Technical White Paper

Harnessing the Power of DC Microgrids for Industrial Applications

ABSTRACT

The world of electrical power is undergoing a significant transformation, spurred by increasing demand for energy efficiency, renewable energy integration and technological advancements. For over a century, AC power was the dominant form of electricity distribution; it maintains efficiency over long distances and easily adjusts to different voltage levels. However, with the rise of distributed energy resources, controlled energy flows, and motor power recuperation for reduced system losses, DC microgrids have emerged as a compelling alternative.

This paper introduces DC microgrids, their implementation in industrial applications, and several Texas Instruments (TI) reference designs that help enable efficient implementations.

Table of Contents

List of Figures

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1 Introduction

DC microgrids are localized energy systems operating from a DC bus within a defined voltage range. These systems can vary greatly in size and power, from small islands with several motors on a shared DC bus up to large-scale applications, such as entire factories or data centers with combined loads reaching up to the megawatts. While smaller island systems can extend existing factory infrastructures, larger installations significantly benefit from the economies of scale, achieved through their shared infrastructure. These larger DC grids facilitate more efficient integration of renewable energy sources, such as solar and wind, and enhance energy management, especially in industries with a high number of dynamic loads and increasing amounts of energy storage.

Additional components in a DC microgrid besides the AC/DC grid connection, renewables, battery systems and various loads include circuit breakers, precharge units, monitoring systems and auxiliary supplies for attached systems. Figure 1-1 shows a DC microgrid and possible system blocks.

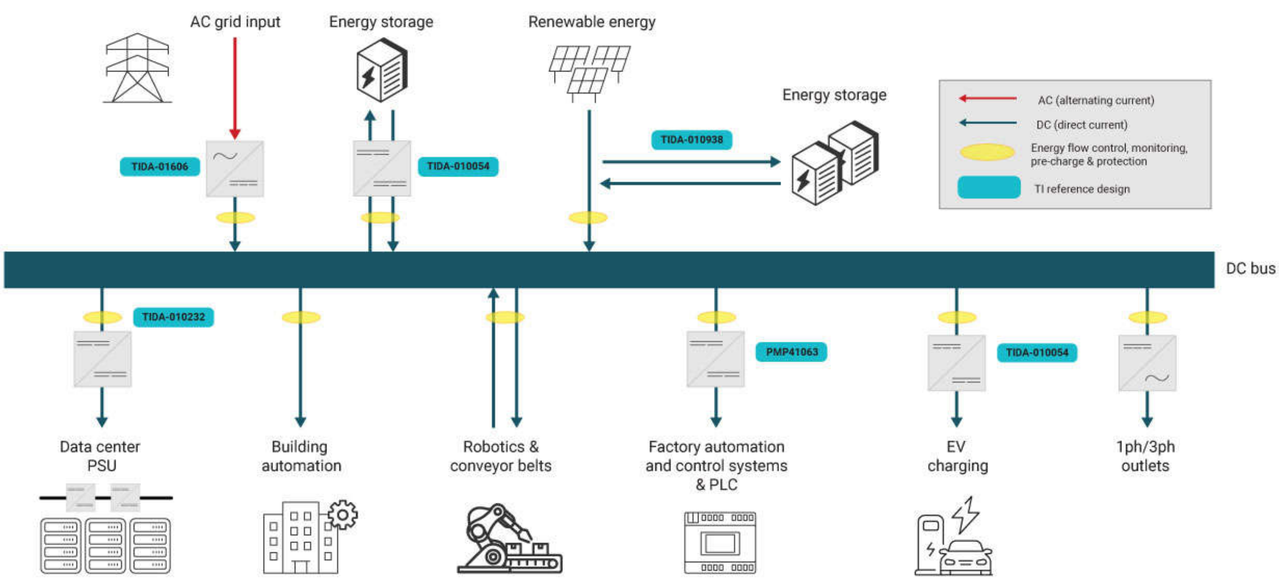

Figure 1-1. Components and Loads in a DC Microgrid

This technical white paper provides an overview of the advantages of DC over AC power grids; a description of DC microgrids; and an exploration of their applications in factory automation, data centers and building automation. We also explore how innovative semiconductors are enabling the transition to DC microgrids by enhancing isolation measurement systems, power supplies and solar inverters.

2 DC vs. AC Power Grids: A Comparative Overview

Historically, the debate between AC and DC power grids has revolved around the efficiency of transmission, safety and infrastructure. During the War of the Currents in the late 19th century, AC power emerged victorious because of its superior transmission capabilities over long distances. But with modern technology and shifting energy needs, DC power is making a resurgence, especially in localized microgrid applications.

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Advantages of DC power grids

DC microgrids offer these advantages over traditional AC connections:

- **Higher efficiency through optimized power conversion.** DC microgrids centralize AC-to-DC rectification, resulting in a reduced number of power-conversion stages and a shared DC bus. Centralization reduces conversion losses and improves overall system efficiency. Motor recuperation systems feed brake energy directly into the DC link, optimizing load sharing and energy distribution. Additionally, DC systems eliminate issues such as skin effects and eddy current losses. In industrial applications, these improvements can contribute to energy savings of as much as 20%. [3]
- **Seamless integration of renewable energy sources.** Renewable energy sources, such as solar panels and wind turbines, typically generate a DC voltage before converting power for the AC grid. DC microgrids enable the integration of these sources without an additional DC-to-AC (inverter) stage. Again, the reduced number of power conversions improves system efficiency and equips the DC system for applications that prioritize sustainability.
- **Scalability and flexibility in load management.** Because DC microgrids are highly scalable, engineers can tailor them to meet the specific power needs of various scenarios, from small buildings to large industrial facilities, or independent DC islands in an AC-powered factory. The ability to directly connect DC-powered loads such as industrial machinery; automation equipment; server racks; lighting; and heating, ventilation and air-conditioning (HVAC) systems simplifies the overall system architecture.
- **Improved power quality and stability.** DC power is less susceptible to harmonic distortion and reactive power issues, which can affect the quality of AC power. Power delivery is thus more stable, and the performance of sensitive electronics equipment improves. Additionally, the implementation of an energy storage system can bridge AC grid interruptions and balance an unstable energy supply.
- **Simplified wiring and reduced infrastructure costs.** DC microgrids require fewer wires than AC grids. Depending on the system architecture, a DC link uses two- or three-wire connections vs. the five-wire cabling in AC grids. Fewer wire connections and fewer power converters can result in as much as 50% copper savings, along with reduced installation costs. [1] [4] During operation, the renewable power generation and energy storage systems in DC grids help decrease peak power demand from the AC grid, which can lead to significantly lower connection fees.

DC Power Grid Design Challenges

While DC microgrids offer many advantages, specific challenges exist related to safety and reliability. One significant challenge is the management of electrical arcs. Unlike AC power, DC power does not naturally have zero-crossing points, making it more difficult to extinguish arcs and increasing the risk to users. Therefore, advanced control and protection systems are essential to manage the power flow; provide real-time monitoring of voltages, currents and temperatures; and quickly detect and counteract faults. Another challenge is that the DC grid is a polarized system, where corrosion can occur in the presence of continuous leakage currents.

Because DC microgrids are a relatively new technology, industry standards are still under development, limiting the availability of mass-produced equipment. There is also a shortage of trained professionals familiar with DC grid installation and maintenance. Examples of ongoing standardization efforts to build a broader foundation for DC systems include the Low Voltage DC Systems committee at the International Electrotechnical Commission and the Open DC Alliance in Germany.[4] [5].

3 DC Microgrids Across Industries

Given the advantages of DC microgrids and their growing ability to handle challenges, DC power is gaining traction across several sectors, three of which are highlighted below:

- **Factory automation.** Factory automation systems such as machines, robots and control systems benefit significantly from a shared DC grid by reducing energy losses and simplifying power distribution. In production environments with robots, lifts and conveyor belts, regenerative braking introduces a primary advantage over AC systems, where brake energy dissipates thermally. Early results from model installations in the automotive industry suggest significant energy savings, highlighting DC microgrids as a cost-effective and energy-efficient solution for modern factory operations. [6] In November 2024 the German VDE released the “System Description DC-INDUSTRIE” under VDE SPEC 90037 that gives detailed overview DC grids in the context of industrial applications.[2]

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- **Data centers.** Data centers are among the most energy-intensive facilities, and depend heavily on an uninterrupted power supply. A DC-powered data center enhances power efficiency by reducing the number of AC/DC power-conversion and power factor correction (PFC) stages, and reduces problems associated with harmonics. Moreover, these systems increase the reliability of power distribution by as much as 200%, making DC microgrids a more reliable, cost-effective and sustainable solution. [8] [9]
- **Building automation and lighting.** DC microgrids offer substantial advantages in building automation, especially for LED lighting systems, which inherently run on DC power. Furthermore, typical loads in building infrastructures such as HVAC systems and appliances also benefit from optimized power distribution and battery-buffered energy consumption. [7] Beyond the building infrastructure itself, most household electronics, such as computers, televisions and chargers, are already DC loads, opening up further potential for optimization.

4 TI Solutions for DC Applications

As shown in Figure 1-1, TI has designed both products and reference designs to help solve some of the challenges in DC microgrids, enabling more efficient power conversion, more accurate measurements, and more reliable control.

- TIDA-010938 - 10kW GaN-Based Single-Phase String Inverter with BESS
- TIDA-010054 – 10kW Bi-directional, dual active bridge DC/DC reference design
- TIDA-01606 – 11kW bi-directional 3phase AC/DC inverter/PFC reference design
- PMP41063 – 48W DCDC AUX Supply
- TIDA-010232 – AFE for insulation monitoring

4.1 10kW GaN-Based Single-Phase String Inverter with Battery Energy Storage System

Solar energy is an important part of a DC microgrid, with the main goals to save energy costs and reduce dependency on the AC power grid. A dedicated power converter conditions the variable voltage from the solar panels to a stable DC link voltage.

TI's 10kW gallium nitride (GaN)-based reference design was originally designed as a string inverter with battery energy storage system (BESS) capability. While it features three main stages, only two are essential for a DC microgrid application.

The input boost stage converts the solar panel voltage (50V to 500V, from two to 10 photovoltaic cells) to a defined DC link voltage. This output voltage can either directly power the microgrid or is adjustable to a different voltage level through a downstream DC/DC converter stage.

The bidirectional DC/DC converter stage manages the BESS by efficiently charging and discharging the battery. It ensures smooth energy flow to and from the battery, maintaining grid stability and supporting energy storage needs.

The third stage of the design consists of a configurable bidirectional DC/AC converter. In a PFC configuration, it takes power from the AC grid to the DC link to charge the BESS. In an inverter configuration, it converts the power from the BESS or the solar panels and feeds energy back to the AC grid (see Figure 4-1).

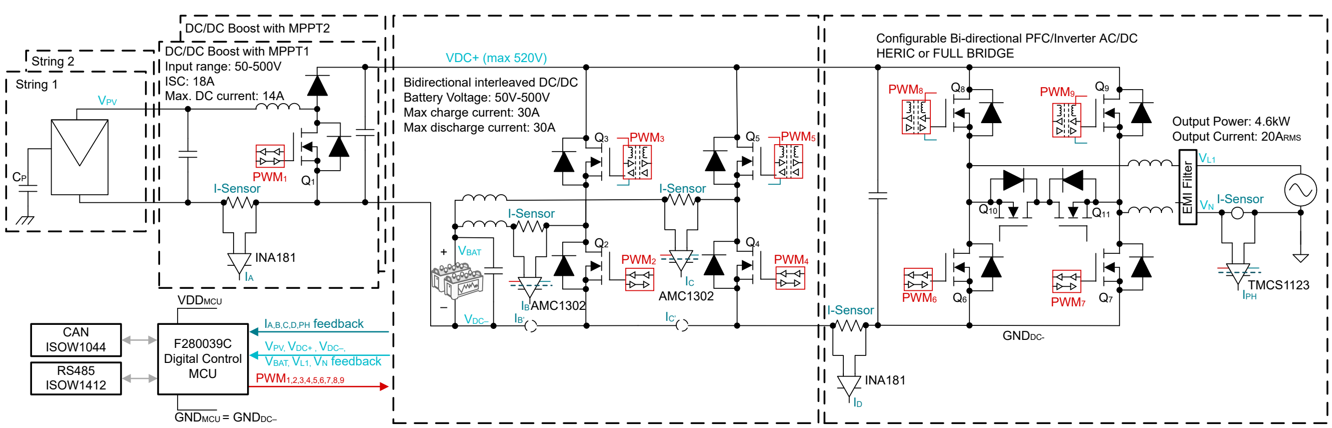

Figure 4-1. 10kW GaN-Based Reference Design Block Diagram

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4.2 Bidirectional, Dual Active Bridge Reference Design for Level 3 Electric Vehicle Charging Stations

TI's bidirectional dual active bridge reference design is a 10kW reference design that includes an isolated bidirectional dual active bridge DC/DC converter. The main targets for this reference design are power-conversion systems for energy storage or DC charging piles. The design supports an input voltage range of 700V to 800V, which is in the range for a typical microgrid DC bus voltage, making it a good fit for powering distributed loads and integrating battery backup systems.

The reference design achieves a power density of 2.25kW/L by using a high-performance control circuit that drives SiC power MOSFETs. The symmetrical structure in the dual active bridge allows converter stacking to achieve even higher power throughput, and the bidirectional design enables flexible energy transfer between the battery storage and the DC bus. Figure 4-2 is a block diagram of the system components.

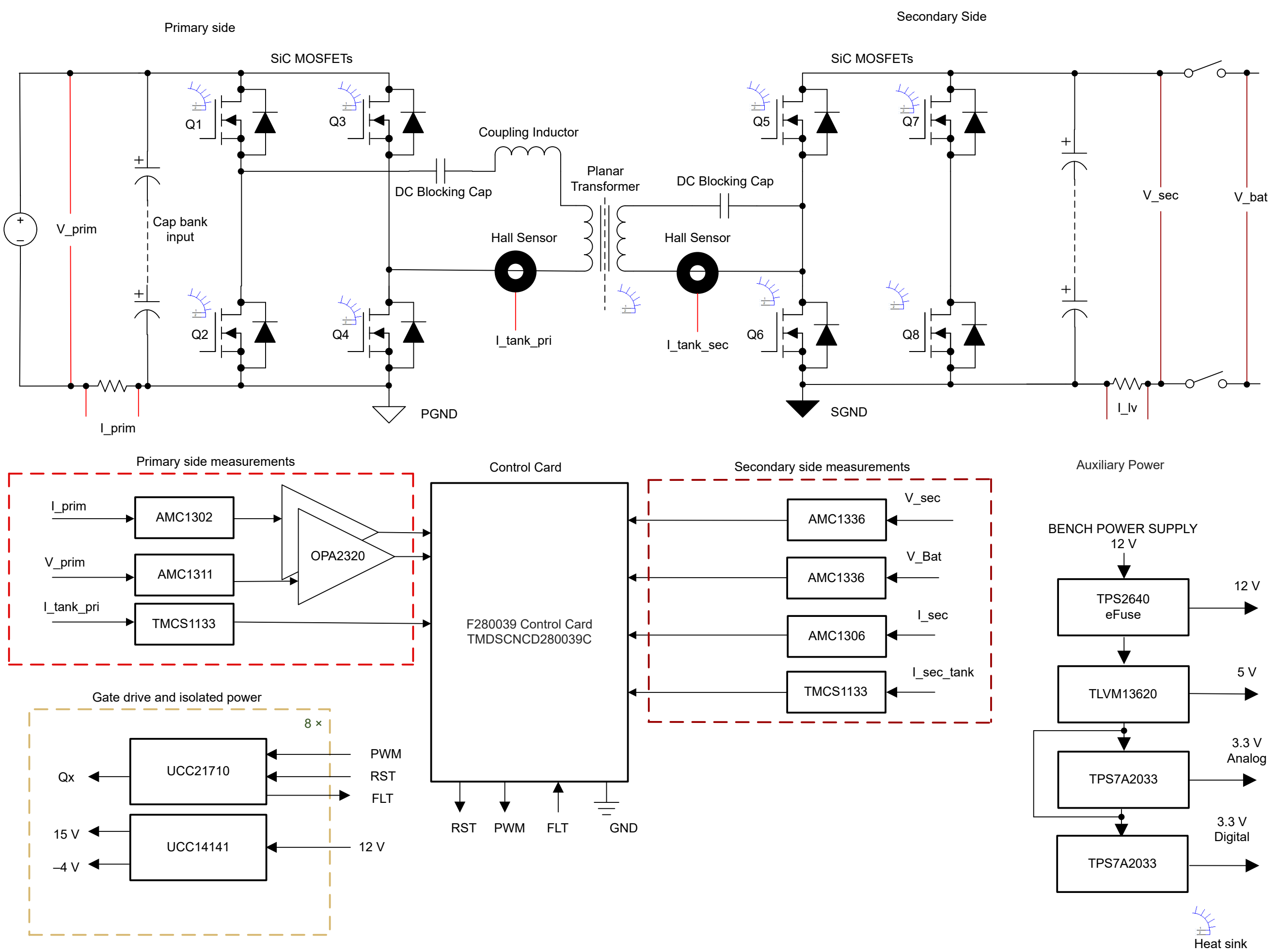

Figure 4-2. Bidirectional Dual Active Bridge Reference Design Block Diagram

4.3 11-kW, Bidirectional Three-Phase Three-Level (T-Type) Inverter and PFC Reference Design

Connecting the DC microgrid to the AC grid requires a bidirectional power supply. This supply handles AC-to-DC conversion with a high power factor and must be able to perform DC-to-AC conversion as an inverter. Because of the power levels, efficiency as well as thermal management are of top concern.

TI's bidirectional three-phase reference design, shown in Figure 4-3 and Figure 4-4, has a 11kW bidirectional inverter and PFC stage that can handle 600V to 900V on the DC bus, as well as three-phase 400VAC from the grid.

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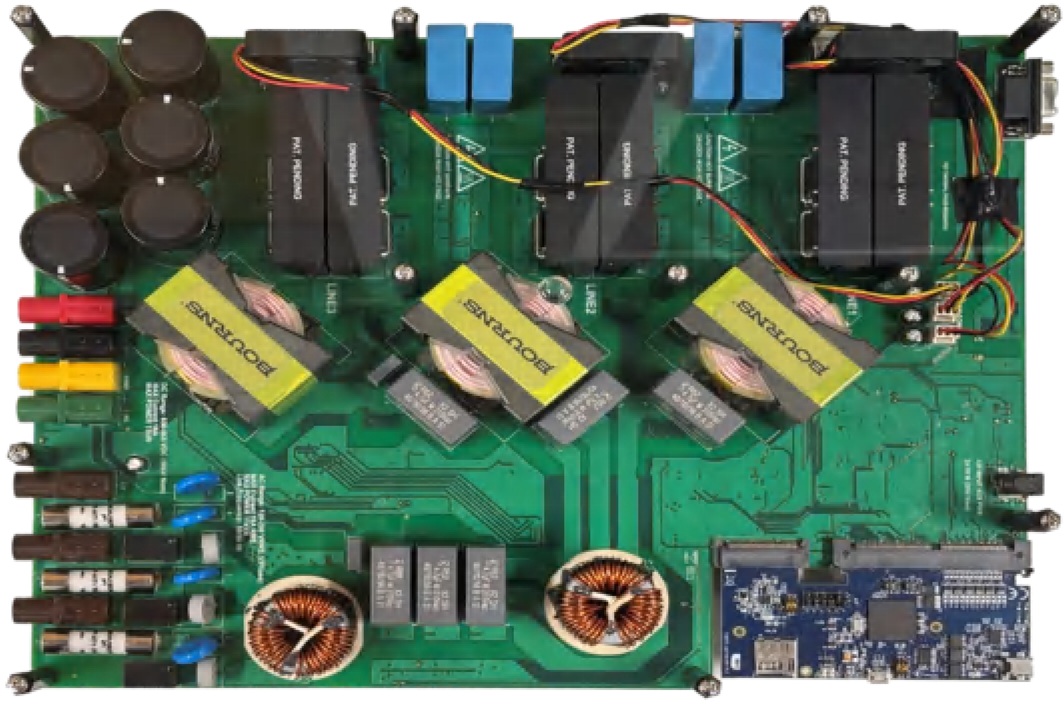

Figure 4-3. Bidirectional Three-Phase Reference Design Board Photo and Block Diagram

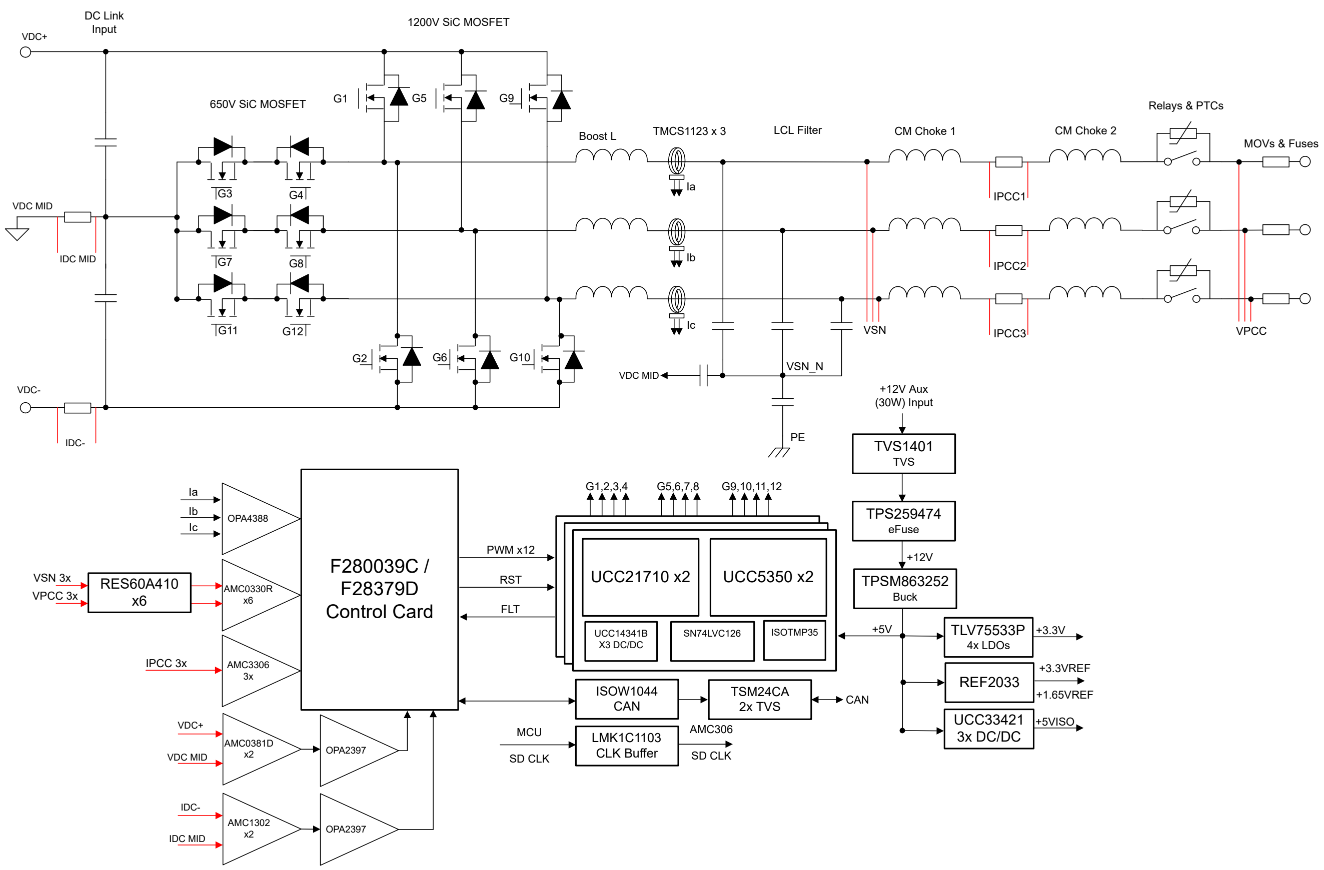

Figure 4-4. Bidirectional Three-Phase Reference Design Block Diagram

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The full reference design consists of two separate boards. The main board has all the switching devices, an LCL (inductor-capacitor-inductor) filter, sensing electronics and power structures. The second board hosts the control circuitry, based on a C2000™ digital signal processor control card. The complete design achieves a peak efficiency of 98.6% and has a power density of 2.2kW/L.

4.4 300V-1,000V Input 48W Isolated Auxiliary Power Reference Design with Low Standby Power

The isolated auxiliary power reference design is an optimized 48W auxiliary power supply for high-voltage DC applications. It supports DC input voltages from 300VDC to 1,000V, which enables flexible usage in subsystems such as control systems and monitoring equipment that require a stable DC voltage with limited power needs.

The design provides high reliability, as it is a primary-side regulated flyback topology that does not need an optocoupler to keep the output in regulation. This is an advantage in harsh environments, where the optocoupler tends to be less reliable given LED degradation over time.

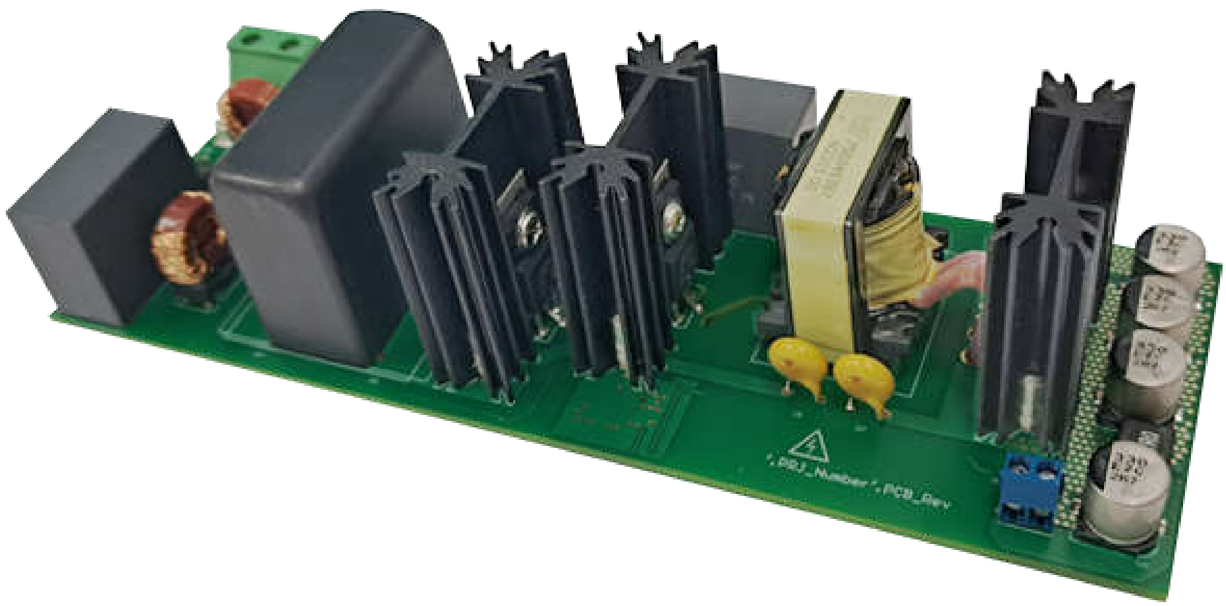

Figure 4-5. Isolated Auxiliary Power Reference Design Board

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4.5 AFE for Insulation Monitoring in High-Voltage EV Charging and Solar Energy Reference Design

Ensuring the operational safety of a DC microgrid is mandatory for each system operator. The insulation monitoring reference design measures isolation resistance and insulation leakage from DC to protective earth in regular intervals using the electric bridge DC insulation monitoring (DC-IM) method. The signal chain, shown in Figure 4-6, is based on isolated data converters and isolated power switches and enables fast system evaluation, as it is compatible with the C2000 BoosterPack™ plug-in module.

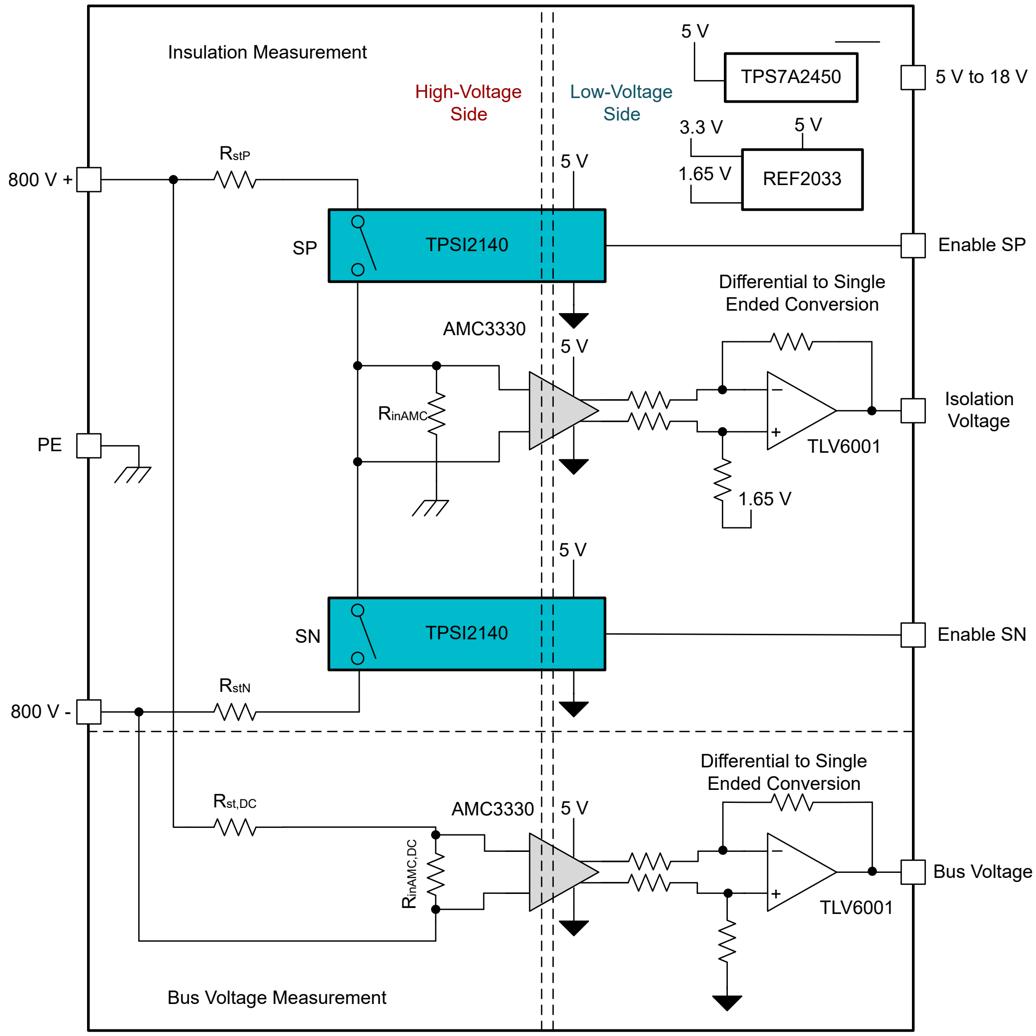

Figure 4-6. Analog Front End for Insulation Monitoring Reference Design Block Diagram

5 Conclusion

The growing demand for higher energy efficiency, more reliable power delivery, and the integration of renewable energy is driving streamlined and cost-effective solutions for DC microgrids. From isolation measurement to solar inverters and power supplies, TI's reference designs are helping various industries harness the power of DC microgrids to meet their sustainability goals and reduce their carbon footprint.

Visit TI.com to learn more about TI's innovative products and how they play an important role in enabling the next generation of energy systems.

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6 Reference

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