DC/DC Converter Application Notes

CONTENTS

PHI-CON

HY-LINE®
POWER COMPONENTS

Deutschland:
Inselkammerstraße 10
D-82008 Unterhaching
Tel.: 089 614 503-10
E-Mail: power@hy-line.de

Schweiz:
Gründenstrasse 82
CH-8247 Flurlingen
Tel.: 052 647 42 00
E-Mail: power@hy-line.ch

DC-DC Converter Application Notes

1. Terminology

The data sheet specification for DC/DC - converters contains a large quantity of information. This terminology is aimed at ensuring the user is explaining the data provided correctly and obtaining the necessary information for their circuit application.

Absolute Maximum Ratings
The absolute maximum ratings are the limits to which the devices can be stressed without causing permanent and irreparable damage. These limits are not the normal operating or functional limits of the devices and operating at the absolute maximum ratings will produce different parametric results to those quoted in the data sheet.

Input Voltage Range
The range of input voltage that the device can tolerate and maintain functional performance.

Load Regulation
The change in output voltage as the load is changed from no load / minimum to maximum, at constant line and constant temperature.

$$\text{Load regulation} = \frac{\text{Vout min load - Vout full load}}{\text{Vout full load}} \times 100\%$$

Line Voltage Regulation
The change in output voltage as the input voltage is varied over its specified limits, with load and temperature constant.

Vout max: Output voltage at maximum input voltage.
Vout min: Output voltage at minimum input voltage.
Vout nom: Output voltage at nominal input voltage.

$$\text{Line regulation}(+) = \frac{\text{Vout max -Vout nom}}{\text{Vout nom}} \times 100\%$$

$$\text{Line regulation}(-) = \frac{\text{Vout min -Vout nom}}{\text{Vout nom}} \times 100\%$$

Output Voltage Accuracy
Typically specified on DC/DC - converters, this is the tolerance of setting of the output voltage (it is some times specified as "Output Voltage Tolerance" or "set point accuracy"). Normally specified as a percentage under nominal input line and full load conditions. For multiple output supplies, it is specified for the main and auxiliary outputs.

Output Voltage Adjustment (Trim)
Some DC/DC - converters include adjustable outputs (typical ly the primary output only). This specification gives the range (usually ±10%) that may be changed by the user.

Input to Output Isolation
The dielectric breakdown strength test between input and output circuits. This is the isolation voltage the device is capable of withstanding for a specified time, usually 3 seconds.

Isolation Resistance
The resistance between input and output circuits. This is usually measured at 500V DC isolation voltage.

Efficiency at Full Load
The ratio of output load power consumption to input power consumption expressed as a percentage. Normally measured at full rated output power and nominal line conditions. It is derived by the equation:

$$\text{Efficiency} = \frac{\text{Vout x Iout}}{\text{Vin x I in}} \times 100\%$$

A low efficiency results in higher power levels being dissipated within DC/DC - converter as heat. In medium / high power or space critical applications, DC/DC - converter efficiency can be a major factor in the expected field reliability.

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Over Voltage Protection
(OVP) An output protection device that will clamp the output voltage to a preset level. Typically, OVP circuits are only added to the primary output of a supply.

Short Circuit Protection
Most DC/DC - converters include circuitry to limit the output current in the event of a fault condition. The set point is normal ly 110% to 150% of specified full load current. There are a number of ways to achieve output protection (foldback limiting, pow er limiting, "hiccup" control, etc.).

No Load Power Consumption
This is a measure of the switching circuits power consumption; it is determined with zero output load and is a limiting factor for the total efficiency of the device.

Input Current, Surge
Also called inrush current, this is the maximum input current DC/DC - converter can withstand without potential damage.

Reflected Ripple Current
The AC component, generated by the switching circuit, that is kicked back onto the input source by a DC/DC - converter. Given as a peak to peak or RMS value, it is measured over a bandwidth of 0 to 20 MHz.

Soft Start
A feature on some power supplies. Soft start is a circuit that limits the input inrush current at power on.

Maximum Output Current
The maximum current that may be continuously drawn from an output without potentially damaging a DC/DC - converter or triggering an output protection circuit. At times called "Rated Current". Some guard band (15% - 20%) should be allowed when selecting a DC/DC - converter so as not to exceed this limit.

Minimum Output Current
Most manufacturers will specify a required (minimum) level of output current to maintain proper operation of the DC/DC - converter. Typically specified at 10%, operating the DC/DC - converter below this limit will normally cause a degradation in load regulation.

Isolation Capacitance
The input to output coupling capacitance. This is not actually a capacitor, but the parasitical capacitive coupling between the transformer primary and secondary windings. Isolation capacitance is typically measured at 1 MHz to reduce the possibility of the onboard filter capacitors affecting the results.

Operating temperature range
Operating temperature range of the DC/DC - converter is limited due to specifications of the components used for the internal circuit of the converter.

The diagram for temperature derating shows the safe operating area (SOA) within which the device is allowed to operate. At very low temperatures, the specifications are only guaranteed for full load.

Up to a certain temperature 100% power can be drawn from the device, above this temperature the output power has to be less to ensure function and guarantee specifications over the whole lifetime of the converter.

These temperature values are valid for natural convection only. If the converter is used in a closed case or in a potted PCB board, higher temperatures will be present in the area around thermal converter because the convection may be blocked.

Temperature Coefficient
The change in voltage, expressed as a percentage of the nominal, per degree change in ambient temperature. This parameter Is related to several other temperature dependent parameters, mainly internal component drift.

Switching Frequency
The nominal frequency of operation of the switching circuit inside the DC/DC - converter. The ripple observed on the input and output pins is usually twice the switching frequency, due to full wave rectification and the push-pull configuration of the driver circuit.

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Ripple and Noise
Because of the high frequency content of the ripple, special measurement techniques must be employed so that correct measurements are obtained. A oscilloscope is used, so that all significant harmonics in a 20MHz bandwidth of the ripple spike are included. This noise pickup is eliminated as shown in Fig.1.1, by using a scope probe with an external connection ground or tube and pressing this directly against the output common terminal of the DC/DC - converter, while the tip contacts the voltage output terminal. This provides the shortest possible connection across the output terminals.

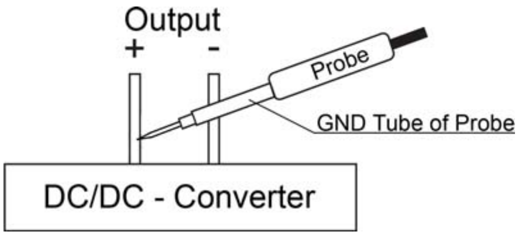

Fig.1.1: Output ripple and noise measurement with oscilloscope probe

Fig.1.2 shows a complex switching ripple voltage waveform that may be present on the output of a DC/DC - converter. There are three components in the waveform, first is a charging component that originates from the output rectifier and filter, then there is the discharging component due to the load discharging the output capacitor between cycles, and finally there are small high frequency switching spikes imposed on the low frequency ripple.

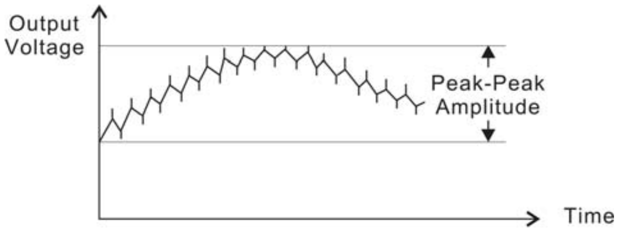

Fig.1.2: Amplitude

Transient Recovery Time
The time required for a DC/DC - converter to return to within a specified error band after a step change in load current as shown in Fig.1.3.

If the DC/DC - converter has multiple outputs, auxiliary outputs should be set to 100% load while transient recovery time is measured, normally specified only for the primary output.

Undershoot / Overshoot
The time required for a converter's output to return to within its specified regulation range following a step change in line or load.

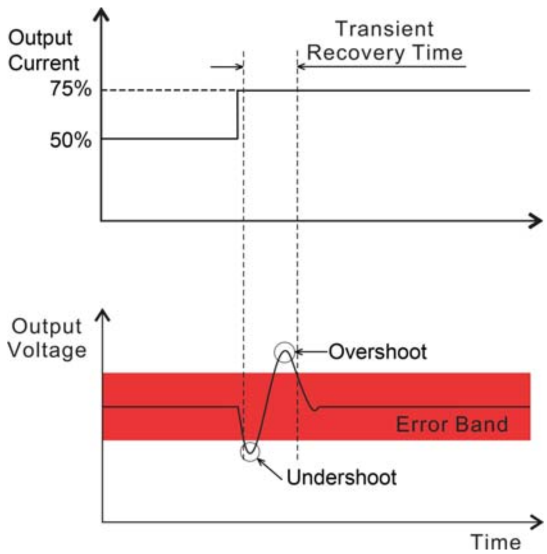

Fig.1.3: Transient Recovery Time

Soft Start
A soft start circuit limits the inrush current to the converter at turn on. Typically, it consists of a timing network that ramps up the PWM control signal to the switching transistors at start-up. This limits high start-up currents and their potential problems (output overshoot, transformer saturation, etc). The start-up delay is typically less than 50 ms.

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Maximum Output Capacitance
A simple method of reducing the output ripple is simply to add a large external capacitor. This can be a low cost alternative to the LC - filter approach, although not as effective. There is, however, also the possibility of causing start up problems, if the output capacitance is too large.

With a large output capacitance at switch on, there is no charge on the capacitors and the DC/DC - converter immediately experiences a large current demand at its output. The inrush current can be so large as to exceed the ability of the DC/DC - converter, and the device can go into current limit or an undefined mode of operation. In the worst case scenario the device continuously oscillates as it tries to start, goes into overload shutdown and then retries again. The DC/DC - converter may not survive if this condition persists.

If instead of single capacitors on outputs an LC - filter is used, the maximum capacitive load can be higher because the choke is preventing too high rising speed of the current peak. However the practical maximum capacitive load is dependent on the quality of the filter and the ESR of the capacitors used.

Remote ON/OFF Control
Many converters (especially those with more than 12W output power) include a logic input that can be used to turn the unit on or off. Sometimes called an "Enable" or "Inhibit" input, this feature typically utilizes the "Shutdown" input to the PWM controller IC. If this PWM function is pulled low, all PWM control outputs will shut down, effectively turning off the converter.

The Remote ON/OFF signal is typically TTL (open collector) and CMOS (open drain) compatible. Depending upon the model series, it may be enabled by a logic high or low. This feature is particularly useful in mobile or remote/battery operated applications where power conservation is critical.

Under Voltage Lockout
Some DC/DC - converters have an under voltage lockout circuit that shuts the converter off in the event of a low line voltage condition. The converter is usually placed in a low power condition to prevent excessive input current from the source.

Ambient Temperature
The temperature of the still-air immediately surrounding an operating DC/DC - converter. Care should be taken when comparing manufacturer's datasheets that still-air ambient temperature and not case temperature is quoted.

Thermal Impedance
This is the temperature rise of the case for each watt dissipated in the converter. The power dissipated is the difference between the input and output power.

Thermal Shutdown (OTP)
This is the case temperature above which the converter will shut down operation. Thermal shutdown halts the PWM operation placing the converter in a low current drain mode until the case temperature decreases.

Derating
The specified reduction in an operating parameter to improve reliability. Generally for DC/DC - converters, it is the reduction in output power at elevated ambient temperature. Operate units in each specified range shown in Derating Curve.

Mean Time Between Failure
The failure rate of DC/DC - converter, expressed in hours, established by the actual operation or calculation from a known standard such as MIL-HDBK-217 or BELLCORE TR-NWT-000332.

$$\text{MTBF} = \frac{1}{\text{failure rate}} \text{ (h)}$$

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2. Isolation

One of the main features of the majority of DC/DC - converters is their high galvanic isolation capability. This allows several variations on circuit topography by using a single DC/DC - converter.

The basic input to output isolation can be used to provide either a simple isolated output power source, or to generate different voltage rails and/or dual polarity rails (see Fig.2.1).

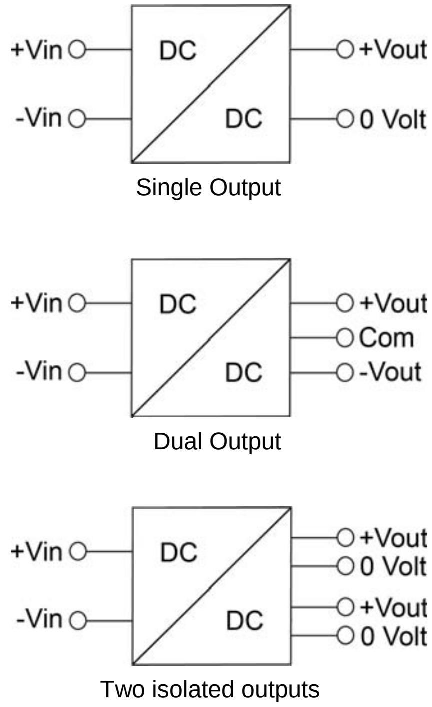

Fig. 2.1: Standard Isolated Configurations

These configurations are most often found in instrumentation, data processing and other noise sensitive circuits where it is necessary to isolate the load and noise presented to the local power supply rails from that of the entire system. Usually local supply noise appears as common mode noise at the converter and does not pollute the main system power supply rails. The isolated positive output can be connected to the input ground rail to generate a negative supply rail if required. Since the output is isolated from the input the choice of reference for the output side can be relatively arbitrary, for example an additional single rail can be generated above the main supply rail or offset by some other DC value (see Fig.2.2).

Regulated converters need more consideration than the unregulated types for mixing the reference level. Essentially the single supply rail has a regulator in its +Vo rail only, hence referencing the isolated ground will only work if all the current return is through the DC/DC - and not via other external components (e.g. diode bias, resistor feed). Having an alternative return path can upset the regulation and the performance of the system may not equal that of the converter.

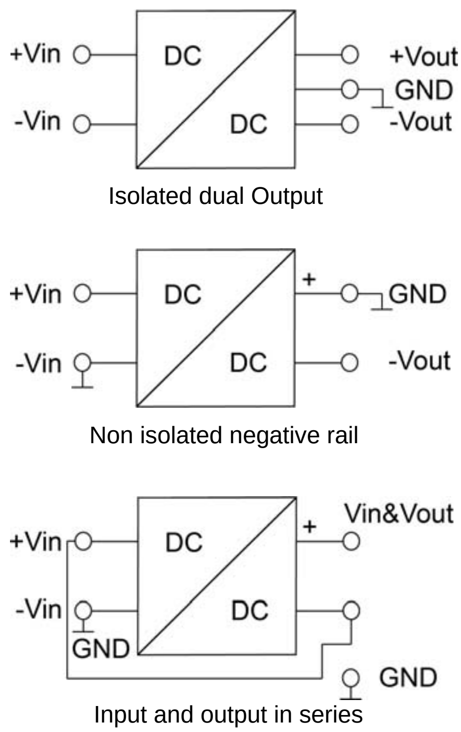

Fig. 2. 2: Alternative Supply Configurations

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Deutschland:
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Tel.: 089 614 503-10
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3. Isolation Capacitance and Leakage Current

The isolation barrier within the DC/DC - converter has a capacitance which is a measure of the coupling between input and output circuits. Providing this is the largest coupling source, a calculation of the leakage current between input and output circuits can be estimated.

Assuming we have a known isolation capacitance (CIS - refer to DC/DC - converter data) and a known frequency for either the noise or test signal, then the expected leakage current (IL) between input and output circuits can be calculated from the impedance.

The general isolation impedance equation for a given frequency (f) is given by;

$$X_{Cisol} = \frac{1}{2*\pi*f*C_{isol}}$$

For a P1B0505S, the isolation capacitance is 60pF, hence the isolation impedance to a 50Hz test signal is;

$$X_{Cisol@50Hz} = \frac{1}{2*3.14*50*60*10^{-12}} = 53M\Omega$$

If using a test voltage of 1kVrms, the leakage current is;

$$I_{leakage} = \frac{V_{test}}{X_{C50Hz}} = \frac{1000}{53*10^6} = 19\mu A$$

It can be easily observed from these simple equations that the higher the test or noise voltage, the larger the leakage current, also the lower the isolation capacitance the lower the leakage current. Hence for low leakage current, high noise immunity designs, high isolation DC/DC - converters should be selected with an appropriate low isolation capacitance.

4. Parallel Operation

This is only recommended with DC/DC - converters specifically designed for parallel connection. A general comment is that it is much lower cost and causes far fewer problems to use a single power converter correctly rated for the application rather than two or more in parallel. However, there are
power converters which feature master slave parallel operation. These units are intended for modular expansion schemes and fault tolerant parallel redundant power systems. Where power converters are overload protected by constant current limiting simple paralleling of the outputs can work to an acceptable standard. Output voltages must be set to equality as precisely as possible. In a two unit system the unit with the slightly higher output voltage will reach its current limit and the voltage will drop to equal that of the other unit.

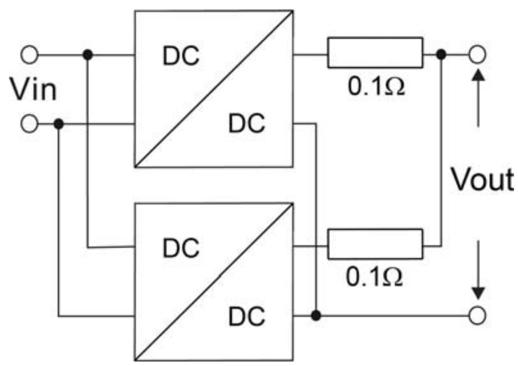

Fig.4.1: Current sharing resistors used to pa rallel two converters

This converter will then supply the remaining current demanded by the load. So regulation can never be better than the difference between the output voltage settings of the two converters, and one unit will always be operating in current limit, therefore above its rating. Where current limits are adjustable to below maximum rating simple paralleling is satisfactory if the degradation of regulation can be tolerated. To improve load current sharing precisely equal series resistors can be used as shown in Fig 4.1

For the best results the wiring resistance must also be exactly balanced. Small differences in the output voltage settings of the converter outputs still creates considerable current unbalance. In the example illustrated (Fig.5.1), the load is 5V to 2A. Converter output voltage setting are 5V and if they are unequal by 0.1V, the current out of balance from the nominal 1A is ±0.5A. This requires that each unit individually rated at 1.5A. It is clearly not a cost effective method of providing 5V 2A of stabilized power. Also that the 0.1Ω series resistors degrade the regulation to worse than 2%.

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In critical applications where continuous operation is essential, parallel redundant power systems are often specified. The system has to keep running even when a power unit fails. Current sharing is not such an important criterion since each power unit must be rated to supply the total load. But to enable both units to be continuously monitored for faults it is advisable that some measure of current sharing takes place. Both units are then always operating. Isolating series diodes which are continuously rated at the full load current allow either power converter to continue operation unaffected by a fault in the other. Matching the forward resistance of the diodes and balancing the wiring resistance helps with the current sharing. However, these series impedance degrade the regulation.

In the parallel redundant scheme illustrated in Fig.4.2 one of the power converters could be replaced by a battery followed by a DC/DC - converter to provide a no-break power system in the event of main supply failure.

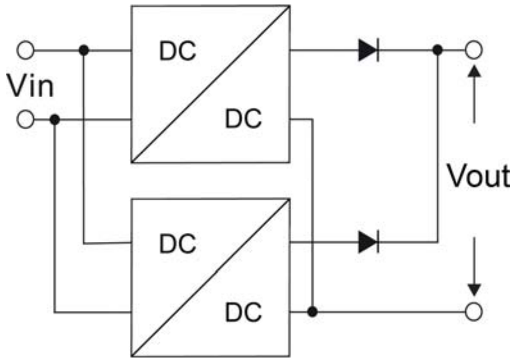

Fig.4.2: Isolating diodes used for parallel redundant connection of two converters

5. Series Operation

Most power converters can be operated in series if they have overload limitation by either constant current or constant power circuits. With some switching converters series operation is prohibited because one unit upsets the feedback regulation system of the other. With linear and switched mode units using foldback current limiting lock out at switch ON can occur because of the different ramp up times of two units in series. Care must be taken not to exceed the safe working voltage at the outputs of converters in series. This may be considerably lower than the dielectric strength test voltage which is a short term test between outputs and ground.

The output ripple of converters in series is additive but this of course does not change the value of ripple expressed as a percentage of total output voltage. To protect each output from the reverse voltage applied by the other unit in the event of load short circuits, reverse biased diodes are used as shown in Fig.5.

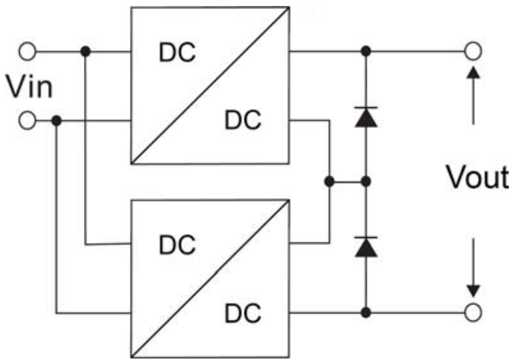

Fig.5: Outputs connected in series include reverse voltage protection diodes

Deutschland:
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Tel.: 089 614 503-10
E-Mail: power@hy-line.de

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CH-8247 Flurlingen
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