INCREASED HOSTING CAPACITY BY MEANS OF ACTIVE POWER CURTAILMENT

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ABSTRACT

Active power curtailment is already in use and is also finding its path into national regulatory frameworks. One of the advantages of active power curtailment of fluctuating distributed energy resources, e.g. photovoltaics, is to increase the hosting capacity avoiding or postponing network reinforcement, or to avoid the disconnection of inverters due to overvoltage tripping. Active power can be limited to a fixed percentage of the nominal power (e.g. 70 %) or voltage-dependent (VoltWatt control). In this paper the fixed curtailment is compared to VoltWatt-control. First, an approach to compare the curtailed energy for the two approaches is presented followed by an evaluation of their effectiveness and impact on the yield for installations in six different countries. Finally, a high PV penetration scenario is simulated on a sample LV feeder and main conclusions derived.

INTRODUCTION

The steadily increasing number of distributed energy resources (DER), particularly in low voltage networks ([1]) is a challenging task in terms of cost-effective network integration. Due to a rather high simultaneity factor of DER infeed within a limited area (e.g. photovoltaics (PV) or wind power), the hosting capacity of distribution networks is quickly exhausted in some regions (due to the over-loading of some networks assets or violation of voltage limits, especially in rural areas). Smart solutions can be interesting as an alternative to costly network reinforcement [2] which would only be necessary for a few hours in the year. In recent years, several alternatives to network reinforcement were developed and tested in the field (e.g. reactive power controls, on load tap changer, etc.) [3]–[6]. The benefits of reactive power control are mainly determined by the R/X ratio which is known to be unfavorably high in distribution networks. For example [7] mentions a reachable compensation of the maximum voltage rise by 20 % for a 150mm² AL cable and 30 % for a 70mm² AL overhead-line. In order to reach a further reduction of the voltage rise, a combined active/reactive power control strategy seems natural and has been recently introduced in the Austrian connection guideline [8].

GENERIC INVESTIGATION OF ACTIVE POWER CURTAILMENT OPTIONS

Active power curtailment is suitable to ensure that the voltage rise does not exceed planning limits and that the disconnection of inverters is avoided (soft instead of hard curtailment [9]). In this section, the fixed curtailment and the voltage dependent curtailment are presented, followed by a worst-case comparison. Nevertheless, the curtailment of active power is a sensitive and complex issue due to the preferential treatment of renewable generation in energy markets and on the fluctuating nature of renewable generation [10], [11].

Fixed Curtailment

A fixed curtailment control limits the injected power to a pre-defined threshold level (e.g. 70 % of the nominal power), which is the very basic form of curtailment. However, the network conditions (e.g. voltage) are not considered at all, which means that more power might be curtailed than necessary. In Figure 1 the duration curve of an exemplary PV installation is depicted. Thereby, the green dotted line indicates the 70 %-threshold of the fixed curtailment. From network planning point of view, under such conditions the power used for the connection assessment can be reduced to 70% of the nominal power, hence increasing the hosting capacity of the network. In fact, the hosting capacity can be increased by approximately +42% (1/0.7) assuming a linear relation between power and loading or voltage rise.

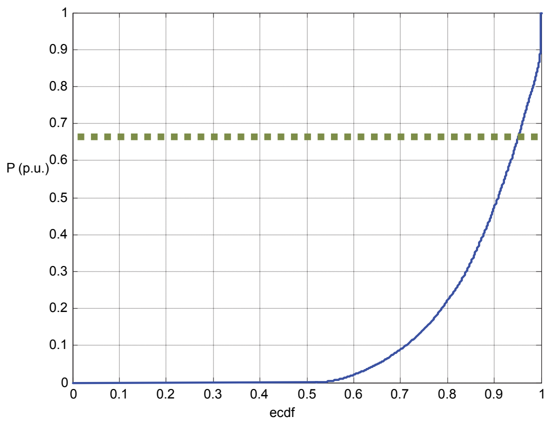

Figure 1. PV duration curve and fixed curtailment

VoltWatt-control

The VoltWatt-control curtails the infeed of an installation according to the voltage situation at the point of connection. It has been identified as one of the most promising solution to increase the hosting capacity in the project IGREENGrid [12]. Furthermore, the VoltWatt-control was recently introduced as functionality to avoid “hard-curtailment” [8] in the Austrian connection guideline. Figure 2 shows the VoltWatt-control function. The VoltWatt-control may be influenced by several factors. First, the local load situation has a balancing effect on injected power leading to a lower or even no voltage rise. Accordingly, full power can be injected when the consumption of nearby loads is high enough. Second, the voltage rise caused by the installation depends on the resulting network impedance at the connection point. Compared to a fixed curtailment, these factors are rather hard to consider and lead moreover to the problem of unequally curtailment depending on the position of an installation in the network.

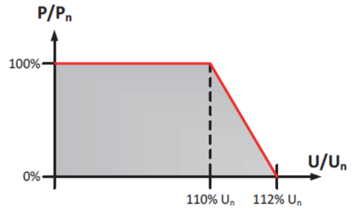

Figure 2. VoltWatt-control [8]

Comparison of the curtailed energy

The comparison of the curtailed energy under a fixed curtailment regime and a VoltWatt-control is rather complex since it depends on the particular network situation (network strength, impact of loads…) and that the available power is unknown and not easily measurable. Therefore, a worst case assumption is necessary, considering that the VoltWatt-control cuts off the full theoretically available power during activation. With this approach, the curtailed energy obtained under a fixed curtailment regime (e.g. 70 %) can be transformed into an equivalent activation time. Figure 3 shows this equilibrium for a given PV duration curve. In this depicted example a VoltWatt-control may be active for 0.25% of the time of a year (approximately 66 hours) and is considered to curtail 100% of the installed power to reach the same amount of energy as the fixed curtailment (with a curtailment to 70 % of the nominal power). Under these assumptions, the highest feed-in power with a VoltWatt-control would be 90 % of the installed power (see Figure 3). This value may be interpreted as highest infeed power (compared to the 70 % threshold of the fixed curtailment).

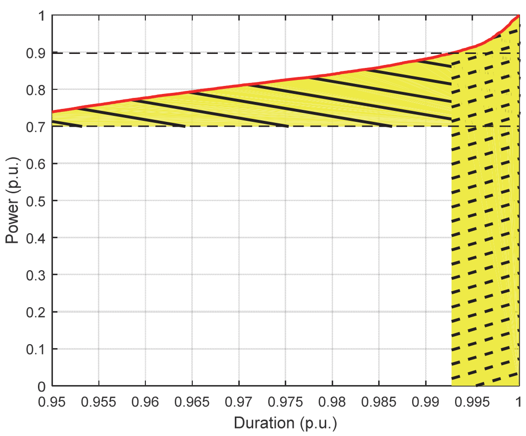

Figure 3. Curtailed Energy Equilibrium

Comparison for different countries

There are several factors that are needed to be considered to compare the curtailment of the presented options. One important issue is the duration curve of photovoltaic production which varies depending on the location, tilt, orientation, shadowing effects, thermal conditions, etc. of the installation. In Figure 4 the duration curve for 6 different countries is depicted (5-min average values during a year) [12]. While the annual yield in Mediterranean countries is of course higher, high output power levels are more seldom. In Austria and Germany for example, the power values close to the maximum power occur more often.

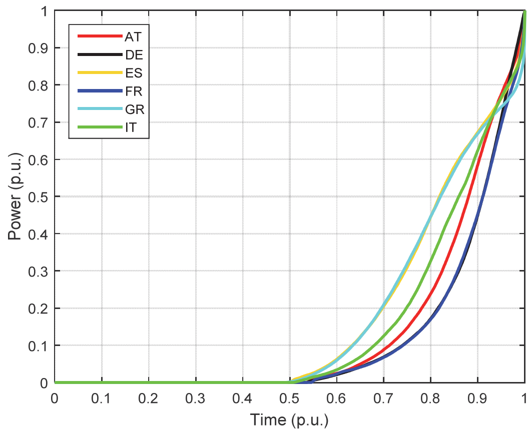

Figure 4. PV duration curves

The presented comparison method was performed for the duration curves depicted in Figure 4.

Table 1 shows the results of this comparison. The curtailed energy under a fixed curtailment regime varies between 2.9% (Greece) and 6.7% (Germany). The reader should note that the installations used for this study should not be considered as representative for the countries. With the method presented in the previous section, the curtailed energy obtained with a fixed curtailment can be converted into operating hours for a VoltWatt-control. The operating hours vary between 50 hours (France) and up to 81 hours (Austria). In analogy to Figure 3, the resulting reduced feed-in power varies between 84 % (Greece) and 95 % (Germany) of the maximal power. Converting this values of the reduced power and converting them into an additionally connectable power leads to an increase of the hosting capacity by a factor between 5 % (Germany) and 18 % (Greece), which is significantly lower than the hosting capacity gain from fixed curtailment (+42 %).

Table 1. Comparison of curtailed energy

Country	AT	DE	ES	FR	GR	IT
Yield (MWh/kWp)	1.2	1.0	1.6	1.0	1.6	1.3
Curtailed energy (P>0.70 p.u.) (%)	6.4	6.7	4.3	4.8	2.9	4.8
Operating hours (h)	81	70	74	50	51	71
Pred (p.u.)	0.91	0.95	0.89	0.9	0.84	0.88
ΔHC (%)	9	5	12	11	18	14

CASE-STUDY ON VOLTWATT CONTROL

Considered network scenario

In this section, the setup of the conducted study is presented, based on [13]. For the case-study, a scenario with a high PV penetration was assumed (one single-phase generator of 3 kWp per roof). Figure 5 shows the location of the PV-installations. Unbalanced load profiles were used and 18 characteristic days were simulated (combinations of: sunny / unsettled / cloudy – summer / winter – Monday / Friday / Sunday) and extrapolated to a year [13].

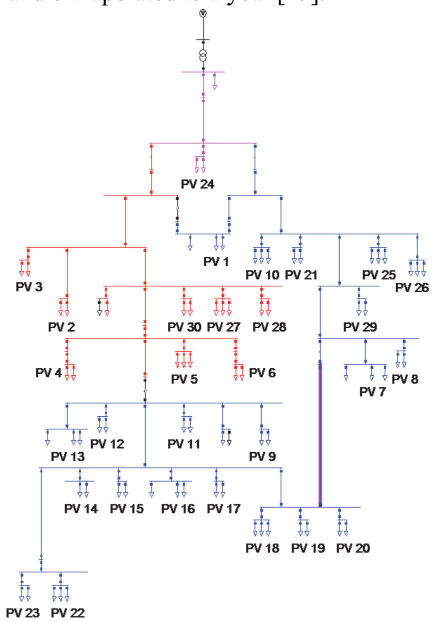

Figure 5. Considered LV feeder

In the reference scenario, the infeed was not limited at all (no hard-curtailment). In a second simulation run, a combined Q&P(U)-control (VoltVar and VoltWatt-control) was implemented in the inverters models (Figure 6). A combined control strategy of both reactive and active power ensures that active power is only curtailed if the reactive power control reaches its limits. Reactive power control (Q(U)) is used to decrease the voltage rise within the voltage area of 1.06 p.u. to 1.08 p.u. The 1% gap between the saturation of the Q(U)-control and P(U)-control ensures that many installations contribute to their maximum to the reactive power control before curtailment is activated. Starting from 1.09 p.u., the active power is capped linearly from 0 to 100 % of the nominal pow, ensuring that the voltage never exceeds 1.1 p.u.

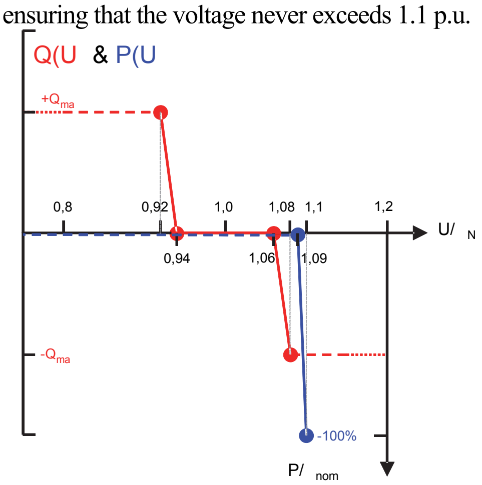

Figure 6. Implemented Q&P(U)-control

Simulation results

In this section the results of the study case are presented. First the impact on the voltage is discussed, followed by an overview of the curtailment at feeder level and finally, the impact on each installation is discussed. In Figure 7, the voltage duration curve per phase is depicted for the uncontrolled simulation run. Under such circumstances, inverters would normally disconnect (hard-curtailment) from the grid and long-lasting over-voltage would actually be avoided. The scenario considered here is beyond the hosting capacity of the feeder (3kWp per roof).

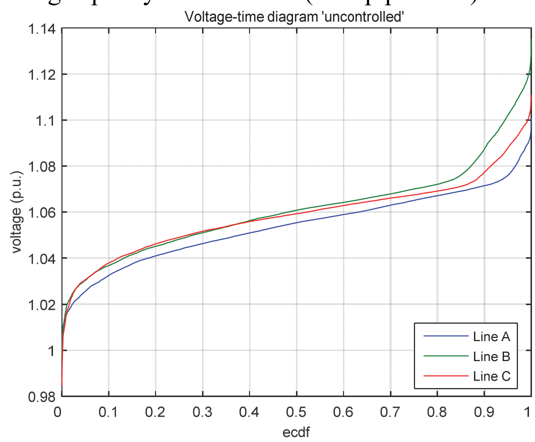

Figure 7. Voltage duration curve - reference scenario

For the combined Q&P(U)-control simulation run, the voltage duration curve is depicted in Figure 8. The figure shows that the voltage limits were met for all time steps. Additionally, also the unbalance of the voltages is slightly lower compared to the reference case due to the fact that each generator controls the voltage in its own phase.

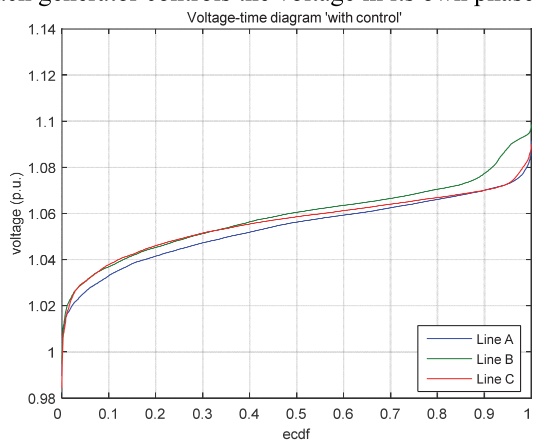

Figure 8. Voltage duration curve – P&Q(U)-scenario

Figure 9 shows the aggregated infeed for each scenario (highest occurring infeed during 20 % of the time of the year). In the reference case, full power is injected to the grid. Under a VoltWatt-control regime, only a small share is curtailed, about 1 %. The duration curve shows that the curtailment is not proportional to the infeed power. Contrary to that, the fixed curtailment leads to curtailed energy of about 6 % in this case. This means, that 5 % of the yield is curtailed unnecessarily.

Figure 10 shows, that the curtailment on feeder level is not evenly distributed among the generators: some generators had to curtail significantly more than most of the other installations. Due to the single phase injection of the installations, only physically self-consumption (consumption and production on the same phase) tends to limit or avoid the curtailment. The reason for the unevenly distributed curtailment is basically a mismatch between local production and consumption per phase and unfavorable phase connections of some installations.

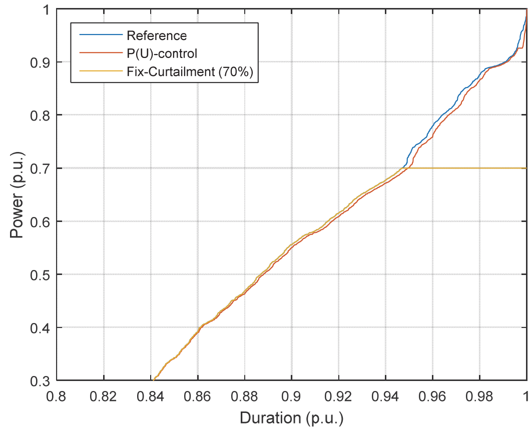

Figure 9. Duration curve feed-in

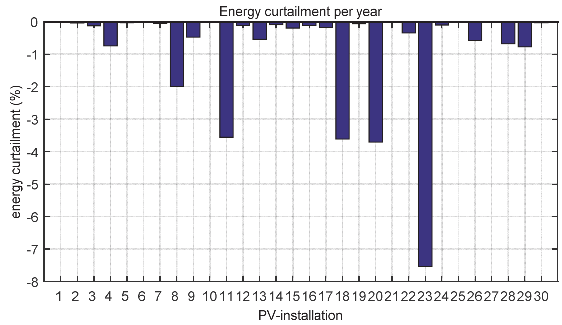

Figure 10. Curtailed energy with VoltWatt-control

OUTLOOK AND CONCLUSION

The estimation of the curtailed energy based on the necessary worst-case consideration leads to the conclusion that the potential of VoltWatt control is generally smaller than the potential of fixed curtailment (due to the necessary worst-case assumption). The case-study showed however that the VoltWatt-control resulted in about 1 % curtailed energy of the annual yield for the whole feeder, with however an unevenly distribution among generators.

The worst-case assumption to compare the curtailment with the presented strategies showed to lead to a strong overestimation of the yield reduction for the whole feeder. Further studies are needed to effectively and precisely estimate the curtailed energy with a VoltWatt-control. In conclusion, network planners and operators are facing several uncertainties which might severely the actual potential of this smart solution (curtailment / non-firm connection contracts). Further uncertainties such as the connection of further generators or the migration of large customers are further barriers to the deployment of this solution.

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