INNOVATIVE ARCHITECTURES FOR SOLAR ENERGY APPLICATIONS: ST MICROINVERTER SYSTEM SOLUTION

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ABSTRACT

New technologies for the manufacture of more efficient solar cells, understandably, receive a lot of attention from the media. However, the global efficiency of a photovoltaic system depends not only on solar panels but also on the power electronics in charge of performing, in the optimal way, the conversion of the DC electricity produced by the panels and to keep it at the operating point corresponding to maximum power production. This function is performed by algorithms called Maximum Power Point Tracker - MPPT-.

Depending on how the power electronics is allocated, various photovoltaic grid connected system architectures can be implemented. In this article we'll discuss the new trend based on the microinverter approach as well as the STMicroelectronics solution including advantages, market data, electronics topologies, key products and test results of the ST solution.

INTRODUCTION

Central and string inverter architectures represent traditional grid-connected photovoltaic systems.

The central inverter architecture is characterized as a system where the entire DC output of a PV array is brought to one point, and then converted to AC by one inverter. In this kind of architecture the MPPT is implemented at the system level. String inverters architectures are used in systems where power conversion occurs at each string in which the PV panel array is divided.

Due to their low per watt costs and the simplicity of design, central and string inverters are the power conversion systems of choice for large PV power plants.

For this approach, STMicroelectronics has developed a 3kW grid connected solar inverter evaluation board (order code STEVAL-ISV002V2). Adopting MPPT at the system level means simply that because the panels could have different performance, contamination or shade, the MPPT would not perform the proper function, since the panels are connected in series. It would adapt to the module with the worst performance, and thus penalize the entire energy system production. PV solar systems with central or string inverters are relatively expensive to maintain. The monitoring of the installation is implemented at a system level rather than at the module level, so finding a faulty solar module or one that is overcast with shadow or debris is a time-consuming and expensive. The reliability of the system in terms of electronics essentially depends on the central inverter operation so a possible failure can cause the full system to shut down.

The new trend of photovoltaic architecture is towards distributed systems which mean using module level power management (MLPM). With this approach, thanks to using MPPT at the module level, it is possible to improve system energy production, having complete monitoring and control of each panel, increased safety and system reliability, and a greater flexibility in system design.

MODULE LEVEL POWER MANAGEMENT (MLPM) BASED ARCHITECTURES

Power Optimizer

The power optimizer implements, at the panel level, the DC-DC power conversion with MPPT and the communication capability. The AC grid connection, at the array level, is made by means of one DC-AC converter called the central inverter. Two different power optimizer architectures can be identified depending on the output voltage of the DC-DC converter: low voltage architecture (in each string the power optimizers are connected in series, fig. 1), and high voltage architecture (the power optimizers are connected directly in parallel to the main inverter, fig. 2). For the low voltage architecture STMicroelectronics has developed dedicated products like the SPV1020 interleaved DC-DC boost converter. This device is a monolithic 4-phase interleaved DC-DC boost converter with embedded logic that performs the MPPT algorithm on the PV cells connected to the converter. It's possible to evaluate the performance of the SPV1020 by testing one of the system evaluation boards developed (e.g. STEVAL-ISV009V1). For the high voltage architecture, other evaluation boards are available (e.g STEVAL-ISV013V1).

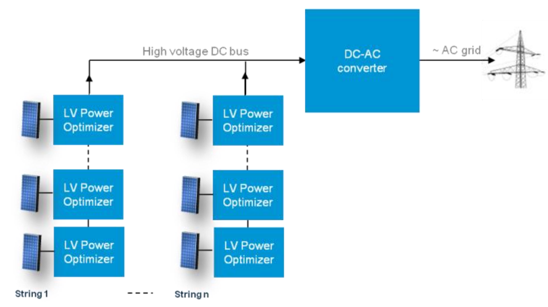

Figure 1: Low voltage power optimizer based architecture

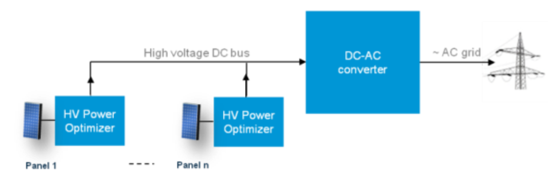

Figure 2: High voltage power optimizer based architecture

Microinverter

The microinverter implements, at the panel level, the power conversion stages (DC-DC with MPPT and DC-AC), the communication capability and the connection to the AC grid. In this way, each panel is connected in parallel directly to the AC grid.

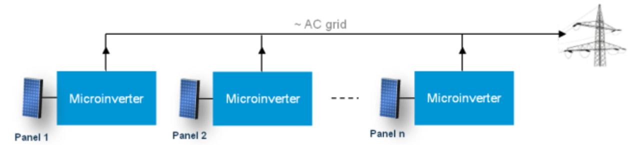

Figure 3: Microinverter based architecture

STMicroelectronics, based on its full products portfolio, has developed a complete and efficient solution in an evaluation board, the STEVAL-ISV003V1: 250 W microinverter for plug-in PV panels. The details about it will be discussed in the next section.

By performing MPPT at the module level, it’s possible to increase energy production from a solar installation by as much as 25%.

According to IHS iSuppli, because of the capability to increase the efficiency of solar systems, MLPM solutions are set for fast growth, with almost 40 percent of residential photovoltaic (PV) installations expected to use the technology by 2014. Global shipments of MLPM system are projected to rise to 6.2 GW by 2014, up by nearly a factor of 40 from 160 MW. By the end of 2014, 38% of residential PV installations worldwide will employ MLPM solutions, up from 2 percent in 2010.

Figure 4: Global MLPM shipment forecast (in Megawatts)

MLPM based architectures are appropriate for residential applications with low power requirements and where partial shading is a critical issue.

In an MLPM based architecture, the microinverter has more advantages than a power optimizer. The microinverter solution helps reduce fire risk because an arc in an AC system self extinguishes 120 times per second (on a 60Hz power system) while a DC arc is continuous. With this approach, there is no distribution of dangerous high voltage DC power. In terms of reliability if one panel or microinverter fails, the outage is limited to that single module. The rest of the array will continue to operate normally. But when adopting power optimizer architecture, the failure of the central inverter will cause an outage of the entire system. Another benefit of the distributed microinverter architecture is the possibility to expand the power installation over an exented period of time. An initial set of solar panels can be installed and thereafter other modules can be added to increase the power plant without requiring replacement of a centralized inverter.

MICROINVERTER TOPOLOGIES

There are two main categories of microinverter topologies: the single stage and the two stages.

The single stage (fig. 5) is so called because the power conversion from the panel to a rectified sinusoid is done in a single stage. Different topologies are used like interleaved flyback (quasi-resonant or not) and forward converter. A silicon controlled rectifier (SCR) full-bridge is used to unfold rectified output voltage/current to sinusoidal voltage/current. Therefore, the SCR is switched at line frequency.

STMicroelectronics offers dedicated SCRs like TN805 / TN815 or TYN608 / TYN812 characterized to have a repetitive peak off-state voltage V_{DRM}/V_{RRM} of 600V and 800V, the reverse blocking capability (mandatory for AC line connection), and the ZCS operation.

The advantages of the single-stage topology microinverters are their lower component count, low switching frequencies of the unfolding bridge, and ease of implementing isolation.

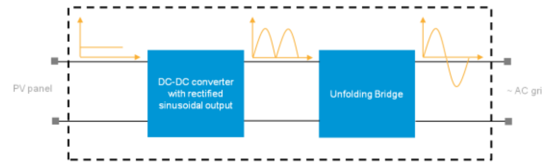

Figure 5: Microinverter, single stage topology

Disadvantages include high voltage ratings on both the primary side switches and the secondary side diode, and high amplitude 100/120Hz ripple current at the input that can cause a power loss (owing to the deviation from the max power point of the PV panel).

The second category, the two stages topology (fig. 6), is composed of a DC/DC converter that boosts the PV panel voltage to a high constant DC-bus voltage, and of a conventional PWM DC/AC converter that produces sinusoidal output voltage and current in synchronization with the grid voltage. Generally for the DC/DC converter, the topologies used are push-pull or full bridge or interleaved flyback. The topology used for the DC-AC converter is full bridge.

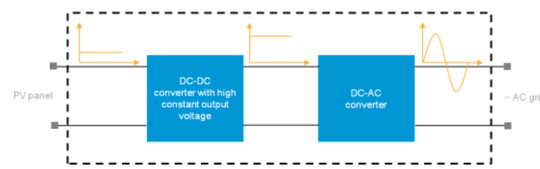

Figure 6: Microinverter, two stages topology

The advantages of the two-stage topology are the possibility to manage the reactive power and the low input ripple current of the PV input side. The first benefit is very important in countries where there are reactive power regulations in place. The second benefit allows the use of small and highly reliable capacitors (film type instead of electrolytic ones) to give the microinverter a longer life. The complexity and cost are higher than with the single stage topology.

STMicroelectronics supports the development of the microinverter through its broad product portfolio (fig.7): power management, data processing and interface.

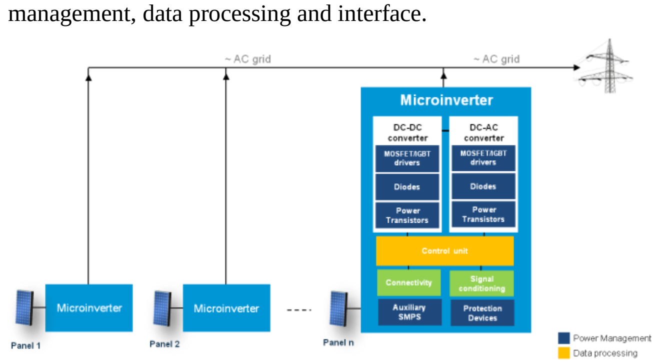

Figure 7: Microinverter, STMicroelectronics products offer

Power management products offer includes:

Power MOSFETs

- 650V MDmesh V series: STL18N55M5, STL17N65M5, STL19N65M5
- 850V SuperMESH 5 series: STL23N85K5
- STripFET VI DeepGATE series: STL80N75F6, STL75N8LF6

Diodes

- 600V Silicon-carbide (SiC) series: STPSC1006, STPSC1206, STPSC2006CW, STPSC406, STPSC606, STPSC806
- 600V Ultrafast series: STTH15L06D, STTH60L06CW, STTH30L06CW, STTH6006W, STTH3006W, STTH806DTI, STTH1506DPI
- MOSFETs/IGBT drivers: PM8834, L6386E, L6390, L6391, L6393, TD220, TD350, TD351, TD352
- IGBT/MOSFET protections: SMAJ, SMA6J, SMBJ, P6KE, SM15T, 1.5KE Transil
- Auxiliary SMPS: VIPerPLUS family

Data processing products include 32-bit ARM Cortex MCU family members: STM32F1, STM32F2, STM32F4.

Connectivity products include:

- In the RF MCU family: STM32W
- In the Power Line Transceiver and STarGRID (Power Line Networking SoC) family: ST7540, ST7570, ST7580, ST7590
- Ethernet transceivers: ST802RT1A, ST802RT1

STMICROELECTRONICS' SYSTEM SOLUTION: 250 W MICROINVERTER FOR PLUG-IN PV PANELS

STMicroelectronics, supports the microinverter approach with its 250W dedicated system solution (order code STEVAL-ISV003V1) showed in the fig. 8.

Figure 8: STEVAL-ISV003V1, 250 W microinverter for plug-in PV panels

The design is based on the two power stages topology, showed in the fig. 9, namely an interleaved isolated boost DC/DC converter and a mixed frequency full bridge DC/AC converter. In the terms of efficiency, the key point is the selection of the proper power devices.

The main electrical system specifications of the solution are summarized in Table 1.

The interleaved isolated boost DC/DC stage is used to boost the output voltage of the PV module up to about 400V DC and to

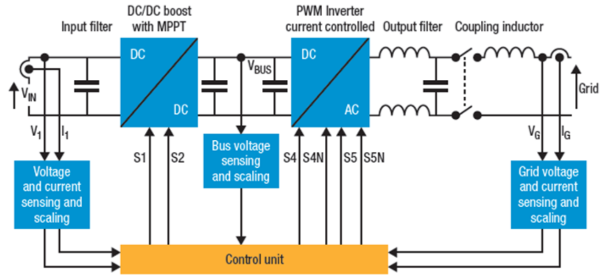

Figure 9: STEVAL-ISV003V1, block diagram

process the Maximum Power Point Tracking (MPPT).

For it, the common and easy Perturb & Observe (P&O) method was used in which the DC-DC converter duty cycle is incremented or decremented by the STM32F1, ST's 32 bit ARM Cortex ™-M3 processor based microcontroller, according to both PV panel power and voltage change (fig. 10 shows this method).

Table 1: STEVAL-ISV003V1, main electrical specifications

V_{in} (nominal input voltage)	35.8V
$V_{in\text{-}max}$ (maximum input voltage)	55V
$V_{in\text{-}min}$ (minimum input voltage)	18V
MPPT voltage range	20V to 40V
I_{in} (nominal input current)	7.6A
$I_{in\text{-}max}$ (max input current)	11A
$V_{out\text{-}DC}$ (DC nominal output voltage)	380V
$V_{out\text{-}DC\text{-}max}$ (DC max output voltage)	450V
$V_{out\text{-}AC}$ (nominal output voltage)	230V, 50Hz 240V, 60Hz
$I_{out\text{-}AC}$ (nominal output current)	1.1A @230V_{AC} 1.06A @240V_{AC}
Power Factor	0.98 @ full load
P_{out} (nominal output power)	250W
DC/DC converter switching frequency	35kHz
DC/AC converter switching frequency	17.4kHz

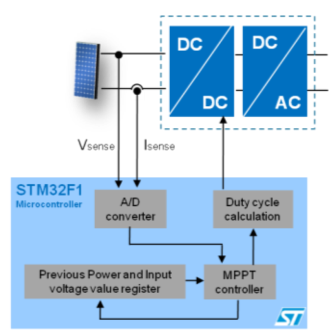

Figure 10: STM32F1 microcontroller and MPPT/P&O method

The galvanic isolation of the DC-DC converter is guaranteed by a high frequency transformer that is connected between the input stage and its output rectifier stage. In the first stage STH180N10F3-2 - 100V/3.9 mOhm STripFET™ III Power MOSFETs are used; STMicroelectronics' STripFET™ III technology, is specifically designed to minimize on-resistance and gate charge to provide superior switching performance. These Power MOSFETs are driven by the PM8834 the dual low side driver specifically designed to work with high capacitive MOSFETs. In the output rectifier stage STTH12R06 - 600V/12A TURBO 2 Ultrafast High Voltage Rectifiers are used.

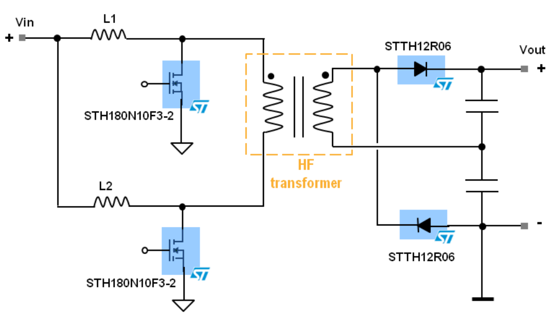

Figure 11: isolated interleaved boost DC-DC converter

The DC/AC converter is a Full Bridge (fig. 12) characterized by a high frequency leg switching (17 kHz) with sinusoidal PWM and low frequency leg switching at grid frequency (50Hz). The adoption of this modulating strategy allows the optimization of the microinverter's efficiency in the low load part of the operating profile since a sensible reduction in switching losses is achieved. In the DC/AC converter, STPSC606 - 600V/6A Silicon Carbide (SiC) diodes are used like freewheeling diodes, STPS1545C – 45V/15A Schottky diodes are used like blocking diodes, and STB18N65M5 - 650V/ 0.198 Ohm MDmesh™ V Power MOSFET are used. The gate drivers used were PM8834 jointly with the L6390 (half bridge driver).

The devices based on Silicon Carbide have a lot of advantages. This is an innovative material for power semiconductors. It exhibits four times better dynamic characteristics and 15% less forward voltage than the fastest bipolar silicon diodes available on the market.

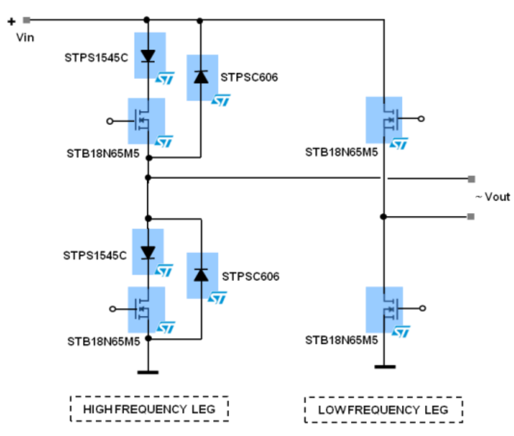

Figure 12: mixed frequency full bridge DC-AC converter

The low reverse recovery characteristics make ST silicon-carbide diodes a key contributor to energy savings in microinverters.

As for the switches, MDmesh™ V is a revolutionary Power MOSFET technology based on an innovative proprietary vertical process, which is combined with STMicroelectronics' well-known PowerMESH™ horizontal layout structure. The resulting product has extremely low on-resistance, which is unmatched among silicon-based Power MOSFETs, making it especially suitable for applications which require superior power density and outstanding efficiencies.

The control section is based on the same STM32F1 microcontroller managing the MPPT. In particular STM32F103ZE was used because it is perfectly suitable for PV applications. This series is characterized by the following main features: 72MHz Cortex-M3 CPU, 64 Kbyte SRAM, 512 kbyte Flash, SPI, I2C, USB FS device, 2 x 16 bit PWM timers with dead-time generation

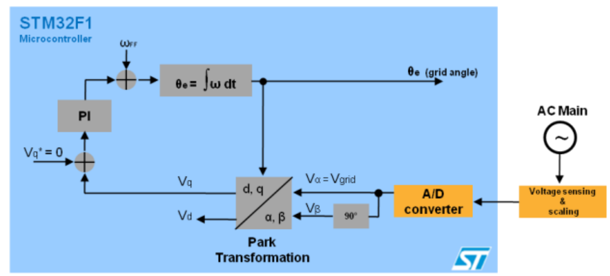

Figure 13: STM32F1 microcontroller and DQ-PLL structure

and emergency stop, CAN 2.0B and 12-channel DMA controller. The STM32F103ZE microcontroller also manages the grid connection operation. For this, DQ-PLL axes control is used (fig. 13), which offers the advantages of zero steady state error (thanks to the use of PI controllers) and simple implementation.

The grid voltage and the 90 degrees phase shifted voltage are used to perform the reference frame change, or "Park transformation", and create two voltage components on the d-q reference frame called Vd and Vq. One of the two components is controlled to zero with a PI regulator. The output of the PI regulator is the grid frequency which can be integrated to obtain the grid angle.

Other operations are implemented by the same microcontroller: input voltage/current monitoring, bus DC voltage control, burst mode operation at start up, line voltage and frequency detection and anti-islanding feature, out over current, open loop operation and the LCD display managing.

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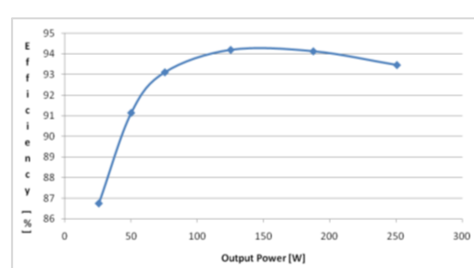

Figure 14: STEVAL-ISV003V1, efficiency

The control algorithm has been developed to allow system operation both with 230V AC, 50Hz grids and with 240V AC, 60Hz without any hardware modifications. The connection to 120V AC, 50/60 Hz grid requires few hardware modifications to ensure the best system performance. The peak system efficiency is higher than 94% and the CEC efficiency is 93.4%. In the fig. 14, the complete efficiency curve at different output power values is shown.

STMicroelectronics' products used in the STEVAL-ISV003V1 are reported in the table 2.

More comprehensive information about ST's microinverter solution is reported in the application notes AN4070 and UM1538.

Table 2: STMicroelectronics products used in STEVAL-ISV003V1

Device Part Number	**Description**
STPS3L60U	Schottky diode
STPS2L25U	Schottky diode
STTH12R06G	Ultrafast rectifier
STTH108	Ultrafast rectifier
STPS3L40S	Schottky diode
STPSC606	Silicon Carbide diode
SMBJ70A	Transil TVS
PM8834	Dual low side driver
TS912	Rail to Rail CMOS dual operational amplifier
LD1086DT33TR	Low drop voltage regulator
STB18N65M5	MDmesh™ V Power MOSFET
STH180N10F3-2	STripFET™ III Power MOSFET
2STN2340	Low voltage fast switching PNP power transistors
L6390	High Voltage Half-bridge gate driver
L4971	Step down switching regulator
ST3232EBTR	RS-232 serial interface
74HCT7007RM13TR	CMOS Hex buffer
TS272AIN	Dual operational amplifier
STM32F103ZET6	32-bit Microcontroller