HOSTING CAPACITY OF ITALIAN LV DISTRIBUTION NETWORKS

Danilo BERTINI
RSE – Italy
danilo.bertini@rse-web.it

Diana MONETA
RSE – Italy
diana.moneta@rse-web.it

Juliano SILVA DE ASSIS CARNEIRO
consultant – Brazil
jsacbh@yahoo.com.br

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

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

Andrea SILVESTRI
Politecnico di Milano – Italy
andrea.silvestri@polimi.it

ABSTRACT

The increasing diffusion of DG in the distribution networks can eventually lead to operational issues. In this paper, the authors propose a systematic approach to evaluate the Hosting Capacity of LV distribution networks according to most significant technical constraints: thermal limits of transformers and lines, steady-state voltage limits and fast voltage variations. The proposed methodology has been applied to estimate the Hosting Capacity of Italian LV networks. Simulation results could support DSOs in identifying the inherent limits of distribution systems and guide their decisions on solutions to facilitate the DG diffusion.

INTRODUCTION

Pressured by energy shortages and climatic issues, National Governments have been offering different incentives to the large-scale deployment of Renewable Energy Sources (RES), especially in Germany and Spain [1]. This energy policy has significantly increased the amount of Distributed Generation (DG) over the past decades, having as result several benefits on the power systems, such as power loss reduction and lower greenhouse gas emissions. However, the DG diffusion has also some important drawbacks on the electrical networks' operation, which must be properly addressed in order to avoid a reduction of their power quality and reliability levels.

In the past, distribution systems have been planned and operated as passive networks, characterized by unidirectional power flows from High Voltage (HV) and Medium Voltage (MV) networks down to Low Voltage (LV) systems. In the current scenario, where several DG units are connected to LV networks, power flows have completely changed, which might result in odd voltage profiles, overloaded components, increased short circuit power and incorrect operation of protection systems. Therefore, from the DSO perspective, it is extremely important to estimate the available capacity of electrical networks (Hosting Capacity; HC), in terms of DG penetration, without requiring additional investments in the system. A first survey on the HC of the Italian LV distribution system is presented in [2].

This paper aims at proposing a systematic approach to evaluate the Hosting Capacity of LV networks with respect to three important technical constraints: thermal limits of transformers and lines, steady-state voltage limits and fast voltage variations. The analysis is based on load-flow studies without considering the dynamic phenomena that might take place in distribution networks.

The paper is organised as follows. Firstly, a set of representative models of Italian LV distribution networks is described. Then, the proposed procedure is presented, as well as the technical constraints adopted in the study. Later on, simulation results are illustrated and discussed in details. Finally, some concluding remarks are provided.

LV NETWORK MODELS

LV networks present a great variety of topologies and several components, which hampers the production of significant databases for real LV networks. Therefore, a set of representative models has been created according to statistical data obtained from national standards and power utilities. In particular, a simplified two-level representation has been adopted, where feeders (trunk) and lateral busses are modelled separately. By combining such modular structures, it is possible to recreate different topologies of both urban and rural distribution networks found in real LV systems. Moreover, these models are characterized by key parameters such as loading condition, length of trunk and lateral branches, conductor type and nominal power of transformers, among others. This parametric model allows to compose different networks by varying the above parameters, thus encompassing a significant part of the national electrical system. As generally found in literature [3], the models will be divided into rural and urban networks.

Main feeders

Main feeders are the backbones of LV distribution networks and have different features depending on the geographical region: rural or urban. Rural areas are characterized by low load densities, long lines with overhead conductors and small sections. On the other hand, urban areas have high load densities, short lines with underground cables and high sections. In both cases, but more commonly in rural areas, conductor sections can be reduced as the distance from the MV/LV transformers increases. However, the planning of LV networks considers lines with constant section (sometimes, this is done in order to ensure service availability by feeding loads from the opposite MV/LV substation in case of faults). Therefore, this study refers only to LV lines with constant section.

In the Italian scenario, it is possible to consider six main categories of Low Voltage networks, each one corresponding to the nominal power of transformers located at the MV/LV substation. Generally, small transformers, i.e., 50 kVA, 100 kVA and 160 kVA, are used in rural networks, whereas large transformers, i.e., 250 kVA, 400 kVA and 630 kVA, are adopted in urban networks [2].

Main feeders are composed of conductors with cross sections from 70 mm^2 to 240 mm^2, usually in copper (Cu) or aluminum (Al). Generally, 70 mm^2 and 95 mm^2 Al conductors are used in rural areas with overhead structures, whereas 95 mm^2 and 150 mm^2 Cu cables, or 240 mm^2 Al conductors, are used in urban networks with underground structures.

The total length of main feeders, which are composed of several trunk nodes to which lateral branches are connected, also depends on the geographic region. In particular, long lines, typically between 300 m and 900 m, are associated with rural networks, whereas reduced line length, normally from 100 m to 300 m, are used in urban networks. Figure 1 shows a typical 50 kVA rural feeder.

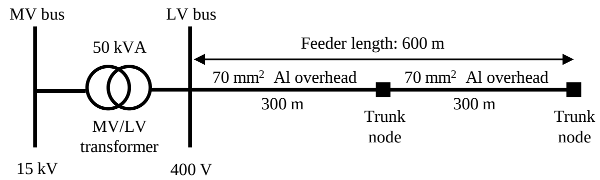

Figure 1. Feeder model: 50 kVA transformer.

Lateral branches

Lateral branches are the most capillary element of distribution systems. In this work, a common, representative model for both geographical areas is proposed. The lateral model, called "rigid connection", is composed of a branch with a single bus, as shown in Figure 2. This model is certainly not exhaustive, considering the different possibilities of connecting lateral busses to the main feeders. However, it is the simplest and most widely used connection in distribution systems.

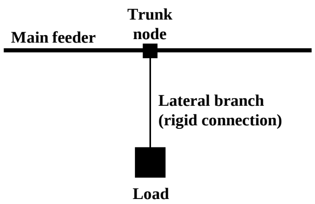

Figure 2. Lateral model.

Even if the lateral connection is the same for rural and urban networks, the model parameters of each geographical zone are quite different. For rural networks, 10 mm^2 Cu and 35 mm^2 Al overhead conductors are employed. The lateral length is set equal to 30 m. For urban networks, 16 mm^2 and 25 mm^2 Cu conductors are the most common solution. The lateral length is equal to 30 m as well.

An example of proposed LV networks

As aforesaid, different LV networks can be formed by combining feeder models with lateral models and varying their parameters. Figure 3 shows an example of rural network formed by the combination of feeder and lateral models.

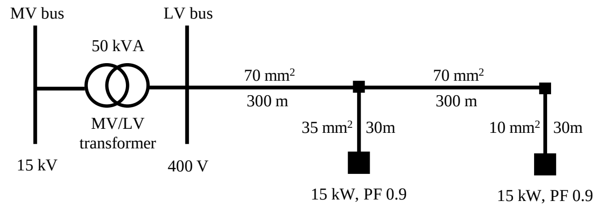

Figure 3. Example of rural network.

Each bus of the network represents a passive, symmetric three phase load with active power P = 15 kW and a power factor PF = 0.9. These values were derived from average contractual data of Italian LV consumers [3].

According to Italian technical standard CEI 11-20 [4], each transformer should be loaded up to 60% - 65% of its rated power, under normal operation. This recommendation is used to calculate the amount of load connected to each transformer. Table 1 summarizes the LV networks considered in this study.

Table 1. Proposed set of LV networks.

Network model	Feeders	Laying	Section [mm^2]	Total length [m]	Load [kW]
TR 50*	1	overhead	95/70	300/600/900	30
TR100*	2	overhead	95/70	300/600/900	60
TR 160*	2	overhead	95/70	300/600/900	96
TR 250**	4	underground	150/95	100/200/300	150
TR 400**	4	underground	240/150	100/200/300	240
TR 630**	4	underground	240/150	100/200/300	378

* Rural lateral branch: 10/35 mm^2 conductors, 30 m.

** Urban lateral branch: 16/25 mm^2 conductors, 30 m.

ALGORITHM FOR EVALUATING THE HOSTING CAPACITY

The main objective of this paper is to provide a systematic approach for evaluating the Hosting Capacity of LV distribution networks. The basic idea consists in iteratively increasing the DG penetration in a given bus until the operating limits are violated, as illustrated in Figure 5. After that, the next bus is investigated using the same algorithm. The study ends when all busses of a given distribution network are checked.

The DG is simulated by means of a negative load (PQ Load Flow representation), evaluating the impact of increasing power injections (1 kW step). DG power factor is assumed equal to 1, complying with technical standard CEI 11-20 [4], which prevents generators from sustaining local voltage. Only one generator at a time is connected to a specific LV network (nodal analysis).

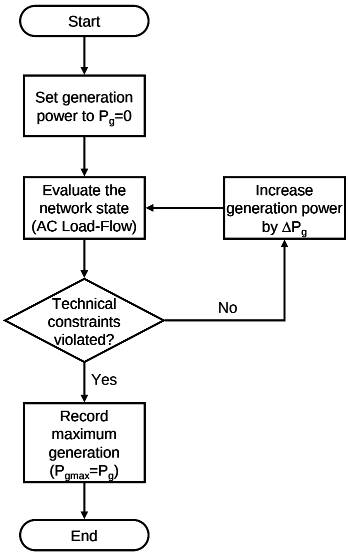

Figure 4. Algorithm for evaluating the Hosting Capacity of distribution networks.

The technical constraints herein considered regard the thermal limits of transformers and lines, steady-state voltage limits and rapid voltage changes. A brief description of each operating limit is given in the following paragraphs.

Steady-state voltage variations (SSVV)

EN 50160 [5] specifies that SSVV for LV distribution networks must remain within ±10% of the rated voltage (i.e., from 360 V to 440 V). These limits must be satisfied during 95% of time to avoid malfunctions of equipment connected to the grid.

Rapid voltage changes (RVC)

There are no hard constraints on RVC, since EN 50160 [5] establishes bounds of 4÷6% as reference values. Nevertheless, connection rules fixed by DSOs usually require a RVC threshold equal to 5%. This limit is used here to evaluate the Hosting Capacity.

Thermal limits

Thermal limits depend strictly on the characteristics of a specific component, apart from considerations regarding technical-economic evaluations for equipment operation. Therefore, current ratings indicated in component datasheets are used to calculate the maximum power flows through all branches.

SIMULATION RESULTS

For the sake of simplicity, simulation results are focused on two significant LV systems:

- *urban network*: 400 kVA transformer, 150 mm^2 Cu conductor, 200 m feeder length;
- *rural network*: 100 kVA transformer, 70 mm^2 Cu conductor, 600 m feeder length.

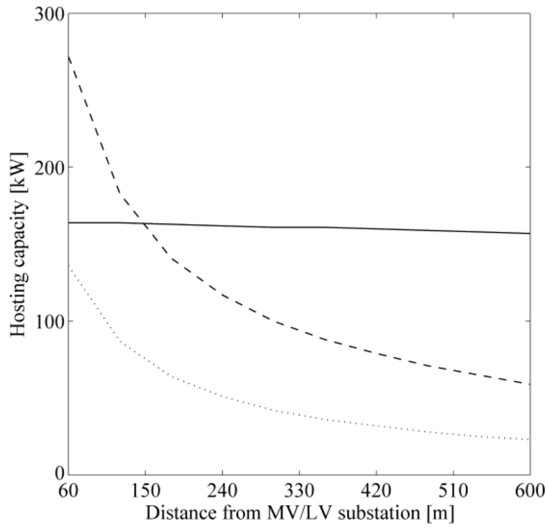

Figure 5. Hosting Capacity of 100 kVA rural network. Solid line is for thermal limits; dashed and dotted lines are for RVC and SSVV, respectively.

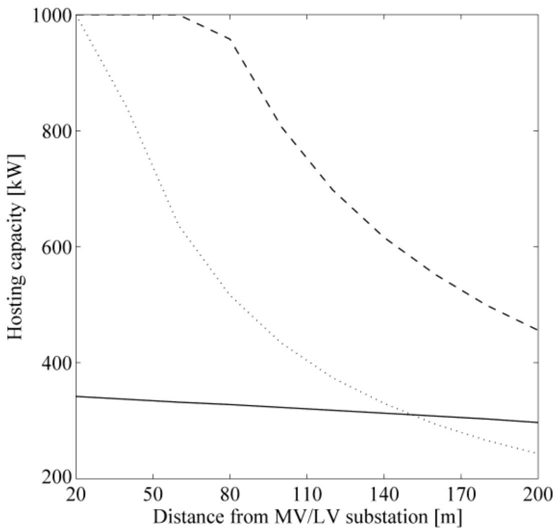

Figure 6. Hosting Capacity of 400 kVA urban network. Solid line is for thermal limits; dashed and dotted lines are for RVC and SSVV, respectively.

The HC profile of main feeders is shown in Figures 5 and 6 for rural and urban networks, respectively. It is interesting to note that the Hosting Capacity of both rural and urban networks reduces as distance of the DG connection point from the MV/LV substation increases. In rural networks, the limiting constraint is represented by rapid voltage changes (HC from 20 kW up to 140 kW, indicatively). In urban networks, thermal constraints represent the limiting factor for short electrical distances (near to the MV/LV substation), while RVC and SSVV are binding for generators connected at the end of feeders. In any case, the calculated HC is greater than 200 kW.

Summary of results

Figures 7 and 8 show the estimated range for DG diffusion in rural and urban networks described in Table 1. The results are given separately by connection type (feeder or lateral busses) and MV/LV transformer.

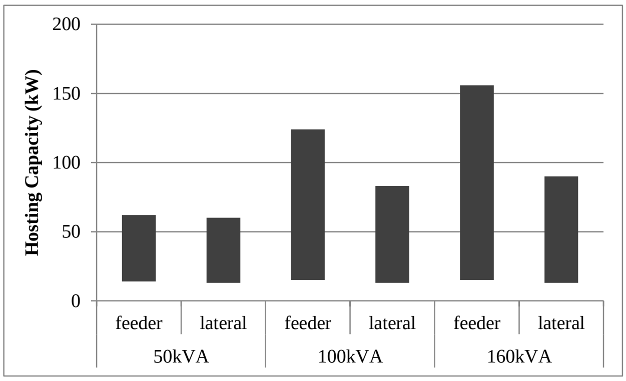

Figure 7. Summary of results: rural networks.

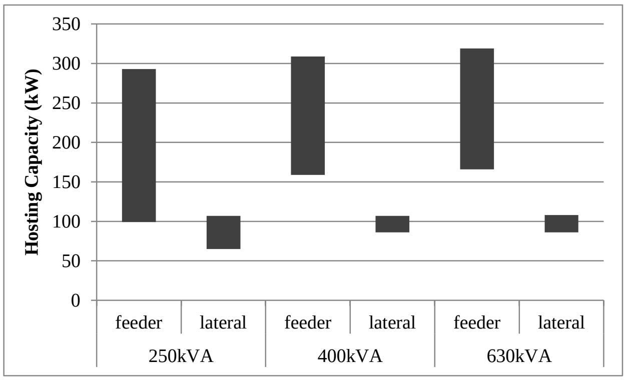

Figure 8. Summary of results: urban networks.

The results show that:

- rural networks are characterized by small transformers, overhear lines with limited cross sections and long distances. These features result in a limited Hosting Capacity: the minimum value (15 kW) occurs far from MV/LV substations, where RVC is the limiting factor, regardless of the connection type. On the other hand, the maximum HC is always observed near to MV/LV substations, where thermal limits or RVC represent the binding constraints. At this location, the Hosting Capacity increases significantly, reaching up to 160 kW.
- Urban networks are characterized by large transformers, underground cables with large cross section and short distances. This implies higher HC than rural networks, especially for connection in feeders and near to MV/LV substations (up to 320 kW). Thermal limits are most restrictive constraints for DG connection near to MV/LV substations, whereas RVC and SSVV become the limiting constraint for DG connection far from the MV/LV substations. In urban networks, the DG connection to lateral busses results in a drastic reduction of Hosting Capacity and should be avoided.

FINAL CONSIDERATIONS

This paper described a systematic approach to evaluate the Hosting Capacity of LV distribution networks according to three important technical constraints: thermal limits of transformers and lines, steady-state voltage variations and rapid voltage changes limits.
A set of representative models have been created according to statistical data obtained from national standards and power utilities. In particular, a simplified two-level representation has been adopted, where feeders (trunk) and lateral busses are modelled separately. Simulations have shown that RVC and SSVV represent the major constraints to DG penetration in rural networks, while thermal limits are the most restrictive factor in urban networks. The Hosting Capacity of rural networks ranges between 20 and 160 kW, whereas urban networks can accept from 100 to 300 kW in case of direct connection to the feeders.
As final consideration, it is worth underlining that the analysis is based on network models which, though representative of existing conditions, cannot provide an exhaustive description of each possible situation. Nevertheless, the results presented in this paper can be used as a reference for further considerations about the limits to DG diffusion in Italian LV distribution systems.

ACKNOWLEDGMENTS

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE (formerly known as ERSE) and the Ministry of Economic Development – General Directorate for Nuclear Energy, Renewable Energy and Energy Efficiency stipulated on July 29th, 2009 in compliance with the Decree of March 19th, 2009.

REFERENCES

[1] International Energy Agency, 2010, *Renewables Information 2010 [2009 data]*, www.iea.org.

[2] AEEG, 2010, *Resolution ARG/elt 223/10 "Monitoraggio dello sviluppo degli impianti di generazione distribuita in Italia per l'anno 2009 ed analisi dei possibili effetti della generazione distribuita sul sistema elettrico nazionale", available in italian on www.autorita.energia.it*.

[3] EU Project DISPOWER, 2004, *Technical Report "Structure and data concerning electrical grids for Italy, Germany, Spain, UK and Poland"*, www.dispower.org.

[4] CEI, 2000, *Technical standard CEI 11-20 "Electrical energy production system and uninterruptible power systems connected to I and II class network"*, www.ceiweb.it.

[5] CENELEC, 2007, *Technical Standard EN 50160, "Voltage characteristics of electricity supplied by public distribution systems"*.