CONTROL ARCHITECTURES TO PERFORM VOLTAGE REGULATION ON LOW VOLTAGE NETWORKS USING DG

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ABSTRACT

Increasing levels of small scale generation units connected to lower voltage levels are causing problems on distribution network operation. The implementation of smart grids enables the operator to have an extended view over the system operational parameters and even to control active participants (loads and generators).
Voltage profile volatility is one of the main problems associated with DG units connected to LV networks. The adequate architecture, technical requirements and algorithms for voltage regulation are addressed on this paper.

INTRODUCTION

Distribution system is becoming more volatile than ever. Several different actors are introducing more unpredictability on network operational parameters. Various customer types with high diversity factor establish the base load of the system. However, the installation of new micro/minigeneration units is being incentivized and several consumers are also becoming producers at lower voltage levels. To be able to control all these participants and optimise network operation, smart grids introduce the distributed intelligence and communication capabilities to enable smart control schemes. The Distribution System Operator (DSO) has now the possibility to interface with field equipments and even low voltage loads and generation units through their communicative equipment interfacing with inverters and controlling its power output.
Moreover, voltage profile volatility is one of the main problems of weak radial networks which is a common characteristic of LV networks. This issue is even more aggravated with DG units connected to LV networks.
Voltage magnitude must be maintained within the statutory limits at all times. Voltage regulation is therefore considered one of the basic operational requirements of power systems, both at transmission and distribution levels. As the voltage level decreases, the variations of voltage profile increase and this issue can be even more severe on weak networks. Low voltage networks are mainly radial with high R/X ratio making them prone to voltage drop/rise problems. These can be aggravated if DG is not carefully integrated on the network. Also, since LV loads are predominantly single-phase, DG units with low installed capacity (up to 3.68kVA in Portugal) can also be connected to the same phase. This can create potential problems of high unbalance factor on the network [1].

CURRENT VOLTAGE REGULATION

European electricity supply regulations (EN 50160) stipulate that steady-state voltage magnitude for low voltage systems should be 230/400V ±10%.
Traditionally, voltage regulation is done through On-Load Tap Changer (OLTC) using AVC relay at primary substations, reactive power injection at HV or MV network using capacitor banks or topology changes leading to load transfer between substations. However, these control options are not available at LV network since transformers only have off-load tap changers, reactive power does not have a significant impact on voltage control since the physical network characteristics dictate that R is predominant over X and LV system usually does not have remotely controlled switches. Therefore, only controlling load and active power injection, can voltage be kept within regulatory limits. Moreover, if a feeder coming out of a primary substation has several DG units presenting a rising voltage profile and the neighbour feeder has only loads and no DG with voltage decreasing along the feeder, primary transformer OLTC could face conflicting objectives.
When the voltage profile reaches the statutory upper limit, individual protection of DG units will trip for overvoltage. When this happens, it is likely that other DG units on the same area will sense the same problem causing their protections to also trip. If a cascading series of DG are disconnected from the network at the same time, a sudden voltage drop can be felt.

IMPACT OF DG ON VOLTAGE PROFILE

When there is a high penetration level of DG, voltage tends to rise [1][2]. If the upper limit is reached, the individual protections of each generating unit trip. On the other hand, if there is a sudden decrease in the injection of power due to intermittency of renewable sources, voltage decreases rapidly. If lower voltage limit is reached, then the generating unit protection is also configured to trip causing the voltage to drop. This propagates through the network causing other units to trip aggravating even more this problem and further reducing system voltage.
Until a few years ago, the main function of the power electronic generating devices used in DG was to inject

the maximum active power into the grid with a power factor very close to unity. Currently, the DG generation devices are equipped with mechanisms to limit the contribution for this voltage rise profile, namely, the output power limitation and reactive power control regulation. The limitation of the output power can have a noticeable negative economic impact, from the producer perspective. This impact is dependent of the type of installation, local distribution network and load conditions, but usually is more perceptible in PV installations. The reactive power control regulation is another method that is implemented on some generating units. This feature implies an oversizing of the generation unit, to support the reactive power control injection. As a consequence, the losses on the distribution network will be higher on this mode of operation. These approaches don't take full advantage of the power electronics equipments capabilities, as there is no integrated control of the distribution network.

On the other hand, the Maximum Power Point Tracking (MPPT) algorithm of modern DG inverters operates regardless of the grid, feeding active power in order to maximize energy production and monitoring the voltage level. Currently, the control strategies are implemented without modelling the grid impedance values and demand profiles at the injection point, thus providing conditions to allow voltage profile to rise above operational standard limits.

Also, the fact of several generators being connected to the LV line, working independently and with different input energy conditions, can cause voltage transients derived from line impedance and different power/energy conditions [3]. These conditions lead to exceed the overvoltage and undervoltage limits affecting both consumption and energy production.

This case is more critical in PV installations with tracking systems due to almost constant power output. Figure 1 shows an example of the power output of a real PV system.

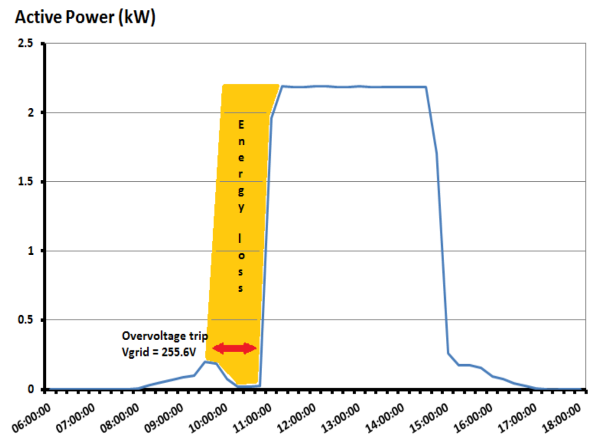

Figure 1 - Photovoltaic system with tracker, 3.68kW PV module on 20/01/2012.

It can be seen that a voltage trip occurred at 9:30am originating the loss of the correspondent energy not injected on the network. This disturbance was caused by an overvoltage from the grid where voltage reached a value of 255.6V causing the protection to trip. This situation had a duration of 75 minutes accounting for 2.75kWh not injected on the network and, hence, not billed to the microgenerator's owner. This is roughly 30% of the daily energy produced. Also, from the system perspective, it is a loss of 2.2kW peak of active power for a single DG unit.

LV CONTROL STRATEGIES

Today, equipments are already being used in Europe [4][6] to grant MV/LV distribution stations with supervision and remote control capabilities, thus bringing automation and management features to the neighbouring of LV network segments and also to manage data and communications from smart meters

A controller of this kind (DTC – Distribution Transformer Controller) has plenty of computational resources to deal with LV consumption and microgeneration, including supervising and managing the topological status and the related operational values of LV feeders.

At LV level, DG's power electronic converters play a passive role, as they inject as much power as they produce, with no particular real time tuning of their generation as network conditions could dictate.

But power electronics technology can drive the real time converters response, provided that the desired active and reactive power references are available for their algorithms.

These set-points can be calculated locally at the MV/LV secondary distribution substation by the Distribution Transformer Control (DTC) and coordinated centrally by mechanisms running at the SCADA/DMS level [5]. These set-points are sent to the DG controllers via the smart meter associated with the generating unit (to measure energy produced in order to be billed), using existing communication infrastructures typical of a smart grid, featuring standard protocols and different technologies (RF, PLC, GPRS, ZigBee, etc.) [6].

The Renewable Energy Source (RES) converter integrates the active and reactive power reference in its dynamic control algorithm allowing a fast and distributed regulation mechanism. This control must take into consideration the market conditions that enable the DG unit to optimize the economic return of the investment.

Although DG economic performance relies only on the amount of energy injected in the network, some regulatory flexibility should then be considered for allowing that one or more DG units could be temporarily affected for the benefit of the voltage profile of the network area where they belong, which is also a regulatory goal.

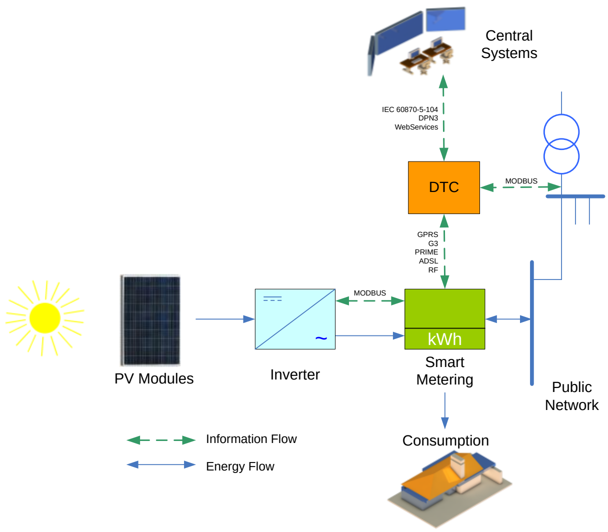

Figure 2 – Technical architecture for local voltage regulation

An integrated approach to these micro/minigeneration units must then be considered since an effective control would coordinate several units in the same geographical area. The VPP (Virtual Power Plant) [7] approach allows the implementation of block coordination in order to achieve the desired voltage regulation for a specific part of the network using microgeneration control complementarily to Demand Side Management set-points for load control, especially during more severe network conditions, such as contingencies, or preventively, anticipating them.
The implementation of this kind of control architectures allows performing voltage regulation at the MV/LV substation, improving the overall stiffness, meeting network regulatory requirements.
Such strategy must take into consideration the fact that the network model and the data volume will reach another magnitude level, since new network components need to be recognized at that level, e.g. consumers and micro-producers.
At each DG unit of a specific LV feeder, there would be dynamic P and Q reference settings able to be dynamically set by the DTC via the smart meter. The DTC would then have to consider the real time conditions of its downstream consumer loads, in particular the voltage level at each node and the power flowing across the feeder segments.
Some kind of autonomy is expected to be granted to DTC, since the control scope is limited. The set-points are calculated depending on the locally measured real-time voltage profile, the information from smart meters on the network and assessing the position on the feeder the DG unit is installed. In case this unit is near the secondary substation, its impact on voltage profile is different from a unit located at the end of the feeder. Therefore, set-point with voltage reference to be sent can be different for each inverter depending on a sensitivity analysis carried by the DTC.
As the DTC itself represents a dynamic node for the MV network, it plays an important role for adapting the power consumption and injection it supervises. At this level, the DTC would respond hierarchically to the Control Centre set-points, under the mentioned VPP model, executing orders from the operator and/or SCADA/DMS applications tuned also for MV networks, these also possibly including DG, where these same principles could apply.

IMPLEMENTATION EXAMPLES

The following case shows a 3.68 kW PV generator with the traditional scheme.

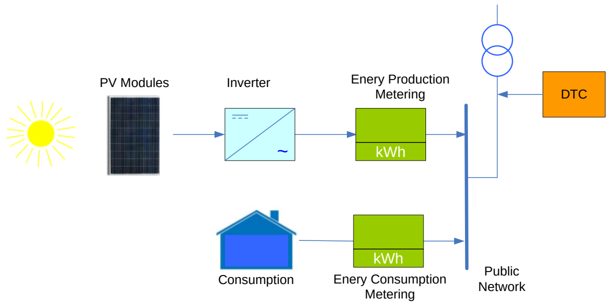

Figure 3 – Current implementation architecture in Portugal

The grid voltage and the produced power profiles registered at the generator smart meter can be found in figure 4.

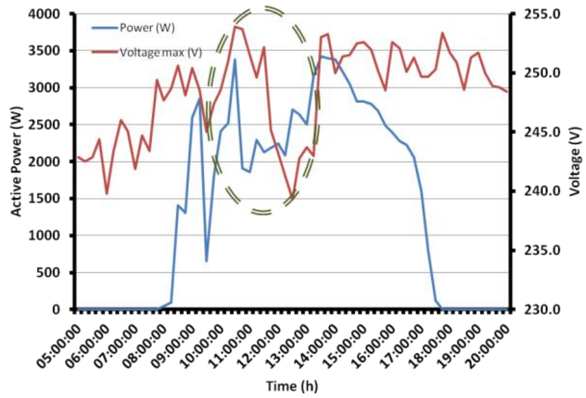

Figure 4 – 3.68kW PV output with set-point control actions

Since no coordination exists the voltage profile crosses the over/under voltage limits causing problems in the connection point and adjacent grid nodes.
Voltage problems are known for being local; meaning that in a certain area, the problems felt by one unit would probably cause a similar disturbance on the nearby DGs. Therefore, if generation level is high and demand is low at some point in time, voltage rise is felt and can cause a cascading series of events, disconnecting several DG in a short time. The operator

sees a sudden demand growth at the MV/LV substation causing volatility on network operation parameters. Furthermore, legislation [8] imposes that DG can only be connected 3 minutes after voltage has been re-established and is stable. This is a serious limitation to voltage regulation.

The implementation of local interfaces and control of DG creates conditions for mitigating this occurrence. On this specific example, Figure 4 shows the power output and the network voltage profile for a weekday of February 2012 of a single-phase 3.68kW PV plant installed in a controlled environment (weak network). It can be seen that voltage follows production, peaking when production output also peaks (due to intermittency) but never reaching statutory limits. An exception occurs on the signalled zone with a dashed circle (from 10:30am to 1pm) where control actions to limit power output were sent to the inverter. This was due to the voltage value reaching the upper limit 253V (V_n +10%) but before the overvoltage protection tripped. The set-point was received by the inverter reducing the active power output about 40% leading to a local voltage drop.

This example illustrates how control actions can avoid a total curtailment of the PV unit by limiting its output and maximizing their contribution to voltage regulation and economic viability.

CONCLUSIONS

Low voltage networks face voltage variations responding to local loads and generation. These are one of the main problems associated with DG units that have protections for over/undervoltage. The microgenerators are then curtailed when voltage reaches the statutory limit $\pm$10% of the nominal voltage. The adequate architecture for voltage regulation was presented and the methodology for local voltage regulation was explained. Set-points are calculated depending on real-time local measurements of voltage at the LV/MV substation, information from the smart meters and location of the microgeneration unit. The DTC will then send the set-point to each smart meter connected to the DG inverter. An example of the control actions was given limiting the output of a PV installation before the tripping of the overvoltage protection. This way, there was no energy lost and the DG was maintained connected to the grid.

This control structure may also evolve and integrate new strategies to improve grid stability, contributing for the sustainable DG penetration, supporting other ancillary grid support services, for instance, anti-islanding detection methods based on communications, or improved LV fault ride trough capabilities. Together with flexible loads, the VPP concept can be implemented at the DTC level enabling new and advanced control capabilities to distribution networks.

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