BrightLoop
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WHITE PAPER

Reducing Common-Mode Voltage at the Source

Multiverter Technology

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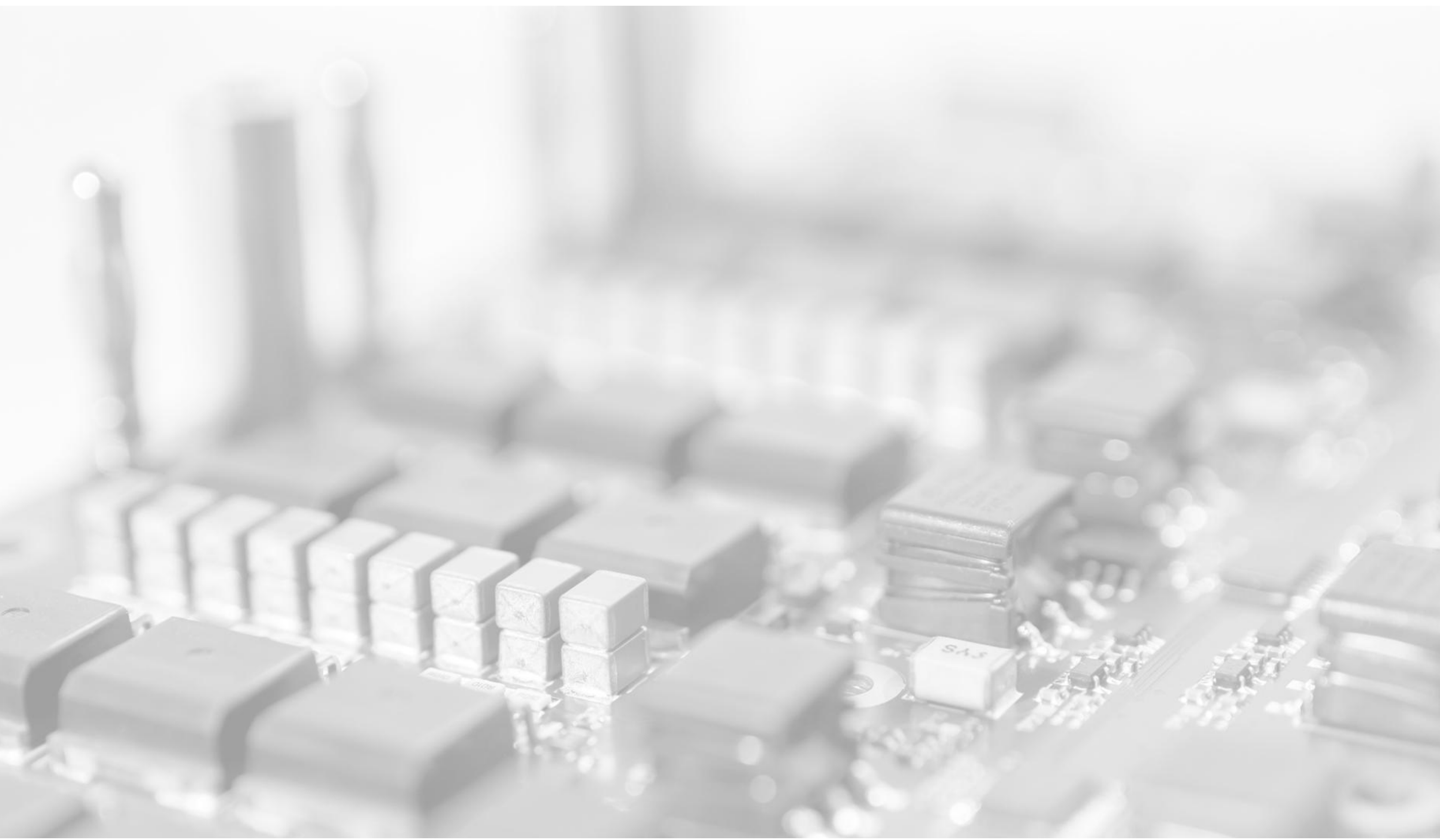

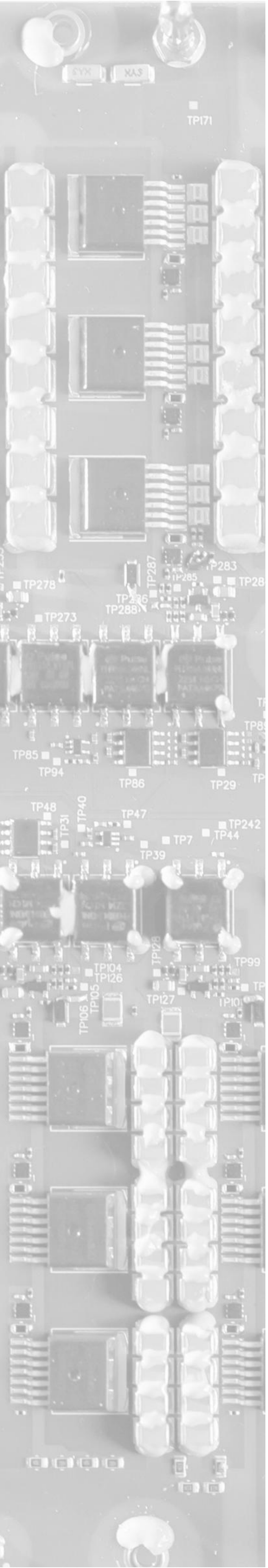

How BrightLoop's Clamped Star-Point Architecture Simplifies EMC Compliance and Reduces System Complexity.

A new architectural approach to minimizing common-mode voltage, leakage current and electromagnetic emissions in high-power three-phase AC/DC converters

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Figure 1 – BrightLoop ACHV LP, 200 kW AC/DC bidirectional converter 240 A/phase, 950 V_{DC} / 400 V_{AC} max., 52 x 35 x 8 cm, 25 kg 13 kW/L and 8 kW/kg power densities.

Executive Summary

The global electrification of heavy industries (industrial equipment, electric vehicles, aerospace, marine, defense, renewable energy…) is fundamentally reshaping power distribution. As modern microgrids grow in complexity, Systems Architecture Engineers are facing unprecedented design constraints. Balancing SWaP-C (Size, Weight, Power, and Cost), thermal management, and stringent EMC compliance has become a massive engineering overhead.

Traditionally, DC/AC power conversion has been a major source of this friction. Legacy converter architectures inherently generate high common-mode (CM) currents, forcing engineers to patch the problem with bulky isolation transformers and heavy, complex EMI filters. This "necessary evil" adds weight, increases points of failure, and drains valuable design time.

But what if common-mode noise was eliminated at the source?

BrightLoop's Clamped Star-Point Architecture is designed to alleviate this design burden. By intrinsically suppressing CM generation, it removes the need for heavy external filtering, empowering engineers to streamline system architecture, radically reduce weight and complexity, and focus on overall system performance.

This white paper explains the principles behind BrightLoop's ACHV architecture (see Fig. 1) and presents both simulation and experimental results demonstrating its benefits.

1. The Traditional Common-Mode Challenge

Conventional three-phase AC/DC converters have always naturally generated common-mode voltage during PWM switching. However, modern power converters often resort to faster switching to increase their power density and efficiency, which creates steeper common-mode voltage transitions. They, in turn, create larger common-mode currents through safety Y-class and parasitic capacitances distributed throughout the electrical system as illustrated in Fig. 2.

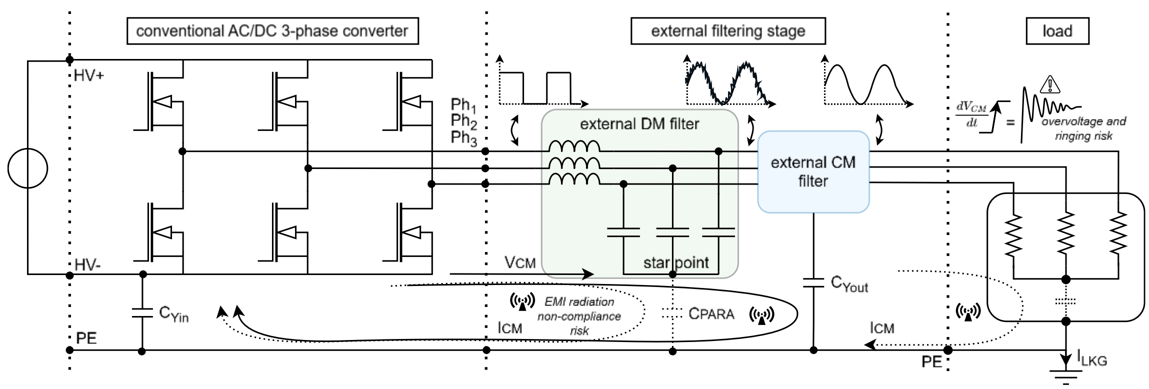

Figure 2 – Conventional three-phase AC/DC converter architecture requiring external differential-mode and common-mode filtering.

The resulting common-mode current flows outside the converter enclosure and creates large current loops capable of radiating electromagnetic interference. Because these current paths extend beyond the converter boundaries, they become extremely difficult to control during EMC certification.

The consequences extend well beyond electromagnetic emissions as synthesized in Fig. 3:

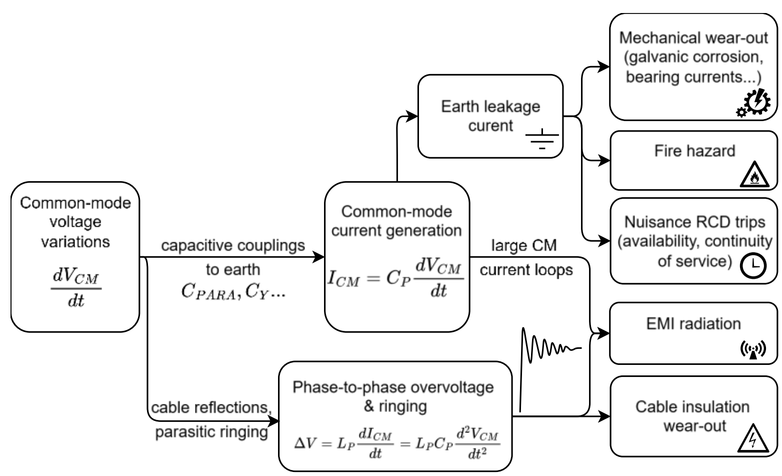

Figure 3 – Consequences of large common-mode voltage variations.

2. Traditional Solutions Increase System Complexity

To satisfy EMC requirements, conventional converter architectures commonly rely on additional hardware such as:

- External common-mode filters
- External differential-mode filters
- Isolation transformers
- Shielded cables

Although these solutions improve compliance, they do not prevent common-mode current generation. Instead, they attempt to mitigate its effects.

This results in increased:

- System volume
- Weight
- Bill of materials
- Installation complexity
- Certification effort

For system integrators, this often translates into **longer development cycles** and **higher overall costs**.

3. A Different Architectural Philosophy

BrightLoop approached the problem differently. Instead of asking:

"How can we filter common-mode current?"

The design team asked:

"How can we prevent common-mode current from being generated in the first place?"

The result is the ACHV platform's clamped star-point architecture shown in Fig. 4. By internally clamping the three-phase capacitor star point to the negative DC bus (HV−), the converter maintains an almost constant common-mode voltage. Because the common-mode voltage remains stable, its time derivative is drastically reduced ($dV_{CM}/dt \approx 0$), and **common-mode current generation is minimized at its source.**

Unlike conventional converters, the ACHV architecture also integrates both differential-mode and common-mode filters directly inside the converter. This optimizes integration and constrains EMI inside the aluminum enclosure, further facilitating system engineering effort.

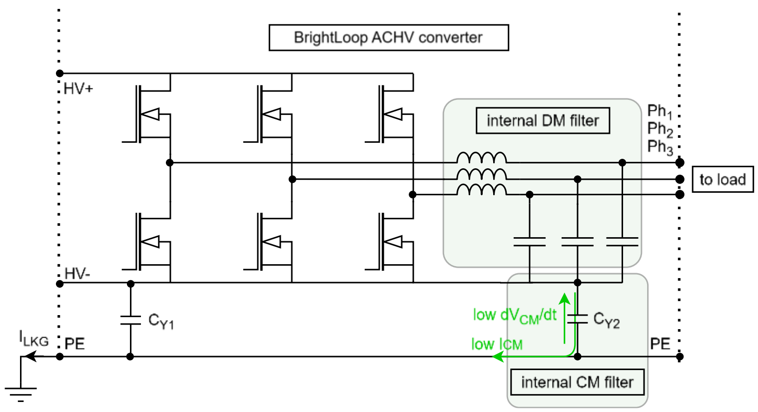

Figure 4 – BrightLoop clamped star-point architecture with integrated differential-mode and common-mode filtering.

4. Experimental Validation

To validate the superiority of the ACHV architecture, BrightLoop compared its converter against a conventional floating capacitor star-point architecture under identical operating conditions. The experimental setup is shown below in Fig. 5.

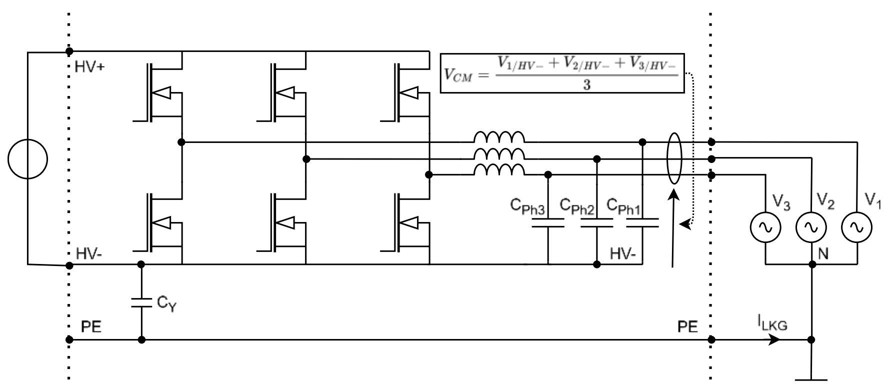

Figure 5 – ACHV common-mode voltage and leakage current assessment experimental setup ($V_{123\text{-}N}$ = 120 V_{RMS}, f_{GRID} = 60 Hz, V_{BUS} = 900 V_{DC}, Grid Forming Mode).

Simulation results in Fig. 6a for a conventional converter exhibit the well-known six-step common-mode voltage waveform with large and steep voltage transitions. These abrupt changes are the very source of all issues previously listed in Fig. 3.

Experimental measurements obtained from the ACHV converter in Fig. 6b demonstrate a fundamentally different behavior: **common-mode voltage variations are completely eliminated.**

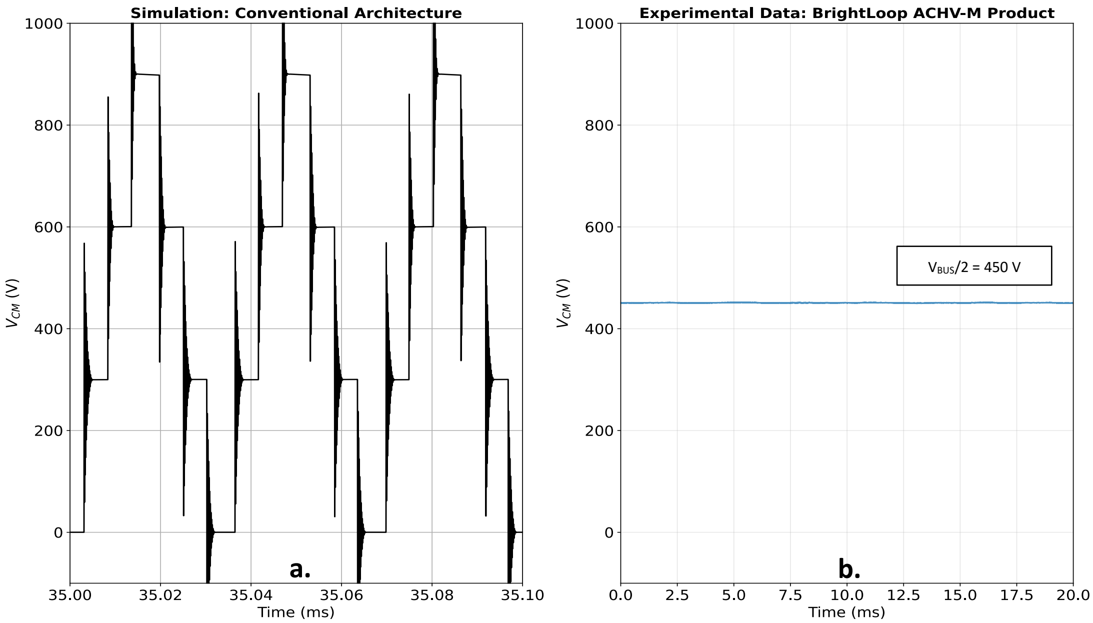

Figure 6 – CM voltage comparison between a simulated traditional converter (a) and experimental data from BrightLoop ACHV-M solution (b).

This reduction in common-mode voltage variations directly tackles the problem at its source. It translates into significantly lower common-mode current generation and less parasitic overvoltage and ringing.

5. Leakage Current Performance

The portion of the CM current that escapes through the PE (Protective Earth) conductor is defined as leakage current (I_{LKG}). It can lead to several issues:

- Galvanic corrosion, especially in marine environments
- Bearing current in rotating machines
- Hotspots and fire hazard
- Nuisance RCD (Residual Current Device) tripping, loss of continuity of service
- Lethal contact voltage in case of bad earth connection

As illustrated in Fig. 3, reducing CM current ensures ultra-low leakage current generation. Leakage current measurements in Fig. 7 further confirm the effectiveness of the architecture.

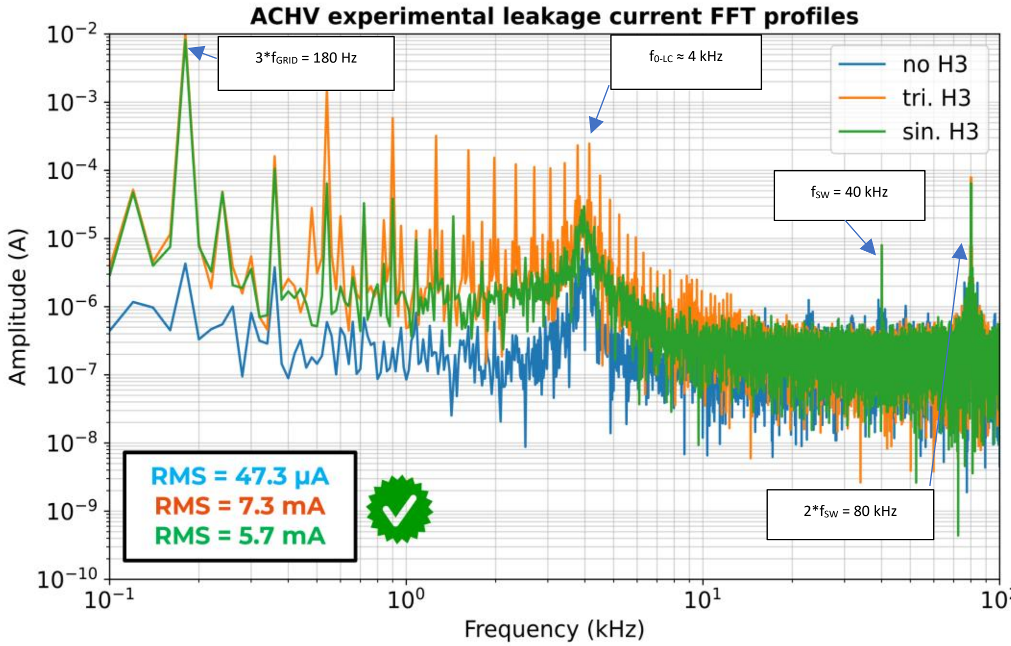

Figure 7 – Experimental frequency content of the leakage current depending on the H3 injection method (none / triangular / sinusoidal).

As expected, in normal operating conditions (indicated by the blue trace), **an extremely low leakage current of only 47 μA_{RMS} is measured.**

The measured spectra also compare several third-harmonic (H3) injection techniques. When the DC bus voltage offers minimal margin relative to the AC output, H3 injection is commonly utilized to secure additional voltage headroom. This injection introduces a component at 3 times the grid frequency on the common-mode voltage which generates leakage current. Two H3 injection strategies are compared: the traditional triangular injection in orange, and BrightLoop's sinusoidal injection in green.

Experimental measurements show **22% lower leakage current** using BrightLoop's sinusoidal third-harmonic injection compared to triangular injection.

Key Takeaway

Most users do not require H3 injection. In such standard operating configuration, ACHV achieves exceptionally low leakage current without relying on bulky external common-mode filters or isolation transformers.

Even when H3 injection is needed, leakage current values remain comfortably below many typical regulatory limits. This simplifies regulatory compliance. Leakage current limits vary significantly depending on the target application. Medical equipment, EV charging systems, laboratory equipment, defense applications and industrial installations all impose different requirements as illustrated (for reference only) in Tab. 1.

Application	Standard	Max. $I_{LKG\,(RMS)}$	Motivation
EV Systems	IEC 62955:2018	30 $mA_{(AC)}$ / 6 $mA_{(DC)}$	User protection
Medical	IEC 60601-1	500 µA (Annex A – Test Limits)	Strict limit for patient protection
Marine	IEC 60092	1 A (< 1000 V systems)	Fire prevention, continuity of service
Measurement, control, lab use	IEC 61010-1	300 µA	User protection, noise limitation
Defense	MIL-HDBK-454B	3.5 mA (DC or RMS) (unofficial guidelines: Section 4.5.2.5)	User protection
Information technology equipment	IEC 60950-1	3.5 mA	User protection
Domestic appliances	IEC 60335-1	3.5 mA	User protection
PV	IEC 62109-2	30 mA (Table 30)	User protection

Tab. 1 – Non-exhaustive and informal list of different regulations and their leakage current threshold.

By minimizing common-mode current at its source, the ACHV architecture helps system designers satisfy these requirements with significantly fewer external components.

The result is a simpler electrical architecture and reduced certification risk.

6. Earthing System Considerations

Vulnerability to excessive leakage current actually depends on the leakage current path and earthing configuration. any leakage current flowing outside the Residual Current Device (RCD) measurement loop can trigger protection mechanisms if the threshold is exceeded (Fig. 8a and 8b).

In TN-C systems (Fig. 8c), leakage current returns through the combined neutral-earth conductor (PEN) and does not cause RCD tripping. Nevertheless, minimizing common-mode current remains essential for EMI control and compliance.

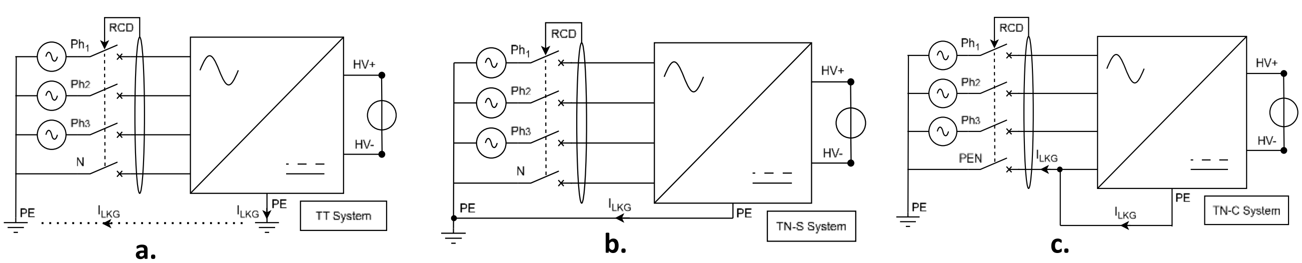

Figure 8 – Different earthing configurations: leakage current consideration

7. Benefits for System Designers

The advantages of the ACHV product family extend beyond EMC performance. By reducing common-mode current generation at its source, the ACHV platform enables engineers to design simpler electrical systems.

Key benefits include:

- Reduced common-mode emissions
- Lower leakage current
- Easier EMC certification
- Reduced external filtering
- Smaller and lighter systems
- Lower integration effort
- Improved long-term reliability

Conclusion

Conventional three-phase AC/DC converters typically address common-mode current after it has already been generated by relying on increasingly large external filters and additional passive components.

BrightLoop's ACHV architecture adopts a fundamentally different strategy.

Through its clamped star-point architecture, optimized switching techniques and integrated filtering, the converter inherently minimizes common-mode voltage variations before they can generate common-mode current.

Experimental measurements confirm that this approach significantly reduces common mode and leakage current while simplifying EMC compliance and lowering overall system complexity.

Rather than adding components to solve the common-mode problem, BrightLoop solves it at the source through architecture.

About BrightLoop

BrightLoop develops high-performance power conversion platforms that enable engineers to rethink electrical architectures rather than simply selecting individual converters.

Its configurable product family supports applications across motorsport, heavy-duty mobility, aerospace, marine, defense, industrial automation and renewable energy systems.

By combining high power density, modularity and advanced control strategies, BrightLoop helps engineers accelerate development while reducing system complexity.

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