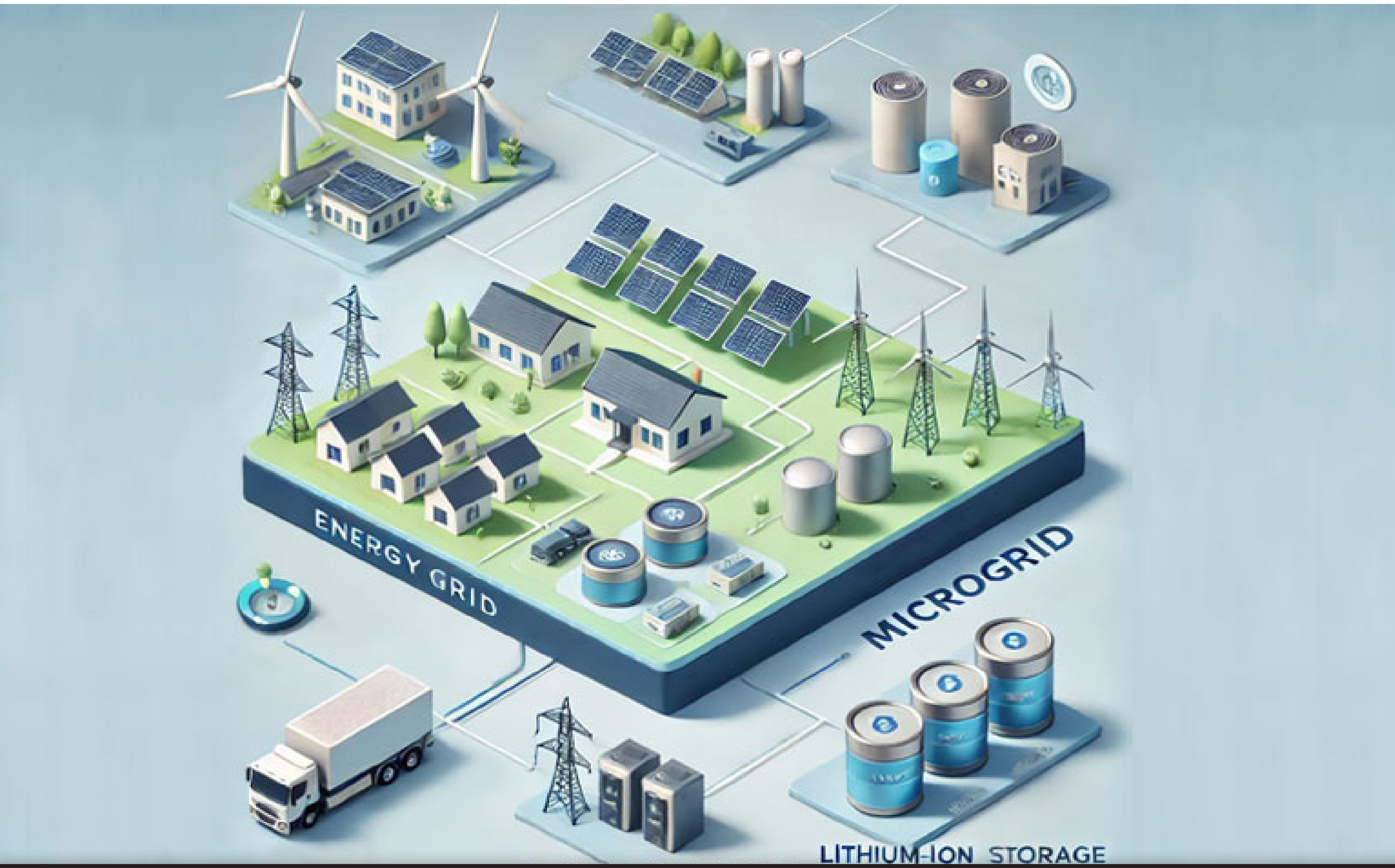
DC MICROGRID POWER SUPPLIES: UNIVERSAL SOLUTIONS FOR INDUSTRIAL AUTOMATION



Mains electrical distribution in buildings varies by voltage levels and specifications based on factors like application needs, safety, and history. For AC distributions, nominal voltage and frequency are key, with global standards influencing the different voltage levels.

WHITEPAPER: 01/2025

TABLE OF CONTENT

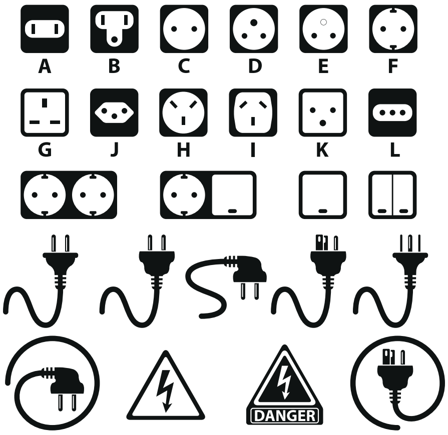
LIST OF FIGURES

INTRODUCTION

We are used to the mains electricity coming out of our wall sockets being AC (Alternating Current), but this was not always the case. In the early days of electricity, Direct Current (DC) was also widely implemented. The history of the AC versus DC battle between Edison and Tesla is well-documented [1], with Tesla's AC solution ultimately becoming accepted worldwide. Today's dynamic industrial environment calls for unprecedented flexibility and efficiency in power supply solutions, and DC is returning as an option, especially as many green energy systems, such as solar panels and house batteries, are DC-powered.

AC VERSUS DC POWER IN BUILDING DISTRIBUTIONS

When it comes to mains electrical distributions in buildings, one can find a whole slew of different voltage levels, specifications, form factors, and tolerances. The majority of the logic for determining either an AC- or DC-distribution's requirements can be based on application needs, safety, economics, history, and ideally pragmatics. Even if we just focused our discussion on AC distributions, there are many different voltage levels/ranges dictated by any number of global standards. The very basic traits that define a voltage bus are its nominal voltage and frequency characteristics (maximum currents are more applicable to sizing conductors, infrastructure, etc.). A quick overview of global AC mains [2] is summarized in figure 1.



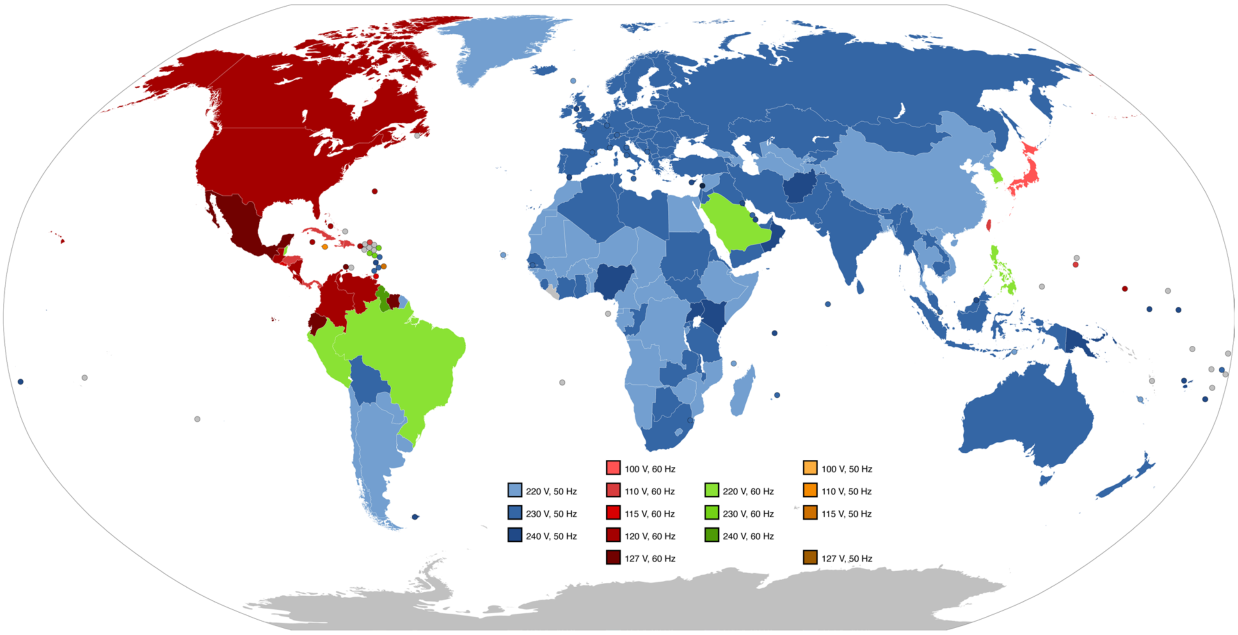
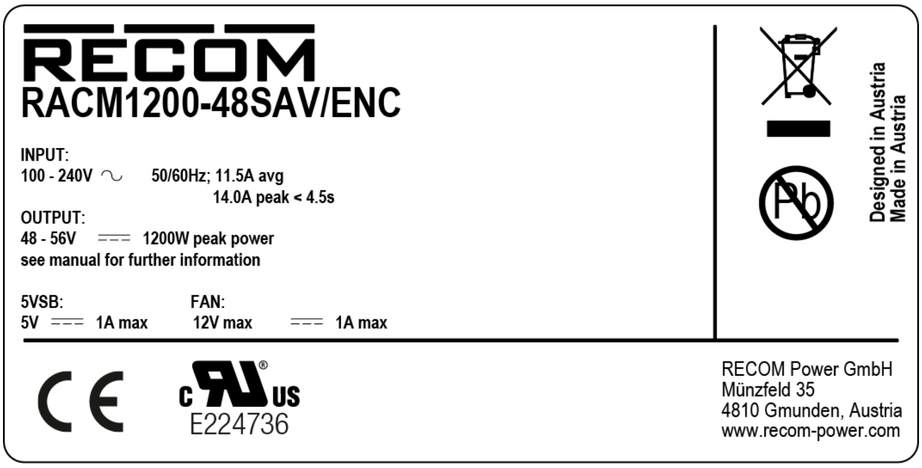


Figure 1: Mains electricity by country and, especially for continental Europe, Public Domain, https://en.wikipedia.org/wiki/Mains_electricity_by_country

Providing a stable, well-regulated gate voltage supply, independent of the main power supply, is another benefit of isolated DC/DC converters. In typical gate drive circuits, the primary supply derives the gate voltage using a linear regulator or a bootstrap circuit. Linear regulators, while simple to implement, tend to have poor efficiency and greater power dissipation when there is a large difference between input and output voltages. Excessive power dissipation can lead to thermal management issues and may require additional heat sinks or cooling solutions. Bootstrap circuits, on the other hand, rely on a charge pump mechanism to provide the high-side transistor's gate voltage in a half-bridge configuration. As such, carefully size the bootstrap capacitor to ensure an available sufficient charge to drive the transistor's gate over the entire on-time. The duty cycle and switching frequency can affect the circuit's performance, leading to voltage droop and instability.

Careful observation of the global voltage levels yields an overall range of 100-240VAC at either 50 or 60Hz, which leads one to believe if we have a single power supply capable of supporting the full voltage/frequency ranges, then it is universally-compatible with any AC source, but this is not the case. See the example image of a power supply safety label below, which one can find on any certified, shipping, international solution in figure 2.


RECOM
RACM1200-48SAV/ENC

INPUT:
100 - 240V ∿ 50/60Hz; 11.5A avg
14.0A peak < 4.5s

OUTPUT:
48 - 56V ⎓ 1200W peak power
see manual for further information

5VSB:
5V ⎓ 1A max

FAN:
12V max ⎓ 1A max

Designed in Austria
Made in Austria

C US
E224736

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4810 Gmunden, Austria
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Figure 2: RECOM AC/DC Power Supply Safety Label (Example)

It may seem natural to want to support as wide of a range as possible, but as with anything in life (especially power) there are tradeoffs we must make to optimize a solution for a given application or use space. There are also tolerances that must be built into all designs to account for non-ideal situations. In terms of voltages, this can be related to protections for overvoltage scenarios (typically related to personal safety in addition to protecting equipment), undervoltage scenarios (maximizing uptime, also for equipment protection), and balancing of phase currents in multiphase solutions. For line frequency, this can be related to power quality and grid stability. How these protections/mechanisms are achieved and why are beyond the scope of this discussion, but are covered extensively in the RECOM "AC/DC Book of Knowledge: Practical tips for the User" [3] document freely available. When we take a common tolerance figure of ±10%, it quickly becomes obvious how we can define a universal range of 90-264VAC, 47-63Hz that is seen on many power supply safety labels. This was merely a quick example to demonstrate how we get from so many international standards to consolidated ranges for more universal support, but is very general and does not go into the motivations for any given mains specifications. There are other support ranges specific to military and/or industrial applications, such as a 400Hz standard for aircraft/shipboard power. Multiple, single-voltage sources can also be separated by phase angle to maximize power delivery, while minimizing currents, which can be seen in three-phase AC systems.

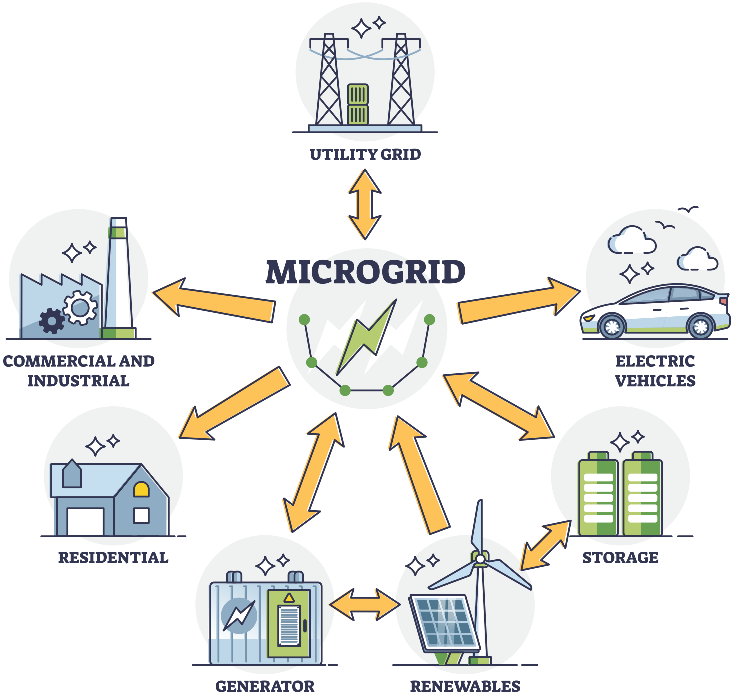
Ultimately, most end systems and loads will run off of DC power (AC motors being the glaring exception), which is why there are even more standards for DC voltage supplies than AC, though not typically for facilities/building-scale distributions. High voltage is defined as >1,000/1,500V (AC/DC, respectively) though pretty much anything >=60VDC is considered a higher voltage for safety purposes (human contact), also known as Safety Extra Low Voltage (SELV). While no one standard exists (actually numerous worldwide) for what is commonly known as the high-voltage data center (HVDC, not to be confused with direct current), there are many different standards to call out a distribution architecture in the 300-400VDC range. The logic is if server/networking hardware and supporting infrastructure is all designed to support a universal AC input with a power-factor-correcting (PFC [4]) AC/DC power supply, then all the same equipment can handle the DC voltage derived from the rectified, AC-input waveform, thus justifying the mitigation of a conversion stage (and all that is gained by its removal). 24VDC distributions can be common for industrial settings with small relays/breakers/motors and smaller systems optimized for a standard, mechanical form factor, such as the DIN rail [5] standard. Other well-known DC distributions include the universal serial bus (USB, 5-20VDC) and Power over Ethernet (PoE, 44-57VDC), also combining power with data conductors in hybrid cables.

The choice of a main distribution voltage for a facility is driven by many factors related to decisions driving capital and operational expenditures (CAPEX/OPEX, respectively), not merely what equipment is supposed to plug into it. Safety is nearly always a key factor determining distribution architectures and must be considered based on worst-case expectations for operator exposure, conductor-to-conductor spacing, and constraints of the operating environment. Consolidation of voltage distribution bus architectures offers many advantages in the streamlining of equipment purchases (CAPEX) and efficient utilization of equipment/machines (OPEX). The less conversion stages from upstream source (i.e. – utility grid, energy storage, etc.) to end load (i.e. – system, ASIC, motor, etc.), the more to be gained in terms of streamlining equipment purchases and taking advantage of economies of scale. Commonality can also help mitigate net load dynamics, which enable optimization of energy efficiency by narrowing unpredictability and therefore enhanced opportunity for intelligent power management (IPM [6]) techniques.

A common mains or distribution carries far more benefits than can be comprehensively reviewed here, but should be recognized is some other categories. The ability to have a more predictable maintenance schedule and fewer part numbers to manage can offer significant savings in short- and long-term expenses. Reduced number of parts to replace/manage carries many obvious advantages that ripple from saving user cycles at the point of consumption to reducing overhead and shipping costs for replacements.

As we transition to Smart Buildings and factories of the future, getting the best of both configurability and agile changes with common form factors is critical for success. From a Quality perspective, systems (particularly components and motors) will last longer when they can function in more-constrained, predictable operating/environmental conditions and maintenance cycles. These first-order benefits lead to an immense list of second-order benefits, depending on far deep one wants to analyze. For instance, a common distribution may mitigate costly back-up power and/or energy storage solutions that would otherwise need to act as energy buffers for intermediary voltages. If the entire power delivery solution gets just a couple percent more efficient in commutating input-to-output power, then there is justification from CAPEX savings that ripple all the way from the point of load up to the power plant.

DISTRIBUTED ENERGY RESOURCES (DER) CHANGE THE LANDSCAPE



The concept of distributed energy resources (DER [7]) is not a new one, but is being adopted in a modern sense to enable a transition to a more sustainable world. The idea is to have many smaller, modularized, total utility solution blocks (i.e. – source, distribution, conversion, storage, etc.) that are confined for control and use, also known as a microgrid. Microgrids of DERs are typically characterized by their ability to operate completely independently (known as "stand-alone" or "islanded" mode) or also be compatible when grid-connected (NOTE: the term "compatible" is highly broad and was intentionally chosen for this context because the extent of compatibility can be a very large discussion of hardware compatibility and regional regulatory requirements.).

The majority of technology to transform the grids of yesteryear to the smart grids of intelligent power management of tomorrow exists and has been around for many years, but the macroeconomic motivations required to make a multigenerational shift to upgrade utility-scale power infrastructure still seem to evade most governments and even the most-developed nations. Photovoltaic (PV) solar panels have been commercially available for nearly 50 years now, but the grid infrastructure to make the most use of a bidirectional flow of power management is a newer concept. Unfortunately, investment in advanced energy storage technologies tends to lag investment on the load side (faster, cheaper systems).

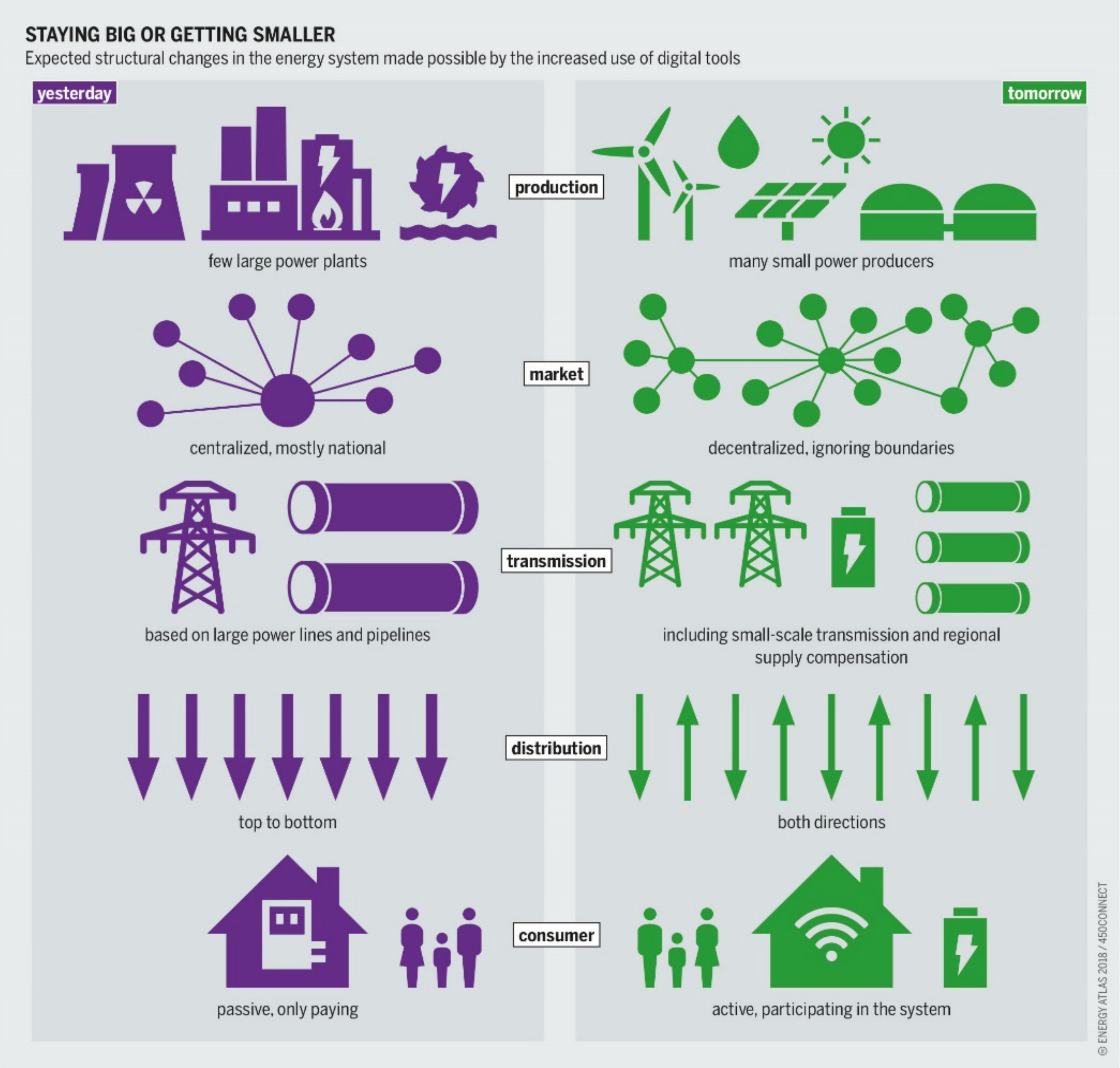


Figure 3: Centralized (left) vs distributed generation (right), Chronological Comparison, Graphic: Bartz/Stockmar, CC BY 4.0

The application of energy storage in multiple use cases for both critical energy backup and economic maximization of intermittent energy sources (such as wind or sun) are also forcing new thinking for consideration of upgrading existing resources and creating future-proofed facilities for the foreseeable future. The modular nature of a DER means any energy storage needs can also be right-sized to the application as well as disaggregated from bulk needs. Furthermore, this should be applied in different aspects of energy storage implementation. For instance, storage can provide a purely economic function by storing excess, renewably-generated energy when there is plentiful wind and sun and the real-time cost of energy is low, then wait to sell it back to the operator when the cost is high. Then there are the more traditional functions of critical energy backup and emerging functions, such as using for “peak shaving” or servicing infrequent energy peaks with localized storage so the overall infrastructure (e.g. – “virtual power plants”) can be designed to more of a max steady-state than an absolute, max peak (yields very significant CAPEX and OPEX savings potential).

DERs have the ability to completely upend the economics of electric utilities as we know them today. Traditionally, the time-based relationship of grid energy sources over the course of a day follows what is known as a “duck curve” [8] because the bimodal distribution of peaks at the beginning and end of a common day form a shape resembling that of a duck’s back. Electrical economics assume peak demand at these points of the day, with lulls in between. What happens when all devices become “smart” and have the ability to optimize their source utilization during the lulls in the curve? From a controls system perspective this eventually becomes a paradox. The otherwise predictable characteristics of the duck curve give way to a scenario in which large numbers of loads can wait for the traditional lull and once aggregated enough, will flip the duck curve right on its head!! What does this do for the dynamic energy market that sees the cost of power change several times an hour based on demand?

The issue of grid economics is more of a problem for grid operators, regulators, and lawmakers, but the ability to quickly adapt to changing macro and micro utility scenarios is one of the things that make DERs so attractive and impactful. Moving from a centralized to a modular infrastructure enables agility for both grid operators and lower-level users to adapt to vigorous changes in sources and loads and do so by the virtual reappropriation of energy resources instead of the painfully-slow process of macro infrastructure upgrade.
Though it is clear and established that utility grid infrastructure will not change overnight, modularity and intelligence in systems and loads can help bridge this gap. Furthermore, advances in power electronics such as wide-bandgap power semiconductors and the integration of microcontrollers and energy storage (all enabled by fantastic advances in power packaging technologies) continue to enable the exploitation of DERs and modularity in power systems. Power supplies can accept ultra-wide-input-voltage ranges without having to make major sacrifices in terms of efficiency, density/space, and form factor.

Everything electrical and electronic in the world requires power to operate so it also makes sense that power should be the most adaptable, amenable resource. It seems the most ideal situation will be a ubiquitous infrastructure of that perfect AC or DC voltage with a single plug used by all devices. That infrastructure is run on DERs so can make the most (economically) from being grid-tied, yet still have the confidence in reliability to maximize renewable energy sources, while being able to service any kind of system, device, or motor. Given several of these idealities are in direct conflict, it seems the best compromise is to design as much modularity into the power subsystem as possible since it sits right in the middle of all sources and loads.

Even if it were somehow possible to find the best of all worlds, then it would still be for a mere snapshot in time. Unless you already have the ultimate in AI-driven architectures and digital twins (“Terminator” meets “Tron”?!?), even the Smart Factory of today is not enabled to be tomorrow’s Factory of the Future. It is natural to drive commonality on the load side (i.e. – 3.3/5-V transistor–transistor logic or TTL), but tends to be more generalized on the source side as described above.

A more novel, monumental change could be commonality on the input-voltage side of systems, which implies the ideal target for such intelligence is in the system power supply. Architecting the universal factory of the future requires new thinking that starts with the power distribution infrastructure. Why gamble on choosing the best power architecture(s) for the lifetime of a Smart Factory and not make your objective to be compatible with, and make highly-efficient utilization of, them all?

SIMPLIFYING & CONSOLIDATING POWER INFRASTRUCTURE

There is a ton of value, and therefore motivation, to consolidate power infrastructure in most scenarios. Multiple stages of voltage conversion are used for any number of reasons. The main one being that stakeholders all along a power value chain (PVC [9]), or energy flow across all the distribution/conversion steps between source and load, are very siloed from each other. *Figure 4* shows an example of a PVC in the world of 5G&Beyond, which combine utility generation/transmission with conversion steps for supporting different infrastructures (i.e. – data center, telecommunications, wireless edge, etc.). While outside the scope of this discussion, this PVC concept also introduces the unitless metric, power cost factor (PCF [9]), to assess the cost of power at the point of utilization within a PVC. If people do not talk (e.g. – intentionally siloed for competitive edge), then how can they learn to be compatible with one another? More specifically, if businesses are not economically-motivated (e.g. – euphemism for “forced”) to be harmonious, they will not consider it. This proves true even amongst the conflicted, separate stakeholders responsible for CAPEX and OPEX under a common umbrella (Infrastructure Architect at odds with Facility Manager of same company...first role is to minimize CAPEX, where second role is to minimize OPEX).

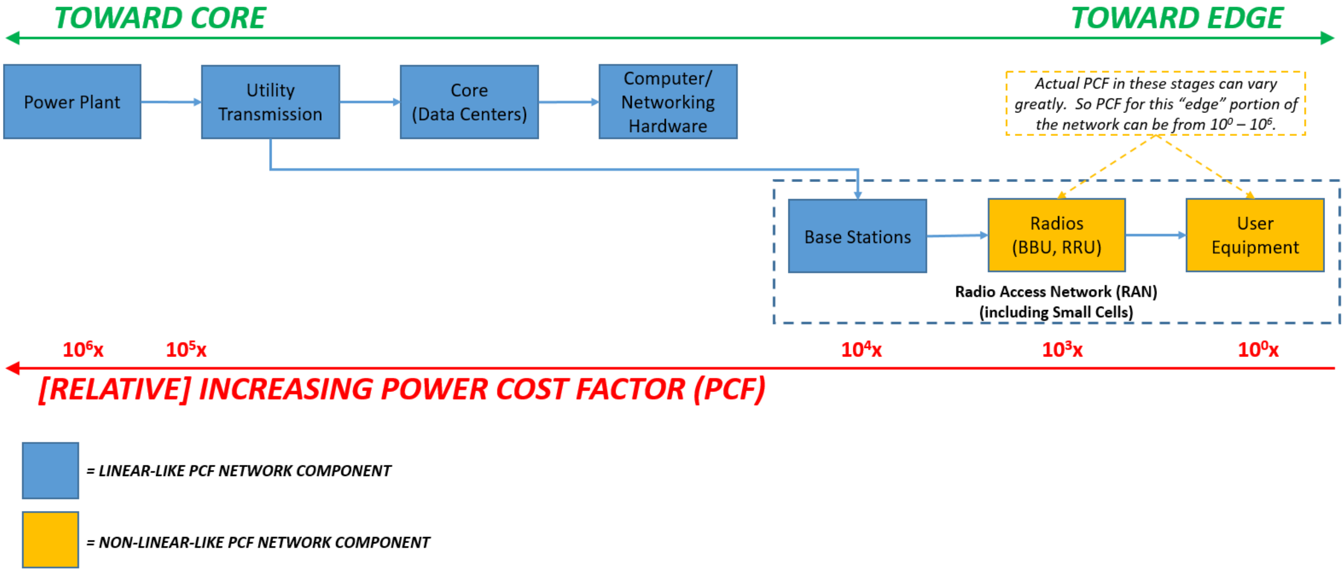


Figure 4: A Power Value Chain (PVC) for a 5G & Beyond Deployment, Graphic: [9]

Each power conversion/commutation stage yields a cost in many ways. There is the obvious CAPEX of extra hardware resources, but how we pay in many other ways may not be as apparent. This was hinted to earlier in discussions of the opportunities for CAPEX/OPEX savings via the consolidation techniques described in this paper. Perhaps this is best exemplified in the oversimplified diagrams of *figures 5 & 6*, which show how the complete mitigation of intermediary voltage conversion and energy storage stages streamline the infrastructure. These may be cartoon boxes, but each represents a significant stake in CAPEX and OPEX associated with supporting each substructure.

Data Center Power Architecture (Legacy) Block Diagram

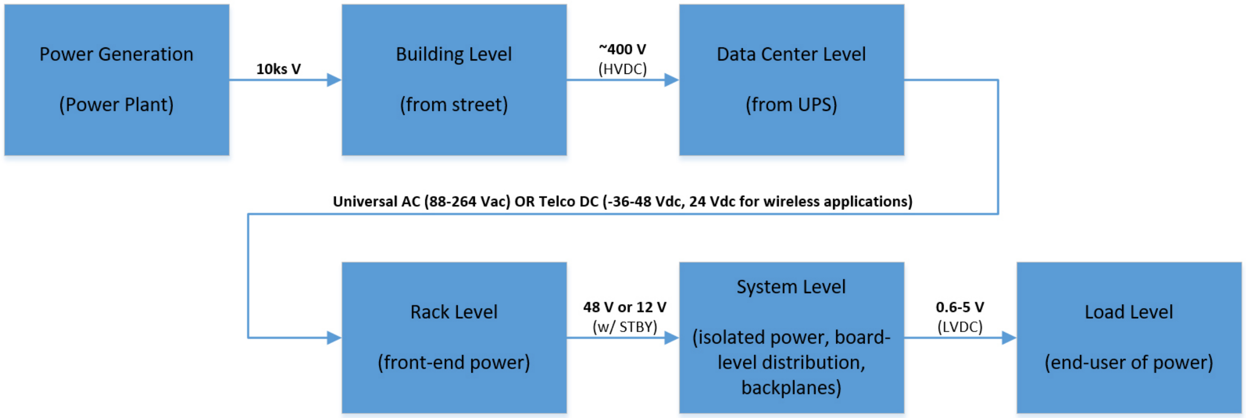


Figure 5: Data Center PVC w/ Legacy Power Architecture, Graphic: courtesy of PowerRox

Data Center Power Architecture (Consolidated) Block Diagram

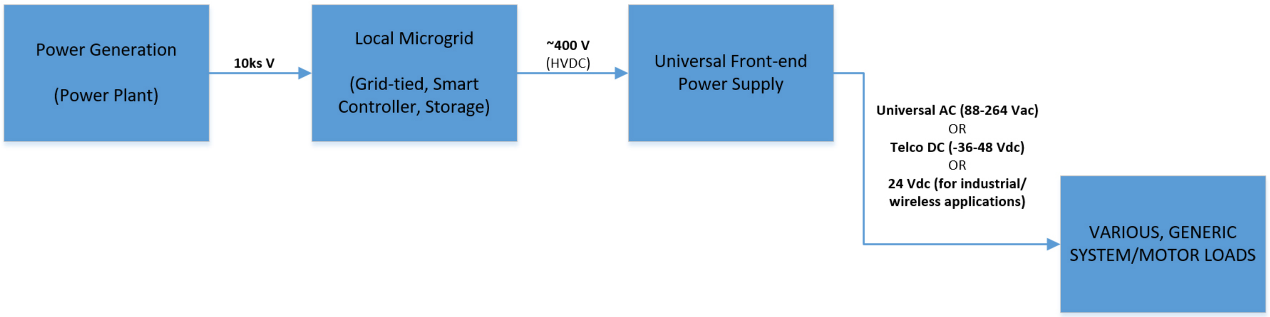


Figure 6: Data Center PVC w/ Improved, Consolidated Power Architecture, Graphic: courtesy of PowerRox

In order to start getting an idea of how quickly the savings of consolidation add up, then see *figure 7*, which breaks down many of these stages and characterizes by their efficiency losses. Even starker is when one looks at the PVC holistically and sees the end-to-end impacts of each stage’s losses (red box/text in figure).

When assessing the prospects for savings in both CAPEX and OPEX, one should also be careful not to get too swept up in generic guidance. For instance, a machine shop running hundreds of small motors will not yield the same savings from identical changes applied to a large data center. The real key variable is the cost of power and how dynamically it is exploited. An infrastructure with many, small, intermittent loads will benefit more from consolidation of loads, which still roll up to a more consolidated power distribution architecture. Conversely, an infrastructure with larger and/or more consistent, steady loads can be highly optimized with a decreased variability in power sources that can utilize enhanced energy storage to take more economic advantage of the changing costs of the real-time energy market.

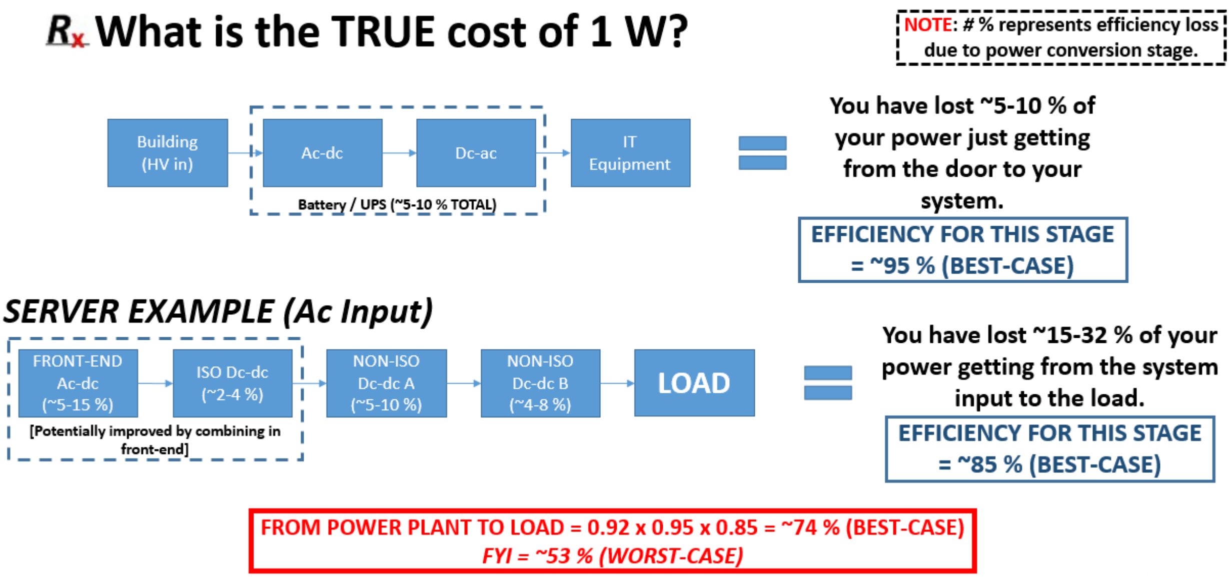


Figure 7: Data Center PVC w/ Efficiency Losses of Each Stage, Graphic: [10]

SUMMARY/CONCLUSIONS & FOLLOW-ON INFO

With great power resource options come great responsibility for controlling and exploiting them in an intelligent manner. The opportunities afforded by a TRULY-universal power supply that can accept a wide range of AC- and DC-inputs opens the doors to a level of streamlining and consolidation not previously thought possible.

DERs have completely decentralized and disaggregated energy grids so they can be sized to their needs, both in the sense of power delivery and economic optimization. The increasing incorporation of DERs into the grid sends us all racing toward sustainability targets, which can be in conflict with uptime requirements for reliable power on legacy, unidirectional grid flows. At the same time, they continue to add control so sustainable energy can be tapped at full potential and applied without sacrificing quality and reliability.

Learn more about how RECOM is revamping industrial power electronics to enable future-proofed power supply infrastructure with their RECOM RACxx-SK/480 series here. These Class II power supplies (no earth connection required) can operate from 85-526VAC or 120-750 VDC - covering 100VAC, 115VAC, 230VAC, 277VAC, and 480VAC mains supplies as well as high voltage batteries.

Figure 8: RECOM's RACxx-SK/480 Series

Reconfigurability yields the market agility that companies will need to adapt to the needs of a Factory of the Future or Smart Factory. It is the dream of any Facilities Manager to have a single, harmonized power infrastructure, where all equipment plugs into a common interface that can be quickly installed from place to place without having to put much thought into the voltage distribution network (or the many, ensuing CAPEX/OPEX implications detailed above). Why make the difficult decision on the hard pros or cons that come along with selecting a traditional AC- or DC-input distribution when you can potentially have the best of all worlds?

The concept of an industrial DC grid is that many electrical drives and equipment in existing AC installations already use DC internally. For example, variable frequency drive (VFD) inverters are commonly used to control the acceleration, speed, and deceleration of AC motors, but internally they consist of an AC to DC converter followed by a variable frequency DC to AC converter. Operating VFDs from high voltage DC eliminates the inefficiencies of the input AC to DC converters, which multiplied by all the variable speed motors, fans, conveyor belts and other rotary equipment needed in a factory means considerable overall efficiency savings.

In addition, DC microgrids can be used to interconnect these DC powered links with each other as well as with DC storage batteries and renewable energy supplies such as solar power (which is inherently DC) and a bidirectional connection to the AC supply grid. The use of bi-directional VFDs also enables the recuperation of energy within the DC grid rather than wasting energy in motor braking resistors. On-site energy storage within the DC installation also provides power outage ride-through capacity, thus reducing factory downtime significantly. The stored energy provides an efficient way to reduce peak infeed power from the supply grid - in one case, 80% reduction of infeed power was reached – 50kVA for DC rather than 450kVA for AC ([1]).

The typical operating voltage of DC microgrids is 600V to 750VDC when the connection to the AC grid is made with a bi-directional active infeed converter (AIC). For an uncontrolled AC rectifier, the DC voltage range is from 485V to 750VDC.

RECOM is ready to meet the challenges of rewiring existing and building new factories based on the DC Microgrid concept with the RACPRO1-T series. The units are designed to operate from triple phase 400VAC/480VAC (3x323VAC to 576VAC) or from a nominal 650VDC input (480V to 850VDC), meaning that they are compatible with existing three phase power grids, AIC generated DC microgrids and uncontrolled AC rectifier supplies. The high surge immunity of 2.5kVAC/6kVDC handles load dumps, switching transients and power surges that can be expected to occur in a harsh industrial environment and the exceptionally long design lifetime of 80khrs (40°C) mean that a long operational life can be expected.

The whole point of the DC Microgrid concept is to maximize efficiency, so the RACPRO1 also feature technology leading conversion efficiencies of up to 97.1% and active inrush current limitation to reduce losses due to overloading the power supply wiring during system power activation. Many industrial loads also require higher start-up current than their nominal operating current. It is more efficient (and cheaper) to select a power supply that can safely handle temporary overload conditions than it is to over dimension the power supply to cope with worst case short-term load. The RACPRO1 can deliver a power boost of 150% for up to 5 seconds, plus a long-term bonus power of 120% up to 45°C ambient. The high temporary output overcurrent capability means that if secondary side fuses or circuit breakers are used that they safely trip before the power supply goes into short-circuit protection.

Despite their advanced specifications, the RACPRO1 series are exceptionally compact slim design power supplies needing only 43mm (240W), 52mm (480W), or 80mm (960W) of DIN-rail space. Assembly is also quick and easy with tool-less mounting and demounting and streamlined push-in 25° cable connectors. Full output power is available over a wide ambient temperature range of -40°C to +60°C, making the power supplies ideal for both inside or outside locations or for use in unheated warehouses. If more power is needed or a redundant power supply system is needed, the RACPRO1 outputs can be paralleled.

Figure 9: RECOM’s RACPRO1-T series

For PCB-mount applications such as an on-board auxiliary power supply for bidirectional AICs, battery chargers, power flow monitoring, motor condition-based monitoring or smart metering, RECOM also offer the RAC05-SK/480, RAC15-SK/480, and RAC25-SK/480 with 5W, 15W and 25W output power respectively, and standard output voltages of 5V, 12V, 15V, or 24VDC.

These compact power converters operate over an extra wide input voltage range of 85-528VAC or 120-750VDC, making them suitable for standard phase-to-neutral connection (100VAC, 120VAC, 230VAC, or 240VAC), phase-to-phase connection (277VAC, 400VAC, or 480VAC) or DC microgrid supplies (485 – 750VDC). They are certified to Over-Voltage Category III and pollution degree PD3 for installation in industrial switchgear cabinets, with constant high efficiency over a wide load range, low no-load power consumption of <300mW, and -40°C to +60°C ambient temperature operation without power derating.

Full certification (including CB report) to the global safety standards UL/ IEC/EN62368-1, CSA52368-1-14, IEC/EN61010, and IEC/EN60335-1 means that they can be used in industrial, communication technology, measurement, control and laboratory, and household applications. Integrated EMI filters mean that the parts are also certified to class B EMC standards EN55032 and EN61204-3 without the need for any external components.

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