Title of the Invention

Modular and Scalable DC Power Distribution System with Dynamic Voltage Tiers and Load Prioritization

Cross-Reference to Related Applications

This application claims priority to Singapore Patent Application No. 10202501817Q, filed on 1 July 2025, titled “Modular Solar Power Distribution System with Intelligent DC Switching and Load-Prioritized Routing,” the contents of which are incorporated herein by reference for subject matter disclosed therein.

Technical Field

The present invention relates to systems and methods for direct current (DC) power distribution, particularly in solar energy environments. More specifically, it concerns a modular architecture for dynamic DC voltage-tier generation and load-prioritized routing, enabling efficient and scalable allocation of solar panel output to diverse DC loads without relying on centralized switching matrices or per-load converters.

Background and Prior Art

In the field of DC power distribution, particularly in solar power systems, most traditional architectures focus on collecting energy from photovoltaic (PV) panels and delivering it to either a centralized inverter or a maximum power point tracking (MPPT) controller for battery storage. Power is typically transmitted in a single voltage range, and loads are either connected in fixed wiring topologies or through converters. These systems often rely on alternating current (AC) transformation, even when loads could operate more efficiently on DC, resulting in conversion losses and increased hardware complexity.

Recent advancements have introduced panel-level DC optimizers and microinverters, which improve per-panel efficiency and safety but do not address the broader challenge of dynamic routing of power to DC loads based on real-time demand, capacity, and system state. In particular, the ability to reconfigure available DC voltage levels on demand and selectively allocate them to prioritized loads has remained largely unaddressed.

Moreover, many systems, such as the inventor’s prior Singapore Patent Application No. 10202501817Q, rely on centralized switching matrices to manage energy routing. These architectures become complex and hardware-heavy as system scale increases, requiring thousands of switches to connect all panels to all loads in all combinations. This increases cost, reduces fault tolerance, and makes the system difficult to maintain or expand. In systems that support multiple DC voltage levels, loads are typically hard-wired to a specific rail or depend on local DC-DC converters, introducing further inefficiencies.

Prior Art

Several prior systems attempt to address aspects of this challenge:

- **US8102144B2** and related systems from SolarEdge describe panel-level DC-DC boost converters feeding a centralized high-voltage DC bus, but do not support modular reconfiguration or dynamic multi-tier voltage distribution. Loads are connected via converters or AC inversion.
- **WO2022110507A1** teaches relay-based DC source switching based on voltage thresholds, but lacks load awareness, tier management, or modularity in routing logic.
- **EP4133531A1** focuses on internal PV module reconfiguration (e.g., bypassing shaded cells), but this logic remains localized within the panel and does not support system-level voltage construction or flexible load allocation.
- **US20190302488A1** provides a smart load management algorithm based on solar production forecasts but assumes fixed wiring and does not support dynamic tier switching or per-load routing logic.
- **US6421259B1** (IBM) introduces a modular backplane for power distribution with plug-in rectifier and converter modules, but uses a fixed high-voltage DC bus and dedicated per-load converters, with no concept of dynamically assigning voltage tiers or minimizing conversion stages.
- **US20090085553A1** describes reconfigurable battery modules, but focuses on energy storage rather than dynamic solar power distribution or voltage tier construction.
- **Cence Power System**: Cence Power (founded in 2020, merged with Argentum Electronics Inc. in 2022) provides a modular DC power distribution system for lighting, telecom, and data centers, supporting voltage ranges from 12V to 450V DC with fault-managed power and smart controls. It claims up to 40% energy savings but lacks the dynamic Voltage Tier assignment and solar-specific load prioritization of the present invention, relying instead on fixed voltage distribution without standardized Power Modules or Load Connect Modules for real-time reconfiguration.

Patents such as US20120299386A1 and US20150130277A1 explore DC microgrids and multi-voltage management strategies but focus on utility-scale or battery-centered routing without modular plug-in architectures or dynamic load-tier assignment as taught by the present invention. These and other references fail to describe a system in which standardized Power Modules can build flexible series-based voltage levels from distributed solar inputs, and Load Connect Modules can dynamically tap into any one of several voltage tiers based on their needs, all under the supervision of a Central Controller.

Unmet Needs

What is lacking in the prior art is a system that:

- Allows modular creation of multiple DC voltage tiers using standardized Power Modules, without central switching matrices or full crossbar complexity.
- Enables per-load tier selection through configurable Load Connect Modules (LCMs), without requiring dedicated DC-DC converters at each load.
- Uses a Central Controller to dynamically manage Voltage Tier assignment and load prioritization in real time, based on demand, capacity, and safety features (e.g., real-time monitoring, transient load management).
- Supports plug-and-play modularity for both solar input and DC loads, allowing the system to scale or adapt with minimal reconfiguration.
- Minimizes total hardware complexity and MOSFET count compared to centralized switching matrices, while improving thermal management and fault isolation.

The present invention addresses these gaps through a modular DC distribution system with tiered bus bars, software-configured voltage routing, per-load current limits, and a controller-managed reconfiguration logic that delivers power where and when it is needed.

Summary of the Invention

The present invention provides a modular direct current (DC) power distribution system that enables dynamic, load-prioritized routing of renewable energy through reconfigurable Voltage Tiers. Load Connect Modules (LCMs) (300) interface with DC appliances, including MPPT charge controllers for battery charging, reliably detecting startup and assigning appropriate Voltage Tiers under the guidance of a Central Controller Unit (100). An AUX Line connects the Central Controller Unit to all High-Voltage Distribution Cases, containing wires for wired control and monitoring signals, a 48V AUX line transmitting power at 48V from a Power Module to the Central Controller Unit, and a 12V AUX line transmitting power at 12V from the Central Controller Unit to HVDC components. The Central Controller Unit houses a Primary Controller (110) and a 48V@12A bus, powered via a 48V AUX Line from a Power Module or a 48V@5A adapter, feeding a 12V buck converter for the Primary Controller and 12V AUX Line, and a 6–24V buck converter for a low-voltage appliance. The system operates with at least one power input (solar or adapter), ensuring reliability in low-sun scenarios, such as emergency response centers. Its linear-scaling modular architecture minimizes switching complexity, reducing component count (e.g., ~50% fewer switching elements in typical medium scenarios compared to the exponential-scaling crossbar matrix of SG 10202501817Q), and supports plug-and-play integration of DC sources and loads,

suited for renewable-energy-powered buildings or microgrids, where appliances operate directly at variable DC voltage levels.

The system comprises four core components:

1. A Central Controller Unit (100) housing the Primary Controller (110), which manages Voltage Tier assignments, load prioritization, and LCM configurations, dynamically reassigning idle LCMs based on real-time demand, with a web-based interface for configuration, monitoring, and logging.

2. Power Modules (200) that accept multiple solar panel inputs, generating multiple 48V Power Units combined into Voltage Tiers via a Switching Matrix. A Power Module in “AUX” mode dedicates one Power Unit to the 48V AUX Line via a hardware-based switch.

3. Load Connect Modules (LCMs) (300) that power a single DC appliance, defaulting to the external adapter and switching to a Voltage Tier based on appliance needs (e.g., MPPT charge controllers), with support for synchronized multi-input configurations for high-current loads.

4. The High-Voltage Distribution Case (400) with bus bars and breakers, connecting Power Modules to LCMs, with ventilation fans powered via the 12V AUX line.

Safety features include resettable fuses and breakers for overcurrent protection, temperature sensors and fans for thermal management, dynamic LCM disconnection before Voltage Tier reassignment to prevent faults, and voltage sensors validate series string voltages before connection to Voltage Tiers, ensuring safe and accurate assignments. All modules communicate via wired or wireless protocols, optimizing Voltage Tiers, prioritizing critical loads, and reducing solar panel requirements by ~12% at peak load and up to 50% under typical demand.

Brief Description of Drawings

FIG. 1 is a system-level block diagram of the modular DC power distribution system, showing six arrays of five rooftop solar panels (30 panels total, each boosted to 96V), the Central Controller Unit (100) with Primary Controller (110) and 48V@5A External Adapter (120), two High-Voltage Distribution Cases (400).
Each Distribution Case contains three Power Modules (200), seven Load Connect Modules (LCMs) (300), Power Bus Bars (410), Load Bus Bars (430), and a row of seven 60A Tier Bridge Breakers (420), labeled as “BREAKER ROW”.
Connected loads include an MPPT charge controller (via eight LCMs from both cases), two DC air conditioners, a DC fridge, DC lights, a pool pump (dump load), and a sprinkler system (dump load).
The AUX Line (150) interconnects the Central Controller Unit (100), Power Modules (200), and LCMs (300), distributing control signals and auxiliary power (48V and 12V).

FIG. 2 is a block diagram of the Central Controller Unit (100), showing the Primary Controller (110) with Software Module (130) and a 48V@12A Bus (140) powered by a 48V AUX line, protected by a 12A fuse (144), or a 48V@5A adapter (120), both diode-

isolated (143). The bus feeds a 12V DC Buck (141) for the Primary Controller, High-Voltage Distribution Cases (400), and fans, and a 6-24V DC Buck (142) for a low-voltage appliance. The AUX Line (150) carries control signals and 48V/12V pairs.

FIG. 3 is a block diagram illustrating the physical layout of a High-Voltage Distribution Case (400), depicting two Power Modules (200) at the top and three Load Connect Modules (LCMs) (300) at the bottom, connected to seven positive and seven negative Power Bus Bars (410) above and seven positive and seven negative Load Bus Bars (430) below at the backplane via modular high-current connectors such as clamping terminals or insulated busbar forks rated for 60A DC, allowing tool-less insertion and safe disconnection. Seven 60A Tier Bridge Breakers (420) are positioned between corresponding Power and Load Bus Bars to enable power flow. The AUX Line (150), passing from the Central Controller Unit (100) through the High-Voltage Distribution Case, provides wired control and monitoring signals, a 48V AUX line, and a 12V AUX line supplying control electronics (e.g., sensors, Mini Controllers) and Ventilation Fans (440), as described in the Central Controller Unit (100) section. A dashed area indicates space for additional modules to support system scalability.

FIG. 4 is a functional block diagram of a Power Module (200) receiving up to five boosted solar panel inputs, comprising five DC-DC Buck Converters (208), each producing two 48V outputs, resulting in ten power units. The module includes a semiconductor-based Switching Matrix (240) for Voltage Tier routing and an AUX Switch (225) enabling one power unit to directly power the AUX line.

FIG. 4A illustrates the first embodiment of the switching matrix with 244 semiconductor switching elements, including 14 validation switching elements and 7 voltage sensors.

FIG. 4B illustrates the second embodiment of the switching matrix with 220 semiconductor switching elements and 5 voltage sensors.

FIG. 5 is a functional block diagram of a Load Connect Module (300), showing a Switching Matrix (340) with 16 MOSFETs (14 for seven positive and negative Voltage Tiers, 2 for the EXT Connector (370)), an A/V Sensor (330), and a resettable Fuse (320) protecting the APPL Connector (360).

FIG. 6A is a main logic flowchart of the tier assignment and reconfiguration process, initiated upon system boot or trigger event, and based on continually updated system telemetry data. The process evaluates load demand, available power, and the need for reconfiguration. If reconfiguration is required, the flow continues to FIG. 6B. The background loop represents the continual monitoring of power modules, LCMs, sensor data, and AUX load, with results stored in the system state for future decisions.

FIG. 6B is a reconfiguration and assignment flowchart detailing the sequence initiated when the Primary Controller decides a reconfiguration is needed. It includes instructions to LCM Mini Controllers to disconnect and reconnect from Voltage Tiers, and instructions to Power Module Mini Controllers to form series strings and connect them after voltage validation. Each stage includes error handling and logs the resulting configuration.

Detailed Description

While the inventor's prior Singapore Patent Application No. 10202501817Q, filed on 01 July 2025, focuses on distributing DC power from solar panels to multiple loads based on capacity, load demands, and a user-defined schedule of priority loads using a centralized switching matrix, the present invention emphasizes modularity, scalability, and safety by decoupling direct power-to-load connections and introducing an intermediate layer of Voltage Tiers—dynamically assigned voltage levels powered by modular components. This solution addresses limitations in prior systems (e.g., US8102144B2, US6421259, SG 10202501817Q), enhances modularity, scalability, and safety, simplifies maintenance and replacement of faulty parts, reduces complexity (e.g., approximately 50% fewer switching elements compared to SG 10202501817Q), and improves performance (e.g., fractional solar panel distribution, reducing the need for six dedicated solar panels to five combined panels).

Voltage Tiers are dynamically configured voltage levels, implemented via lines or bus bars, powered by Power Modules (200) and accessed by Load Connect Modules (LCMs) (300) to deliver power to DC appliances. The Central Controller Unit (100) calculates and compares current capacity and demand, instructing Power Modules and LCMs to activate specific MOSFET gates to maximize simultaneous powering of DC loads, minimizing wasted solar power.

While the preferred embodiment is optimized for a wide range of modern DC appliances with seven Voltage Tiers (48V to 336V in 48V increments), alternative embodiments include variants for cost-sensitive applications (e.g., three tiers at 48V, 144V, 336V), industrial needs (e.g., up to 10 tiers with voltages to 450V), or custom tiers (e.g., 25V, 50V, 100V, 200V, 400V).

Table1: Labeled components

Label	Unit Name	Description
100	Central Controller Unit	Physical case housing low-voltage components
110	Primary Controller	Computing unit managing system operations
120	PC External Power	External 48V DC backup power source
130	Software Module	Software within the Primary Controller for configuration and control
140	48V Bus	Shared Bus powered by 1 Power Unit or an external adapter (120)
141	12V DC Buck	Supplying 12V for the Primary Controller, four High-Voltage Distribution Cases, and the systems ventilation fans in the Central Controller Unit and High-Voltage-Distribution Cases
142	6-24 DC Buck	Supplying 6–24V for a low-voltage appliance, adjustable via a potentiometer
143	Diodes	Isolating Diodes (e.g. Schottky) to prevent reverse current

		flow
144	12A Fuse	12A Fuse on AUX 48V input
150	AUX Line	Contains one 48V pair (powered by 1 Power Unit), one 12V pair (powered by DC Buck output (141)). Communication lines (between Central Controller Unit and High-Voltage-Distribution-Cases)
200	Power Module	Modular power supply interface
205	Input Connector	Connectors for power supply (e.g., five connectors for 96V boosted solar panels in the preferred embodiment)
208	DC Buck Converter	Converts input power into multiple Power Units (210)
210	Power Unit	Units within a Power Module forming series strings via a Switching Matrix
215	Low-Voltage and Signal Adapter	Connects to the 12V AUX Line (150), powers the Mini Controller (220) and gate drivers, and includes the communication bus interface for wired protocols
220	Mini Controller	Local controller within a Power Module, receiving commands from the Primary Controller (110), controlling MOSFET gates, and reporting telemetry (voltage, current, temperature) and faulty Power Units
225	AUX Switch	Hardware switch manually connecting one Power Unit to the 48V AUX Line (150), bypassing the Power Module's circuitry
230	A/V Sensor	Ampere/Voltage sensors (one per Power Unit) measuring voltage and current
231	Probing Circuit	Enables current measurement for idle Power Units
235	Temperature Sensor	Measures internal temperature within the Power Module
240	Switching Matrix	Connects Power Units in series to form up to five strings and links to Voltage Tiers (2 Embodiments, see
250	Voltage Tier Connectors	Connects the Power Module to all Voltage Tier lines or bus bars
300	LCM	Load Connect Module interfacing a single DC appliance
305	Low-Voltage and Signal Adapter	Connects to the 12V AUX Line (150), powers the Mini Controller (310) and gate drivers, and includes the communication bus interace for wired protocols
310	Mini Controller	Local controller within an LCM, receiving commands from the Primary Controller (110), controlling MOSFET gates,

		and reporting telemetry (voltage, current, temperature)
320	Fuse	Resettable fuse (12A in the preferred embodiment) within an LCM
330	A/V Sensor	Ampere/Voltage sensor within an LCM measuring appliance voltage and current
331	Voltage Sensor	Voltage Sensor, measures if there is any voltage at the EXT Port.
335	Temperature Sensor	Measures internal temperature within the LCM
340	Switching Matrix	Connects the appliance to one Voltage Tier or the external power source
350	Voltage Tier Connectors	Connects the LCM to Voltage Tier lines or bus bars, with only one connection active
360	APPL Connector	Connection terminal (+/-) for the appliance powered by the LCM
370	EXT Connector	Connection terminal (+/-) for an external power source (e.g., MPPT or power adapter)
400	High-Voltage Distribution Case	Case housing high-voltage components
410	Powerlines/Power Bus Bars	One pair (+/-, rated for 75–100A) per Voltage Tier, connected to Power Modules
420	60A Breakers	Double-pole 60A breakers (rated for 450V) connecting Power Bus Bars to Load Bus Bars
430	Loadlines/Load Bus Bars	One pair (+/-, rated for 75–100A) per Voltage Tier, connected to LCMs
440	Cooling Fans	12V fans, powered by the 12V AUX Line, controlled by temperature sensors
500	Switching Matrix Embodiment 1	Power module’s Switching Matrix Embodiment 1 with with 244 semiconductor switching elements
505	Voltage Sensors	Voltage sensors measure each string’s positive and negative poles before connection to voltage tier
510	7x10 Switching Elements	7 x 10 Switching elements to connect seven Voltage Tiers + to each PU’s +
520	7x10 Switching Elements	7 x 10 Switching elements to connect Voltage Tier - to each PU’s -
530	10x9 Switching	9 Switching elements per Power Unit, to connect the Power

	Elements	Unit's - with another Power Unit's +
540	2 x 7 Switching Elements	Validation switching elements to interrupt direct connections to Voltage Tier Connectors (250)
550	Switching Matrix Embodiment 2	Power module's Switching Matrix Embodiment 2 with with 220 semiconductor switching elements
560	35 Switching Elements	35 (7 x 5) switching elements to connect seven Voltage Tiers + to the positive output of each power line
570	35 Switching Elements	35 (7 x 5) switching elements to connect seven Voltage Tiers - to the negative output of each power line
580	150 Switching Elements	150 (5 x 10 x 3) elements include or bypass a Power Unit from the series string.

Preferred embodiment

The preferred embodiment features seven Voltage Tiers (48V, 96V, 144V, 192V, 240V, 288V, 336V in 48V increments), compatible with a wide range of modern DC appliances, such as hybrid solar air conditioners, DC refrigerators, LED lighting, and MPPT charge controllers, which typically operate within these voltage ranges. This configuration supports residential, microgrid, and mobile applications, offering broad compatibility without claiming universal applicability.

Central Controller Unit (100)

The Central Controller Unit (100) is a physical case housing the Primary Controller (110), the computing unit coordinating Voltage Tier assignments, load prioritization, and system operations. It communicates with Power Modules (200) and Load Connect Modules (LCMs) (300) via wired (e.g., CAN bus, I2C, RS-485) or wireless (e.g., Wi-Fi) protocols through a dedicated multicore cable or individual cables passing through all High-Voltage Distribution Cases (400) as an AUX line (150). The AUX line contains wired control and monitoring signals, a 48V AUX line powered by one Power Unit from a Power Module (200), and a 12V AUX line powered by a DC-DC buck converter (141) in the Central Controller Unit.

The Central Controller Unit includes a shared 48V@12A bus (140), fed by the 48V AUX line as the primary power source or a 48V@5A external adapter (120, e.g., MPPT or AC/DC adapter powered by an inverter from a battery charged via an LCM) as backup, both diode-isolated (143) and the 48V AUX line protected by a 12A fuse (144). The bus powers two DC-DC buck converters: the first (141) supplying 12V for the Primary Controller, four High-Voltage Distribution Cases, and the systems ventilation fans in the Central Controller Unit and High-Voltage-Distribution Cases; the second (142) supplying 6–24V for a low-voltage appliance, adjustable via a potentiometer. A temperature sensor and fan in the Central Controller Unit, controlled by the Primary Controller, maintain safe operating temperatures. Total system demand is ~110W. The system requires at least one power input (solar or adapter) and supports battery-backed operation by powering an MPPT charge controller via an LCM to charge a battery, which can power an inverter supplying AC to the 48V@5A adapter, ensuring reliability in low-sun or emergency scenarios. The Primary Controller monitors the 48V AUX line via Power Module A/V Sensors (230) to ensure stable voltage (e.g., ≥46V) and sufficient current (e.g., ≥2.3A). The Central Controller Unit is designed for indoor installation with an IP20 or higher

ingress protection rating, consistent with standard practices for MPPT controllers, inverters, and battery banks.

The software module (130), accessible via a web-based interface, enables administrators to register and configure Power Modules and LCMs, set priority schedules, monitor performance, manage event/error logs, perform firmware updates, and enable maintenance mode, which disconnects all modules from Voltage Tiers. When a Power Unit (210) is rerouted via the hardware-based AUX Switch (225) in a Power Module (200) to power the 48V AUX line, it reports 0A, potentially triggering “Faulty Power Unit” logs; the software module allows configuration to mark such a Power Unit as an AUX Unit, suppressing these logs to prevent false fault indications.

The software module periodically (every 1–5 seconds) or upon events—such as new load activation, voltage sag, overcurrent, transient load spikes, Power Module status changes, or solar generation fluctuations—recalculates Voltage Tier assignments based on real-time demand, available capacity, and user-defined priority schedules. It compares total demand against capacity, disconnecting lower-priority LCMs if necessary, and retains stable LCM assignments when their Voltage Tier matches the appliance’s requirements and capacity is sufficient to minimize switch wear. The module determines optimal series string configurations within Power Modules to construct required Voltage Tiers (e.g., combining three 48V Power Units for 144V), ensuring current compatibility for efficient power delivery. Multiple series strings, whether from the same Power Module or different Power Modules, can be connected in parallel to the same Voltage Tier as needed, with the total current limited by the 60A Tier Bridge Breaker (420) rating. The system enables efficient Power Unit utilization through current sharing among multiple LCMs connected to the same Voltage Tier. For example, two LCMs each drawing 2.5A at 48V (total 5A), can be served by a single 48V Power Unit rated at 6A, rather than requiring two separate Power Units. This sharing capability significantly improves system efficiency and reduces the number of active Power Units required, particularly for partial-load conditions. After recalculation, the Primary Controller sends instructions to the Mini Controllers (220, 310) of the Power Modules and LCMs to implement the new Voltage Tier assignments.

Each Power Module’s Mini Controller (220) first constructs the requested series string internally and measures its voltage output using integrated sensing elements (e.g., A/V Sensors, 230). Upon confirming the voltage falls within the expected threshold range for the assigned tier, the Mini Controller activates switching elements (e.g., MOSFETs) to connect the series output to the appropriate Voltage Tier Connectors (250). This pre-connection validation ensures accuracy and safety before connection to the high-voltage bus infrastructure.

LCMs may be reassigned to higher or lower Voltage Tiers based on demand changes and their configured voltage ranges. The software module updates the assignment table dynamically, balancing active and idle LCM needs with bus bar availability. A safety protocol verifies voltage compatibility across Power Modules, Voltage Tiers, and LCMs, ensuring reconfiguration latency remains below 200 ms to maintain continuous appliance operation.

Power module (200)

The Power Module (200) serves as the interface between a power supply, such as solar panels, and the Voltage Tiers, processing input power for distribution within the system.

In the preferred embodiment, it accepts up to five boosted solar panel inputs (205) at 96V, processed through five DC Buck Converters (208) to produce ten 48V Power Units

(210). A semiconductor-based Switching Matrix (240) combines Power Units into multiple series strings simultaneously (up to 7 Power Units in series, e.g., one Power Unit for 48V, two for 96V, three for 144V, up to seven for 336V) and connects them to Voltage Tiers via Voltage Tier Connectors (250). Each Power Unit includes an A/V Sensor (230) and a Probing Circuit (231) to measure voltage and current, enabling telemetry reporting even when idle, ensuring accurate availability detection. A Temperature Sensor (235) monitors internal conditions. The Mini Controller (220) manages the Switching Matrix and Probing Circuits, executing commands from the Central Controller to form multiple series strings simultaneously and connect to Voltage Tiers. The switching matrix enables simultaneous creation of series strings with different voltages (e.g., one string at 48V, another at 144V) or multiple strings at the same voltage, which can be connected to the same or different Voltage Tiers based on system requirements. The system enables efficient Power Unit utilization through current sharing among multiple LCMs connected to the same Voltage Tier via the parallel connection inherent in the bus bar architecture. When multiple LCMs are connected to the same Load Bus Bar (430), they naturally share the available current from all Power Module series strings connected to the corresponding Power Bus Bar (410) through the Tier Bridge Breaker (420). The Primary Controller (110) monitors the aggregate current demand from all LCMs on each Voltage Tier via their A/V Sensors (330) and allocates only the minimum number of Power Units necessary to meet this total demand. For example, two LCMs each drawing 2.5A at 48V (total 5A) can be served by a single 48V Power Unit rated at 6A, rather than requiring two separate Power Units. This sharing capability, enabled by the bus bar architecture and real-time monitoring, significantly improves system efficiency and reduces the number of active Power Units required, particularly for partial-load conditions. It reports telemetry (voltage, current, temperature) and configuration status in real time.

A hardware-based AUX Switch (225) allows one Power Unit to bypass the Switching Matrix and power the 48V AUX line for the Central Controller Unit, independent of semiconductor switching element gate control or Central Controller commands. A Low-Voltage and Signal Adapter (215) connects to the 12V AUX line and communication bus for power and telemetry exchange. The AUX Switch may be implemented as a semiconductor-based switch, using silicon MOSFETs, Gallium Nitride (GaN), or Silicon Carbide (SiC) transistors, or as a mechanical relay, to dedicate one Power Unit to the 48V AUX line, bypassing the semiconductor-based Switching Matrix.

Power Module Diagnostics

Each Power Module (200) includes ten probing circuits containing a semiconductor switching element and a Ampere/Voltage sensor, one per Power Unit (210), for current measurement of idle Power Units. Controlled by the Mini Controller (220), these circuits enable fault detection and status monitoring, separate from the switching matrix (240), and are used when Power Units are not in a series string.

Switching Matrix Embodiments

The switching matrix (240) connects ten Power Units (210) in series-only configurations to form series strings for Voltage Tiers (e.g., 48V to 336V in 48V increments), under control of the Mini Controller (220) and Primary Controller (110). Two embodiments are disclosed, balancing flexibility and efficiency, as shown in FIG. 4A and 4B, with switching element counts compared in Table2: Switching Element Count Comparison.

First Embodiment (500): Full Interconnection Matrix (244 Switching Elements)

This embodiment uses 244 semiconductor switching elements for full interconnection flexibility:

- 70 switching elements (510) connect seven series strings to the positive poles of ten Power Units (7 × 10).
- 70 switching elements (520) connect the negative poles (7 × 10).
- 90 switching elements (530) enable any-order connections between Power Units' negative and positive poles.
- 14 validation switching elements (540) (7 positive, 7 negative) prevent Voltage Tier connections until 7 voltage sensors (505) (one per string, measuring positive-to-negative pole pairs, e.g., 1+ to 1-) confirm the correct voltage.

This configuration supports seven simultaneous series strings with unrestricted Power Unit ordering.

Advantages: High flexibility for complex load profiles; robust voltage verification.

Disadvantages: Higher switching element count increases cost and complexity; interconnected design reduces fault isolation; 14 validation switching elements add active components.

Second Embodiment (550): Optimized Line-Based Matrix (220 Switching Elements)

This preferred embodiment uses 220 switching elements, a 9.84% reduction per Power Module compared to the First Embodiment, organized into five lines with ten slots each:

- 35 switching elements (560) connect seven Voltage Tiers to the positive output of each line (7 × 5).
- 35 switching elements (570) connect seven Voltage Tiers to the negative output of each line (7 × 5).
- 150 switching elements (5 × 10 × 3)(580) include one bridge element (M1) to bypass a Power Unit and two elements (M2, M3) to include it in a series string, with exclusive control logic.
- 5 voltage sensors (505) (one per line) verify series string voltage before Voltage Tier connection, eliminating validation switching elements.

This configuration supports five sequential series strings per line.

Advantages: Reduced switching element count lowers cost and power use; independent lines enhance fault isolation; simpler PCB layout; fewer validation components improve reliability.

Disadvantages: Limited to five series strings; sequential Power Unit ordering reduces flexibility, though mitigated by multiple Power Modules.

Summary: Both embodiments enable dynamic Voltage Tier assignment, with the first offering maximum flexibility and the second optimizing efficiency, reduced complexity and reliability. The modular tiered system's linear-scaling architecture confines series connections within Power Modules, significantly reducing switching elements compared to the exponential-scaling crossbar matrix of SG 10202501817Q. For example, in typical medium scenarios (e.g., 20 solar panels, 40 Power Units, 10 loads), estimated switching element reductions reach ~56,87%, with higher reductions (e.g., up to 74.24%) in larger configurations (e.g., 80 Power Units, 20 loads with 2 HVDCs). Probing switching elements, described separately, support diagnostics.

Load connect module (LCM) (300)
The Load Connect Module (LCM) (300) interfaces a single DC appliance, such as a DC air conditioner, DC refrigerator, or MPPT charge controller, via an APPL Connector (360) and defaults to connecting to the EXT Connector (370), even during system failure, ensuring power availability from an external source (e.g., MPPT or AC/DC adapter) during low solar capacity or nighttime operation. Appliances with built-in MPPT controllers are powered exclusively through the Voltage Tiers and not via the EXT port. A dedicated Voltage Sensor (330) measures the voltage at the EXT Port, with the Mini Controller (310) transmitting this data to the Primary Controller (110). This allows the Central Controller Unit to assess external power status and adjust LCM configurations accordingly.

The LCM's MOSFET-based Switching Matrix (340), with 16 MOSFETs (14 for seven positive and negative Voltage Tiers, two for the EXT Port), ensures exclusive connection to either the EXT Port or a single Voltage Tier (350). The Mini Controller (310) controls the Switching Matrix, reporting telemetry (voltage, current, temperature) and configuration status in real-time via wired (e.g., CAN bus, I2C, RS-485) or wireless (e.g., Wi-Fi) protocols. An A/V Sensor (330) monitors appliance parameters, and a Temperature Sensor (335) tracks internal conditions.

The Central Controller Unit's logic for LCM management is as follows:

- **Default Behavior**: Upon connection or system failure, the LCM connects the APPL Connector (360) to the EXT Connector (370) unless overridden by a Voltage Tier assignment.
- **Startup Detection and Assignment**: The Central Controller Unit infers appliance activation from a non-zero current reading reported by the A/V Sensor (330), while the LCM is connected to its assigned idle Voltage Tier. If an appliance begins drawing current, the Primary Controller dynamically assigns the LCM to the appropriate available Voltage Tier based on its configured range and the appliance's activation, ensuring continuous operation without exceeding voltage tolerances, completing the reassignment within 200 ms to ensure continuous operation.
- **Idle State Management**: If an appliance is not drawing current (e.g., turned off), the Primary Controller:
    - Reverts the LCM to the EXT Port if an external power source is detected and viable.
    - Assigns the LCM to the lowest allowed and available Voltage Tier (e.g., 48V) if no external power is present, based on the LCM's configured voltage range.
- **Reassignment Process**: When the Primary Controller reassigns a Voltage Tier to a bus bar (e.g., Bus Bar 3 from 96V to 336V), it first disconnects all LCMs (active and idle) from that bus bar. Post-reassignment, it:
    - Informs active LCMs of their new Voltage Tier connections.
    - Assigns idle LCMs to either their available external power source or a compatible Voltage Tier within their range, prioritizing available tiers.
    - If no suitable tier exists (e.g., only 240V devices on a 240V bus, but idle 96V LCMs), the Primary Controller instructs Power Modules to create the

required tier (e.g., 96V) by reconfiguring series strings, ensuring all LCM needs are met.

Each LCM includes a resettable Fuse (320) with transient current handling logic to manage overloads and fault conditions. In the preferred embodiment, the Fuse is rated at 12A, tolerating transient spikes up to 1.5× the rated current for 500ms, disconnecting immediately for spikes exceeding 2× the rated current, or prompting the Primary Controller to reassign the LCM to a higher Voltage Tier if current exceeds 90% of the rated current for over 2 seconds. Each LCM must be registered within the Primary Controller's software module (130) before use, with configuration including the LCM's name, allowed voltage range, and optional coupling with another LCM. Coupled LCMs operate synchronously, switching to the same Voltage Tier to support dual-input appliances (e.g., MPPT charge controllers), enabling doubled current capacity.

The LCM connects to the 12V AUX line and communication bus through a Low-Voltage and Signal Adapter (305) and to the Load Bus Bars (430), rated for 75–100A, within the High-Voltage Distribution Case (400) via Voltage Tier Connectors (350) for high-current power delivery.

High-Voltage distribution case (400)

The High-Voltage Distribution Case (400) connects the Power Bus Bars (410) with the Load Bus Bars (430) through Tier Bridge Breakers (420). Each Power Bus Bar and connected Load Bus Bar represent a Voltage Tier (e.g., if Power Bus Bar 1 is powered by one or multiple Power Modules with 144V, the corresponding Load Bus Bar also has 144V).

In the preferred embodiment, the High-Voltage Distribution Case features a 2×2×7 bus bar arrangement, with 14 horizontal Power Bus Bars (410) (7 positive, 7 negative) at the top and 14 horizontal Load Bus Bars (430) (7 positive, 7 negative) at the bottom, each rated for 75–100A. The Bus Bars maintain clearance and creepage distances, with polycarbonate or phenolic sheets installed between adjacent Bus Bars for arc suppression. A row of seven double-pole 60A breakers (420), rated for 450V, connects the Power Bus Bars to the Load Bus Bars, interrupting power flow during overcurrent conditions to protect the system.

The case can house up to five Power Modules at the top, connected to the Power Bus Bars, and ten Load Connect Modules at the bottom, connected to the Load Bus Bars. It is grounded and equipped with Ventilation Fans (440) powered by the 12V AUX line and controlled by temperature sensors to maintain safe operating temperatures, with environmental suitability as described for the Central Controller Unit (e.g., IP20 or higher ingress protection).

The High-Voltage Distribution Case (400) is configured to support modular connections, with Power Modules (200) and Load Connect Modules (LCMs) (300) interfacing to the Power Bus Bars (410) and Load Bus Bars (430), respectively, via high-current modular connectors, such as clamps or terminal blocks, rated for 60A DC and compatible with AWG4 or AWG6 bus bars. The physical layout accommodates additional modules, ensuring scalability for varying system sizes. The AUX Line (150), described in the Central Controller Unit (100) section, passes through the High-Voltage Distribution Case and provides wired control and monitoring signals (e.g., CAN bus, I2C, RS-485) for communication with Power Modules and LCMs, a 48V AUX line for system power, and a 12V AUX line supplying control electronics (e.g., sensors, Mini Controllers) and Ventilation Fans (440).

Quantification of Benefits

The system's modular architecture may involve higher initial hardware costs but achieves significant savings in solar panel capacity and battery lifespan, particularly in multi-load applications such as homes with multiple air conditioners or microgrids. In conventional systems, each DC appliance typically requires a dedicated set of solar panels, often resulting in overprovisioning. For instance, powering four 12000 BTU hybrid air conditioners individually would require 12 dedicated 590W solar panels. In contrast, using the present system with dynamic Voltage Tier assignment and fractional panel routing, the same appliances can be powered with 10.5 panels at peak load, achieving a savings of 12.5% (See Table 3: Panel Requirement Comparison (Peak Load)). Under typical demand patterns, where appliances rarely operate simultaneously at full load, the system can reliably power the same appliances with 6 panels, reducing panel requirements by 50% compared to dedicated panel schemes (See Table 4: Panel Requirement Comparison (Typical Load)) This optimization also enables surplus solar energy to charge batteries or power dump loads, enhancing overall system efficiency.
In addition to hardware-level and system-sizing savings, the present invention also addresses a major but often overlooked source of inefficiency: energy lost during AC/DC conversion.
The modular DC power distribution system offers significant efficiency and cost advantages over conventional AC-based systems. Traditional solar-powered systems convert DC power from panels to AC via inverters, then back to DC at the load level via rectifiers, incurring cumulative energy losses of 12–30% per cycle, depending on component quality and configuration.

This invention eliminates these inefficiencies by enabling direct DC routing from renewable sources to DC loads, bypassing intermediate AC conversion stages. Many modern devices—such as data center servers, electric vehicle chargers, and home appliances—operate natively on DC, making direct delivery both feasible and desirable. By avoiding inverter and rectifier losses, the system can reduce energy conversion losses by up to 30% in DC-heavy configurations.

Additional efficiency gains are achieved through the use of wide band-gap semiconductor switching elements, such as Gallium Nitride (GaN) or Silicon Carbide (SiC) transistors, which offer 95–98% efficiency compared to 90–95% for silicon-based components, and a modular architecture reducing switching complexity by approximately 3.79–74.24% (see Table 2: Switching Element Count Comparison).

These efficiencies translate into multiple benefits:

- Reduced power generation requirements
- Smaller or eliminated inverter hardware
- Lower heat generation and improved system reliability
- Reduced battery cycling and extended battery lifespan
- Potential downsizing of solar panel arrays in partial-load scenarios

With adoption in just 20-30% of suitable applications across data centers, EV charging infrastructure, and modular DC-powered buildings, the system could realistically save 50–100 terawatt-hours per year by 2030—equivalent to the annual electricity consumption of countries like Belgium or New Zealand. Under theoretical full adoption in DC-rich environments globally, savings could eventually approach 500 TWh/year, highlighting the system's transformative potential for energy efficiency.

System scalability

The modular DC power distribution system (100) supports scalability by allowing multiple High-Voltage Distribution Cases (400) for larger solar-powered buildings or microgrids and by enabling the addition of Power Modules (200) and Load Connect Modules (300) within an existing case for smaller upgrades. Each case is electrically isolated, ensuring that an LCM in one case cannot access Voltage Tiers powered by a Power Module in another case, enhancing fault isolation by preventing cross-case faults. Additional cases or modules are integrated with minimal software adjustments via the Primary Controller (110), supporting plug-and-play modularity.

System Safety Features

The system embeds safety at multiple levels. Power Units (210) and Load Connect Modules (LCMs) (300) incorporate A/V Sensors (230, 330) and Temperature Sensors (235, 335) for real-time monitoring of voltage, current, and thermal conditions, enabling fault detection and isolation. LCMs (300) manage transient currents, tolerating spikes up to 1.5× the Fuse (320) rating for 500 ms, with reassignment to a higher Voltage Tier if current exceeds 90% of the fuse rating for over 2 seconds, or immediate disconnection for spikes above 2× the fuse rating. Tier Bridge Breakers (420) limit current to 60A per Voltage Tier, preventing overcurrent conditions. Ventilation Fans (440), controlled by temperature sensors, maintain safe operating temperatures. Event logging captures faults and reconfigurations, enhancing diagnostic traceability and supporting preventative maintenance. Distributed switching logic across independent modules and separation of low- and high-voltage circuitry avoid centralized bottlenecks and enhance system robustness.

The modular architecture ensures graceful degradation under component failure. If a Power Module fails, the Central Controller redistributes loads among remaining modules. If an LCM fails, only its connected appliance is affected. If a Voltage Tier's breaker trips, the system automatically reassigns affected LCMs to alternative tiers where possible.

Alternative Embodiments and Tier Configurations

The preferred embodiment features seven Voltage Tiers ranging from 48V to 336V in 48V increments. Alternative configurations may employ fewer tiers, such as three levels (e.g., 48V, 144V, 336V) for cost-sensitive residential or microgrid applications or expand to ten or more tiers with voltages up to 450V, using increments like 50V, 60V, or 75V for industrial or high-power deployments. Alternative embodiments may use AWG4 or AWG6 cables, rated for 75–100A, instead of Power Bus Bars (410) and Load Bus Bars (430), maintaining clearance, creepage, and arc suppression for safety.

In an alternative embodiment, the Load Connect Module (300) defaults to connecting the APPL Connector (360) to the EXT Connector (370) when none of the 14 Voltage Tier semiconductor switching elements in the Switching Matrix (340) are enabled, such as during system failure or insufficient power on the 12V AUX Line (150), with logic ensuring the EXT port is disconnected when any Voltage Tier semiconductor switching elements is activated to prevent simultaneous connections. In further alternative embodiments, the semiconductor-based Switching Matrix (240, 340) in Power Modules and Load Connect Modules may utilize Gallium Nitride (GaN) or Silicon Carbide (SiC) transistors instead of silicon MOSFETs to achieve higher switching efficiency, lower power losses, and improved thermal performance, while maintaining the functionality of forming series strings and connecting to Voltage Tiers or external power sources.

These variants utilize the same architecture: modular Power Modules (200) forming series voltage strings from real-time solar inputs, a shared backplane with high-current

Power Bus Bars or cables (410) and Load Bus Bars or cables (430), and Load Connect Modules (300) dynamically configured by the Central Controller Unit (100). Voltage Tier assignment, load matching, and power routing are governed by the software module (130), ensuring flexibility across different tier configurations and distribution media. Unlike prior systems, such as US6421259’s backplane-tiered battery architecture or US20090085553A1’s reconfigurable battery modules, this invention dynamically constructs Voltage Tiers from solar generation, prioritizing load distribution, safety, and scalability.

These alternative embodiments illustrate the system's flexibility and support broader claim interpretation while remaining distinct from energy storage-oriented prior art.

Table 2: Switching Element Count Comparison

The centralized crossbar matrix, as disclosed in Singapore Patent No. 10202501817Q, requires full connectivity between all Power Units and loads, necessitating extensive switching elements for series and load connections. In contrast, the modular tiered switching matrix of the present invention confines series string formation to within each Power Module, connecting up to 10 Power Units (maximum 7 in series) to 7 Voltage Tiers, with Load Connect Modules interfacing to Voltage Tiers, significantly reducing switching requirements. The table below compares switching element counts for series connections, load connections, and Voltage Tier connections as described in Embodiment 1 and 2 across 3 scales.

A - Small scale: 10 Solar panels (20 Power units), 5 Loads			
Component	Centralized Crossbar	Modular tiered First Embodiment	Modular tiered Second Embodiment
PU- to PU+	380	180 (2 PMs x 90)	300 (2PMs x 150)
Load to PU+	100	-	-
Load to PU -	100	-	-
PU+ to Voltage Tier+	-	140 (2 PMs x 7 x 10)	70 (2 PMs x 7 x 5)
PU- to Voltage Tier-	-	140 (2 PMs x 7 x 10)	70 (2 PMs x 7 x 5)
Validation Logic	Not available	28 (2 PMS x 14)	Included above
Voltage Tier+ to LCM+	-	35 (5 LCMs x 7)	35 (5 LCMs x 7)
Voltage Tier- to LCM-	-	35 (5 LCMs x 7)	35 (5 LCMs x 7)
Total	**580**	**558**	**510**
Reduction		**-3,79%**	**-12,07%**
B - Realistic Medium Scale: 20 Solar panels (40 Power units), 10 DC Loads			
Component	Centralized Crossbar	Modular tiered Embodiment 1	Modular tiered Embodiment 2
PU- to PU+	1560	360 (4 PMs x 90)	600 (4PMs x 150)
Load to PU+	400	-	-
Load to PU -	400	-	-
PU+ to Voltage Tier+	-	280 (4 PMs x 7 x 10)	140 (4 PMs x 7 x 5)
PU- to Voltage Tier-	-	280 (4 PMs x 7 x 10)	140 (4 PMs x 7 x 5)
Validation Logic	Not available	56 (4 PMS x 14)	Included above
Voltage Tier+ to LCM+	-	70 (10 LCMs x 7)	70 (10 LCMs x 7)
Voltage Tier- to LCM-	-	70 (10 LCMs x 7)	70 (10 LCMs x 7)
Total	**2360**	**1116**	**1020**
Reduction		**-52,71%**	**-56,78%**

C - Large Scale: 40 Solar panels (80 Power units), 20 Loads			
Component	Centralized Crossbar	Modular tiered Embodiment 1	Modular tiered Embodiment 2
PU- to PU+	6320	720 (8 PMs x 90)	1200 (8PMs x 150)
Load to PU+	800	-	-
Load to PU -	800	-	-
PU+ to Voltage Tier+	-	560 (8 PMs x 7 x 10)	280 (8 PMs x 7 x 5)
PU- to Voltage Tier-	-	560 (8 PMs x 7 x 10)	280 (8 PMs x 7 x 5)
Validation Logic	Not available	112 (8 PMS x 14)	Included above
Voltage Tier+ to LCM+	-	140 (20 LCMs x 7)	140 (20 LCMs x 7)
Voltage Tier- to LCM-	-	140 (20 LCMs x 7)	140 (20 LCMs x 7)
Total	**7920**	**2232**	**2040**
Reduction		**-71,82%**	**-74,24%**

Table 3: Panel Requirement Comparison (Peak Load)

This scenario assumes each 12K BTU hybrid air conditioner previously required three dedicated 590W solar panels, as specified by the manufacturer. The proposed modular DC system reduces the total panel count by dynamically aggregating load across a shared 144V voltage tier. Seven 144V power strings, each composed of three 48V Power Units, supply the total 6,000W demand. With each solar panel yielding two Power Units, only 10.5 panels are needed — achieving a panel reduction of approximately 12.5%.

Scenario	Conventional System	Proposed System
AC Units (Hybrid-Solar)	4 x 12000 BTU	4 x 12000 BTU
Panels per Unit	3 x 590 W	-
Total Panels	12	10,5
Max Power per Unit	1.500 Watt	1.500 Watt
Aggregated Power requirement	6.000 Watt	6.000 Watt
Voltage Tier	-	144V
Strings Required	-	7
Power Units per String	-	3
Total Power Units	-	21
Panels needed (2 PU per Panel)	-	10,5
Panel Savings		-12,5%

Table 4: Panel Requirement Comparison (Typical Load)

In traditional systems, each hybrid air conditioner is permanently assigned three dedicated solar panels, regardless of utilization. In this typical-load scenario, only two out of four units operate simultaneously at any given time. The proposed system dynamically reallocates available Power Units to active LCMs and redistributes unused panel output, requiring only 12 Power Units (6 solar panels) to meet the 3,000W demand. This results in a panel reduction of 50%, while freeing up capacity for other uses (e.g., battery charging, dump loads, or lower panel count installation).

Scenario	Conventional System	Proposed System
AC Units (Hybrid-Solar)	4 x 12000 BTU	4 x 12000 BTU
Active Units (Typical Load)	2 at any time	2 at any time
Panels per Unit	3 x 590 W	-
Total Panels	12	6-7
Max Power per Unit	1.500 Watt	1.500 Watt
Active Power requirement	3.000 Watt	3.000 Watt
Voltage Tier	-	144V
Strings Required	-	4
Power Units per String	-	3
Total Power Units	-	12
Panels needed (2 PU per Panel)	-	6
Panel Savings		-50%

Claims

Claim 1: A modular direct current (DC) power distribution system for dynamic routing of renewable energy to DC loads, comprising: a plurality of Power Modules, each configured to receive DC inputs from renewable energy DC sources and generate a plurality of Power Units, each providing a base DC voltage, wherein the Power Units are selectively combined via a semiconductor-based switching matrix to form one or more series strings outputting configurable voltages to a plurality of Voltage Tiers; a plurality of Load Connect Modules (LCMs), each configured to connect a DC appliance, such as an MPPT charge controller for battery charging, to one of the Voltage Tiers or an external power source via a semiconductor-based switching matrix, wherein each LCM includes a resettable fuse and a sensor for monitoring voltage and current; a High-Voltage Distribution Case comprising a plurality of power distribution lines, each corresponding to a Voltage Tier and configured to connect the Power Modules to the LCMs, wherein the power distribution lines include bus bars or cables rated for high current; a plurality of breakers, each connecting a power distribution line from the Power Modules to a corresponding distribution line for the LCMs, rated to interrupt overcurrent conditions; and a Central Controller Unit comprising a Primary Controller and a shared bus powered by a 48V AUX line from a Power Module or a 48V@5A external adapter, which may be powered by an inverter from a battery charged via an LCM, feeding two DC-DC buck converters: one supplying 12V for the Primary Controller, High-Voltage Distribution Cases, and a Central Controller Unit fan, and another supplying a configurable voltage for a low-voltage appliance, with a temperature sensor and fan controlled by the Primary Controller to manage thermal conditions, wherein the Primary Controller dynamically assigns Voltage Tiers based on real-time demand, available capacity, and load prioritization, wherein the Voltage Tiers are reconfigurable to support a range of DC voltages.

Claim 2: A method for dynamically distributing DC power from renewable energy sources to DC loads in a modular system, comprising: receiving DC inputs from renewable energy DC sources at a plurality of Power Modules, each generating a plurality of Power Units at a base DC voltage; selectively combining the Power Units in series via a semiconductor-based switching matrix in each Power Module to form one or more Voltage Tiers with configurable voltages; distributing the configurable voltages to a plurality of Load Connect Modules (LCMs) via power distribution lines, wherein the power distribution lines include bus bars or cables; connecting each LCM to a selected Voltage Tier or an external power source based on appliance requirements, using a semiconductor-based switching matrix in the LCM; monitoring real-time voltage and current data from the Power Modules and LCMs using sensors; dynamically assigning Voltage Tiers to the Power Modules and LCMs using a Central Controller Unit based on real-time demand, available capacity, and load prioritization schedules; and reconfiguring the Voltage Tier assignments in response to changes in demand, capacity, or system conditions, while enforcing safety protocols to ensure voltage compatibility and fault isolation.

Claim 3: The system of claim 1, wherein the renewable energy DC sources comprise solar panels.

Claim 4: The system of claim 1, wherein the Voltage Tiers comprise a plurality of configurable voltage levels ranging from a minimum voltage to a maximum voltage, the voltage levels being determined by series combinations of Power Units in the Power Modules.

Claim 5: The system of claim 1, wherein the power distribution lines comprise AWG4 or AWG6 cables rated for 75–100A, configured with clearance and arc suppression for high-voltage operation.

Claim 6: The system of claim 1, wherein the power distribution lines comprise bus bars arranged in a 2×2×N configuration, where N is the number of Voltage Tiers, with N positive and N negative bus bars for Power Modules and N positive and N negative bus bars for LCMs, rated for 75–100A with clearance and arc suppression for high-voltage operation.

Claim 7: The system of claim 1, wherein each Power Module includes a plurality of DC Buck Converters to generate Power Units at a base voltage, and the semiconductor-based switching matrix comprises switching elements configured for series-only connections to form Voltage Tiers.

Claim 8: The system of claim 7, wherein each Power Module further comprises an AUX Switch, implemented as a semiconductor-based or mechanical switch, to dedicate one Power Unit to a 48V AUX line, bypassing the semiconductor-based switching matrix.

Claim 9: The system of claim 1, wherein each LCM includes a semiconductor-based switching matrix with switching elements configured to connect the DC appliance to one Voltage Tier or the external power source, wherein the switching elements are rated to support the Voltage Tier range.

Claim 10: The system of claim 1, wherein the resettable fuse in each LCM is rated at 12A and configured to tolerate transient current spikes up to 1.5 times the rated current for 500 milliseconds, trigger reassignment to a higher Voltage Tier if current exceeds 90% of the rated current for over 2 seconds and immediately disconnect for spikes exceeding 2 times the rated current.

Claim 11: The system of claim 1, wherein multiple Load Connect Modules connected to the same Voltage Tier share current from common Power Module sources, enabling improved Power Unit utilization under partial load conditions.

Claim 12: The system of claim 1, wherein the Central Controller Unit supports battery-backed operation by powering an MPPT charge controller via a Load Connect Module to charge a battery, which may power an inverter supplying AC to the 48V@5A external adapter, enabling sustained operation in low-sun or emergency scenarios.

Claim 13: The system of claim 1, wherein the Central Controller Unit includes a software module accessible via a web-based interface for configuring Power Modules and LCMs, setting load prioritization schedules, and monitoring system performance.

Claim 14: The system of claim 1, wherein the breakers are double-pole, rated for 60A and 450V, configured to connect corresponding power distribution lines for each Voltage Tier.

Claim 15: The method of claim 2, wherein reconfiguring Voltage Tier assignments is performed with a latency of less than 200 milliseconds to ensure continuous appliance operation.

Claim 16: The system of claim 1, wherein the system supports plug-and-play integration of additional Power Modules and LCMs, and multiple High-Voltage Distribution Cases are electrically isolated to prevent cross-case faults.

Claim 17: The system of claim 1, wherein the Central Controller Unit is configured to register and configure the Power Modules and LCMs during setup, including assigning allowed voltage ranges and coupling LCMs for synchronized multi-input loads to increase current capacity.

Claim 18: The system of claim 9, wherein the Load Connect Module is configured to default to connecting the APPL Connector to the EXT Connector when none of the 14 Voltage Tier semiconductor switching elements in the Switching Matrix are enabled, such as during system failure or insufficient power on the 12V AUX line, with logic ensuring the EXT Connector is disconnected when any Voltage Tier semiconductor switching element is activated to prevent simultaneous connections.

Claim 19: The system of claim 1, wherein the Central Controller Unit is configured to detect startup of a DC appliance connected to a Load Connect Module (LCM) by monitoring current data from the LCM's A/V sensor, wherein a non-zero current draw triggers the Central Controller Unit to dynamically assign the LCM to an appropriate Voltage Tier based on the LCM's configured voltage range, with reconfiguration completed within a latency of less than 200 milliseconds; and wherein, if no current is drawn and an external power source is detected at the EXT Connector, the Central Controller Unit reverts the LCM to the EXT Connector.

Claim 20: The system of claim 1, wherein the semiconductor-based switching matrix in the Power Modules or Load Connect Modules comprises Gallium Nitride (GaN) or Silicon Carbide (SiC) transistors to enhance switching efficiency and thermal performance.