Application Brief

Wireless Technologies for Solar Micro Inverters and Trackers

The demand for renewable energy is growing. Utilities, businesses, and homeowners are considering alternative energy sources to reduce carbon footprint and cost. Solar panels are quickly becoming a popular option. This document discusses the different inverter architectures and the impact each has on users.

Types of Solar Inverters

String Inverters

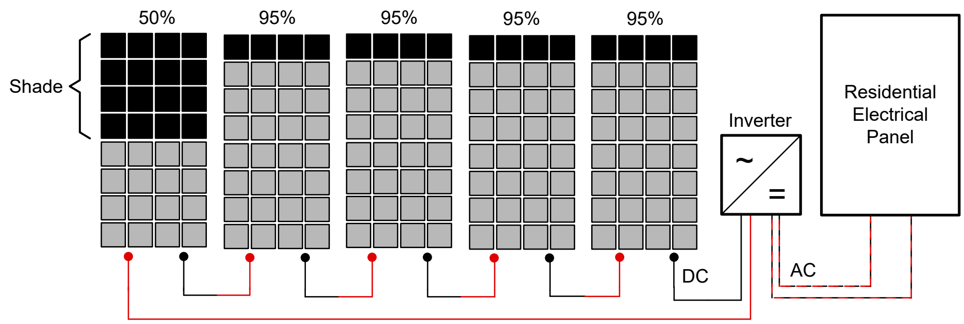

Figure 1. String Inverters

As shown in Figure 1, a string inverter offers the lowest system cost because of reduced hardware complexity and labor cost for installation. However, a string inverter does not allow users to monitor the performance of each solar panel individually. Pin-pointing the panel that requires maintenance or replacement can be difficult because the panels are all connected in series. Single inverter topologies come with an inverter optimized for a specific power rating, proportional to the number of panels, which limits the flexibility to expand or upgrade the panels. Another drawback of this architecture is that shade on one panel affects the performance of other panels. The DC voltage generated by the panels is sent to a centralized inverter that is not installed on the roof. This introduces a safety concern with a high DC voltage line (approximately 48V per panel) across the roof. The inverter then converts the DC into AC voltage that can be used to power electronics in the building. String inverters trade off quick installation and low cost for manual troubleshooting, higher safety risk, decreased robustness, and scalability.

String Inverters With Power Optimizers

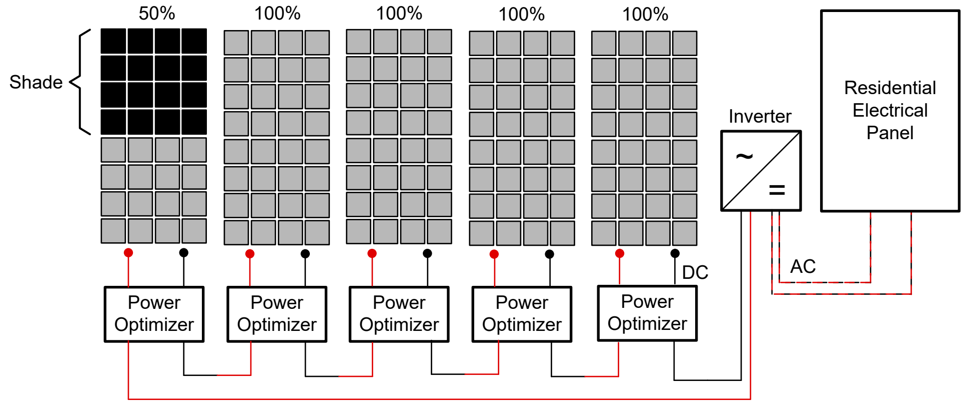

Figure 2. String Inverters With Power Optimizers

To address drawbacks, power optimizers can be added to the string inverter. As shown in Figure 2, with power optimizers the inverter can control the outputs of each panel and individually disconnect panels from the string. Disconnecting panels reduces the DC line voltage and eliminates the safety concern. Panel output control provides robustness to shade and other impairments that cause one panel to produce less power. With power optimizers the other panels can continue to generate full power. This architecture also allows better monitoring of the performance of each panel by the user but still suffers from the scalability limitations of a single inverter topology. Power optimizers improve the systems efficiency, robustness, safety, and telemetry relative to a stand-alone string inverter.

Micro Inverters

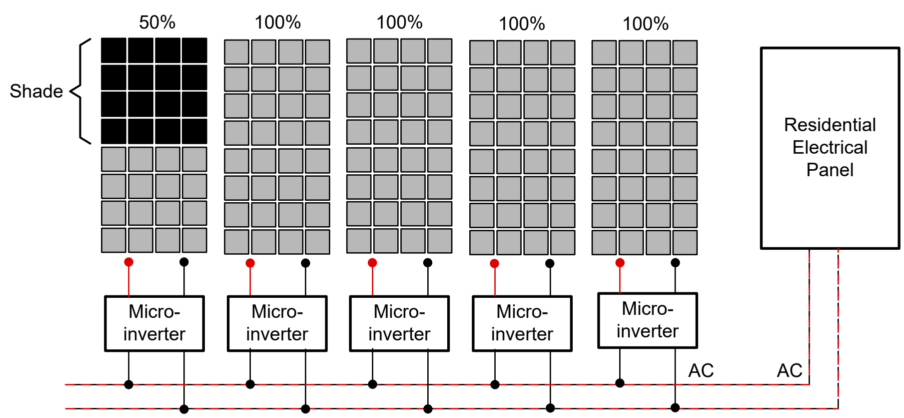

Figure 3. Solar Micro Inverters

Solar micro inverters are designed to provide power efficiency and maintenance for users. Each panel has a micro inverter which allows for full telemetry of every panel. A user can monitor for many different conditions including temperature, voltage, and current. Any defective panel is identified directly, allowing for targeted repair or replacement without manual troubleshooting. Additionally, system performance is not affected if one or more panels are generating less power; thereby maximizing the power generated by the system. Micro inverters address the scalability concerns enabling the addition or upgrade of panels. If the inverters are installed in close proximity to the panels, there are no high-voltage DC line related safety concerns. Micro inverters optimize efficiency, robustness, scalability, and telemetry relative to single inverter topologies.

Why is Wireless Connectivity a Great Technology for Solar Panels?

Figure 3 shows how the electricity flows from the solar panels to the circuit breakers and the trade-offs of different architectures. The next section discusses how users monitor the solar panel system and the system requirements.

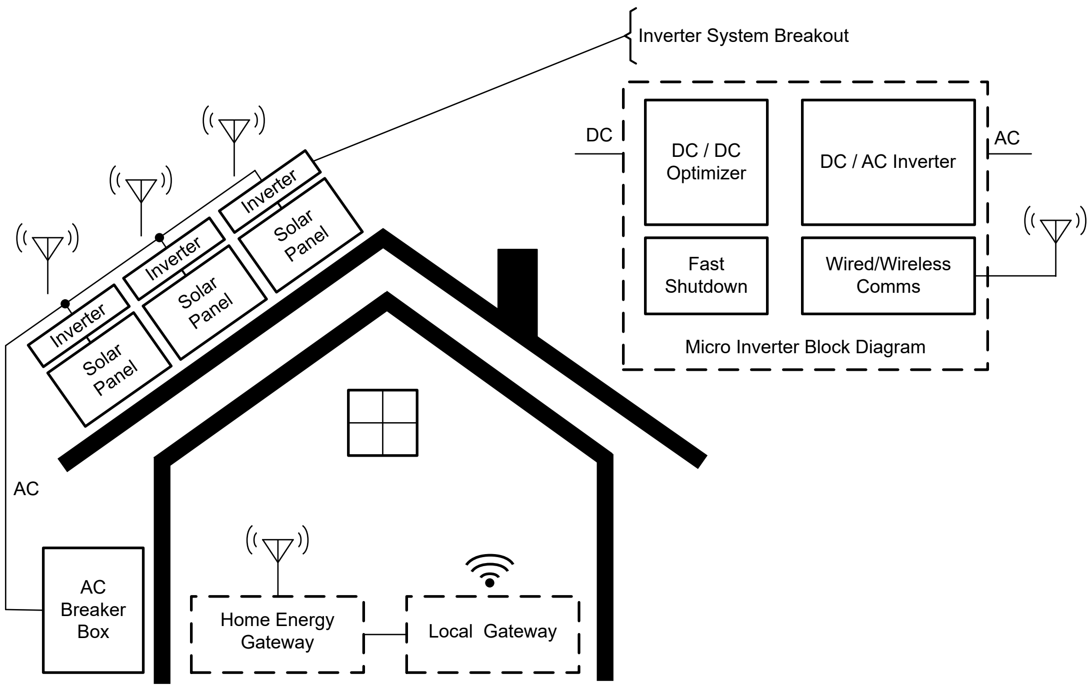

Figure 4. Wireless Technology and Solar Panels

To enable remote monitoring, the information collected from each panel needs to be sent to the cloud where the information can be accessed by smartphones or other connected devices. First the data from the panels is sent to a home energy gateway. This gateway then transmits the data via Wi-Fi® to a local gateway that is connected to the cloud. The user can then view the data from anywhere.

There are multiple technologies available for panel-to-home-energy-gateway communication. The next section discusses the solar panel requirements and the trade-offs of each technology.

Solar Panel Requirements

Table 1 lists the solar panel requirements by priority.

Table 1. Solar Panel Requirements Listed by Priority

Requirements	PLC[1]	TI WSMS[2]-Star	TI WSMS[2]-Mesh	Zigbee® 2.4GHz	Wi-Fi®
Rapid shutdown	Yes	Yes	Yes	Yes	Yes
Data rate	Low-cost PLC: < 1kbps OFDM[3] PLCs: 31kbps	5kbps to 200kbps	50kbps to 300kbps	250kbps	> 1Mbps
Interference	Low-cost PLC: highly affected OFDM PLCs: robust	Interference avoidance thru frequency hopping	Interference avoidance thru frequency hopping and mesh routing	Interference avoidance thru mesh routing only	No mesh routing and no frequency hopping
Range | link budget	Low-cost PLC: short range OFDM PLCs: 1000m	1000m | 125dB	1000m | 125dB	50m | 105dB	50m | 105dB
Security	Yes (AES[4] MAC[5])	Yes (AES MAC + pre-shared network keys)	Yes (AES MAC + Certificate exchange + pre-shared network keys)	Yes (AES MAC + pre-shared keys)	Yes (AES MAC + pre-shared keys)
Set up and maintenance	Issues where panel board is shared	No issues and easy commissioning process	No issues and easy commissioning process	No issues and easy commissioning process	No issues and easy commissioning process
Network formation time	< 5 min	< 5 min	5 min for 100 nodes	< 5 min	< 5 min
Production test enablement	Vendor dependent	RF[6] diagnostics and prop test mode integrated	RF diagnostics and prop test mode integrated	Not available, can be implemented	Not available, can be implemented
Home energy gateway	Required	Required	Required	Required	Optional (balcony install)
Additional repeater	Not needed	Not needed	Not needed	Optional	Optional
Practical limits	20 (Low-cost PLC) > 20 (OFDM PLC)	< 50	100+	< 50	< 10
Over-the-air protocol	Non-IP based	Non-IP based	IPV6	Non-IP based	IPV4 and IPV6

(1) Power Line Communication (PLC)
(2) Texas Instruments Wireless Solar Management System (WSMS)
(3) Orthogonal (OFDM)
(4) Advanced Encryption Standard (AES)
(5) Message Authentication Code (MAC)
(6) Radio Frequency (RF)

Rapid Shutdown

Rapid shutdown is a critical safety feature to protect the first responders and occupants. The safety standard in the US, the National Electric Code (NEC) defines the parameters in Article 690.12: "Controlled conductors shall be limited to not more than 30 volts and 240 volt-amperes within 10 seconds of rapid shutdown initiation."

Table 1 shows that all existing technologies meet this safety critical requirement. Wireless technologies accomplish this by sending a broadcast package to all micro inverters with a command to shut down.

Data Rate

Unlike rapid shutdown, data rate requirements do vary based upon which PLC option is chosen. For example, a mid-size house, with 60 panels. Information from each panel normally consists of collecting voltage (V), current (C), temperature (T), panel identification (ID) and status (S) data. The data needs to be transmitted every 15 seconds, according to solar micro inverter manufacturers. Based on the calculations in Equation 1 and Equation 2, the data rate requirement for this example is 736 bits per second.

Calculations

$$60\ \text{panels} \times (3\text{V} + 2\text{C} + 4\text{T} + 2\text{ID} + \text{S}) \times \left(\frac{16\ \text{bits}}{\text{field}}\right) = 60 \times 184\ \text{bits} = 11{,}040\ \text{bits} \quad (1)$$

$$\frac{11{,}040\ \text{bits}}{15\ \text{seconds}} = 736\ \text{bps} \quad (2)$$

There are different types of connectivity options that solar panel manufacturers consider to meet this requirement. Historically, there are two types of wired Power Line Communication (PLC) options: Orthogonal (OFDM), and Frequency Shift Keying (FSK). OFDM PLC is standards-based and has a high enough data rate (> 1Mbps) to support communication between the solar panels and the home energy gateway. FSK PLC is often proprietary and is commonly used in cost-sensitive designs. FSK PLCs offer a data rate of approximately 100bps which is not enough throughput for many use cases, including the mid-size house example.

Wireless technologies provide designers with a cost-effective high data rate option. TI offers Sub-1GHz, 2.4GHz and Wi-Fi radios which have high data rates (> 100Kbps) that can support the necessary data rate communication. Additionally, wireless technologies allow for remote in-field firmware updates without the need for a technician.

Interference

Another trade-off between the different communication options is interference. Buildings have appliances with motors that generate a significant amount of noise. If the data from the panels is coming via wired communication, like low-cost PLCs, the noise can interfere with the data. If the interference is high enough, the data from the panels can be unreadable. Common ways to avoid interference in wired systems include toroid ferrite ring filters or having a dedicated socket or circuit for the solar panels, which can increase the cost of the system.

In wireless designs, frequency hopping and mesh routing help avoid interference. TI WSMS-Mesh uses both of these techniques. TI WSMS-Star utilizes frequency hopping only and Zigbee utilizes mesh routing only to avoid noise interference. Most wireless options have interference protection techniques built in while PLC interference mitigation can present additional cost.

Range

For solar panel manufacturers, range is not just a simple requirement related to the distance between the panel and the home energy gateway. The specification decides which market and buildings the product is compatible with. Low-cost PLCs, Wi-Fi, and Zigbee are short range, limited to balcony and single-family home installations. Sub-1GHz options, TI WSMS-Mesh and TI WSMS-Star are 20 × longer range, optimized for multifamily homes, apartments, and commercial installations.

Security

Security is an important consideration for solar panel development. Low-cost PLC offers little to no encryption, relying on physical barriers for preventing access. Wireless options connect the panels to the internet and have to address an additional path for malicious attacks on systems. Security systems can span from relatively simple pre-shared key architectures to more elaborate systems. These elaborate systems include provisions for secure key exchanges, key management, secure and reliable firmware updates, and anti-tampering sensors. All security measures come at additional cost in development time and product cost. Therefore, each vendor needs to complete a threat model assessment and pick the correct level of security for the products.

Set up and Maintenance

Set up and maintenance is another area where wireless options offer an advantage.

For example, consider a duplex, where two homes share the same electrical panel. One home has an existing solar panel system installed, the other home wants to install a solar panel system. The duplex scenario introduces the challenge of separating data in a multi-home building.

If both the existing and new solar panel systems are based on PLC and connected to one electrical panel, the data becomes impossible to separate and the two home energy gateways cannot distinguish between the solar panel systems. Consequently, there is no way to monitor the power generation and usage of each home separately.

Wireless technologies provide an elegant option to this problem by assigning each node a unique identifier. Installers assign the unique identifier of each solar panel to a specific home energy gateway during the commissioning process. As a result, each user only has access to the information from a single solar panel system. Referring back to the duplex example, if the solar panel systems rely on wireless technology, there is no problem routing the data to the right home owner. This allows each neighbor to monitor power generation as well as easily identify panels in need of maintenance.

Network Formation Time

Overnight, each panel loses power and shuts down. As the sun rises each morning, the entire solar panel system reboots and reconnects. Wired and wireless technologies meet the 5-minute requirement for network formation (5 minutes is an arbitrary number that is acceptable for users to have the system up and running.)

Production Test Enablement

Wireless option designers use SmartRF™ Studio for prototype development and testing with a Microsoft® Windows® PC. However, when the design moves into the production flow, manufacturers need a different toolkit to test without a PC or a debugging port. For instance, BLE and Wi-Fi standards require fully-automated test suites to enable inline automated testing. There is a similar option for Sub-1GHz called RF Diagnostics. This embedded tool helps manufacturers create automated inline test systems on TI Sub-1GHz ICs. For TI WSMS-Mesh specifically, our SDK after version 7.40 implemented special test features requested by solar panel manufacturers directly into the stack.

Home Energy Gateway

For users to have remote access, the information coming from the panels needs to be sent to the local gateway (see Figure 4). If the micro inverters are using Wi-Fi, micro inverters can connect directly to an existing local gateway without a separate home energy gateway. All other technologies require a separate home energy gateway, since the local gateway typically does not support technologies besides Wi-Fi.

Additional Repeaters

Additional repeaters are not needed for micro inverters using either wired or Sub-1GHz technologies (like TI WSMS-Star or TI WSMS-Mesh). Sub-1GHz operates at lower frequencies that have longer wavelengths that travel further, penetrate physical barriers like concrete walls, and suffer less interference compared to 2.4GHz. By contrast 2.4GHz and Wi-Fi technologies need repeaters to achieve the same range.

What is the Right Sub-1Hz Protocol to Use?

There are two options available to capture the benefits of Sub-1GHz technologies for solar panel systems. The TI WSMS-Mesh option is recommended for larger installations (50+ micro inverters), and the TI WSMS-Star stack for smaller installations (less than 50 micro inverters.)

Why Use TI WSMS-Mesh for Solar Micro Inverters?

TI WSMS-Mesh is based on an open-standard protocol (IEEE 802.15.4 and WI-SUN) driving unification in the market. Texas Instruments is an active Wi-SUN Alliance® member, providing interoperable options, royalty-free software, and standards-based multilayer security. The Wi-SUN protocol is appropriate for applications that require long RF transmission range, high node count, and robust network performance with self-healing mesh such as connected smart meters, EV charging, street lighting, and solar micro inverters.

Specific options are available in the TI WSMS-Mesh stack to better address the requirements of micro inverters and trackers markets:

- **Only join to specific border router** – Allows the manufacturer to scan the QR code of a panel and make sure the panel joins a specific border router, simplifying the installation process when there are other solar panel networks around. This also lowers the cost of the border router by allowing a headless device to be used.
- **Pre-configured MAC keys** – This feature reduces the code size, allowing the use of microcontrollers with smaller flash memory, which significantly improves the join time of the panel to the network and reduces the installation time.
- **Rapid join for small networks** – For networks consisting of 1 border router and up to 100 panels, this feature reduces the network formation time to less than 5 minutes. This feature can be selected using the SysConfig utility.

- **Production test mode** – This feature enables production line testing and can be used during production to verify the TI WSMS-Mesh application within 3 to 10 seconds, improving the confidence in production that the product works correctly in the field as well as allowing multiple production lines to run in parallel. Another benefit is the simplicity. The same image can be used during production test and deployment.
- **Low latency broadcast for small networks** – This feature implements a low-latency broadcast feature that enables the network to be compliant with requirements like *Rapid Shutdown*. This feature has been tested successfully in networks up to 3 hops.
- **Performance metric monitoring feature** – Customers can access real time monitoring (joining time, number of disconnections), allowing field support to retrieve this information from the nodes.

Why Use TI WSMS-Star Stack?

For smaller installations where mesh is not required, TI offers a star-network stack called TI WSMS-Star stack. This product enables low-cost options with similar functions as TI WSMS-Mesh security and onboard commissioning, but does not support mesh configuration. TI WSMS-Star stack was designed to target applications where microcontrollers have smaller flash memory. This stack has low overhead and a smaller footprint, lowering the cost of the option.

This royalty-free WSMS-Star stack is a complete software platform for developing applications that require extremely low-power, long-range, reliable, robust, and secure wireless star-topology-based networking options. The 802.15.4 standard is the underlying technology supporting many protocols such as Zigbee, Thread, and Wi-SUN. The MAC layer was expanded and more higher layer features were added such as commissioning and addressing.

Figure 5 shows an example of the bench units TI uses for testing products, including hardware and software, so that customers can have confidence when using TI options.

Figure 5. Example of Sub-1GHz Products Being Tested During Development

To get started with either WSMS-Mesh or WSMS-Star, download the SimpleLink™ low power software development kits (SDKs).

To learn more, refer to TI's Solar energy applications page and look for wireless connectivity.