Single Stage Microinverter Topology: A Full System Design Solution for both On/Off-Grid applications

Nagesha Chitpadi*, Staff Hardware Engineer, Renesas Power Product Group*

Abstract

The Microinverters are single PV panel low power inverters characterized by high power density and superior efficiency. This white paper explores a single stage microinverter capable of delivering power up to 500 W exploiting Gallium Nitride (GaN) power switches technology.

The microinverter consists of primary full bridge, high frequency magnetics and secondary AC-AC bridge stage delivering power to both on grid or off grid loads (50 Hz/60 Hz) with THD less than or equal to 3 %. The Renesas bidirectional GaN switches on AC-AC bridge enables fast switching with low losses improving overall power density. The solution offers soft switching operation throughout the wide varying input and load variation, hence improving overall system efficiency.

In this article the Microinverter operation is detailed with respect to power and control network. Renesas Components are used for overall system solution achieving faster product development and minimum time to market.

Introduction

The Conventional microinverter architecture used in industry is based on Flyback converter followed by an unfolder circuit, as shown in Figure 1. The flyback based microinverters are generally rated for load power less than 250 W. Thus, multiple flyback converter stages are exploited to achieve higher load power. This results in higher BOM cost, reduced power conversion efficiency and lower power density.

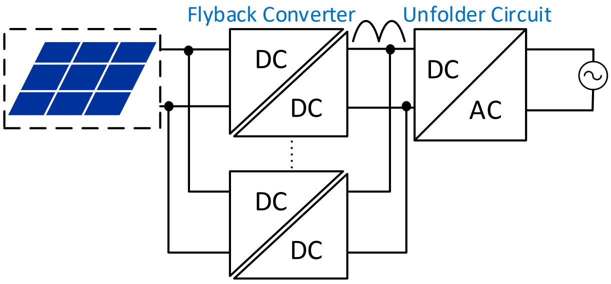

Figure 1: Conventional Microinverter System Block Diagram based on Flyback and Unfolder network

This article presents a single stage microinverter solution with minimum BOM and high-power conversion efficiency. The general system block diagram for the intended solution is shown in Figure 2. The DC-AC stage consists of primary full bridge with high frequency transformer isolation followed by AC-AC bridge formed by bidirectional switches. The presence of high frequency transformer and Renesas Bidirectional GaN FETs ensure high power density operation making the solution suitable for on grid and off grid load.

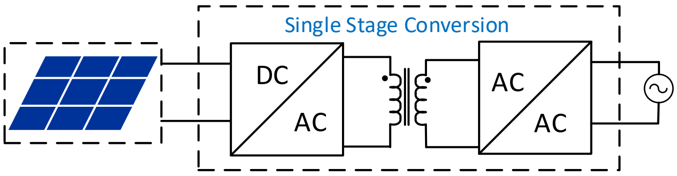

Figure 2: Microinverter with secondary AC-AC bridge System Block Diagram

The system block diagram with Renesas components is explained in the below section in detail.

Single Stage Microinverter: Solution Overview

The detailed System level block diagram for the Microinverter solution is shown in Figure 3. The Microinverter solution consists of

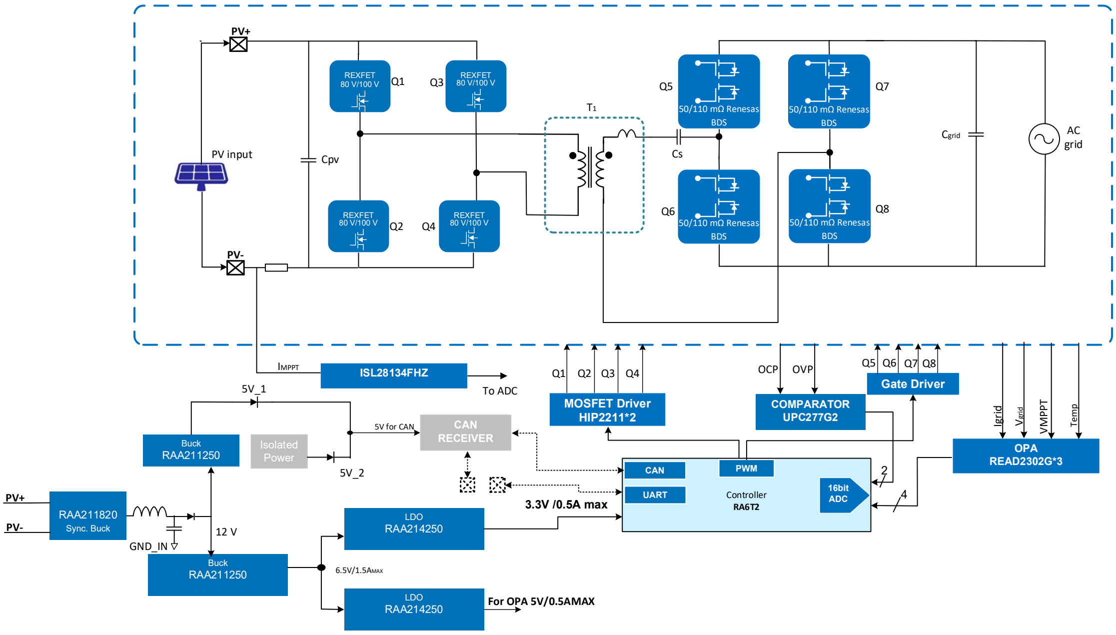

Figure 3: Microinverter System Block diagram

a) Primary full bridge network:

- The Full bridge network is formed by low voltage Renesas REXFETs (80/100 V rated) considering low on state resistance to achieve high efficiency. The primary bridge circuit is fed from a PV source with input range of 20 V – 50 V / 60 VDC. As shown in Figure 4, with the sine triangle modulation technique is used to generate the unipolar PWM. A high frequency switching waveform with sine envelope is seen across the transformer input terminals.

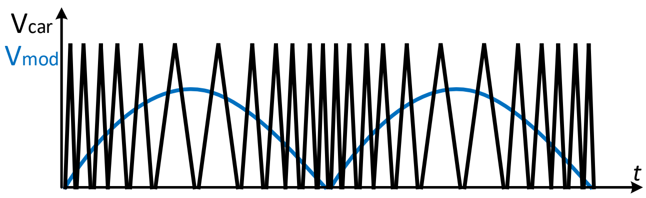

Figure 4: Sine Triangle Modulation to generate Unipolar PWM

b) High frequency Isolation:

- With the switching frequency intended to be around 400 kHz to 500 kHz, the transformer size is significantly reduced with improving overall power density. Additionally, the leakage inductance of the transformer resonates with the secondary AC-AC bridge capacitance to form the resonant network. This network enables soft switching operation improving the power conversion efficiency significantly.

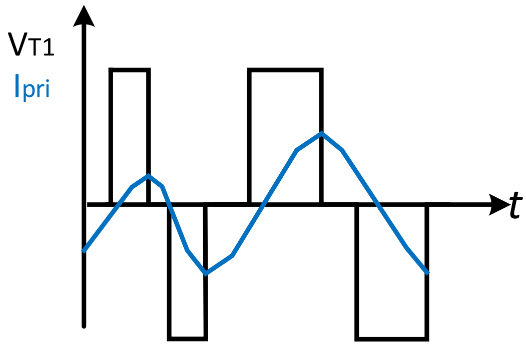

Figure 5: Transformer Voltage and primary current with unipolar PWM

Figure 5 shows the high frequency transformer voltage and current through the transformer primary with unipolar PWM. As shown the current lags the voltage ensures zero voltage switching (ZVS) operation for the primary MOSFETs, considerably minimizing the switching losses.

c) Secondary AC-AC bridge:

- The AC-AC bridge at the secondary of the microinverter uses Renesas 50 mΩ/110 mΩ bi-Directional GaN devices. The AC-AC bridge converts high frequency AC to low frequency (50 Hz/60 Hz) AC voltage feeding on grid or off grid loads. During each half-line cycle, one of the GaN FET in the BDS operates at the line frequency, while the other operates at a high frequency, as illustrated in Figure 6.

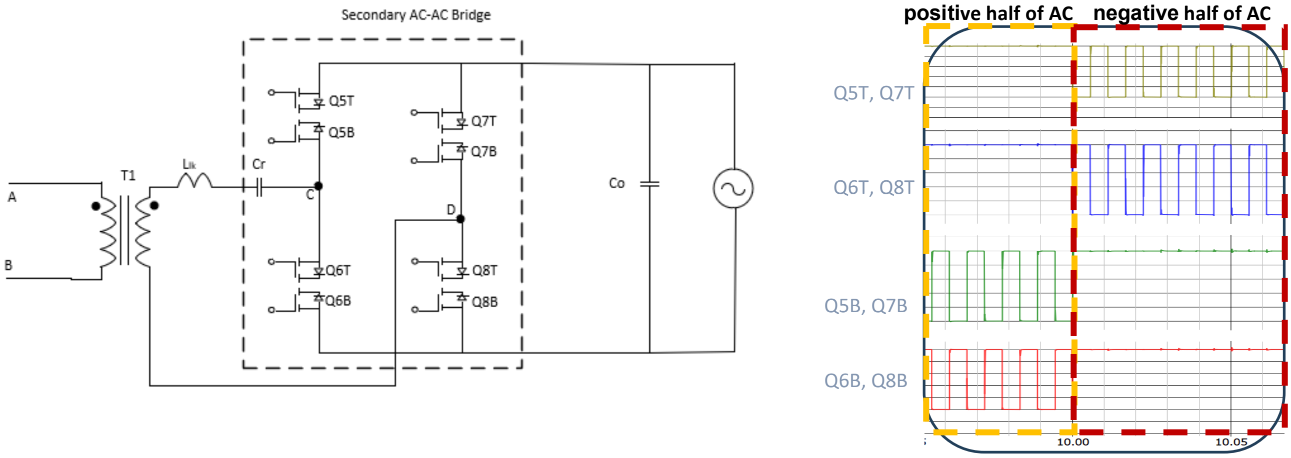

Figure 6: AC-AC bridge network and PWM signals

During the positive half of the AC line cycle, the top GaN FETs in the BDS (Q5T, Q6T, Q7T, Q8T) remains ON, while the bottom devices (Q5B, Q6B, Q7B, Q8B) switch at high frequency. Conversely, during the negative half cycle, the bottom devices are ON and the top GaN FETs switch at high frequency. With four

GaN switches operating at high frequency in each half cycle, this modulation strategy effectively reduces switching losses and enhances overall system efficiency.

Aux. Power supply and Signal conditioning circuits

The Renesas Microinverter Solution Consists of the following critical components as shown in Table 1.

Part no.	Description
RA6T2	240MHz Arm Cortex-M33 TrustZone, High Real-time Engine for Motor Control.
RAA211820	Synchronous buck controller with input voltage range 4.5 V to 75 V with adjustable output voltage. It can deliver up to continuous 2A of continuous output current with premium load and line regulation performance.
RAA214250	Low dropout linear voltage regulator operates from 2.5V to 20V and provide up to 500mA with adjustable output upto 18 V. The regulator provides stable Vcc for sensing and control ICs.
READ2302G	The output voltage, output current, and input PV voltage are sensed through the differential amplifier formed by the READ2302G operational amplifier.
ISL28134FHZ	Precision OPAMP with low offset voltage, useful for conditioning the input PV current sensed via a low-value shunt resistor.
HIP2211	100V, 3A Source, 4A Sink, High Frequency Half-Bridge Drivers with HI/LI or Tri-Level PWM Input and Adjustable Dead Time.
UPC277G2	General-purpose Comparators Utilizing CMOS Process Suitable for Low Voltage, Low Power Consumption, and Fast Response.
MOSFET REXFET-1	80 V/100 V N-Channel Power MOSFET with low Rds,on
Renesas GaN BDS	650V GaN Bidirectional Switch (BDS)

Control Architecture

Modes of Operation

Microinverters can operate in different modes depending on the system's configuration, the grid's availability, and specific operational requirements. The key operating modes of the Microinverters are on grid and off grid modes as detailed below.

On grid operation

In this mode, the microinverter transfers the power to grid based on the available PV power by operating at MPPT. Capable of providing both active and reactive power based on the utility requirement.

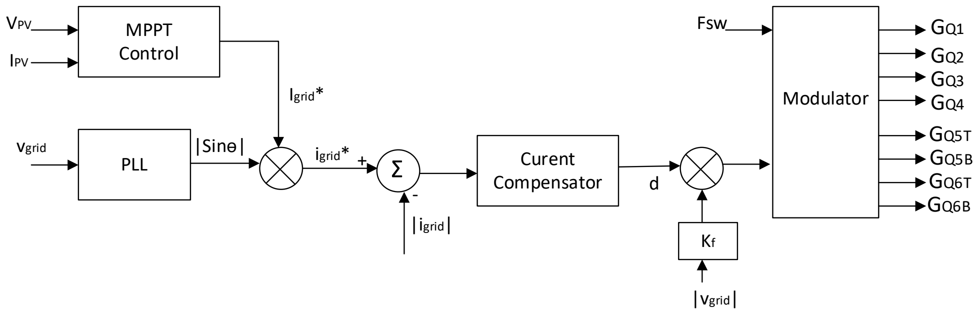

Figure 7: Control block diagram for on grid operation

The typical control architecture for on-grid operation is illustrated in Figure 7. The MPPT control algorithm generates the grid current reference (Igrid*) by sensing the input voltage and current. The sensed grid voltage, along with an appropriate Phase-Locked Loop (PLL), determines the angle (θ) and the corresponding absolute value of the unit sine wave. The sine wave envelope is then multiplied by Igrid* and compared with the actual grid current (Igrid). The resulting error is corrected by a current compensator to calculate the duty cycle (d). A feed-forward duty is added to the duty (d) from grid voltage to ensure stable dynamics for the sinusoidal wave, enabling faster control response. Additionally, the switching frequency (Fsw) is provided as a control command to the modulator block. Its value is varied to being highest near the zero crossing of the sine wave and lowest at its peak. This prevents grid current discontinuous conduction mode operation during light load condition and minimizes the overall total harmonic distortion (THD).

Note: The angle θ represents the phase difference between the grid current and the grid voltage, where θ = 0 indicates unity power factor operation with active power being supplied to the grid. A lagging or leading angle signifies the supply of reactive power to the grid or the absorption of reactive power from the grid, respectively.

Off grid Operation

In this mode, the Microinverter is disconnected from the grid and feed the power based on the load requirement. The typical control architecture for on grid operation is shown in Figure 8.

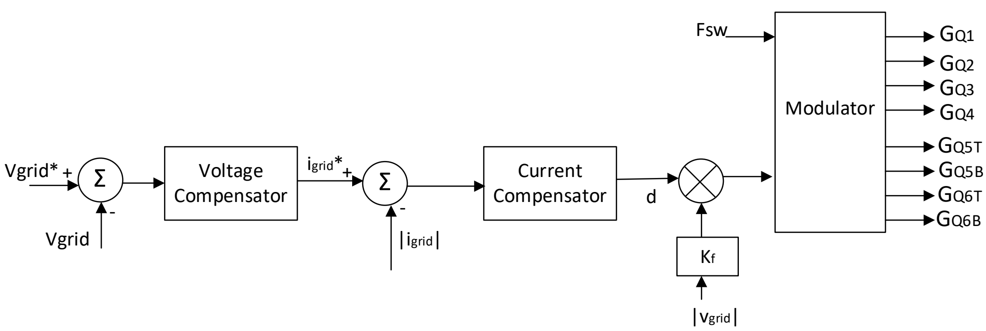

Figure 8: Control block diagram for off grid operation

The sensed grid voltage (v_{grid}) is compared with grid voltage reference (v_{grid}*); the obtained error is fed to voltage compensator to generate grid current reference (I_{grid}*). The reference is compared with actual grid current (I_{grid}). The obtained error is compensated through suitable current compensator to obtain the duty (d), followed by modulator to generate primary and secondary PWMs.

Microinverter Design Challenges

Microinverter with compact design is essential for residential application, making high power density and high frequency of operation mandatory requirement. Designers face following challenges while design such converters:

- The single stage power conversion typically requires higher electrolytic capacitor (of the order of mF) on low voltage PV side to achieve Power decoupling, occupying space, increasing cost and reducing solution reliability. The capacitance value could be reduced significantly by active power decoupling circuit.
- Precise Zero cross detection of the grid current for AC-AC bridge PWM sequencing to eliminate zero crossing distortion and there by minimize the grid current THD.
- While microinverter switching at few hundreds of kHz, it is critical to select suitable processors for control operation with high resolution ADC sensing, faster PLL and PI loop execution, MPPT control and protection implementation.
- The high-frequency operation required to achieve high power density makes the system susceptible to EMI/EMC issues. Therefore, addressing EMI/EMC concerns becomes crucial to achieve excellent system operation.

Summary

Single-stage topology Microinverter enables compact design without compromising on efficiency performance. Renesas Microinverter solution facilitates faster time to market with reduced development and testing cycle. The proprietary Bi-Directional GaN switch technology, together with broad power portfolio ensures reduced sized and high-power density operation.

Renesas product portfolio includes a wide range of DC-DC and AC-DC controllers, Si REXFETs, GaN switches and various other essential parts, making the perfect one-stop-shop for Microinverter and in general, renewable energy related developments.

References

[1] RAA211250, Product Webpage, Renesas Electronics.
[2] RAA211820, Product Webpage, Renesas Electronics.
[3] RAA214250, Product Webpage, Renesas Electronics.
[4] HIP2211, Product Webpage, Renesas Electronics.
[5] UPC277G2, Product Webpage, Renesas Electronics.

[6] READ2302G, Product Webpage, Renesas Electronics.

[7] ISL28134FHZ, Product Webpage, Renesas Electronics.

[8] RA6T2, Product Webpage, Renesas Electronics.

[9] MOSFET REXFET-1 Middle Voltage Product Technology, Application Note, Renesas Electronics.

[10] Renesas GaN BDS, IEEE Power Electronics Magazine.

Corporate Headquarters

TOYOSU FORESIA, 3-2-24 Toyosu, Koto-ku, Tokyo 135-0061, Japan

https://www.renesas.com

Contact Information

For further information on a product, technology, the most up-to-date version of a document, or your nearest sales office, please visit:

https://www.renesas.com/contact-us

Trademarks

Doc Number: R30WP0011EU0100