EFFECTS OF DISTRIBUTION SYSTEM CHARACTERISTICS ON TSO-DSO ANCILLARY SERVICES EXCHANGE

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ABSTRACT

Distribution resources are becoming more and more attractive to ancillary services markets, especially since their continuous evolution is gradually replacing the flexibility of conventional power plants. Forwarding distribution flexibility to the transmission system can be significantly affected by the distribution network characteristics (impedance, voltage/current constraints, etc.) and, for this reason, flexible resources has to be aggregated by taking into account grid limitations. A possible way of merging distribution flexibility consists of defining an equivalent capability curve (representing the maximum amount of active/reactive power that can be delivered to the transmission system) which shapes depends on the operational limits of each controllable energy resource and of the hosting distribution network.

INTRODUCTION

In many countries, distributed renewable resources are becoming a large portion of the electricity mix and their participation to both transmission and distribution ancillary services will be likely necessary in the near future. In this scenario the coordination between Distribution System Operator (DSO) and Transmission System Operator (TSO) becomes a key element, since their necessities in terms of ancillary services can be concurrent [1] (i.e. congestion management at distribution level has an impact on system balancing). Here, for simplicity, we will refer to network operators as the only involved actors, even if some of the functionalities related to network management and coordination can be delegated to other entities (e.g. market, aggregators…). In literature many coordination schemes have been proposed [2] and most of them consider the concept of distribution network equivalent capability [3]-[5].

The equivalent capability represents the aggregated flexibility (from the transmission network perspective) of all the resources connected to a distribution network, which is computed by the DSO taking into account network constraints (e.g. voltage and loading limits). It is immediate to recognize that the equivalent capability plays a fundamental role since the DSO can guarantee that, if a set point coming from the TSO falls within the capability area, one or more combinations of activations and control actions can be applied without endangering the safe operation of the network.

In addition to the practical applications, the study of the equivalent capability (the shape, the time evolution, etc.) provides a set of interesting indicators on the performance of the distribution network in transferring energy flexibility from MV/LV devices to transmission system reserves.

In order to investigate the impact of network characteristic on the shape of the equivalent capability, an extensive set of tests have been carried out: simulations were performed with the goal of computing the capability for a set of different distribution networks. Position of generators, total installed power flexibility, strategy in network asset management (e.g. optimization of tap-changing distribution transformers) have been investigated together with other relevant parameters (e.g. line impedances). In the following chapters, the main outcomes of the proposed calculation methodology and selected test cases are reported.

THE EQUIVALENT CAPABILITY

The equivalent capability of a distribution network is processed according to one of the methodologies described in [6]. The adopted calculation procedure can be adapted to any generic optimal power flow engine and, thanks to few modelling tricks, the capability curve can be easily extracted with few algorithm iterations. The methodologies proposed in [6] is designed to reconstruct the flexibility curve with the desired accuracy, which can be selected on the basis of the timing requirements of the algorithm. However, even few iterations can return a usable estimation of the distribution capability curve.

The possibility of running any optimal power flow tool, opens the selection of the optimization algorithm to the ones that are currently used by network operators and/or are supporting particular network control strategies.

These two properties are useful in order to investigate the correlation between the equivalent capability, the network and generators characteristics. In this paper, the investigations have been carried out by adopting a network optimization tool developed by RSE [9], capable of reconstructing the network capability with the radial method described in [6] (Figure 1).

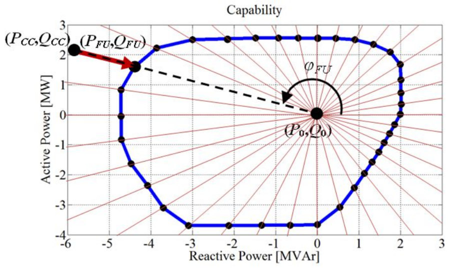

Figure 1: Aggregated capability, computed with the fixed power factor method [6].

PERFORMED TESTS

The main factors affecting the shape of the equivalent capability can be identified by running one of the possible estimation techniques on a given set of electricity networks. Thanks to the random distribution grid generator proposed in [7], the investigation can be extended to a large number of cases. Alternatively, a large number of scenarios can be defined also for a single distribution network: the position of the controllable devices, the impedance of the lines, the operational limits can be tuned in order to evaluate the effects of each investigation dimension. This is the case presented in this paper.

Test Network

The network used for the proposed tests is reported in Figure 2. It consists of four main feeders, characterized by different lengths. According to the simplifications assumptions reported in [7], all the branches have been modelled with the same resistance and reactance (equal to 0.2 Ω and 0.1 Ω respectively). The loading limits go from 8 MVA, in proximity of the primary substation, to 5 MVA in correspondence of the secondary derivations, while voltage constraints are limiting the voltage variations to ±5 % with respect to the the nominal value. The power limit of the network transformer is assumed to be 10 MVA and the total load (uniformly distributed over the distribution nodes) about 6.5 MW.

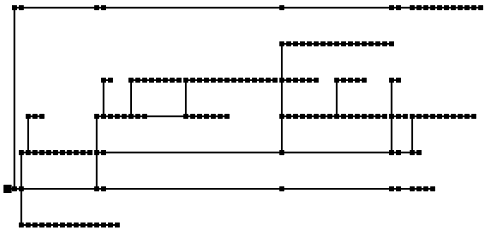

Figure 2: Topology of the selected distribution network.

Generators and installed power

Ten generation units are supposed to operate on the selected network. They are assumed to feature a rectangular capability (with a minimum power factor of 0.9) and to be controlled by a central dispatching algorithm. Of course, the investigation can be extended to other control architectures [8].

For the considered investigation, twenty different scenarios of generation evolution have been investigated. Both the nominal power of the ten generators and their location on the grid have been randomly selected. At this point the equivalent capability is computed by gradually increasing the size of generators and the area of the capability is proportionally enlarging. Figure 3 reports the trend of the capability areas for the considered scenarios. In particular, all of them start to saturate when the total generation exceeds 12 MW, which corresponds to the minimum Hosting Capacity (HC) featured by one of the scenarios (Figure 4). Larger values of generated power lead the curves to different asymptotes, which are also related to the hosting capacity of each scenario.
For values lower than 12 MW, instead, all the returned flexibility curves feature about the same area of the ideal capability (which is increasing as a quadratic function with respect to the generation power). Interestingly, for low values of generated power, the capability areas of the selected scenarios are slightly larger than the ideal one. This is due to the presence of network losses.

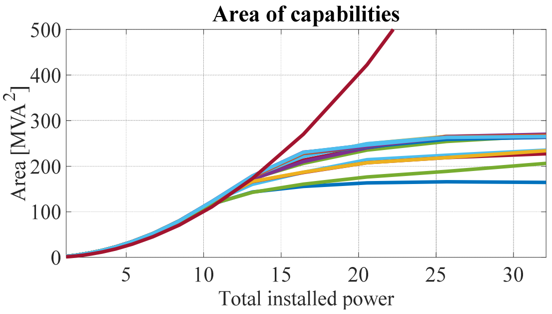

Figure 3: Areas of the equivalent capabilities for different values of generated power. In addition to the twenty considered scenarios, the ideal capability (network with no losses and constraints) is reported in dark red.

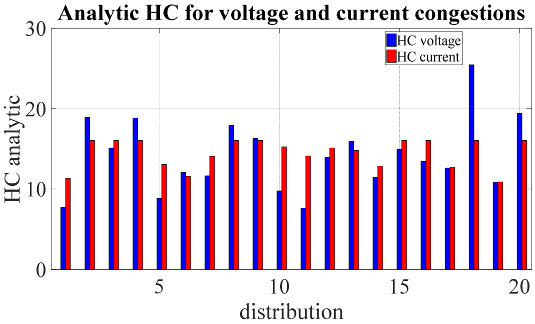

Figure 4: Hosting capacity computed with the method developed in [10] for the different generation scenarios**.** HC is computed separately for both voltage and current constraints.

This means that all the distributions of generators return the same capability if the installed power is lower than the minimum HC: since no constraints are active, all the generators are able to exploit their full capabilities. Around the value of minimum HC some constraints start to limit the potential power exchange in the less favourable scenarios. This can be seen with higher details analysing the most extreme values of capabilities, plotted in Figure 5.

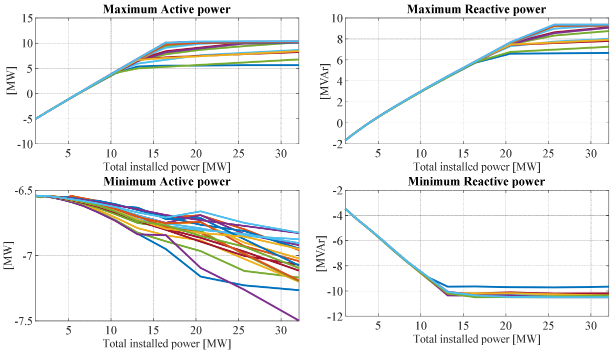

Figure 5: Maximum and minimum values of active and reactive power exchanges that can be featured by the considered twenty scenarios for an increasing installed power of generators.

The considered scenarios are featuring different positions and sizes of the generators. For this reason, distinct network constraints can limit the full exploitation of the available capability (as it can be deduced by Figure 4). Limitations of different nature determine capabilities with different shapes and areas. Looking at Figure 3 and Figure 5, it can be noticed that the capability curve of a generic scenario can be significantly different with respect to the ones of other generators distributions. Significant distortions often are due to the reactive power management performed by the capability aggregation routines in order to solve voltage constraints. However, as soon as power factor modulation is not effective any more in solving congestions (in case of overloading issues), the capability tends to assume a circular shape, especially when the distribution transformer is the network bottleneck (Figure 6). This is happening with the scenarios characterized by the largest capability areas.

On the contrary, scenarios with the lowest flexibility areas are limited by the secondary derivations of the main feeders, which have lower current limits. In this case, voltage constraints are not affecting the capability shape.

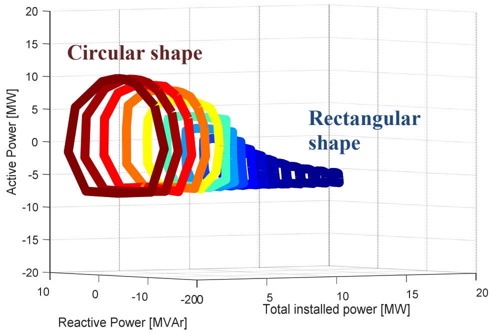

Figure 6: Capability of the scenario characterized by the largest flexibility area for different values of generated power.

Impedance of branches

According to the results presented in the previous section, it is clear that the voltage constraints are significantly affecting the capability shape for values of generated power close to the HC. Generation levels higher than the HC values determine situations in which the reactive power flexibility can effectively solve voltage congestions. In order to verify this hypothesis, the previous tests have been repeated by doubling the impedance of the network. According to the results plotted in Figure 7, low generation values are still characterized by matching capability curves. The higher network impedances are increasing the voltage impact of distributed generation. In fact, the areas of the flexibility curves are starting diverging at 9 MW (minimum value of HC for the modified network). At this point the trends of the areas is not creating groups (as it happened in Figure 3) except for large power values, where loading constraints are becoming predominant.

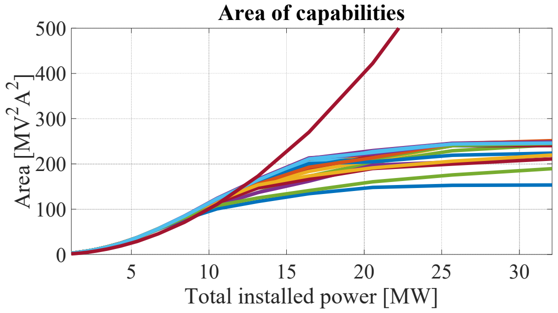

Figure 7: Areas of the equivalent capabilities for different values of generated power (network with twice the impedaces). In addition to the twenty considered scenarios, the ideal capability (network with no losses and constraints) is reported in dark red.

One particular distribution has been isolated to see the effects of voltage constraints in determining the shape of the capability more in details. By doubling the impedance, the capability significantly decreases in the first and third quadrant (Figure 8). In fact, these working areas are characterized by

- the simultaneous injection of active power and exchanged capacitive reactive power, determining a high voltage increase;
- the simultaneous consumption of active power and exchange of inductive reactive power, determining a high voltage decrease

In the other capability sectors the effect is less relevant since the active and reactive power exchanges are mutually compensating their voltage impact. The marginal increase of the capability in some areas is due to higher losses, which allow higher local share of reactive and active power.

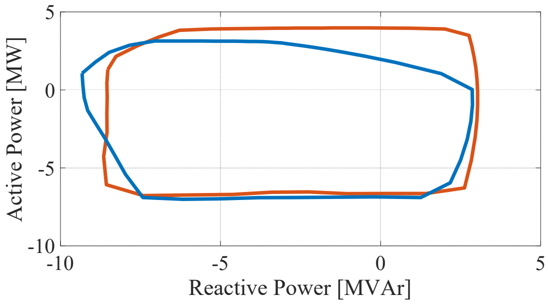

Figure 8: Areas of the equivalent capability for one generation scenario (10.5 MW of installed power) in the base case (red) and with double impedance (blue).

Loading limits

The line/transformers loading limits are the most relevant factors that define the capability curve for the highest values of installed power. In order to evaluate their effects, the previous simulations are repeated, excluding the current constraints. Having removed the loading limits, the area curves returned by the twenty scenarios results much more similar among themselves (with respect to the cases described above). Interestingly, the worst matching is featured in correspondence of curves knee (Figure 9).

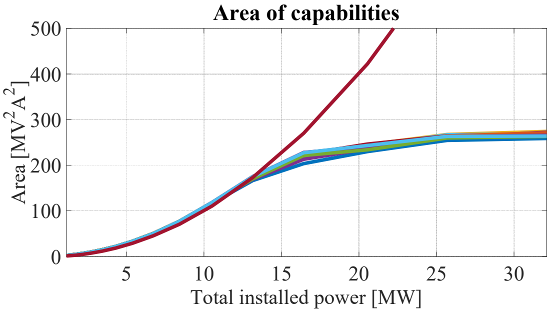

Figure 9: Areas of the equivalent capabilities for the twenty considered scenarios, having excluded current constraints.

From the analysis of one single scenario, the effects of current constraints on the shape of the capability can be further investigated. Since loading limits determine circular capabilities (current is affected by both active and reactive power – Figure 6), a network without current constraints is featuring large flexibility areas. According to Figure 10, the removed limits are particularly affecting the capability when negative reactive power is exchanged. This is happening when the reactive power has the same sign of the one exchanged by loads. This effect can be seen also in Figure 5, where the minimum exchange of reactive power is reached for low values of generated active power (if compared to active power flexibility).

Thanks to this analysis, network bottlenecks can be easily identified, and possible solutions investigated. For instance, by reintroducing the current constraints, the considered generation scenarios feature a severe overloading condition in one of the branches (Figure 11).

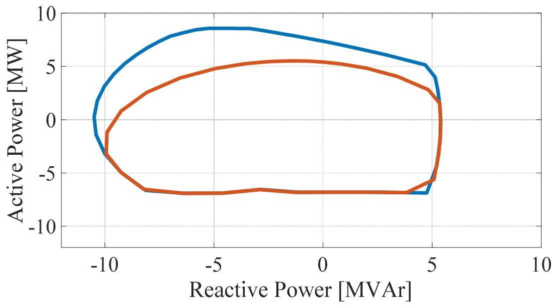

Figure 10: Areas of the equivalent capability for one generation scenario (16 MW of installed power) in the base case (red) and without current constraints (blue).

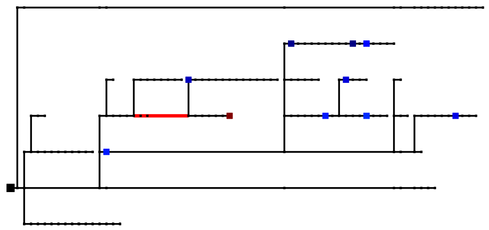

Figure 11: Topology of the considered distribution network, where the simulated generators are indicated with blue squares, and the congested line is highlighted in red.

CONCLUSIONS

The paper shows how the tool for reconstructing the equivalent capability of distribution networks can be effectively used in order to investigate the issues related to the participation of distributed resources to the ancillary services markets. In particular, for a given generation scenario, it supports the analyses aimed at identifying the most critical network sections and constraints.

The tests described in the paper demonstrated also the connection between the network capability and the HC. In fact, for generation power below the value of HC, different distributions of generators return the same capability. In this situation, all the flexible resources are capable to transfer their full capability to the upstream network. On the contrary, when generation is above the HC value, the reactive power flexibility is often a sufficient measure for the solution of most of the voltage issues, while only loading constraints effectively limits the exchange of power. Around the HC value, both current and voltage limits are impacting the capability area significantly. This behaviour between HC and aggregated flexibility curves will be further investigated in future works.

Acknowledgments

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