Integration of Isolation for Grid-Tied Photovoltaic Inverters

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IDEA IN BRIEF

The photovoltaic (PV) industry has been enjoying great growth over the past few years, mostly driven by high oil prices and environmental concerns. However, PV cost remains to be the greatest barrier for further expansion, and it needs to come down further to compete with traditional coal based grid electricity. Besides solar panels, the electronic components, such as PV inverters, are the major cost components. For safety and operational concerns, grid-tied PV converters need to have harvested dc be isolated from the ac grid. Isolation is usually required to satisfy safety regulation to prevent dc injection into the ac grid that may impact distribution transformers and traditional watt-hour meters. Traditional isolation solutions such as optocouplers can't satisfy the 25 year warranty typical for PV panels. Microinverters also become the trend where the system availability is improved and performance under shading condition is also dramatically improved. In those cases, the PV inverter is installed at the back of the PV panel where the high temperature there can accelerate the degradation of the optocouplers. This paper discusses the signal and power isolation needs in PV inverters and how integration of isolation functions using microtransformers can improve the system performance and reliability and reduce the system size and cost.

There are two major types of PV inverters, transformer-less and transformer isolated ones. Transformer-less inverters can suffer from large ground leakage current and injected dc current because of large panel capacitance and lack of isolation between the PV panel and ac grid, as shown in Figure 1(a). A dc component in the injected ac currents into the grid is less than desirable as it can potentially saturate distribution transformers. There are strict grid requirements for the amount of dc injection in many safety standards and, in some cases, transformer isolation is mandatory. Transformer isolation between the panel and grid would eliminate such a dc injection path arising from the voltage variation of the panel relative to the grid, as shown in Figure 1(b). Besides dc injection, grid-tied inverters need to meet other grid requirements, such as total harmonic distortion and individual harmonic current levels, power factor, and detection of island operation. The grid voltage and the current injected into the grid need to be monitored accurately. If the controller to perform MPPT and the gate driving function sits on the panel side, these measurements need to be isolated. To operate the PV panel for maximum efficiency, maximum power point tracking (MPPT) algorithms need to be used. To achieve MPTT, the panel voltage and current also need to be monitored. The panel voltage can get quite high as people try to connect many PV inverters in series to minimize the number of inverters needed. The current measurement from the high side terminal of the PV panels also needs to be isolated.

Besides isolated current and voltage measurements, there are also needs for some interface functions such as RS-485, RS-232, and CAN. RS-485 or RS-232 is typically used for communication to these PV inverters to obtain real-time performance data, and the communication bus needs to be isolated because of the large distance of travel and for safety reason. An isolated CAN may also be used for communication over not as large distances. These transceivers also need isolated power to be extracted from the panel side to the bus side.

Traditionally the isolation is provided by optocouplers. However, its current transfer function degrades over time, and it may become inoperable in a few years, much shorter than the 20 year lifetime warranty offered for many of these solar panels. Here we propose microtransformer based signal and power isolation that can address a variety of integration needs in PV inverters. Not only can it eliminate the lifetime degradation limitation for the optocouplers, it also allows integration of sensing functions such as ADCs or

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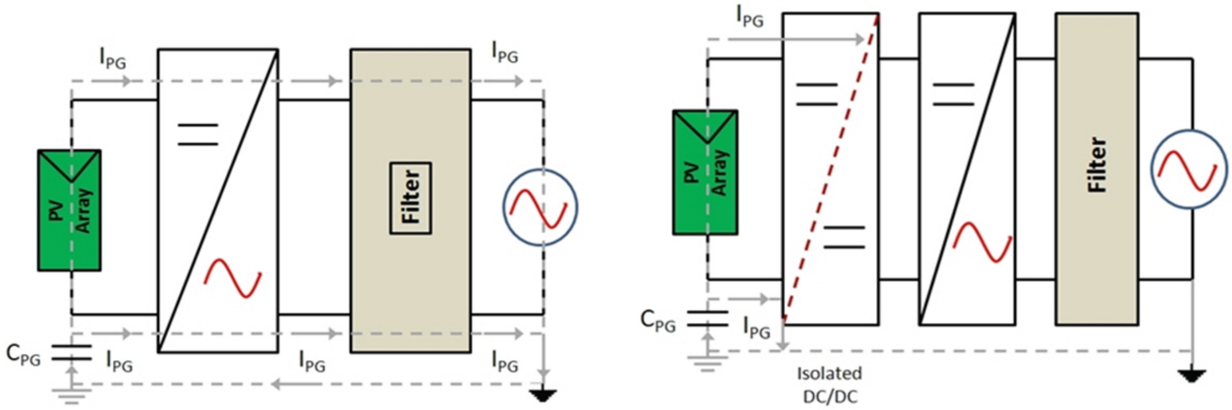

Figure 1. (a) DC Injection into Grid for Nonisolated Inverter (b) Interruption of DC Injection by Isolation

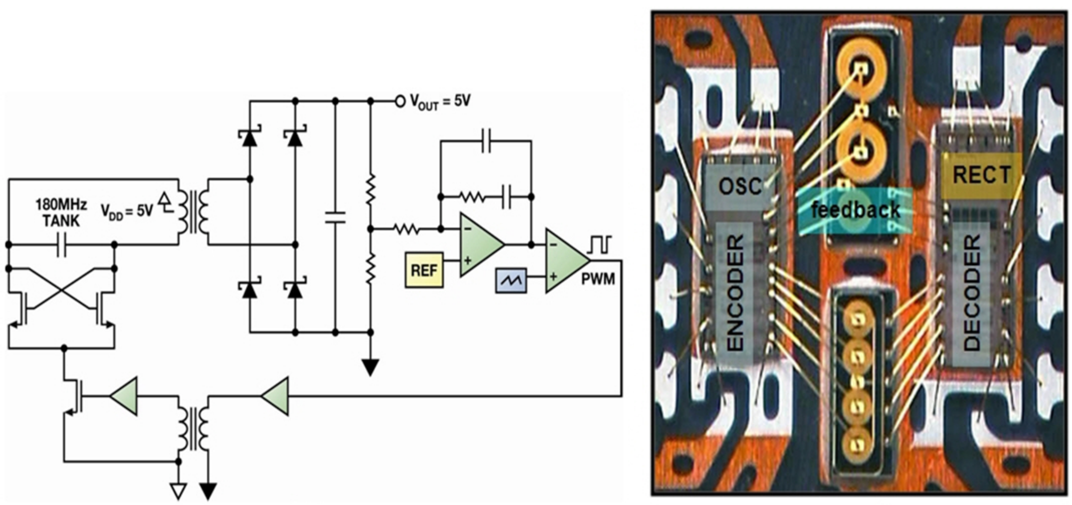

Figure 2. (a) Schematic Diagram for an Isolated DC-to-DC Converter (b) Package Implementation for a 4-Channel Isolator with 500 mW Isolated Power

interface functions such as gate drivers and RS-485 or RS-232 transceivers. Furthermore, it provides isolated power to power these sensing ICs, isolated transceivers, or isolated gate drivers. The optocoupler based gate drivers are also power hungry and suffer from large variations for the gate driver timing. The microtransformer based gate drivers not only consume much less power but also provide much better matched gate driver timing to improve total system power conversion efficiency. The isolated signal and power integration reduces the component count significantly leading to lower system cost and improved reliability.

SIGNAL AND POWER ISOLATION USING MICROTRANSFORMERS

Microtransformers can be used to provide integrated signal and power isolation for up to 5 kV rms [1]. For signal transfer, the input data is usually encoded before being transmitted to the primary of a data transformer. A decode is used at the secondary side to recover the signal. Isolation between the input and output is provided by the insulation layers between the primary coil and the secondary coil. For efficient power transfer across isolation, a self oscillating high frequency oscillator is used to drive the primary for the power transformer, and high frequency Schottky diodes are used to provide rectified dc voltage. The regulation is done

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by a PWM generated by a secondary controller to pass through a feedback transformer to turn on and off the oscillator in a frequency much lower than the oscillation frequency as shown in Figure 2(a). The feedback signal transmitted through the feedback transformer works the same way as that for other data channel signals through the data transformers. With separate control paths for energy conversion and feedback, energy conversion efficiency is optimized while stable regulation is maintained. An example 500 mW isolated dc-to-dc converter with four separated isolated data channels is shown in Figure 2(b).

In this example, the transformers are built on separate chips from those of the encoder or the primary chip and the decoder or the secondary chip. However, this is primarily driven for cost reasons, and the transformers can in principle be built on top of one of the IC chips. Additional circuit functions such as gate drivers, transceivers, and ADCs can all be integrated.

INTEGRATION OF ISOLATION IN PV INVERTERS

Figure 3 shows a typical 3-stage grid-tied PV inverter. The 1st stage is an optional boost converter to boost the panel voltage before it is sent through the isolated dc-to-dc converter stage. The isolated dc-to-dc converter includes a full bridge dc-to-ac conversion through a high frequency transformer. The high frequency transformer has the advantage of small size and high efficiency. The ac at the secondary is rectified to a dc voltage that is typically higher than the grid peak voltage. The rectified dc is converted to grid line frequency through the 3rd inverter stage. Panel output voltage and current needs to be sensed and fed into a microcontroller to perform Maximum Power Transfer Tracking (MPTT) algorithms. The microcontroller is also responsible for gate driver control for isolated dc-to-dc and output inverter. The output inverter sits on the grid side with a different ground from the dc panel ground and the communication from the microcontroller to the inverter driving stage needs to be isolated. Usually four optocouplers would be needed, but they are power hungry, their large propagation delay may impact the gate driver timing accuracy and thus inverter efficiency, and most of all, their ability to back the PV panel's 20 to 25 year warranty is questionable. On the other hand, microtransformer based isolators [1, 2] consume much less power, have much shorter propagation delay, and there is no performance degradation over time. Moreover, multichannel isolators can also be integrated with on chip dc-to-dc converters to provide isolated power for the gate drivers. The relays between the inverter output and grid tie are used to ensure synchronization of the inverter output frequency and phase with the utility voltage and allows for anti-island protection by being able to quickly disconnect from grid fails or when utility voltage or frequency goes outside of acceptable limits. Voltage sensing is needed at the grid side to detect zero crossing and current sensing needed to ensure a sine wave current is fed into the load. The sensing information can be communicated to the controller through an isolated ADC. The isolated ADC integrates a 16-bit 2nd order sigma-delta

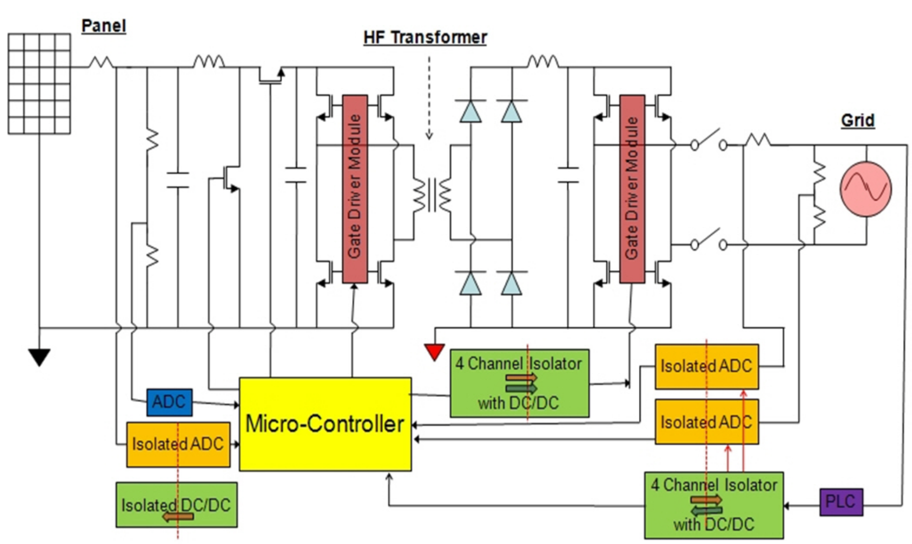

Figure 3. Isolation Implementation in a 3-Stage PV Inverter

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modulator with microtransformer based digital isolation, capable of 3.75 kV isolation, ideal for shunt based current sensing. Current transformers can be used for current sensing, but they are expensive, bulky, and can be sensitive to external magnetic fields. Hall Effect sensors can also be used but they suffer from nonlinearity and offsets that would impact the accuracy of the current measurements. Shunt together with integrated isolated ADC provides a reliable and low cost alternative. The isolated ADC also needs isolated power on the grid side to get self powered, and the isolated dc-to-dc using microtransformers can be integrated to save the hassle of the need for a discrete dc-to-dc converter. In a case where PLC communication is needed, a PLC chip on the grid side can be powered by the isolated dc-to-dc while its communication with the controller on the panel side is through a multichannel isolator.

The microtransformer based isolation can also be integrated with high current output gate drivers to provide fully isolated half-bridge gate drivers. Figure 4 is an example gate driving scheme for a grid-tied PV inverter. For the primary side dc-ac full bridge switches, there is usually no need for isolation for low side gate drivers, especially for low power inverters. 2-channel 1 kV isolated drivers with 4 A driving capability would be suitable for two high side switches. The switches for the inverters sit at the ac side, so both the low side and high side need isolated gate drivers.

Usually 2.5 kV or 5 kV isolated gate drivers would be needed for the microcontroller at the dc side to communicate directly to the ac side inverters. The low side gate driver can be powered by the integrated dc-to-dc deriving the power from the panel side, and the high side power can be provided by a bootstrap solution.

Each half-bridge gate driver consists of 3-way isolation, i.e., there is isolation between input and outputs and there is isolation between the two outputs. The input to output isolation is provided through on-chip transformers. Figure 5(a) is the transformer structure for the 1 kV gate driver and Figure 5(b) is that for the 5 kV gate driver. The 1 kV half-bridge gate driver is implemented with three dies in a package, one input die and two identical gate driver chips.

Two 1 kV transformers, as shown in Figure 5(a), were implemented on the input chip, one for each gate driver output. The inputs are connected to the bottom coils that are isolated by 2.64 μm thick oxide from top coils, and each top coil is isolated from each other through lateral oxide isolation. The two gate driver chips sit on their own split paddles and are connected to the top coils at the input chip through chip-to-chip bond-wires similar to those shown in [2]. The 5 kV gate driver is implemented in a similar way except that the top coil is isolated from the bottom coil through 20 mm thick polyimide.

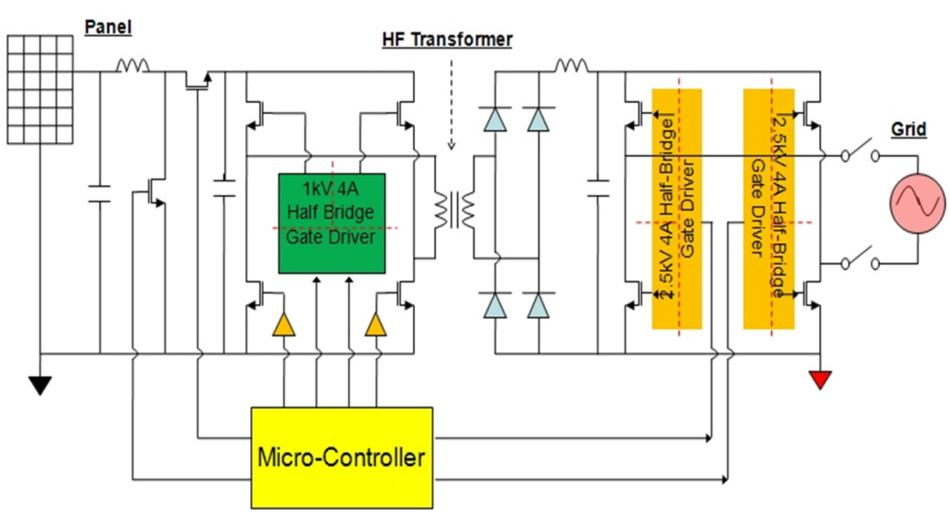

Figure 4. Gate Driver Implementation in a 3-Stage PV Inverter

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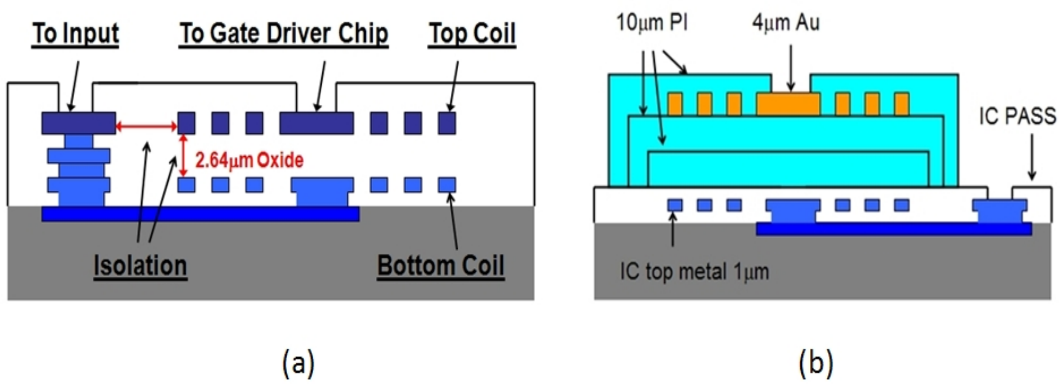

Figure 5. Transformer Structure (a) 1 kV Gate Driver (b) 2.5 kV Gate Driver

For a multi-inverter parallel system as the case for string inverters, there are also needs for communication among the inverters, and they are realized typically through an RS-485 bus, an RS-232 bus, or a CAN bus where isolation would be required. A self powered isolated transceiver would be able to derive the power for the bus side from the panel side.

Micro-inverters also start to gain traction to improve system reliability and performance. They also solve the potential dc arcing problem suffered by the string inverters. The microinverters are usually installed under the panels on the roof where the ambient temperature can be high. High temperature will accelerate the LED degradation inside the optocouplers; microtransformer based isolation, on the other hand, experiences no performance degradation over time and works well under those extreme conditions. Instead of full three stage inverters, single stage inverters can be used for micro-inverters to reduce system cost. Each micro-inverter can be only about a couple of hundred Watts, and at this power level, isolation integration presents many system integration possibilities to reduce system cost and improve system reliability.

CONCLUSION

Microtransformer based isolation integration is the ideal solution for the isolation needs for grid-tied PV inverters, central inverters, or microinverters. Its integrated signal and power isolation capability reduces component count dramatically and improves system reliability and lifetime and its precise gate drive timing can lead to higher inverter efficiency. An isolated ADC using microtransformers enables more accurate grid current and voltage measurements that would lead to high quality, unity power factor sinusoidal current into the grid.

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