Hosting Capacity Evaluation in Networks with Parameter Uncertainties

S. Mina Mirbagheri
Energy Department
Politecnico di Milano
Milan, Italy
sayedehmina.mirbagheri@polimi.it

Matteo Moncecchi
Energy Department
Politecnico di Milano
Milan, Italy
matteo.moncecchi@polimi.it

Davide Falabretti
Energy Department
Politecnico di Milano
Milan, Italy
davide.falabretti@polimi.it

Marco Merlo
Energy Department
Politecnico di Milano
Milan, Italy
marco.merlo@polimi.it

***Abstract*—Nowadays, the maximum generation that can be hosted by distribution grids and how to increase it without violating technical constraints are main concerns of DSOs. In this paper, a novel model (named Bricks approach) is discussed, that is designed to estimate the hosting capacity of distribution grids even in case of uncertainties in grid parameters or lack of data. The proposed approach results particularly useful when it is not possible to collect all the necessary data for a classical load flow based analysis, as in the case of studies relevant to emerging countries electrification processes, or when data gathering is difficult, as in the case of complex modern distribution grids. In order to validate the approach, a real-life case study relevant to the Italian city of Aosta is presented.**

***Index Terms*—hosting capacity; steady-state voltage; rapid voltage change; thermal limit; distribution grid; dispersed generation; emerging countries.**

I. INTRODUCTION

Nowadays, distribution networks are being subjected to an increasing penetration of active users on both low and medium voltage levels, typically based on small size power plants from renewables (the so-called Distributed Generation: DG). Distribution grids are designed for providing electricity to the customers and could take some advantages from the Renewable Energy Sources (RES) production: sustainability, less maintenance and low carbon emissions. However, upward trends of installing dispersed generators cause some issues for Distribution System Operators (DSOs). Such power injected into the grid is leading to several operational problems, which could affect the distribution grids' power quality and reliability [1], [2]: in particular, power quality challenges such as harmonics, voltage regulation issues and interface protection problems could arise [3], [4].

Despite the fact that DG itself has some merits, the impact of DG on the operation of electrical grids motivates a strong research activity based on statistical, deterministic and heuristic approaches [3], [5], [6]. The goal of some research studies is defining the optimal DG location and sizing [7]; though grid regulation typically requires DSOs, e.g. in Italy, to reinforce the distribution grid in order to allow DG connection in any node where users request it [8]. Therefore, DG optimization studies, in terms of connection point in the grid and size, have a scarce applicability in real-life. In this regard, the estimation of the maximum amount of DG that can be connected to the distribution grid without violating the operating criteria is one of the main performance indicators that should be considered for its planning and operation. This capacity of the electrical network is commonly known as Hosting Capacity (HC). The interest in numerical methods for the HC evaluation is based on the fact that power system performance is affected by the actual generation and load patterns. Hence, the HC is defined as the amount of DG acceptable by the grid without endangering its power quality and reliability w.r.t. given limits [1], [9]–[11].

In Italy, the Energy Authority commissioned studies to evaluate the nodal HC in LV and MV grids [3]. Such studies had been based on an extended sample of the Italian distribution system (the database was detailed in about 5% of the Italian MV distribution grid, and 1% of the LV one) [12]–[14]. The approaches suggested in these researches are based on iterative calculations, aiming at estimating the maximum DG penetration admitted in each single bus according to the considered technical limits; the HC is evaluated considering a single constraint at a time and assuming the overall HC as the minimum HC amount obtained for all the constraints. Hereinafter, such an index, evaluated through the novel method proposed in this work, will be referred as "*nodal HC*".

The novelty of this paper is summarized in the ability to define a model that could be representative of a generality of network structures of the area under evaluation; moreover, the model is asked to results effective in the evaluation of the nodal HC w.r.t. the following operational constraints: Steady-State Voltage (SSV) limits, Rapid Voltage Changes (RVC) and thermal limits of transformers and lines.

The paper is organized as follows: after this introduction, the HC evaluation method and the considered technical constraints are discussed (Section II). The Bricks approach and the distribution grid modeling are explained in following Section III. Then, in Sections IV, the validation of the proposed approach is presented and, in Section V, the

978-1-5386-0517-2/18/$31.00 ©2018 IEEE

results of the proposed method compared to the traditional one are discussed. Finally, conclusion of this research is enlightened.

II. HOSTING CAPACITY EVALUATION

HC could be formulated as an objective function maximizing the active power injected by DG in a specific bus of the network (nodal HC).

$$HC = Max(NodalLoadingParameters) \tag{1}$$

In order to evaluate the nodal HC, DG power injections into a specific bus of the grid could be increased iteratively until the defined constraints are violated. However, in this paper, in order to limit the computational effort of the procedure, a bisection method has been adopted. This method is defined as an iterative procedure, in which at each loop a power flow calculation is performed: if the technical limit is respected, DG active injections are increased of an half of the amount considered in the loop before the considered one, otherwise DG injections are decreased of the same amount. The procedure ends when the power variation between a loop and the previous one is lower than a prefixed resolution (1 kW in our study). The procedure is applied to all the buses of the network, obtaining for each bus the estimated amount of HC. To perform this HC evaluation procedure, the constraints are defined as described in the following.

A. Steady-State Voltage Variations

Adding a DG to the MV feeder causes a voltage increase at the hosting bus and generally on the whole hosting feeder. Hence, in order to avoid malfunctions of grid connected equipment, the SSV variations, according to the CENELEC standards [15], must remain within ±10% of the rated voltage during 99% of the time.

$$V_{min,k} \le V_{DG,k} \le V_{max,k} \tag{2}$$

B. Transformers and Lines Thermal Limits

If DG exceeds the load, the thermal limits of each MV line should be considered in the originating reverse power flow condition. Each branch of the network has a specific limit, depending on its own design and installation criteria. Thus, this limit is different for each network component.

$$I_{DG,kj} \le I_{max,kj} \tag{3}$$

C. Rapid Voltage Changes

RVC depends on the short-circuit power in the users' point of common coupling [16]. Generally, RVC is evaluated as the difference between the voltage amplitude when DG is connected and is injecting power into the grid and after its sudden disconnection. There is no restrict constraint for RVC in Italy [15]; only an approximate range of 4% to 6% of rated voltage is defined for MV networks.

$$|V_{DG,k} - V_k| \le 4\% \div 6\% \tag{4}$$

where $V_{DG,k}$ and V_k are the voltage amplitudes, respectively, with and without DG.

III. MODELING OF DISTRIBUTION GRID

In order to perform the HC analysis detailed in the previous chapter, a complete model of the distribution grid is required. Actually, HC is impacted by the topology of the grid, by grid parameters and also by power profiles of loads and generators, resulting in a quite heavy data set to be properly managed. Practically speaking, the data collection and reprocessing in many cases could be very difficult and, in some cases (e.g. in emerging countries), DSOs could be even unable to gather all the required information. Consequently, in this paper, a novel approach is proposed for the distribution grid modeling, named Bricks approach. Actually, the standard structure of distribution grids is shown in Fig. 1; this structure includes the main feeder and the branches connected to it, typically named collaterals.

The proposed method is based on the assumption that the HC of one feeder is marginally affected by other feeders (this is true in Italy, and in general in other EU countries, because the voltage amplitude on MV busbars of HV/MV substations is kept constant by transformer's Automatic Voltage Regulator). For limiting the computational effort of the study, the grid is modeled in a simplified way, i.e. as an aggregation of "bricks", each one representing a portion of the grid which can be added, removed and replaced easily, in order to evaluate all the possibilities of the grid structure in shorter time. Moreover, only critical nodes of the grid are assessed by the Bricks approach; as a matter of fact, HC along feeders decreases by going further from the primary substation to the connected collaterals, thus evaluating it in some nodes, the HC in the other nodes can be estimated consequently. In the following, the Bricks approach components are presented in detail.

A. Feeders

In the Bricks approach, all feeders are categorized into 3 groups: Short Feeder (F1), Medium Feeder (F2) and Long Feeder (F3). Main feeders are the backbones of distribution networks. In rural areas, the main feeders are usually very long with overhead conductors with section that often has an inverse relationship with the distance from the HV/MV transformer, while in urban areas feeders are shorter and, due to the high load density, with higher sections [12]. In order to implement the proposed method, feeders are categorized according to their characteristic. The feeders'

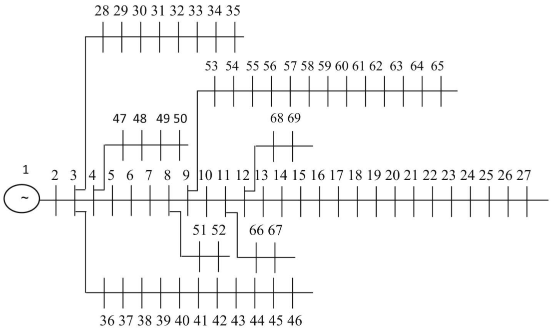

Fig. 1: Standard structure of 67-bus distribution grid [17].

characteristic mean value in each category is considered as the main characteristic of the Bricks approach feeders.

B. Collaterals

Collaterals are such as body's capillary for distribution networks. In the observed scenarios, collaterals connections to the main feeders, both rural and urban, are the same. However, the model parameters and the geographical zones are different. In rural areas, as for feeders, collaterals are longer and the cable section is smaller. In the proposed method, collaterals are divided into two groups: Short Collateral (C1) and Long Collateral (C2). Please consider that in our method short feeders are allowed to have only short collaterals. Coupling, stochastically, collaterals in each feeders' node is possible to represent a wide range of grid's topologies. Obviously, the procedure requires to define generic models for feeders and collaterals, representative of the context under evaluation (rural/urban area, etc.).

C. Nodes

Basically, the HC is higher at the beginning of the feeder; then, it decreases moving far from the primary substation toward the end of the line. Although the amount of HC is related to many factors, its changing trend could be considered approximately the same along feeders having similar electric parameters. In addition, HC along collaterals is lower compared to the HC in the connection point of the collateral to the main feeder. Thus, in order to evaluate the HC on collaterals, it is necessary to consider all their significant nodes in the Bricks approach. To this purpose, three critical nodes in each feeder, which represent the whole feeder, and two significant nodes in each collateral are considered in the HC evaluation. Their position is determined based on their impedance (Z): the first node of the feeder, which is the equivalent of the nodes near the primary substation, is located at the 10% of total amount of feeder's impedance (N1); the second one, representing intermediate nodes, is defined at the middle (N2); finally, the last one is positioned at the 90% of total amount of feeder's Z (N3), and is evaluated on behalf of the nodes farthest from the primary substation. For collaterals, the first one is at its middle (N4) and the second one is at the end (N5). Fig. 2 shows a long feeder with 3 long collaterals and its 9 nodes for implementing the HC calculation.

D. Loads

According to Italian DSO practice, in primary substations each transformer can be loaded up to 65% of its rated power to ensure an adequate degree of redundancy [18]. In the Bricks approach, such a limit has been assumed as the peak load the grid is asked to feed. In particular, the loads are divided into 3 groups: the yearly minimum value (L1), the mean value (L2) and the peak value (L3), simulated at a power factor of 0.9.

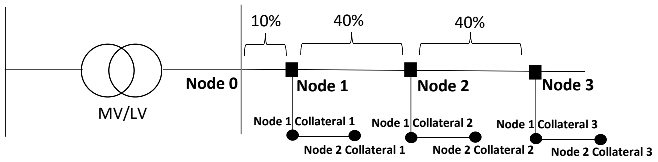

Fig. 2: Long feeder with 3 long collaterals and relevant nodes.

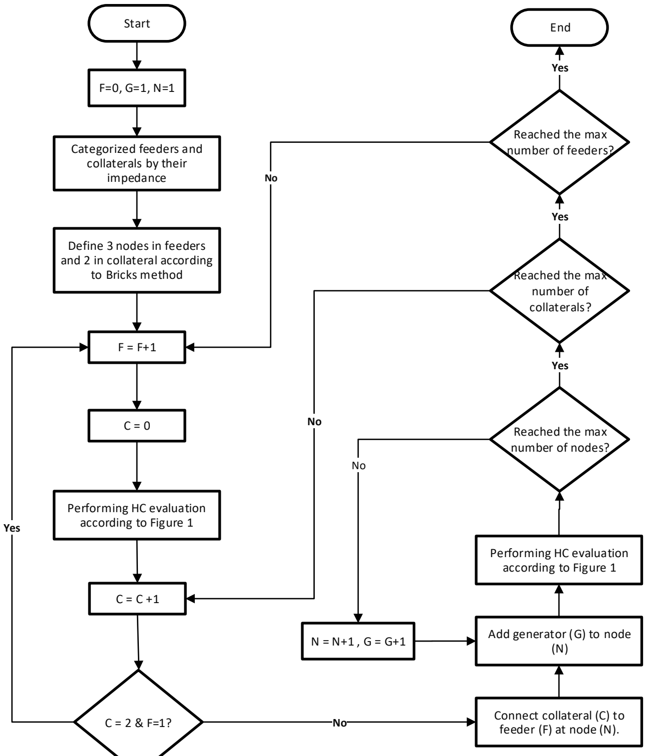

Fig. 3: Bricks approach flow chart.

E. Generators

In the Bricks approach, a generator is added to each defined-node of each combination of feeder and collaterals: in case of Fig. 2, there are 9 nodes able to host DG. The power injected into the grid by generators will change in the simulation to define the HC. Fig. 3 shows the Bricks approach flowchart. First, short feeder (F1) without any connected collateral and low value of load (L1) in all nodes is considered. The DG for the first scenario is in the first node of the feeder, while the second combination has the same structure but with DG positioned in the second node. The algorithm will continue until considering all the 3 load possibilities in each node for this structure. The next structure is the short feeder (F1) with a short collateral (C1) in the first node (N1). All possible scenarios of the previous structure are repeated, the only difference is the number of nodes, which in this case are 4 (3 nodes for main feeder and 1 node for the collateral). The last structure is a long feeder (F3) with a long collateral (C2) at node 3 (N3) of the feeder and DG located in the node 5 (N5), i.e. the second node of the collateral. This structure is the same structure of Fig. 2 with only 1 collateral at the end. By this procedure, 10449 combinations are needed to evaluate HC precisely.

IV. VALIDATION OF THE PROPOSED APPROACH

The HC evaluation method formulated in this paper is applied to the MV network of Italian city of Aosta. "Ponte

TABLE I: Thermal limits for different cable sizes [19].

Cable Section (mm^2)	**Thermal Limit** (A)	**Cable Section** (mm^2)	**Thermal Limit** (A)
16	119	95	345
25	155	120	398
35	188	150	450
50	225	185	517
70	280	240	613

Pietra” primary substation, which supplies this network, is located in the east of the city. The Aosta grid departs from two 25 MVA transformers 132/15 kV and has 486 nodes and 16 main feeders; 9 feeders are connected to one transformer, and the other 7 are connected to the second one. According to standard EN 50160 [15], voltage magnitudes are assumed to be acceptable when between 90% and 110% of the nominal value. In addition, thermal limits in this test case are considered according to Table I, reporting values for the feeder ampacity (considering an overloading admitted for conductors of 20% w.r.t. the nominal value) compliant with the Italian scenario. In spite we tested the proposed method on a distribution network supplying a urban area, the Bricks approach has been designed so that it could effectively manage all network grids where data are difficult to collect or reprocess (e.g. emerging countries).

Each branch is modeled by a π-equivalent circuit with series impedance $Z = R + jX$ and susceptance B. Table II reports Aosta grid electrical parameters according to this representation. In this network, loads are modeled as PQ buses with power factor of 0.9 lagging. Fig. 4 shows the load profile of all nodes of the grid for each hour in one year. In our validation test, in each time step, a DG power plant is installed in each node of the network and the HC is evaluated assuming the DG operating with two different Power Factors (PF): a) PF equal to 1 and b) PF equal to 0.9. Different PF are considered in the study to investigate the usefulness of DG reactive power control in increasing HC.

V. EXPERIMENTAL RESULTS AND DISCUSSION

In order to validate the Bricks approach, a comparison between the proposed approach and the HC evaluation based on the complete model of the Aosta city grid is performed. This section shows in detail the results obtained for the 3 categories of feeders and a feeder with collaterals. Considering the impedance of each feeder, its length, and the number of nodes, feeders number 8, 11, 12, 13, 16 are included in the short feeders’ category, feeders 1, 2, 3, 4, 5, 7, 9 and 15 in the medium feeders’ category and feeders 6, 10 and 14 in the long feeders’ category. In order to implement the proposed method, the mean values of the electrical parameters of feeders in each category are considered as electrical parameters of the relevant feeder in the Bricks approach.

TABLE II: Branch parameters in pu.

Feeder	**Nodes No.**	**Coll. Nodes**	**Coll. Nodes No.**	**R(pu.)**	**X(pu.)**	**B(pu.)** (10^{-3})
1	42	3	15	0.0157	0.0084	0.0311
2	47	4	24	0.0368	0.0297	0.0411
3	18	1	3	0.0523	0.0415	0.0912
4	28	2	6	0.0236	0.0136	0.0497
5	28	0	0	0.0274	0.0178	0.0708
6	54	7	21	0.0568	0.0513	0.0220
7	28	1	1	0.0255	0.0163	0.0631
8	6	1	1	0.0224	0.0188	0.0867
9	37	4	13	0.0265	0.0110	0.0348
10	48	4	13	0.0466	0.0357	0.0417
11	24	3	5	0.0212	0.0116	0.0407
12	12	2	3	0.0377	0.0202	0.0540
13	2	0	0	0.0681	0.0390	0.1420
14	60	5	22	0.0269	0.0139	0.0477
15	26	1	2	0.0229	0.0113	0.0374
16	23	1	3	0.0106	0.0060	0.0220

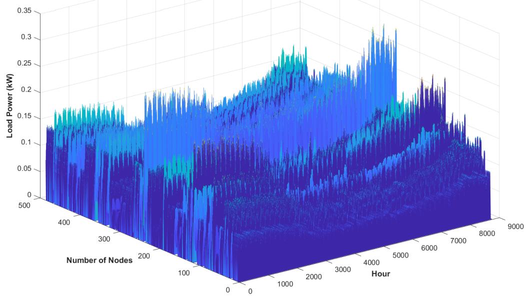

Fig. 4: Load power (kW) in each node along a year.

A. Short feeder

Table III details the branch parameters of the short feeder in Bricks approach. Table IV represents the HC for short feeder without any collateral with PF equal to 1 and 0.9, considering all the constraints (SSV, RVC and thermal limits). First, each constraint is considered separately, then the worst-case scenario is defined as the HC limit. In the short feeders, the main constraint that defines the HC is usually the thermal limit, whereas the voltage limits including SSV variations and RVC result not binding in defining the HC. As it is obvious, the HC for $PF = 1$ is bigger than HC for $PF = 0.9$. The reason of this difference is based on the fact that, activating the reactive power control, the amount of current injected by DG power plants increases, due to the contribution of the reactive power, so the thermal limits affect more the grid’s HC.

TABLE III: Branch parameters in Bricks approach for short feeder.

From	**To**	**R(pu.)**	**X(pu.)**
0	1	0.0232	0.0134
1	2	0.0939	0.0545
2	3	0.0939	0.0545

B. Medium Feeder

Table V details the medium feeder category branch parameters in Bricks approach. Table VI represents the maximum possible DG injection into the grid for medium feeder without any collateral, with PF equal to 1 and 0.9, in the 3 defined nodes. As one can observe, the HC for medium feeder category with $PF = 1$ is greater than $PF = 0.9$ in the first part of the feeder. Near the end of the feeder, when the

PF is equal to 1, the dominant constraint is converted to RVC and the HC drops sharply, while the HC for $PF = 0.9$ continues its steady behavior. Moreover, the comparison of the results obtained with the Bricks approach and the complete electrical model of the network highlights the effectiveness of the approach in representing in a simplified way the complexity of real-life distribution grids.

TABLE V: Branch parameters in Bricks approach for medium feeder.

From	To	R(pu.)	X(pu.)
0	1	0.0621	0.0367
1	2	0.2514	0.1486
2	3	0.2514	0.1486

C. Long Feeder

Table VII describes the long feeder category branch parameter in Bricks approach. In Table VIII, the HC in long feeders with the 3 technical constraints and 2 different power factors considered is shown. It can be seen that in long feeders the HC with $PF = 1$ is bigger than $PF = 0.9$ until the middle of the feeder, whereas from the middle of the feeder the HC with reactive power generated by DG is greater compared to the situation when there is no reactive power contribution. The dominant constraint in long feeders with unity power factor at the beginning is the thermal limit, while from middle of the feeder it is replaced with RVC. In long feeders with PF equal to 0.9, the main constraint defining the HC is represented by thermal limits of conductors in the first part of the lines, while it is converted to RVC near their end. Once again, the results obtained with the Bricks approach proved to be consistent with the actual grid model.

TABLE VII: Branch parameters in Bricks approach for long feeder.

From	To	R(pu.)	X(pu.)
0	1	0.1314	0.1099
1	2	0.5318	0.4449
1	2	0.5318	0.4449

D. Feeder with Collateral

In order to show that the proposed approach is designed properly, a random feeder from Aosta city with its complete structure is considered to be modeled in the Bricks approach. Feeder 9 has 24 nodes and 4 collaterals with 13 nodes, collaterals are located in nodes number 4, 7, 9 and 16 of the main feeder. The first collateral has 1 node, the second one 3 nodes, the third and last one have 2 and 7 nodes, respectively. According to the Bricks approach, the first, second and the third collaterals are categorized as short collaterals and the last one is modeled in the long category. In addition, the first and the second collaterals should be connected to the first node of the main feeder with 10% of the total impedance, the second collateral should be connected to the second node, which is at the middle, and the last one should be connected

TABLE IV: Hosting Capacity evaluation results for short feeder (MW).

Method		First Node			Second Node			Third Node		
		Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
PF 1	**Bricks**	10.58	10.82	11.10	10.63	10.79	10.98	10.67	10.75	10.85
	Real-Grid	10.70	11.06	11.62	10.63	10.76	10.97	10.61	10.65	10.72
PF 0.9	**Bricks**	9.53	9.78	10.06	9.53	9.70	9.89	9.53	9.62	9.71
	Real-Grid	9.65	10.02	10.59	9.53	9.67	9.88	9.49	9.53	9.60

TABLE VI: Hosting Capacity evaluation results for medium feeder (MW).

Method		First Node			Second Node			Third Node		
		Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
PF 1	**Bricks**	10.78	11.25	11.79	11.03	11.34	11.71	9.79	9.84	9.88
	Real-Grid	10.79	11.13	11.65	10.89	11.00	11.65	9.97	10.01	10.04
PF 0.9	**Bricks**	9.71	10.19	10.73	9.82	10.14	10.50	9.88	10.05	10.23
	Real-Grid	9.70	10.04	10.57	9.69	9.81	9.99	9.80	9.83	9.88

TABLE VIII: Hosting Capacity evaluation results for long feeder (MW).

Method		First Node			Second Node			Third Node		
		Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
PF 1	**Bricks**	11.13	12.01	13.00	9.36	9.55	9.70	5.18	5.29	5.38
	Real-Grid	10.81	11.18	11.75	10.27	10.37	10.45	5.13	5.21	5.27
PF 0.9	Bricks	10.02	10.91	11.93	10.06	10.65	11.33	9.95	10.14	10.31
	Real-Grid	9.71	10.08	10.66	9.86	10.14	10.59	9.87	9.92	9.99

TABLE XI: Hosting Capacity evaluation results for real feeder 9 (MW).

Method		First Node Feeder			Second Node Feeder			Third Node Feeder			First Node Collateral One		
		Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
PF 1	**Bricks**	10.78	11.25	11.79	11.01	11.31	11.65	9.80	9.85	9.89	10.58	10.70	10.83
	Real-Grid	11.10	11.58	11.95	11.01	11.18	11.31	9.94	9.97	10.01	10.53	10.53	10.54
PF 0.9	**Bricks**	9.71	10.19	10.74	9.77	10.01	10.28	9.85	9.98	10.12	9.49	9.61	9.75
	Real-Grid	10.03	10.52	10.90	9.81	9.98	10.11	9.82	9.84	9.87	9.42	9.43	9.43
Method		**First Node Collateral 2**			**First Node Collateral 3**			**First Node Collateral 4**			**Second Node Collateral 4**		
		Min	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**
PF 1	**Bricks**	10.58	10.70	10.83	10.75	10.87	11.01	10.52	10.59	10.65	9.35	9.40	9.44
	Real-Grid	10.70	10.72	10.74	10.73	10.74	10.75	10.67	10.70	10.74	9.38	9.40	9.44
PF 0.9	**Bricks**	9.49	9.61	9.75	9.59	9.71	9.86	9.70	9.90	10.12	9.73	9.83	9.95
	Real-Grid	9.54	9.56	9.58	9.54	9.55	9.56	9.77	9.79	9.81	9.77	9.78	9.79

to the last node, with 90% of the total impedance of the feeder. Table IX and Table X represent the branch electrical parameters of short and long collaterals in Bricks approach. In the following, Table XI and Fig. 5 show the HC evaluation for the real feeder 9. As it can be seen, from the beginning, the HC for $PF = 1$ is greater than $PF = 0.9$, however near the end of the feeder this trend reverses due to the different technical constraints. In addition, HC on collaterals is lower than the main feeder at the DG connection point, and by going toward the end of the collateral it decreases.

TABLE IX: Branch parameter in Bricks approach for short collateral.

From	To	R(pu.)	X(pu.)
2	5	0.0411	0.0239

TABLE X: Branch parameter in Bricks approach for short collateral.

From	To	R(pu.)	X(pu.)
3	7	0.1536	0.1535
7	8	0.1536	0.1535

VI. CONCLUSION

In this paper a new method, namely Bricks approach, has been introduced in order to evaluate the hosting capacity (HC) of distribution grids. The proposed method is useful when network data are complex to collect or when the computational effort could result critical. According to Bricks approach, feeders and collaterals are classified in given categories according to their electrical characteristics. The tests performed, taking into account 3 main technical constraints (steady-state voltage variations, rapid voltage changes and thermal limits), proved the method to be effective in estimating the HC in real-life distribution networks, if compared to the method based on the complete grid model. The results have been confirmed with two different reactive power control contributions by DG. The benefits of Bricks approach are less-required information (i.e. is not required the detailed topology of the grid and the detailed power profile for all the nodes) and limited computational time, e.g. in the presented case-study, HC computation required a processing time with Bricks approach of 5 minutes and 37 seconds, whereas with the complete model approach it was over 92 hours.

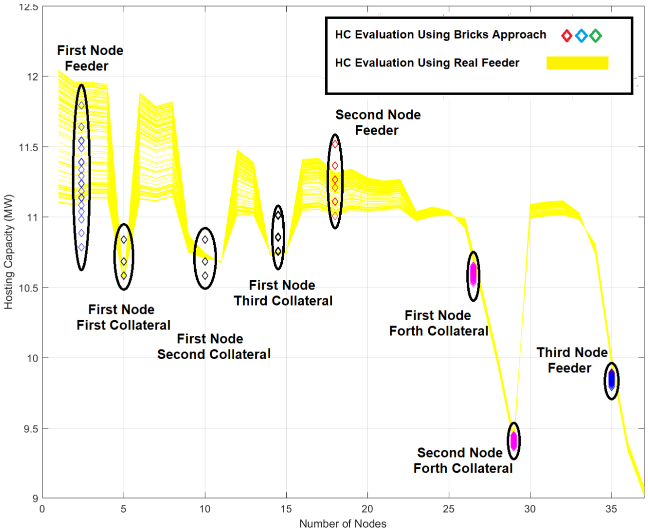

Fig. 5: Real feeder 9 hosting capacity evaluation, PF=1.

REFERENCES

[1] M. Bollen and M. Häger, *Power quality: interactions between distributed energy resources, the grid, and other customers*, Leonardo Energy, 2005.

[2] R. Walling, R. Saint, R. C. Dugan, J. Burke, and L. A. Kojovic, *Summary of distributed resources impact on power delivery systems*, IEEE Transactions on power delivery, vol. 23, pp. 1636-1644, 2008.

[3] J. P. Lopes, N. Hatziargyriou, J. Mutale, P. Djapic, and N. Jenkins, *Integrating distributed generation into electric power systems: A review of drivers, challenges and opportunities*, Electric power systems research, vol. 77, pp. 1189-1203, 2007.

[4] M. Delfanti, D. Falabretti, M. Merlo, G. Monfredini, and V. Olivieri, *Dispersed generation in mv networks: performance of anti-islanding protections*, in Harmonics and Quality of Power (ICHQP), 2010 14th International Conference on, 2010, pp. 1-6.

[5] M. Bollen, Y. Yang, and F. Hassan, *Integration of distributed generation in the power system-a power quality approach*, in Harmonics and Quality of Power, 2008. ICHQP 2008. 13th International Conference on, 2008, pp. 1-8.

[6] N. Jenkins, *Embedded generation*, Power Engineering Journal, vol. 9, pp. 145-150, 1995.

[7] H. Iyer, S. Ray, and R. Ramakumar, *Assessment of distributed generation based on voltage profile improvement and line loss reduction*, in 2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition, 2006.

[8] [AEEG] 2008, *Integrated Text of the technical and economic conditions for connection to electricity grids with the obligation to connect third of the production facilities of electricity*, [Online]. Available: http://www.autorita.energia.it/it/docs/08/099-08arg.htm

[9] N. Etherden and M. H. Bollen, *Increasing the hosting capacity of distribution networks by curtailment of renewable energy resources*, in PowerTech, 2011 IEEE Trondheim, 2011, pp. 1-7.

[10] M. Delfanti, M. S. Pasquadibisceglie, M. Pozzi, M. Gallanti, and R. Vailati, *Limits to dispersed generation on Italian MV networks*, in Electricity Distribution-Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on, 2009, pp. 1-4.

[11] J. Deuse, S. Grenard, K. Karoui, O. Samuelsson, L. Gertmar, P. Karlsson, et al.,*Interactions of dispersed energy resources with power system in normal and emergency conditions*, in CIGRE 2006 Conference, 2006.

[12] D. Bertini, D. Falabretti, M. Merlo, D. Moneta, and J. S. D. A. Carneiro, *Hosting capacity of Italian LV distribution networks*, in 21st International Conference on Electricity Distribution, 2011.

[13] M. Delfanti, M. Merlo, G. Monfredini, V. Olivieri, M. Pozzi, and A. Silvestri, *Hosting dispersed generation on Italian MV networks: Towards smart grids*, in Harmonics and Quality of Power (ICHQP), 2010 14th International Conference on, 2010, pp. 1-6.

[14] M. Delfanti, M. Merlo, M. Pozzi, V. Olivieri, and M. Gallanti, *Power flows in the Italian distribution electric system with dispersed generation*, in Electricity Distribution-Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on, 2009, pp. 1-5.

[15] Technical Standard EN 50160, CENELEC, *Voltage characteristics of electricity supplied by public distribution systems.*

[16] V. Allegranza, A. Ardito, E. De Berardinis, M. Delfanti, and L. Lo. Schiavo, *Assessment of short circuit power levels in HV and MV networks with respect to power quality*, in 19th International Conference on Electricity Distribution (CIRED), Vienna, 2007.

[17] A. Abdelaziz, E. Ali, and S. A. Elazim, *Optimal sizing and locations of capacitors in radial distribution systems via flower pollination optimization algorithm and power loss index*, Engineering Science and Technology, an International Journal, vol. 19, pp. 610-618, 2016.

[18] CEI 0-16, *Reference technical rules for the connection of active and passive Users to HV and MV networks of electricity distribution Companies*, April 2009.

[19] IRCE, *Cavo unipolare e tripolare di media tensione non propagante la fiamma*, Available: http://www.irce.it/, in Italian.