



Effects of DC current injection into the grid

The effects of DC current injection into the grid have been studied in some reports and papers. Generally the opinion persists that a small level of DC does not have any noticeable effects on grid equipment like transformers etc. For example, Task V of the PVPS Implementing Agreement of the International Energy Agency (IEA) examined this topic and conducted tests. It concluded that even a DC component of 10% of rated transformer current does not jeopardize the proper operation of a transformer [Task V Report IEA PVPS T5-01:1998 "Utility aspects of grid connected photovoltaic power systems", Chapter 13; Dec. 1998].

In many countries appliances like hairblowers are sold which achieve running at half-power by simple one-way rectification, thereby inducing a considerable amount of DC current without any effects on the grid. IEC standard IEC 61727, which is just about to become a European standard, limits DC injection to 1% of nominal AC current of the inverter, thereby giving a much stricter limit.

Inverters for grid-connection of PV systems

For a long time standard inverters for grid-connection included a low-frequency transformer. This component is heavy and big; however, one inherent advantage is the fact that it cannot feed DC current into the grid.

In the past years progress has been made in reducing the size and weight of PV inverters for grid-connection. One way to achieve this is the use of modern high-frequency transformers (or even transformerless inverters). Both concepts are ways to reduce size, weight and, equally important, cost for inverters. As cost pressure is increasing these concepts will become more and more widespread.

However, without any additional measures inverters with high-frequency transformer or without transformer could, in the case of defective components, feed a DC current component into the grid. The following will explain the theory of operation of FRONIUS IG inverters and the measures that have been taken to guarantee that no DC current component is induced.

Theory of operation of the FRONIUS IG inverter

Figure 1 below shows a block diagram of the FRONIUS IG inverters. The DC input from the solar modules is fed into a filter capacitor; the energy is transferred by full bridge B1 via the HF-transformer Tr to the rectifier R. Full bridge B1 is switched at a frequency of approximately 20 kHz and it is controlled so that a DC input voltage between 150 V and 500V DC is converted into a fixed DC voltage of 380V after rectifier R.

Transformer Tr provides full galvanic isolation between the DC side and AC side as indicated by the dotted line.

Full bridge B2 now transforms the DC energy stored in capacitor C2 into 50 Hz AC current which is fed into the grid. It is to be noted that during the positive half-wave of the grid voltage (L1 positive with respect to N) only switches S1 and S3 are active while switches S2 and S4 are open (i.e. non-conducting). During the negative half-wave S2 and S4 are active, while S1 and S3 are open.

In the positive half-wave the upper active switch S1 is constantly closed (=conducting). By pulse-width modulation of the lower active switch S3 the Digital Signal Processor forms the wave-shape of the current fed into the grid almost perfectly like a sinewave. In the negative half-wave S2 and S4 take the role of S1 and S3. The DSP includes a fully digital current controller which keeps the total harmonic distortion of the AC current below 4%.

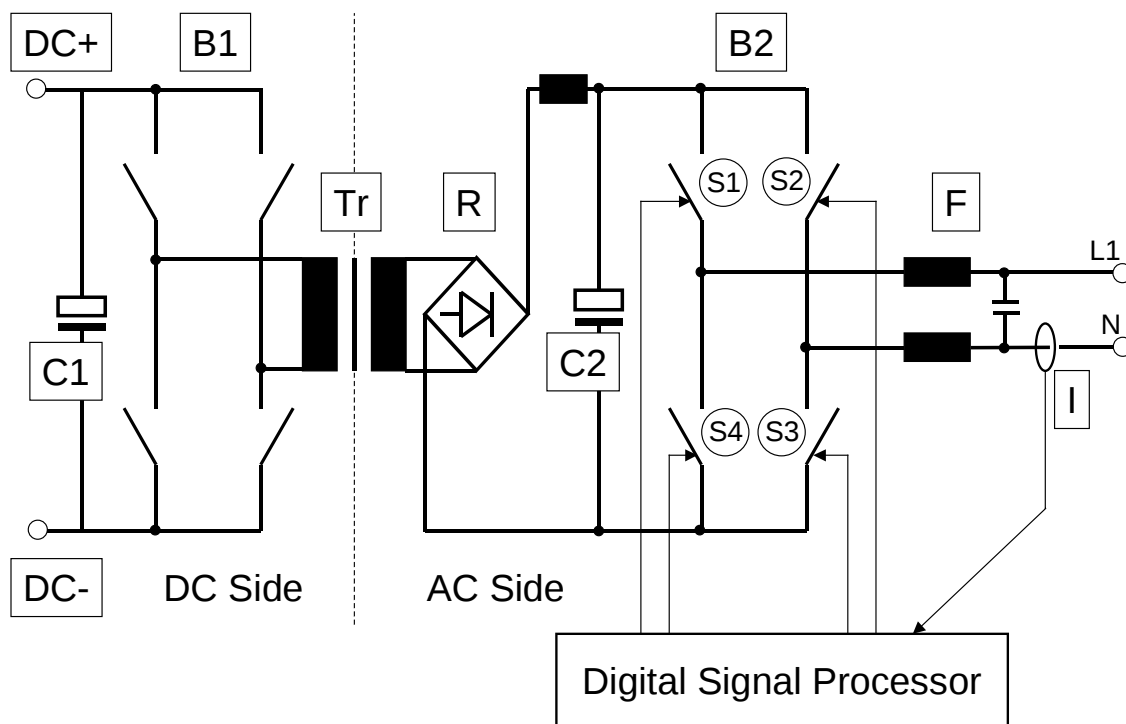


Figure 1: Block diagram of the FRONIUS IG 30.

Preventions of the FRONIUS IG series against feeding DC current into the grid

The structure of the output stage B2 and the filter F are absolutely symmetrical; in addition the digital current controller keeps the pulses of switch S3 (for the positive half-wave) and S4 (for the negative half-wave) also symmetrical. This guarantees a perfectly balanced AC current fed into the grid.

There is just one possible case which could lead to a DC component of the current: a defective switch.

For example, if switch S1 does not close any more, no current is fed into the grid in the positive half-wave while the inverter could feed current in the negative half-wave.

This is prevented by actively monitoring the symmetry of the positive and the negative half-wave of current. The measurement is made by current sensor I which enables the DSP to monitor this parameter.

The current into the grid is sampled 400 times per period; the DSP computes an independent average value of the positive and the negative half-wave and performs averaging over 5 periods. If it turns out that the average value of the positive and negative half-wave differ by more than 1% of full nominal current, the operation of the inverter is instantaneously stopped. This threshold is therefore far below the DC currents that would flow in case of a switch failure.

How to prevent DC currents of photovoltaic inverters - the solution with the FRONIUS IG series



Summary

DC current injection is prevented by:

- design of the digital current controller which keeps the positive and negative half-wave symmetrical
- active measurement of the average DC current component with a shutdown time of 5 periods in the case of more than 1 % of DC current
- shutdown and blocking of device operation in case of a defect of the current measurement sensor I which is checked each day before startup of the inverter.

The FRONIUS IG therefore fully complies with the requirements of the new standard IEC 61727, which limits DC injection at a level of 1% of nominal AC current of an inverter.

In practice measurements have shown that on the average the DC current component is below the measurement error of most instruments. Figure 2 shows a picture of a typical case of an IG 30 at full load. AC current is 11.08 A, measured DC current is 4.4 mA which corresponds nominally to 0.04%. It should be added that this is below the measurement accuracy of the current probe which is used.

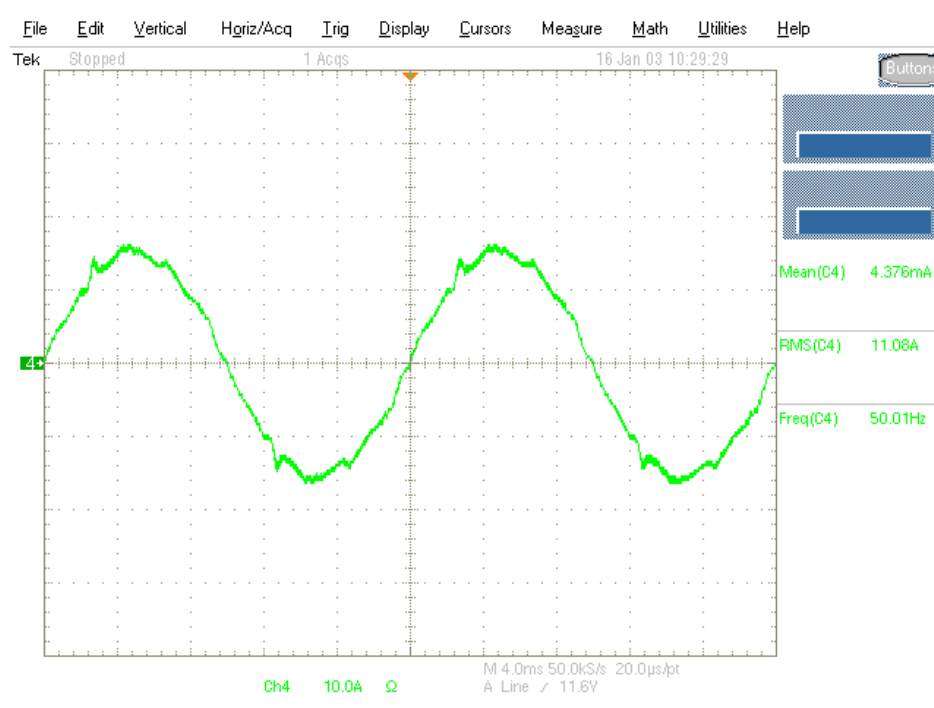


Figure 2: measurement of DC current component of a FRONIUS IG 30 at full load. AC current: 11.08A, measured DC component: 4.4 mA (=0,04%).

How to prevent DC currents of photovoltaic inverters - the solution with the FRONIUS IG series



Tests that simulate a breakdown of one component like switch S1 (Figure 3) show that this leads to the immediate shutdown of the inverter after 5 periods (0,1s at 50 Hz).

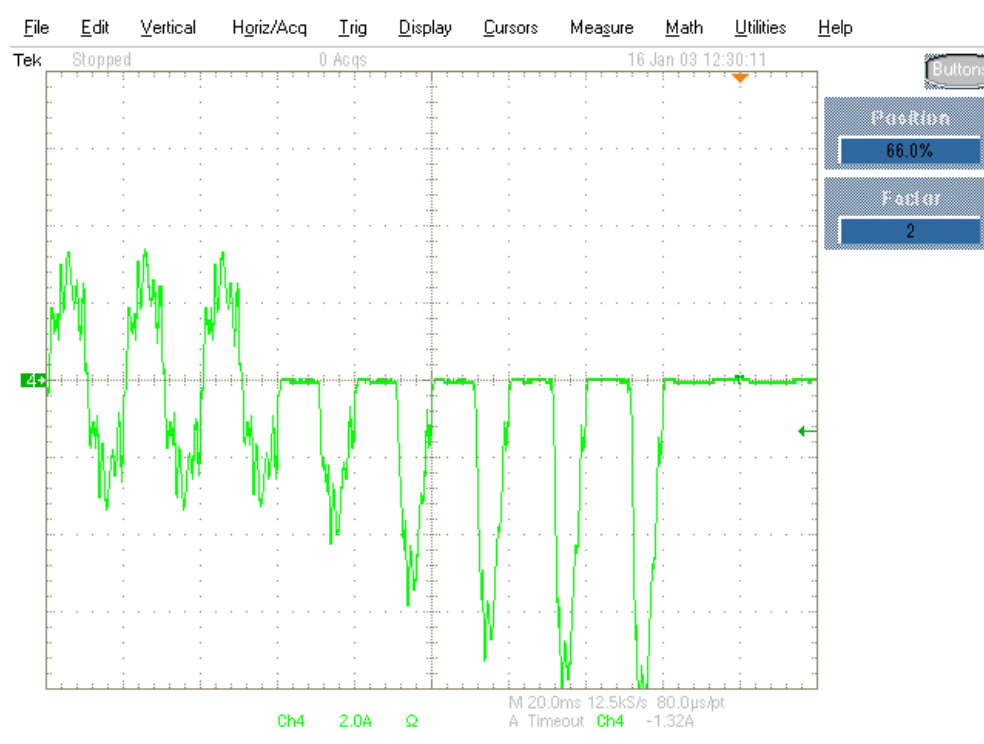


Figure 3: Simulated breakdown of switch S1. It can be seen that after 3 full periods suddenly only the negative half-wave of the current remains. After 5 faulty periods the inverter stops operation.

Conclusion

Transformerless inverters and inverters with a high-frequency transformer are the natural next step in the technical evolution of inverters. These concepts lead to lower weight, volume and cost and are therefore important in promoting PV technology.

From a technical point of view the problem of possible DC current injection (especially in the case of a component fault) exists. However, if necessary precautions are taken in the inverter to actively detect DC current components and block inverter operation in such a case, the negative consequences of DC currents can be avoided.

All FRONIUS IG models are equipped with such a detection system, which makes it impossible that such an inverter feeds DC current into the grid even in case of a component breakdown or similar fault condition.

Every FRONIUS IG inverter is also tested for DC current injection after final assembly. Fronius International can thereby certify and prove by way of production documentation that every inverter has a maximum DC current component below 0,5% of nominal current.