Application Note

Summary of Solar Application Scenarios Using In-package Hall-effect Current Sensors

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ABSTRACT

Through-hole board mount hall-effect current sensor (or say magnetic current sensor) has been widely used in solar inverter system for a dozen years. This process is convenient for wiring and installation, no need to cut off the cable. However, open-loop through-hole hall-effect current sensor usually can't achieve high accuracy over both lifetime and temperature. Meanwhile, this is easy to fail during the installation and transportation processes due to the brittle magnetic core damage, which reduces the system reliability. On the contrary, in-package hall-effect current sensor can provide high accuracy combined with low drift, enabling accurate current measurements over both lifetime and temperature. Additionally, the in-package design also provides a compact design without sacrificing isolation performance, while reducing system complexity and cost. So, in recent years, there has a trend in solar inverter system to use in-package hall-effect current sensor to replace the traditional thorough-hole one, that benefits solar system performance, power efficiency and reliability.

This application note summarizes common solar application scenarios where in-package hall-effect current sensors, such as TI's portfolios TMCS112x and TMCS113x, can be used. This document helps engineers to understand the basic requirements of current sensing in solar end equipment and how current sensors are used accordingly.

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1 Introduction

Current measurement accuracy and reliability is critical to solar inverter system, because this determines the control accuracy of the power stage and further affects the energy harvest efficiency. For high-voltage solar inverter systems, through-hole board mount hall-effect current sensor (or for example, magnetic current sensor) have intrinsic isolation nature and the measurement does not intervene the measured circuit that provides wiring and installation convenience.

Close-loop hall-effect current sensor can provide high accuracy, fast response, low sensitivity and low non-linearity error, the sensor needs extra magnetic core, coil and high-power amplifier to drive the coil that makes close-loop hall-effect current sensor has more complex structure, large size, higher power consumption and higher cost than those of open-loop hall-effect current sensor. So, considering the tradeoff between performance and complexity, open-loop through-hole board mount hall-effect current sensor have been widely used in solar inverter system for a long time.

However, open-loop through-hole hall-effect current sensor usually cannot achieve high accuracy over both lifetime and temperature. Meanwhile, this is easy to fail during the installation and transportation processes due to the brittle magnetic core damage, which reduces the system reliability. This can be great if open-loop hall-effect current sensor can provide sufficient performance of accuracy, response, sensitivity, and non-linearity as close-loop one. The better option is using in-package hall-effect current sensor such as TMCS112x and TMCS113x. TI's in-package hall-effect current sensor can provide high accuracy combined with low drift, enabling accurate current measurements over both lifetime and temperature. Additionally, the in-package design also provides a compact design without sacrificing isolation performance, without adding system complexity or cost. In recent years, there has been a trend in solar inverter system to use in-package hall-effect current sensor to replace the traditional thorough-hole one, that benefits solar system performance, power efficiency, and reliability.

2 Solar Application Scenarios with Hall-effect Current Sensing

Common solar application scenarios with hall-effect current sensing include string inverter, residential inverter, hybrid inverter, micro inverter, solar power optimizer and smart combiner box of central inverter, and so on.

2.1 String Inverter

String inverter is usually three-phase inverter deployed in commercial-industrial system and utility system. The power level is usually larger than 50KW. Figure 2-1 shows the typical 3-phase string inverter block diagram with hall-effect current sensors used to measure the following currents.

- String current sampling.
- Arc current detection (optional).
- MPPT Boost current sampling.
- three-phase current sampling.

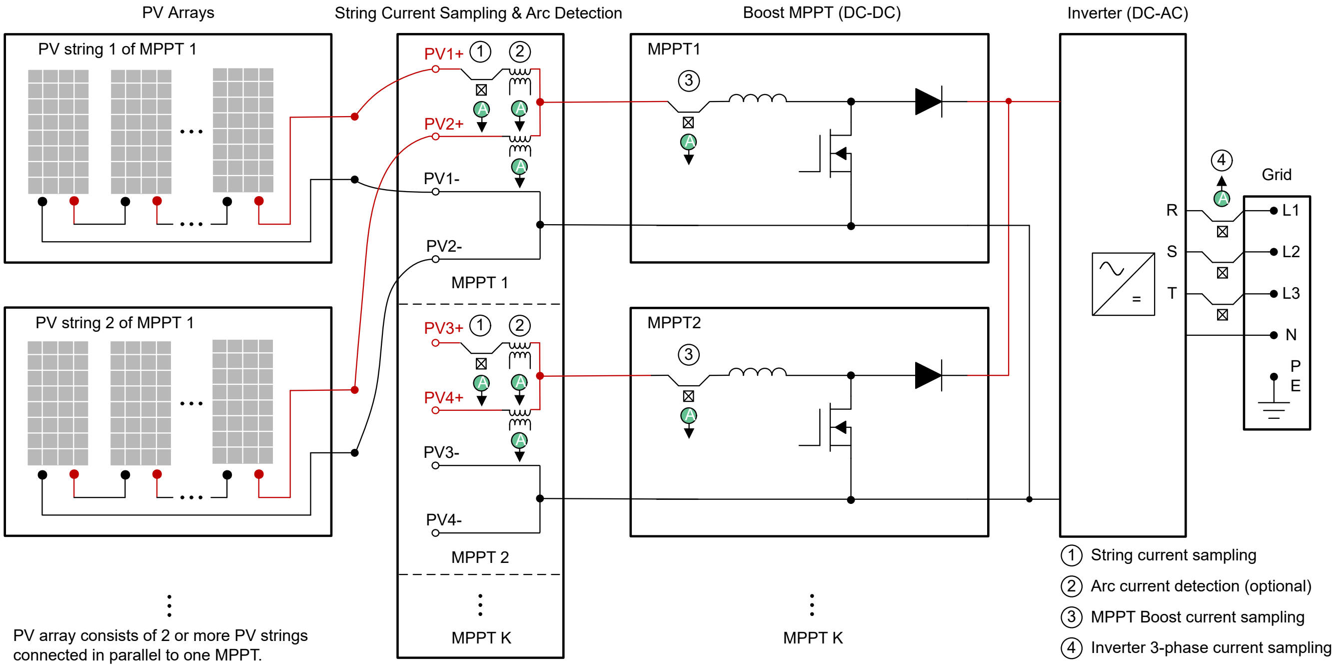

Figure 2-1. 3-phase String Inverter Block Diagram with Hall-effect Current Sensors

2.1.1 String Current Sampling

Apart from string current display function, the purpose of string current sampling is used for I-V curve scanning and diagnosis for smart maintaining work. The PV plant has a large number of PV strings. Meanwhile, one PV string also consists of multiple PV modules (PV panels). The fact is that any PV module or electrical connection can have potential failures or risks that can lead to power generation loss. For example, shadow, dust shielding, and glass panel cracking can cause current mismatch in the string. Diode short circuit, cable disconnect, Potential-induced degradation (PID) and hotspot can cause low string open circuit voltage.

The challenge in the PV system is how to accurately and rapidly locate and process these failures or risks. The traditional method is offline manual inspection which has very low efficiency and high cost. The current popular way is online I-V curve scanning and diagnosis to improve the efficiency and accuracy of PV system fault identification.

Figure 2-2 shows an example of normal and abnormal I-V curves scanning and diagnosis. As abnormalities of the PV system can cause different changes in the I-V characteristic curve, the I-V curve monitoring results can be used to analyze the potential failures or risks during PV system operation. So, the accuracy of string current and voltage sampling is one of the key factors to determine the final failure diagnosis accuracy, and indirectly determine the power generation efficiency. This is very important to commercial-industrial PV plant and utility PV plant which care a lot about output.

Also notice that maximum power point tracking (MPPT) in string inverter is usually implemented in PV array level, while I-V curve scanning is implemented in single string level.

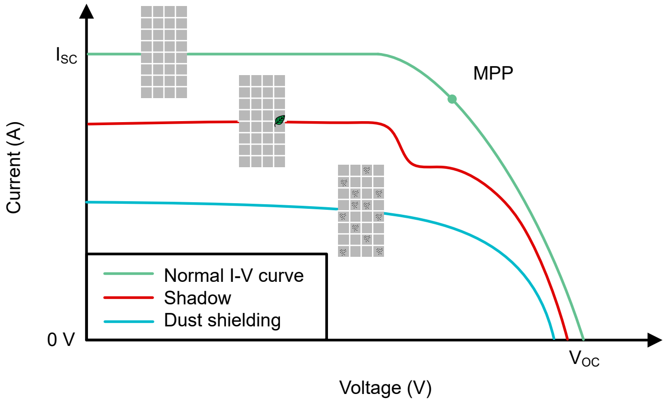

Figure 2-2. Example of Normal and Abnormal I-V Curves Scanning and Diagnosis

2.1.2 Arc Current Detection (Optional)

Arc-Fault Circuit Interrupter (AFCI) is an emerging requirement in solar system and also gradually becomes the mandatory requirement in some countries or areas according to the laws and regulations. Based on UL 1699B, AFCI is required to employ for solar equipment to prevent dangers, especially fires occurring in PV panel installations. Arc current detection is needed to collect and analyze the AC noise current present on the DC current between the PV string and inverter, then distinguish an arc and non-arc event.

Arc current can range from a dozen mA to several Amperes, and the frequency spectrum can be low to several KHz and up to several hundreds of KHz. The frequency requires the current sensor has high sensitivity, high bandwidth, and low noise level. Current transformer (CT) can provide high measurement accuracy and safety isolation between the primary high current side and the secondary low current side. This has been widely used as arc current detection sensor. While the disadvantages of CT are, the CT has burden power loss and occupies large PCB size. In-package hall-effect current sensing design is also becoming one of the new trends in arc current detection.

2.1.3 MPPT Boost Current Sampling

As shown in Figure 2-1, MPPT stage is usually implemented with Boost topology. PV array voltage and current are sampled as the control input signals to achieve MPPT. Usually the average inductor current is sampled and MPPT control frequency is much lower than the switching frequency. The accuracy of MPPT boost current sampling is also critical as that of string current sampling, since this determines the MPPT accuracy which finally affects the power generation efficiency.

2.1.4 3-Phase Current Sampling

Inverter 3-phase current sampling includes inverter's AC current (R phase, S phase, T phase) and corresponding DC components. The typical block diagram of 3-phase current sampling and signal conditioning is shown in Figure 2-3. The phase current is sampled by the DSP ADC to be used for the inverter power stage control and power generation statistics. The AC component of the phase current is filtered out and only DC component is left, amplified and then sampled by the DSP ADC to be used for DC component suppression control.

For grid-connected inverter, theoretically, only AC current is allowed to inject into the grid. But in fact, inverter output current inevitably contains some DC component which does harm to the grid, grid load and grid equipment. Therefore, this is unlikely to completely remove inverter's DC component but need to control this in a certain low range. Standards such as IEEE 1547-2018 have defined the limit for dc component in the grid-side ac current, for example, below 0.5% of the rated output current.

The accuracy of 3-phase current sampling is very important for inverter power stage control, power generation statistics and DC component suppression. Especially for DC component excess issue, using hall-effect current sensor with high accuracy and low drift can help a lot to solve the issue at the beginning.

Another issue regarding to the accuracy of current sensor is reactive power generation. For active power generation, the reference of current loop is generated by the voltage loop. The error of current sensor can be greatly alleviated by the current controller, in this case, the accuracy of DC bus voltage sensing is important. But for reactive power generation, the reference of reactive current is generated directly by the MCU. So, if the current sensor is not accurate, the output current of the inverter can not be the set value. Using a high accurate TI hall-effect current sensor can also help a lot of this problem.

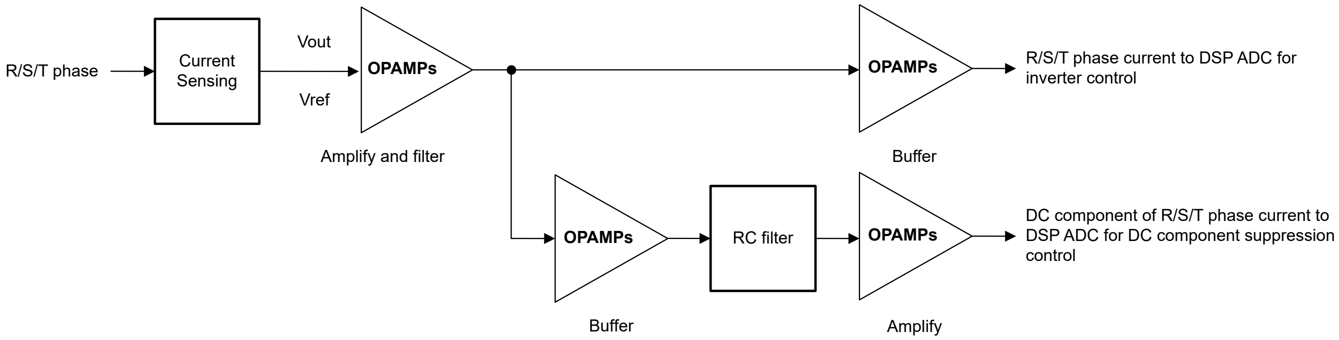

Figure 2-3. Typical Block Diagram of 3-phase Current Sampling and Signal Conditioning

2.2 Single-Phase Residential Inverter

Residential inverter usually refers to single-phase inverter and 3-phase inverter deployed in residential system. The power level of single-phase inverter is usually less than 10KW and 10KW to 50KW for 3-phase inverter. The system architecture of 3-phase residential inverter is very similar to that of string inverter discussed before.

The biggest difference is that residential inverter has much smaller number of independent MPPT inputs, and the number of PV strings per MPPT can be 1 or 2 depending on the power level. For example, a 50KW 3-phase residential inverter has 4 MPPT inputs and total 5 to 8 PV string inputs. This is much simpler for single-phase inverter. For example, a 10KW single-phase residential inverter has 3 MPPT inputs and total 3 PV string inputs. Figure 2-4 shows the typical single-phase residential inverter block diagram with hall-effect current sensors.

Considering the inverter power level and the target application scenarios, residential inverter does not have strict high accuracy requirement in string current sampling and MPPT boost current sampling, compared with string inverter. Because residential system is usually independent from each other and the deployment scale is minimal, this is not a big deal even low current sampling accuracy can cause some power generation output losses. While for phase current sampling, residential inverter has the same high accuracy requirement and reasons as those of string inverter.

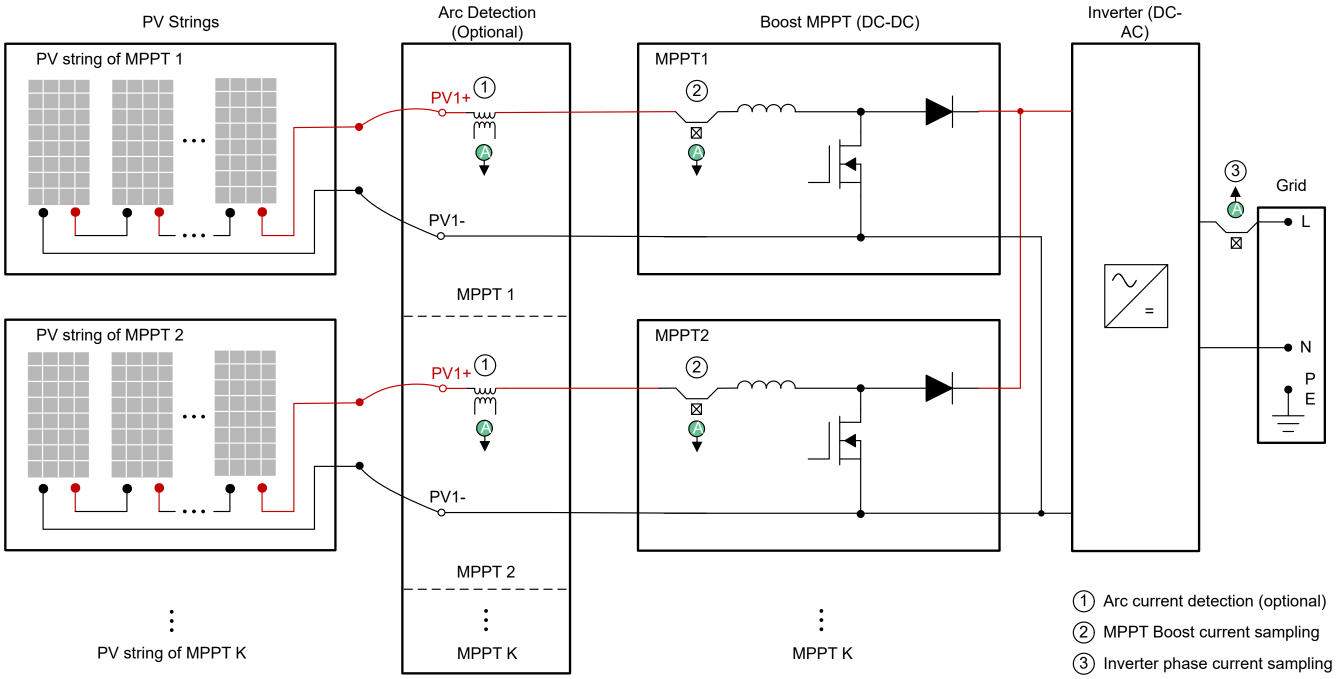

Figure 2-4. Single-phase Residential Inverter Block Diagram with Hall-effect Current Sensors

2.3 3-Phase Hybrid Inverter

Solar hybrid inverter is one device that combines the benefits of the traditional solar inverter with battery power conversion system. This process allows users to have more alternatives for cleaner power production, storage and use. Hybrid inverter is not only designed to connect multiple PV strings and convert the DC to AC, but also support DC directly to Battery Energy Storage System (BESS). By integrating the battery power conversion system, for example, bi-directional DC-DC converter, hybrid inverters eliminate unnecessary DC to AC power conversion through DC BUS coupling and thus reduce losses.

Hybrid inverter mainly targets residential and small commercial-industrial application scenarios. The power level of single-phase hybrid inverter is usually less than 10KW. The power level of 3-phase hybrid inverter usually ranges from several KWs to dozens of KWs. Figure 2-5 shows the typical 3-phase hybrid inverter block diagram with Hall-effect Current Sensors, and so on.

- String current sampling.
- Arc current detection (optional).
- MPPT Boost current sampling.
- Inverter 3-phase current sampling.
- Bi-directional Converter (BDC) current sampling.
- Off-grid Emergency Power supply (EPS) 3-phase current sampling.
- Neutral current sampling for midpoint potential balancing.

Compared to above string inverter or residential inverter, hybrid inverter has more hall-effect current sensors because of ESS and off-grid EPS functions. In addition, for the market where power cut occurs frequently, such as in Africa, hybrid inverter also supports acquiring energy from diesel generator. There has extra off-grid 3-phase current sampling of the diesel generator port.

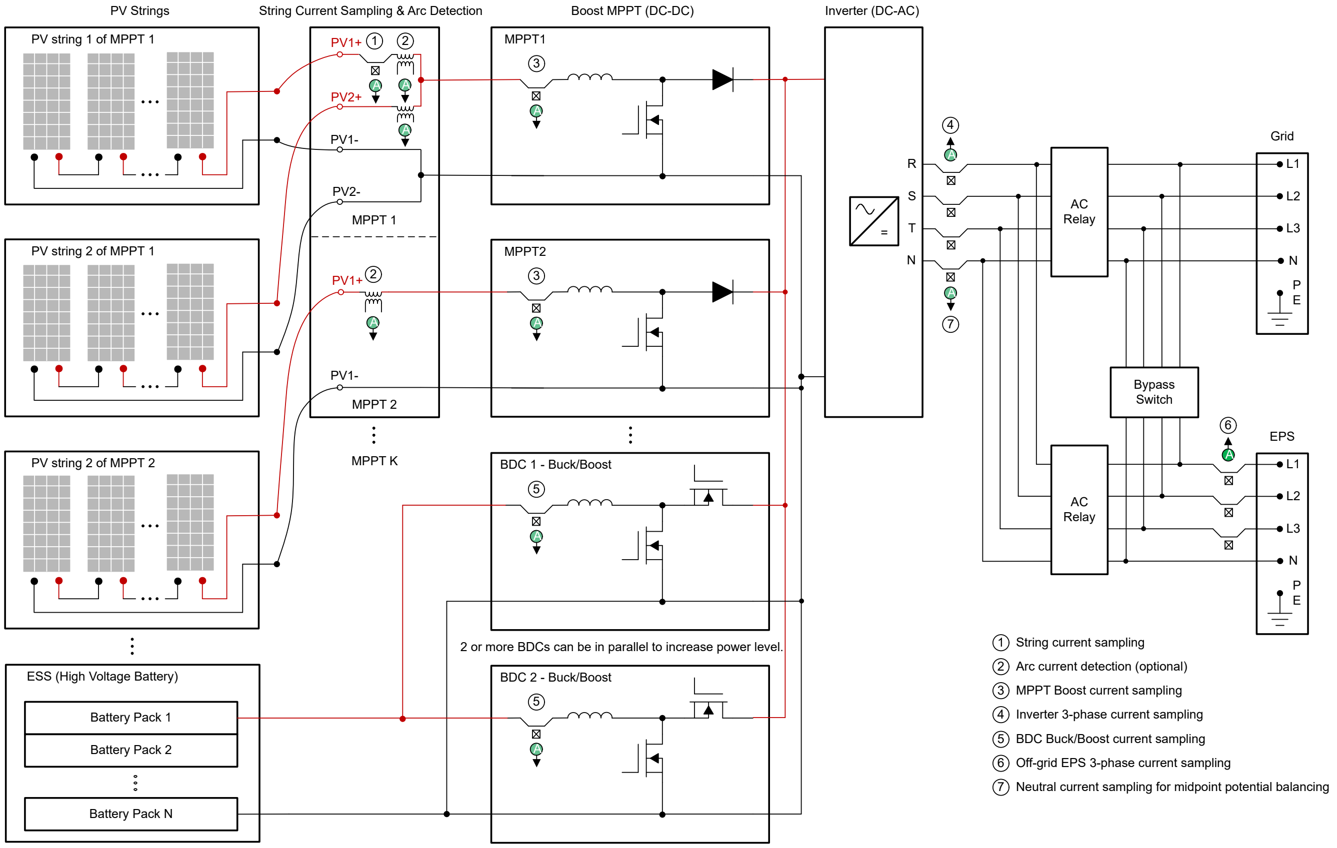

Figure 2-5. 3-phase Hybrid Inverter Block Diagram with Hall-effect Current Sensors

2.3.1 BDC Current Sampling

Figure 2-5 shows the inverter with High voltage battery. For the high voltage battery (typical 150V to 600V) charging and discharging BDC, non-isolated, 2-level Buck/Boost topology is usually used. Hall-effect current sensor can be used for inductor current sampling for control and protection purpose. In addition, the average inductor current is equal to the battery current that can be also used for battery power statistics function.

For the low voltage battery (typical 40V to 60V) charging and discharging BDC, isolated topology such as DAB and CLLLC etc. is usually needed. Hall-effect current sensor can be used for primary-side current, secondary-side current and resonant tank current sampling. Read more in this application brief Isolated Bidirectional DC/DC in Power Conversion System (PCS).

2.3.2 Off-Grid EPS 3-Phase Current Sampling

EPS (also known as backup power) increase versatility of hybrid inverter. EPS enables the inverter to work in both grid-connected mode and off-grid mode (island mode). In grid-connected mode, solar energy firstly goes to backup loads and normal loads. The excess energy is stored in the battery or goes to the grid. Meanwhile, the battery, or the grid, or both can supply power for the backup loads under the condition that power from the PV and battery is less than the backup load power. The maximum output power (for example, the max output current) capability for backup loads, can be larger than inverter's rated AC output power. Take the popular 25KW 3-phase hybrid inverter in the market as an example, the inverter allows 37.9A maximum AC output current, while In grid-connected mode supports 43KW maximum output power (63A maximum output current) for backup loads. In off-grid mode, hybrid inverter makes sure of a seamless energy supply by obtaining energy from the solar or battery during grid outages or emergencies.

Different from inverter 3-phase current sampling, theoretically speaking, EPS 3-phase current sampling is not used for power stage control, and does not need to consider DC component suppression because for the backup loads and does not do harm to the grid, grid load and grid equipment even out of range. However, this is used for backup loads power statistics, using hall-effect current sensor with high accuracy and low drift benefits the metering accuracy and reliability.

2.3.3 Neutral Current Sampling for Midpoint Potential Balancing

Another important hall-effect current sensor in hybrid inverter is neutral current sampling for midpoint potential balancing. In a designed for 3-phase system, the load on each phase needs to stay the same. However, in some 3-phase household or commercial application scenarios, such as in Germany and Austria, both 3-phase and single-phase loads are used, which can cause unbalanced power consumption among the three phases. This means that one or two phases can have higher power demands than the other phases. This can lead to neutral line voltage imbalances, which can cause problems for grid and grid equipment. To power single phase load in the system, which means the output power on each phase depends on the corresponding load consumption and can not be the same, hybrid inverter usually has *unbalanced output function*. Solar inverter vendors usually have some feature description, such as *support 100% unbalance output in backup and on grid mode* (even 110%) in the vendors data sheets. Read more in this blog *What is 100% or 110% unbalanced output inverter*?

If the loads in 3-phase are balanced, then there needs to have no current in the neutral line and the midpoint potential is balanced, for example, half of the BUS voltage. On the contrary, the neutral line source or sink current if there has load imbalance, which can cause the midpoint potential variation. This needs to compensate the midpoint potential imbalance.

Figure 2-6 shows the conventional way of 2 split capacitors. The neutral point is the midpoint of the two bulky electrolytic capacitors C1 and C2 with equivalent capacitance. The neutral current keeps charging one split capacitor while discharging another one for a certain period to keep midpoint potential balancing. Though in fact there has some small capacitance or voltage mismatching between the two split capacitors, this design is easy for implementation and still widely used in string inverter and residential inverter where 3-phase output must be balanced to the grid. However, for obvious unbalanced output, DC component in the neutral current can cause severe voltage mismatching, then further leads to inverter fault shutdown protection.

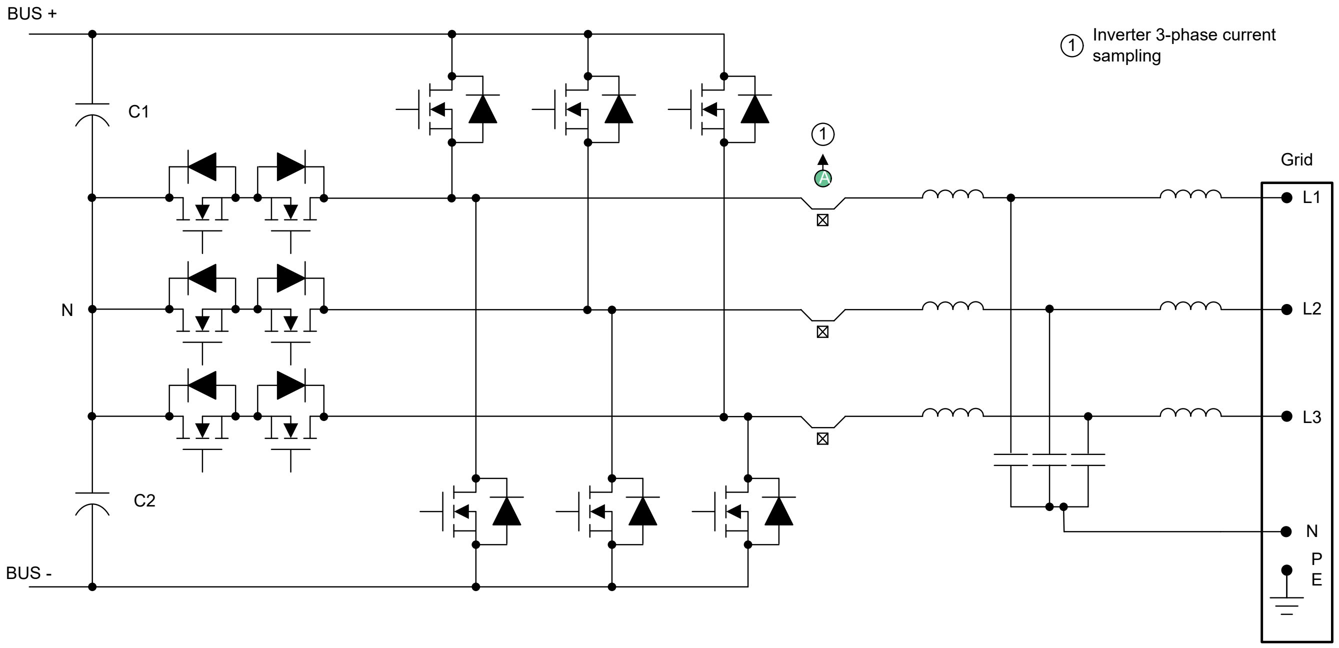

Figure 2-6. 2 Split Capacitors Design for Midpoint Potential Balancing in 3-phase Inverter

Unlike string or residential inverter, hybrid inverter has a fourth-leg (also known as balancing bridge, the inverter is then called 3-phase 4-leg inverter) to actively control the midpoint voltage that allows the inverter to support unbalanced output, as shown in Figure 2-7. The control of the fourth switching leg is decoupled from the 3-phase inverter. The balancing bridge control involves neutral current sampling in where hall-effect current sensor can be used.

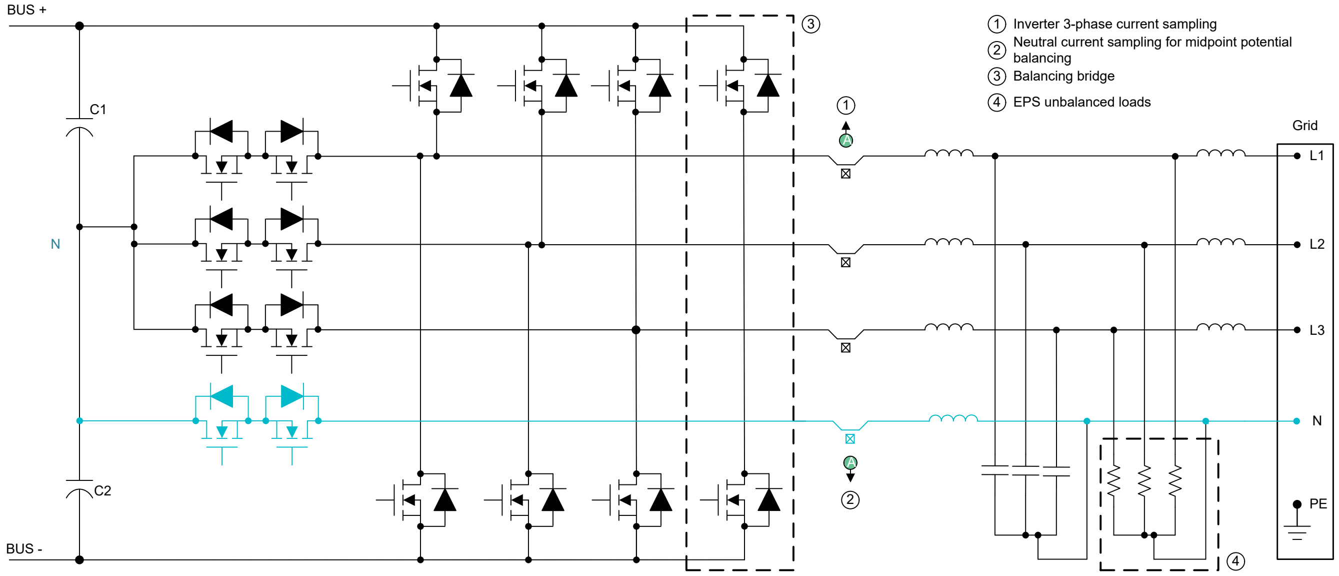

Figure 2-7. Balancing Bridge Design for Midpoint Potential Balancing in 3-phase Inverter

2.4 Split-Phase Hybrid Inverter

Split-phase hybrid inverter is specially designed to split the single-phase power output into two separate phases. This is usually for where the grid supports split phase, such as in North America (115V/230V) and Japan (100V/200V) market. The split-phase inverter has the same demand of unbalanced loads output as the 3-phase hybrid inverter does. Figure 2-8 shows the typical split-phase hybrid inverter block diagram with Hall-effect Current Sensors.

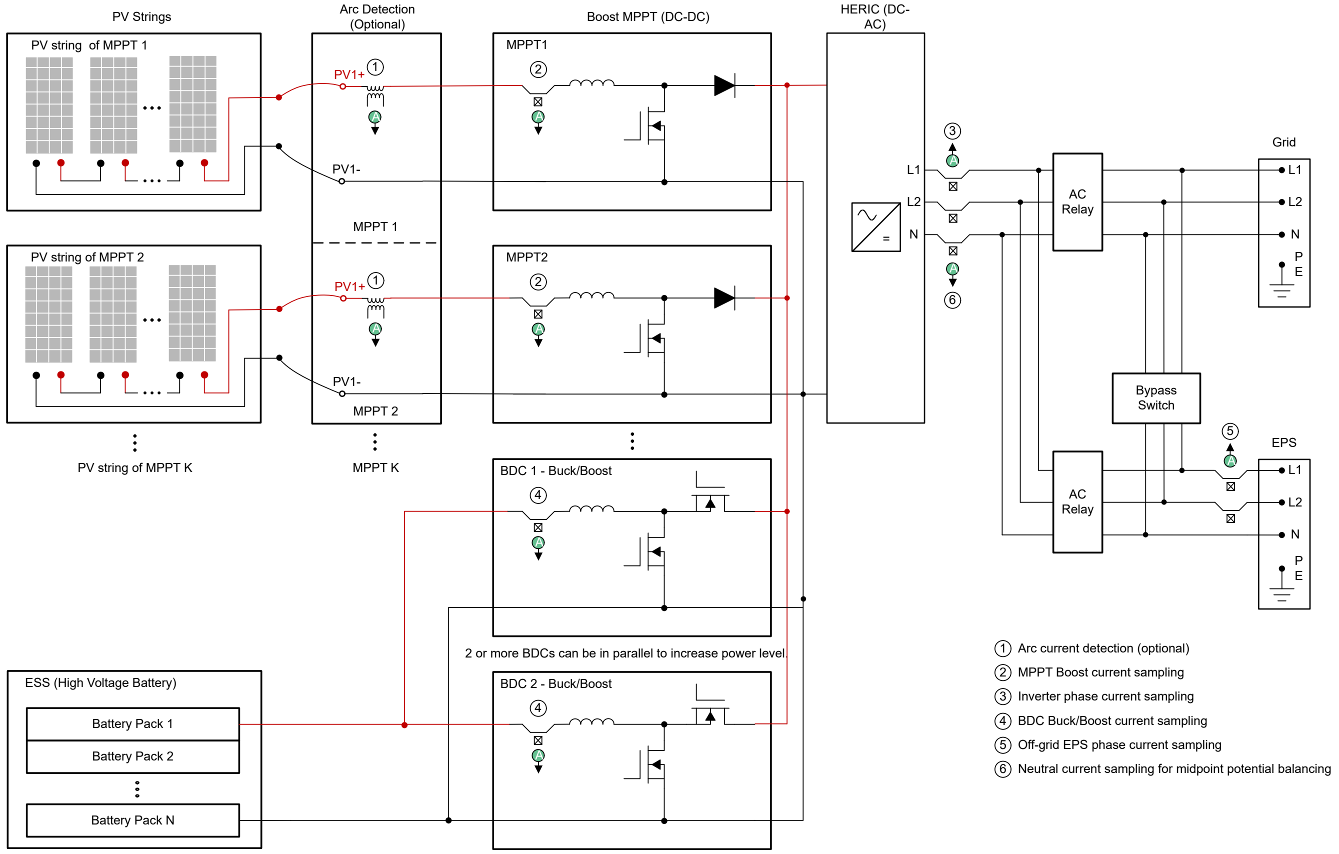

Figure 2-8. Split-phase Hybrid Inverter Block Diagram with Hall-effect Current Sensors

Figure 2-9 shows the HERIC inverter with the fourth-leg (also known as balancing bridge) to actively control the midpoint voltage that allows the inverter to support split-phase (unbalanced loads) output.

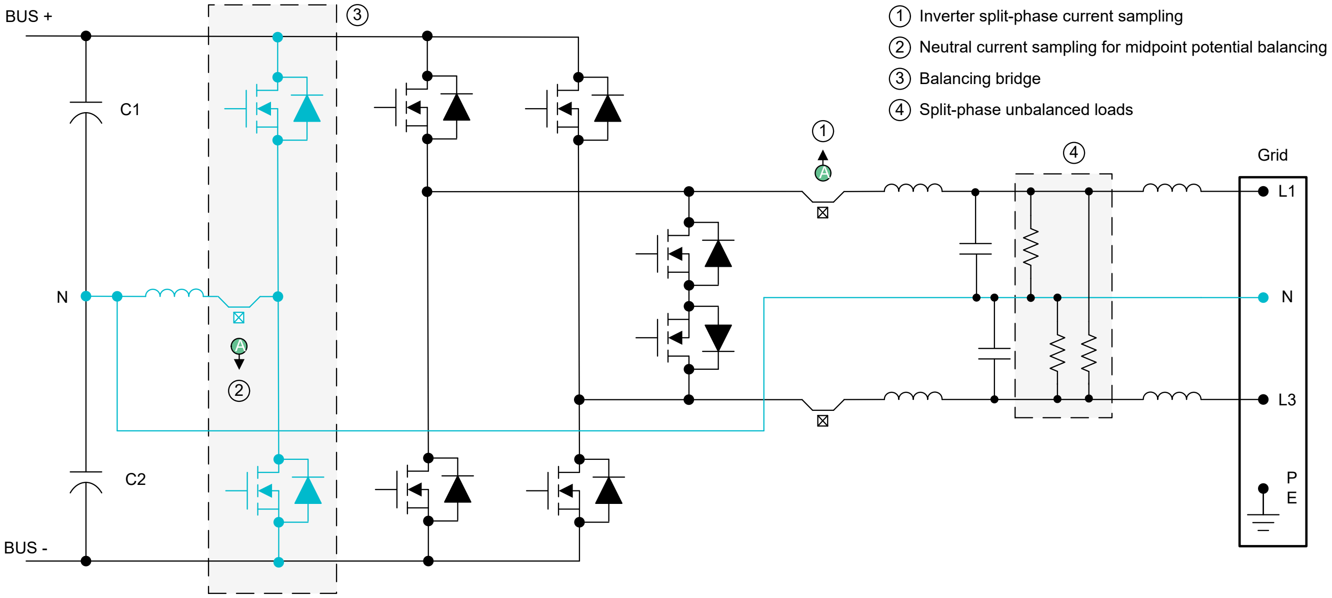

Figure 2-9. Balancing Bridge Design for Midpoint Potential Balancing in Split-Phase Inverter

2.5 Micro Inverter

Micro inverter is an end equipment mostly used in residential case, the rating power of a micro inverter can range from several hundred watts to several kilowatts. The micro inverter can flexibly be used in small rooftop and balcony, and integrate the BESS to generate and store power for home appliances, which helps save electricity bills more efficiently.

In-package hall-effect current sensor can be used in micro inverter application to minimize the PCB size and improve the reliability of the system. Figure 2-10 shows the typical micro inverter block diagram with hall-effect current sensors, for example,

- AC current sampling
- Resonant tank current sampling

The AC current sampling mainly senses the 50Hz current injected into the grid, this current information can be also utilized to protect the power devices of the DC/AC converter. The AC current sampling of micro inverter has the same high accuracy and low drift requirements as those decried in previous sessions.

The resonant tank current sampling, by judging this current, accurate turning-on or turning-off of synchronous rectifier transistor and overcurrent protection can be achieved. So, the timing of this current information is very important to improve the efficiency, high bandwidth and low propagation delay of the hall sensor are required. Read more in the *Synchronous Rectification Control in CLLLC Converters Based on Hall-Effect Current Sensors*, application brief.

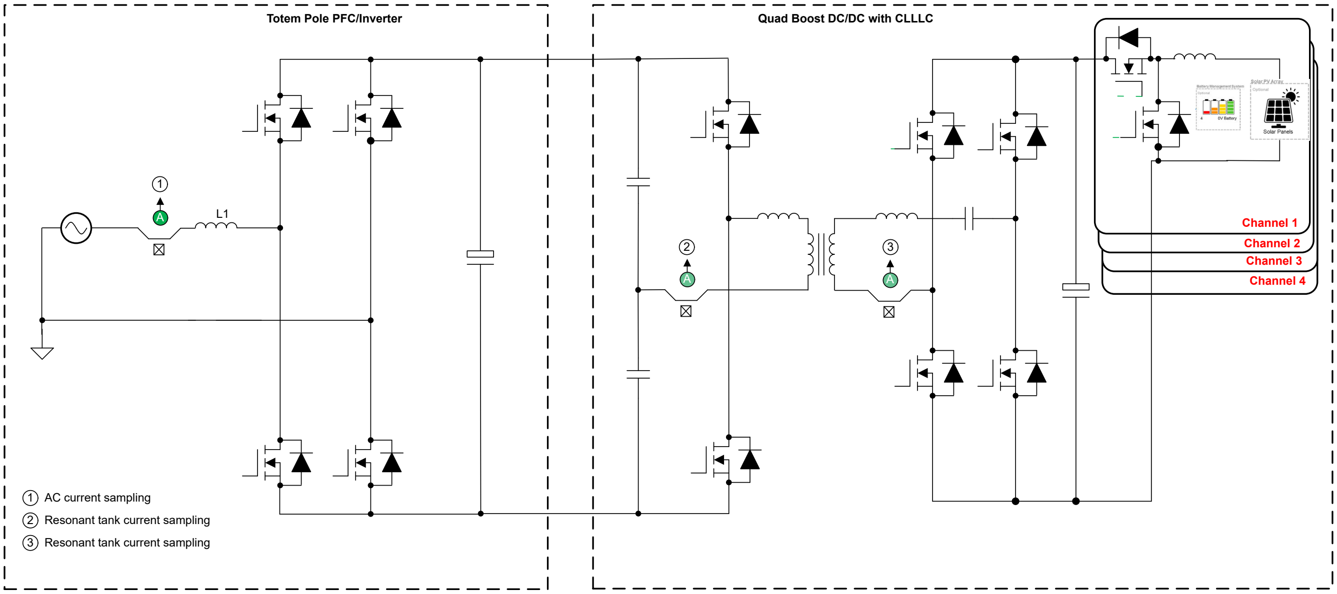

Figure 2-10. Micro Inverter Block Diagram with Hall-effect Current Sensors

2.6 Solar Power Optimizer

Power optimizer is an end equipment that usually used along with string inverter. The power optimizer provides module level monitoring function, rapid shut down function and module level MPPT function which improves the PV system safety and helps generate more power for the whole PV strings, especially when the strings are in partially shaded and other abnormal situations.

Power optimizer uses common topologies of Buck and 4-switches Buck-Boost. The buck topology usually uses low-side current sampling by shunt resistor and amplifier. While the 4-switches Buck-Boost usually uses high-side current sampling. The input of optimizer is connected to one PV panel or two PV panels in series, the common-mode voltage can be up to 150V with 2 PV panels in series. In-package hall-effect current sensor is a good choice for the 4-switches Buck-Boost optimizer, as shown in Figure 2-11. The inductor current is sampled for current loop control and protection purposes.

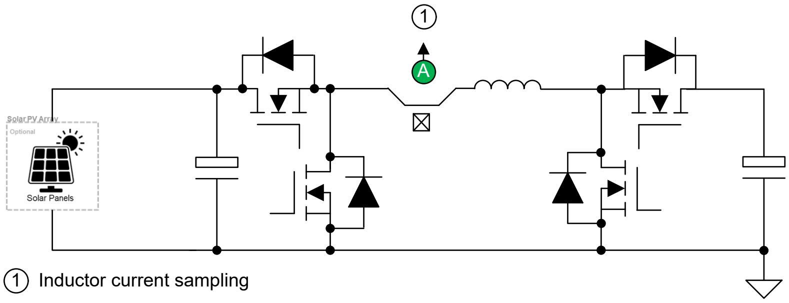

Figure 2-11. 4-Switches Buck-Boost Optimizer Block Diagram With Hall-effect current Sensor

2.7 Smart Combiner Box of Central Inverter

Smart Combiner Box (also called PV Stream Box, PVS) is used together with central inverter in middle to large-scale PV grid-connected power generation systems. PVS added between the PV strings and inverter for the purpose of reduction of connection lines between PV strings and inverters, easier maintenance and higher reliability. The smart combiner box usually supports 16/18/20/24/32 channels based on the central inverter size, and all PV strings current are sampled in the box. Figure 2-12 shows the smart combiner box application scenario with hall-effect current sensors. Like the string current sampling described in string inverter section, current monitoring function of smart combiner box also needs high accuracy to achieve high failure diagnosis accuracy and power generation efficiency.

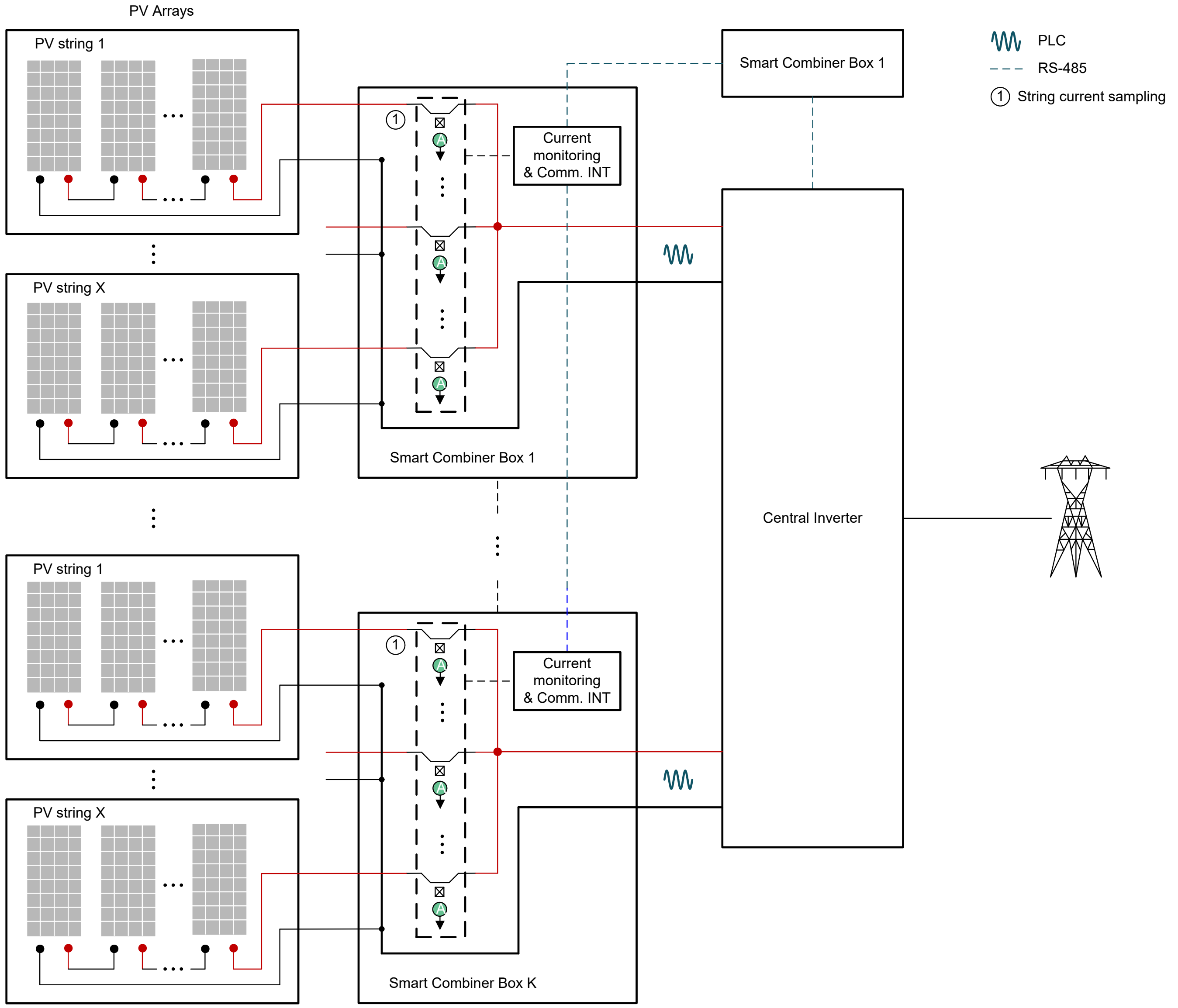

Figure 2-12. Smart Combiner Box Application Scenario With Hall-effect Current Sensors

2.8 Summary of Solar Inverter System and In-package Hall-effect Current Sensor

Table 2-1 summarizes solar inverter system with the key information to help analyze in-package hall-effect current sensor usage, as shown in Table 2-2.

Table 2-1. Summary of Solar Inverter System

Solar Inverter System	String Inverter	Residential Inverter		Hybrid Inverter		
Phase type	3-phase	3-phase	1-phase	3-phase	Split-phase	1-phase
Power level	Typ. 100 to 320KW	Typ. 5 to 50KW	Typ.3 to 10KW	Typ. 5 to 25KW	Typ. 5 to 10KW	Typ. 3 to 6KW
Bus voltage	Typ. 1100V/1500V	Typ. 1100V	Typ. 600V	Typ. 1000V	Typ. 600V	Typ. 600V
No. of independent MPPT	K (Typ.9/12/14/16)	K (Typ.2/3/4)	K (Typ.1/2/3)	K (Typ. 2/3)	K (Typ. 2/3/4)	K (Typ. 2)
No. of PV strings per MPPT	Typ. 2	Typ. 2/1	Typ. 1	Typ. 2/1	Typ. 2/1	Typ. 1
No. of total PV strings	J (Typ.18/24/28/32)	J (Typ.2/3/4/5/6/7/8)	J (Typ.1/2/3)	J (Typ. 2/3/5)	J (Typ. 4/6)	J (Typ. 2)
No. of BDC	N/A	N/A	N/A	M (Typ. 2/3)	M (Typ. 1/2)	M (Typ. 1)
Neutral current sampling (Y/N)	No	No	No	Yes	Yes	No
Off-grid EPS (Y/N)	No	No	No	Yes	Yes	Yes

Table 2-2. In-package Hall-effect Current Sensor Usage Statistics

Where Used	String Inverter	Residential Inverter		Hybrid Inverter		
MPPT Boost current	K	K	K	K	K	K
String current	J-K	J-K	J-K	J-K	J-K	J-K
Inverter phase current (1)	3	3	1	3	2	1
Off-grid EPS current	N/A	N/A	N/A	3	2	1
BDC Buck/Boost current (2)	N/A	N/A	N/A	M	M	M
Neutral current	N/A	N/A	N/A	1	1	N/A
Total Quantities (3)	J+3	J+3	J+1	J+M+7	J+M+5	J+M+2

Note

1. For inverter phase current sampling, whether in-package hall-effect current sensors can be used or not depends on the power level (current rating) of the inverter. In-package hall-effect current sensors can have thermal issues in high power inverters.
2. The table data is based on Buck/Boost BDC of inverter with high voltage battery. Isolated topology such as DAB and CLLLC, and so on of inverter with low voltage battery have more current sensors are not shown in this table.
3. Diesel generator and arc detection are optional functions, the corresponding current sensor quantities are not included in the total quantities. There has extra off-grid phase current sampling of the diesel generator port. The quantities for arc current sensors are equal to the number of total PV strings.

Table 2-3 and Table 2-4 show examples.

Table 2-3. Solar Inverter System Examples

Solar Inverter Systems	String Inverter	Residential Inverter		Hybrid Inverter		
Phase type	3-phase	3-phase	1-phase	3-phase	Split-phase	1-phase
Power level	320KW	25KW	8KW	20KW	10KW	5KW
Bus voltage	1500V	1100V	600V	Typ. 1000V	600V	600V
No. of independent MPPT	K = 16	K = 3	K = 2	K = 3	K = 4	K = 2
No. of PV strings per MPPT	2	2	2/1	2/2/1	1	1/1
No. of total PV strings	J = 32	J = 6	J = 3	J = 5	J = 4	J = 2
No. of BDC	N/A	N/A	N/A	M = 3	M = 2	M = 1
Neutral current sampling (Y/N)	No	No	No	Yes	Yes	No
Off-grid EPS (Y/N)	No	No	No	Yes	Yes	Yes

Table 2-4. Examples of In-package Hall-effect Current Sensor Usage Statistics

Where Used	String Inverter	Residential Inverter		Hybrid Inverter		
MPPT Boost current	K = 16	K = 3	K = 2	K = 3	K = 4	K = 2
String current	J-K = 16	J-K = 3	J-K = 1	J-K = 2	J-K = 0	J-K = 0
Inverter phase current	3	3	1	3	2	1
Off-grid EPS current	N/A	N/A	N/A	3	2	1
BDC Buck/Boost current	N/A	N/A	N/A	M = 3	M = 2	M = 1
Neutral current	N/A	N/A	N/A	1	1	N/A
Total Quantities	J+3 = 35	J+3 = 9	J+1 = 4	J+M+7 = 15	J+M+5 = 11	J+M+2 = 5

3 Summary

With the continued investment and development of solar energy and ESS, more accurate and reliable current sensing technologies can make the grid safer and more efficient on energy harvest. In-package hall-based technologies such as *TMCS112x* and *TMCS113x* from Texas Instruments, can not only provide high accuracy combined with low drift, enabling accurate current measurements over both lifetime and temperature, but also have ease of use and low cost, which makes this popular to replace the traditional thorough-hole hall-effect current sensors. This application note summarizes common solar application scenarios where in-package hall-effect current sensors can be used. Read the following *Design Considerations of In-package Hall-effect Current Sensor in Solar System*, application note to learn more design challenges and how to solve those challenges.

4 References

- Texas Instruments, *TMCS1126 Precision 500kHz Hall-Effect Current Sensor With Reinforced Isolation Working Voltage, Overcurrent Detection and Ambient Field Rejection*, data sheet.
- Texas Instruments, *Isolated Bidirectional DC/DC in Power Conversion System (PCS)*, application brief.
- Texas Instruments, *Synchronous Rectification Control in CLLLC Converters Based on Hall-Effect Current Sensors*, application brief.
- Texas Instruments, *Design Considerations of In-package Hall-effect Current Sensor in Solar System*, application note.
- Texas Instruments, *Power Topology Considerations for Solar String Inverters and Energy Storage Systems*, application note.
- IEEE, *IEEE 1547-2018*.
- PowMr, *What is 100% or 110% unbalanced output inverter?*, blog.
- Springer Nature Link, *Power balance modulation strategy for hybrid cascaded H-bridge multi-level inverter*

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