Designing Wide Range Power Supplies for Three Phase Industrial Applications

Three-phase regulated supplies operate under demanding conditions

With the volatile nature of a three-phase source, special design considerations and techniques need to be applied. The StackFET configuration provides a design solution at significantly lower cost.

By Rahul Joshi, Power Integrations

Industrial equipment operating from a three-phase AC supply often requires an auxiliary power stage that supplies regulated, low-voltage DC to the control electronics. Specifications for these supplies are much more demanding than for the typical single-phase supply. The nominal input voltage is higher, and equipment designed for three-phase input has to tolerate larger input supply-voltage variations. Line surges, extended sags and sub-cycle drop-outs often occur in an industrial environment as a result of large loads being switched off and on, or as a result of fuses being cleared for fault conditions elsewhere on the line. Three-phase applications can occasionally lose a phase or a neutral connection. Industrial equipment is expected to handle all of these conditions without malfunctioning. Applications such as energy meters must work reliably over these extreme conditions.

This article looks at the challenges of designing switched-mode power supplies for three-phase applications, and presents a compact, cost-effective design that operates over a very wide input voltage range.

Design Goal

A three-phase input, off-line switching power supply that has wide input voltage range, high overall operating efficiency, and good immunity to input voltage perturbations.

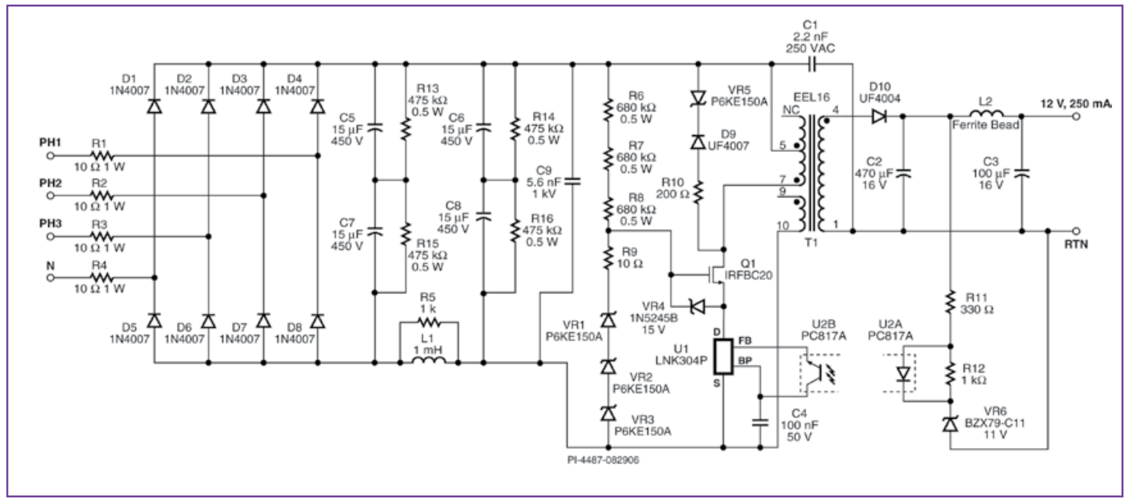
Most switching power supplies can operate over the universal input voltage range to provide worldwide coverage. For three-phase applications such as energy meters, the power supply must work from 57 to 580 VAC, from all three phases and with the occasional loss of a phase or a neutral connection.

For auxiliary power supply designs, the flyback topology is best-suited, and offers these advantages:

- Use of a single active switch that simplifies circuit design
- Use of a single-wound component in the topology (eliminates large filter chokes on the output)
- Easy-to-create multiple output voltages
- Very low component count and cost

A flyback converter typically requires a minimum MOSFET breakdown voltage of 1.6 times the rectified peak of the maximum AC input voltage. For 580 VAC, a 1200 V MOSFET would be required, adding cost and (normally) ruling out the use of an integrated switching IC that could dramatically simplify the solution (when compared to a discrete design).

An IC such as the LinkSwitch®-TN from Power Integrations incorporates a 700 V MOSFET and controller into a single device, and can eliminate 20 to 30 external components when compared to a circuit using a discrete MOSFET and external control IC. The 700V rating of this IC would normally limit use to single-phase applications. However, by adding an external MOSFET in a cascode or StackFET™ configuration, it is possible to distribute the voltage stress across two devices, resulting in an overall voltage rating equal to the sum of the individual MOSFET voltages.



Note: A standard fixed-frequency PMW controller would suffer from poor efficiency under high-line and light-load conditions, due to the short duty cycle relative to the operating frequency. ON/OFF control eliminates this problem.

Figure 1. Circuit Schematic.

Design Solution

The circuit in Figure 1 is a 12 V, 250 mA wide-range flyback power supply that operates from a single-phase or a three-phase input. Using the StackFET technique with a low-cost 600 V MOSFET results in an overall voltage rating of 1300 V and allows supply operation over the desired wide input voltage range of 57 to 580 VAC. The supply will work from 47–63 Hz, single- or three-phase 110 VAC, 220 VAC or 440 VAC. This supply comfortably handles the loss of one or more phases or the neutral, as well as extended sags and surges.

Circuit Operation

The circuit in Figure 1 is based on a LinkSwitch-TN IC, the LNK304P (U1) that is configured as a flyback, to leverage its 66 kHz switching frequency. This reduces switching losses and improves efficiency. The IC's ON/OFF control regulates the output by skipping switching cycles. As the load is reduced, the effective switching frequency decreases, scaling the switching losses and maximizing the operating efficiency.

The AC input is full-wave-rectified by diodes D1 through D8. Resistors R1 through R4 provide in-rush current limiting and protection against catastrophic circuit failure. Capacitors C5 through C8 are used to filter the rectified AC supply. To meet maximum bus voltage of 820 VDC, 450 V input capacitors C5, C7 and C6, C8 are connected in series with balancing resistors R13 to R16 to equalize the voltage. The C5/C7 and C6/C8 capacitor sets are used in conjunction with L1 to form a p filter for EMI reduction. Capacitor C9, which is placed very close to U1 and T1, shunts switching induced noise currents, to minimize differential mode EMI generation. Combining this EMI reduction technique with 1) the jittering of the switching frequency of U1, 2) E-Shield™ winding in the transformer, and 3) the safety Y-rated capacitor C1 across the isolation barrier, allows the design to easily meet conducted EMI limits (as specified in EN55022-B).

The high-voltage DC is applied to one end of the transformer primary, and the other end driven by MOSFET Q1. MOSFET Q1 and the MOSFET inside the LNK304P effectively form a cascode arrangement. When the internal MOSFET of U1 turns on, the source of Q1 is pulled low, which allows gate current to flow through the resistor string R6, R7 and R8 from the junction capacitance of VR1, VR2 and VR3, to turn on Q1. Zener VR4 limits the gate-source voltage applied to Q1. When turned OFF, VR1 to VR3 (connected in series) form a 450 V clamping network that ensures the drain voltage of U1 remains close to 450 V; any input voltage above 450 V will be dropped across Q1. This arrangement distributes the sum total of flyback voltage and DC bus voltage across Q1 and the internal MOSFET within U1. Resistor R9 limits high frequency ringing that occurs when VR1 to VR3 conduct. The clamping network, VR5, D9 and R10, limits the peak voltage that appears across Q1 and U1 (due to leakage inductance) during the flyback interval.

The circuit on the secondary of transformer T1 provides output rectification, filtering and feedback. Diode D10 rectifies the output. Capacitor C2 filters the rectified output. Inductor L2 and capacitor C3 form a second-stage filter, which helps to reduce the high-frequency switching ripple in the output. Zener diode VR6 conducts when the voltage at the output exceeds the total drop of VR6 and the optocoupler diode inside U2. A change in output voltage results in a change in the current through the optocoupler diode. This, in turn, increases the current through the transistor inside U2B.

When this current exceeds the FEEDBACK (FB) pin threshold current, the next switching cycle is disabled. Output regulation is maintained by adjusting the number of enabled and disabled switching cycles. Once a switching cycle of U1 is enabled, the current ramps to the internal current limit of U1. Resistor R11 limits the optocoupler current during transient loads, and sets the gain of the feedback loop. Resistor R12 provides bias current to the Zener diode, VR6.

If the FEEDBACK pin is not pulled high for a period of 50 ms, the internal power MOSFET switch in U1 is disabled for 800 ms. Alternately enabling and disabling the switch protects the circuit against output overload, an output short circuit, or an open feedback loop.

No auxiliary winding or bias wind-

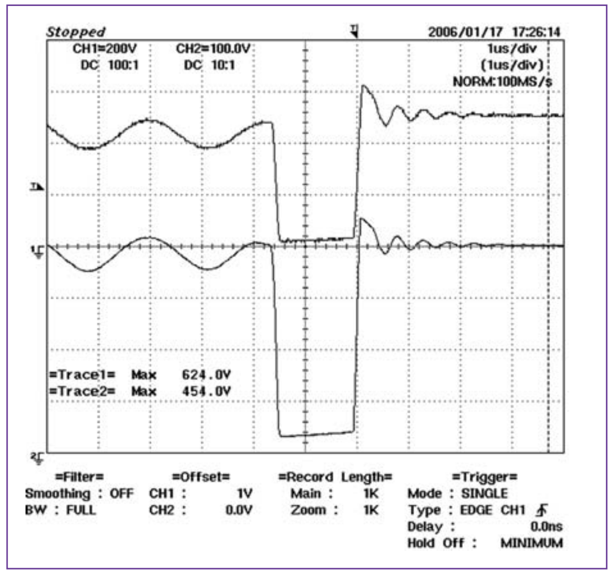


Figure 2. Trace 1 - U1 Drain Voltage (200 V / div) and Trace 2 - Q1 Drain Voltage (100 V / div).

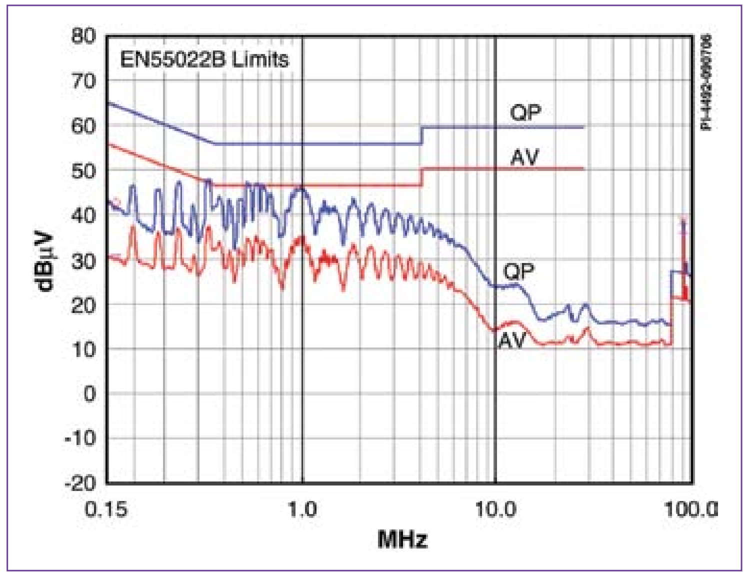


Figure 4. Conducted EMI at 230 V.

ing on the transformer is required to power U1, as it is self-powered from the DRAIN (D) pin. At start-up and during the off-time of the internal MOSFET, the local decoupling capacitor (C4) is kept charged via an internal high-voltage current source.

Circuit Test Results

The oscilloscope plot shown in Figure 2 was captured at an input voltage of 312 VAC (440 VDC bus voltage). At turn off the drain voltage of U1 (trace 2) is clamped to a voltage of 450 V, which is the total voltage across VR1, VR2 and VR3. This clamping ensures safe operation of U1. Trace 1 shows the voltage on the drain of Q1 referenced to primary ground (negative of C8). The actual voltage across the MOSFET Q1 in the OFF state (trace 1) is the difference between the two traces, in this case 170 V.

As the AC input voltage is increased to 580 VAC (820 VDC), the voltage drop across the MOSFET Q1 in the OFF state is less than 550 V, which allows the use of a low cost 600 V to 800 V external MOSFET.

The efficiency characteristic of this design is shown in Figure 3. The curve reveals that the efficiency drops at higher input voltage due to increased switching losses and dissipation in the cascade connected power stage (Q1 and the internal MOSFET within U1). However this is still significantly higher than a regulated linear transformer supply.

The circuit meets conducted EMI requirements with a comfortable margin when tested at 230 VAC, as shown in Figure 4. The blue and red upper lines represent the quasi-peak and average limits, perEN55022 B. The lower lines represent the corresponding quasi-peak and average test results.

Conclusion

The StackFET technique provides a cost-effective solution for auxiliary power supplies in industrial applications. This technique allows the designer to benefit from the simplicity afforded by an integrated switching IC when used for high input voltages required by three-phase AC input.

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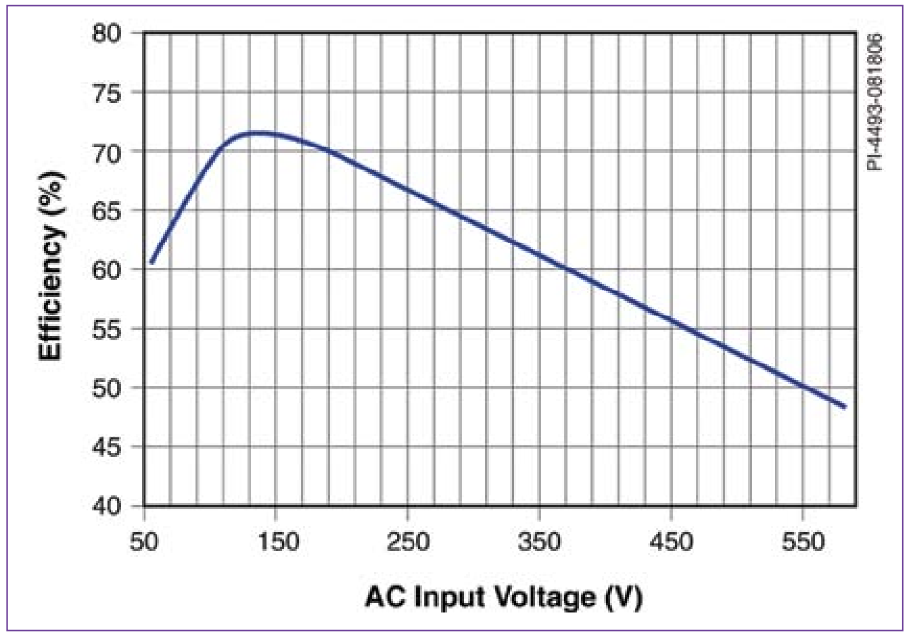

Figure 3. Efficiency vs. Input Voltage.

20V Solid-State photovoltaic relays have 50 percent lower on-state resistance

International Rectifier has introduced a series of photovoltaic relays for applications including power supplies, power distribution, audio equipment, and instrumentation, computers and computer peripherals.

Compared to its predecessor, the PVN012A family offers a 50 percent reduction of AC/DC on-state resistance (RDD-on) and 37.5 percent increase of maximum AC/DC load current rating at full (100%) duty cycle. The new series is also rated for maximum pulsed (surge) load current.

With extremely low on-resistance and high volumetric load current density in such a small package, the PVN012A family exceeds the performance capabilities of traditional electromechanical relays. In comparison, the PVN012A family offers a smaller footprint, high input-to-output isolation, bounce-free operation, solid-state reliability, stable on-resistance over life, and greater input sensitivity.

These new 20V single-pole, normally open, solid state relays utilize a HEXFET® MOSFET output switch, driven by a unique integrated photovoltaic generator circuit. The output switch is controlled by radiation from a GaAlAs light-emitting diode (LED) that is optically isolated from the photovoltaic generator. The new series is available in 6-pin DIP, 6-pin SMT, and in tape and reel.

Specifications:

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Part Number	Package	On-resistance AC/DC [Ohm]	On-resistance DC-only [Ohm]	Load current AC/DC [Amp]	Load current DC-only [Amp]	Input-Output Isolation [VACRMS]
PVN012APbF	DIP-6	0.050	0.015	4.0	6.0	4,000
PVN012ASPbF	DIP-6,SMT	0.050	0.015	4.0	6.0	4,000
PVN012AS-TP	DIP-6,SMT,T &R	0.050	0.015	4.0	6.0	4,000

Dual DC/DC Converter Delivers 1.6A per Channel from a DFN Package

Linear Technology Corporation announces the LT3506 and LT3506A, dual current mode PWM step-down DC/DC converters with two 2A power switches packaged in a 16-lead 5mm x 4mm DFN package. Each channel is capable of delivering up to 1.6A of output current. Their wide input range of 3.6V to 25V makes them suitable for regulating power from a wide variety of sources, including four cell batteries, 5V and 12V rails, unregulated wall transformers, lead acid batteries and distributed power supplies. The LT3506 switches at 575kHz while the LT3506A switches at 1.1MHz enabling the use of tiny, low cost inductors and ceramic capacitors, while delivering low, predictable output ripple.

The LT3506 and LT3506A's low VCESAT (210mV @1A) internal switches offer efficiencies of up 88%, minimizing thermal constraints and maximizing battery run-time. Low voltage outputs are easily attended due to an internal reference of 0.80V. Each channel has independent shutdown and soft-start pins as well as independent power good indicators to ease power sequencing. The channels switch 180 degrees out of phase with respect to the other, reducing input ripple and minimizing capacitance needs. Internal cycle-by-cycle current limit provides protection against shorted outputs while soft-start eliminates input current surge during start up. The low current (<30uA typ) shutdown provides easy power management in battery-powered systems.

The LT3506EDHD and LT3506AEDHD are available in a thermally enhanced 5mm x 4mm DFN-16 package

Photo Caption: 25V, 1.1MHz Dual 1.6A (IOUT) Step-Down Switching Regulator

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