Fly-Buck™ converter provides EMC and isolation in PLC applications

By Timothy Hegarty
Systems Engineer, Non-Isolated Power Solutions

How do you provide galvanically-isolated positive or negative voltage rails while keeping cost and complexity to a minimum? At the same time, how do you fend off a diversity of challenges tied to wide input voltage range, multiple outputs, small solution size, electromagnetic compatibility (EMC), and high reliability?

Consider factory automation and control end equipment segments such as programmable logic controllers (PLC), field transmitters, sensors and process instrumentation, industrial communication, data acquisition systems (DAS), human machine interface (HMI), and IGBT-based motor drives. There is an inescapable requirement in many of these applications for more functionality in less space. Solution footprint and height are critical, meaning system designers must explore all avenues to conserve valuable PCB real estate. For the power solution in particular, a key requirement is a robust design that provides one or more isolated voltage rails. This article focuses on PLCs in particular, examines EMC and safety isolation requirements, and describes a multi-output power converter solution.

PLC I/O module

An illustrative block diagram of a PLC I/O module is given in Figure 1. Used in modular rack-based PLC systems, an I/O module establishes the physical connection between the PLC and factory or field equipment. The rack can accept various types of I/O modules that effectively slide into slots in the rack to accomplish backplane connection.

The system in Figure 1 includes a microcontroller, data converters, isolators, input amplifiers, I/V output drivers, references, wired and/or wireless connectivity, and a multi-output DC/DC Fly-Buck™-based power solution[1,2]. Analog I/O signal ranges are usually selected from the voltage options of 0 to 5 V, 0 to 10 V, ±5 V, and ±10 V, or the current options of 0 to 20 mA and 4 to 20 mA.

Figure 1. Factory automation PLC I/O module

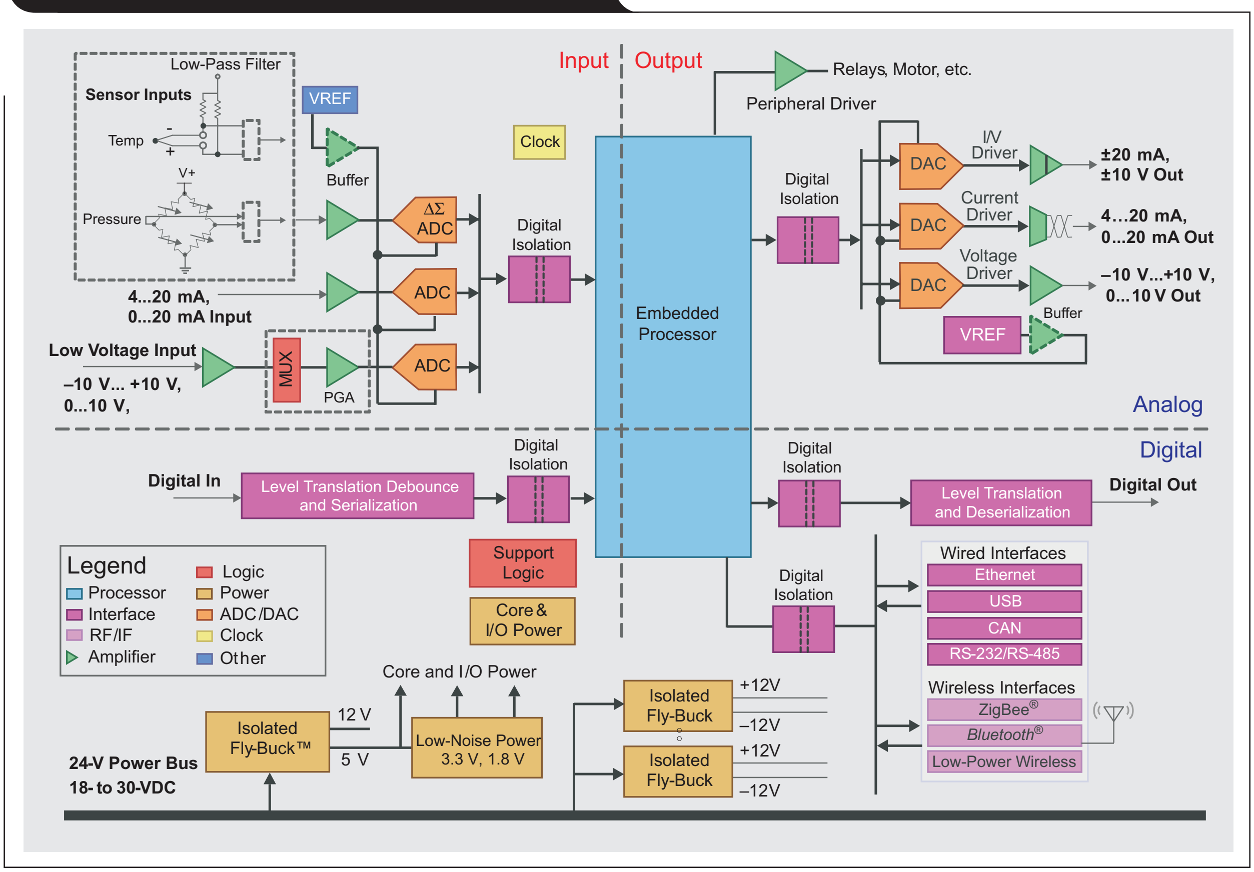


Table 1: Summary of popular harmonized standards for EMC and electrical safety

Standard	Applicability	Remarks
IEC/EN 61131-2	Listed in EMC Directive	PLC equipment specific requirements and tests
IEC/EN 61000-6-2/-4	Listed in EMC Directive	Generic immunity/emission standard for industrial environments
IEC/EN 61326-1/-2	Listed in EMC Directive	Electrical equipment for measurement, control and laboratory use
IEC/EN 61000-4-2	High-frequency disturbances	ESD immunity test
IEC/EN 61000-4-3		Radiated EM field immunity test
IEC/EN 61000-4-4		Switching transients (EFT/burst) immunity test
IEC/EN 61000-4-5		Surge impulse (lightning) immunity test
IEC/EN 61000-4-6		Conducted RF current immunity test
IEC/EN 61000-4-8	Low frequency disturbances	50/60-Hz magnetic field immunity test
IEC/EN 61000-4-11		Voltage dips and short interruptions immunity test
IEC/EN 61000-4-12		Damped oscillatory waves immunity test
IEC/EN 55011 (or CISPR 11)	Low- and high-frequency emissions	Conducted and radiated emissions for industrial, scientific, and medical (ISM) equipment
IEC/EN 60664-1	Listed in Low Voltage Directive	Insulation for equipment within low-voltage systems. Low voltage defined as 75 to 1500 VDC or 50 to 1000 VAC_{rms}
IEC/EN 61010-1	Safety	Safety requirements for electrical equipment for measurement, control and laboratory use
IEC/EN 60950-1	Safety	Safety of IT equipment

Emissions, immunity, and safety requirements for PLCs

Factory equipment placed into the European Union (EU) market should generally comply when fully installed with the EMC Directive (2014/30/EU) and low-voltage (LV) directive (2014/35/EU). These directives point to compliance of the main requirements using a list of harmonized standards based on several generic and product specific standards. Table 1 lists several European Norm (EN) standards[3-5] that apply to EMC and electrical safety. Many of these tests are performed at the system level, either at the enclosure power or data port(s). Note that the Low Voltage Directive applies if the applicable input or output voltage lies within 75 to 1500 VDC or 50 to 1000 VAC_{rms}.

EN 61131-2 specifies requirements and related tests specifically for PLCs and their associated peripherals. However, while this standard supersedes generic standards for immunity (EN 50082-2) and safety (EN 61010-3), generic standards are still used for emissions (EN 61000-6-2) and AC harmonics/fluctuations (EN 61000-3-2) for AC-powered equipment. Also, various tests referenced within the EN 61000-4 transient immunity specification cater to electrostatic discharge (ESD), electrical fast transient (EFT)/burst, lightning surge, and conducted/radiated RF immunity[6,7].

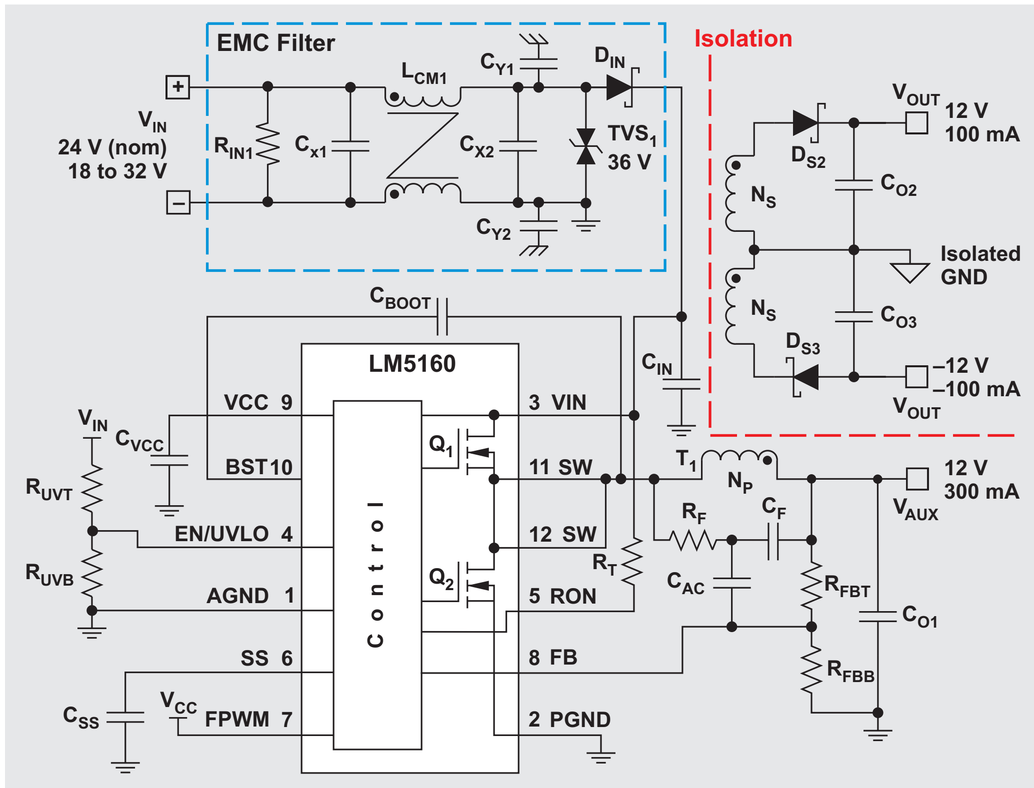
Choosing a power solution

Converter- or controller-based IC solutions are widely available, and the choice hinges initially on input voltage and output current specifications. However, solutions specifically with a large input voltage range (wide V_{IN}) offer outsized voltage rating and operating margin to deal with supply rail voltage transients described in EN 61000-4. For a given PLC application, the power solution must be chosen to provide sufficient power for the given I/O configuration and the number of base/option module slots to be powered. Multiple isolated-converter outputs are required, particularly if isolation is required on a per-channel basis to protect against transients and ground loops.

The wide-V_{IN} Fly-Buck circuit has gained prominence from a range of buck-based topologies. The concept is becoming a more mainstream solution for power system engineers. The most noteworthy feature of a Fly-Buck converter is what is missing. Built from the reliable synchronous buck regulator, the Fly-Buck has neither loop compensation nor feedback optocoupler components. A compensated error amplifier is not needed, and a constant on-time (COT) control approach gives nearly instantaneous response for excellent transient dynamics. Feedback regulation is from the primary side through a standard resistor divider. Switching frequency is kept steady with line feedforward and continuous conduction mode (CCM) operation.

For maximum flexibility, both isolated and non-isolated outputs are available. This makes the Fly-Buck ideal for auxiliary and bias rails, floating supplies for digital isolators (Figure 1), and bipolar supplies for powering high-precision amplifiers and data converters[2]. To customize for additional outputs, simply add a transformer secondary winding with requisite number of turns, a rectifier diode, and an output capacitor. For space-constrained designs, dual, triple, quad, or more outputs are easily obtained with a small-size magnetic component. As a multi-output converter, the Fly-Buck is an excellent fit for PLCs where a high level of integration is needed as PLC channel count and functional density increase while the enclosure gets smaller.

Figure 2: EMC-compliant Fly-Buck™ regulator supply for PLC applications



Fly-Buck™ circuit implementation

Based on the 65-V, LM5160 synchronous regulator, the schematic of Figure 2 details an EMC-compliant Fly-Buck converter that delivers ±12-V isolated rails from a center-tapped secondary winding. Output voltages are scaled commensurate with turns ratio N_P/N_S of transformer T_1, and a 12-V primary-side output, V_{AUX}, is also provided. The red dashed line shows the isolation boundary. The upper circuitry is the EMC filter with common-mode inductor, X and Y capacitors, damping resistor, bidirectional transient voltage suppressor (TVS) voltage clamp, and reverse-polarity protection diode.

Optimizing EMC and isolation

The Fly-Buck topology has broad versatility to meet EMC and isolation performance objectives[1, 8]. Generally, the goal of EMC-protected circuits is to shunt the external transients to ground with low impedance and protect the circuit from damage. A Fly-Buck regulator with wide-V_{IN} capability permits a higher voltage TVS diode with a lower power rating and a smaller footprint that still meets the input transient immunity specifications for the power stage. Selection of TVS voltage rating is based on the dynamic impedance of the TVS and the expected peak current. Y capacitors, denoted as C_{YI} and C_{Y2} in Figure 2, shunt transient energy from the input lines to the enclosure's chassis ground. This approach is supplemented by small ferrite beads to provide high impedance at particularly sensitive nodes in the signal chain where high attenuation is required[8].

Off-the-shelf transformers are readily available with slim form factor and isolation rating of up to 4.5 kV peak, based on the requisite creepage and clearance. Certainly, larger isolation ratings dictate increased winding spacing, which means higher leakage inductance. Fortunately, the Fly-Buck is more tolerant of leakage inductance than an equivalent flyback converter. The Fly-Buck has no primary-side voltage spike related to leakage inductance, which provides an increased operating voltage margin against input-voltage transients. Also helpful for EMC, the Fly-Buck has a primary-side current waveform with lower harmonic content compared to the flyback.

Note that the 24-V industrial bus is normally double or reinforced insulated. Thus, functional isolation to 500-VDC continuous is usually adequate for the downstream power stages. As an example, most sensors adopt a 4- to 20-mA loop to transmit the measured quantity without noise or line-length concerns. In this case, an isolated rail increases signal accuracy and avoids any ground noise current issues related to interconnection of other equipment. As an example for basic or reinforced isolation, when powering digital data isolators, select the magnetic component that meets the isolation grade requirement and design the PCB layout to meet the relevant creepage and clearance specification of the referencing standard.

Conclusion

PLCs for factory automation and control applications have unique power-stage design requirements. Testament to its ease-of-use, small size, safety isolation, EMC regulatory compliance, and low overall bill-of-materials cost, a wide-V_{IN} Fly-Buck solution meets these requirements. Looking forward, as more demanding isolated applications come to fruition, complying to regulatory specifications is clearly a benchmark of power solutions for industrial applications that is becoming more important.

References

1. "Isolated Tri-output Fly-Buck Power Supply for Industrial PLC Applications," LM5160 reference design, Texas Instruments. Available: **www.ti.com/tool/PMP10532**
2. Tim Hegarty, "Post-Regulated Fly-Buck Powers Noise-Sensitive Loads," Power Electronics, October 14, 2014. Available: **www.powerelectronics.com/**
3. "Introduction to IEC 61131-2, PLC Equipment Requirements and Tests." Available: **www.plcopen.org/pages/tc1_standards/iec61131-2**
4. Harmonized standards to the EMC and Low Voltage Directives, description and guidance. Available: **ec.europa.eu/enterprise/sectors/electrical/**
5. EMC Directive list of harmonized standards, *Journal of the European Union*, February 25, 2014. Available: **eur-lex.europa.eu/homepage.html?locale=en**
6. Ian Williams, "EMC testing explained," Precision Hub, TI E2E™ Community. Available: **e2e.ti.com/blogs/**
7. "8-Channel Digital Input Module for Programmable Logic Controllers (PLCs)," TI Design. Available: **www.ti.com/1q15-tidu196**
8. LM5017 Fly-Buck™ PLC Reference Designs:
   - "16-Bit Analog Mixed Input and Output Module for Programmable Logic Controller (PLC)." Available: **www.ti.com/tool/TIDA-00170**
   - "16-Bit, 8 Channel, Integrated Analog Input module for Programmable Logic Controllers (PLC)." Available: **www.ti.com/tool/TIDA-00164**
   - "PLC I/O Module Front-End Controller Using a Tiva™ C Series ARM® Cortex™ M4 MCU." Available: **www.ti.com/tool/TIDA-00123**

Related Web sites

www.ti.com/1q15-LM5160

TI Worldwide Technical Support

Internet

TI Semiconductor Product Information Center Home Page

support.ti.com

TI E2E™ Community Home Page

e2e.ti.com

Product Information Centers

Americas	Phone	+1(512) 434-1560
Brazil	Phone	0800-891-2616
Mexico	Phone	0800-670-7544
	Fax	+1(972) 927-6377
	Internet/Email	support.ti.com/sc/pic/americas.htm

Europe, Middle East, and Africa

Phone

European Free Call	00800-ASK-TEXAS (00800 275 83927)
International	+49 (0) 8161 80 2121
Russian Support	+7 (4) 95 98 10 701

Note: The European Free Call (Toll Free) number is not active in all countries. If you have technical difficulty calling the free call number, please use the international number above.

Fax	+(49) (0) 8161 80 2045
Internet	www.ti.com/asktexas
Direct Email	asktexas@ti.com

Japan

Fax	International	+81-3-3344-5317
	Domestic	0120-81-0036
Internet/Email	International	support.ti.com/sc/pic/japan.htm
	Domestic	www.tij.co.jp/pic

Asia

Phone — Toll-Free Number

Note: Toll-free numbers may not support mobile and IP phones.

Australia	1-800-999-084
China	800-820-8682
Hong Kong	800-96-5941
India	000-800-100-8888
Indonesia	001-803-8861-1006
Korea	080-551-2804
Malaysia	1-800-80-3973
New Zealand	0800-446-934
Philippines	1-800-765-7404
Singapore	800-886-1028
Taiwan	0800-006800
Thailand	001-800-886-0010

International	+86-21-23073444
Fax	+86-21-23073686
Email	tiasia@ti.com or ti-china@ti.com
Internet	support.ti.com/sc/pic/asia.htm

A021014

IMPORTANT NOTICE

Texas Instruments Incorporated and its subsidiaries (TI) reserve the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products (also referred to herein as “components”) are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

TI does not warrant or represent that any license, either express or implied, is granted under any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

Reproduction of significant portions of TI information in TI data books or data sheets is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Resale of TI components or services with statements different from or beyond the parameters stated by TI for that component or service voids all express and any implied warranties for the associated TI component or service and is an unfair and deceptive business practice. TI is not responsible or liable for any such statements.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards which anticipate dangerous consequences of failures, monitor failures and their consequences, lessen the likelihood of failures that might cause harm and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed a special agreement specifically governing such use.

Only those TI components which TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components which have ***not*** been so designated is solely at the Buyer's risk, and that Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265