

RESERVE IRISH DEMO – VIRTUAL OUTPUT IMPEDANCE CONTROL FOR VOLTAGE STABILITY

Sriram Karthik GURUMURTHY, Marco CUPELLI, Antonello MONTI
ACS, RWTH Aachen – Germany
[Sgurumurthy, Mcupelli, Amonti]@eonerc.rwth-aachen.de

Ronan MURPHY, Jonathan SANDHAM
ESB Networks - Ireland
[ronan.murphy, jonathan.sandham]@esb.ie

ABSTRACT

One of the important goals of Project RESERVE (www.re-serve.eu/) is to develop and demonstrate voltage control algorithms for low voltage distribution systems in high RES penetration contexts. On this basis, an impedance based decentralised algorithm to monitor dynamic voltage stability margins and virtual output impedance control is developed. This paper presents the field trials that are planned in ESB Networks, Ireland to validate the technique and the network code proposals derived from the technical work. Additionally, this paper also performs an impedance based stability analysis for an exemplary 3-Node LV network.

INTRODUCTION

The number of renewable energy resources (RES) like photovoltaics (PV) and wind power is growing. Those RES are volatile and mainly employed as distributed generation (DG) on the distribution level and interfaced via a power electronics interface towards the distribution grid. To allow the large-scale diffusion of local energy communities depicted in Figure 1, the power electronics and power engineering communities are facing profound problems, which have to be solved. A photovoltaic power plant was recently reported to suffer from unexplained instability problems characterized by distortions, which can vary within a wide frequency-range [1]. Power quality and stability problems in grid-connected power electronics, such as photovoltaic, wind power and battery inverters have become a serious concern in the field of power electronics. Interaction between the inverter and the equivalent grid impedance has been identified as one of the most likely causes for the reported stability and power quality problems [2]. In the classical scenario, where there are no or very less power electronic converters and where the power flow is unidirectional, the voltage control was performed centrally through tap changing transformers or capacitor banks. The ideology that only the fundamental component (50Hz) would be the major contributor will not be true when the number of power electronic interfaced RES increases. The entire impedance spectrum needs to be considered for accessing dynamic stability. The large substation transformer impedance would not provide sufficient grid impedance to stabilize the grid and the concept of OLTC transformer based

centralized control will not be suitable for maintaining dynamic stability [3].

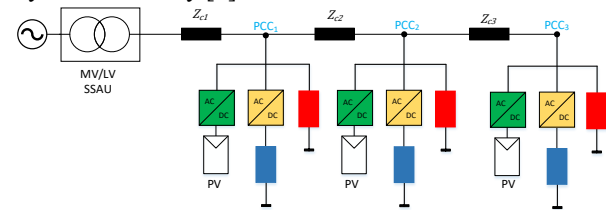


Figure 1 Local Energy Community - PV penetration and Batteries

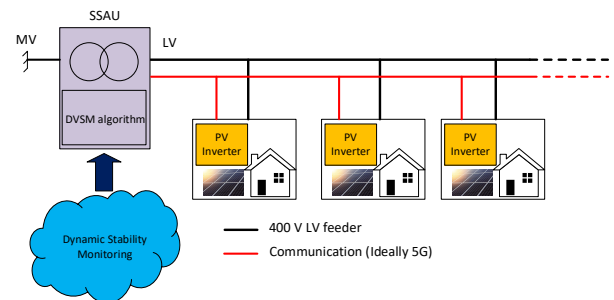


Figure 2 Decentralised voltage control of LV distribution grids

However, power electronics converters still lack the necessary diagnostic tools to identify the presence of impedance-related instability. The output currents and voltages can be monitored and recorded to facilitate post-fault diagnostics. Stability is preserved if the inverter impedances are shaped to remain passive [4]. However, the grid impedance varies over time and may experience multiple resonances, which makes impedance design of grid-connected converter a challenging task. Moreover, the inverter impedance is affected by control delays and necessary control functions, such as grid synchronization using a phase locked loop (PLL), which may introduce negative resistance-like behavior [5]. A small stability margin may cause poorly damped oscillations in grid current and voltage during faults and transients, whereas, zero or negative stability margin causes instability. Our proposal is an impedance-based analysis, which is to enable more informative monitoring and diagnostics, since the stability margin can be directly visualized from the return ratio of the grid and inverter impedances, equivalently represented through the Nyquist diagram in Figure 3. The method has its origins from DC Shipboard

power systems, which are pure power electronics, based systems and a microgrid, exhibiting already the behavior, which future microgrids and power electronics distribution system will show [4].

In this paper a decentralised online stability analysis method is proposed and the basic architecture is shown in Figure 2. This method will help to identify and mitigate the resonance phenomenon which leads to instability. The method is implemented within the control system of grid connected converter without the need of additional sensors. The measured impedance is used to plot the ratio of inverter and grid impedance in real-time. This is then sent to the SERVO platform of ESB Networks allowing online monitoring of stability margin. The SERVO platform, allows energy actors the greatest possible freedom to control generation and load without compromising network existing performance and integrity. The platform is being developed by ESB in Ireland. The proposed method is based on injection of a pseudorandom binary-sequence signal (PRBS) [6]. The PRBS is a wideband perturbation with controllable frequency resolution and power spectrum. Moreover, the maximum amplitude of the PRBS signal can easily be controlled.

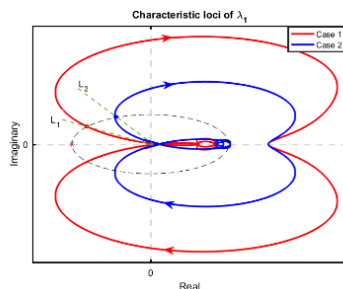


Figure 3 Nyquist diagram to show the impact of grid impedance on stability margins

IMPACT OF HIGH RES PENETRATION IN LV DISTRIBUTION SYSTEMS

A typical low voltage (LV) distribution grid consists of a secondary substation automation unit (SSAU) to which residential households are connected through a radial feeder. At present, OLTC based centralised solutions are applied for steady state voltage control. Considering the paradigm shift in the nature of LV distribution systems, the challenges that are most likely to be encountered are briefly discussed in this section.

Parallel resonance

Parallel operation of tightly coupled PV inverters leads to a possible overlap of closed loop output impedance spectrum in a certain range [1], [2], [3]. This can cause multiple resonances to occur at high frequencies possibly leading to oscillatory modes or unstable modes.

Constant power loads

With more investments in development of DC technology for households such as illumination and motor drives, a solution towards hybrid AC/DC homes

or complete DC homes are on the outlook. Typically, studies on DC nano grids are carried out, where active rectifiers interface the DC nano grid with the utility [7], [8]. From the AC grids perspective, these loads are constant power loads. Constant power loads are non linear and they affect the stability margin of the system due to their destabilising nature [3].

A simulation test case is conducted on an exemplary 3-Node LV feeder and the impact of control parameters on bus voltage stability is studied. Figure 3 and Figure 4 shows the stable and unstable scenario respectively. Figure 5 shows the characteristic loci of the return ratio impedance matrix for the two cases. In the unstable case, the return ratio matrix has unstable modes, but the characteristic loci does not have any counter clockwise encirclements of the critical point $-1+j0$ indicated in red. Thus, the closed loop system is unstable. For the stable case however, there are no unstable modes in open loop and there are no encirclements of the critical point, hence stable in closed loop.

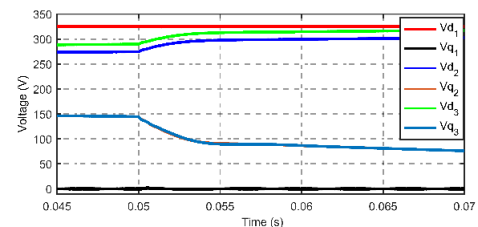


Figure 4 Stable case: Inverter Voltages

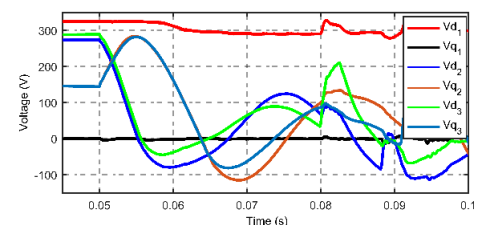


Figure 5 Unstable case: Inverter voltages

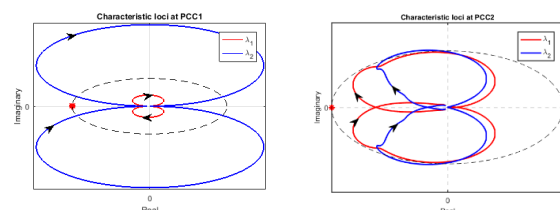


Figure 6 GNC based stability analysis: (Left) Stable, (Right) Unstable

DYNAMIC VOLTAGE STABILITY MONITORING

The Dynamic Voltage Stability Monitoring (DVSM) is a decentralized approach for the monitoring of dynamic voltage stability margins for LV distribution grids. The method heavily relies on ICT infrastructure ideally requiring communication systems with very low latency. DVSM

is an impedance based monitoring tool which is based upon the generalisations of the Middlebrook criterion for three phase AC systems, formally referred to as Generalised Nyquist Criterion [9], [10]. Impedance transfer function of the grid and the inverter from the point of common coupling is required to calculate the stability margins of the system. While the impedance of the inverter can be derived mathematically, the grid impedance computation requires further hardware. The Wideband System Identification (WSI) tool is used to measure the grid impedance. By perturbing the grid injection current and the voltage at the PCC by injecting a PRBS signal at the controller of the converter, the grid impedance can be effectively measured. Upon calculation of stability margins at a given PCC, the SSAU decides whether to take control actions or not. When the dynamic margins are low, the desired impedance of the inverter is calculated at the SSAU and sent back to the VOI controller present in the inverter hardware.

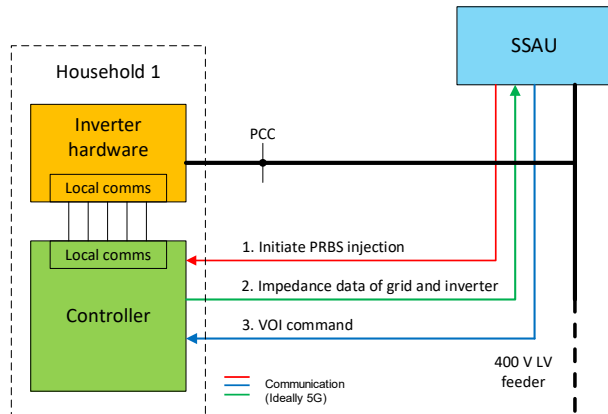


Figure 7 Dynamic voltage stability monitoring technique

The three step process of the DVSM technique as shown in Figure 7 can be summarised as follows. The first step is the initiate noise injection command from the SSAU to the inverter. Following which the inverter measures the grid impedance and estimates its output impedance. In the second step, the inverter hardware communicates the impedance data to the SSAU. Following which the SSAU calculates the dynamic stability margins and VOI command. The third step is where the SSAU communicates the VOI command back to the inverter. This completes 1 computation cycle of DVSM for 1 household, let's denote it as t_p seconds. This process is repeated for every household with RES inverter, one at a time. The time period t_p and the number of houses N under a given SSAU is a crucial factor in determining the number of cycles of DVSM (denoted by f_{dvsm}) that can be performed for a given LV distribution system in 1 hour, which is given by (1).

$$f_{dvsm} = \frac{3600}{N t_p} \quad (1)$$

The algorithm envisions to use 5G technology. Tests will be performed with the DVSM algorithm and the

goal is to determine the latency when using 5G and determine the number of cycles that can be completed in an hour.

VIRTUAL OUTPUT IMPEDANCE CONTROL

The desired output impedance of the inverter is computed in the SSAU based on the grid impedance measurement such that the system is stable and the stability margins are above defined thresholds. Altering the output impedance of the inverter is basically done in two ways: with control parameter variation and active damping techniques.

VOI with control parameter variations

In the literature, it was shown that the inverter output impedance is affected by setpoints of real and reactive power in a power controlled inverter, proportional and integral gains of the inner (current/voltage) controller and gains of the PLL [5], [12]. Therefore, developing systematic procedures to alter the above mentioned parameters helps in shaping the output impedance of the inverter.

VOI with active damping techniques

Another approach shown in the literature is to apply active damping techniques to the output filter in order to damp the resonance peaks [13]. The capacitor current is measured and the stability of the converter and the harmonic suppression can improve significantly when active damping techniques are applied [14]. In this approach, systematic procedure to compute damping impedance is required.

RESERVE aims to develop novel and systematic procedures to design the VOI for the RES inverter. Once the desired output impedance of the inverter is designed, these parameters can be sent from the SSAU to the inverter hardware using 5G communication.

IRISH VOI FIELD TRIAL

The objectives of the field trial are to test the effectiveness of the WSI tool by examining the quality of extracted impedance, validate the DVSM algorithm and validate LV network codes that are proposed in the project. The field trials would provide feedback to further improve and modify the DVSM algorithm to realise practicability in the foreseeable future. The field trials are planned to be deployed in the 38/20kV substation of ESB Networks, Ireland as shown in Figure 8. The tests will be conducted in the 400V section in the second half of 2018. The setup of field trials are shown in Figure 9. A high bandwidth, low power inverter is under development at ACS, RWTH for this purpose to enable measurement of impedance achieving ranges of 20-30 kHz. The inverter is equipped with WSI tool and VOI controller. The LV network under test is isolated from the MV network using isolation transformer to create a controlled area where the raw impedance data

can be precalculated. The inverter uses its WSI tool to inject the PRBS noise and calculate the grid impedance practically. The measured grid impedance will be used to compute the stability margins and an optimal VOI controller with post processing. The added new functionality of inverter serves as an ancillary service to DSOs of the future and this aspect will be validated in the field trials.



Figure 8 38/20 kV 'Burnwood' GIS Substation in ESB networks

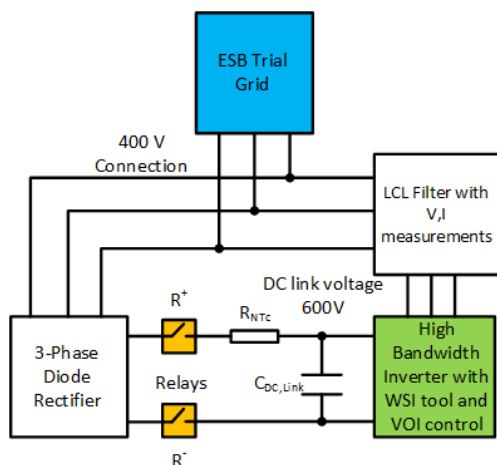


Figure 9 Field trial setup

CONCLUSION

The paper shows instability effects in a local energy community and proposes the DVSM algorithm to monitor the stability margin and to allow control actions to be performed to improve the stability margin. Field trials are to be conducted in the Irish test grid at ESB Networks for validating the concept and to determine the implication of the new technique on network codes and ancillary services. This paper reports the planned activities pertaining to Irish VOI field trials.

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