APPLICATION NOTE 601

Energy Storage Systems Utilizing the SunDial™ Plus 30PV+S Inverter

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1.0 PURPOSE AND SCOPE

The SunDial™ (Inverter) by Ideal Power is the solar industry's first 3-phase PV Commercial String Inverter that also can be configured to support energy storage. The 30PV may be utilized as a standalone 6-String PV Inverter, ('+S' option not required), or alternatively, as a multifunctional system coupling PV with energy storage ('+S' option installed). This Application Note highlights key considerations and provides high-level guidance for integrating the SunDial™ 30PV+S into an 30 kW commercial or industrial scale Energy Storage System (ESS) based on typical North American application requirements.

Note that the +S option may be factory or field installed. SunDial™ 30PV String Inverters may be deployed without the +S upgrade kit, minimizing installed system costs, while "future-proofing" the PV Array. You can add the +S upgrade kit, along with batteries and controls, at any point in the future. The +S upgrade kit is UL approved for field upgrades, requiring no more than 30 minutes per Inverter, when installed by certified field service personnel.

Lastly, note that a separate and expensive bidirectional PCS dedicated to the batteries is NOT required: the +S kit supports direct Solar + Storage integration utilizing the existing SunDial™ Inverter and existing AC interconnection. Depending on local AHJ requirements, a new interconnection agreement may not be required when energy storage is added to the Inverter's PV Array.

2.0 DISCLAIMER

This application note should be used in conjunction with other product and safety documentation provided by Ideal Power. The intended audience is engineering and lab personnel familiar with high-voltage/high-power systems and the general safety issues related to the wiring and use of 3-phase AC electricity, battery systems, and PV energy sources. This document does not purport to make recommendations regarding conformance with applicable electrical codes. A qualified electrical engineer should be engaged to do detailed system design and ensure conformance with applicable codes. Refer to the product datasheet for detailed specifications upon which to base any detailed designs.

3.0 OVERALL ENERGY STORAGE SYSTEM

The primary and secondary components of an ESS are described here. An indicative, generic single line diagram follows but does not include all components listed.

Inverter: controls the power flows between the PV Array and the grid. Ideal Power's 30PV+S Inverter also supports the direct integration of energy storage. The Inverter incorporates low-level self-protection and grid-protection features as required by UL and IEEE standards.

Battery: stores electrical energy and supports bidirectional DC power flows to charge the battery from PV; or discharge the battery to the grid as desired. Additionally PV + battery power can be "summed" and exported to the grid. Chargin the battery from the grid is not supported. The grid power port is external only. Most modern battery technologies incorporate their own battery management system (BMS) along with DC contactors to handle low-level self-protection.

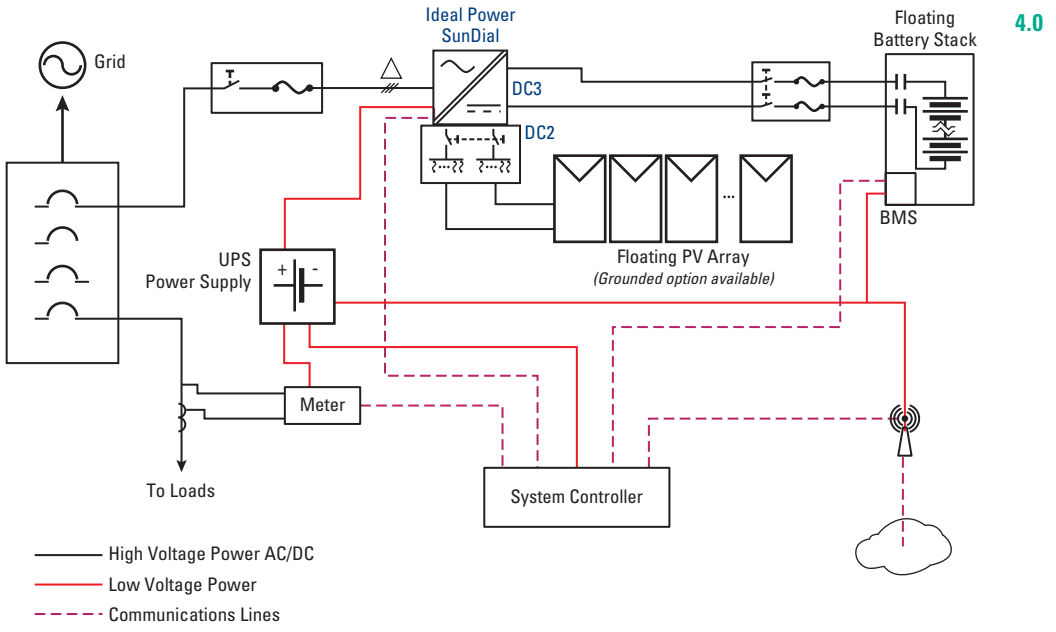
Energy Management System (also known as system or site controller): Usually contained within an embedded computer the EMS monitors and controls the 30PV+S Inverter; batteries; and other in-building energy resources such as smart meters. With knowledge of building energy use, the EMS makes economically-driven decisions on power charging/discharging and provides an interface for customers and operators.

Electrical Meters: One or more precision power meters are often employed to monitor different segments of the sites electrical system to provide building energy use intelligence for the Energy Management System. Revenue grade metering may be necessary on multiple legs, including the ESS, to thoroughly reconcile building usage and energy production for government or utility energy storage incentive programs.

Personnel and Circuit Protection Devices: This may include fuses, circuit breakers, surge protection devices, disconnect switches, emergency stop buttons and grounding systems to protect humans, equipment and the grid from electrical malfunctions and dangers.

Control Panel: Houses a collection of electronics and communications devices to support the ESS such as power supplies, uninterruptible power supplies (UPS), meters, relays, communications adapters, Ethernet switches, modems and the embedded control computer.

FIGURE 1: ESS Schematic Example



4.0

ELECTRICAL INTERFACES

AC Grid Connection

- The SunDial™ is electrically connected to the utility grid through the AC1 port in a 3-phase, 3-wire delta configuration. Bare wires are landed at built-in power terminal blocks.
- The SunDial operates at 480 Vac, 60 Hz. For lower AC line voltages such as the 3-phase, 208 V standard, an external step-down transformer is required.

AC Circuit Protection & Switchgear

- The SunDial™ has integral overvoltage surge protection built-in at its AC terminals.
- Overcurrent protection is handled within the Inverter through software-managed rapid fault detection and shut down. Hardware-based overcurrent protection must be provided separately, typically by way of an external fused AC disconnect switch or AC circuit breaker. Specific external disconnect requirements may vary by jurisdiction. Circuit disconnect functionality, manual or automatic, is not provided by the Inverter.
- If a contactor is required by a local authority having jurisdiction (AHJ) for grid disconnection, the SunDial™ includes a relay driver output that can control an external contactor consistent with such utility interconnection requirements.

DC Connections

- Up to six PV Strings are directly terminated on MC4 connectors located at the bottom of the 30PV's internal string combiner. A DC Disconnect is also provided, which isolates the combined string outputs from the DC2 'PV' power port.
- The +S option provide utilizes bare wire connections which are landed at built-in power terminal blocks on the DC3 'battery' power port.
- The SunDial™ requires a minimum PV or battery bus voltage of 200 Vdc and can accommodate up to 1000 Voc, with full 30 kW power nameplate rating available above 500 Vdc. Typical PV string voltages range from 600 to 900 Vdc; with similar ranges for battery systems.
- The SunDial™ is galvanically isolated between the AC and DC ports thereby allowing the DC2 and DC3 connections to be either ground referenced or floating. Note that the Inverter's integral 6-String PV Combiner is available in either a grounded (30PV+S) or floating (30PVF+S) version. The 30PV+S Combiner requires the use of a ground-referenced battery. If employing the 30PVF+S, both battery and PV array must be floating.
- Multiple parallel battery stacks may be required for increased energy capacity in the ESS. In this case an external battery combiner box may be necessary, including applicable overcurrent protection as required by code.

DC Circuit Protection & Switchgear

- The SunDial™ has integral ground fault detection built in at its DC terminals. Depending on the PV Combiner configuration selected, the appropriate ground fault detection method will be utilized: GFDI for ground-referenced DC circuits and IMI for floating DC circuits.
- Overcurrent protection is handled within the Inverter through software-managed rapid fault detection and shut down for both DC2 and DC3. The internal DC2 disconnect located at the Inverter's integral 6-string combiner output is generally acceptable as an appropriate PV disconnect means by most AHJ's. The PV combiner individual string fuses provide internal protection to the DC2 port.
- DC3 battery circuit disconnection functionality, manual or automatic, is not provided by the Inverter. A nearby, external fused DC disconnect switch is typically required for code compliance. Battery systems will typically have integrated contactors which may be employed for controlled DC3 connection and disconnection.
- DC voltage limits (minimum/maximum) as applicable to an individual battery, and/or PV operating voltage ranges may be configured within the Inverter software which will treat them as fault limits.

5.0 CONTROL PANEL

System Controller

- The system controller hosts the Energy Management System software that generally provides the economic decision making for the ESS operation. It is typically an industrial computer running a Linux or Windows Embedded operating system, or alternatively a Programmable Logic Controller (PLC).
- The controller requires communications interfaces with all the other primary and secondary hardware components for monitoring, data capture and analysis and control. The 30PV+S physically connects to the controller by way of a serial RS485 link or Ethernet, utilizing Modbus RTU or Modbus TCP respectively as the communications protocol.
- Battery Management Systems (BMS) will generally connect to the controller by way of a CAN bus interface, but other BMS communications may also be available.
- Electrical meters will also require a communications link to the system controller: RS485 Modbus RTU is the most common meter interface with Ethernet Modbus TCP also available.
- Remote connectivity over the internet is a critical feature for an ESS for monitoring, support and updates. This may be accomplished through a local LAN or a cellular internet connection and may require additional hardware for a wireless connection.

Low Voltage Power Supply & Control

- The SunDial™ draws its auxiliary supply power first from the AC grid when present or from an external 24 Vdc power supply (not included) when the grid is unavailable. Most of the other hardware devices such as the battery BMS and controller will also require a power supply to operate. Standardizing on 24 Vdc power may be possible for all devices including low voltage control of relays or contactor coils.

- A small backup UPS is recommended to supply power to all the devices in the case of a grid loss or other fault conditions.
- The SunDial™ includes an input for an emergency stop device which may be linked to a battery system to provide a mechanism for a system-level emergency stop for safety.

6.0 MECHANICAL & ENVIRONMENTAL REQUIREMENTS

- The SunDial™ weighs approximately 140 lbs. and is vertically mounted on an included bracket. The Inverter's enclosure is rated NEMA3R for outdoor applications.
- The Inverter is cooled by forced convection drawn from underneath and vented out the top-front of the enclosure. For outdoor installations, clearance of 36" is required underneath the Inverter and 18" in front for sufficient air flow. If the Inverter is installed indoors, clearance underneath may be reduced to 18". If the ambient temperature exceeds 50°C additional active cooling of the Inverter may be required.
- Batteries will require additional racking: many lithium battery packs from leading vendors are designed to fit in a standard 19" equipment rack. Both DC and AC disconnect switches, when mandated by electrical code, must be mounted to be visible and accessible on or near the outside of the ESS for safety.
- Check with the battery manufacturer as to their cooling requirements. Source other components such as the system controller to be rated for rugged environmental conditions.
- Other ESS components such as the system controller will require enclosures and applicable environmental protection whether for indoor or outdoor applications. The ESS may be enclosed in one overall package or installed as separate pieces.

7.0 ENERGY MANAGEMENT SOFTWARE

Inverter Supervision

- Basic interfacing with the 30PV+S requires building a software driver to communicate by Modbus, polling relevant monitoring registers for data on regular intervals along with functionality to read and write relevant registers to configure and control the unit.
- Modbus interfacing includes interpretation of data types and scaling factors. At the next higher level of abstraction, it is necessary to understand and build broader functions to process logical state transitions and control methods of the Inverter.
    - The 30PV+S provides status information along with basic electrical data for monitoring voltage, current, frequency and power. Operating setpoints and configurations may be set including power limits, ramp rate and control methods whether current or AC and DC power control. During regular operation, the Inverter may be dynamically commanded to change power or current level. This description is not comprehensive, please refer to the Quick Start Guide and Modbus Map for full details of available data and commands.
- For ongoing operations and maintenance of the system it is important to incorporate Inverter fault-handling logic, logging of data and events and support for an FTP link to facilitate remote firmware updates to the system.
    - The 30PV+S includes some ability to do automatic fault handling and reset. Active, ongoing fault conditions are indicated while historical and transient fault conditions are logged with a timestamp on the most recent.

Battery Supervision

- Similar to the 30PV+S, the battery management system will also require a low-level software driver to poll for data and send commands then higher-level functions to manage transitions and operate within applicable limits such as voltage limits and state of charge.
- For ongoing operations and maintenance of the battery system it is important to incorporate battery fault-handling logic, logging of data and events and support remote updates if offered by the battery supplier.

Energy Storage System Supervision

- The control software will have to establish and manage the system-level state machine and applicable coordination between the inverter, battery and other connected assets. This will include operating sequences such as commanding the Inverter appropriately to ensure overcharging, or deep discharging of the battery never occurs.

- In addition to the primary ESS components, such as the battery and the Inverter, other hardware components and assets will also require software monitoring and control, energy meters are a prime example
- The primary value of the Energy Management Software is to make decisions to charge or discharge based on economic factors such as reducing peak power demands, effectively shifting or reducing loads on the local utility and storing excess solar energy for use at a later time. Typically, this will require building software intelligence for tracking and predicting both loads and local generation and responsiveness to utility signals.
- When a grid-connected SunDial™ Inverter is used with both solar PV and battery energy storage together, energy may flow between all three power ports. The system controller must regularly decide and control where to direct available solar energy and battery energy. This requires slightly more complicated control decision logic but will help achieve all the possible economic advantages of combining solar with storage.
- Remote monitoring and control of the system is essential to address long-term O&M needs, build customer engagement and provide continuous improvements. This part of the system will typically include a web browser-based user interface, mechanisms for operator alerts and remote diagnostics and historical data analytics. Information security is a critical element of any internet-connected system and appropriate firewalls, authentication and encryption should be employed.

8.0 ADDITIONAL ESS CONFIGURATIONS

The following additional configuration options are provided in brief for high-level consideration.

Multiple Parallel Inverters

- The SunDial™ may be operated in parallel connected to the same bus on both the AC grid connection and DC battery side if desired for a particular power-to-energy ratio. The Inverter has appropriate impedance and filtering on both AC and DC sides to handle electrical dynamics on both the AC and DC busses.
- To take advantage of the built-in ground-fault detection of the inverter and reduce or eliminate need for DC combiners it may be worthwhile to employ separate DC busses for different Inverters.
- Controlling multiple SunDial™ Inverters requires independent data collection and commands for each separate unit. The Inverter does not inherently accommodate a master/slave control scheme.
- Note that the SunDial™ does NOT support critical load backup or microgrid functionality. Contact Ideal Power at support@idealpower.com if your application requires in-building critical load support during grid outages.

DISCLAIMERS AND INTELLECTUAL PROPERTY NOTICE

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