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Study Committee C6

ACTIVE DISTRIBUTION SYSTEMS AND
DISTRIBUTED ENERGY RESOURCES

Paper 10827 2022

Power quality issues due to PV integration in distribution systems – Two Swedish case studies

MATTIAS PERSSON and EMIL HILLBERG

Research Institutes of Sweden (RISE)

Motivation

As renewable integration of domestic photovoltaic systems (PV) increases in distribution systems worldwide it is important to study their impact on the power quality closest to the end users. Smart meters deployed today at the end users can be used to estimate the impact of the PV increase. Hosting capacity studies worldwide have shown various impacts depending on system configuration, standards for grid dimensioning and standards for power quality [1], [2], [3], [4]. A substantial overview from issues regarding hosting can be seen in [5] indicating a need for a lot of data when doing time series modelling, especially if 1 s data is needed to get a full view of the situation.

Smart meter data has been used extensively for grid studies in for example [6] indicating the need for accuracy, time synchronization, resolution, and the possibility of use cases for future smart meter variables such as voltage, apart from current hourly energy data.

This paper aims at providing knowledge from two Swedish case studies, based on interviews with distribution system operators DSOs, detailed power quality measurements and hourly smart meter data from two different distribution grids. Several already published methods for increasing the hosting capacity were evaluated, including the alteration of tap-changer setpoints, changing power factor, curtailment, and energy storage. The presented case studies illustrate issues which can arise and suitable remedies in a Swedish (i.e. Northern European) context, considering the questions:

1. How much information do we miss with only hourly data sets?
2. What is the impact of measurement quality for estimates of hosting capacity calculated by DSOs?
3. To what extent can simple solutions be used for allowing additional capacity?

Studied distribution systems

For these studies, information from two distributions systems have been provided by the DSOs. The topology of the two systems, D1 & D2, are presented in Figure 1. D1 is a larger area with 29 connections to customers, including relatively new energy efficient houses where 18 of the houses have a PV installation of 5.4 kWp. D2 is smaller with a set of remote feeders with long distances where connection point 5 has a PV installed capacity of 10 kWp and connection point 6 has an installed capacity of 18 kWp. All PV installations are connected through three-phase inverters.

D1

D2

Dedicated Class A power quality meters were placed on the secondary side of the transformers in both studied systems as well as directly at load points 5 and 6 in D2, and at #31 in D1. Recordings were made for one year, including monitoring of the harmonic distortions in current and voltage (THD_I and THD_V) and the short-term flicker (*Pst*), every 10 minutes in accordance with the IEC 61000-4-30 [7].

Furthermore, active power, reactive power, voltages, and currents for all three phases were provided for approximately one year with a sampling frequency of 1 Hz from all power quality meters.

Data from smart meters from all loads in both distribution systems were also made available for the case studies. Several DSOs also have hourly metering of energy measured down to 10 Wh resolution. Transformer secondary voltage is of great importance to be able to model hosting capacity of a distribution system.

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Measurements and Power Quality

High resolution measurements

In both distribution systems high resolution data series allow for comparisons with hourly data sets. The hourly data sets could, if transformer measurements are lacking, be extracted from summarized smart meter data from the underlying customers. In order to evaluate the information which may be lacking in such smart meter data, analysis have been made using the 1 Hz resolution power measurements from the transformer station and load points at buses 5 and 6 in distribution system D2.

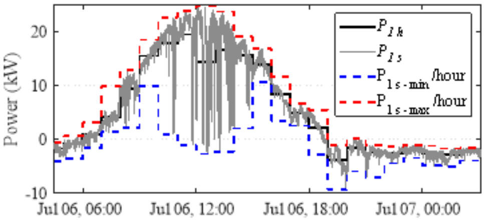

Figure 2. Power measurements and the lack of observability in the transformer at D2 during a sunny day in July when comparing to hourly data sets.

From Figure 2, the hourly average (as could have been provided by smart meter data) is compared with high resolution data for one example day during summertime. Apart from the power sampled at each second, P1s, each hour is indicated with an averaged power, P1h, and the corresponding max/min-power sampled at 1 Hz for that specific hour, P1s-max/hour and P1s-min/hour. As DSOs introduce more smart meters with hourly resolution these can also be used to study the impact on the bus voltage amplitude. However, currently the voltage quality indicator is based around a 10 min average that must be within ±10%. Hence, it is interesting to study the lack of information in the hourly data compared to potential 10 min data.

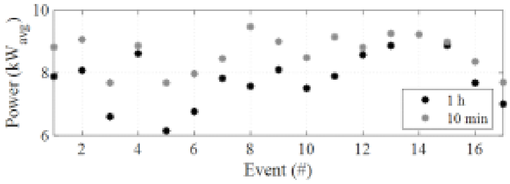

Figure 3. The observed difference in average power when observing a customer with 10 kWp PV with hourly data versus 10 min values for all sunny days during a month.

The current harmonics indicated a filtering phenomena from customer 5 and 6 can be observed in relation to the transferred power through the transformer, see Figure 2. Most recordings from the transformer secondary side experience less harmonics than recording from the customer locations. Furthermore, current harmonics seem to be unaffected by the transferred power. Similar patterns but even lower were seen in D1.

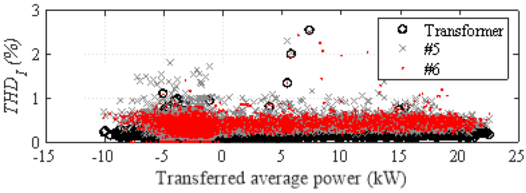

Figure 2. THD_I at various locations versus transferred power in the substation at D2 for one month.

Hosting capacity evaluation

The PV hosting capacity, and how the hosting capacity could by easy means be increased, has been evaluated for the rural distribution system D2. The studies consider maximum bus voltage as the capacity limiting factor, required to be below 1.1 p.u. on all buses in the studied grid. The grid model parameters used, presented in Table I, are based on information provided by the DSO together with assumptions.

Study 1: Maximum level of PV installation, no curtailment allowed

In Study 1, the goal was to identify to which extent the actual PV installations could be increased, while maintaining the voltages within the specified range. It is assumed that curtailing PV is not allowed, instead two type of control actions were considered to increase the PV capacity: tap-changer control and PV reactive power control.

Table I: Hosting capacity levels (PVmax) and resulting system losses, with and without utilising no-load tap-changer (NLTC) and PV power factor (PVPF) control.

Case	Results	
	PV_{max}	P_{loss}
a) Base case (NLTC=1.0, PVPF=1.0)	140%	7%
b) NLTC = 0.95 p.u.	240%	12%
c) PVPF = 0.95	160%	10%
d) NLTC = 0.95 p.u. & PVPF = 0.95	280%	18%

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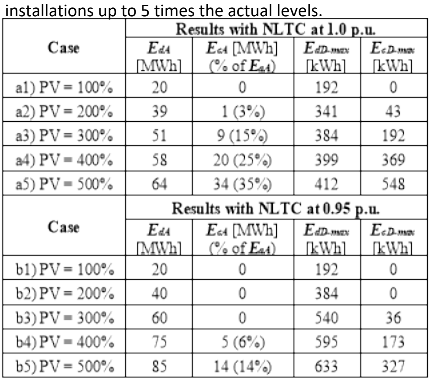
Hosting capacity evaluation, cont.

Study 2: Over dimensioned PV installations, with curtailment allowed.

Table II: Delivered and curtailed PV energy, for PV installations up to 5 times the actual levels.



Case	E_{dA} [MWh]	E_{cA} [MWh] (% of E_{aA})	$E_{dD\text{-}max}$ [kWh]	$E_{cD\text{-}max}$ [kWh]
	Results with NLTC at 1.0 p.u.			
a1) PV = 100%	20	0	192	0
a2) PV = 200%	39	1 (3%)	341	43
a3) PV = 300%	51	9 (15%)	384	192
a4) PV = 400%	58	20 (25%)	399	369
a5) PV = 500%	64	34 (35%)	412	548
	Results with NLTC at 0.95 p.u.			
Case	**E_{dA} [MWh]**	**E_{cA} [MWh] (% of E_{aA})**	**$E_{dD\text{-}max}$ [kWh]**	**$E_{cD\text{-}max}$ [kWh]**
b1) PV = 100%	20	0	192	0
b2) PV = 200%	40	0	384	0
b3) PV = 300%	60	0	540	36
b4) PV = 400%	75	5 (6%)	595	173
b5) PV = 500%	85	14 (14%)	633	327

Table II also shows the PV energy delivered during the peak production day (***$E_{cD\text{-}max}$***), and the maximum curtailed energy during the peak production day (***$E_{cD\text{-}max}$***). These levels are also illustrated in Figure 5, for the two cases with 500% installed PV. These daily energy curtailment needs can be related to the value gained by a daily storage solution for a specific scenario.

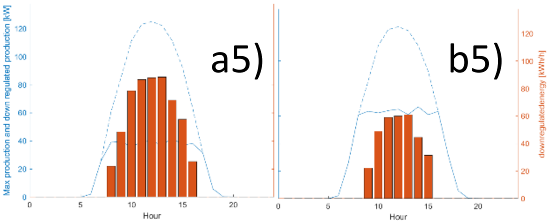


Figure 5: PV production (available and delivered in kW) and curtailed energy (staples, in kWh/h) on the day with maximum solar radiation for case a5 and b5.

Similarly, as in Study 1, the results from Study 2 illustrates the effectiveness of active tap-changer control. Furthermore, when curtailment is allowed, Pmax could increase significantly with only minor needs for curtailment. Without tap-changer control by an additional 60% (curtailing only 3% of the yearly PV energy), or by an additional 160% (curtailing only 6%) if also tap-changer control were used.

Conclusions and discussion

The case studies presented in this paper highlight the value of high-resolution measurement information to study detailed power quality phenomena, however the low-resolution information can be sufficient in many situations if relevant margins are included based on the added uncertainties which this type of measurements bring. There is a value to assess making 5-minute interval data available from smart meters, making the data valuable for power quality monitoring, energy billing, and hosting capacity evaluation.

Harmonics, and short-term flicker (although not presented in this paper) were not an issue in the studied distribution system, and their changes could not be traced to increased production from PV. However, this could be the fault of the chosen indicators rather than the lack of power quality issues. It should be noted that the total current harmonics result in peaks when the fundamental frequency current is close to zero, which can result in faulty analysis of results.

From the studied scenarios it could be seen that setting of tap-changers have significant impact on the power quality and therefore also on the ability of the grid to integrate additional load and/or generation.

It is illustrated that increased utilisation of tap-changer control can significantly impact the available hosting capacity, and investments in on-load tap-changers should be regarded as effective solutions. However, this solution may not always be practically possible, as it also may involve communication to control the voltage on other buses than the local transformer bus. In the studied scenarios, utilising reactive power to decrease bus voltages did not provide much room for additional PV installations, mainly due to the X/R ratio of the studied distribution network.

For a case where curtailment of PV is allowed, a broader perspective is needed to consider the values gained of additional renewable energy production in relation to the investments as well as revenue losses related to the curtailment need and increased grid losses. One may also consider other solutions that curtailment, such as various PV-energy storage solutions