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TECHNOLOGY
The Engineer's Guide to Design & Manufacturing Advances

3-Phase Single-Step Power Correction *in MilAero Systems*






As OEMs seek advantages in Size, Weight, Power and Cost (SWaP-C), focus is shifting to advancements in power electronics. Gaining an advantage requires close attention not only to performance requirements such as power factor and current distortion, but also size, weight, efficiency and cost. This is no small feat, given that power solutions must seamlessly handle the multi-step regulation and isolation of electronic circuits, a costly and complex process commonly required for AC to DC conversion in high-performance power applications.

Existing power electronics solutions highlight the challenge; based on autotransformer rectification units (ATRUs) or Vienna rectifiers, these systems can be heavy, overly complicated and inflexible as power needs evolve during long-term system deployment. The landscape is evolving to address this, and today includes a new circuit topology that achieves three-phase active power factor correction, power regulation and electrical isolation in a single conversion step. The resulting high-power conversion efficiency solves a long list of potential design challenges, helping drive advancements in military platforms, shipboard systems and commercial aircraft.

High Performance Power Conversion

Three-phase AC power must routinely be converted to DC voltage for safe and ready use in military and industrial applications. Typical devices for converting a three-phase power input to an adjustable DC output generally require two steps: 1) a rectification stage for converting AC input into DC output, followed by 2) a DC-DC conversion stage for regulating and isolating the DC output voltage.

The DC-DC conversion stage may be capable of raising or lowering the DC voltage level, or both, depending on the particular features of a given device.

At the same time, this type of advanced power solution must pose a low technical risk, reducing the threat of failure as well as the cost of designing, manufacturing and maintaining the circuitry. The resulting circuitry must be operable in applications supplied by high-frequency power, such as the 115V 400Hz AC power commonly used for aircraft. Ultimately, the goal of rectification is to provide isolated, regulated DC output, free of input harmonics and with a unity power factor.

Power Electronics Design Landscape

Existing rectification options include passive power factor correction, ATRUs, single phase x3, and Vienna solutions – each requiring a multi-step approach. The addition of a single-step solution is unique; developed by Marotta Controls, this topology enables power electronics engineers to achieve extremely efficient circuit performance and eliminate wasted power, weight, volume and cost associated with a second DC-DC conversion. Achieving regulation and isolation in one conversion simplifies complicated circuitry; systems have a tangible design advantage with reduced size and weight, improved performance based on low harmonics (<3%), and unity power factor of one at both full and partial loads. Looking at the primary features of contrasting solutions illustrates the value and design challenges of each option.

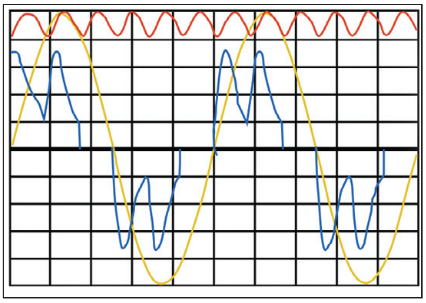

Figure 1. This graph illustrates unwanted power performance, with extreme disparity between perfect sine wave voltage and current waveform. (Marotta Controls)

Passive Power Factor Correction (PPFC)

Passive power factor correction keeps costs down with the absence of active components, but requires increased inductance and capacitance. Solutions are heavy, not inherently smart, and limited to low-power applications ranging from a kilowatt to ~1500W. Output power is limited to ~2kW of voltage and power factor is only achieved at upper-end loads. Frequency is usually around 400Hz; for military and industrial applications in the range of 60Hz, the device would be too large for practical deployment.

ATRUs

No regulation or isolation is available in PPFCs or ATRUs, leading to a more difficult second step DC-DC conversion. ATRU topologies do have an advantage over PPFCs, as they can handle higher power and achieve power factor through the entire load. Yet solutions remain costly and impractically heavy for SWaP-conscious, high-performance applications. ATRU power density is just 444 watts per pound, while a single step topology may be as high as 930 watts per pound.

Single Phase x3

Using three lines of single-phase power is an option; however, this results in no isolation, step-up voltage only, and not one but two stages of DC DC conversion to yield converted power. The solution is risky and intricate, requiring nine independent control circuits working together – one for each of three DC converters, DC-DC converters, and load share circuits. Power factor is achieved through the entire load as well as low current total harmonic distortion (THD), although overall efficiency is reduced based on a complicated, costly and heavy design. The device is opened up to greater engineering requirements and additional points of failure, while cost, weight and space are added to the design.

Vienna Rectifiers

Vienna rectifiers are complex, with three switch-controlled rectifier circuits. A single control circuit uses heavy calculations to determine a separate control instruction set for each rectifier. Output voltage may only be stepped up and not down, a drawback that limits Vienna devices to high voltage output. The system offers no isolation and can regulate only to 350 volts and above without a second DC-DC conversion. When a particular application requires something lower, perhaps 270 volts, the output is actually lower than the line voltage. The Vienna solution would require a second DC-DC conversion to accommodate down-conversion, adding unwanted cost and technical risk, as well as increased weight and space.

Single Step Topology

The single-step topology includes a rectifier circuit for rectifying three-phase power input into a plurality of rectified outputs, a converter circuit for converting each of the rectified outputs, and a control circuit for generating the control signal based at least in part on the single DC output.

Because regulation and isolation are handled in one step, total power efficiency is maintained at 96% or equivalent efficiency at 100%. Ideal power factor of one is achieved through the entire load; output is regulated and isolated without a second DC-DC conversion and can be stepped up or down depending on the needs of the application. Load sharing occurs automatically with one converter that does not require current sensing. As a result, the device can scale by linking multiple 3kW modules to achieve 6kW, 9kW, 12kW, 15kW performance and more.

Engineering Challenges

In power rectification, design issues related to power factor correction, electrical isolation, and input current distortion often consume the most engineering resources.

Power Factor Correction

In many applications, and particularly high-power applications, power conversion circuitry ideally provides power factor correction (PFC) to minimize the input current. PFC is required to reduce overall current for a given power requirement, and prevents input current distortion. As a result, both input voltage and current waveforms are kept in phase and maintain an acceptable power factor of the three-phase power input.

Electrical Isolation

Electrical isolation protects circuits, equipment and operators from shocks and short circuits occurring in the system. In some applications, output voltage must be electrically isolated from the input, creating infinite resistance between the two. The single-step power design enables complete isolation between output and input; if a short circuit occurs at the output, the function stops and the system is safe.

Input Current Distortion

A fullwave rectifier is often used to convert three-phase AC to DC voltage. This type of device incorporates six

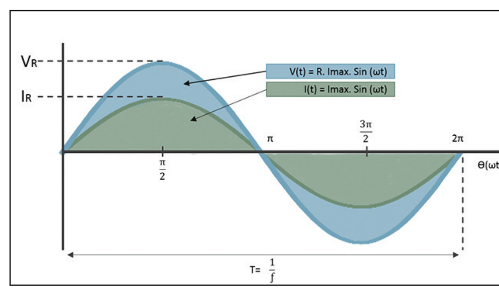

Figure 2. This graph illustrates the power performance ideal, with current following voltage and power factor of one. (Marotta Controls)

Single Step Power Topologies in Context

Power systems deployed onboard military vehicles and aircraft, naval ships, or civil aircraft must meet a range of industry certifications to ensure military and commercial performance standards. For example MIL-STD-461 defines performance for all electronic, electrical and electromagnetic equipment and subsystems procured and used by all branches of the Department of Defense (DoD), while validation to MIL-STD-1399 further ensures the circuit meets the required characteristics for shipboard equipment using AC electric power. Further, conducted emissions (CE101) validation ensures that low frequency conducted emissions are properly controlled by the circuit, and that its harmonics do not conflict with any operational requirements of related systems. Single step power topologies are poised to play an important role here, meeting these standards while ensuring high power conversion efficiency and power factor of one, reducing cost and size, and minimizing moving parts and complex control circuits.

For shipboard systems, inherently difficult harmonics distortion and power factor requirements commonly dictate that any application over 1500 Watts requires an active power factor solution; however traditional solutions can be too large for shipboard deployment. Applications often include switch-mode power supplies, for example running a large bank of electronics equipment, which present a difficult load that does not appear resistant. Using a 60Hz application as an example, a single step topology offers a size and performance advantage in contrast to a magnetics-based solution such as an ATRU or Vienna device containing large inductors.

Airborne electronics have similar stringent requirements, defined in the RTCA-DO160 specification, a key section of the industry's DO160 standard for power quality requirements. Commercial aircraft have numerous power converters onboard; the engine generates three phase power which must in most cases be converted to DC to be used safely. When these systems run AC motors, they also require an intervening device to control the power factor. In addition to its own set of conducted emissions ratings, RTCA-DO160 assures avionics safety and reliability by requiring very low current harmonic distortion and high power factor of one, or close to it.

	PPFC	ATRU	3 PFCs + DC-DC	VIENNA	MAROTTA 1-STEP
PF Entire Load	NO	YES	YES	YES	YES
Regulation	NO	NO	Requires 2 conversions	YES	YES
Output Voltage Level	Follow the input	Follow the input	Stepped up or stepped down Requires 2 conversions	Limited to stepped up only	Stepped up or stepped down
Isolation	NO	NO	Requires 2 conversions	NO	YES
Limited to 400HZ	Limited	Limited	Not Limited	Not Limited	Not Limited
Efficiency	96%	95%	95%	95%	96% Eq. 100%
Weight and Volume	Very Heavy	Very Heavy	Heavy	Light	Very Light
Technical Risk	Low	Low	High Risk	Very High Risk	Low
Cost	Low	High	High	High	Low

Design options for power electronics offer a range of advantages and drawbacks in the quest for lighter, less costly circuitry. For example, passive power factor correction is low risk but applicable only to lower performance applications, while a single-step solution offers low risk, high performance, and applicability to a wider range of rugged applications. (Marotta Controls)

diodes in a full bridge configuration. However, this topology allows just two of three phases to provide power at one instant, while the third phase is inactive. The resulting current discontinuity causes problems in realizing ideal harmonics and power factor. To overcome this, all three phases must provide power simultaneously and the load must appear resistive for all three phases.

Figure 1 demonstrates the problem, showing essentially a perfect voltage sine wave (yellow) but extremely distorted current waveform (blue). When current waveform is distorted, power generation is disrupted because the circuit must conduct greater amounts of current where there is insufficient voltage. Designers must guard against circuits that draw power in this way. To ensure reliability and optimal performance, current waveform must be directly coincident with voltage waveform. Because the single-step topology draws power continuously from all phases, it meets this need and creates a perfect sine wave current in phase with voltage. In contrast to Figure 1, Figure 2 illustrates ideal resistance; current follows voltage and power factor is one.

Power Electronics Advancements

Single-step topologies are evolving power electronics design – providing unity power factor correction at full and partial loads, as well as rectification of three-phase AC input, regulation of DC output, and isolation of DC output from AC input, all in a single conversion step. Technical risk is low, size and weight are minimized, and costs are reduced for both development and long-term performance.

With rectification and power factor correction occurring in a single conversion stage, the device achieves an overall high power conversion efficiency of up to 96% including current harmonic distortion at 3% or less, automatic load sharing, and modular scalability. These attributes solve a cascade of costly problems for the power conversion engineer: no power is wasted, no heat is added to the conversion process, and no cooling equipment is needed to mitigate thermal impact. By realizing comprehensive improvements in power factor, harmonics, weight, and cost, OEMs can distinguish their own systems and equipment – capitalizing on high power conversion efficiency as a new opportunity for competitive edge and design innovation.

This article was written by Joseph Youssef, Senior Electrical Engineer, Marotta Controls (Montville, NJ).

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