Technical White Paper

Evolution of the Power Supply Unit in Data Center Servers and Key Technologies Supporting 800V DC Architecture

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ABSTRACT

With the exponential growth of power requirements for AI servers, the distribution voltage of data centers is moving from 400V AC power to 800V DC power. Power supply units (PSUs) in servers are the core components of data center power systems. These PSUs are responsible for converting the grid alternating current (AC) into the stable direct current (DC) that powers IT equipment. This report analyzes the characteristics of PSUs in servers, as the servers evolve through the transition from a 400V AC architecture to an 800V DC architecture, and explores the key technologies addressing the emerging challenges in the AI server industry.

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1 The Evolution of Power Supply Units in Data Center Servers

The power architecture of data centers is moving from an AC distribution to a DC distribution; the long-term goal is to develop DC microgrids integrated with solid-state transformers (SSTs). In the final vision, the rack-level PSUs are replaced by the ultra-compact IBC (intermediate bus converter) in the IT tray. This converter does not require the power factor correction (PFC) stage under the DC input and only requires handling the isolation and voltage conversion. However, at the moment, changing the whole power infrastructure in a data center is difficult and risky because most traditional equipment still does not support an 800V DC architecture.

The power sidecar is excellent for making a smooth and manageable transition to the 800V DC power architecture. As documented in the technical article, *Data Centers Evolve to Meet AI's Massive Power Needs* [see reference 5], Figure 1-1 shows that sidecar converts the traditional 480V AC into 800V DC, so the new compute rack with an 800V DC input can continue using 480V AC under the traditional power distribution. Additionally, the PSU in the sidecar includes all the functions of the traditional rack-level PSU. Therefore, this technical white paper focuses on the PSU in the sidecar.

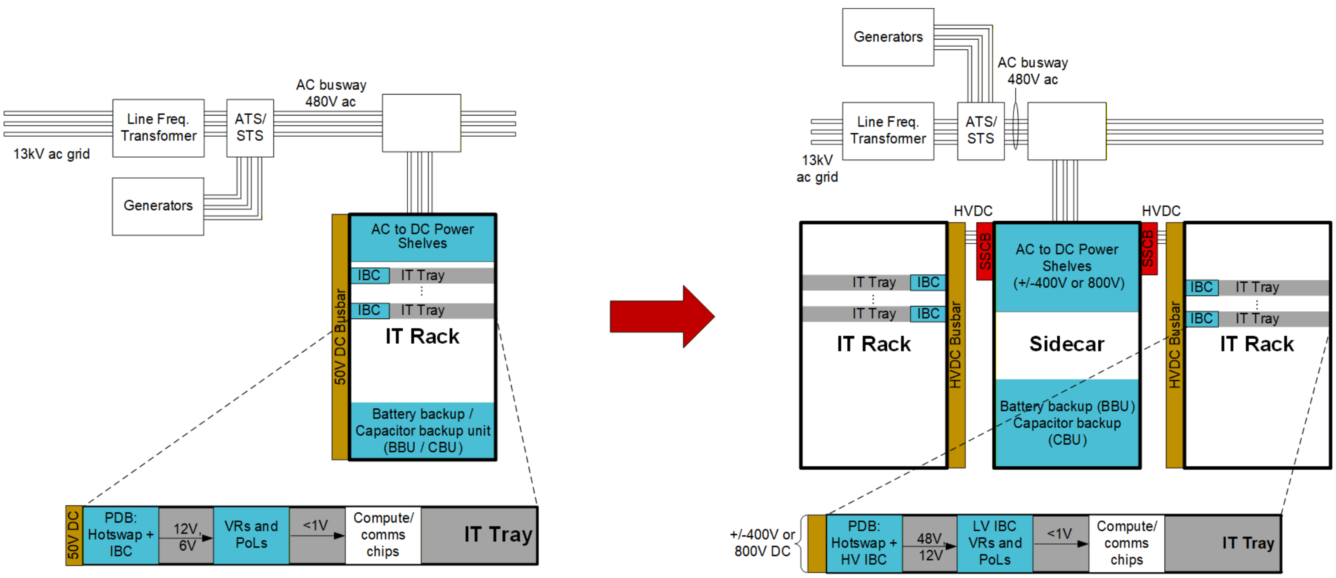


Figure 1-1. Data Center Power Architecture Evolution

2 The Requirements of PSUs in Data Center Servers

The PSU, as the foundational building block of the power conversion system, must fit the necessary power architecture transitions and meet all demands of the whole system. The core requirements of a PSU are efficiency, stability, and security.

2.1 Higher Efficiency Demands

Contemporary data centers impose far stricter efficiency standards on PSUs than the traditional 80 PLUS® certification. For PSUs in traditional servers, the highest standard in the 80 PLUS certification is the *Ruby* class, which calls for 96.5% efficiency at half load. While in a modern data center, the PSU is pursuing 98%+ peak efficiency with the included cooling fan power.

2.2 Fast Transient Response Driven by GPUs

In modern data centers, graphics processing units (GPUs) are the primary load of power infrastructure. All GPUs are co-working with each other, and the power consumption of these GPUs fluctuates rapidly with a synchronized operation, switching between idle and peak load within milliseconds [see reference 2].

These transient load characteristics pose significant challenges for PSUs. The PSUs must respond quickly to the load transient (to keep the output voltages) and maintain current sharing among all the paralleled PSUs during the transient (to avoid overloading the individual power supplies). At the same time, the PSUs must level this power fluctuation on the AC input side with the internal energy storage. In the Mt. Diablo 400 specification, the voltage deviation during load transients must be tightly controlled within ±3% of the output voltage. Additionally, NVIDIA® has presented clear requirements on AC fluctuation during a huge load transient.

2.3 Intelligence and Security

Modern PSUs are no longer standalone components. PSUs are evolving into intelligent, connected devices enabling real-time monitoring, management, and adjustment. This transformation is driving the communication ports to fast ports, such as CAN, EtherCAT®, or Ethernet.

Crucially, this intelligence must be safeguarded by robust security methods to protect power systems from malicious attacks. Key security safeguards include encrypted communication protocols, secure firmware updates with digital signatures (to prevent tampering), and access control mechanisms to restrict unauthorized configuration modifications.

3 PSU Variations in 800V DC Architecture

The sidecar PSU design is mostly the same as the traditional power-shelf PSU under the 800V DC architecture but with rack power. Meaning, the sidecar PSU design retains the power factor correction (PFC) input stage, the isolated DC-DC output stage, and uses the flyback stage to generate the control power and standby power. However, the structure of the sidecar PSU also has some variation due to the huge power capacity and the input and output voltage changes. These two structures are shown in Figure 3-1 and Figure 3-2, and the following lists a detailed comparison between the structures.

In a traditional power-shelf PSU:

- The PFC topology is a single AC, totem pole PFC with SiC or GaN.
- The DC-DC stage uses mostly 600V or 650V power switches.
- The auxiliary power is using a 400V DC link. Generally, this is a single switch flyback.
- The ORing circuits are for a 48V rating.
- The communication interface does not require isolation.
- The cooling fan can be supplied from the 48V main output.

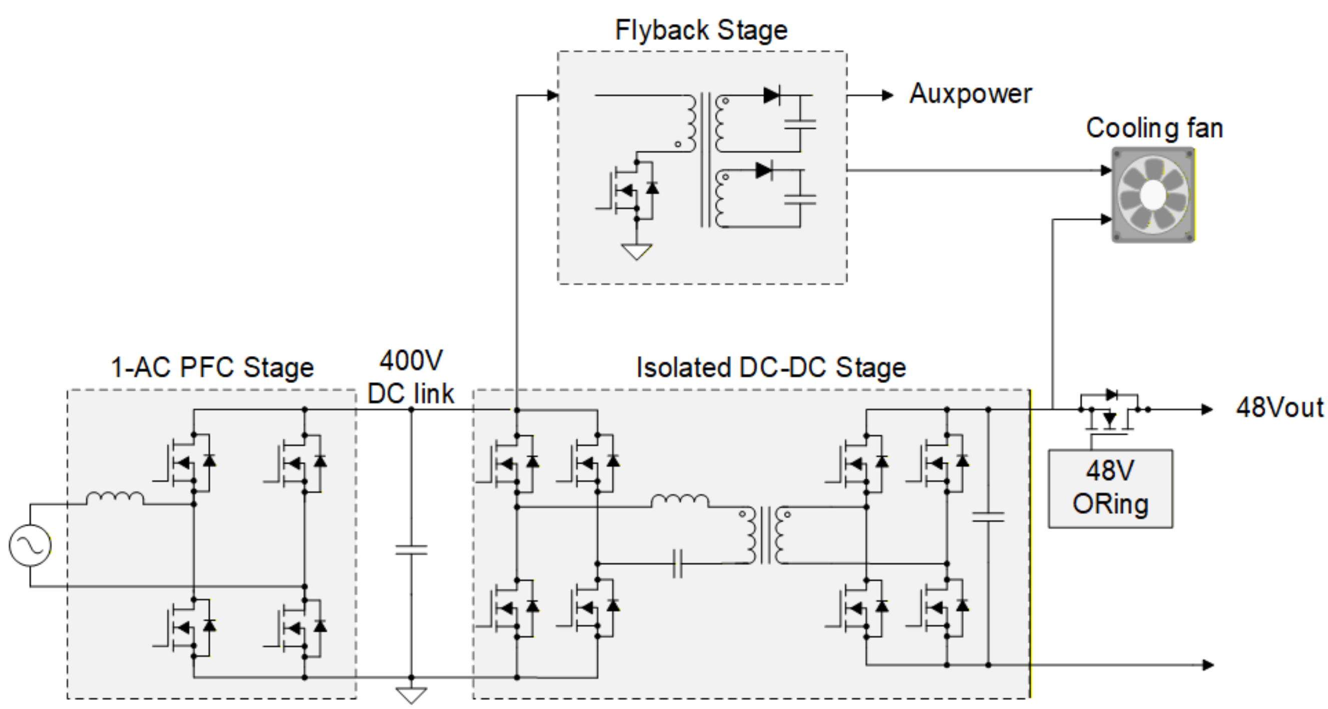


Figure 3-1. Traditional Power-Shelf PSU Block Diagram

In a 800V sidecar PSU:

- The PFC stage uses mostly a 3-phase AC, Vienna PFC, so the power switch is mostly back-to-back or bidirectional.

- The DC-DC stage requires a 1200V SiC or 650V serial topology to handle the 800V DC link voltage.
- The auxiliary power requires mostly 1200V devices or a serial flyback.
- The ORing circuits must handle an 800V rating with dedicated bias power.
- The communication interface can potentially require isolation with the 800V bus bar.
- The cooling fan cannot use the main output because 800V is too high.

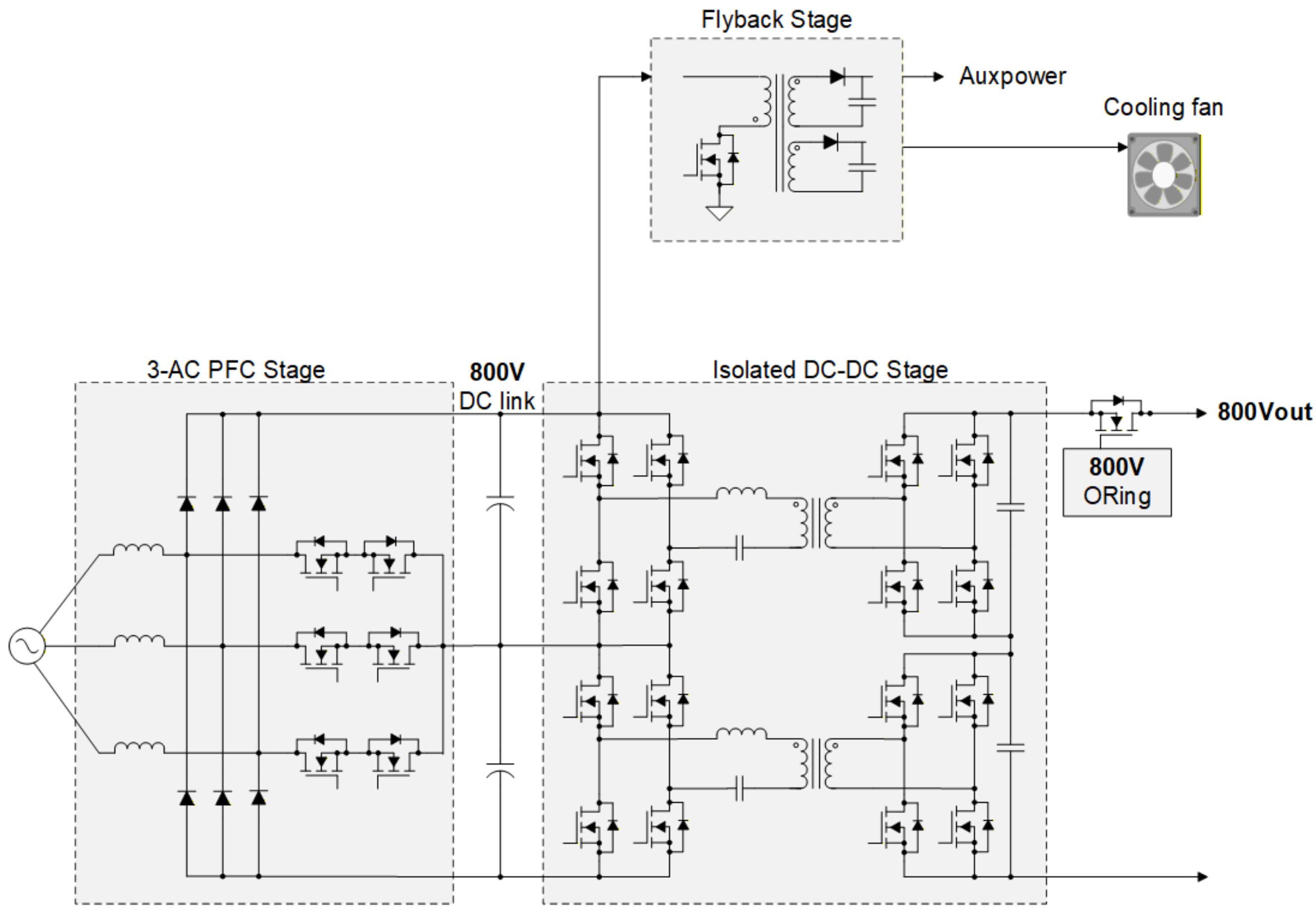


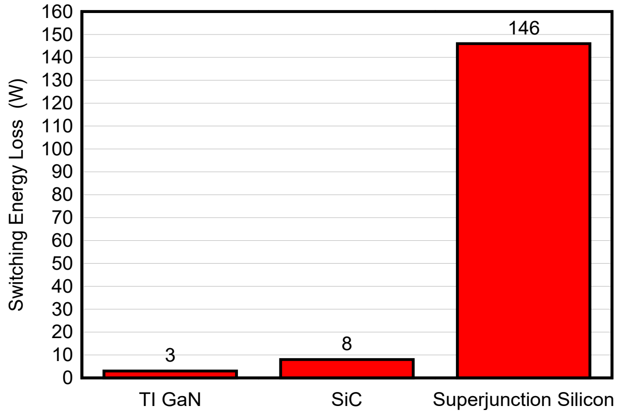
Figure 3-2. 800V DC Sidecar PSU Block Diagram

4 Key Technologies Shaping the Next Generation of PSUs

4.1 Gallium Nitride (GaN) Reduces Switching Energy Losses and Increases Efficiency

Both GaN and silicon carbide (SiC) are transforming PSU designs by offering higher efficiency when compared to traditional silicon (Si) devices. GaN offers even lower reductions in switching energy losses than SiC, and GaN is appropriate for high switching frequencies.

Figure 4-1 compares Texas Instruments' (TI) GaN technology with industry leading SiC and super-junction Si devices. The comparison demonstrates that GaN from TI achieves substantially lower switching energy losses and enables higher operating frequencies [see reference 6].



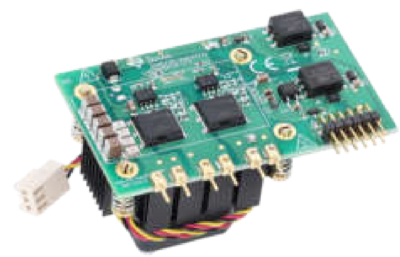


Figure 4-1. Switching Energy Losses Comparison

This efficiency improvement is proven in the transition conduction mode (TCM) totem pole PFC reference design (PMP40988 in Figure 4-2), which leverages the zero-voltage detection (ZVD) function of the LMG3526 GaN device, and another design (PMP23475), which utilizes zero-current detection (ZCD). Both of these designs have achieved a peak efficiency of higher than 99.0% [see references 8 and 10].

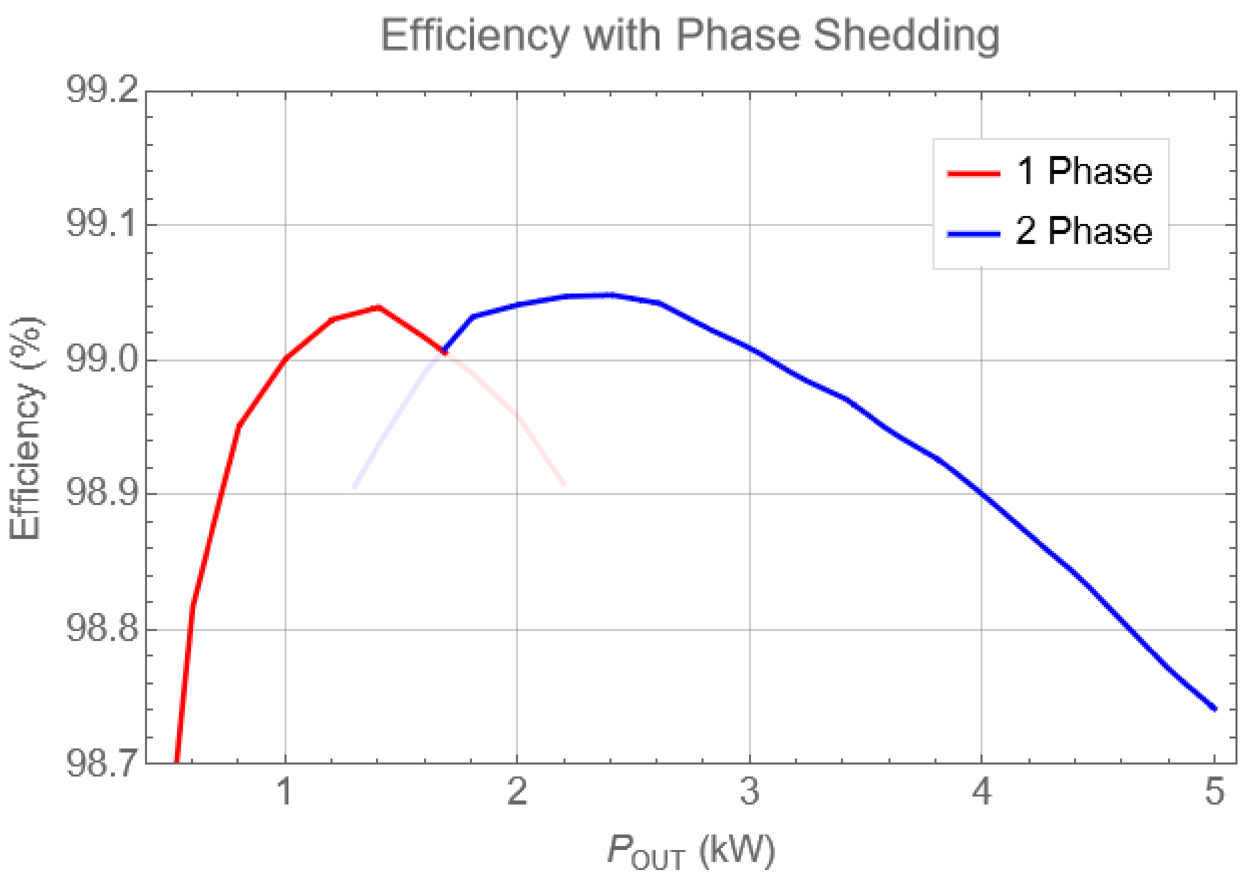


Figure 4-2. Efficiency of PMP40988

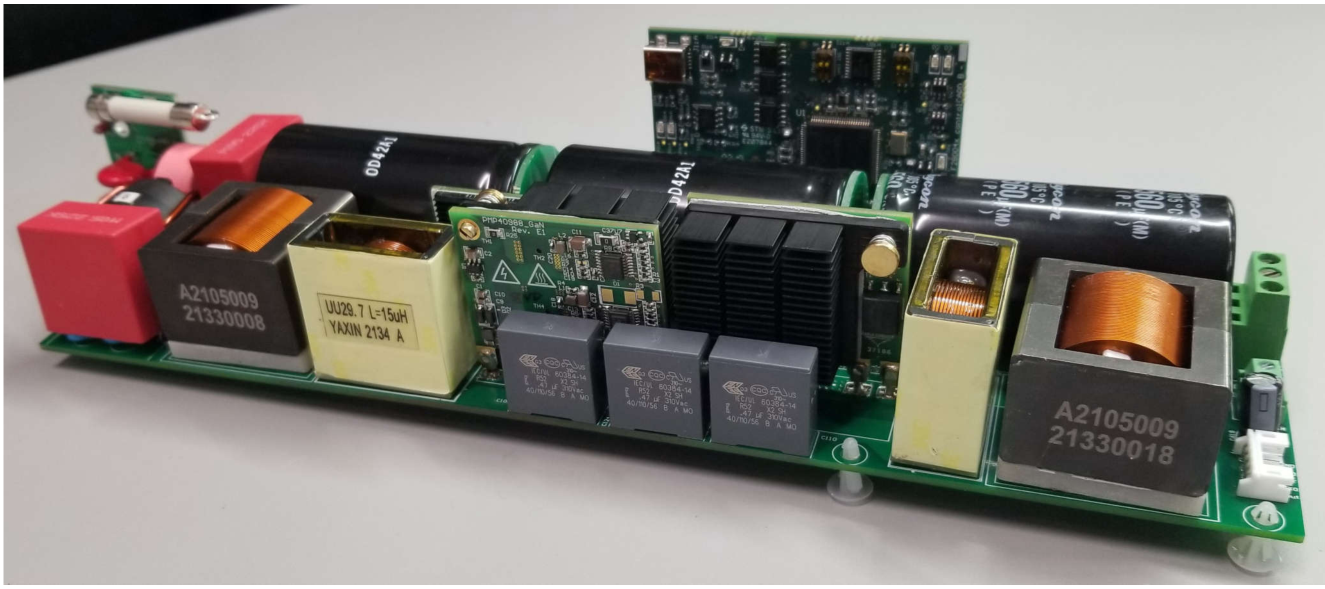


Figure 4-3. PMP40988 TCM Totem Pole PFC With ZVD GaN

4.2 Bidirectional GaN Cost Down Vienna PFC Solution

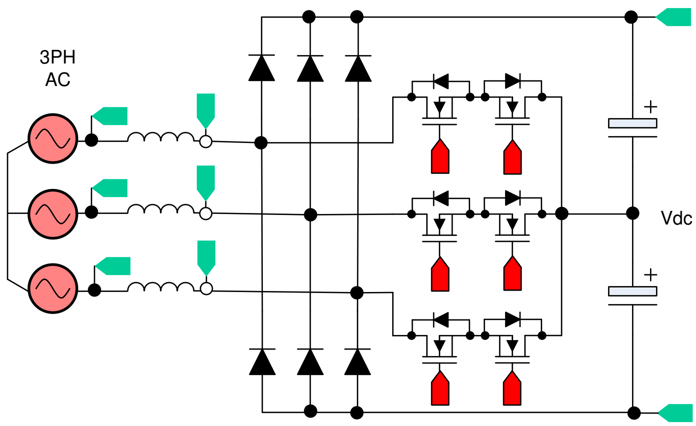


Figure 4-4. TIDM-1000 3-Phase Vienna PFC Rectifier

In 800V DC architectures, 3-phase Vienna PFC topology is widely adopted in the PFC stage (see Figure 4-4) because this topology reduces the voltage stress on power devices to half of the DC link voltage, enabling the use of mature 650V MOSFETs and delivering lower switching losses compared to two-level converters [see references 7 and 12].

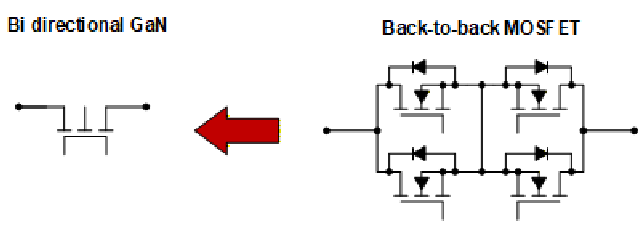


Figure 4-5. One BDG Equals Four Back-to-Back Si MOSFET

In Vienna PFC circuits, the power switches are used in serial with a back-to-back configuration, to handle the AC in two directions. But, the bidirectional GaN (BDG) is a true, *normally-off*, monolithic, bidirectional switch, which can directly handle the current in two directions, so the BDG can be equal to four Si or SiC MOSFETs with the same on-resistance, as Figure 4-5 presents. This innovation holds significant promise, but requires further market validation. The TIDA-01606 reference design demonstrates the application of the BDG in T-type converters and provides preliminary data supporting the potential of this application [see reference 3].

4.3 Hybrid Hysteretic-Controlled LLC Helps Quicken Transient Response

In the DC-DC stage, the resonant topology of the inductor-inductor-capacitor (LLC) is generally the preferred choice for achieving high efficiency and power density. However, traditional direct frequency control (DFC) struggles to enhance the control bandwidth due to a variable double pole in the control loop. Hybrid hysteretic control (HHC) addresses this limitation by regulating the energy transfer per switching cycle, enabling fast dynamic performance with a simple proportional-integral-derivative (PID) compensator.

As shown in Figure 4-6, the HHC loop combines charge mode control and direct frequency control with a compensation slope on the inner resonant capacitor voltage (VCR) loop. Figure 4-7 shows a comparison of a bode plot using DFC and one using HHC in this design. The test results indicate that the hybrid hysteretic-controlled LLC maintains a better load transient response across a wide input voltage range, while the loop bandwidth with DFC is hard to compensate due to the influence of the double pole. The reference design for PMP41081 showcases the HHC method, more details are explained in references 1, 4, and 11.

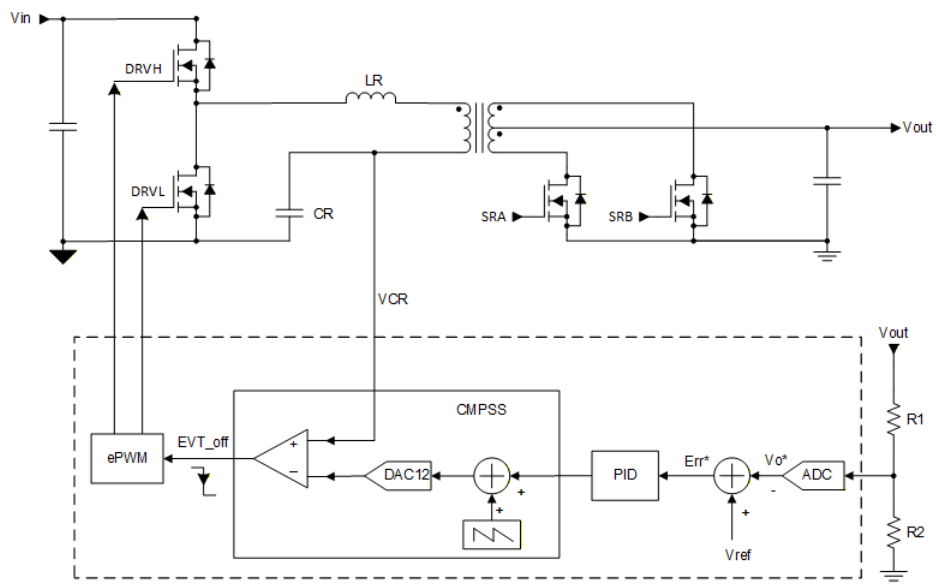
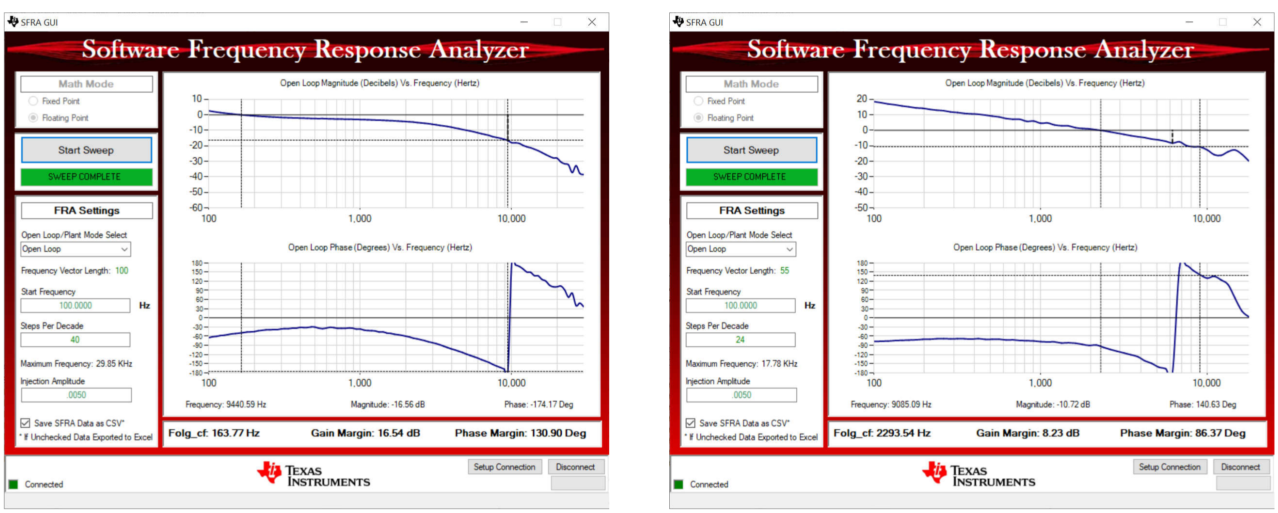


Figure 4-6. LLC With HHC Loop



A. Bode Plot with DFC. **B. Bode Plot with HHC.**

Figure 4-7. Bode Plot Comparison Between DFC and LLC

4.4 High-Voltage ORing Control Supports 800V Hot Swapping

Migrating from 48V bus bars to ±400V or ±800V bus bars reduces copper losses by lowering current. However, this migration also poses challenges for the ORing circuits, which must sense and withstand the higher voltages. Figure 4-8 presents a 400V DC high-side ORing design with a low-voltage ORing controller. In this design, the voltage sensing is handled by voltage clamping circuits, and the bias power of the controller is supplied by an isolated power supply, which can minimize the static power consumption.

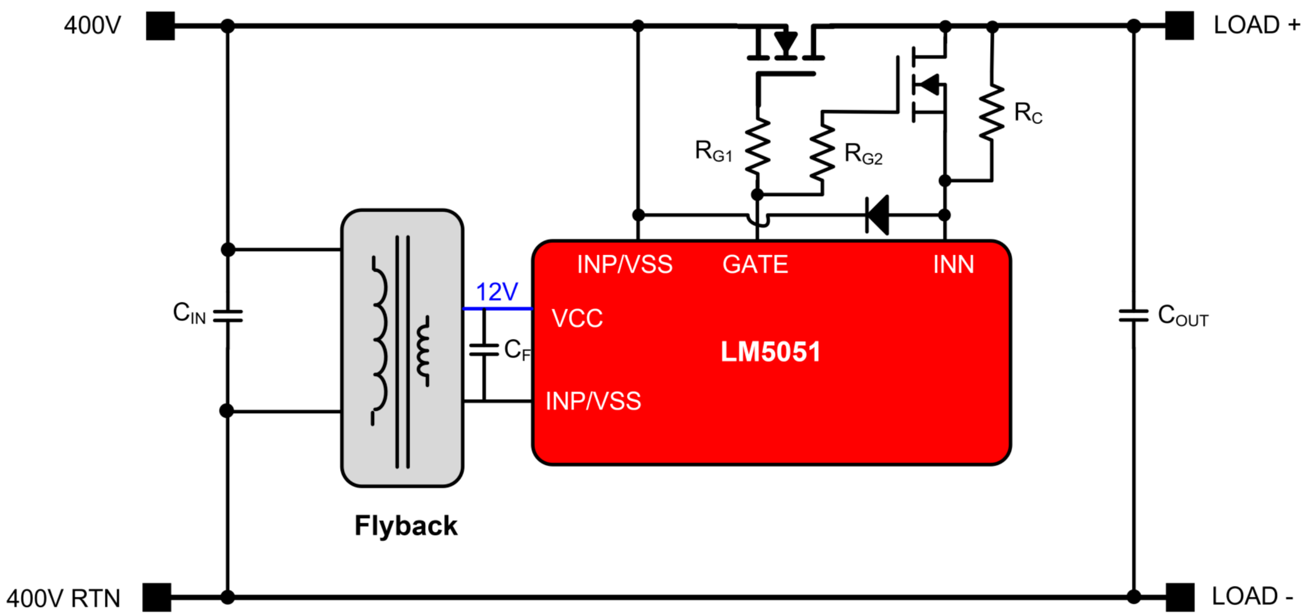


Figure 4-8. 400V High-Side ORing

5 Conclusion

As data centers evolve from an AC distribution to a DC distribution, the PSUs in data center servers are becoming IBC in the front of the IT tray, and the power sidecar makes this evolution a smooth and manageable transition. The power sidecar forms the connection between the traditional AC distribution and the future 800V DC distribution—smoothing the load transient by providing huge amounts of power with energy storage.

The PSU in the sidecar has the same functions as a traditional PSU with slight modifications, and new technologies are driving PSUs in data centers to be more efficient and reliable; including GaN devices, HHC LLC, and 800V rated controllers and converters.

6 References

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