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A NEW LOW-COST MODULAR INVERTER USING ADVANCED ASIC CONTROL

Rigorous performance tests result in rapid adaptation to market demands

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ABSTRACT: Laboratory tests on a new modular inverter using an application-specific integrated circuit are discussed. The inverter design is optimised for Ascom's large-scale telecom production facilities. The ASIC is developed by means of sophisticated simulation tools and is the key controlling unit in the design. The electrical properties of the inverter, such as efficiency of power conversion, quality of delivered energy and behaviour of a large number of inverters in parallel are tested by the Energy research Centre of the Netherlands (ECN). Special attention is paid to the behaviour of inverters in parallel in relation to harmonic distortion, to estimate the effect of large-scale PV integration. This design process resulted in a rapid adaptation to market demands for a new low-cost inverter and brought the final user price below one €/W and the warranty period to ten-years.

Keywords: Qualification and Testing - 1: Small Grid-connected PV Systems - 2: Inverter - 3

1. MOTIVATION AND GOALS

All new designs of PV inverters are tested either by the manufacturer or by external test institutes. The latter can perform safety or EMI tests as demanded for CE qualification or they can test the electrical and mechanical properties of the device. The Energy research Centre of the Netherlands (ECN) has developed a (national) guideline for type approval of PV inverters. The recommended tests have been implemented in hard- and software, by which these tests can be carried out fast and efficiently. The test outcome gives insight in the device characteristics, which in turn can help to avoid costly field problems during the market introduction.

The new Ascom PV inverter using the modular concept with an application-specific integrated circuit (ASIC) was thus designed and tested.

The ASIC is developed with sophisticated simulation tools at the University of Paderborn and is the key controlling unit in the design [1]. Because highly flexible parameter configuration was a primary criterion for the design of the ASIC, the control unit can easily be adapted to changing boundary conditions. This flexibility is used for incorporation of ECN's recommendations after the lab and field tests to gain the highest performance.

By optimising the inverter design for Ascom's large-scale telecom production facilities, a low production price can be set. To achieve this the printed circuit board layout and the component choice totally fit in this production process. The automatic production process brings a continuous high quality level and with this a highly reliable product.

The electrical properties of the inverter, such as efficiency of power conversion, quality of delivered energy and behaviour of a large number of inverters in parallel are tested and reported by ECN. Special attention is paid to the behaviour of inverters in parallel in relation to harmonic distortion in order to estimate the effect of large-scale PV integration.

The sole supplier of this new PV inverter is Exendis [2], which coined the name of the product Gridfit 250. Exendis did most of the field tests and was responsible for the specification of the product. In figure 1.1 you can see the second prototype being the result of the first prototype evaluation and input for the first production run. The ratings of the Gridfit 250 are: $250W_{dc}$, $24V_{dc}$ to $50V_{dc}$.

Figure 1.1: the second prototype Gridfit 250

2. DESIGN PROCESS

The design process to result in the first prototype [3] was the most important step, subsequently a design sequence with intermediate tests was followed. After the delivery of the first prototype a number changes had to be made before the first production run. For the Ascom PV inverter the majority of ECN's recommended adjustments could be easily done thanks to the highly flexible parameter configuration of the ASIC control.

3. PERFORMANCE TESTS

Performance tests are developed with the Dutch Guideline as a basis [4]. The recommended tests have been implemented in hard- and software to set up an automatic test site [5]. Hereafter a number of these tests are discussed.

Static Power Efficiency

The static power efficiency test is a test to determine the efficiency of the inverter for twenty or more power levels under nominal conditions according to the specifications of the inverter. Because the integration time is twenty seconds this test does not take into account the long term tracking behaviour of the inverter. The static power efficiency is the ratio of the active output power to the active input power. Both values are calculated as the integral of the product of the instantaneous values, i.e. the component corresponding to the higher-order harmonics are included.

$$\eta_{PS} = \frac{\frac{1}{T_a}\int_0^{Ta} v_{AC}(t)\cdot i_{AC}(t)\cdot dt}{\frac{1}{T_a}\int_0^{Ta} v_{DC}(t)\cdot i_{DC}(t)\cdot dt} = \frac{P_{AC}}{P_{DC}}$$

η_{PS} = Static Power Efficiency [-]
T_a = Time period of integration [s]
$v_{AC}(t)$ = AC voltage [V]; $v_{dc}(t)$ = DC voltage [V]
$i_{AC}(t)$ = AC current [A] ; $i_{DC}(t)$ = DC current [A]

Static Energy Efficiency

The static and dynamic energy efficiency shall be part of the inverter's specification and is measured in compliance with the procedure for grid connected inverters described in IEC 61683.

At five prescribed power amplitudes the static energy efficiency is measured for three array configurations. The power amplitudes are: 10%, 25%, 50%, 75% and 100% of P_{rated}. The array voltages are: minimum, nominal and 90% of the maximum inverter's input voltage. The averaging period of the tests per power amplitude value is 10 minutes. Due to this integration time this test takes into account the long term tracking behaviour of the inverter. The total test time will be more than 3 hours.

The static energy efficiency is the ratio of the output energy to the input energy. Both energies are calculated as the integral of the product of the instantaneous values, i.e. the component corresponding to the higher-order harmonics included.

$$\eta_{ES} = \frac{\int_0^{Ta} v_{AC}(t)\cdot i_{AC}(t)\cdot dt}{\int_0^{Ta} v_{DC}(t)\cdot i_{DC}(t)\cdot dt} = \frac{W_{AC}}{W_{DC}}$$

η_{ES} = Static Energy Efficiency [-]

Static Energy Efficiency at overload

In addition to the static energy efficiency, power amplitudes in the range of 100% to 120% of P_{rated} shall be measured. In many situations the nominal power of the PV inverter is lower than that of the PV modules and the inverter must withstand this situation.

Dynamic Energy Efficiency

In addition to the static energy efficiency the dynamic energy efficiency is measured at an averaged available power equal to the inverter's rated output power. This averaged available power has a sine shaped modulation with a fixed frequency of 10 mHz and various amplitudes simulating moving clouds on a sunny day. The test values for the available power amplitudes are 10%, 20%, 30%, 40% and 50% of the rated output power at the nominal input condition.

Static MPP Efficiency

The maximum power point efficiency is a measure for the inverter's ability to operate the PV-array near its maximum power point. The MPP efficiency includes deviations from the MPP due to the non-ideal behaviour of the tracking algorithm and due to the 100Hz ripple in the DC power in case of a single-phase electric system.
At ten different power amplitudes and for the rated array condition, the static MPP efficiency is measured over a period of time of 60 seconds.

The static MPP efficiency is the ratio of the absorbed DC energy to the maximum available input energy. The absorbed DC energy is calculated as the integral of the product of the instantaneous values, i.e. the component corresponding to the higher-order harmonics included.

$$\eta_{MPPs} = \frac{\int_0^{Ta} P_{DC}(t)\cdot dt}{\int_0^{Ta} P_{MPP}(t)\cdot dt} = \frac{\frac{1}{T_a}\int_0^{Ta} P_{DC}(t)\cdot dt}{P_{MPP}}$$

η_{MPPs} = Static MPP Efficiency [-]
P_{DC} = DC power [W]; P_{MPP} = DC power of MPP [W]

The maximum available input energy is a value of the solar simulator, no ripple or tracking algorithm influences this value. Therefore instead of the maximum available energy the maximum available power is used.

Dynamic MPP Efficiency

The dynamic MPP efficiency is measured at an averaged power equal to 50% of the rated power of the inverter. This averaged available power has a special shaped modulation with a duty cycle of 50%. At four different modulation frequencies (0.25Hz, 0.50Hz, 0,75Hz and 1.00 Hz) the MPP efficiency is measured for six different modulation depths, from 0% to 25%. The averaging period of the test per modulation is 120 seconds.

The dynamic MPP efficiency is the ratio of the absorbed DC energy to the maximum available input energy during each averaging period. The absorbed DC energy is calculated as the integral of the product of the instantaneous values, i.e. the component corresponding to the higher-order harmonics included.

$$\eta_{MPPd} = \frac{\int_0^{Ta} P_{DC}(t)\cdot dt}{\int_0^{Ta} P_{MPP}(t)\cdot dt} = \frac{\frac{1}{T_a}\int_0^{Ta} P_{DC}(t)\cdot dt}{\frac{1}{2}\left(P_{MPP,\,\min}+P_{MPP,\,\max}\right)}$$

η_{MPPd} = Dynamic MPP Efficiency [-]

The maximum available input energy is the mean value of the minimum and the maximum value of the modulation. Instead of the maximum available energy the maximum available power is used.

Two maximum power points are determined and measured. One MPP for the minimum value of the modulation and one MPP for the maximum value of the modulation. As the duty cycle of the modulation is δ=50% the average value of the minimum and maximum is the effective MPP. The total test time for the dynamic MPP efficiency test for four different frequencies is about 3 hours.

MPP tracking range

The MPP tracking range is determined as the voltage range at which the MPP efficiency is higher than 0.95 times the static MPP efficiency at 100% P_{rated} of the test Static MPP Efficiency. The MPP tracking range shall be measured in 25 quasi-static steps of U_{DC}-values from 0V to the maximum voltage level given in the inverter's specification.

4. HARMONIC INTERACTION TESTS

In large scale applications of photovoltaic (PV) energy with a large number of parallel PV inverters the total harmonic current emission can result in harmonic distortion of the grid voltage. The harmonic distortion of the voltage can exceed the standard for voltage characteristics in public distribution systems EN 50160 [6], although the individual inverters easily comply with the standard for harmonic current emissions EN 61000-3-2 [7]. The total harmonic current emission of PV inverters in parallel mode is not completely covered by standards at this moment.

Another issue that is not completely covered by standards is the effect of the production of harmonic current emissions by PV inverters in response to harmonic distortion of the grid voltage. Depending on the design, PV inverters can produce harmonic current emissions in response to harmonic distortion of the grid voltage.

A third issue is the production of harmonic current emissions by PV inverters as a combined effect of the output capacitance of the PV inverters together with the present grid reactance. Depending on the design, PV inverters can amplify these distortions.

All these effects can lead to a high production of harmonic current emissions by PV inverters. These effects can be minimised by good design practice, which anticipates on future standardisation.

In this test the emission of harmonic currents of PV inverters in parallel is examined under laboratory conditions with simulated harmonic distortion of the grid voltage and grid impedance. This will allow an estimate of the amount of harmonic distortion of the grid voltage by application of PV inverters in parallel mode.

With harmonic interaction is meant the effect of the influence of harmonic emissions between PV inverters in parallel mode on one hand and the effect of influence of the harmonic emissions between PV inverters and the grid on the other hand.

The purpose of these measurements is to get an impression of the amount of harmonic distortion of the grid voltage by application of PV inverters in parallel mode and whether this can lead to problems.

Method of examination

In the tests of the Ascom PV inverter the emission of harmonic currents of successively 1, 2 and 20 numbers of PV inverters in parallel connected on the grid simulator were determined in a hard and clean grid as well as in a hard grid polluted with harmonic voltages. Subsequently these measurements where repeated with the use of a soft grid, in this case the harmonic voltages where also measured. A hard grid is a grid with negligible impedance and a soft grid is a grid with a non-negligible impedance.

Grid distortion and impedance

For the investigation with a polluted grid voltage a typical grid distortion was chosen by defining harmonic order, amplitude and phase of harmonic voltages upon the 50th harmonic.

In practice the value of the grid impedance can be difficult to predict. For this investigation the grid impedance was modelled as a resistor in series with a coil. In order to get sufficient grid distortion with the limited amount of inverter power, the grid impedance was scaled. To achieve a relative voltage rise with a given inverter power the scaled grid impedance was related to the inverter power.

5. RESULTS

The performance tests have resulted in an improvement of the efficiency. Together with the advice for an efficiency improvement an infrared photograph, which indicated the location of the losses, was given. The result is that both the losses are equally spread over various components and that the efficiency is improved. Figure 5.1 shows the improvement of the static power efficiency curve of the second prototype.

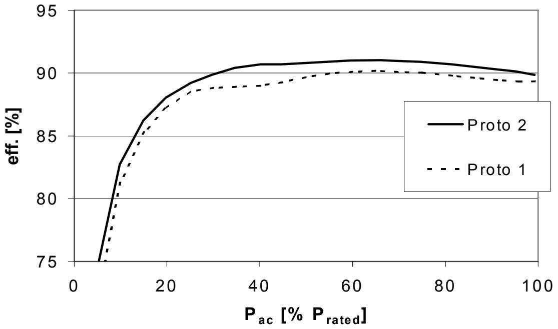

Figure 5.1, Static power efficiency of Proto 1 and Proto 2

Figure 5.2 shows the static energy efficiency curve of the second prototype.

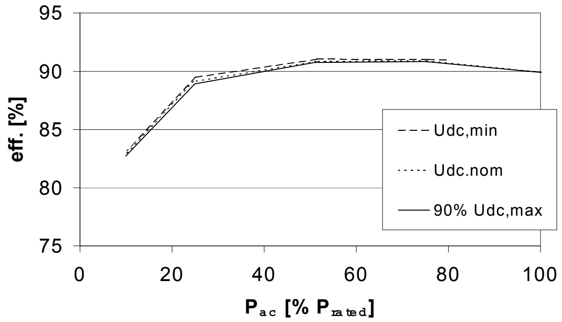

Figure 5.2, Static energy efficiency of Proto 2.

Figure 5.3 shows the dynamic MPP efficiency curve of the second prototype.

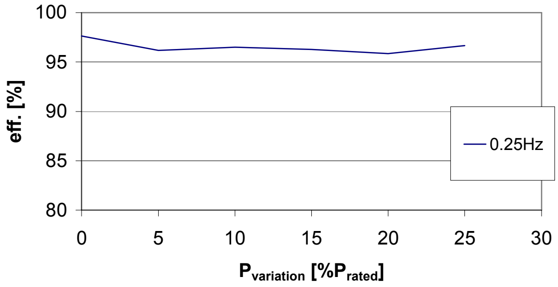

Figure 5.3, Dynamic MPP efficiency of Proto 2.

The harmonic interaction tests have resulted in an improvement of the dependence of the output current of the tested PV-inverter on present harmonic distortion of the grid voltage by reducing the output capacitance.

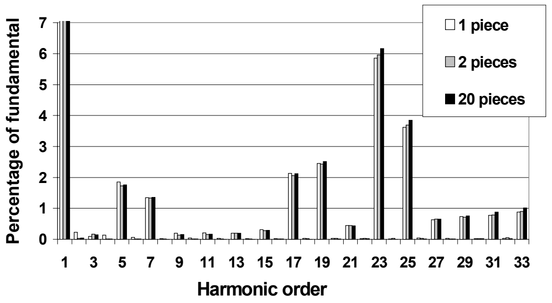

Figure 5.4, harmonic currents of Proto 1 on a strongly polluted grid voltage.

Figure 5.4 shows the harmonic currents of the first prototype while operating on a soft grid with scaled impedance and impressed voltage distortions of the 5th, 7th, 17th, 19th, 23rd and 25th harmonic. The impressed distortions on the voltage can be found back in the current. A part of the harmonic currents is caused by the output capacitor of the inverter. For the 5-th harmonic the current through the output capacitor is about 1% and for the 23rd harmonic the current through the output capacitor is about 3.7%. The rest of the harmonic current is caused by interaction of the inverter with the grid voltage distortion and by resonance of the output capacitor of the inverter with the grid reactance.

6. CONCLUSIONS

Performance tests resulted in:

- an improvement of the static power efficiency
- equally spread losses over various components
- improvement of the MPPT behaviour.

Harmonic interaction tests resulted in an improvement of the harmonic current emission as a response on grid voltage pollution.

This design process resulted in a rapid adaptation to market demands for this new low-cost inverter and brought the final user price below one €/W and the warranty period to ten-years.

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