NETWORK RECONFIGURATION AND STORAGE SYSTEMS FOR THE HOSTING CAPACITY IMPROVEMENT

Davide FALABRETTI
Politecnico di Milano – Italy
davide.falabretti@polimi.it

Marco MERLO
Politecnico di Milano – Italy
marco.merlo@polimi.it

Maurizio DELFANTI
Politecnico di Milano – Italy
maurizio.delfanti@polimi.it

ABSTRACT

In the present paper two methods to increase the Medium Voltage (MV) distribution grids Hosting Capacity (HC) for Distributed Energy Sources (DERs) are investigated.
The first method provides to change the Network Configuration (NC) to optimize the HC in different buses of the distribution system. The second technique exploits Energy Storage Systems (ESSs) to store electricity during grid congestions, and to re-inject it later on into the grid.
Both the proposed approaches have been tested on a model of a real MV distribution grid.

INTRODUCTION

In recent years, one of the most challenging targets for power systems became the effective integration of the increasing energy production from DERs, despite their variability and undispatchability [1].
Given the increasing penetration of Dispersed Generation (DG) in MV/LV networks, the DSO (Distribution System Operator) could face increasing difficulties in satisfying all the DG connection requests within the deadlines established by the existing regulation [2]. In fact, in Italy and other EU countries, DSOs have to accept timely all DG connections; moreover, they must ensure the DG injection at the full power (fit&forget approach) within short deadlines. But the connection of large power plants often needs the introduction of structural improvements in the grid.
A possible simple solution is to connect the DG power plants admitting a temporary (until the network developments) reduction of their injections according to the grid operating constraints: despite this approach allows to reduce the time required for the connection, it leads to considerable costs related to the energy not injected in the network (with a possible reimbursement of the curtailed production; Fig. 1a).
In order to overcome the present problem, a possible solution provides to manage the NC to optimize the HC in the most critical buses of the grid (e.g. where large DG plants are connected). Exploiting this approach, the NC could be optimized according to the load and generation power flows in the grid, with the purpose to limit/avoid congestions and to manage the voltage profiles along lines.
An alternative solution for this problem is the adoption of ESSs, which are able to increase the power systems HC. To this aim, ESSs must absorb the energy in excess during network critical situations (e.g. peak production hours), and release the energy stored when the grid is able to accept it (e.g. during night; Fig. 1b) [3]. This solution is envisaged in some recent resolutions issued by the Italian Regulating Authority (Resolution ARG/elt 199/11 [4]), where pilot projects are incentivized to this purpose.

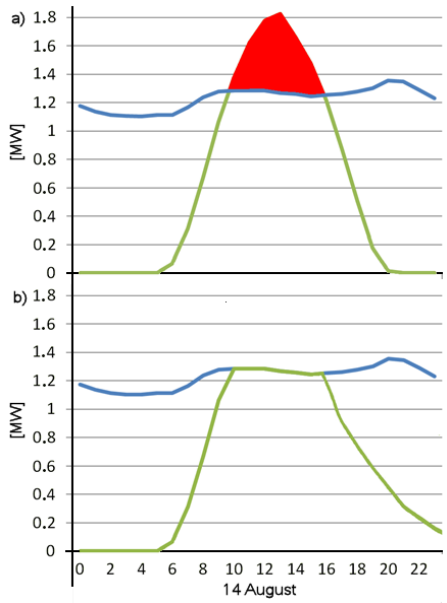

Fig. 1. Power injections (green) of a PV plant with a rated power greater than the network HC (blue), without (a) and with (b) ESS. The curtailed production is reported in red.

In our study, the HC has been defined according to the distribution networks technical constraints reported in the following [5].

- Supply voltage variations: the voltage is considered acceptable if it is included between 96% and 110% of the rated value, according to the limits stated by the standard EN 50160 [6] requiring that on MV level the voltage must be included between the ±10% (-4% allowance is assumed with a conservative approach, taking into account the voltage profiles on LV lines).
- Rapid voltage changes: the limit is considered 6% of rated voltage, according to the (non-binding) requirements of the standard EN 50160;
- Transit limits: the DG power injections can cause the violation of the ampacity limits of the lines, so they must be properly taken into account in assessing the HC.

THE TEST NETWORK

In our study, we assumed a (radial) MV distribution network connected to the HV system through the interposition of an HV/MV transformer sized 10 MVA (Fig. 2; rated voltage 20 kV) [7].
The network is located in central Italy and covers an urban area. The paper will refer to the part of network departing from one MV primary busbar, with 5 feeders underlying and composed of 287 busbars (10 MV users and 109 MV/LV substations; the remaining buses are transit buses, required to represent feeders discontinuities, e.g. transitions from cable to overhead lines) [8].
Because of the complexity and spreading of LV networks, only the MV level is modeled in detail. The LV loads are introduced in the model as equivalent power exchanges at the relevant MV/LV interface.

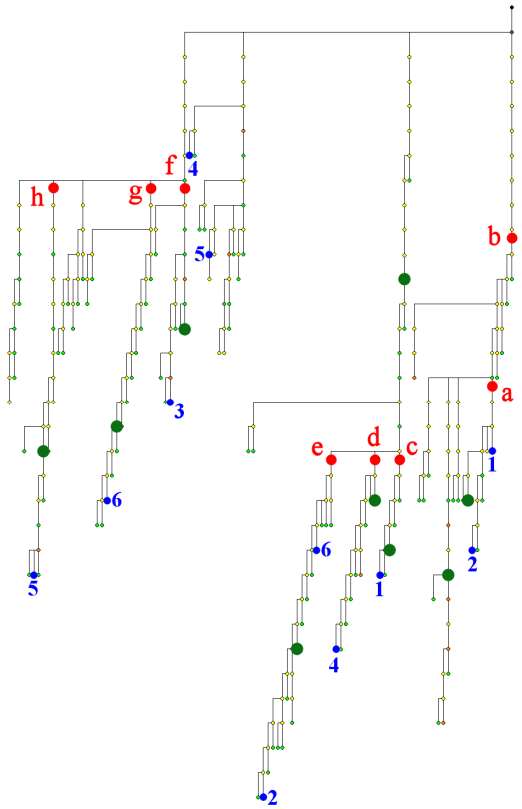

Fig. 2. The MV distribution network under analysis: sectionalizing switches (red), tie switches (blue) and buses subject to the HC assessment (green) are reported.

All the energy flows in the grid are represented on an hourly basis and over a whole year (8760 hours). The loads are classified in two different categories: MV users and MV/LV substations. All users belonging to the same category are assigned the same load profile. These profiles are obtained from the yearly characteristic of the overall national load, suitably shared between the two user classes. All loads are modeled as P,Q buses; according to the Italian regulation [4], the power factor is assumed equal to 0.9 lagging.

On the grid, one can find some DG units: PV generators, run-of-the-river hydroelectric power plants and CHPs. Similarly to the load, each DG technology is characterized by a specific injection profile, obtained by data collection on real power plants and hypotheses compliant with the Italian electricity framework. All DG plants are assumed to inject energy with a unitary power factor.
Some buses are assumed representative of the behavior of the whole grid; they have been selected with an ad-hoc procedure, based on the electrical center of gravity approach. Such buses are used to carry out the HC analysis.

NETWORK RECONFIGURATION

In the present study the impact of network reconfiguration is explored to increase the grid HC: for each configuration of the network under analysis, the HC is calculated for all the buses of the set above described.
The study is based on a procedure that optimizes the network structure during a given time interval (e.g. a day or an entire year) [9], assuming a dynamic NC: i.e. the NC is changed over the time to optimize the HC (up to every hour).
The algorithm is divided into two distinct procedures: the first one identifies the topologically feasible configurations (i.e. without islands and/or meshes) and, managing the expected profiles of load and generation, performs the calculations structuring the results in appropriate matrices. The second procedure (the optimization algorithm) processes the matrices previously calculated, finding the best solution w.r.t. the HC index.
In Fig. 3, the minimum HC assessed on all the network buses w.r.t. to the base case (the NC configuration in Fig. 2) is shown in percentage. The HC is reported in six days considered representative of the grid behavior on the whole year and for all the NCs resulted feasible (256).

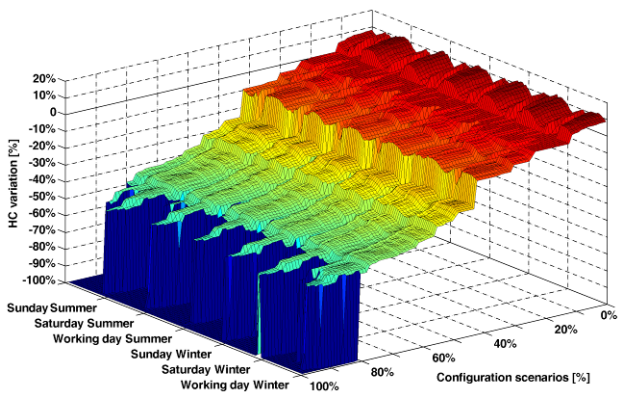

Fig. 3. Cumulative characteristic of the minimum HC assessed on the grid w.r.t. the HC in the standard NC, on six representative days of the year and in all the feasible NCs.

The HC w.r.t. to the base case (which ranges between 3.21 and 3.07 MW) is represented as a cumulated quantity: in a

given time instant (x-axis), a percentage of NCs equal to the value reported on the y-axis offers a HC in all the relevant buses at least equal to the amount shown on the z-axis.
Approximately 10% of NCs always have a HC equal to, or greater than, the HC found in the standard NC. However, the HC increase is quite small: in the best case it is approximately equal to 10% (0.37 MW). One can conclude that a NC able to improve significantly the HC in all the grid buses w.r.t. the standard NC does not exist.
Fig. 4 reports the maximum HC that can be observed on all the buses of the network w.r.t. to the base case (i.e. the HC variation of the best case observed on the grid). The HC is shown for the same days and NCs of Fig. 3. While the previous case quantified the HC improvement achievable through the reconfiguration process using the HC as indicator of the overall network behavior (worst case), in the present situation the HC has a "local" (or "nodal") meaning: it represents the performance of the reconfiguration procedure in maximizing the HC in a well-defined bus of the network.

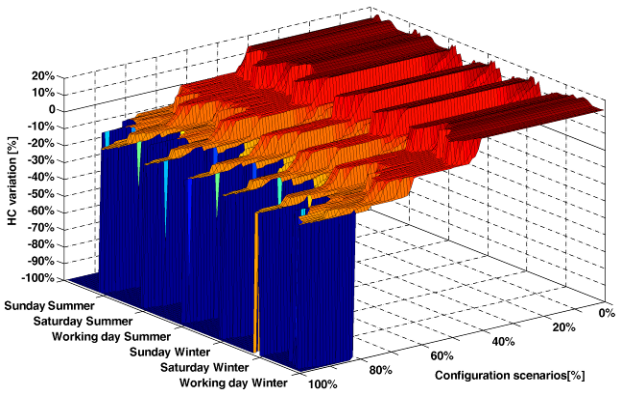

Fig. 4. Cumulative characteristic of the maximum HC assessed on the grid w.r.t. the HC in the standard NC, on six representative days of the year and in all the feasible NCs.

From Fig. 4, it is possible to observe that, despite in this case the advantage achievable through the reconfiguration is greater than the previous one (about 18%; 1 MW), in most NCs there is a HC reduction. So, the network reconfiguration shows typically quite small performances w.r.t. the HC improvement. However, it could be considered an effective method to improve the network acceptance for DERs, thanks to its limited economic impact.

ENERGY STORAGE

This analysis aimed to assess the performance of Energy Storage Systems (ESSs) in increasing the distribution networks HC. To this purpose, when the production of the DG plant exceeds the capacity of the grid to accept DER injection, the corresponding ESS must absorb the energy in surplus; then, the ESS is discharged when the congestions on the network are overcome.

In a first step, the HC of the grid under study has been evaluated (in each one of the selected buses): i.e. for each time slot considered (a hour), the power injectable by a DG power plant has been assessed. The technical constraints taken into account are the same of the previous analysis: voltage variations limits and lines/transformers ampacity.
Then, the study assessed, for each bus, the size (rated power and energy) of the ESS to be installed in the DG connection bus in order to avoid the production curtailment. The assessment of the ESS sizing is strictly dependent on the trend of the injection profile of the DG unit taken into account. In our study, we considered a PV power plant, for the spreading of this DG technology within the national context and the variability of its production, which makes particularly beneficial the coupling with an ESS.
The power of the ESS to be coupled with a PV plant exceeding the HC in its connection bus is almost equal to the difference between the PV plant rated power and the HC of the network (the actual value depends on when the HC is overcome; e.g. during the peak injections).
In Fig. 5, the capacity required to an ESS is reported in equivalent hours of operation at its rated power, according to the PV plant rated power in percentage w.r.t. the HC of the connection bus. For example, if the PV plant has a rated power which exceeds of 5% the network HC, in order to allow the DG to produce always at its full power, we need an ESS with a rated power equal to about 5% of the HC and a capacity equal to 2 equivalent hours at its maximum power. The black bars show the maximum and minimum values assessed on all the buses of the set selected. From Fig. 5, the sizing required for the ESS is quite expensive, ranging from 2 to 6 equivalent hours.

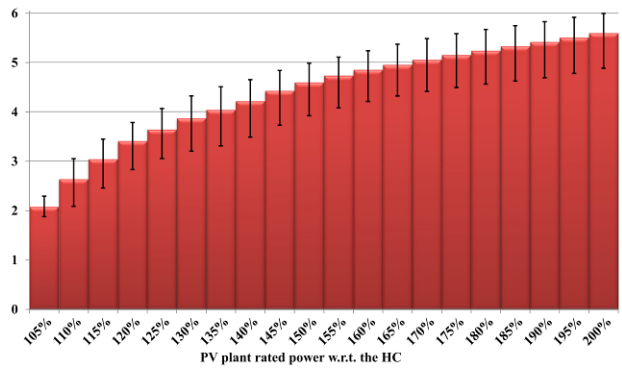

Fig. 5. Capacity required to the ESS in equivalent hours of operation at its rated power, according to the PV plant rated power in percentage w.r.t. the HC of the connection bus (red=average value; black=max/min values).

An interesting aspect is the amount of energy that would be subject to curtailment in case of DG rated power greater than the HC of the connection bus, without ESS (Fig. 6). For PV plants that exceed slightly the network HC, the energy curtailment is very small: lower than 5% of the yearly overall energy production with DG plants smaller than 120% of the HC.

In these cases, a (temporary) loss in production could result acceptable for the user, allowing to shorten the time required for the connection process: the power plant could be put in operation, limiting the DG production during the time required to introduce the structural interventions needed within the network (some months).

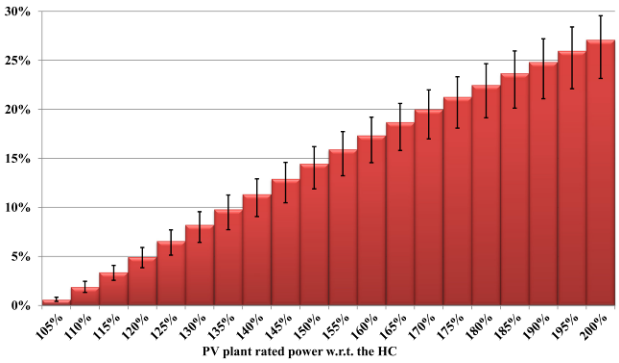

Fig. 6. Energy curtailment (in percentage w.r.t. the total production) according to the rated power of the PV plant w.r.t. the HC of the connection bus (red=average value; black=max/min values).

CONCLUSION

This paper assessed the performances of two methods to increase the HC for DERs of MV distribution networks. The first method provides to change the topology of the network in order to improve its HC in a set of representative buses, while the second technique evaluates the opportunity given by ESSs, storing the energy in excess during network congestions.

Both the approaches have been tested in a real scenario, i.e. a MV distribution really in operation in the Italy.

Concerning the use of the reconfiguration process to increase the network HC, results show that the reconfiguration may entail interesting advantages for the HC. In our case, the HC increase w.r.t. the NC usually adopted by the DSO (standard configuration) ranges between 0 and 20%, depending on the hour and on the case considered. The cost of this approach lies in the automation required on the grid to this purpose, necessary to change dynamically the NC according to the HC needs.

On the contrary, whatever are the values of DG power and HC, ESSs could effectively integrate the DERs production within the system, but with the drawback of an expensive sizing. While the ESS power sizing usually does not represent a problem, the storage capacity is a more binding requirement: even with DG plants slightly exceeding the grid HC, the capacity required to the ESS ramps up to some equivalent hours of operation.

Finally, the energy curtailment has proved to be a viable solution to speed up the connection process of active users: accepting only a temporary small reduction in production. It is possible to limit the time necessary to the DG connection to the grid.

REFERENCES

[1] A. Capone, M. Delfanti, D. Falabretti, L. Megalini, M. Merlo, 2011, “PV production forecast for an effective VPP exploitation”, *Proceedings Cigrè 2011*, Bologna (Italy).

[2] Italian Authority for electricity and gas, 2011, Resolution ARG/elt 99/08, *Testo integrato delle condizioni tecniche ed economiche per la connessione alle reti elettriche con obbligo di connessione di terzi degli impianti di produzione di energia elettrica (Testo integrato delle connessioni attive - TICA)*.

[3] M. Delfanti, D. Falabretti, M. Merlo, P. Mora, 2011, “Dispacciabilità delle risorse di carico/generazione mediante sistemi di accumulo”, *Proceedings AEIT 2011*, Milan (Italy).

[4] Italian Authority for electricity and gas, 2011, Resolution ARG/elt 199/11, *Disposizioni dell’Autorità per l’energia elettrica e il gas per l’erogazione dei servizi di trasmissione, distribuzione e misura dell’energia elettrica per il periodo di regolazione 2012-2015 e disposizioni in materia di condizioni economiche per l’erogazione del servizio di connessione*.

[5] D. Bertini, M. Delfanti, D. Falabretti, M. Merlo, D. Moneta, J. Silva de Assis Carneiro, 2011, “Hosting Capacity of italian LV distribution networks”, *Proceedings CIRED 2011*, Frankfurt (Germany).

[6] CENELEC, Standard EN 50160, 2000, *Voltage characteristics of electricity supplied by public distribution networks*.

[7] A.S.SE.M. S.p.A., http://www.assemspa.it/, 2013.

[8] M. Delfanti, D. Falabretti, M. Merlo, 2013, Dispersed generation impact on distribution network losses, *Electric Power System Research*, Volume 97, April 2013, Pages 10–18.

[9] D. Falabretti, G. Monfredini, D. Moneta, A. Silvestri, 2011, RdS report, *Analysis and optimization of MV distribution networks configuration to maximize the hosting capacity*.