THE INFLUENCE OF CONDUCTED PQ-PHENOMENA ON THE MEASUREMENT ACCURACY OF SMART METERS

Dipl.-Ing. Elmar Stachorra
KoCoS Power Grid Services GmbH
estachorra@kocos.com

Dipl.-Ing.Willi Horenkamp
TU Dortmund University
Willi.Horenkamp@tu-dortmund.de

Dipl.-Ing. Timo Wild
KoCoS Messtechnik AG
twild@kocos.com

ABSTRACT

Earlier investigations [1, 2] have shown that the inverters of decentralized generating plants (DG) can have a negative influence on the latest generation of electronic meters. Measurements of the energy fed into the grid were incorrect by as much as 15%. Against this background, the impact of the increasing number of decentralized generating plants and their influence on the behaviour of smart meters is of particular interest. Another important point is that communication, which is of vital importance for smart meters, should not be persistently adversely affected by power quality phenomena.

This paper discusses the initial results of an ongoing investigation of how smart meters are affected by conducted power quality phenomena up to 9 kHz. This investigation examines and analyses a number of smart meters currently on the market. Special attention is paid to the measurement accuracy of the meters in connection with the inverters which feed the energy generated by decentralized plants into the grid and its relevance to billing accuracy. Consideration must also be given to the reliability of communication, a matter of fundamental importance for the use of smart metering systems in future.

BACKGROUND

Electricity supply systems are fast moving away from a centralized structure towards a decentralized structure. As well as the huge increase seen today in the number of decentralized generating plants (PV, micro-CHP etc.) and their connection to the low-voltage grid by means of inverters, the number of power electronic devices (such as power supply units and low-energy light bulbs, for example) is also increasing significantly.

This already leads to widely fluctuating load situations with decreasing levels of active power and increasing levels of reactive or distortive power, a state of affairs which is aggravated still further by the drop in the amount of resistive loads such as light bulbs. Power electronic devices cause the frequency spectrum of the current to become much higher and ever wider. Changes in the direction of load flow, sometimes as often as several times a day, can also occur at the grid connection point. Nowadays these changes are shaped by the primary energy source (e.g. solar radiation in the case of PV plants) as well as by consumption. If in future these decentralized plants also provide system services such as voltage control and reactive power supply (and they already have the technology to do so), currents with a broad frequency spectrum of up to several tens of kHz and frequent fluctuations in the direction of current and therefore also in the direction of load flow are likely to occur at grid connection points in future.

In practice, appropriate meters are usually installed at these grid connection points. In Germany, Ferraris meters are currently installed in 42 million households. In the future (from 2010 onwards) "intelligent meters" or smart meters, as they are known, are to be installed in their place. Recent studies [1, 2, 3] have shown that significant measuring inaccuracies can occur when smart meters are used to measure the energy fed into the grid by PV plants. The smart meters in these studies displayed significantly less than 90% of the real energy fed into the grid. In one case the IWES (Fraunhofer-Institute for Wind Energy and Energy System Technology) laboratory identified a measurement which was incorrect by almost 60%.

STANDARDISATION

At present, inverters are tested in accordance with the requirements of the generic standards for residential and industrial environments only (DIN EN 61000-6-1 to -6-4) because there is no dedicated EMC product standard for this class of devices. These generic standards stipulate limit values for disturbance measurements on the alternating current side within the frequency ranges 0 kHz to 3 kHz (e.g. flicker, current harmonics, etc) and 150 kHz to 30 MHz. But no limit values exist for the frequency gap between 3 kHz and 150 kHz. This means that it is currently not possible to use a standard to assess the emitted interference or the interference immunity of inverters and other clocked power electronic devices within this frequency range.

Although limit values do exist for the frequency range from 3 kHz to 150 kHz for certain classes of devices (devices with power-line communication or induction hobs) [4, 5], these limit values have not applied to PV inverters up until now. As far as the immunity of electricity meters is concerned, product standards for meters (DIN EN 50470-1 and -3, DIN EN 62052-11) also leave out the frequency range from 3 kHz to 150 kHz.

In this connection it is worth pointing out that this situation, in respect of grid-tie inverters in particular, is currently a subject of much discussion in DKE committees (DKE = German Commission for Electrical, Electronic & Information Technologies of DIN and VDE). The EMC behaviour of these inverters, and possibly of all equipment affected in this connection, can only be reliably appraised when the feed-in power of the inverter is taken into account. When the inverters are in stand-by mode, as is the case when a PV plant is not feeding in power to the grid, for example, they behave in a similar way to other electronic loads with low power levels (such as computer power supply units) and must be treated as such.

Contents	Standards			Applica-bility
	IEC	EN	VDE	
Harmonic currents for devices up to 16A	61000 -3-2	61000 -3-2	0838-2	Mandatory
Voltage fluctuations, flicker for devices up to 16A	61000 -3-3	61000 -3-3	0838-3	Mandatory
Harmonic currents for devices over 16A	61000 -3-4	-	-	Informative
Voltage fluctuations, flicker for devices over 16A	61000 -3-5	-	-	Informative
Voltage fluctuations, flicker for devices up to 75A	61000 -3-11	61000 -3-11	0838-11	Mandatory
Harmonic currents for devices up to 75A	61000 -3-12	61000 -3-12	0838-12	Mandatory

Table 1: Application of various standards with reference to current

As the primary energy supply increases, the inverters switch from stand-by mode to feed-in mode. They must now be treated as active equipment which is feeding energy in to the grid (e.g. DIN EN/IEC 61000-3-2). If the feed-in current exceeds a value of 16 A, a different standard must be used when considering the permissible limit values for harmonic currents (DIN EN/IEC 61000-3-12). Table 1 gives an overview of the various standards. In this connection it is also important to remember that many of the standards used today were created for conventional loads and not for the inverters for decentralized plants considered in this paper.

THE PROBLEM AND THE PROCEDURE

Against the background of the information given above, the authors of this paper ask to what extent currents with high harmonic content lead to incorrect measurements of the energy taken from or fed into the grid when smart meters are used. Another important aspect for consideration is the impact on the reliability of communication which is often based on power-line carrier (PLC) technology, for the "last mile" at least. Secure and reliable communication is of paramount importance for the economic use of smart meters in future.

In order to develop a test set-up, the available studies on incorrect energy measurements were examined in detail to identify the influential factors involved. Against the background of these findings and the phenomena described above, a test signal was developed and an existing test set-up for smart meters was then modified at TU Dortmund University. The aim of the investigations was to assess the quality of meter behaviour with regard to negative impacts on their energy measurement and communication capabilities.

Influential factors [1]

Modern PV inverters often generate a sinusoidal feed-in current with the aid of clocked semi-conductor bridges and using pulse width modulation. Filter networks with smoothing inductors and capacitors are used to suppress the clock frequency. In very low-resistance grids, current division may occur between the smoothing capacitor and the grid impedance (current divider). Part of the high-frequency ripple current now flows into the low-voltage grid via the meter and causes the meter to malfunction as observed (see Figure 1). The observed clocked ripple current of many PV inverters lies within the frequency range between 3 kHz and 150 kHz for which present standards contain no limit values. Figure 2 shows the frequency spectrum of a measured ripple current by way of example.

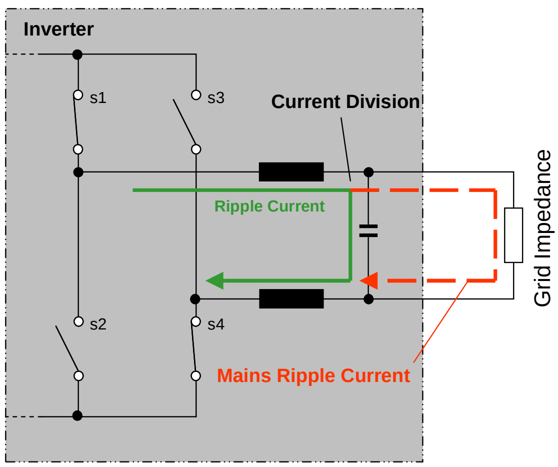


Figure 1: Current division of the clocked ripple current. [1]

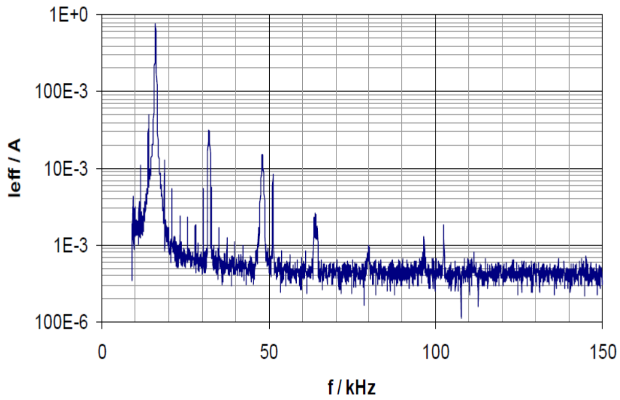


Figure 2: Section of the frequency spectrum of the observed ripple current [1]

This behaviour was not observed in high-resistance networks or with measurements with the EMC grid impedance simulation prescribed in applicable standards. It was also possible to prove that there is a relationship between the magnitude of the ripple current and the malfunctioning of affected meters.

TESTSCENARIO / MEASUREMENT SETUP

A test scenario was developed against the background of the facts described above. The test setup is operated with the mains voltage from the laboratory network of the TU Dortmund University ensuring that the voltage wave shape is realistic. The load situation was simulated using three analogue four-quadrant power amplifiers made by Rohrer and operated as electronic loads. The power amplifiers were controlled by an ARTES 460 protection relay test system made by KoCoS and used here as a signal generator. The signal generator provides a three-phase rectangular-wave test signal making the power amplifiers cause a rectangular wave signal with an rms value of 2 A per phase. The rectangular-wave current input ensures coverage of a broad frequency spectrum in the current (see Figure 3).

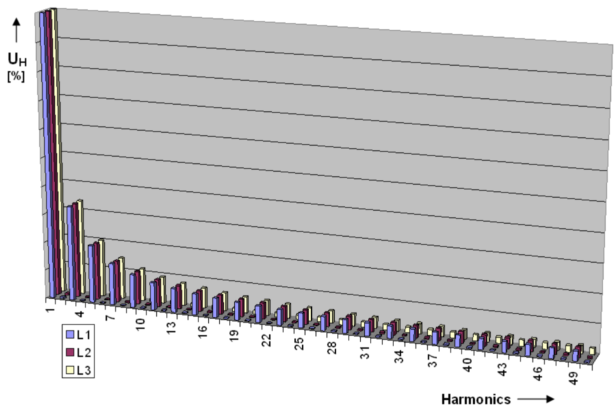


Figure 3: Frequency spectrum of the current

The phase relationship between voltage and current was chosen to ensure that the load flow direction changes periodically (see Figure 4). There is no simple means of varying the grid impedance with the chosen test setup (see Figure 5).

The following graph shows a section of the active power recorded with the EPPE C8 power quality analyser.

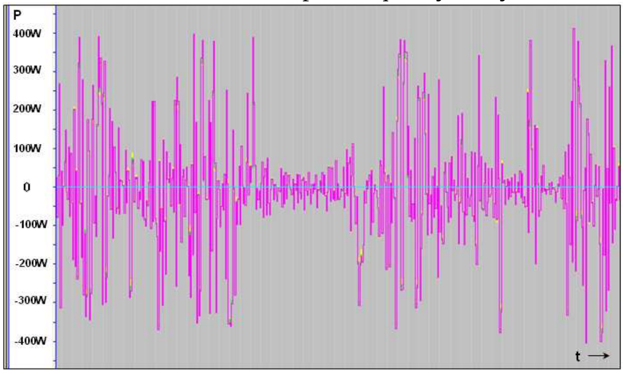
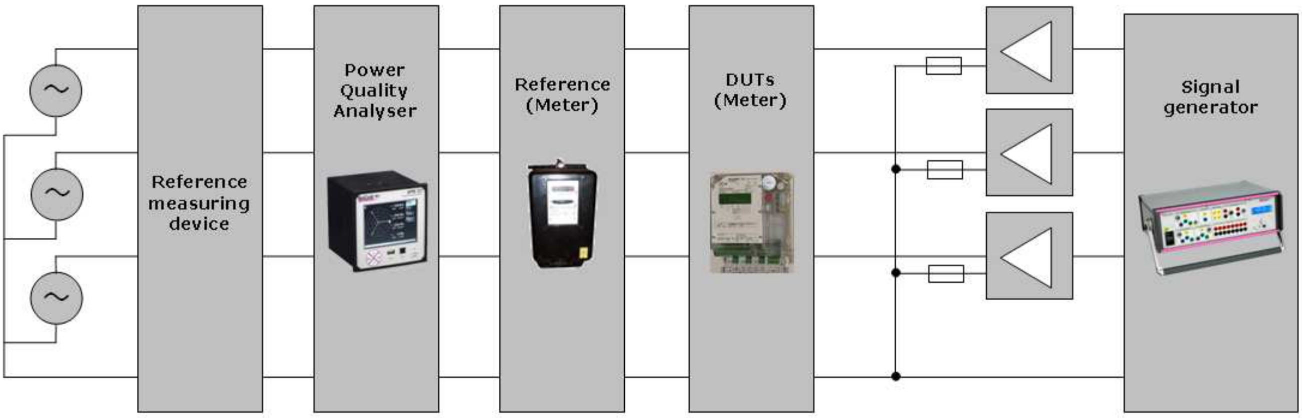


Figure 4: Recorded active power



Figures 5: Measurement setup

A WT3000 high-precision power analyser made by Yokogawa was used as the reference device. Four different electronic meters currently on the market were used as DUTs. They included the meter which has already shown irregularities on a number of occasions [1, 3] and a standard Ferraris meter. A bi-directional PLC communication interface can be tested with one of the meters. The power quality was monitored with an EPPE C8 power quality analyser with a built-in energy meter made by KoCoS.

MEASUREMENTS RESULTS

The whole measurement lasted for a period of 165 hours. The amount of energy measured by the meters (65 kWh) corresponds to the values of the reference device in line with the accuracy of the individual meters. The measurement results for the amounts of energy fed into or taken from the grid (this measurement is not possible for all the meters used) were also within the permissible measurement uncertainties of the individual meters.

The test of bi-directional PLC communication did not reveal any negative impact. It was possible to read out data without error and switch a relay across the same distance.

SUMMARY

The measurement results do not show any unacceptable impact on the meters or measurement results. Neither was it possible to identify a negative impact on the PLC communication observed during the present investigation. This confirms the results of the analysis of the influential factors. Only a coincidence of certain factors leads to the incorrect measurements observed. These factors are listed below:

- a certain meter
- the "right" combination of output circuit filter and the respective low-resistance grid impedance
- the choice of an inverter with a critical clock frequency at this grid connection point.

Each of the devices, meters and inverters considered in this investigation conforms to the appropriate EMC limit values and regulations. However, incorrect measurements can occur under the circumstances described above. Statistically speaking, the number of incorrect measurements is set to increase as smart meters penetrate the grid still further in the coming years. This means that realistic immunity tests for meters and a limitation of the ripple currents fed into the grid by inverters (emitted interference) in the frequency range which is not covered by any standards at the present time are vital if electricity meters and inverters are to interact faultlessly in future. Measurement methods must also be updated accordingly. IWES has already communicated initial results of studies in this field to the appropriate DKE committees.

In practice it is extremely difficult to judge whether or not there is a critical combination of the various individual factors before a decentralized generating plant is put into operation. The publication of positive lists which is currently under discussion [3] seems unlikely.

REFERENCES

[1] J. Kirchhof et al., 2009, "EMV - Grenzwertlücke", *Proceedings of 24th Symposium Photovoltaische Solarenergie*, Bad Staffelstein, OTTI.

[2] J. Kirchhof et al., 2009, "Results of the Optinos project – Deficits and Uncertainties in photovoltaic inverter test procedures", *Proceedings of 24th.European Photovoltaic Solar Energy Conference and Exihibition*, Hamburg, p. 3695-3698

[3] M. B. Krause, 2010, "Zählstörung", PHOTON Profi. vol. 11 32-35

[4] DIN EN 55011, „Industrielle, wissenschaftliche und medizinische Hochfrequenzgeräte (ISM-Geräte) - Funkstörungen - Grenzwerte und Messverfahren“

[5] DIN EN 50065-1, „Signalübertragung auf elektrischen Niederspannungsnetzen im Frequenzbereich 3 kHz bis 148,5 kHz - Teil 1: Allgemeine Anforderungen, Frequenzbänder und elektromagnetische Störungen“