High Voltage Non-Isolated Converters

Summary

This application covers the available features and design considerations of SynQor's high-voltage, non-isolated DC-DC converter product families. Examples included in this application note explain how to select the correct part number for a given requirement and how the unique features in these products can be used to simplify the overall system solution.

Introduction

This application note is intended to help designers understand some of the key design features that make the high-voltage, non-isolated converter (HV NiQor®) product families unique. The HV NiQor family is a wide input voltage range, non-isolated, buck-boost regulator module with adjustable output voltage and current limit. The modules employ synchronous rectification to achieve high conversion efficiency. The modules can be configured to deliver a positive voltage or a negative output voltage. The units self-protect from overcurrent, short circuit, output overvoltage, and excessive temperature fault events. Their packaging allows for easy use with different thermal cooling solutions. The product can be mounted to a heat sink, cold plate, or chassis to easily manage heat dissipation in different thermal environments. This family of converters is ideal for low-weight, compact applications due to the product's superior efficiency and small form factor.

These products offer great flexibility in traditional distributed power architecture systems (DPA). In DPA systems, an isolated, unregulated power converter such as SynQor's Bus Converters products is combined with a non-isolated, regulated converter (HV NiQor) to implement an efficient, compact, isolated multi-output system solution. Due to its unique features, the HV NiQor family of converters can be used to meet very different requirements for systems implemented using the distributed power architecture. This includes systems with near-infinite load capacitance requirements and/or battery charging solutions.

This application note discusses how to select the correct HV NiQor product for a given specification and how different design criteria influence the amount of power the unit can deliver. For example, the output power on NiQor modules is a function of the module type, the input voltage, the output voltage, the set current limit, and the operational conditions. Understanding how these parameters affect the available power is critical when selecting which module is appropriate for a given requirement. It also discusses how to program the adjustable output voltage and current limit functions and how an analog voltage can be used to dynamically adjust the output voltage and current limit set points.

Lastly, this document will discuss the load-sharing and frequency synchronization features. Not all SynQor HV NiQor products offer these features. Please consult the product datasheet for the specific product capabilities.

SynQor offers two versions of its non-isolated HV NiQor converters for two different markets, the military and industrial markets. Each version is uniquely designed to meet the requirements of the specific market. The targeted applications determine component selection and packaging solutions. SynQor products targeted for the Military market are designed, built, and tested to meet higher reliability requirements and have an increased temperature range. Units with a part identifier that begins with "MCOTS-N" are designed for military applications. Units whose part identifier begins with "NQ" are geared towards industrial applications. Both the MCOTS-N and NQ versions of the product will be referred to as HV (high voltage) NiQors (non-isolated SynQor bricks) throughout this application note.

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Terminology

Boost mode – Converter operating mode when the input voltage is lower than the output voltage.

Buck mode – Converter operating mode when the input voltage is higher than the output voltage.

Buck-Boost mode – Converter operating mode when the input voltage equals the output voltage.

Brick – Form factor name referring to the physical converter (physical appearance). Electronic subassembly packaged into an enclosure composed of a Liquid Crystal Polymer case and an aluminum baseplate. The space between the electronic components, the case, and the baseplate is filled with a non-conducting thermally enhanced compound.

Constant Current Operation Mode – Operation mode given when the unit behaves as a current source. The output voltage changes as the current remains constant.

Current Limit – Current threshold at which the module switches from voltage control operation mode to a constant current operation mode.

Constant Voltage Operation Mode – Operation mode given when the unit behaves as a voltage source. The output voltage remains constant as the current varies.

Efficiency – Ratio of output to input power.

EMC – Electromagnetic Compatibility.

EMI – Electromagnetic Interference, undesirable electromagnetic emissions.

Heat Dissipation – In the context of this application note, the total heat flux that flows through the baseplate.

I-Share – Feature that allows two or more units to be connected in parallel to load share.

Load share – Parameter that quantifies and describes how multiple units in a parallel arrangement contribute to power a single load. Good load sharing means each paralleled unit contributes the same amount of power to the load.

MCOTS – Acronym used to refer to military-encased converters. The acronym means Military Commercial Off the Shelf component.

NiQor – SynQor High-efficiency non-isolated DC-DC converter.

NQ – Acronym used to refer to a non-isolated industrial DC-DC converter.

Ripple – AC component, the residual periodic variation of the DC signal.

SENSE Lines – Feature that allows the DC-DC converter's control loop to compensate for any voltage drop between the converter output pins and the point where the SENSE lines are connected.

Section 1 – Description of High Voltage NiQor Family of Converters

SynQor's high-voltage, non-isolated switching converters (HV NiQors) are uniquely designed to boost or buck the input voltage to a desired output voltage. Where most non-isolated converters only step the input voltage one way (up or down), the SynQor HV NiQor can provide a controllable output voltage above or below the input voltage. For applications requiring a specific current limit, MCOTS-N and some NQ units include a dedicated pin to control the output current limit set point. A second pin is available to monitor the output current; this is done without the need for additional current sensors in the customer board. These features and a wide input voltage range make the NiQor product family ideal for many different complex and unique applications. HV NiQor's can power loads with nearly infinite capacitance, such as battery charging solutions. In addition, the half-brick versions of the HV NiQor products include built-in current-sharing capabilities. The half-brick HV NiQor products can be easily configured in parallel for high-power applications.

Section 2 – Feature Summary

Fixed Current Limit Feature

HV NiQor converters are equipped with a fixed output current limit (set at the factory) that limits the output current to ~ 120% of the product current rating. Once the current drawn by the load surpasses the current limit, the unit transitions to a constant current operation mode. In this operation mode, the unit behaves as a constant current source. The output voltage is automatically adjusted, allowing the unit to maintain a constant output current. The units can operate in this mode indefinitely, assuming sufficient cooling. Once the current drawn by the load drops below the current limit value, the output transitions automatically back to behaving as a constant voltage source. This transition happens in a well-controlled manner. This feature makes these modules ideal for applications having large capacitive loads.

Adjustable Current Limit and Current Monitor

MCOTS, NQXXWXX[EP,QT,HG], and "C" version units, Table 1, include adjustable current limit and current monitor features. The voltage across the IMON and the VOUT- terminals is proportional to the unit's output current. For the quarter-brick and eight-brick size products, the current monitor and current limit adjust functions are offered at the expense of output voltage sense lines.

The adjustable current limit function allows the current limit set point to be changed to a value below the fixed current limit set point. As with the fixed current limit function, the output behaves as a constant current source once the settable current limit is surpassed. The output returns to a constant voltage operation mode once the output current drops below the set current limit. This is one of several features that make these modules ideal for battery-charging applications.

Figure 1. Clockwise from upper left: NQ20 eighth brick, NQ60 half brick, NQ40 quarter brick.

Back-Drive Switch
HV NiQor products have an output voltage disconnect switch that prevents the modules from processing power in the reverse direction. Furthermore, HV NiQors have been designed to minimize the output leakage current once the output is disconnected from the power line. This is a necessary feature for battery charging applications.

Built-in Current Share
MCOTS and NQ Half-Brick products include built-in current share capabilities. The I-Share pin in the half-brick version of the units can be used to implement load-sharing between different modules and/or to monitor the output current. Load share is implemented by tying together the I-Share pins of multiple HB modules while connecting the output rails in parallel. Load-sharing units exhibit similar power dissipation, which translates to similar baseplate temperatures. The I-Share pin's voltage is proportional to the module output current and can, therefore, be used to monitor the output current.

Table 1: *HV NiQor converters vs. Vin and Features*

Modules	Vin Range	Vout Range	Max Output Current	Freq Sync	Current limit adjust
NQ20 (EG, ET, QG)	9-20 V	0-20 V	up to 40 A	No	"C" version only
NQ40 (EG, ET, QG)	9-40 V	0-40 V	up to 30 A	No	"C" version only
NQ60 (EG, ET, QG)	9-60 V	0-60 V	up to 20 A	No	"C" version only
NQ40 (EP, QT)	9-40 V	0-40 V	up to 35 A	No	"C" version only
NQ60 (EP, QT)	9-60 V	0-60 V	up to 25 A	No	"C" version only
NQ90 (EP, QT)	9-90 V	0-90 V	up to 18 A	No	"C" version only
NQ40 (HG)	9-40 V	0-40 V	up to 55 A	Yes	Yes
NQ60 (HG)	9-60 V	0-60 V	up to 40 A	Yes	Yes
NQ90 (HG)	9-90 V	0-90 V	up to 26 A	Yes	Yes
MCOTS 28V (EP, QT)	9-60 V	0-60 V	up to 25 A	No	Yes
MCOTS 28VE (EP, QT)	9-90 V	0-90 V	up to 18 A	No	Yes
MCOTS 28V (HG)	9-60 V	0-60 V	up to 40 A	Yes	Yes
MCOTS 28VE (HG)	9-90 V	0-90 V	up to 26 A	Yes	Yes

Note: *EX: Eighth brick, QX: Quarter brick, HX: Half brick*

Section 3 – Application of HV NiQor and Design Considerations

Output Voltage Configuration

The output voltage can be programmed to any voltage between 0V and the module's specified Vmax by connecting a resistor between the Vset pin and Vsense- (Figure 2). The Vset resistor (RVset) is placed between the Vset and Vout- pin in units where the Vsense- pin is not present. The equations shown in Table 2 determine the RVset trim resistor value needed as a function of the desired output voltage (Vset) and product maximum output voltage rating (Vmax) for the different HV NiQor products.

Table 2. RVset and Vvset expressions.

Module Type	Vmax	RVset (Ohms)	Vvset (Volts)
MCOTS-N-28V-60-[EP,QT,HG]	60	$\left[\left(\frac{11830 * Vmax}{Vset + 0.058 * Vmax}\right) - 10912\right]\Omega$	$2.366 - 2.316 * \left(\frac{Vset}{Vmax}\right)$ V
MCOTS-N-28VE-90-[EP,QT,HG]	90		
NQ40[T,W]40[EP,QT,HG]	40		
NQ60[T,W][60]	60		
NQ90[T,W]90[EP,QT,HG]	90		
NQ40[T,W]40[EG,ET,QG]	40	$\left[\left(\frac{11900 * Vmax}{Vset + 0.0543 * Vmax}\right) - 10912\right]\Omega$	$2.366 - 2.284 * \left(\frac{Vset}{Vmax}\right) V$
NQ20[T,W][20]	20	$\left[\left(\frac{12465 * Vmax}{Vset + 0.0569 * Vmax}\right) - 10912\right]\Omega$	$2.366 - 2.180 * \left(\frac{Vset}{Vmax}\right) V$
MCOTS-N-12-Q3P1N-QT (Positive)	N/A	$\left[\left(\frac{1200}{V_{pos} - 0.8}\right) - 100\right]\Omega$	$\left[0.8 + \left(\frac{1200}{R_{trim\_pos}(\Omega) + 100}\right)\right]V$
MCOTS-N-12-Q3P1N-QT (Negative)	N/A	$\left[-\left(\frac{100 * Vneg + 122.5}{V_{neg} + 13.475}\right) * 1000\right]\Omega$	$\left[-\left(\frac{13.475Rtim\_neg(k\Omega) + 122.5}{R_{trim\_neg}(\Omega) + 100}\right)\right]V$

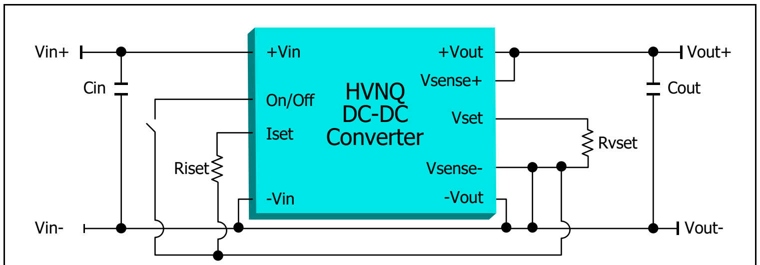

Figure 2. HV NiQor typical connection diagram when delivering a positive output voltage.

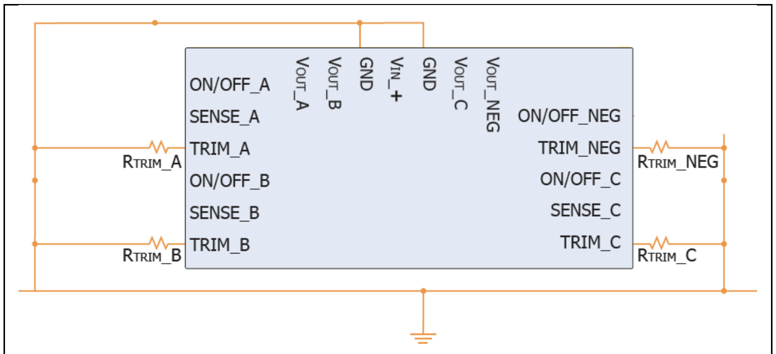

Figure 3. MCOTS-N-12-Q3P1N-QT typical connection diagram for positive output voltage.

Current Limit Configuration
The maximum output current limit set point can be adjusted to any value between 0 and module specified Imax by connecting a resistor between the Iset pin and Vsense- (Figure 2). If the Vsense- pin is not present, the Iset resistor is placed between the Iset pin and the Vout- pin. The value of the Iset trim resistor (RIset) for a desired current limit set point (Iset) is determined by the expression shown in Table 3, where Imax is the current rating of the selected NiQor. Alternately, the current limit set point can also be adjusted by forcing the Iset pin to the voltage given by the expression shown in the last column of Table 3.

Table 3. RIset and VIset expressions.

Module Type	Imax (A)	RIset (Ohms)	VIset (Volts)
MCOTS-N-28V-60-[EP,QT,HG]	15, 25, 40	$\left[\left(\frac{0.0469 * Imax + Iset}{1.153 * Imax - Iset}\right) * 10200 - 10\right]\Omega$	$\left(0.0953 + 2.085 * \left(\frac{Iset}{Imax}\right)\right) V$
MCOTS-N-28VE-90-[EP,QT,HG]	10, 18, 26		
NQ40[T,W]40[EP,QT,HG]	20, 35, 55		
NQ60[T,W]60[EP,QT,HG]	15, 25, 40		
NQ90[T,W]90[EP,QT,HG]	10, 18, 26		
NQ20[T,W]20[EG,ET,QG]	5, 10, 20		
NQ40[T,W]40[EG,ET,QG]	7.5, 15, 30		
NQ60[T,W]60[EG,ET,QG]	5, 10, 20		

If the Iset pin is left open (not connected), the Iset pin floats to ~ 2.5V, and the current limit set point corresponds to the factory set current limit (~ 120% Imax).

The HV NiQor Iset pin can be used to set the maximum output current the module will deliver as long as the selected current limit is lower than the module-rated output current. The current limit set point can be adjusted dynamically while the module is in operation as long as the adjustment rate is below 1V/100 ms. When the output demands current beyond the set limit, the output will behave as a current source, and the output voltage is no longer regulated (Vo droops – see discussion below). All HV NiQor products can control the output voltage level almost to zero when in constant current mode, resulting in excellent current control for the complete output voltage range. This feature can be used to charge near-infinite capacitors (large capacitor banks) in a graceful manner or, alternatively, for battery charging applications.

Note: If the unit is operating in boost mode, the unit might engage current limit before the set current limit is reached (See Section 5).

Controlling Voltage and Current

Output voltage and current set point levels can be controlled via the Vset and Iset pins. These can be controlled/adjusted in various manners:

Setting voltage and Current Limit with Resistors

The converter output voltage set point and the maximum output current limit set point can be determined by placing a resistor between the Vset and Vsense- pins and the Iset and Vsense- pins, respectively (Vout- pin for modules with no Vsense- pin). The formulas to determine the value of the needed resistors can be found in Tables 2 and 3 for each module. When using multiple converters, each converter's output voltage and current must be individually set by placing the necessary resistor between its Vset and/or Iset pins and Vsense-/Vout- pin. When the output current is below the set current limit, the output voltage is controlled by the Vset resistor. When the output current exceeds the set Ilimit, the output voltage automatically droops as the unit regulates the output current to the set Ilimit value.

Setting voltage and Current Limit with a Voltage

Alternatively, the output voltage set point and the maximum output current limit set point can be programmed by controlling the voltage between the Vset pin and Vsense- pin and Iset pin and Vsense- pin (Vout- pin when Vsense- pin is not available). See Tables 1 and 2 to obtain the formula to determine the voltage level to set the desired output voltage and/or maximum output current for each module. The voltage source should be directly terminated (referenced) to the Vsense-/Vout- pin. Failure to do this can result in the wrong programmed output voltage and current limit set points.

Variable Inputs (Digital pot or DAC)

A digital pot can be used in place of a resistor in order to add the ability to dynamically change the Vset and/or Iset pin voltage with respect to Vsense- /Vout- Similarly, a digital-to-analog converter (DAC) can also be used to provide a variable controlling voltage at the Vset and/or Iset pin with respect to Vsense- /Vout-.

Only slow adjustments of the output voltage level and/or the maximum output current are possible. These signals' maximum change rate must be limited to 1 V / 100 ms. Adjusting the output voltage and maximum output current set point at a faster rate will not damage the converter but can result in unpredictable behavior.

Digital control

All SynQor HV NiQor products were designed using digital control. Great effort was taken to minimize limit cycling. Unfortunately, the limit cycle cannot be eliminated when using digital control. The limit cycle manifests as steps in the output voltage and/or current as the converter tries to regulate the output voltage or current. The step sizes depend on several factors, including input and output voltage, the selected microcontroller, and component tolerances. These factors are all included in the Total Output Voltage Range specification provided in the data sheet.

Any additional tolerance of the Vset or Iset control signal (system implementation) will add further variance to the total set point tolerance.

Current Monitoring Feature

The IMON and I-Share pin voltage available in specific products can be used to monitor the value of the output current. A simple, inexpensive microcontroller can use the information from the IMON and I-Share pin to control the module's output current (output current set point). As stated before, the rate at which the current can be adjusted should remain below 1 V / 100 ms.

SENSE Line Connection, Bypass Capacitor

SENSE lines allow the module to compensate for voltage drops across the interconnecting power traces between the module output pins and the load. Adding a 1 uF ceramic cap between the Vsense+ to Vsense- pins can reduce noise pick-up. When possible, run SENSE lines as a differential pair, only splitting near their final load connection points. Also, be aware that large differences between the Vsense pins of a converter and the corresponding Vout pins can result in an over-voltage shutdown or even damage to the converter. The voltage measurement that triggers the over-voltage protection feature is measured across the output pins and is independent of the voltage measured at the sense pins.

If an inductor in series with the Vout pin is needed for filtering purposes, the Vsense+ line should be connected directly to Vout+ (before the inductor). Connecting the SENSE lines across the inductor (between the load and the inductor) can affect the module's stability (system stability).

Reverse Current Blocking

All SynQor HV NiQor products include an OR'ing diode feature on the forward output path. The feature prevents current flow in the reverse direction. This feature is a must for battery charger applications. It effectively disconnects the output from the battery when not in charging mode; very low output voltage leakage current. However, it can prevent the unit from bringing back the output into regulation in case of an output surge (output voltage remains above the desired value). The surge could be a result of a load transient or motor drive back EMF. A bleeding circuit (typically a resistor) on the output is recommended to help mitigate this behavior and help return the output voltage to regulation.

Section 4 – Input Stability

At low frequencies, all regulated converters appear as a negative incremental resistance, which can negatively interact with the source impedance (including any filter elements that have been added between the input terminals and the source). This can lead to unstable operations under certain conditions (system instability). In these cases, the converter could operate erratically (oscillate) and may even damage itself and/or the load. A systems engineer must ensure this "system instability" does not occur under any condition. Avoiding system instability is a straightforward process. Add some positive resistance in the external input filter components to negate the effect of the incremental negative resistance of the regulated DC-DC converter. The question is, "How much positive resistance is required?" For a more detailed explanation, please refer to SynQor's "Input System Stability" application note.

The most practical solution to solve the incremental negative resistance system stability problem is to add a capacitive damping network in parallel with the input of the regulated converter (capacitor in series with a resistor network across the input power pins). Due to its properties, an electrolytic capacitor is typically selected/used to provide the proper damping necessary to ensure system stability. It is important to remember that the properties of a typical electrolytic capacitor can change significantly at cold temperatures. If an electrolytic capacitor is used to provide damping, verify that the system has proper damping and is stable over the entire line, load, and temperature range.

SynQor has developed a simple Excel-based "Input Stability Calculator" that incorporates the concepts discussed in the SynQor Input System Stability application note to help select the proper damping circuit. The tool calculates the proper damping network needed based on the system filtering components and the selected regulated converter. The answer provided is relatively conservative to ensure proper system stability. Contact SynQor FAE with questions regarding the required parameters. Selecting what value to use for the different parameters is not always straightforward; for example, the converter's effective input capacitance is a function of the input and output voltages. Always verify (experimentally) system stability over the entire intended operating range (load, voltage, and temperature).

Section 5 – Selecting the Appropriate Module

Checking for Maximum Current Limit

It is important to note that the maximum current specification of the SynQor HV NiQor products applies to both the input and the output currents. This can be somewhat confusing. This means a 20A-rated module's maximum input and output current should remain at or below 20A while in continuous operating mode. The current limit feature will take action and limit the current in the event either current (input or output current) surpasses this limit. When selecting the appropriate module for your application from the different HV NiQor products available, it is important to consider both the input and output current requirements.

Modules like the HV NiQor can operate seamlessly in buck, boost, or buck-boost modes. In buck mode, the input voltage is greater than the output voltage. The principle of power conservation dictates that the input current must be lower than the output current when operating in buck mode. When selecting the appropriate module for an application that only requires the HV NiQor to operate in buck mode, it is sufficient to only consider the output current requirement to ensure proper selection.

On the other hand, units operating in boost mode exhibit an input voltage lower than the output voltage. In this case, the input current is greater than the output current. When selecting a converter, look at the input current at the lowest input voltage; this will dictate the minimum current rating of the required HV NiQor product. Do not forget to consider the effect of the product efficiency when using the input current to determine which HV NiQor product to select.

In buck-boost mode, the input voltage is comparable to the output voltage. Because of the efficiency losses, the input current would be slightly higher than the output current. The limiting factor in this setup is the input current once again. The input current will determine the minimum current rating for the required HV NiQor product.

- The input current is a function of output power, the input voltage, and the module's efficiency. The maximum input current can be easily calculated by dividing the output power by the product of the minimum input voltage and the module's efficiency. If the calculated maximum input current is greater than the current rating of the selected converter, then the converter is undersized for the application. Select an HV NiQor product with a higher current rating or consider placing multiple HV NiQors in parallel (half-bricks only). The following examples will better explain how to select the correct HV NiQor product for your application. The MCOTS-N-28V-60-HG module is used as a reference in the following examples. The maximum rated current for the MCOTS-N-28V-60-HG product is 40 A (from the datasheet)

Example #1

Requirements:

- Vin = 12V
- Vout = 24V at 35A

This is a boost application (Vin < Vout). Hence, the deciding factor when selecting the appropriate HV NiQor product is the input current. The required output power for this application is 24V X 35A or 840W. With this information, if we neglect the efficiency, we can approximate the input current required at 12V by dividing 840W by 12V, which results in a maximum input current of ~ 70A. The estimated 70A is much greater than the 40A rating of the selected module. Therefore, a single MCOTS-N-28V-60-HG is not suitable for this application. However, two of these modules can be placed in parallel, which, at first glance, should be sufficient to meet the requirement.

Two of these modules running in parallel would be able to deliver approximately 80A. Because the maximum input current value of two modules running in parallel is close to our estimate of 70A, it is necessary to include the efficiency in the input current calculation. Assume the input/output is evenly split between the two converters. The efficiency of the modules when delivering half the output current, 17.5A, can be determined from the module's efficiency charts shown in Figure 4 (Figure 1 of the product datasheet). According to the chart, the efficiency of the modules under these operating conditions is approximately 94%. The total input current, when accounting for the efficiency, can be estimated by simply dividing the previously calculated input current by the efficiency number → 70A/0.94 or 74.5A. The maximum input current two of these modules can provide is ~ 80A (2 x 40A). Therefore, two MCOTS-N-28V-60-HG satisfy the requirements for this application.

An alternative way to quickly determine if the selected module is able to deliver the desired amount of current is to use the datasheet efficiency plot. The efficiency curve for Vin = 12V is limited to 20A, as shown in Figure 4. This suggests that the HV NiQor cannot operate at output currents above 20A. To deliver 35A, at least two of these modules (35A/20A) are needed.

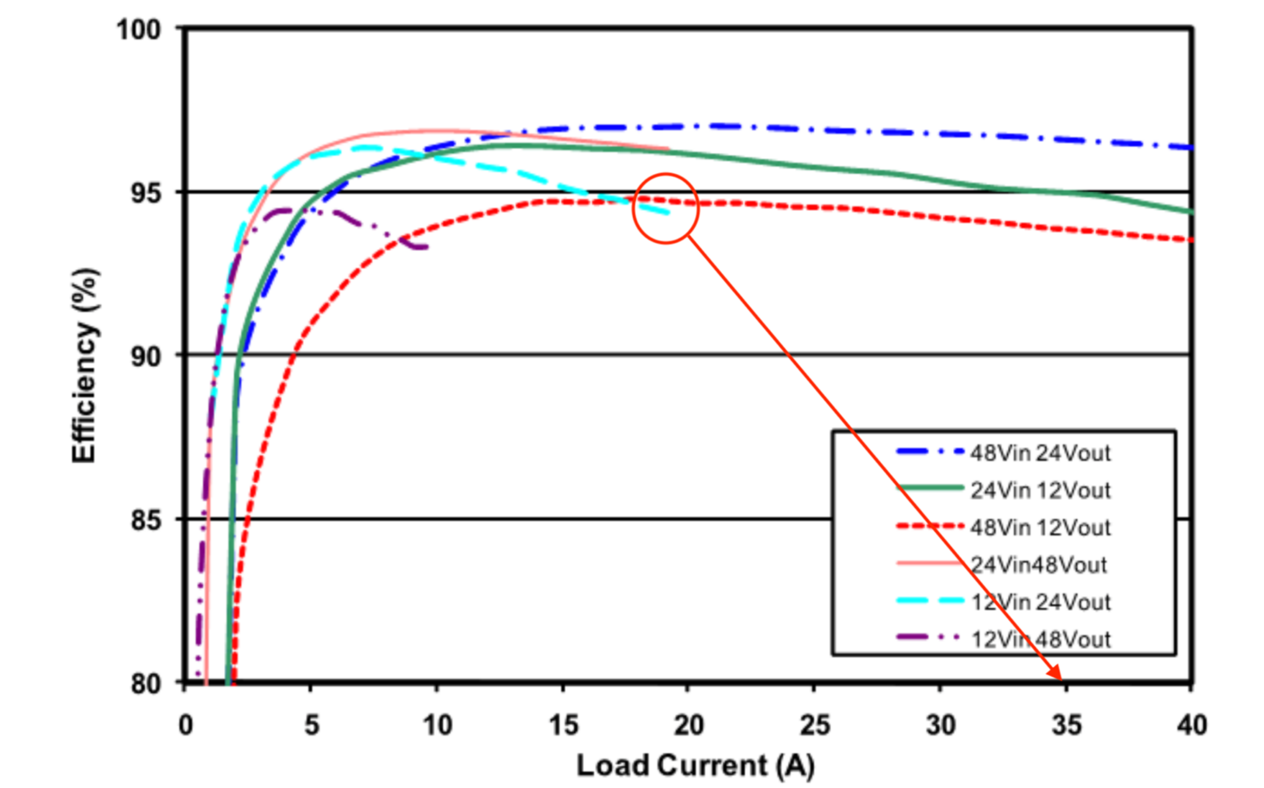

Figure 4. Efficiency at Vo vs load current for various Vin: Example #1 discussion.

Example #2

Requirements:

- Vin = 12V
- Vout = 48V at 5A

This is a boost application (Vin < Vo). Hence, the deciding parameter when selecting the appropriate HV NiQor is the input current. The product efficiency for this example is shown in Figure 5 (Figure 1 of the product data sheet). For an input voltage of 12V and an output current of 5A at 48V, the efficiency is ~ 94%. The maximum input current can be determined by dividing the output power (Po = 48V X 5A = 240W) by the product of the minimum input voltage and the efficiency (12V X 0.94), resulting in a current of ~ 21.3A. Since the selected HV NiQor has a current rating of 40A, the selected part number is appropriate for this requirement.

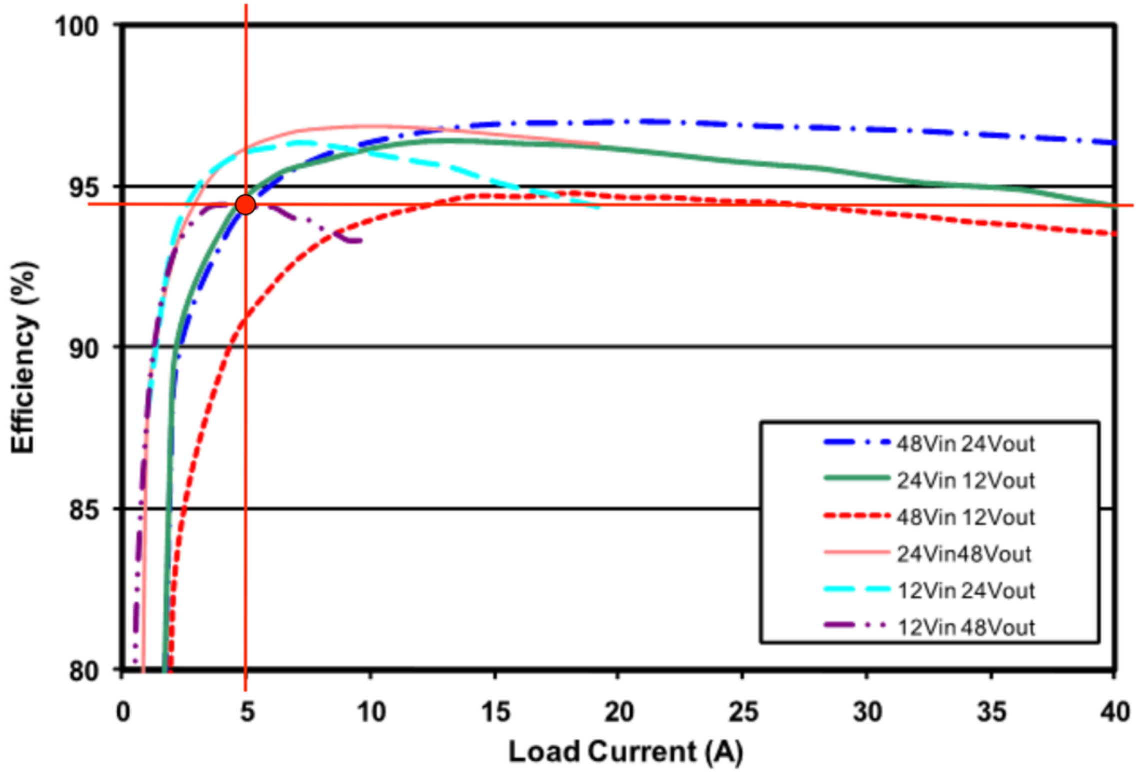

Figure 5. Efficiency at Vo vs. load current for various Vin: Example #2

Thermal Design

Another important power module design consideration when selecting the appropriate HV NiQor for your application is the thermal performance. All HV NiQor modules have a baseplate. Heat dissipated inside the device needs to be removed through the baseplate. A heat sink or cold plate can be easily attached to the baseplate to improve the heat removal capabilities of the device. All HV NiQor products are designed to have a maximum baseplate temperature of 100°C. Steps should be taken to limit the maximum baseplate temperature to no more than 100°C (proper thermal solution). Refer to the product datasheet of the selected HV NiQor for a more complete description of the device's thermal capabilities. All HV NiQor products have an over-temperature protection feature. The device will shut down if the baseplate reaches the over-temperature set point. Once the module cools down, it will automatically restart. The feature is designed to safeguard the unit against most over-temperature events. Still, it does not guarantee that an over-temperature event can not damage the unit. Do not operate the converter outside its recommended temperature range.

Continuing with Example #2, let’s look at the thermal derating to determine with certainty that this product is suitable for the given requirements (the thermal derating curve for MCOTS-N-28V-60-HG is shown in Figure 6 of this application note). From the plots, it can be determined that for an input voltage of 12V and an output voltage of 48V, the converter can deliver ~ 10A as long as the baseplate is maintained at or below 100°C. Since this application only requires 5A of load current, the selected converter is a good fit for this application, assuming a proper thermal solution.

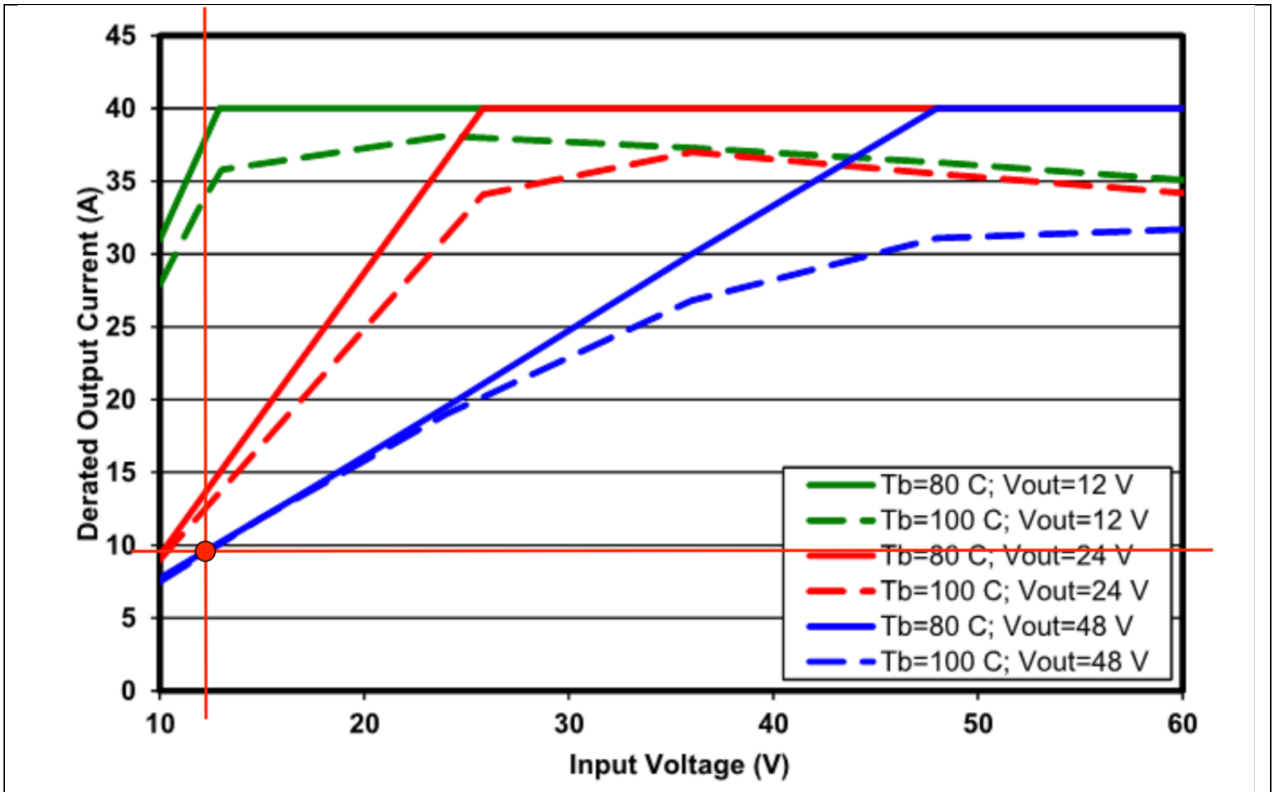

Figure 6. Maximum derated output current vs. input voltage and temperature

Determining Power Dissipation

Any proper thermal design requires knowledge of the power dissipation of the selected HV NiQor. The power dissipation can be inferred from the power dissipation graphs provided in the product datasheet. A couple of examples will be discussed to show how the power dissipation of an HV NiQor product can be estimated using the information provided in its datasheet.

Continuing with Example #2 (Vin = 12V and Vo = 48V with a maximum baseplate temperature of 100°C), Figure 6 of this application note shows the thermal derating curve for the MCOTS-N-28V-60-HG device. From the graph, we can determine that with the given requirements, the converter can process at most 10 A as long as the baseplate temperature is limited to 100°C.

The module power dissipation can now be determined from Figure 7 (copy of power dissipation curve from product datasheet). The curves show that power dissipation can be estimated at 14.5W at the specified conditions.

For this discussion, assume the system solution can provide at least 300 LFM of air at a maximum ambient temperature of 55°C. The thermal impedance of the heatsink required to remove 14.5W under these conditions can be easily calculated as follows:

$$Rth_{Baseplate-Ambient} = \frac{T_{Baseplate} - T_{Ambient}}{Power\ Dissipation}$$

$$Rth_{Baseplate-Ambient} = \frac{100°C - 55°C}{14.5W} = 3.1\,\frac{°C}{W}$$

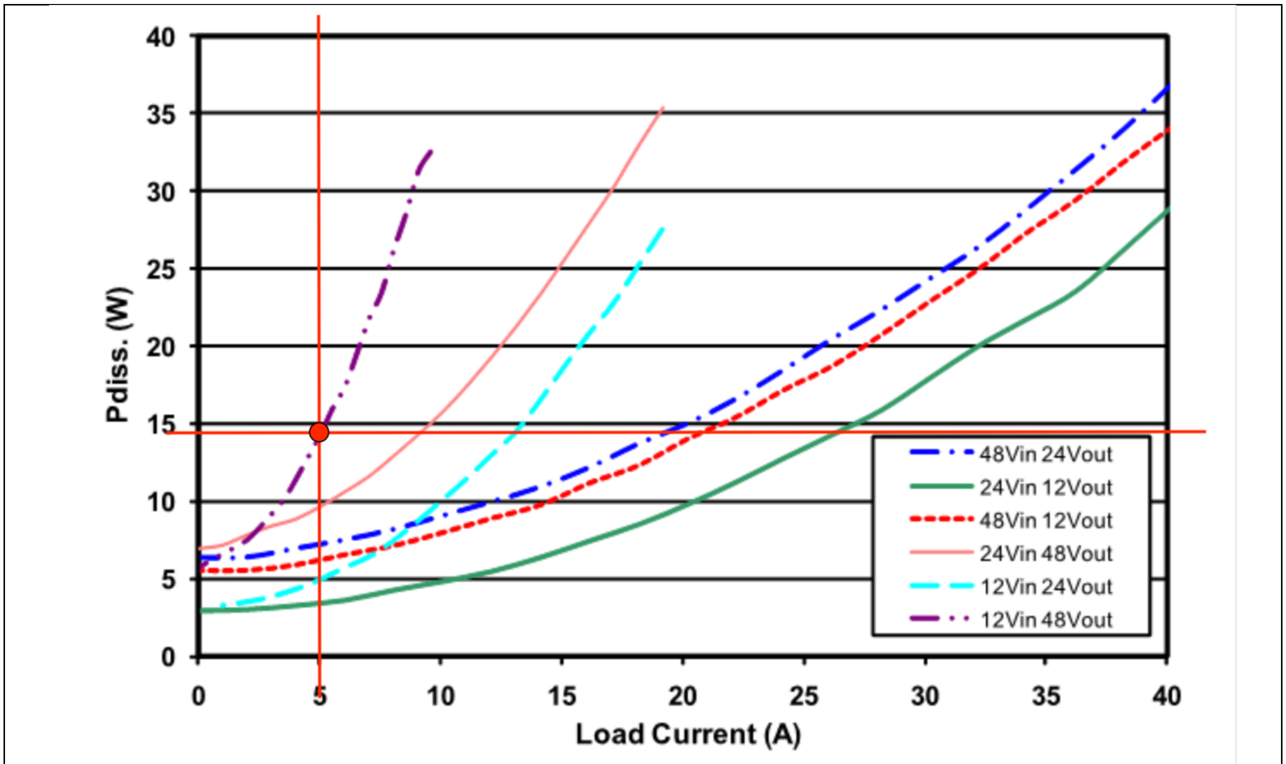

Figure 7. Power dissipation vs. load at 25°C

The selected heatsink needs to have a thermal impedance specification of 3.1°C/W or lower. The ATS-1144-C1-R0 heatsink from Advanced Thermal Solutions has a thermal impedance of 2.2°C / W at 300LFM. This heatsink looks like a suitable selection to meet the requirements listed in Example #2.

Section 6 – Parallel Operation

Paralleling HV NiQor Converters with the I-Share Feature for Increased Output Power Solutions

HV NiQor converters with an I-Share pin have an active current/load share option that can be used to force load sharing between modules connected in parallel. HV NiQors can be connected in parallel without the need for additional circuitry. Connect the I-Share pins together to force load sharing. These HV NiQor products have a typical load-sharing accuracy of +/-10% under heavy loads. The load share accuracy can decrease at lighter loads. The load share accuracy also decreases as the number of modules in parallel increases. SynQor does not provide an absolute current sharing accuracy specification for its products since the overall load-sharing accuracy will also be affected by the final system solution. Please refer to SynQor's application note titled "Current Sharing and other Full-Feature Applications" for more details regarding active load sharing using a democratic load-sharing scheme.

OR MOSFET Feature

The HV NiQor products include an OR'ing-MOSFET on their output that disconnects/prevents negative current flow from the output bus. This feature results in a very low leakage output current, even when the input voltage is not present. It also prevents circulating currents between parallel modules. However, this feature does not allow for the implementation of true redundancy. A few components are not isolated from the output bus when the OR'ing-MOSFET disconnects, like the reverse output protection diode and output filter capacitors. Therefore, if true redundancy is required, an external OR'ing switch needs to be added to the output of each individual HV NiQor module.

Partial Current Load-Sharing without an I-Share Bus Connection

HV NiQor products can be connected in parallel without connecting the I-Share pins. With the I-Share pins not connected together, the modules will not load share under most conditions. However, at near full load, the current limit feature in each HV NiQor will allow units to share some of the load. A system load that requires more current than a single converter can deliver will force the module with the highest output voltage set point into current limit, causing its output voltage to droop. This action will force the module with the next highest output voltage set point in the system to start picking up a greater percentage of the load.

Suppose the system load exceeds what two converters can deliver. In that case, the second HV NiQor will also go into current limit, forcing a third module to start picking up the excess load current. This pattern will repeat while at least one unit operates in constant voltage mode. Partial load sharing can be achieved at heavy loads using this method. The programable current limit feature can be used to adjust the maximum output current limit set point to implement load sharing. Units with both the I-Share and programable current limit features can use either current sharing scheme. Alternatively, both schemes can be used in tandem. At low power levels, the I-Share feature will govern load sharing. At very heavy loads, the adjustable current limit feature can be used to improve load sharing. This feature can be used to improve the overall load-sharing accuracy at heavy loads in systems having a large number of converters in parallel.

Enabling Multiple Modules Together

In a system utilizing multiple modules, it is often desirable to start all modules simultaneously. This is especially desirable in systems where multiple modules are connected in parallel, and the load becomes active as soon as a partial output voltage is detected. Having the modules start synchronously allows the load current to be distributed between the different converters during the start-up sequence. This will prevent one or more modules from hitting current limit during the start-up event. For most applications, SynQor would recommend starting multiple converters connected in parallel in a synchronized manner. The on/off enable feature can be used to synchronize the turn-on and turn-off of events.

However, for a system consisting of multiple HV NiQors in parallel, a heavily loaded output voltage will eventually start even if all the units are not started in synchronously. The unit that starts first will quickly enter current limit, forcing its output voltage to drop (output voltage will not rise). This process will repeat until sufficient units are enabled to supply the total load current and allow the output voltage to rise and reach regulation.

Connection of the SENSE Lines when Paralleling

When using multiple converters in parallel, it is critical to connect Vsense- at a common point, but connecting Vsense+ at the output of the converter can actually improve sharing. If redundancy diodes are added, it is also critical that Vsense+ be connected upstream of Or’ing diodes, or some converters can go to zero output when at no load.

Switching Frequency Synchronization

Half brick NQ40, NQ60, NQ90, and all MCOTS HV NiQor modules have a frequency synchronization feature (SyncIn), which allows a TTL level clock to synchronize the frequency of the different modules.

Synchronizing the switching frequency of multiple converters connected in parallel can prevent beat frequencies from appearing in both the input and output buses. The beat frequency is defined as the difference in switching frequencies between any two given converters. Output/input ripple noise at this beat frequency can disrupt/confuse the control circuitry, resulting in increased jittering of the power converters. Beat frequencies are low enough that practical input and output filter implementations will not adequately attenuate these signals. Beat frequencies will typically result in increased output voltage/current ripple.

Synchronizing the switching frequency of the different power modules in any given system can also be useful when trying to avoid known sensitive frequencies.

For half brick NQ40, NQ60, NQ90, and all MCOTS HV NiQor modules, connect a TTL level clock signal to the SyncIn pin referenced to Vsense- to implement clock synchronization. The synchronization frequency range of the HV NiQor products is limited between 200kHz to 300 kHz. A frequency outside this range will be ignored by the converter and the converter will operate at the factory set frequency.