Open DSS simulations of power fluctuations induced by rooftop PV generator on a building LV electrical grid

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***Abstract*— The high penetration of photovoltaic (PV) installations in urban areas raises the problem of power quality and voltage stability during external atmospheric fluctuations. Densely populated PV installations, connected in a remote node of the grid may degrade power quality or multiply power fluctuations if not properly designed. Computer simulation of power flows in bidirectional grid can reveal weak points of the grid. It can imply measures for mitigation of fluctuations and creation of algorithms for energy management of future "smart grids".**

This report gives and overview of bilateral impact between decentralized generator and LV grid. Daily profiles of electrical load in a building and generated power are extracted from grid monitoring devices. Based on experimental data software simulations are performed in Open DSS environment - an open-source simulation tool.

***Keywords*— Photovoltaic systems; PV power generation; Impact on grid stability; Smart grids;**

I. INTRODUCTION

In the context of a smart grid and smart office environment, renewable energy resources are getting immensely popular as many homeowners are now opting for renewable energy systems at their residence. This paper addresses the question of RE generators integration at building level by proposing a method to allow integration in an incentive-based office/home energy management (EM) system.

Development of EU Smart Grid Platform requires development of new simulation tools which can correctly describe the Decentralized Power Generation (DG). Integrating the PV plants to grid may reverse power flow direction and at certain moment to send upstream to power line [1]. A high PV penetration may result in voltage drops out of acceptable voltage range. The effect of a drop in solar generation due to passing cloud also has to be taken into account. Individual monitoring unit of grid stability in any inverter have to be adjusted to withstand short interruptions because they may cause a consequence of switch-off of several inverters and thus, bigger voltage instability of the grid. These technical challenges should be predicted and managed smoothly in the grid in order to deliver power with sufficiently high quality.

Recent smart energy systems look beyond the already traditional solar or wind energy. More frequently they use several energy sources in one system which means – new Hybrids and higher energy efficiency. However, energy hybridization in urban area is still a challenge and good practices are expected. We present here small hybrid energy system utilizing solar and wind energy, battery energy storage and grid-connection technologies.

10 kW PV SYSTEM

AcadPV rooftop is a 10kWp PV electricity generating facility connected to LV grid at the main power distribution box of the 1-floor Laboratory building. The PV modules are Isofoton I – 165 Wp, mono-Si and ASE 100Wp, poly-Si separated in 3 PV strings. The PV strings are connected to 3x3 kW single-phase SunPower string inverters. The peak AC load do not exceeds 15 kW during work hours. The minimum daytime load is about 2.0 kW.

During summertime, the PV system power output exceeds the load and it happened to reverse the power flow toward the nearest LV/MV substation. Thus, the PV penetration level defined as total installed power divided by max load would be above 100 %.

Fig.1. *10kWp PV rooftop - general view*

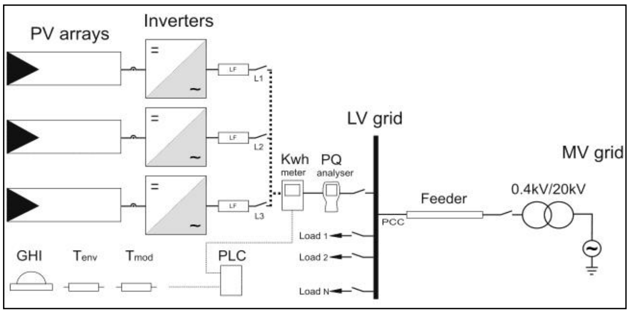

Fig.2. *Diagram of power electrical circuit*

The inverters are linked separately to L1, L2 and L3 grid phases and they are operating independently. Inverter morning start-up and evening shut-down sequences performs at solar irradiation level of about 40 W/m^2. The Laboratory building and the PV rooftop system are situated 150 m far from MV substation and they are supplied independently from other customers by underground LV cabling. No other DG is located on this feeder.

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II. MEASUREMENTTS

The electrical measurements carried out are addressed to observe voltage variations and power quality. The Eac energy from PV is injected to the building main distribution box. A PQ-analyzer collects data for active and reactive power, grid events, THD, PF, etc. The impact on power quality has been investigated at the distribution box in 10 sec resolution by switching–on/off every inverter in phases L1, L2 and L3 successively at full power and disconnecting the 10 kW PV generator from the grid. At noon the AC current injection per phase is above 8 A, which corresponds to approx. 2kW of AC power sudden interruption.

The form of voltage response (in blue color) has an edge (width below 1 sec) with slow increase due to compensating current flow coming from the grid. Obviously, the PV power injection causes voltage drop of almost 0.7 Vac. The effect is similar in switch–on and switch-off direction. Additional harmonics measurements indicate THD harmonics produced by inverters are non-uniform in L1, L2, L3 but exhibits low level of distortions VTHD < 3%, ITHD < 5% with waveform close to a sine wave.

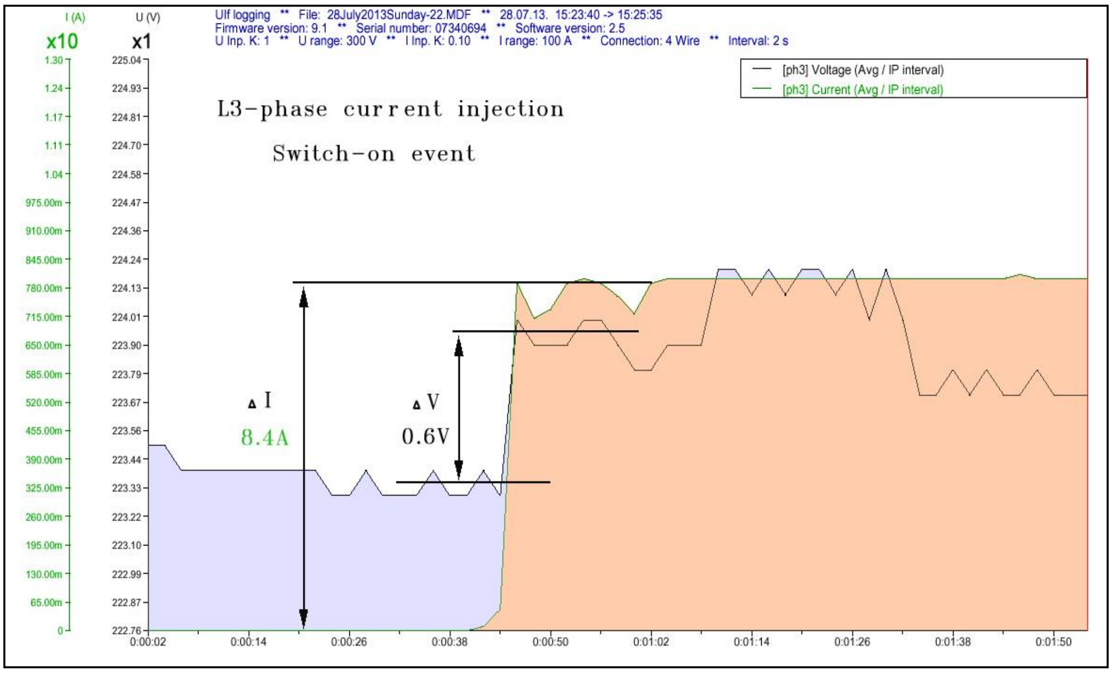
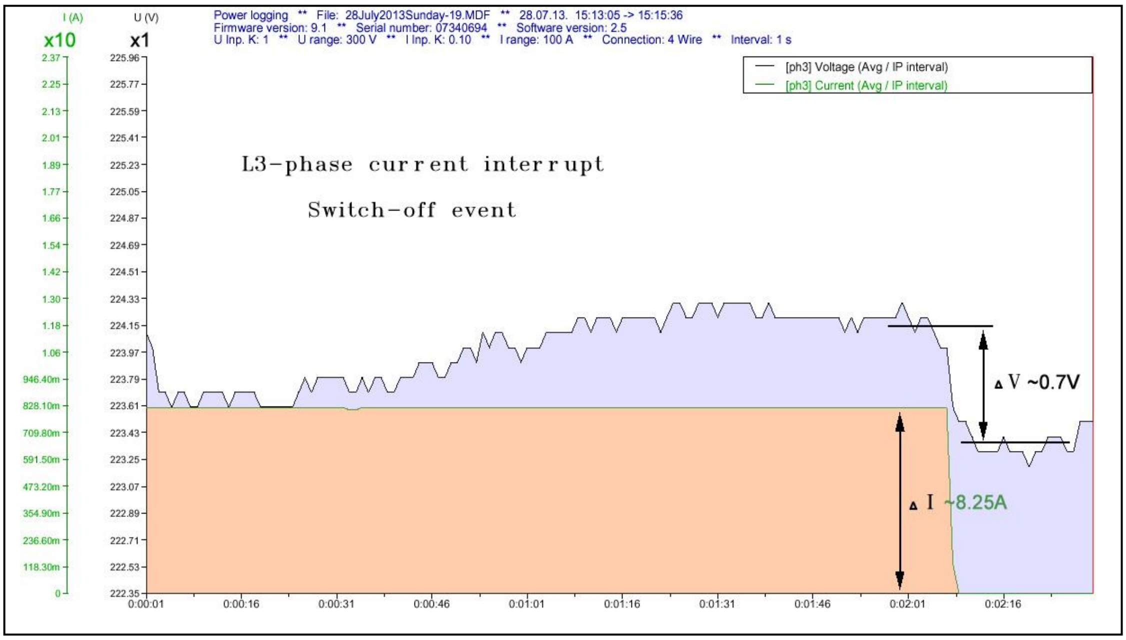


Fig.3. *AC injection switch-on effect*



Fif.4. *AC injection switch-off effect*

III. SIMULATION

Grid behavior simulation needs input parameters as peak demand forecast, layout of the grid, equipment specifications. Controlling active and reactive voltages and powers on each steady-state node, the possible overloads can be identified. The grid node simulation tool Open DSS solves the circuit by using an impedance matrix with a particular current injection method [2]. The advantage of Open DSS software engine is combination of real PV generator parameters (Solar Irradiation, PV power, Inverter Power) together with detailed modeling of grid parameter (MV grid source, MV/LV transformers, feeders, AC loads). Faults and interruptions as well as calculation of cloud passing effects are based on assumption of electricity generation falls down for a seconds and then resumes according to a slope of just a few seconds. If the slope of generation variation is known then the voltage drop on the line can be determined.

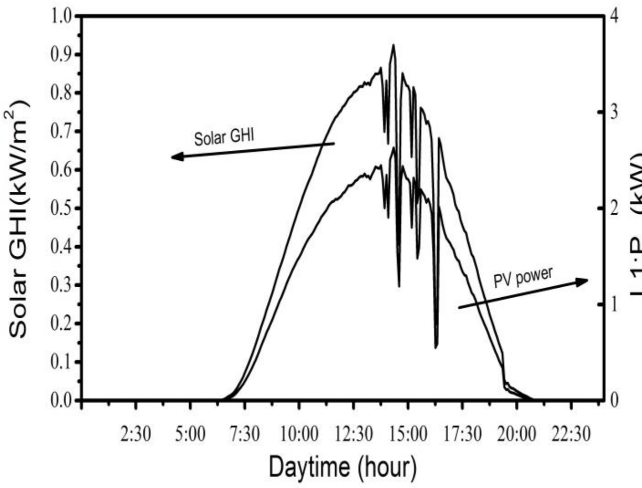


Fig.5. *Solar Irradiation and PV generated power daily profiles*

The coincidence of solar irradiation daily variation and respective PV generated power can be seen at Fig.5. During afternoon, the variation in solar radiation due to clouds is a sudden drop from 900 to 400 W/m^2.This dramatic change has immediately lead to PV power decease from 2.0 to 0.5 kW. Obviously, in small power ranges, small string inverters are highly sensitive to DC input power and AC power injection follows strictly the input power.

The Daily profiles are based on measurement of Solar GHI, T_{module}, $T_{environment}$ at 06 of August 2013 and imported in the simulation as data points CSV files. Different PV generation/Load Demand situations have been simulated by changing AC load from 0 kW to10 kW.

Source and Load Profiles Definition

PV System base kv=20.0 base freq=50
Loadshape. My Irrad npts=288 minterval=5 mult=(file=pvsystem_meteo.csv)
Tshape.MyTemp npts=288 minterval=5 temp=(file=tempmod_meteo.csv)
Loadshape.MyLoad npts=288 minterval=5 mult=(file=pvsystem_load.csv)
Transformer.TR1 Buses=[L1bus, L1subbus] Conns=[Delta Wye] kVs= [20 0.38] kVAs=[630 630] XHL=10
PVSystem.PV phases=3 bus1=PVsubbus kV=0.38 kVA= 10 irrad=1.0 Pmpp=9.6 %cutin=0.1 %cutout=0.1
Load.LOAD Bus1=L2subbus enabled=yes kV=0.38 kW=4 PF=.98 Daily=MyLoad

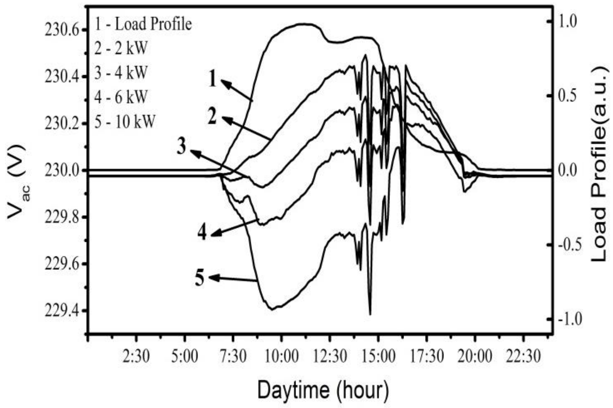


Fig.6. *Modeling of PV and Load Impact on LV grid voltage*

The simulation reveals LV voltage fluctuations ΔV due to variation and time shifting between AC load peak and PV power peak.

HYBRID: PV AND WIND SYSTEM

The prototype system is equipped with 720 Wp PV generators, 600W vertical-axes wind generator along with a battery bank of 2.4 kWh (100Ah, 24Vdc).

PV generator: The generator is configured to supply DC power to intelligent charge controller and to charge 24 VDC voltage battery block. It consists of 3 standard PV modules (240Wp, c-Si) connected in parallel and protected using additional power diodes.

Maglev Wind Turbine: Vertical Axis Wind Turbine (VAWT) combines magnetic levitation AC motor with S-type of Savonius rotor and 3 air-foil Darrieus blades to maximize the electrical output performance. A boosting type wind energy MPPT charger is used to convert AC energy of the rotating motor to DC energy. Maglev generators use magnetic suspension technology based on NdFeB magnets. It creates frictionless, efficient, far-out-sounding motors which provide excellent rotational stability, eliminating vibration, typical wobble, shaking and noise. Unsymmetrical airflows around the rotor are producing the lateral thrust to the turbine blades. It not only has the advantages of traditional VAWT to accept the wind from all horizontal directions, but also the advantages of low threshold starting wind-speed, high wind power efficiency, etc. These advantages are most important factors for urban, highly populated areas with dense buildings where the wind direction is changing frequently and the noise should be strongly reduced.

Intelligent charge controller: Two different type controllers and charging algorithms are combined in one device to charge a battery bank. It main function is to protect the generators and the batteries from malfunctions – overvoltage, short-circuit events, high wind speed limit, overcharging or deep discharging limits.

Grid-connected inverter: A 1000 W DC/AC inverter provides AC power to the building LV grid. It is a high-quality battery, but grid-connected inverter. It fulfills all grid requirements for island protection, true-sine waveform, synchronized to grid parameters – frequency, amplitudes, active and reactive power.

Fig.7. *General view of hybrid (solar and wind) system for building application*

CASE STUDY: Three case studies were conducted to determine the effect of amount of battery power drawn during typical sunny day, windy day and cloudy day to determine a suitable amount of battery power for real case studies.

Case	*Into the grid (from 9.00 to 17.00h)*	*Averages PV prod.*	*Averages Wind prod.*
Case 1: (high solar, no wind) PV and batteries are connected to the system. The demand limit occurs for 3 hours from 17:00 to 20:00. To keep the total consumption below demand limit, the EM algorithm has reduced non-critical loads.	3.6 kW	448 W/h	2 W/h
Case 2: (low solar, small wind) PV and batteries are connected to the system but the battery is not charging. The inverter still injects into the grid. The use of RE system in this case resulted in lower amount of load reduction for shorter periods.	2.0 kW	226 W/h	24 W/h
Case 3: (no solar, middle wind) PV, Wind turbine and batteries are connected to the system but the battery is not charging. The inverter still injects into the grid. The use of RE system in this case resulted in lower amount of load reduction for very short periods.	1.2 kW	20 W/h	128 W/h

Conclusion

The experimental measurements reveal that 3 x 2 kW PV power injection in LV grid of a building can induce voltage drop of 0.7 V per phase. THD harmonics produced by inverters exhibits low level of distortion V thd < 3%, I thd < 5%. Daily behavior of PV generator can be modeled by an open source simulation tool.

At morning and mid-day hours, the load is rather low, the PV power is dominating and the grid voltage is increasing slowly. However, at “peak load” hours the PV generation is not enough to compensate higher AC loads and voltage goes down.

The “picture” gets complicated when passing heavy clouds sharply interrupt PV generation in a minute. The local variation of solar irradiation due to cloud over the PV roof installation is a source of grid instability. Power output fluctuations caused by irradiance fluctuations have been investigated by other authors [3] and analytical correlation between PV plant size and AC injected power has been proposed earlier. In our case, the output power of a single-phase string inverter is close in shape to the modeling curve even in a day with strong irradiation variations. The observed and simulated grid voltage variations are still maintained in the range 229 -231Vac, which means in acceptable range of local grid code. The installed 10 kW PV generator do not saturate the local grid conditions but is capable to reverse the power flow. A small energy storage unit would be preferable for grid stability.

The proposed RE supply system uses solar and wind energy to deliver additional “free” electrical energy to office building at “midday peak hours” or it utilizes the battery bank when PV output and Wind output are not sufficient or not available. This type system provides good stability and constancy of the electrical grid.

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