A BENCHMARK LOW VOLTAGE MICROGRID NETWORK

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1. INTRODUCTION

The increasing penetration of distributed generation resources to the low voltage (LV) grids, such as photovoltaics, CHP micro-turbines, small wind turbines in certain areas and possibly fuel cells in the near future, alters the traditional operating principle of the grids. A particularly promising aspect, related to the proliferation of small-scale decentralized generation, is the possibility for parts of the network comprising sufficient generating resources to operate in isolation from the main grid, in a deliberate and controlled way. These are called Microgrids and the study and development of technology to permit their efficient operation has recently started with a great momentum ([1,2]).

Microgrids are foreseen within public distribution grids and therefore suitable study case networks are required to perform simulation and analysis tasks. Moreover, standardizing study case grids to provide "benchmark" networks suitable for Microgrid design would further enhance their merit and utility.

The objective of this paper is to present and discuss a benchmark LV network developed within the EU project "Microgrids", Contract ENK5-CT-2002-00610 and later adopted as a benchmark LV system by CIGRE TF C6.04.02: "Computational Tools and Techniques for Analysis, Design and Validation of Distributed Generation Systems". The network consists of an LV feeder, while a more extended multi-feeder version is also included in the Appendix. The emphasis is placed on the network itself, rather than on the microsources connected and the control concepts applied. The benchmark network maintains the important technical characteristic of real utility grids, whereas, at the same time, it dispenses with the complexity of actual networks, to permit efficient modeling and simulation of microgrid operation.

2. THE BENCHMARK LOW VOLTAGE FEEDER

2.1 General Characteristics of the LV Network

Before presenting the benchmark network, some important technical characteristics of

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public LV distribution grids are summarized (pertaining more to European networks):

Structure. The majority of LV public distribution networks have a radial layout, with a number of LV feeders starting from the LV busbars of the infeeding MV/LV substation. Each feeder may include one or more spurs (branches). Consumers are connected anywhere along the feeder or its spurs.

Symmetry. The connection of single-phase consumers makes LV networks inherently unbalanced. In addition, single-phase lines may exist, particularly as feeder branches.

Substation. The MV/LV substation feeding the LV network typically comprises a single transformer with a rating of a few hundred kVA up to 1 MVA. The transformer is equipped with off-load taps at the HV winding, providing a typical regulation range of ±5%. Its connection group is usually Dyn11, corresponding to a delta-connected primary and a wye-connected secondary winding.

Protection. The only protection encountered in public LV networks typically consists of simple phase overcurrent devices, most commonly fuses. The MV/LV transformer is protected by fuse links at the MV side. A general protection element may not exist at the output of the transformer LV winding, whereas each LV feeder is protected by its own fuses. No other protection means are utilized along the feeder or its branches.

Line types. LV network lines are either underground cable lines, encountered mainly in urban areas with a high load density, or most commonly overhead lines, traditionally constructed by Al (or Cu) bare conductors. Ease of installation and environmental reasons have led to the extensive use of twisted insulated conductors for overhead LV lines during the last decades.

Earthing. Using the classification of IEC 60364, public LV networks are either of the TN or the TT type. The principle of each earthing scheme is illustrated in Fig. 1. More information on the subject is provided in [3,4].

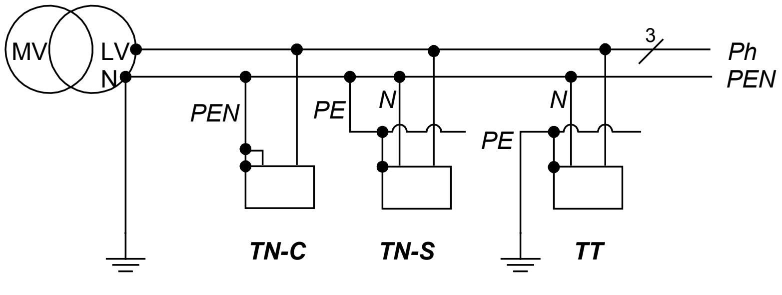

Figure 1. Principle of the TN and TT earthing schemes.

2.2 Description of the Benchmark LV Feeder

Based on the basic requirements discussed in the previous section, the study case LV feeder is illustrated in Fig. 2. The feeder is an overhead line with twisted XLPE cable, serving a suburban residential area with a limited number of consumers connected along its length, as well as at the end of the branch at its middle. Line types are marked on the diagram and the respective parameters are given in the Appendix. Section lengths can be determined from the number of poles, given the fixed pole-to-pole distance of 35 m. The network neutral is multi-grounded, at the substation, at every second pole and at each consumer connection point. At the end of the lateral branch, a connection of the neutral may exist to an adjacent LV line (fed by another substation).

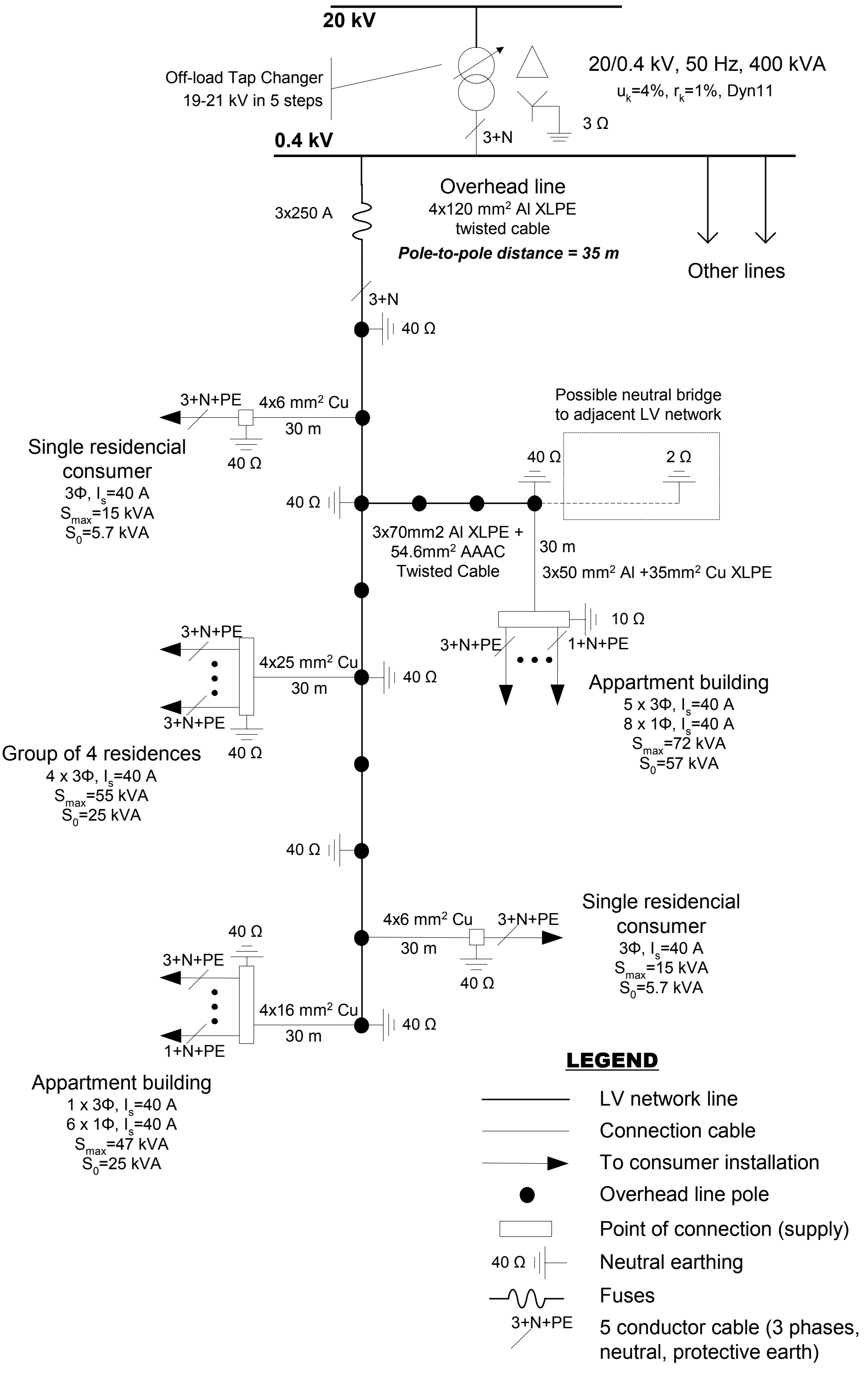

Figure 2. The benchmark LV feeder, in its standard ("non-microgrid") form.

The arrangements at the service connection of each customer are presented in more detail in Fig. 3. Each service connection includes the electricity meter and an overcurrent protection element (fuse links or a miniature circuit breaker for small consumers). For the service cable, a standard 30 m length is adopted in Fig. 2. The earthing scheme of the network may be either of the TN or the TT type, depending on the connection or not of the PE conductor of the consumer installation to the network neutral. The 40 Ω earthing resistances noted on the diagram correspond to a standardized conductive rod, 2.5 m long by 0.02 m in diameter, buried in homogeneous conductive earth of 100 Ω.m resistivity. The apartment building on the lateral is supposed to have a more effective earthing arrangement (either multiple rods or some sort of foundation earth).

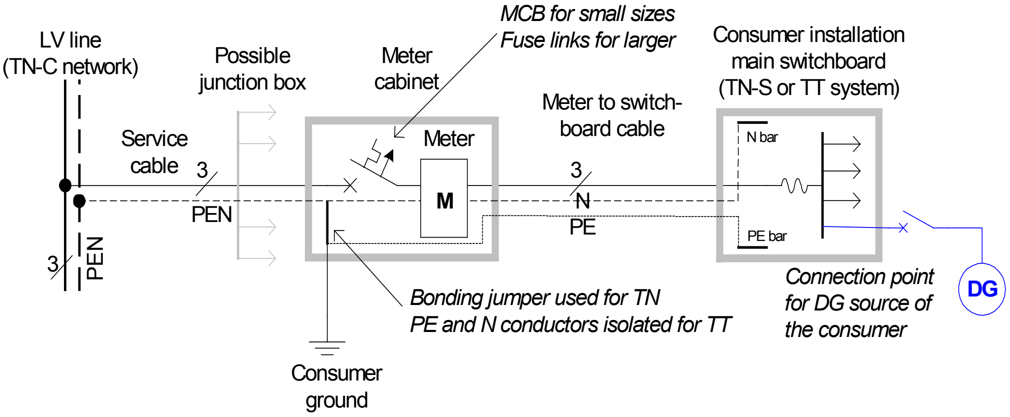

Figure 3. Typical service connection arrangement.

2.3 Consumer Demand Characteristics

Each consumer of the feeder is characterized by a maximum permissible current, I_s, which corresponds to the rated current of the overcurrent protection element in the connection box (Fig. 3). The maximum demand $S_{\max}$ of each consumer group, also given in Fig. 2, depends on the number of individual consumers within each group, and is found using standardized coincidence factors for residential consumers, which become smaller as the number of consumers increases (e.g. [5]). For this reason, the contribution S_0 of each group to the maximum demand of the feeder will be further reduced, as given in Fig. 2. The total maximum demand of the feeder is 116.4 kVA. The power factor of all consumers may be assumed equal to 0.85 lagging. Aggregate daily load curves are provided in the Appendix.

3. THE BENCHMARK LOW VOLTAGE MICROGRID NETWORK

Based on the LV feeder of Fig. 2, the benchmark LV microgrid network shown in Fig. 4 is derived. It includes representative sources from all currently important (or emerging, but promising) technologies, such as photovoltaics, microturbines (CHP generation), wind turbines and fuel cells.

Specific technical details, models for individual sources and control concepts are beyond the scope of this paper and will be specified in application studies. In Fig. 4, only relevant installation locations and sizes are indicated. The total installed capacity of the microsources is about 2/3 of the maximum load demand of the feeder (~100 kW), to provide the possibility of simulating load management scenaria.

To support the islanded operation of the microgrid, a fast-responding central storage unit is also considered, which may be either a battery inverter, or any other device with sufficiently fast response to undertake the frequency regulation task upon disconnection from the grid (e.g. a flywheel). Notably, this constitutes a centralized control approach. Alternatively, the individual microsources might be equipped with local storage (e.g. batteries or ultra-capacitors) and suitable controls to ensure a decentralized active power/frequency concerted regulation ([6]).

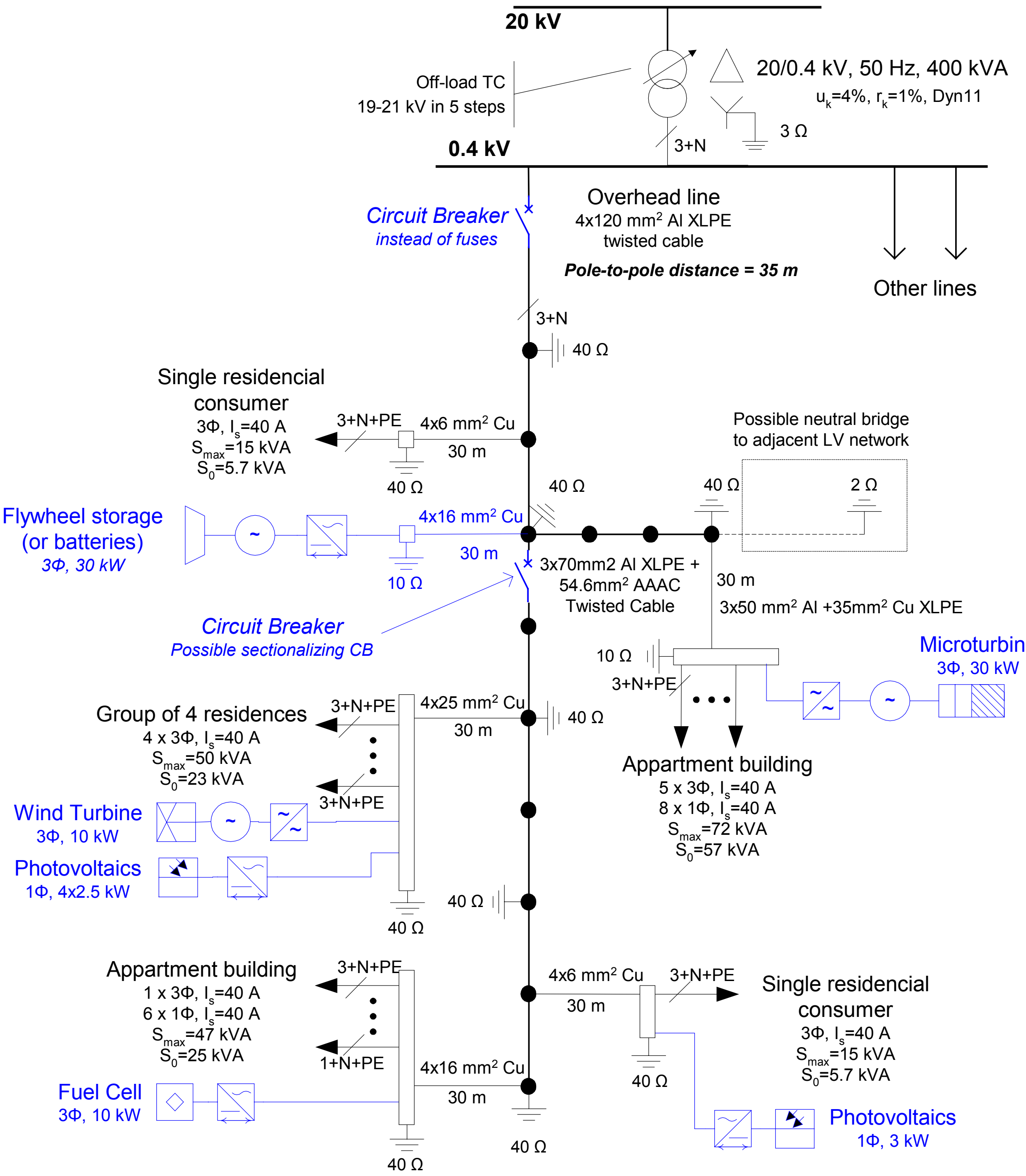

Figure 4. Benchmark LV microgrid network.

Compared to the standard LV feeder of Fig. 2, in Fig. 4 the fuses at the feeder departure have been replaced by a circuit breaker, in order to permit the controlled connection and isolation of microgrid from the main grid. A second sectionalizing breaker may also be inserted at the middle of the feeder, if selective isolation of faulted parts of the microgrid is to be studied. However, in such a case, suitable frequency regulating means should be foreseen in each isolated section.

The earthing arrangements of the network remain unchanged for microgrid operation. Preliminary investigations have shown that this is acceptable ([7]), although further study may be required on this subject. Regarding the protection philosophy, devices and settings, it is certain that modifications will be required to the traditional LV network practice, which have not been incorporated in the study case network of Fig. 4.

4. CONCLUSIONS

In this paper a benchmark LV microgrid network is presented, which is suitable for steady state and transient simulations. The study case network is based on a standard LV feeder, where microsources and storage devices of various types are connected. A more extended network is also provided in the Appendix, to facilitate the simulation of multi-feeder microgrids or multiple microgrids within the same LV grid.

5. ACKNOWLEDGEMENT

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6. REFERENCES

[1] EU Project "MICROGRIDS: Large Scale Integration of Micro-Generation to Low Voltage Grids (ENK5-CT-2002-00610)". Website: http://microgrids.power.ece.ntua.gr/.

[2] R. Lasseter, A. Akhil, C. Marnay, J. Stephens, J. Dagle, R. Guttromson, A.S. Meliopoulos, R. Yinger and J. Eto, "White Paper on Integration of Distributed Energy Resources–The CERTS MicroGrid Concept". LBNL-50829, US Department of Energy, Office of Power Technologies. Contract DE-AC03-76SF00098.

[3] B. Lacroix, R. Calvas, "Earthing systems in LV". Cahier Technique No. 172, Schneider Electric, 2000.

[4] B. Lacroix, R. Calvas, "Earthing systems worldwide and evolutions". Cahier Technique No. 173, Schneider Electric, 1995.

[5] "Standardization of Electricity Meters", Distribution Directive No.45, Public Power Corporation (PPC) of Greece, 1982.

[6] D. Georgakis, S. Papathanassiou, N. Hatziargyriou, A. Engler, C. Hardt, "Operation of a prototype Microgrid system based on micro-sources equipped with fast-acting power electronics interfaces". Proceedings of PESC'04, June 2004, Aachen, Germany.

[7] "Safety Guidelines: Report with proposed earthing and safety procedures to ensure safe operation of the Microgrid", Microgrids Deliverable DE1, Dec. 2004.

7. APPENDIX

A more extended study case LV network is included in Fig. 5, which comprises two additional LV lines, compared to the benchmark network of Fig. 2. The first is a dedicated underground cable line, serving a workshop, whereas the other one is an overhead line serving a small commercial district. The diagram provides for each consumer the same information as in Fig. 2. On the commercial load feeder, where a large number of single-phase consumers are connected, the respective phases are also noted.

The study case network of Fig. 5 permits the simulation of microgrids with multiple LV feeders and diverse load types, or even different microgrid entities within the same LV network (e.g. by considering that the commercial line forms a second microgrid, with CHP microturbines as microsources). Depending on the part of the network, which forms the microgrid (or microgrids), sectionalizing switches need to be inserted at selected locations and suitable microsource scenaria must be adopted.

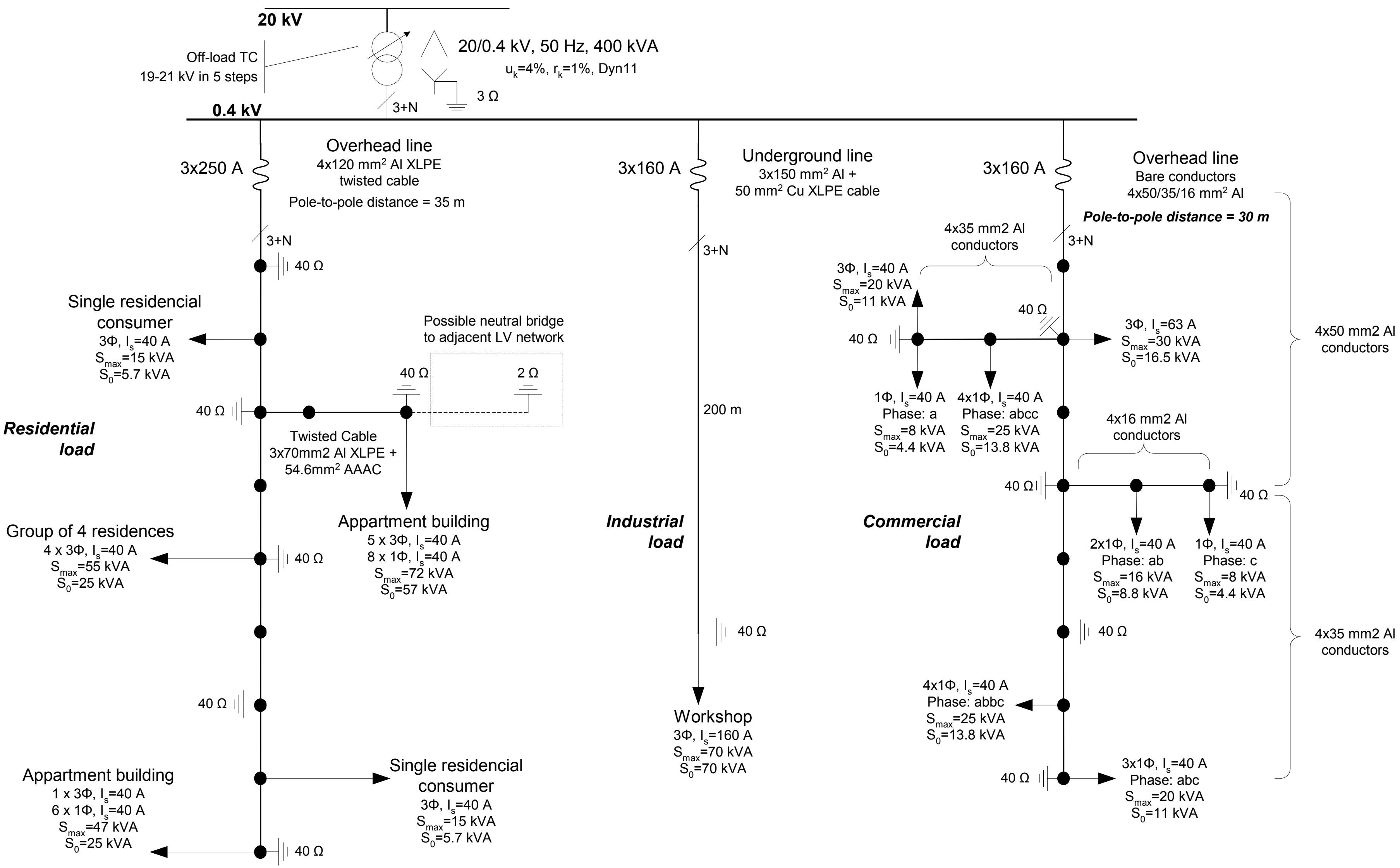

Figure 5. Benchmark LV network for the study of multi-feeder or multiple LV microgrids.

Aggregate daily load curves for the three load types of the benchmark networks are shown in Fig. 6. Impedance data for the various line types are provided in Table 1. Neutral resistances are given where the neutral has a different cross section than the phases. Calculated zero sequence impedances are quoted for selected line types, appearing in the benchmark network of Fig. 4 (derived for combined neutral and earth return path of the current).

Table 1. Impedance data for the benchmark network lines

	Line type	**R_{ph} (Ω/km)**	**X_{ph} (Ω/km)**	**$R_{neutral}$ (Ω/km)**	**R_0 (Ω/km)**	**X_0 (Ω/km)**
1	OL - Twisted cable 4x120 mm^2 Al	0.284 (1)	0.083		1.136	0.417
2	OL - Twisted cable 3x70 mm^2 Al + 54.6 mm^2 AAAC	0.497 (1)	0.086	0.630	2.387	0.447
3	OL - Al conductors 4x50 mm^2 equiv. Cu	0.397 (1)	0.279			
4	OL - Al conductors 4x35 mm^2 equiv. Cu	0.574 (1)	0.294			
5	OL - Al conductors 4x16 mm^2 equiv. Cu	1.218 (1)	0.318			
6	UL - 3x150 mm^2 Al + 50 mm^2 Cu	0.264 (2)	0.071	0.387 (2)		
7	SC - 4x6 mm^2 Cu	3.690 (3)	0.094		13.64	0.472
8	SC - 4x16 mm^2 Cu	1.380 (3)	0.082		5.52	0.418
9	SC - 4x25 mm^2 Cu	0.871 (3)	0.081		3.48	0.409
10	SC - 3x50 mm^2 Al + 35 mm^2 Cu	0.822 (2)	0.077	0.524 (2)	2.04	0.421
11	SC - 3x95 mm^2 Al + 35 mm^2 Cu	0.410 (2)	0.071	0.524 (2)		

OL: Overhead line, UL: Underground line, SC: Service connection
(1): Ohmic resistance at 50 °C conductor temperature
(2): Ohmic resistance at temperature 90 °C for phase conductors and 20 °C for the neutral
(3): Ohmic resistance at temperature 70 °C for all conductors

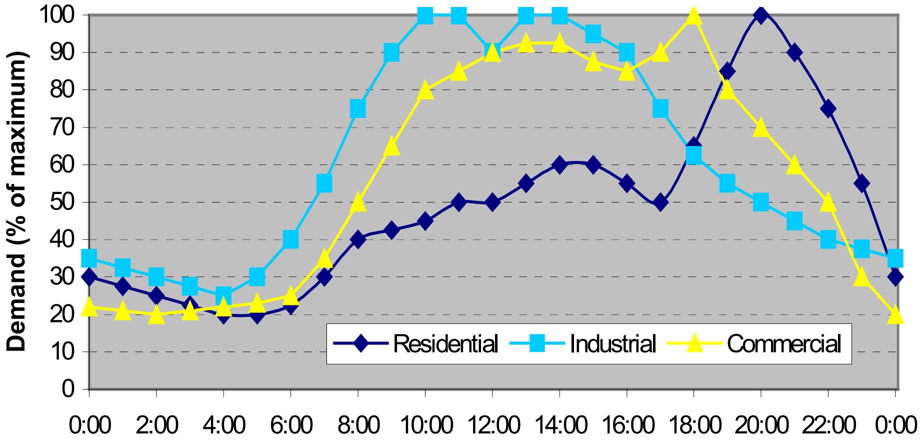

Figure 6. Daily load curves for the three load types of the benchmark LV networks.

Summary

Microgrids are foreseen to be developed within public distribution grids and therefore suitable study case networks are required to perform simulation and analysis tasks. Standardizing study case grids to provide "benchmark" networks suitable for microgrid development, further enhances their merit and utility. In the paper a benchmark LV network is presented and discussed, consisting of a LV feeder supplying a suburban residential area. A more extended version of the benchmark network is also included, suitable for the study of multi-feeder or multiple microgrids. The emphasis is placed on the network characteristics, while microsources, representative of all currently important technologies, are connected to selected nodes. The benchmark network maintains the important technical characteristic of real life utility grids, while dispensing with the complexity of actual networks, to permit efficient modeling and simulation of microgrid operation.