Methods for Improving Efficiency, Reliability and Flexibility in PV Applications
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The operational and purchasing costs of any power electronics system are heavily influenced by system power loss. Reducing power dissipation enables lower cooling costs or the use of smaller magnetic components if using higher switching frequencies. When designing power electronics systems, energy efficiency is a primary goal as it affects so many aspects of size, cost and performance. This applies in particular to photovoltaic (PV) inverters where designers and operators want to convert as much of the Sun’s energy to electrical power as possible.

This paper looks at the evolving requirements for PV power conversion, the benefits of micro inverters (MI), and introduces techniques and technologies that help designers deliver a cost-effective system solution that provides system efficiency improvements while reducing BOM cost and footprint.

The photovoltaic (PV) market has seen substantial changes in recent years and is expected to continue to grow in the future. According to Solar Central, the worldwide energy generation by PV plants had grown to 184GW in 2014. However, with this growth the average module cost per Watt fell to less than $0.70. This has created enormous pressure on the manufacturers of PV systems. The reduction of solar incentive schemes (subsidies) is adding to the problem.

This pressure is not only a matter of cost. It also relates to a system’s ability to provide extended functionality to generate the highest possible level of energy while maintaining high reliability and efficiency under difficult environmental conditions.

The opposing requirements (lowest costs and best functionality) require new and innovative solutions. Various system concepts including centralised inverter, string inverter, MI or power optimiser exist. These offer a range of outstanding features with respect to the controllability of a system in the case of external influences – for instance shading on the modules because of buildings or trees.

Increasing the efficiency of a system is a major challenge for manufacturers and suppliers. The aim is to significantly increase the efficiency of the entire system above the average value of 95%.

Introduction

The inverter that converts DC to AC is an essential component of any PV system. And its efficiency is strongly influenced by the switching losses of the power transistors. Primarily, the selection of the circuit topology and correct components is critical in obtaining the optimum efficiency.

To improve efficiency, there is a trend of making use of transistors based on wide bandgap materials such as GaN or SiC. However, the cost of such technologies remains considerably higher than silicon-based components. Innovations in circuit design are required to cost-effectively deliver the maximum possible efficiency when using today’s silicon-based components.

Based on a half-bridge topology, the following shows how the efficiency of an inverter can be optimised by significantly reducing the switching losses. As an example, we review the commutation of the current flow from the freewheeling diode of the blocking upper switching transistor to the lower switching transistor.

The switching losses occurring alongside the resistive losses are determined by two loss mechanisms. Firstly, the reverse recovery charge (Qrr) causing a peak current in the currently activated and conducting lower switching transistor. Secondly, the charging current peak flowing when the blocking upper switching transistor’s output capacitance (COSS) is being reloaded.

The two circuit topologies in figure 1 – Synchronous Reverse Blocking (SRB) and Advanced SRB (A-SRB) – will greatly reduce switching losses.

Synchronous Reverse Blocking (SRB) adds a second switching transistor Q2 in series, which blocks the reverse current in the freewheeling diode of the actual switching transistor Q1. Controlling Q2 is synchronised to Q1. The reverse current is passed through a parallel silicon carbide (SiC) Schottky diode with a high breakdown voltage and an extremely low reverse recovery charge so that the effect of Qrr is significantly reduced. The polarity of the freewheeling diode of Q2 is chosen such that no high voltage can build up along this transistor. Therefore, a low-voltage (60V) device is sufficient.

With Advanced SRB (A-SRB) the losses caused by reloading the output capacitance of the main switch Q1 are significantly reduced by pre-charging Q1 to a lower voltage. The output capacitance $C_{OSS}$ strongly depends on the drain-source voltage $V_{DS}$. When this is increased from 0V to 40V the capacitance is reduced by a factor of about 100. During turn-on, this voltage dependency causes the main portion of the charging current to flow for low $V_{DS}$ (Q1). However, in a half-bridge configuration, a low $V_{DS}$ across the switch being in off-state means a high voltage across the switch turning on, leading to high turn-on losses due to the charging current peak.

Figure 2: Normalized simulated turn-on current peak for the example of a half bridge circuit. The current peak is drastically reduced by the utilization of A-SRB → reduced switching losses!
If $C_{oss}$ (Q1) of the switch remaining in off-state, is pre-charged before turn-on of the other switch of the half-bridge (the low-side switch in our example) most of the charging current does not flow through the transistor turning on and thus cannot contribute to turn-on losses. The pre-charging is performed by an additional voltage source, which is realised by a charge pump in the gate driver IC.

A-SRB is a new technology developed by Toshiba that dramatically reduces switching losses and can be utilised for a wide range of applications including PV inverters, DC/DC converters, Power Factor Correction (PFC), or motor control.

**A-SRB Effectiveness**

To demonstrate the effectiveness of the A-SRB Technology, device level SPICE simulations of an inverter bridge (H4 topology) have been done with and without utilising A-SRB. For the case of bi-polar modulation, Figure 3 shows the efficiency improvements for different power levels and switching frequencies that can be achieved using A-SRB. In this case, the switching transistor is a Toshiba DTMOS IV type with low $R_{DS(on)}$ (100A, 600V). Since A-SRB reduces switching losses, the efficiency improvement is greatest at higher switching frequencies. The maximum efficiency gain in this example lies at about 4%.

![Figure 3: Efficiency improvement by using A-SRB](image)

**PV inverter options**

The different PV inverter system approaches have advantages and disadvantages dependant on operating conditions.

String inverters are a very common solution in which a series of solar panels is connected to a centralised inverter. This solution is very cost-effective and offers advantages if all modules are in the same plane and have the same view of the sun (i.e. no shading). If the central inverter fails, the energy generated by the entire string cannot be used.

Using power optimisers on each panel offers some benefits in that each panel can be optimised for its own MPP (Maximum Power Point). In this way, shading and different panel orientations are taken care of. This system is more expensive than the string solution and still involves relatively high DC voltages and currents. In common with the string solution, the centralised inverter remains a single point-of-failure.

Many of the drawbacks of the previous systems can be addressed through the use of micro inverters (MIs). The optimisation of the generated energy is made possible by separate inverters and MPP tracking local to each solar panel. This approach addresses shading and panel orientation issues and also eliminates the single-point-of-failure issues.
associated with centralised inverters. In addition, as there are no high DC voltages or currents present on the panel, system security increases.

Although the initial cost of an MI system is higher, it offers a number of real-world benefits. These include the ability to install panels on angled roof structures and having a combination of panels facing different directions without sacrificing system performance.

An overall system can be scaled more easily by the use of MIs. Also, MI systems are not reliant on having identical solar panels. This makes it possible to combine different modules, e.g. for future expansion. A centralised inverter would have to be upgraded to the appropriate power level. Additionally, each panel can be monitored individually for performance or signs of aging.

Since the MIs are installed below the panels on the roof, they are exposed to harsh environmental conditions over their entire lifecycle. This imposes high requirements with regard to reliability. The aim is that MIs achieve a service life of about 20 years - comparable to solar panels.

**PV inverters with A-SRB**

Based on its A-SRB technology, Toshiba has developed a system solution for PV inverters with an output power of up to 5kW. It consists of four main components:

- The inverter bridge with A-SRB technology
- One MCU for controlling the entire system
- Two analogue front-end ICs (AFE) for controlling the DC/DC converter input stages as well as the output inverter.

In addition to the efficiency gains achieved by A-SRB, the two highly integrated AFE ICs contribute to a compact, cost-optimised inverter system.

![Diagram of Toshiba's A-SRB technology](image)

**Figure 4:** Toshiba offers a complete panel-to-grid MI system solution
The system shown in figure 4 is an example of a number of possible implementations. Using the versatile AFE IC TC7716FTG, one-stage and two-stage converter topologies (including LLC resonant and flyback topologies) can be implemented on the input side.

The input-side AFE IC is housed in a QFN-32 package and contains a 12-bit ADC for the acquisition of the input-side current and voltage parameters and can control up to six switching transistors. Via a UART interface, it transmits current and voltage measurement data to the MCU and, in turn, receives the PWM signals required for driving the MOS switching transistors. The control algorithm as well as MPP tracking is implemented in the MCU by software. The IC integrates a number of protection features including over current protection, over voltage protection, under voltage lockout and thermal shutdown.

Figure 5: Different options for realising an inverter with A-SRB functionality

The core of the system is the actual inverter that provides the A-SRB functionality. This can be realised in different ways, depending on the power rating. For MIs with a maximum input power of about 300W, Toshiba offers the module solution T1JM4, which integrates a complete half-bridge, including gate drivers with A-SRB, switching transistors and SiC Schottky diodes.
Figure 6: Block diagram and pin designations for the T1JM4 half-bridge module

For PV inverters with a higher power rating up to about 5kW, discrete gate drivers and switching devices can be provided as a kit.

The TC7717FTG AFE IC with integrated 12-bit ADC is used to detect the input and output current and voltage parameters of the inverter bridge. Housed in a 40-pin VQFN package the IC communicates with the MCU via an SPI interface.

The fourth main component is the MCU based on an ARM® Cortex®-M4F core. The system-in-package (SIP), housed in a LQFP176 package, contains an additional computing unit for generating the control signals required for the inverter bridge. In addition to a 32-bit timer for precise mains frequency measurements, this also includes all the calculation functions for the PID current control. Harmonics up to the seventh order can be calculated. This powerful integrated computing unit avoids a costly external DSP.

The inverter system solution from Toshiba provides all of the necessary control, communication, measurement and intelligence needed. It is highly integrated and offers all the elements necessary to build a scalable and competitive PV inverter.
Summary

In order to extract the maximum efficiency from any power system, consideration has to be given to managing the losses in the most effective way. While the power sector is relatively mature there remains room for incremental innovation. The A-SRB technique from Toshiba is a good example of this and provides substantial efficiency gains within the inverters that form the heart of PV systems.

In bringing the technique / technology to market, Toshiba has developed modular solutions that reduce the system size and the design burden on designers. Toshiba’s complete solution allows designers to realise the benefits of A-SRB technology and also develop their own system solutions rapidly and with confidence. The fully integrated A-SRB technology is not only applicable to MI but also to a wide range of other one-phase or three-phase power applications including DC/DC converters, power factor correction (PFC) or motor drives.

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