MAROTTA®

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1-STEP™
AC-DC Conversion
Patent Pending

Three Phase Active Power Factor Correction in a Single Step

Isolated, Regulated DC Output in One Conversion Reduces Cost, Complexity and Risk

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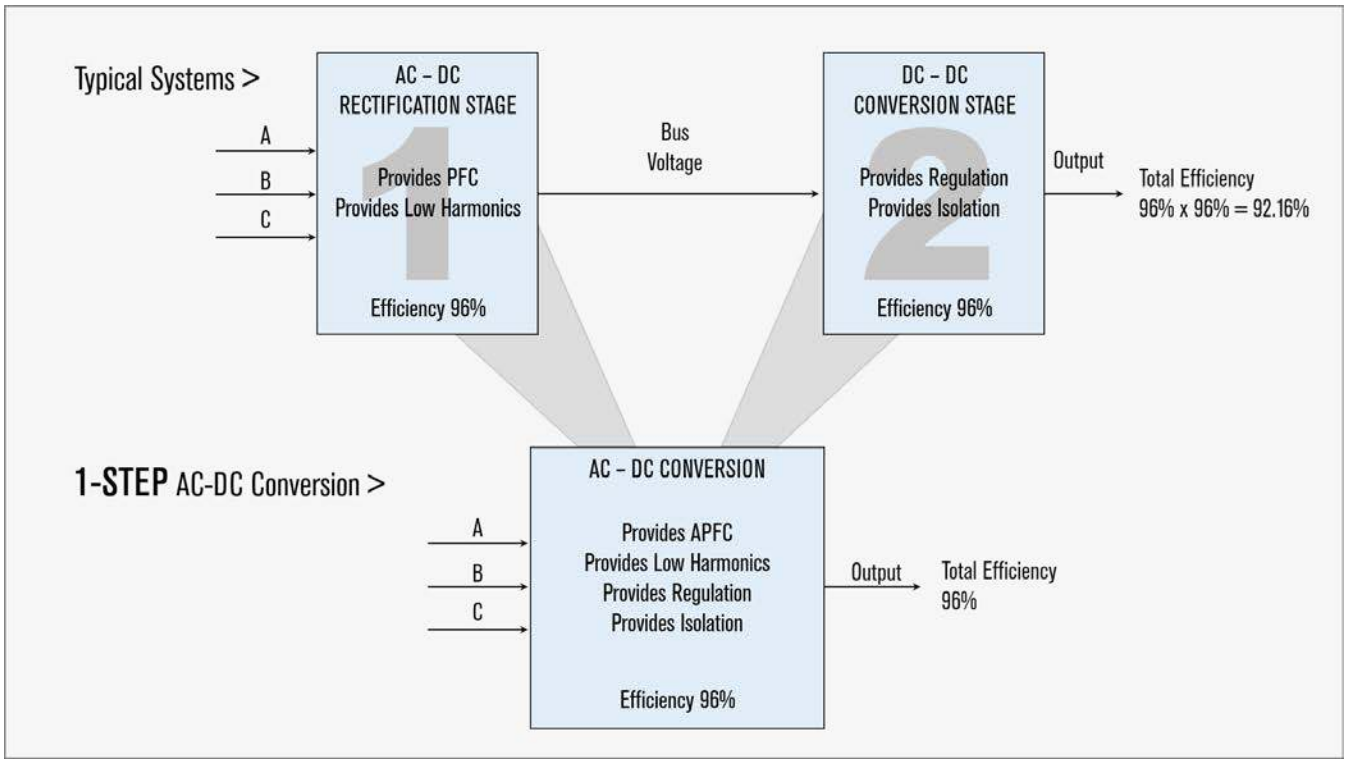
Rev 2015 09

Executive Summary

Military and industrial OEMs seek continuous improvements in power conversion in the extreme environments found in military, shipboard and aviation electronics. Multi-step regulation and isolation of electronic circuits is a complex and costly process that is commonly required for AC to DC conversion in high power applications, demanding close attention to performance requirements such as power factor and current distortion, as well as size, weight, efficiency and cost.

To solve these challenges for the power conversion engineer, Marotta Controls has developed its new patent-pending 1-STEP AC-DC Conversion™, an innovative new circuit solution that uniquely achieves three phase active power factor correction (APFC), power regulation and electrical isolation in a single conversion step. Marotta's new design ensures the highest power and efficiency while reducing costs. This report provides a brief technical overview of 1-STEP AC-DC Conversion, contrasting this new technology to existing conversion options such as auto transformer rectifier units (ATRUs) and Vienna rectifiers, offering quantified test results, and highlighting competitive value and ideal 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. Marotta's 1-STEP AC-DC Conversion Technology executes all stages in a single conversion step.

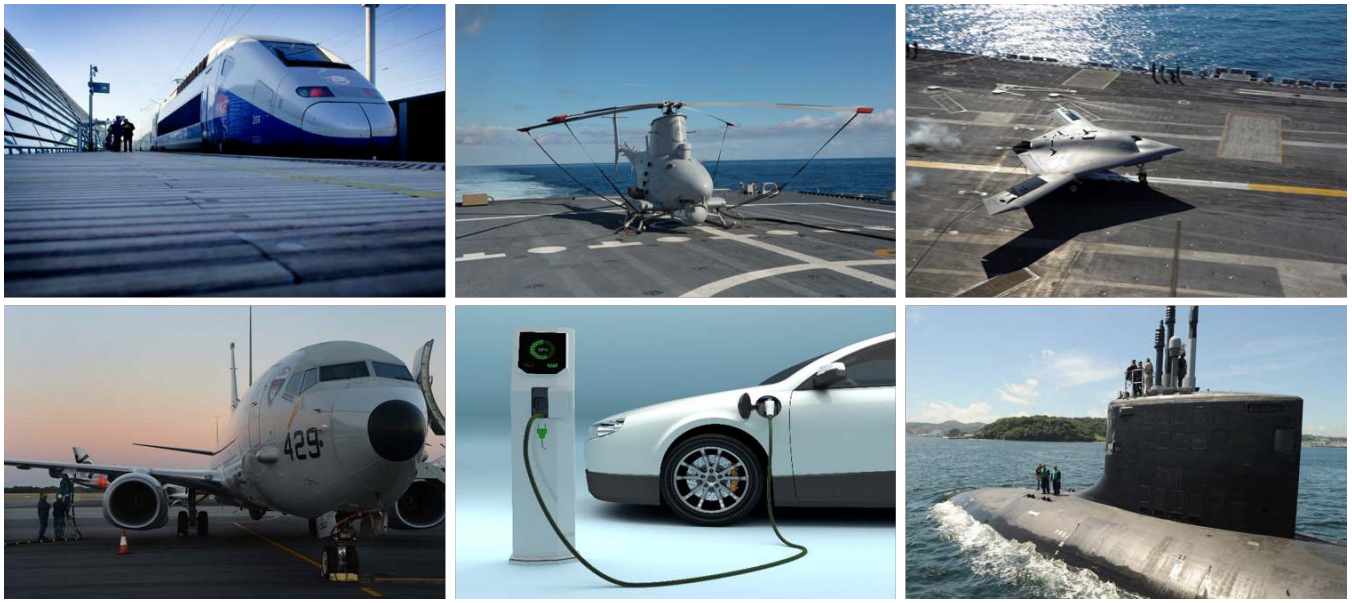
Three Phase Active Power Factor Correction in a Single Step

Isolated, Regulated DC Output in One Conversion Reduces Cost, Complexity and Risk

By converting three phase AC power to DC voltage for ready use in military and industrial applications, today's advanced power electronics circuitry is enabling the replacement of mechanical, pneumatic and hydraulic systems in mission-critical settings. The resulting improvements in Size, Weight, Power and Cost (SWaP-C) are driving advancements in military platforms, shipboard systems and commercial aircraft.

High performance power electronics must continue to improve, yet these solutions historically require a complex multi-step process to rectify AC to DC and further achieve regulation and isolation of output. While power factor correction and current distortion are key challenges in this process, existing conversion options such as auto transformer rectification units (ATRUs) and Vienna rectifiers can only solve these issues by accepting performance trade-offs that negatively impact weight, efficiency, size and cost.

To remove these limitations and improve performance of power electronics designs, Marotta Controls has developed 1-STEP AC-DC Conversion™, an innovative topology for three phase active power factor correction. Groundbreaking because it achieves regulation and isolation in a single step, 1-STEP technology not only simplifies complex circuitry, it creates a significant design advantage with reduced size and weight, extremely low harmonics (<3%) and unity power factor.



Electric circuits are replacing mechanical, hydraulic and pneumatic circuits at an unprecedented rate, enabling the rapid growth of new all-electric technologies such as those found in military and commercial aircraft, satellites, surface ships, submarines, automobiles, railroads and unmanned systems. This global trend towards all-electric is generating greater demands for efficiency in power conversion."

Defining 1-STEP

Devices for converting a three phase power input to an adjustable DC output generally include two steps: a rectifier stage for converting three phase AC input into a DC output, followed by a DC-DC conversion stage for adjusting 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 complex 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. 1-STEP represents a breakthrough in power electronics, meeting these needs with the same or better power efficiency than existing solutions, and uniquely offering three phase AC-DC conversion with regulated, isolated DC voltage in a single conversion step.

With 1-STEP, power electronics engineers are able to achieve extremely efficient circuit performance and eliminate the wasted power, weight, volume and cost associated with a second DC-DC conversion process. The more efficient 1-STEP circuit generates less heat, requires fewer components, and minimizes cooling equipment to manage thermal challenges – meeting the need for lighter, less costly systems.

DESIGN ADVANTAGES

- ✓ Provides APFC, Regulation and Isolation in a **SINGLE STEP**
- ✓ Reduces Size, Weight and Cost
- ✓ < 3% Harmonic Distortion
- ✓ > 96% Efficiency
- ✓ Unity Power Factor
- ✓ Output Voltage Can Be Stepped Up or Down
- ✓ Inherent Load Sharing
- ✓ Wild Frequency Input
- ✓ Output Power from 1k to 200k

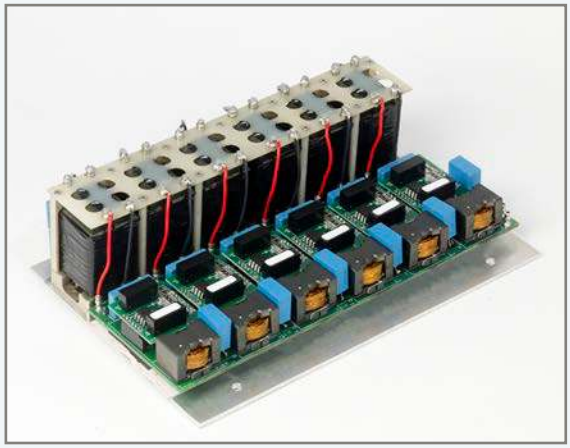


Figure 1: Shown is a 3kW version of Marotta's new patent-pending 1-STEP AC-DC Conversion™ Technology.

1-STEP 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 on the single DC output.

Regulation and isolation are handled in one step, maintaining total power efficiency at 96%. The resulting high power efficiency means less power to dissipate, resulting in lighter weight and lower costs.

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.

Challenges of Rectifying Three-Phase Power

The goal of rectification is to provide isolated, regulated DC output, free of input harmonics and with unity power factor. Key challenges – power factor correction, electrical isolation and input current distortion – consume engineering resources during the design process; the ideal result is high conversion efficiency in order to reduce weight and space required by the power solution.

Power Factor Correction

In many applications, and particularly high power applications, power conversion circuitry ideally provides power factor correction (PFC) to ensure high power efficiency and to minimize the input current. PFC is required to reduce overall current for a given power requirement, and prevents harmonic currents from distorting the supplied power waveform. As a result, both input voltage and current waveforms are kept in phase and maintain the apparent power of the three phase power input. 1-STEP enables unity power factor of one at both full and partial loads.

Electrical Isolation

Electrical isolation may be necessary, protecting 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. Marotta's 1-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; the device incorporates six 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. When using a fullwave rectifier topology, even if the load is resistive at the output of the bridge, these challenges still exist for the power electronics engineer.

Figure 2 below demonstrates the problem, showing essentially perfect voltage sinewave but extremely distorted current waveform, presented in blue and yellow. 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 optimize overall performance, current waveform must be directly coincident with voltage waveform.

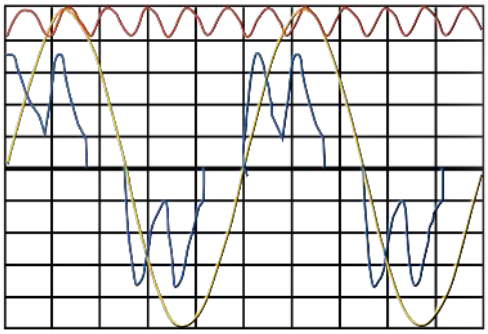


Figure 2: Demonstrates the problem without PFC, showing essentially perfect voltage sinewave (red) but extremely distorted current waveform (blue and yellow).

Because Marotta's 1-STEP circuit draws power continuously from all phases, it meets this need and creates a perfect sinewave current in phase with voltage. In contrast to Figure 2, Figure 3 below illustrates ideal resistance; current follows voltage and power factor is one.

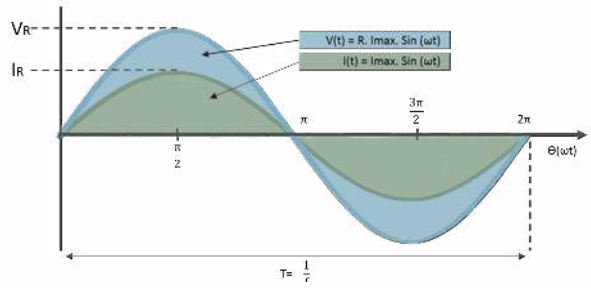


Figure 3: Demonstrates ideal resistance; current follows voltage and power factor is one.

Scalability and Modularity Advantage

1-STEP technology enables a significant advantage with its use of a single controller for all converters in the circuit. Load sharing is inherent, as 1-STEP's single DC output is regulated by the control circuit without the need to perform load sharing techniques or receive a current measurement. Costs and complexity are reduced dramatically, as the circuit eliminates the resources required to engineer separate controllers for each phase. This is in contrast to circuits without inherent load sharing, which need multiple feedback controls. 1-STEP handles this process by sending a single pulse width modulation (PWM) signal to all converters on the circuit, requiring no extra work for current sensing or load sharing. Because of this load sharing advantage, the 1-STEP circuit can easily link multiple 3kW modules to achieve 6kW, 9kW, 12kW, 15kW performance and more.

Solution Comparison Chart

	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 60HZ	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

Passive Power Factor Correction: Passive power factor correction keeps costs down with the absence of active components, but requires increased inductance and capacitance. Solutions are heavy and limited to low power applications ranging from a kilowatt to ~1500W.

ATRUs: ATRUs offer no regulation or isolation, requiring a more difficult second DC-DC conversion. Solutions are costly and impractically heavy for SWaP-conscious, high performance applications. ATRU power density is just 444 watts per pound, while 1-STEP's may be as high as 930 watts per pound.

3 PFCs + DC-DC: Three lines of single phase power can be used; 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 complex, requiring nine independent control circuits working together – one for each single phase PFC, DC converters and load share circuits.

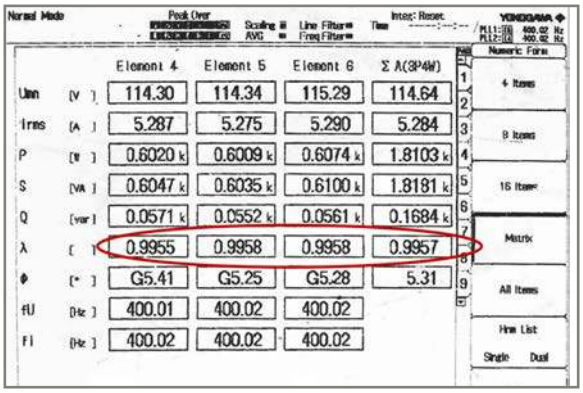
Vienna Rectifiers: Vienna rectifiers are complicated, with three switch-controlled rectifier circuits. A single control circuit uses complex calculations to determine a separate control instruction set for each rectifier. Vienna offers no isolation and can only regulate to 350 volts and above without a second DC-DC conversion.

1-STEP AC-DC Conversion Technology represents a significant advancement over existing rectification technologies.

Test Results for 1-STEP AC-DC Conversion™ Technology

All tests were performed with the 3kW version of 1-STEP.

Power Factor Correction

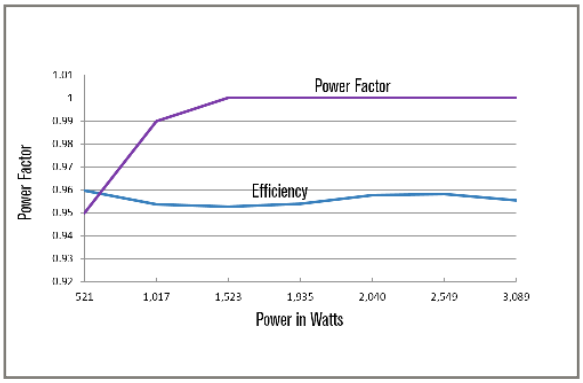


Testing was conducted using a calibrated power analyzer Yokogowa WT1800. As shown above, power factor is at 0.9955 at 60% of the load.

Harmonics Test

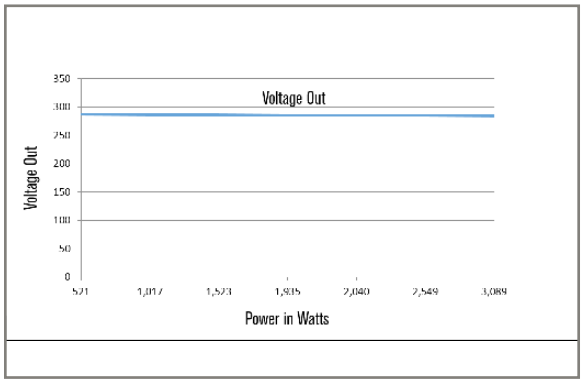
Testing was conducted using a calibrated power analyzer Yokogowa WT1800. As shown above, Total Harmonics Distortion (THD) is 2.1% The fifth harmonics is 1.448%. All single harmonics are shown.

Power Factor & Efficiency vs Load



Unity power factor was achieved quickly and remained steady. Not only is unity power factor achieved at full load, it is achieved at 30% load.

Output Regulation vs Load



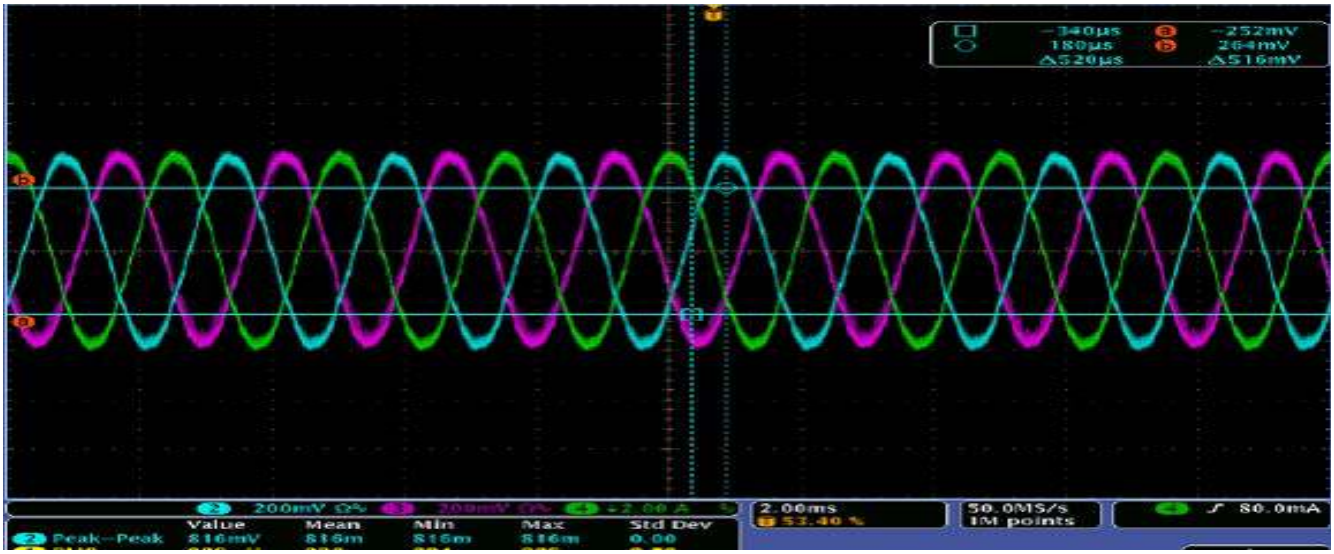
Over the entire load range, the output regulation remains constant, fluctuating within one-half of one percent.

Test Results for 1-STEP AC-DC Conversion™ Technology

All tests were performed with the 3kW version of 1-STEP.

Input Current in Phase with Input Voltage

3 Phase Input Current



1-STEP is Validated for High Performance Power Applications

As more and more heavy mechanical, pneumatic or hydraulic parts are being replaced with electrical equivalents, improvement in circuit performance is essential. Reducing cost and size, minimizing moving parts and complex control circuits, and removing risk from the development equation are key power performance issues for OEMs designing mission-critical applications. In these scenarios, the elegance of Marotta's 1-STEP technology outperforms existing power electronics options – streamlining circuit design, improving performance, and reducing weight.

A range of industry certifications ensure that 1-STEP is proven to military and commercial performance standards for electronic devices. 1-STEP is validated for conducted emissions via the CE101 requirement of MIL-STD-461, the standard defining general requirements for electromagnetic interference and compatibility (EMI/EMC) for all electronic, electrical and electromagnetic equipment and subsystems procured and used by all branches of the Department of Defense (DoD).

1-STEP's validation to MIL-STD-1399 (Naval) further ensures the circuit meets the required characteristics for shipboard equipment using AC electric power. 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. 1-STEP is a valuable addition to this landscape, based on its features, compact size and high density performance. Using a 60Hz application as an example, 1-STEP offers a size and performance advantage in contrast to a magnetics-based solution such as an ATRU or Vienna device containing large inductors.

To ensure compliance with military and commercial aviation needs for electronic equipment compatibility and safety, 1-STEP is also validated to MIL-STD-704 for military aerospace compatibility as well as the RTCA-DO160 specification, the commercial avaition industry's standard for environmental requirements, including power quality. 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 unity power factor.

Better Performance and Competitive Advantage with 1-STEP

Marotta's 1-STEP technology is a groundbreaking solution, addressing the evolving real-world needs of power electronics for military and industrial applications. Unlike any existing solution, 1-STEP provides 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 the DC output from the AC input – all in a single conversion step. Circuitry is simplified, size and weight are minimized, and costs are reduced for both development and long-term performance. Because 1-STEP provides rectification and power factor correction 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.

Technical risk is low, as the device is validated for performance in compliance with a range of rigorous military and industrial electronics standards. These attributes provide a high performance and affordable alternative to less efficient solutions that generate a cascade of costly problems for the power electronics engineer – no power is wasted, no heat is added to the conversion process, and there is no need for cooling equipment to mitigate thermal impact. By realizing 1-STEP's 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.

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INVENTION CREDITS

1-STEP AC-DC Conversion Technology was invented by
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