the previous section should be applied so that the pre-bias on the output is below 0.2 volt prior to attempting a restart of the converter or regulator. This group consists primarily of older product series.

The table below lists the Flex DC/DC power modules that fall into each of the three groups.

Operational with Pre-Bias

Diodes

Converters

PKJ4216
PKJ4316A
PKJ4316
PKR2000A
PKR4000
PKR4000A
PKR5000
PKV3000
PKV5000
PKY2000
PKY4000
PKM4000B
PKU4000*

MOSFETs

Regulators POLA family

PME
PMF
PMG
PMH
PMJ
PMK
PML
PMM

Conclusion

It has been shown how a pre-biased condition on the output can sometimes result in excessive stress to MOSFET synchronous rectifiers for some DC/DC power modules. This situation is industry-wide and not limited to Flex. In fact, as the preceding table indicates, most Flex DC/DC power modules will perform very well in a pre-biased application. It has also been shown that, for products sensitive to pre-biasing, it is possible in many cases to mitigate the effects of pre-bias conditions by using appropriate bleeder resistors across the output capacitor networks. Additional useful information may be found on the Flex website in the specific technical specifications, datasheets and application notes for the individual product series.

Precautions needed with Pre-Bias

MOSFETs

Converters

PKB4000
PKL4000
PKL4000A
PKJ4000B
PKJ4000
PKJ4000E
PKM2000E
PKM4000
PKM4000C
PKM4000D
PKM4000E
PKM4000N
PKR4000B

Regulators

PMB
PMC

* Pre-Bias up to 50-60% of output voltage

Formed in the late seventies, Flex Power Modules is a division of Flex that primarily designs and manufactures isolated DC/DC converters and non-isolated voltage regulators such as point-of-load units ranging in output power from 1 W to 700 W. The products are aimed at (but not limited to) the new generation of ICT (information and communication technology) equipment where systems' architects are designing boards for optimized control and reduced power consumption.

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