DEFINING REASONABLE PV PENETRATION GOALS – ASSESSMENT OF THE EFFECT OF HIGH PV CAPACITY LEVELS ON LOW VOLTAGE NETWORKS

Noel MICALLEF[1], Manfred WEISSENBACHER[1]

Abstract

We analyzed 33 million residential Smart Meter 15-minute period records for electricity consumption and photovoltaic electricity generation from low voltage (LV) feeders with various photovoltaic (PV) penetration levels. In turn we modeled a range of higher PV penetration scenarios and assessed the effect on the LV network. We found that active power losses decreased in modest PV penetration scenarios, but increased beyond the PV-free scenario at PV penetration levels that do not yet experience overvoltage problems. We thus argue that active power loss might be a reasonable metric to define PV penetration targets that do not require any infrastructure upgrades such as on-load tap changers (OLTCs) or energy storage units.

Introduction

The benefits of high renewable energy shares in terms of climate change mitigation and energy security are well documented and reflected in national renewable energy plans around the world. However, the challenges that intermittent renewable energy regimes may pose to electricity grid operators are likewise known. Photovoltaic (PV) electricity generation may coincide well with mid-day electricity demand, but increasingly high PV penetration levels will eventually challenge grid stability and power quality. In this study we attempted to investigate if a rule-of-thumb can be devised that would allow the grid operator to quickly decide how much PV capacity may be added to a LV feeder under a given demand scenario and PV output profile. The data set used came from the central Mediterranean island of Gozo, which is part of European Union member state Malta.

Methodology

We reviewed and processed 15-minute electricity consumption and PV electricity generation SMART meter data for consumers and producers. We focused on meters ultimately connected to four substations known to experience overvoltage issues, and analyzed the data for the period 01/01/2013 to 30/06/2014. The total number of consumer meters associated with these four substations was 1600, while the total number of PV meters was 157. Since many of the PV systems in these locations had been relatively recently installed, we also used the data from 200 PV meters that were randomly selected from locations all over Gozo to create a generic PV output profile. Data from master meters installed in the substations was available as well.

Based on these data sets a Structured Query Language (SQL) model was developed as a first step. Data sets were subjected to filtering routines to exclude data or meters that showed unusual readings. (Significant NULL records; night-time, unrealistic daytime or significant zero PV output.) Notably, the meters installed in households in Malta do not register reactive power. Resulting standard, i.e. “typical”, 15-minute and 60-minute profiles for each type of consumer meter were then combined in the model with the generic PV output profile and compared to the substation master meter data sets.

More precise models utilizing Geographic Information System (GIS) data and physical network information (transformer and cable characteristics such as impedance, distance, etc.) were designed for two of the four substations’ networks using power systems software DIgSILENT PowerFactory. These models were used for load flow studies. We explored different photovoltaic penetration scenarios to reveal their effects on the LV network and to test compliance with the required standard, European Standard EN50160. From the results we derived a general rule of maximum allowable PV penetration (in absence of any mitigation measures) for the case studies’ given electricity consumption and PV generation profiles.

[1] Institute for Sustainable Energy, University of Malta, Msida, MSD 2080, Malta,
{noelmic@maltanet.net},
{manfred.weissenbacher@um.edu.mt}

Results

The SQL model achieved a close correlation between the sum of individual meters and the associated substation master meters. This model showed instances of reverse power flow during the period April to June around 11:00 to 15:00 at the current PV penetration level for all four modeled substations. The DIgSILENT model was initially built with monthly average hour records (consumer and PV output profiles from the SQL model) and then with actual SMART meter consumption data: the results remained largely the same. In the ensuing load flow analysis it was ensured that the maximum cable current loadings were never exceeded. In the Base Case/"No PV" scenario as well as the Present Situation Scenario (meters @ 31/12/2014) all feeders operated within the ±10% voltage range. In a "Plus 1kWp PV" scenario (for those households that were still without PV capacity), existing substation transformers coupled with load balancing were still able to bring all node voltages within EN50160 limits. In a "Plus 2kWp PV" scenario, transformers had to be replaced to allow for greater tapping flexibility. For one of the substations an OLTC 11kV:400V 9-step tap change transformer was required since two tap changes had to happen during the same month to keep all feeders within limits. (Solutions with energy storage are not included in this presentation.) For the other substation it was possible to avoid the investment into a new transformer by switching the inverters to Q(V) control. Since it was noticed that active power losses increased considerably at high PV penetration levels, instantaneous PV penetration ratios at the feeder level were correlated with active power losses.

As expected, low instantaneous PV penetration levels showed a decrease in active power loss, while a steep increase in losses occurred at a certain, relatively high penetration level. One way of defining a goal for PV penetration that does not require any substantial mitigation efforts is to target the penetration level at which active power losses are roughly equivalent to the "No PV" scenario. We found this level to be reached at instantaneous PV penetration ratios of about 200% in the given setting for the 10 LV feeders investigated (Figure 1).

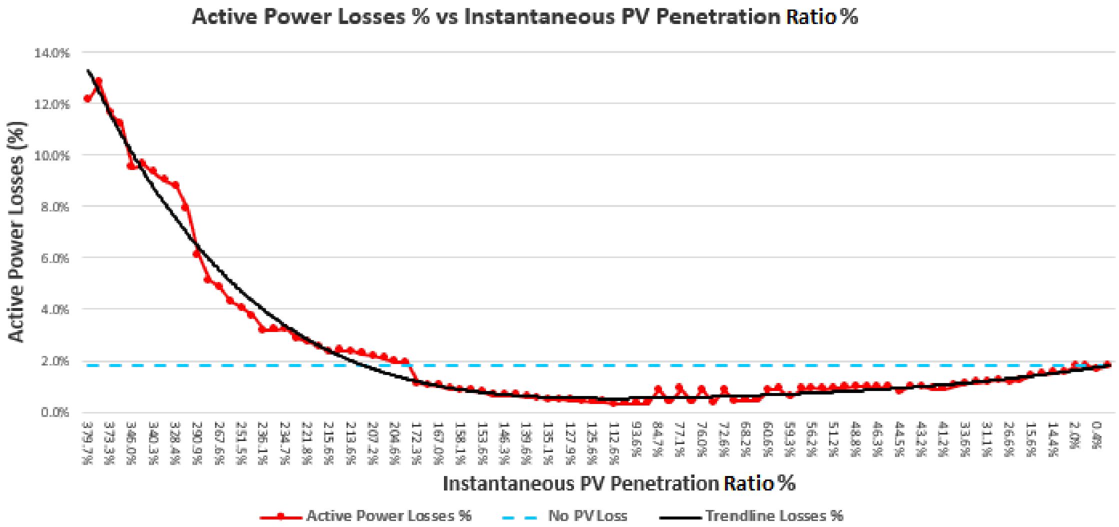

Figure 1: Active power losses decrease below the "No PV" scenario at low instantaneous PV penetration levels, but increase markedly when instantaneous PV penetration ratios above 200% are reached.