GRID IMPACT FROM PV-INSTALLATIONS IN NORTHERN SCANDINAVIA

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ABSTRACT

The use of solar panels is becoming more popular in Sweden. Parts of Scandinavia have many sun hours and the cold temperatures are advantageous as they lead to higher efficiencies and longer lifetimes of the solar cells. Except during the darkest time of the year (Nov-Feb) PV is a suitable complement for power production also in the northern parts of Scandinavia, especially when using a proper tracking system

In this paper power quality issues concerning the connection of photovoltaic systems will be discussed. Emission up to 25 kHz will be presented as well as voltage variations caused by the production. Measurements from three phase connected plants (20 kW) and from smaller (up to 2.5 kW) single phase connected plants are shown.

The harmonic emission from PV-plants is reasonable low and somewhat constant with regards to the production. Some residue from the switching of the inverter can be found typical at a few kHz.

INTRODUCTION

The impact from PV-plants on the power grid differs from that from other types of production typically found in Scandinavia. The variation in production happens on a much shorter time-scale for PV-plants than for hydro power plants. Several parameters impact the amount of power produced by a PV-installation on any given moment in time. The total irradiation that reaches the PV-module, and thereby making it produce power, consists of direct irradiation, diffuse irradiation and reflected irradiation. The direct irradiation is the most intense one. The diffuse irradiation is scattered as it hits clouds or other particles like smog. Some of the irradiation is reflected by the ground and one of the best reflectors is snow. Even though the direct irradiation can be somewhat predicted, one cloud passing the module can result in a rapid drop to zero and as a consequence also a big drop in production [1]. In [1] p. 48 it is also shown that for a group of plants covering 10 km^2 the production can drop as much as 20% within a few minutes, due to passing clouds. This will result in fast voltage variations that the system has to cope with.

The PV-inverter injects current on the power grid that is to some extent distorted. This could lead to high levels of voltage distortions if the grid impedance is high.

MEASUREMENT RESULTS

Continuous measurements have been performed up to 10 month at several different locations with PV installations of various sizes. Some of the results are presented in the forthcoming sections.

Voltage variations

One concern with integration of PV in the LV-grid is the voltage rise or the voltage variations that can occur at the end of a feeder due to the production. This is more critical in rural areas with long feeders where the impedance at the point of connection can be high. Measurements have been performed at four different installations: two installations of 20 kW connected to three phases and two smaller single phase connected installations (1.5 kW and 2.5 kW). The installations are all connected in urban areas where the grid can be considered sufficiently strong.

In Figure 1 the voltage variation measured at the two three-phase connected 20 kW installations during two weeks is shown. At the location on the right side in Figure 1 the 20 kW PV-modules are connected very close to the secondary side of the 10/0.4 transformer and the linear correlation between voltage magnitude and current/production is low, -0.1. For the plant shown on the left hand in Figure 1 one can see a slight increase in voltage amplitude as the current amplitude increases but the voltage variation is dominated by variations not due to the solar panel. The linear correlation between voltage amplitude and current amplitude remains low, 0.06.

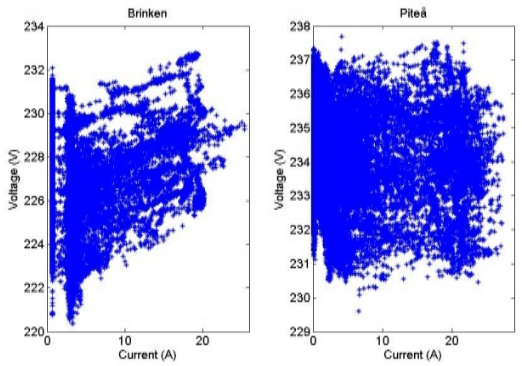

Figure 1 Voltage variation at the two 20 kW three phase connected plants, on the right the fixed system and on the left the system with 2-axis tracking

In Figure 2, right, the voltage magnitude as a function of the current is presented for the single phase connected installation of 2.5 kW. The linear correlation between voltage and current during this time (app 48 h) is strong; 0.84. The voltage variation for low production levels is about ±3 V; these variations are due to normal operation in the grid. As the production increases so does the voltage and magnitude reaches 104 % for maximum

production (the permitted level according to EN 50160 is 110 %). It is however important to mention that this measurement involved a staged experiment where the PV installation was connected at the end of a relatively long LV cable without any other load connected, representing a remote customer during no load.
For PV-plants connected at distribution level the relative voltage variation can be calculated using equation below where U is the nominal voltage, R the source resistance and P is the injected active power.[1]

$$\frac{\Delta U}{U} = \frac{R * P_{PV}}{U^2}$$

The impedance at the phase to neutral connection point for the 2.5 kW installation have been measured to 1.11 Ω. Using the aforementioned equation to calculate the possible voltage rise gives a voltage variation of 5 % with full production, which is in agreement with the measurement.

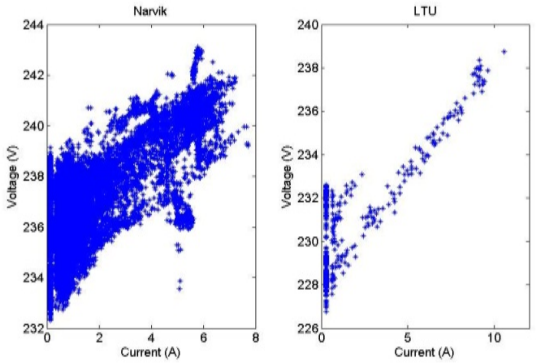

Figure 2 Voltage rise due to increased production

On the left hand side in Figure 2 the voltage and current magnitude for 14 days is presented at a single phase connected PV-installation of 1.5 kW. The voltage variations during low production are somewhat higher, ±4 V, compered with the location presented on the right side. The highest value recorded during these 14 days is 243 V which corresponds to 106 % of nominal and this occurred when the current was just below 6 Arms, note here that the voltage amplitude for low or no production is slightly higher than 230V.

Harmonic Emission

At high production the PV-installations are near unity power factor and the current harmonic emission expressed as percent of fundamental is relatively low. The total harmonic emission from the PV-plants varies over time, it is always present during production but the amplitude is not directly linked to the amount of production as can be seen in Figure 3 where a measurement from one of the 20 kW plants is shown. At zero production the harmonic current amplitude is also close to zero. Some parameters can effect the harmonic emission; the voltage variation caused by the generated current can attenuate the net harmonic currents from an installation and variations in harmonic phase angles from emission originating from other connected equipment can also decrease the total harmonic distortion [2].

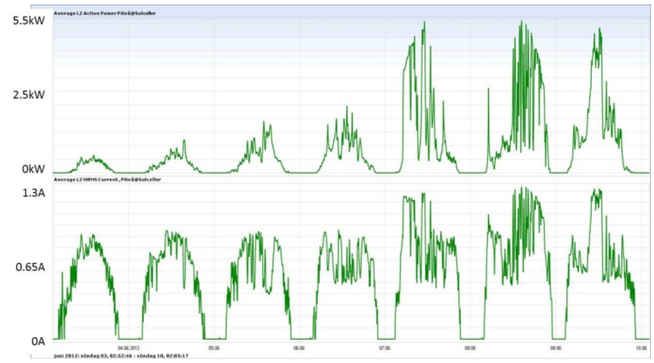

Figure 3 top, production for one phase of the 20 kW plant with 2-axis tracking system during one week. Bottom, rms value of the harmonics during the same period.

The dominating harmonics found during these measurements are the same as those traditionally associated with non-linear loads at the low voltage grid, i.e. the lower order odd harmonics. Some individual harmonics, amplitude and phase angle, for different production levels can be seen in Figure 7 to Figure 10. The phase angle has been taken with reference to the zero crossing of the voltage waveform.

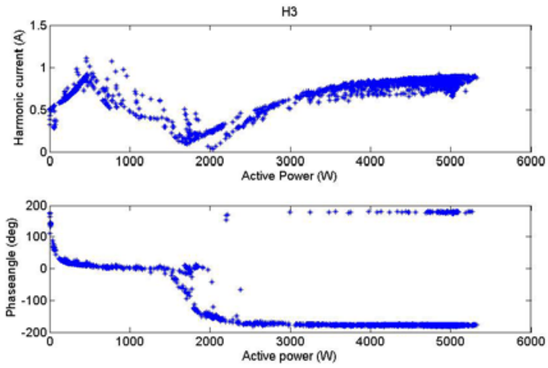

Figure 4 150 Hz component, amplitude and phase angle, at a 20 kW three phase connected plant

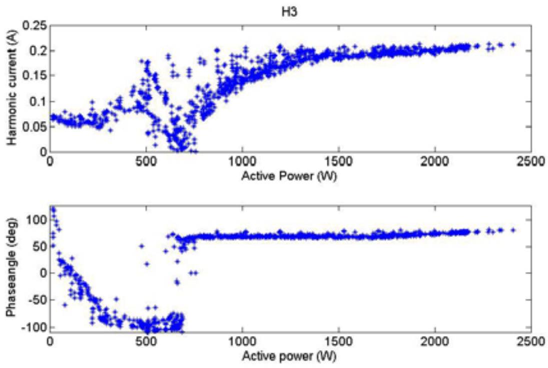

Figure 5 150 Hz component, amplitude and phase

angle, at a 2.5 kW single phase connected plant

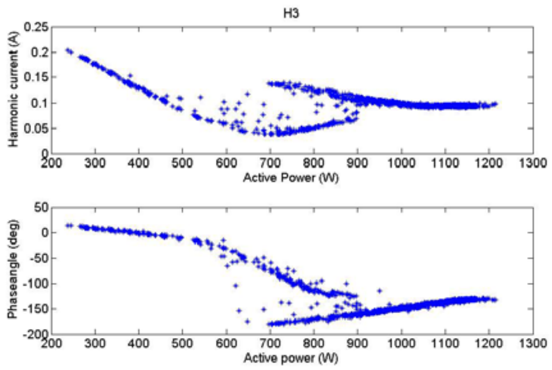

Figure 6 150 Hz component, amplitude and phase angle, at a 1.5 kW single phase connected plant

The third harmonic is the individual highest one for all four plants. For low production the magnitude and phase angle fluctuate some.

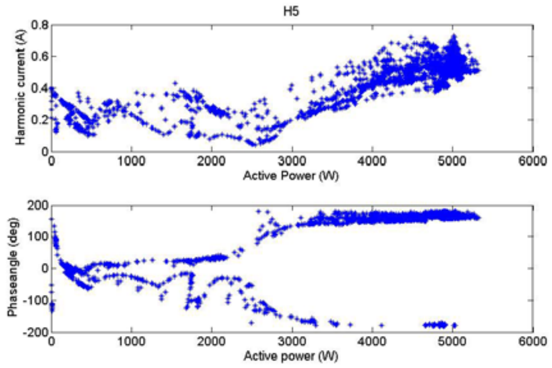

Figure 7 Harmonic five, amplitude and phase angle, at a 20 kW three phase connected plant

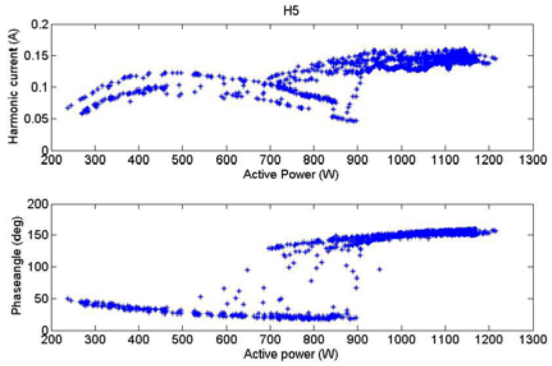

Figure 8 Harmonic five, amplitude and phase angle, at a 1.5 kW single phase connected plant

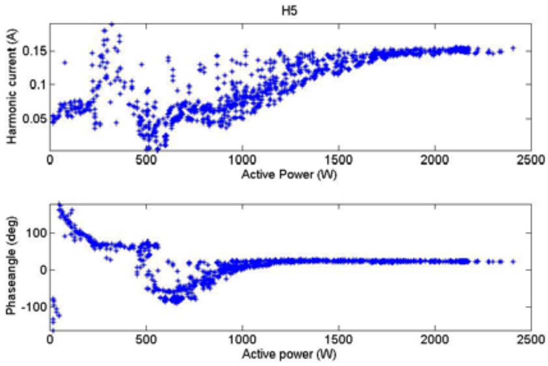

Figure 9 Harmonic five, amplitude and phase angle, at a 2.5 kW single phase connected plant

In Figure 7 to Figure 9 it is seen that for high production, similar to the behaviour of the third harmonic, the amplitude and phase angle for the 5th harmonic remains somewhat constant. As a result, little cancellation between the panels will occur for these harmonics during higher level of production. When the production and the magnitude of the third and fifth harmonic fluctuate, so does the phase angle. The cancellation due to connection of other devices during these times could be bigger [3].

In Figure 10 the seventh harmonic measured at a 20 kW plant is shown. Both the amplitude and phase angle seems to be uncorrelated to the production level. This is more or less the case for all plants measured.

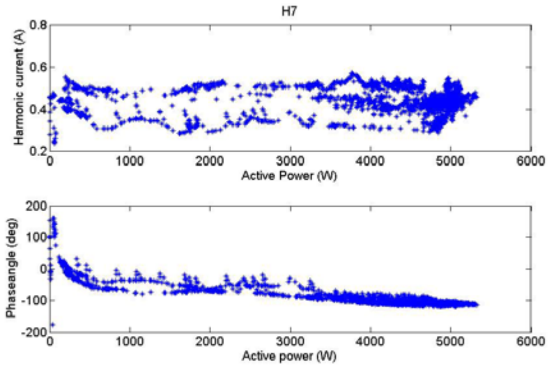

Figure 10 Harmonic seven, amplitude and phase angle, at a 20 kW three phase connected plant

High Frequency Emission

The main contribution to high frequency emission from the PV-installation is primary emission due to residues from the switching in the converter. Measurements at the 20 kW plant reveals that two individual components are present in the current, 3.8 kHz and 4.85 kHz. The 4.85 kHz component has a peak value of 0.26 A, and shows low correlation with the PV-production. This component is due to power-line communication used by the network operator for automated meter reading and appears during instances when data from the meters are pulled. This indicates that there are some interaction between the inverter and other equipment connected nearby [4]. The 3.8 kHz is most likely a residue from the switching since it is always present during production and reaches zero for times with no production. The amplitude of the 3.8 kHz component doesn't increase with increasing production as can be seen in Figure 11 but remains somewhat constant with a peak amplitude of 0.14 A during times of production.

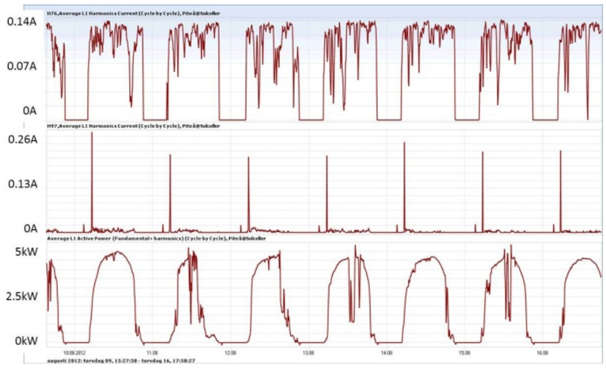

Figure 11 Top; 3.8 kHz component, middle; 4.85 kHz component, bottom; active power. Figure shows one phase during one week.

The strongest high frequency component originating from the single phase 2.5 kW installation is at 16 kHz. In Figure 12 this component is shown for different magnitudes of current. The amplitude of the 16 kHz component show very little variation during production but drops to a value close to zero during times with no production.

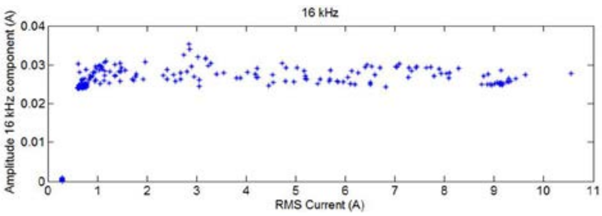

Figure 12 magnitude of the 16 kHz component shown for different magnitudes of rms current measured at the terminal of the PV-inverter.

CONCLUSIONS

Small PV-systems can have a noticeable impact on the voltage at the point of connection. The highest voltage amplitude depends on the size of the solar panel, on the source impedance at the connection point and on other connected loads.

The harmonic emission from PV-plants is relatively low; the highest value found was 5% of rated current. The amplitude and phase angle of individual harmonics varies with production to some extent. The spread of phase angle and magnitude for a given production is small. This indicates that there might only be a small amount of cancellation between individual installations. The emission from one installation might be small, but the joined emission from many installations in a domestic area may potentially be a concern. This calls for further studies.

High-frequency emission is only present when the solar panel is producing power. The emission level is otherwise varying and independent of the power production, which indicates that the cancellation effects between individual installations will be large. PV installations are also shown to absorb high frequency signals present on the grid like power-line communication signals and emission from other sources.

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