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WPG. Evaluation of the system performance on power system operation

TG1. Development of future scenarios and EU network data collection

DG1. Definition of future Microgrid scenarios and performance indices

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Abbreviations

AIT	Average Interruption Time
CAIDI	Customer Average Interruption Duration Index
CHP	Combined Heat and Power
CI	Customer Interruption
C_i	Interruption cost
CML	Customer Minutes Lost
EEX	European Energy Exchange, market place located in Leipzig, Germany
E_i	Energy not supplied (cumulative / per event)
ENS	Energy not supplied
EEA	European Emission Allowances
F_i	Frequency of supply interruptions
GHG	Greenhouse Gas
GSP	Grid Supply Point
GWP	Global warming potential
HV	High Voltage
ICT	Information and communication technology
IPCC	Intergovernmental Panel on Climate Change
LRPD	Lodz Region Power Distribution Company
LV	Low Voltage
MV	Medium Voltage
O&M	Operation and maintenance
Pi	Interrupted power (cumulative / per event)
Q_i	Probability of supply interruptions (unavailability)
RES	Renewable energy source
SAIDI	System Average Interruption Duration Index
SAIFI	Customer Average Interruption Frequency Index
SME	Small-medium enterprise
T_i	Average duration of supply interruptions
VPP	Virtual Power Plant
WP	Work Package
WPG	Work Package G, Project More Microgrids
WPH	Work Package H, Project More Microgrids
μG	Microgeneration

Description of networks

UMV	Urban medium voltage (network)
RMV	Rural medium voltage (network)
ULV	Urban low voltage (network)
RLV	Rural low voltage (network)

Country abbreviations:

DE	Germany
DK	Denmark
GR	Greece
IT	Italy
MC	Macedonia
NL	The Netherlands
PL	Poland
PT	Portugal
UK	United Kingdom

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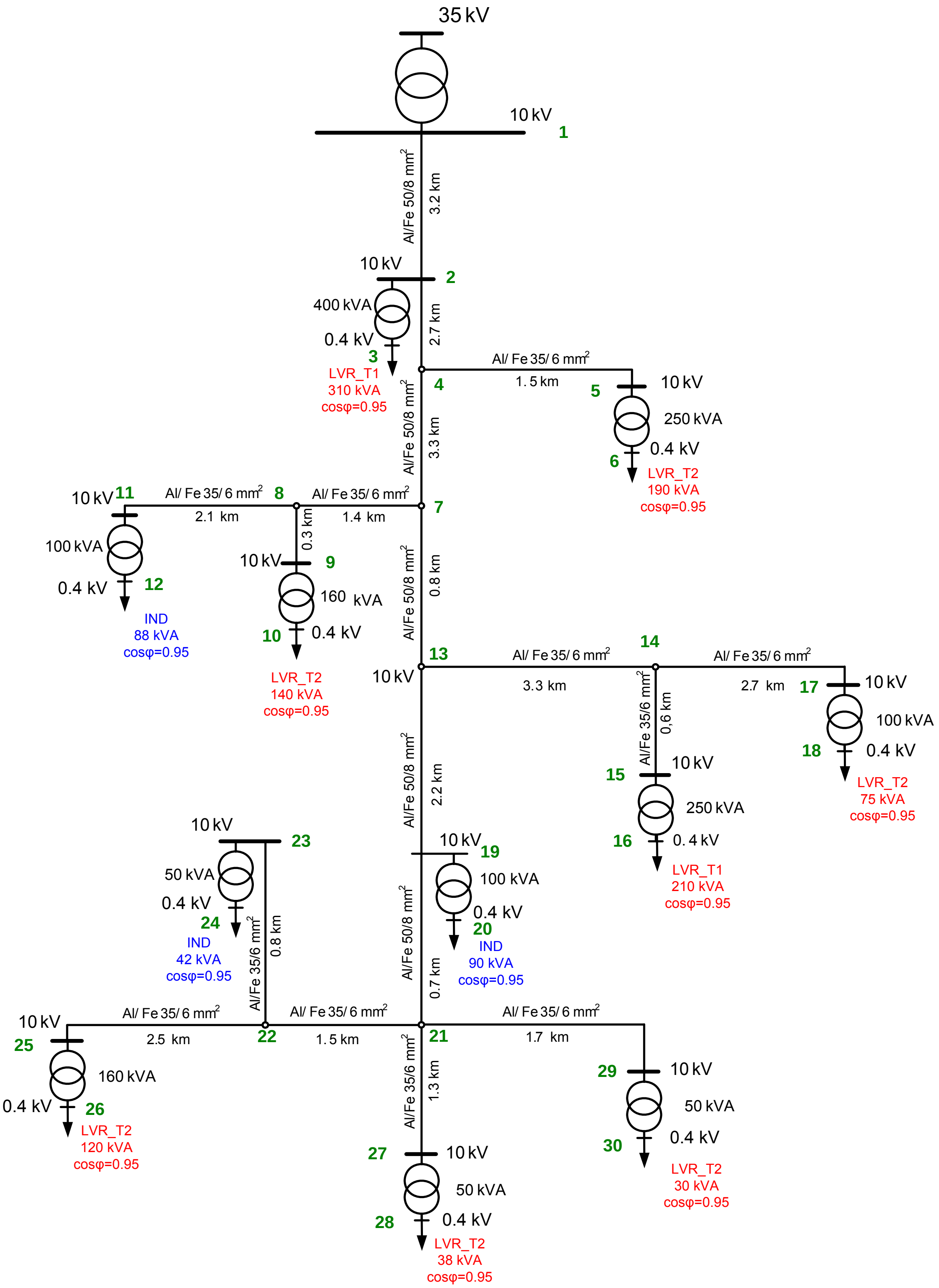

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Executive Summary

In order to quantify the benefits regarding power quality and security of supply, reduction of losses, economics of operation as well as environmental benefits, typical rural and urban distribution networks have been identified for different European countries for Low Voltage (LV), Medium Voltage (MV) and High Voltage (HV) levels. Project partners provided data from Portugal, Germany, United Kingdom, Denmark, the Netherlands, Poland, Italy, Macedonia and Greece.

The evaluation of the impact of Microgrids is done with the help of performance indices that this deliverable provides in chapter 2. While chapter 3 contains the requirements for data collection that were sent out, the results are described in chapter 4. A more detailed description of the data collection done in each country can be found Annex 4.

Chapter 5 provides an outlook about potential Microgrid scenarios that are subject of further analysis in WPG.

1 Introduction

This report summarizes some of the activities done within task TG1 – Development of future scenarios and EU network data collection.

Microgrid structures with its different microsources will change the structure of electric power supply. New essential advantages may result from this new approach – increase of reliability, decrease of energy losses, and improvement of economical parameters. On the other hand the penetration of DER can cause new problems – deterioration of reliability, problems with power quality and so on.

The main objective of Work Package G is therefore to quantify the benefits of Microgrids regarding power quality and security of supply, reduction of losses, economics of operation and environmental benefits at regional, national, and European level. In order to achieve this, participating Utilities provided data on representative residential, commercial and industrial feeders, their technology and structure as well as information about economics and reliability of supply.

2 Performance indices

2.1 Overview

This chapter provides a short description of the main topics that are analysed in WPG as well as some indices according to which benefits of Microgrids are calculated.

The performance of a power system can be quantified in different ways. There are indices describing the overall system performances as well as indices dedicated to specific customers or to a specific (steady state or dynamic) phenomenon. In general, there are indices describing the performance of the network (from operator point of view) as well as the performance as perceived by the consumer (from consumer point of view). To allow a comparison between different energy systems indices are normalized, i.e. related to number or installed capacity of customers, to short circuit power of the system, to the size of the transformer, etc.

Indices always only indicate the expected performance and have different probability distributions. Nevertheless they provide a possibility to value the development of different scenarios, i.e. for different Microgrid penetrations in the future.

2.2 Definition of power quality and security of supply

Main topic for analysis will be the effects of Microgrids on power quality and security of supply (Figure 1).

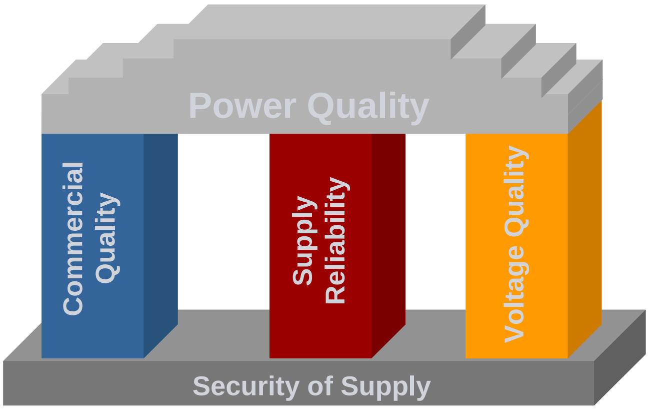


Figure 1 – Overview Security of supply and quality of supply

Security of supply comprises:

- Supply security: Long-term availability of sufficient generation capacity (adequacy)
- Dynamic security: Preservation of a stable and valid system state
- Safe governing of disturbing effects on the system (dynamic security, stability)
- Safe interaction of system domains (Generation, Trading, Network operation)
- Prevention of blackouts (e.g. blackouts in USA and Italy in 2003).

The topic that will be analysed in detail in WPG is system adequacy of Microgrids also in island mode of operation.

Safety in contrary describes protection against dangers and damages as well as human safety and the safety of technical equipment. This must be ensured also in Microgrids, but is out of scope of the analysis done in WPG.

The column commercial quality describes the relation between customers and supply companies. Typical aspects consider

- Time for picking up customer calls,
- Time for answering customer letters,
- Time for connection of new customers,
- Percentage of faulty bills,

for which minimum standards have to be fulfilled either in conventional network or in Microgrids operation and thus are out of scope of the Microgrids project.

Voltage quality, sometimes also referred to as "Quality of supply", describes the characteristics of voltages in 3 phase systems such as

- Network frequency,
- Slow voltage fluctuations,
- Fast voltage fluctuations (flicker),
- Voltage dips,
- Transient over voltages,
- Voltage asymmetry,
- Harmonics.

Microgeneration may have impacts on local voltage quality. Network frequency may vary stronger in island operation mode. Voltage asymmetry becomes an important topic if small scale generation is connected only to a single phase and different generation units are not equally distributed between the phases. Voltage fluctuations are higher due to fast changes in active and reactive power generation especially of renewable energy resources. In WPG it is assumed that acceptable values of voltage and frequency limits given in EN 50160, giving mostly average or 95-percentile values over all measurement sites, are not exceeded in all operation modes of Microgrids due to intelligent control of these structures. Also increased harmonics caused by inverters are considered to be mitigated by intelligent control possibly with filters.

Concerning reliability it has to be distinguished between

- Component reliability,
- Process reliability,
- Supply reliability.

According to EN 50160 / DISQUAL short interruptions (up to 3 minutes) are assigned to voltage quality, while long interruptions (more than 3 minutes) show effects on supply reliability
(Figure 2). Interruptions that last less than 1 second are considered as "transient interruptions".

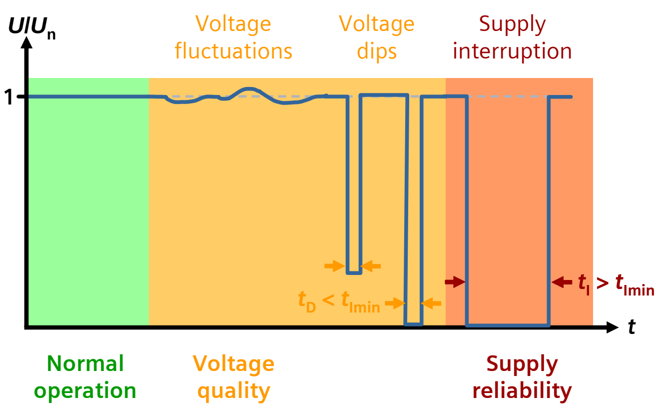


Figure 2 – Voltage quality and supply reliability

Supply reliability refers to the ability of a power system to provide an adequate and secure supply of electrical energy at any point in time. "Continuity of supply" refers to uninterrupted electricity service. It is characterized by the number and duration of supply interruptions (see [1]). Supply interruptions regardless of their cause, mean a reduction in reliability.

A network outage comprises the complete duration from failure occurrence (component outage / forced switching-off) to the reconnection of all failed components and restoration of normal operation state (Figure 3). Durations of supply interruptions and of component outages are independent.

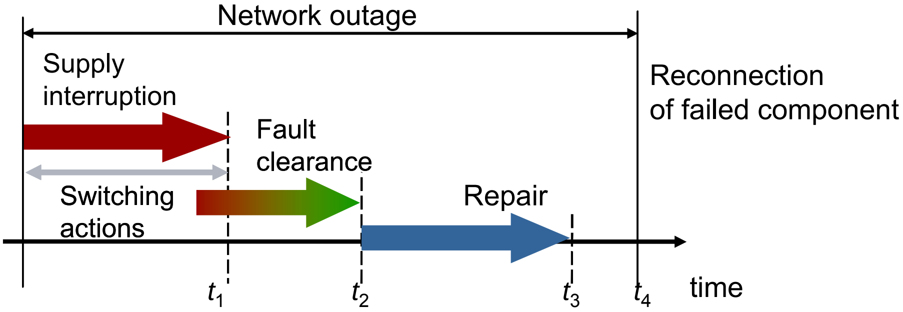


Figure 3 – Duration of network outage

It is widely accepted that it is neither technically nor economically feasible for a power system to ensure that electricity is continuously available on demand as investments increase strongly with increasing reliability requirements (Figure 4). Instead, the basic function of a power system is to supply power that satisfies the system load and energy requirement economically and also at acceptable levels of continuity and quality.

Task of WPG is to define the optimum range where total costs concerning reliability are minimum and how Microgrids can help to achieve this.

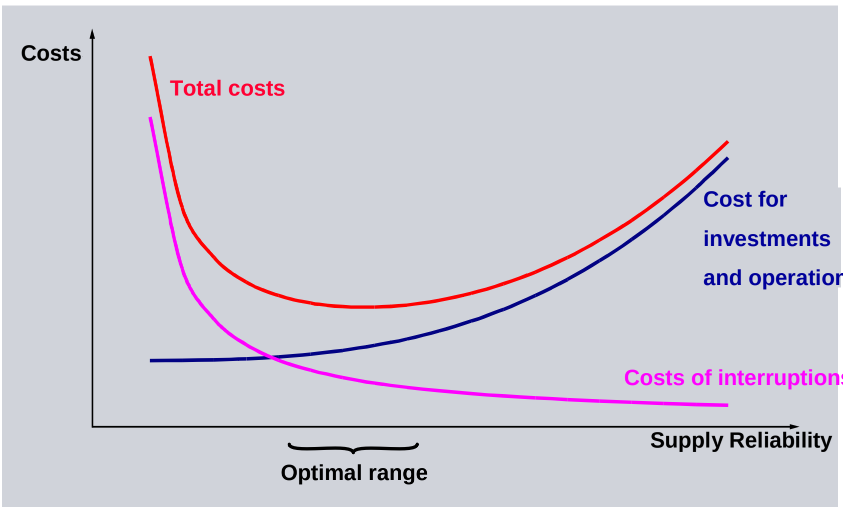


Figure 4 – Qualitative correlation of network cost and interruption cost

2.3 Reliability indices

Continuity of supply matters to all types of customers and for numerous reasons. For large industrial users interruptions of even a relatively short duration can lead to substantial financial losses, whilst for domestic users interruptions can leave people without heating, lighting and cooking facilities.

The four main features of continuity of supply can be summarised as follows [1]:

- The type of interruption: planned or unplanned interruptions. Planned interruptions are scheduled, for instance, to carry out necessary maintenance of the network. Planned interruptions which are not notified to customers should be recorded as unplanned interruptions.
- The duration of each interruption: transient, short or long interruptions.
- The voltage levels of faults and other causes of interruptions: an interruption of supply to final customers can originate at any voltage level, low/medium/high voltage, in the system. At high voltage and extra high voltage levels there is typically greater security and most faults will not lead to customers being interrupted.
- The type of continuity indicators: number/frequency or duration of interruptions.

Reliability indices (calculated according to Table 1) provide useful information on the performance of the network in terms of security and availability respectively. The number of outages per customer in a year, termed Customer Interruption (CI) or System Average Interruption Frequency Index (SAIFI), indicates how many times in a year, energy is not supplied. The cumulative yearly duration of interruptions per customer, generally referred as Customer Minutes Lost (CML) or System Average Interruption Duration Index (SAIDI), indicates how long, in a given year, energy is not supplied (average per customer). Further indices are "Energy Not Supplied" (ENS) or "Average Interruption Time".

Reliability index	Unit	Calculation acc. to Method a	Calculation acc. to Method b
Interruption frequency	1/a	SAIFI $H_U = \frac{\sum_j n_j}{N_{ges}}$	ASIFI $H_U = \frac{\sum_j s_j}{S_{ges}}$
Supply Unavailability	min/a	SAIDI $Q_U = \frac{\sum_j n_j t_j}{N_{ges}}$	ASIDI $Q_U = \frac{\sum_j s_j t_j}{S_{ges}}$
Interruption duration	min	CAIDI $T_U = \frac{\sum_j n_j t_j}{\sum_j n_j}$	$T_U = \frac{\sum_j s_j t_j}{\sum_j s_j}$
Legend Designations acc. to IEEE 1366	n_j Number of interrupted customers per interruption block N_{ges} Total number of customers supplied s_j Interrupted rated apparent power per interruption block S_{ges} Total rated apparent power installed t_j Duration of the interruption block j Interruption blocks		

Table 1 - Reliability of supply indices – DISQUAL / IEEE

All over Europe different indices for different voltage levels are calculated; reliability indicators are not always defined in a comparable way. Continuity indicators can be weighted by three different methods; by number or installed capacity of customers, capacity of transformer or contracted power. This can give rise to differences depending on which weighting method is used (see Annex 1).

There are big differences in supply reliability in Europe as shown in Figure 5 for minutes lost per customer. Annex 1 gives a detailed overview about different indices.

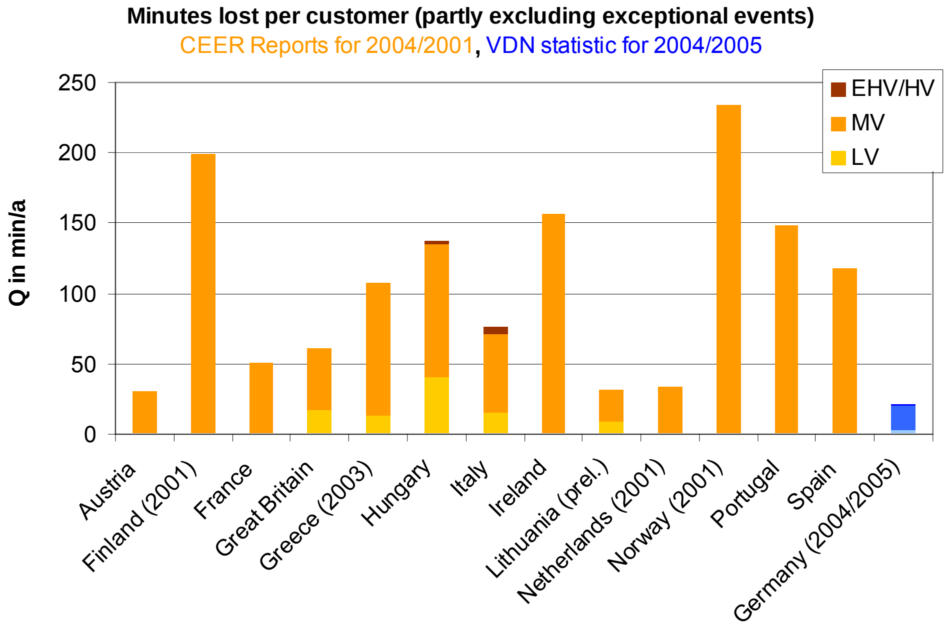


Figure 5 – Supply unavailability in Europe (VDN, 2004/2005, CEER, 2004/2001)

To have coherent evaluations in Microgrid project it is proposed to use indices according to Table 2 that are correlated as shown in Figure 6.

Probabilistic supply reliability index		**Unit**
Frequency of supply interruptions	F_i	1/a
Average duration of supply interruptions	T_i	h
Probability of supply interruptions (unavailability)	Q_i	min/a
Interrupted power (cumulative / per event)	P_i	MVA/a
Energy not supplied (cumulative / per event)	E_i	MVAh/a
Interruption cost	C_i	€/a

Table 2 - Reliability indices proposed for Microgrid evaluations

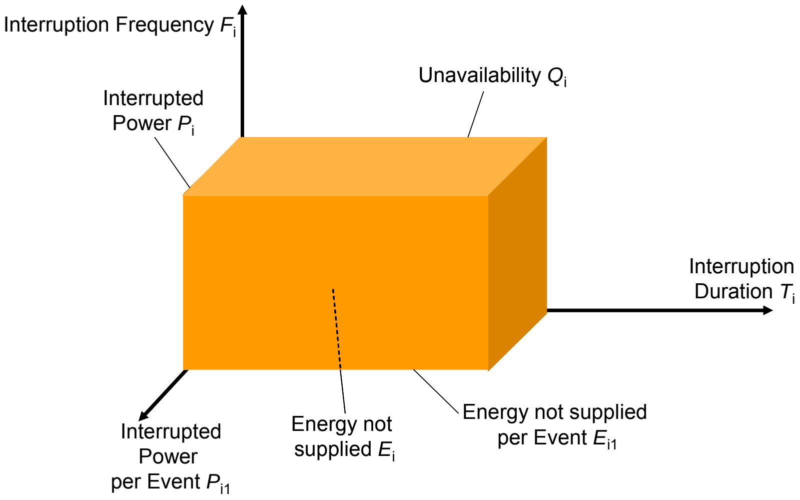


Figure 6 – Correlations of reliability indices

Bigger blackouts have a strong impact on average statistics as demonstrated in Table 3

Event	Max. P_i GW	Max. T_i h	Est. E_i GWh	Est. cost Mio €
US blackout 2003	62	72	919	5735
Italy blackout 2003	28	20	116	722
Outage in western Germany and Luxemburg 2004	0.9	4.5	0.8	5
Est. „normal“ non-availability in Italy (103.7 min/a) 2003	$^2/_3\ P_\varnothing$ 23	1.73	39	245
Est. „normal“ non-availability in Germany (22.9 min/a) 2004	$^2/_3\ P_\varnothing$ 40	0.38	15	96

Table 3 - Rough estimation of indices for selected blackouts and outages

2.4 Further performance indices

In addition to the indices described previously, following the widespread of microgeneration integration in the distribution system, new indices must be defined to evaluate the impact of the presence of these active and controllable cells in the electrical system. Several other technical efficiency indices may be derived in order to be able to quantify the benefits resulting from the massive integration of Microgrids into LV distribution grids such as:

- **Active Power Loss reduction in transmission and distribution networks**

  Microgrids operation can significantly reduce losses in transmission and distribution networks if energy demand is covered locally. WPG will develop techniques to quantify the potential savings that may be achieved.

  Indices calculated will indicate at least total average power of reduction, the percentage of reduction as well as the cost savings for network operator and consumer due to this reduction.

- **Indices to value environmental benefits**

Savings of Greenhouse Gases (GHG) emissions is a big environmental benefit that can be provided by Microgrids. The operation of Microgrids is based to a large extent on RES, characterised by extremely low emissions, and Micro Sources, such as micro CHP that are characterised by high efficiency. In addition, the application of micro-CHP generation in central and northern Europe for heat and electricity production would significantly reduce the amount of electrical energy imported from higher network levels. The operation of Microgrids contributes to the reduction of losses and thus further savings in the produced energy.

Avoided CO_2 emissions resulting from avoided active power losses can easily be calculated. With knowledge of emission performances for different technology options DER credit for avoiding CO_2 emission can be estimated additionally through DER-produced energy ratios from different fuel sources. Other GHG such as NOx will also be part of the studies in WPG. A detailed overview about emissions of different microsources is given in Annex 5.

- **Economic indices**

The successful operation of Microgrids provides a number of benefits to the customer such as higher reliability levels, faster restoration after distribution system disturbances, high overall efficiency by the production of CHP, and/or reduction in electricity costs by self-providing and reducing demand charges by peak shaving.

Economic analysis will already be provided for reliability, loss reduction and environmental benefit evaluation from consumer or network operator point of view. A global analysis while total lifetime costs are compared will provide further economic indices.

- **Contribution to the employment**

The widespread use of Microgrids will provide short and long term employment effects during manufacturing, installation and operation phases of the Microgrids. The project aims at developing and improving solutions for the operation of Microgrids with large integration of RES and microsources and this is expected to create new markets and business opportunities, especially for SMEs (small-medium enterprises). The export potential for the related technologies is particularly high in a growing world energy market, the largest geographical portion of which is devoid of transmission and distribution networks.

Some general impacts will be analysed and presented in the outcomes of task G3.

- **Investment deferral in network reinforcements (investment postponing)**

This topic is analysed in detail in WPH. In order to calculate these indices, one must follow the methodology described within Task TH1.

In long term, development of Microgrids will improve quality of life as a result of more economical and safer energy delivered to consumers, environment protection by promoting dispersed renewable generation and reducing losses and improve employment prospects by aiding European industry competitiveness. To value these impacts is task of WPG with help of the indices provided.

2.5 Microgeneration Penetration Levels

The microgeneration penetration level indicates the share of microgeneration in the total network analysed or in a single Microgrid. It can be expressed as an absolute value, for example the number of microgeneration units, the total rated power of all units, or the total generated power or energy of all units. To make the results independent of the system size and to allow a comparison with other systems, normalization is needed. The absolute value of the power (rated power or generated power) is divided by a reference value. A reasonable definition is the ratio between the installed capacity of the microgeneration and the active power taken by the load

$$\mu G_{penetration} = 100 \cdot \left(\frac{\sum P_{nom}^{\mu G}}{P_{load}^{peak}} \right) \tag{2}$$

Where

$\mu G_{\text{penetration}}$ is the microgeneration penetration (expressed in %),

$\sum P_{nom}^{\mu G}$ is the sum of the installed capacities of all microgenerators connected in a distribution network for a given scenario,

P_{load}^{peak} is the total peak load for a given scenario.

When the ratio is equal to 100%, all loads can supplied by microsources. Nevertheless it has to be considered that load as well as generation profiles follow certain daily, weekly and yearly shapes, what can actually lead to different shares of generation and load in the network.

Another index that could be of interest is the amount of energy generated locally at the microgeneration level. A possible index for further evaluation would be the ratio of self-supplied energy in terms of both, active power and reactive power.

2.6 Future scenario development

2.6.1 Methodology chosen for scenario development

Starting from Microgrid penetration today extended Microgrids penetration is assumed in the studies of WPG. Microgrids characteristic for Northern Europe will be mainly based on based micro CHP, while the ones for Southern Europe will probably be dominated by PV generation.

Three different time horizons are considered for further investigations: **now, 2015** (wider 'More Microgrids' penetration) and **2030** (high Microgrid penetration).

Different methodologies exist to develop future scenarios – mainly based on a scientific approach or an approach based on existing forecasts i.e. on microgeneration penetration combined with reasonable assumptions. Key factors considered for scenario development should be:

- Liberalisation of markets
- Privatisation of infrastructure ownership
- Reliance on energy sources outside EU
- Protection of the environment and energy saving
- Energy market dynamics
- ICT (Information and communication technology) costs
- Business models
- Legislation and development of support schemes
- Degree of Automation, intelligence in distribution
- Availability of technologies, i.e. demand response.

However, it was agreed within WPG to develop the scenarios based on existing forecasts for typical microgeneration in different countries.

2.6.2 Microgrid operation strategies

Technical, economic and environmental impacts of Microgrid operation strongly depend on operation strategy and degree of storage and demand side integration; i.e. a Microgrid operated in secure way allows to continue supply also in case of failure in the network the Microgrid is connected and thus provides a higher reliability of supply, but, this operation strategy may show minor effects in CO_2 reduction.

Therefore different Microgrid scenarios each with different operation scenarios will be further studied in WPG:

- Scenarios classified by constitution of Microgrid
  Fossil- (gas), biomass-, RES-domination or balanced mix, storage capacity
- Scenarios classified by network region or nation
  Urban and/or rural, nation-wise network topology
- Scenarios classified by microgeneration control strategies
  Centralized or decentralized control, autonomous or market-oriented operation
- Scenarios classified by general preference of operation
  Maximized profit or maximized emission reduction

It further has to be distinguished between LV networks, only with a single Microgrid, and MV levels where the control strategies of the multi-Microgrid approach have to be applied.

Each control strategy will also impact flows of active and reactive power that either can be provided locally within a Microgrid or be exchanged with public network to which the Microgrid is connected (Table 4).

	'True Island'	'Econ-Island'	'Tech-Island'	'True Exchange'
P of Microgrid	Autonomous	Autonomous	Exchange	Exchange
Q of Microgrid	Autonomous	Exchange	Autonomous	Exchange

Table 4 – Impact of Microgrid operation on active and reactive power exchange

3 Requirements for EU network data collection

3.1 Analysis performed in WPG

Data requirements strongly depend on what has to be analysed with the data.

Basic steady state investigation is load flow analysis that provides information about loading, losses and also on bottlenecks/weak points in the network and thus allows determination of most of the indices defined in chapter 2. Calculation of reliability indices is also based on the results of load flow analysis. Results of short-circuit analysis in steady state mode are not of main interest in WPG.

To take account of high intermittency of renewable generation units and relatively small loads in distribution networks with low coincidence factor, steady state analysis can be performed via stochastic network calculations.

The aim of the stability study is to determine the dynamic behaviour of the network fed by several microgeneration units in island and in grid connected mode of operation. It must be distinguished between:

- Steady-state stability (outage of lines, transformer, power plant etc.)
- Transient stability (for relevant network configuration and selected fault conditions)
- Determination of critical fault clearing time for relevant nodes of network
- Voltage dip calculation (voltage recovery) after clearing of certain faults

The data base of the performed steady state analysis (Load flow and short circuit) is the same as for the stability study. In addition generator data (d, q-axis data), generator-turbine inertia (H or I or GD2), voltage and governor controller type and block diagram are needed.

The transient stability method is available for providing the answer to the question of whether or not the generators can continue with stable operation in the case of faults or interruptions. To calculate this, further data are required such as a fundamental frequency model for simulating electromechanical phenomena, complex impedances for network modelling, quasi steady state values, differential equations for machines and controllers, higher order generator equations, etc.

Microgrids can substantially boost system reliability if they are allowed to operate autonomously in transient conditions (i.e. when distribution system operation is disturbed). In addition, emergency state, black start functions can minimize down times and aid the reenergisation procedure of the bulk distribution system. Intelligent coordinated control is required to achieve autonomous operation in transient conditions and this is one of the basic technical aims of this project.

Nevertheless, in all investigations done in this WP it is assumed that stability of Microgrids operation is guaranteed by controllers and protection units developed in other WPs of this project. Therefore, only steady-state analysis is performed in WPG.

Impact on protection schemes of transmission and distribution systems is also not topic of WPG. Nevertheless protection schemes must be known for reliability evaluations and are therefore requested as input data.

3.2 Overview data collection

In order to be able to evaluate technical, economical and environmental benefits that may result from the presence of microgeneration in electrical networks, an evaluation approach was developed to determine the indices defined in chapter 2.

The development of this approach requires a first step where typical distribution networks must be identified. In order to obtain a European evaluation of the benefits described previously, the utilities involved in the project were requested to provided data on typical, representative, distribution networks for their countries, considering several voltage levels and present and future operational scenarios of microgeneration penetration, including different generation technologies.

Data requested for typical residential (rural and urban), commercial and (if available industrial) MV and LV networks were:

- Network topology and structure (including simple single line network diagrams which demonstrate typical structure)
- Feeder data and network components (overhead line, cable, transformer, additional technologies…)
- Technical system indices (network operation, system protection, average losses, …)
- Reliability indices (typical power system indices, availability of generation units, restoration times, costs for energy not supplied)
- Costs (i.e. use of system charges, maintenance costs, average consumer prices, costs for reliability, …)

Additional information about microgeneration units typically used per country (Size, generation profiles) and an overview about loads (typical profiles for typical segments, min./max. values, to which extent controllable …) that may occur during a 1 year period of operation is also necessary.

It is not necessary to model HV network with 110 kV upward; in our investigations we will assume that short circuit power of this networks is sufficient and feed back is possible without any congestions (currently, this is not generally true for all European networks, but is sufficient for our Microgrid investigations).

3.3 Network data

For each electric power system it is necessary to have a single line diagram with busbars, transmission lines, cables, transformers, generators, synchronous condensers, reactors, shunt and series capacitors, filters, static compensators, static and motor type load and operating position of switchgears, and to have information about (see Annex 2 for detailed information):

Transformer:

- Capacity (e.g. 630 kVA, 7.5 MVA)
- Peak-load and Zero-load active power losses
- Impedance (p.u. value, based on rated capacity of transformer), short circuit capacity
- Voltage regulation (on-load or off-load tap changer);

Feeder:

- Cross-sections (mm^2) (tapered/ non-tapered) (e.g. 300 mm^2 + 70 mm^2)
- Capacity (MVA), Resistance (Ω/km) and reactance (Ω/km)
- Type of circuits (OH/MX/UC) (Over Head/Mixture/Underground Circuit)
- If available feeder type, e.g. for cables NA2XS2Y, …
- Length (km)
- Total maximum load, distribution of load
- Percentage of load (i.e. percent value of one substation total load) connected to each circuit, Percentage of various load types at each voltage level network
- Power factor of the load for each circuit; is there any compensation (if yes how?)?
- Percentage of total maximum load connected to each voltage level networks

Additionally it is necessary to know about:

Network operation:

- Ring
- Meshed
- (Open-) Loop

Losses:

- Average losses in different network levels,

Technical losses will be calculated with load flow simulations. Information about non-technical losses that can be reduced with help of Microgrids is requested.

System protection:

Rudimentary model of the protection system (which kind of protection devices (overcurrent or distance protection, differential protection) is installed in which places and additionally detailing the operational direction of overcurrent or distance protection relays)

3.4 Reliability indices

*Power system indice*s such as

- customer reliability characteristics and distributions, statistics of interruption records
- SAIDI, SAIFI, CAIDI, ... (average duration, frequency and energy lost/not supplied)
- availability of components such as microgeneration units (for wind i.e. 85 %) or network equipment

Outage management-> to calculate outage duration

- supply restoration strategies (average duration)
- fault response teams deployment strategy
- network maintenance strategy and cost
- replacement and reinforcement strategy

3.5 Consumption profiles

It is necessary to have typical load profiles for residential (with/without electricity heating), industrial and commercial segments for each country profiles as metered on MV bus bars with normalised or real values. It should be daily load profiles with 15 min or 1 h average values for weekday, Saturday and Sunday in winter, summer and spring/autumn.

Further information required is expected load increase rate (%/year) and controllability of the loads (share that can be influenced and how this can be realised i.e. with shift of consumption or switching off loads, etc.).

3.6 Generation profiles

Microgeneration penetration is varied within the studies of WPG to quantify and qualify the effects of Microgrids, so it is not necessary to provide information of microgeneration distribution. Nevertheless it is important to know about typical microsources currently in use per country:

- Which microsource technologies (hydro, on/offshore wind, PV, CHP, biomass, ..)
- Typical unit sizes
- Percentage of penetration per voltage level today
  (e.g. 50 % LV, 35 % MV, 15 % HV)
- Ways of CHP operation (heat or electricity driven, controllability)
- Ways of grid connection (interesting for modelling, e.g. if reactive power supply is possible): inverter, synchronous or asynchronous machine

Typical generation profiles for renewable energy sources are required for simulations in WPG. At least hourly profiles will be provided for summer, winter and spring/autumn

- PV (with solar irradiation < 800 W/a, < 1200W/a, >1200 W/a)
- Wind (only if connected to MW, for regions with different average wind speeds)
- Hydro (if applicable)

For fuel consuming units it is necessary to know:

- Fuel consumption data or at least average efficiency of the units connected

To perform stochastic network planning the probability distribution of wind velocity and solar radiation or of PV and wind turbine generation at least at annual, but preferably monthly level or for typical days is necessary.

Further information required is penetration with storage facilities / possibilities for future installation

3.7 Economic data

Economic impact is calculated as the economic benefits provided to the customers and producers forming the Microgrid compared to the operating situation without Microgrid.

For economic analyses in task WPG.2 financial information must also be provided:

- Operation costs (i.e. maintenance) for components (transformer, cable, overhead line, switchgear, protection, automation, communication, new circuit)
- Tariff structures for different consumers (MV and LV per segment)
- Use of system charges, Connection charges
- Energy market prices
- Fuel prices for the fuel consumed by microgeneration in the Microgrid.
- Average costs for reserve power
- Costs for reliability, power quality, penalties for supply interruptions,
  Cost of alternative reliability improvement options,
  Estimates of the customer worth of supply
- Demand side integration aspects (Controllability of consumer, reliability requirements, costumer worth of supply, number of controllable units)

3.8 Further topics

This is a collection of all topics that could be of interest for technical, financial, environmental and social analysis of Microgrids, at least:

- Communicational infrastructure (possible solutions, installation costs, operation costs and restrictions)

It would be valuable if stakeholder could collect some basic information on business models (who could be owner of Microgrids structures, for whom will this provide advantages, what are the different options of network owner/operator, service provider, energy trader, …).

3.9 Comparison with generic networks modelling in WPH

In WPH a generic distribution network model was proposed to study the impact of various forms of distributed and micro-generation technologies on operation and development of distribution networks, such as losses and reinforcement requirements. It is also intended to quantify the benefits of integration of various forms of generation into active distribution networks (e.g. micro-grids) with this generic model (Figure 7).

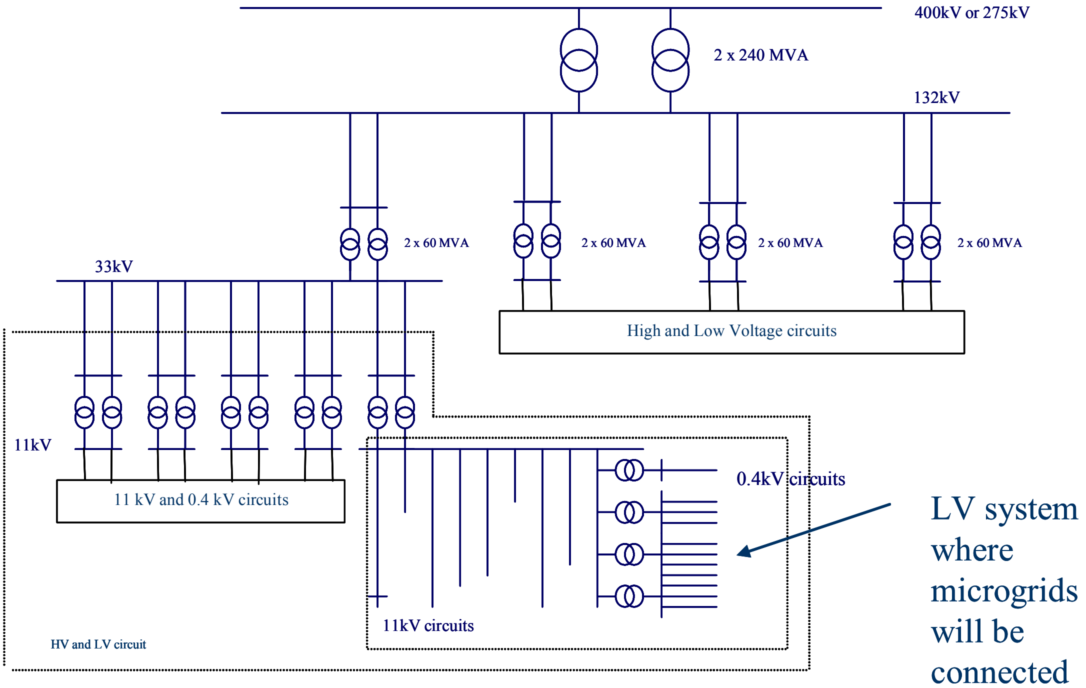
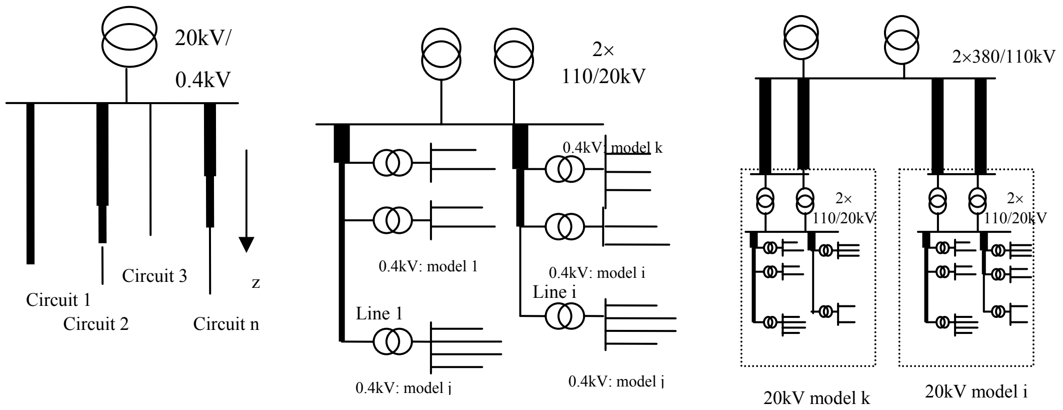


Figure 7 – Generic Distribution Network developed in WPH

Generic networks can then be identified for each voltage level (LV, MV and HV distribution) (Figure 8).



0.4 kV network model 20 kV network model 110 kV network model

Figure 8 – Generic network models identified in WPH

As similar investigations take place concerning network operation this generic model has to be – with some additional information – consistent with the data collected in WPG. But, while WPH provides a generic network, in WPG typical networks are collected (Figure 9).

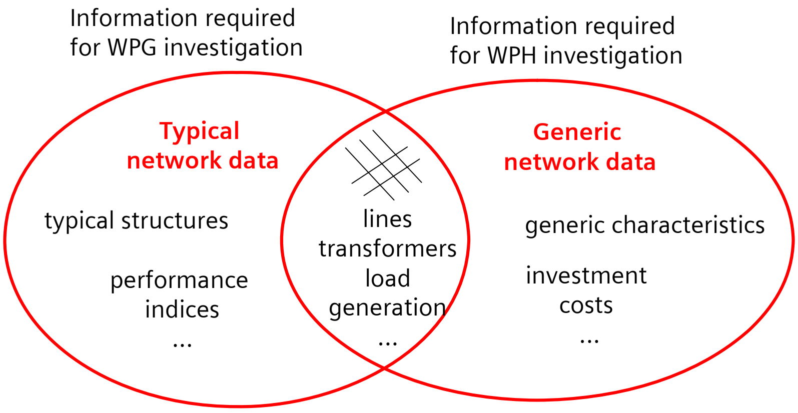


Figure 9 – Differences between the network data collected in WPG and WPH

4 Results of the data collection and future scenario development

4.1 Process of data collection

In order to quantify the benefits of Microgrids, typical networks were identified by each utility for each country, concerning all distribution voltage levels, High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) networks:

- INESC Porto in collaboration with EDP has identified typical networks for HV, MV and LV distribution grids, considered as representative for Portugal.
- Lodz-Region Power Distribution Company and the University of Lodz collected data on typical Polish distribution networks.
- Data collection in the Netherlands was performed by Continuon according to the template given in WPH.
- The activity of CESI RICERCA has consisted in the collection of typical data and information (where available) about the structure and operation of the Italian MV and LV distribution network.
- NTUA collected information on Greek power supply.
- DTU provided data about a typical Danish Microgrid (Bornholm) that is also subject to further field tests.
- Data collection for Germany was done in collaboration between Siemens and MVV.
- Imperial College, London, provided data from United Kingdom.
- UKIM and ICEIM-MANU collected data on typical Macedonian distribution networks.

Data collection has involved contacts with Distribution Network Operators, consulting of technical documents, reports and databases (both public and with restricted access).

Detailed results of data collection for typical European distribution networks (Portugal, Poland, Italy, the Netherlands, Denmark, Germany, UK, Macedonia and Greece) are provided in Annex 4. It comprises simple single line network diagrams for

- 1 typical HV distribution network,
- 2 typical MV distribution networks (Urban MV network, Rural MV network),
- 2 typical LV distribution networks (Urban LV network, Rural LV network),

which demonstrate typical structure as well as data for transformers, lines and other network components.

Due to regional differences it is not possible to give one typical (Northern/Southern …) European network, not even typical voltage levels are equal (Table 5).

	HV [kV]	MV [kV]	LV [kV]
Portugal (PT)	60	30, 15, 10	0.4
Poland (PL)	110	15	0.4
Italy (IT)	132	20	0.4
the Netherlands (NL)	150, 110	50, 10.5	0.4
Germany (DE)	110	20, 10	0.4
Greece (GR)	150	20	0.4
Denmark (DK)	150, 110	60, 10	0.4
Macedonia (MC)	110	35, 20, 10	0.4
United Kingdom (UK)	132	33, 11	0.2

Table 5 - Overview (typical) voltage levels in Europe

4.2 Overview electricity generation and demand

Total yearly generation varies in the countries between 36 and 620 TWh (Table 6).

(TWh)	PT	PL	IT	NL	DE	GR	DK	MC	UK	EU 25
Total gross el. Generation (TWh/a)	49	162	314	98	637	61	36	6.5	398	3358
Final Consumption (TWh/a)	52	142	340	117	556	56	21.8	8.6	270	2710
Peak demand (GW)[1]	9	21	54	17	77	9	6.3		67	479
Installed capacity hydro (GW) [1]	4.8	2.2	20.7	0.04	10.4	3.1	11.0		4.2	131.1
Installed capacity other renewables (GW) [1]	0.9	0.1	3.3	2.0	19.2	0.5	3.1		2.3	40.5
Total Installed generation capacity[1] (GW)	12.6	31.7	81.5	21.4	129.1	13.1	12.6		81.1	706.5

[1] according to [4], 2004

Table 6 – Overview electricity generation and demand in Europe (2006)

Total gross electricity generation covers gross electricity generation in all types of power plants. The gross electricity generation at the plant level is defined as the electricity measured at the outlet of the main transformers, i.e. the consumption of electricity in the plant auxiliaries and in transformers is included. The final consumption describes the demand of the consumers. It equals the energy supplied to the network minus transmission and distribution losses. The electricity supplied to the network is the net electricity production plus imports minus exports and pumping energy for pumped storage.

Hydro-electric installations cover run-of-river and storage installations. As renewable power units all units are considered when its primary energy resource is neither fossil nor hydro, e.g. wind power (on- and off-shore), solar, geothermal, biogas, biomass, or waste.

More detailed European statistics such as share of renewables and CHP generation or of energy dependency are shown in Annex 5.

4.3 System indices

4.3.1 Technical indices

Losses

In Europe, average network losses are around 7%. The differences between European countries are very high, ranging between less than 1% for Luxembourg to 16% for Estonia. The data for Luxembourg contains a lot of transit power that only passes through high voltage transmission lines, while about 75% of the losses are situated within the distribution network.

Network losses in the EU-15 countries didn't decrease much over the past decade. In many Eastern European countries on the contrary, network losses have lowered significantly during the latest years.

When comparing network losses with the size or population density of countries, correlation is weak. This means that technical network losses mainly depend on other factors such as network design, operation, and maintenance.

Technical losses in different Microgrids scenarios that are subject of further investigations in WPG will be calculated with load flow simulations. Table 7 summarises different typical losses in Europe.

	HV (%)	HV/MV (%)	MV (%)	MV/LV (%)	LV (%)	total (%)	total[1] (TWh)
Portugal[2] (PT)						7.29	3.50
Poland (PL)	1.57		7.67		7.67	12.3	14.3
Italy (IT)	2.8	0.5	1.1	0.8	1.7	6.9	20.9
the Netherlands (NL)	0.76		1.01		2.24	4.2	4.5
Germany (DE)	0.3	0.6	0.4	1.5	2.6	5.4	28.6
Greece (GR)		0.46	2.7	1.47	1.9	11.6	4.5
Denmark (DK) [7]	1.54		1.1		2.23	6.9	2.3
Macedonia (MC)	0.04	2.38	1,63	2.38	12.91		
United Kingdom (UK)	0.4	0.4	2.9	2.9	2.5	9.1	32.0
EU 15						6.8	170.3
EU 25						7.2	199.0

[1] according to [4], year 2004; [2] partial values not available; data from the year 2007

Table 7 - Overview typical network losses (in % of final consumption) in Europe

Power quality

Power quality is assumed to be within the limits given in EN 50160 (Table 8) that is providing an equal standard in Europe. It describes maximum values or variations of the voltage characteristics, under normal operating conditions, which can be expected by the customer at any place of the network. It is not applicable under abnormal conditions such as exceptional weather conditions and other natural disasters, third party interference, acts by public authorities or power shortages resulting from external event.

Characteristics of the supplied voltage	Limits		Measurement/evaluation		
	Low-Voltage (U_n<1 kV)	Medium-Voltage (1 kV<U_n<35 kV)	Base quantity	Obs. duration	%
Frequency (interconnected to public network)	50 Hz ± 1% (49.5 Hz to 50.5 Hz) 50 Hz +4 / -6% (47 Hz to 52 Hz)		Mean value (10 s average)	1 week 1 week	95% 100%
Frequency (islanded networks)	50 Hz ± 2% (49 Hz to 51 Hz) 50 Hz ± 15% (42.5 Hz to 57.5 Hz)		Mean value (10 s average)	1 week 1 week	95% 100%
Voltage Variations	U_n ± 10% U_n +10 / -15%	U_c +/- 10%	RMS (10 min average)	1 week 1 week	95% 100%
Fast Voltage Variations	<5% U_n (until 10% U_n only if a few times a day)	<4% U_c (until 6% U_c only if a few times a day)	RMS	1 day	100%
Flicker	Long term flicker intensity $P_{lt} \leq 1$			1 week	95%
Voltage dips (10 ms-1 min, U_{RMS} < 90% $U_{n,c}$)	Indicative: 10 - 1000 / year: Most should last less than 1s and have a depth smaller than 60% In some regions, voltage dips with a 10-15% depth are quite usual		RMS, duration	1 year	100%
Short Interruption of supply (< 3 min, U_{RMS} < 1% $U_{n,c}$)	Indicative: from 10 to several hundreds a year 70% of them should last less than 1 s		RMS, duration	1 year	100%
Long Interruption of supply (> 3 min, U_{RMS} < 1% $U_{n,c}$)	Indicative: less than 10 to 50 a year		RMS, duration	1 year	100%
Voltage Unbalance	Ratio negative/positive sequence less than 2% (3% in some regions)		RMS (10 min average)	1 week	95%
Harmonic distortion	THD (up to 40^{th} harmonic) <8%		RMS (10 min average)	1 week	95%

Table 8 - EN 50160 power quality limits

Aim of Microgrid operation is to stay within the limit in case of grid connection as well as in island mode of operation.

4.3.2 Reliability indices

From the amount of European reliability indices

- **Frequency of supply interruption F_i [1/a],**
- **Interruption duration T_i [min]**, and
- **Supply unavailability Q_i [min/a]**

for unplanned customer interruption were taken for further investigations.

Table 9 provides an overview about different reliability indices in Europe.

		PT[6]	PL	IT[1]	NL	DE	GR	DK[2]	MC	UK
HV	F_i (1/a)		0	0.11	0.112	0.024		0.027		0.04[5]
	T_i (min)		0	25.5	48	21.1		3.6		61
	Q_i (min/a)		0[3]	2.81	5.4	0.50		0.1		2.43
MV	F_i (1/a)	4.77	0.5/0.8	2.05	0.204	0.331		0.49		0.72[5]
	T_i (min)	303	420	27.3	93	50.9		42		98
	Q_i (min/a)	203	230/280	55.9	19	16.85		20[4]		70.8
LV	F_i (1/a)	4.18	0.6/0.9	0.14	0.028	0.02		0.033		0.12[5]
	T_i (min)	266	294	111	158	149.9		98.3		226
	Q_i (min/a)		215/245	15.5	4.5	3.05		3.2		26.9
Total	F_i (1/a)		0.6	2.39	0.347	0.379		0.55		0.88[5]
	T_i (min)		390	26.7	84	55.7		60.0		114
	Q_i (min/a)		230	63.8	29.1	21.10		29.5		100.1

[1] Data from 2004, total values from 2006
[2] Planned and unplanned according to [7], year 2007
[3] Disturbances in HV do not cause power outage in Poland; data for MV and LV are given for urban /rural networks
[4] 60 kV: 29.5 F_i = 0.066 1/a, T_i = 40.15 min, Q_i = 2.65 min/a, 10/20 kV: F_i = 0.423 1/a, T_i = 53 min, Q_i = 22.42 min/a
[5] Data referred to overall number of customers
6 Data for HV and Total not available; Fi – SAIFI (System Average Interruption Frequency Index); Ti – SAIDI (System Average Interruption Duration Index); Qi – TIEPI (Equivalent Interruption Time of the Installed Power)

Table 9 - Overview reliability indices in Europe, year 2006 if not mentioned otherwise

4.3.3 Outage costs

There are many factors that may affect the costs for outages experienced by different customers. An interruption has different levels of impacts depending on frequency, duration, occasion (hour, month) as well as on the time horizon of advance warning. Also the impact on each customer will be different depending on its type, its electricity usage, its size, its energy needs and whether the area affected by an outage is localised or widespread or whether an interruption is complete or partial.

Different impacts of outages can be distinguished [19], [20]:

- Indirect losses (civil disobedience, evacuation for safety)
- Direct economic (lost production, idle resources, restart costs, spoilage, equipment/materials damage, health & safety costs, utility interruption costs)

- Direct social (loss of transport, loss of leisure, lack of heating/cooling, personal injury)
- Short term/long term (future mitigation decisions, extra protection/standby)

There have been many studies to evaluate the outage costs experienced by different customer segments in different voltage levels. Depending on questions asked in each customer survey strongly varying numbers are determined as it is very difficult to weight the impacts of outages apart from direct economic ones. This is especially true for residential customers as their direct economic impact of outages is quite low compared to social aspects and average household customer has no idea about his real outage costs.

In principle, in all papers published on this topic so far, it is distinguished between the duration of supply interruption (costs normally increase with increasing duration) and customer segments affected (residential, commercial, industrial). But, even if commercial and industrial segments are subdivided in more detailed segments strong deviations in outage costs are recognised.

For sake of simplicity coherent values independent from outage duration for all European countries are assumed for further investigations in WPG, independent from outage time. Costs in Table 10 according to a study from Finland [21] are quite low compared to the outcomes of a newer study [22]; however, assumptions from [23] with 2.94 €/kWh for residential, 3.50 €/kWh for agriculture, 9.97 €/kWh for industry and 9.72 €/kWh for commercial customer segments are in a similar range apart from residential customer segment.

	Study from Finland [21]				**Study from Finland [22]**			
outage	**unexpected**		**planned**		**unexpected**		**planned**	
	€/kW	**€/kWh**	**€/kW**	**€/kWh**	**€/kW**	**€/kWh**	**€/kW**	**€/kWh**
Residential	0.068	0.61	0.034	0.3	0.36	4.29	0.19	2.2
Agriculture	0.54	4.9	0.18	1.6	0.45	9.38	0.23	4.8
Industry	2.6	8.7	0.8	3.8	3.52	24.45	1.38	11.47
Commercial	1.9	11	0.8	7.2	2.65	29.89	0.22	22.82

Table 10 - Customer segment's interruption costs in Europe ([20])

To have a common approach in WPG minimum, average and maximum outage costs are considered for further evaluation that cover the whole European spectrum of impacts of outages. Only unexpected outages are further considered, as Microgrids operation will have no significant impact on planned outages.

	€/kW	**Minimum €/kWh**	**Average €/kWh**	**Maximum €/kWh**
Residential	0	0.5	1.5	5
Agriculture	0.5	2	5	10
Industry	3	5	10	25
Commercial	2	5	10	30

Table 11 – European outage costs assumed for further evaluations in WPG

4.4 Load scenarios

Typical daily load profiles with average values for weekday, Saturday and Sunday in winter, summer and spring/autumn are given for each country with the description in Annex 4.

It is assumed for the investigation of different microgeneration scenarios in future that the basic load shape will not change. It is assumed that the share of controllability of the loads, i.e. through shift of consumption or load shedding, will increase in future. The impact of this on Microgrid operation will be analysed in WPG Task 2.

The expected increase in load for different countries is summarised in Table 12.

%/a	PT	PL	IT	NL	DE	GR	DK	MC	UK[1]
2008 – 2010	5.15	2	2	2	0.5	3.8	0.5	3	1.1
2010 - 2020	5.15	2	2	2	0.5	2.6	0.5	3	1.1
2020 - 2030	5.15	1.5	2	2	0.5	2.5	0.5	3	1.1

[1] Estimated on the basis of average growth forecast from UK Seven Year Statement 2008

Table 12 - Average yearly load increase [%/a] in Europe

Table 13 provides information about the development of the annual peak demand [GW] in Europe, Table 14 that of the annual energy demand [TWh]. Table 15 gives the breakdown of the demand for the sectors Agriculture, Industry, Transport, Services and Household.

GW	2004	2010	2020	2030	Month of peak demand
Portugal	9	10	13	16	December (2004) January (from 2010)
Poland	21	23	27	32	December
Italy	54	62	76	91	December (2004) July (from 2010)
the Netherlands	17	20	24	30	December
Germany	77	81	83	-	December
Greece	9	11	14	17	July
Denmark	6.3	6.8	6.9	8.0	February
Macedonia					
United Kingdom	67	74	82	84	December
EU 15	430	474	534	593	-
EU 25	479	527	596	664	-

Table 13 – Annual peak demand [GW] in Europe (according to [4])

TWh	2004	2010	2020	2030
Portugal	50	59	76	97
Poland	131	136	160	181
Italy	325	366	450	550
the Netherlands	113	129	157	191
Germany	561	572	575	572
Greece	57	67	84	101
Denmark	36	38	41	45
United Kingdom	382	420	469	479
EU 15	2681	2927	3294	3662
EU 25	2973	3249	3673	4089

Table 14 – Annual energy demand [TWh] in Europe (according to [4])

TWh	Agriculture	Industry	Transport	Services	Household
Portugal	1.1	19.4	0.4	17.5	15.1
Poland	4.7	54.0	7.6	30.9	23.6
Italy	5.0	165	11.3	88.3	73.7
the Netherlands	14.5	46.1	2.1	29.5	27.5
Germany	8.5	254	17.5	121	144
Greece	2.9	17.5	0.2	20.5	20.0
Denmark	2.8	11.4	0.5	11.0	9.9
United Kingdom	4.0	135	10.1	115	123

Table 15 – Sectoral breakdown of demand [TWh] in Europe in 2010 (according to [4])

4.5 Generation scenarios

Typical daily generation profiles with average values for winter, summer and spring/autumn were identified during data collection process, for each of the microgeneration technologies per country as described in Annex 4.

Microgeneration penetration is varied within the studies of WPG to quantify and qualify the effects of Microgrids.

4.5.1 Microgeneration State of Today

Currently, there is a strongly increasing share of renewable microgeneration due to different regional support schemes (Figure 10, Figure 11)

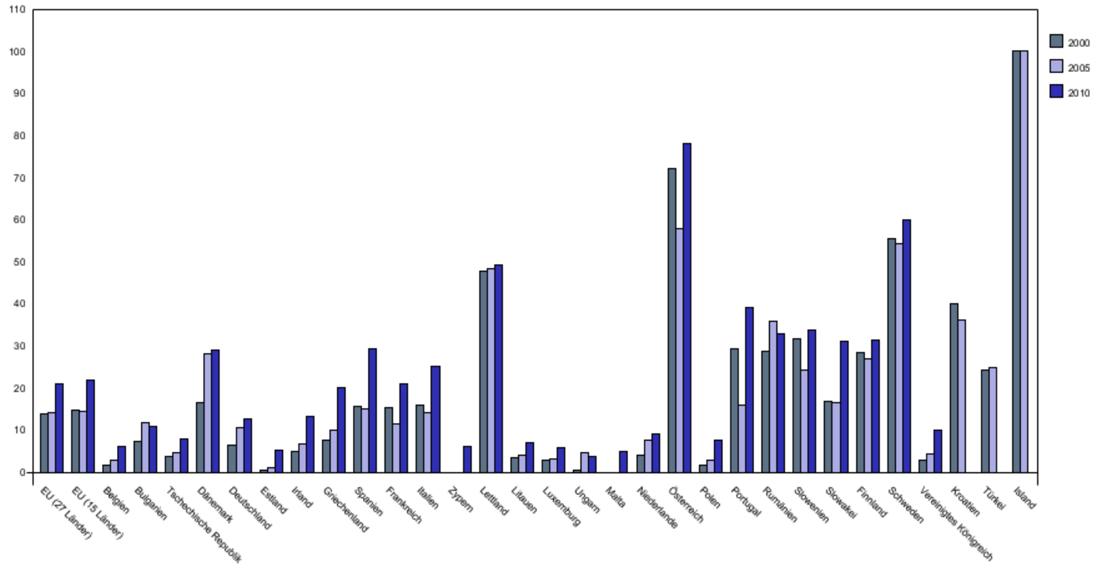


Figure 10 – Share of Renewables share in % on gross energy consumption (source Eurostat)

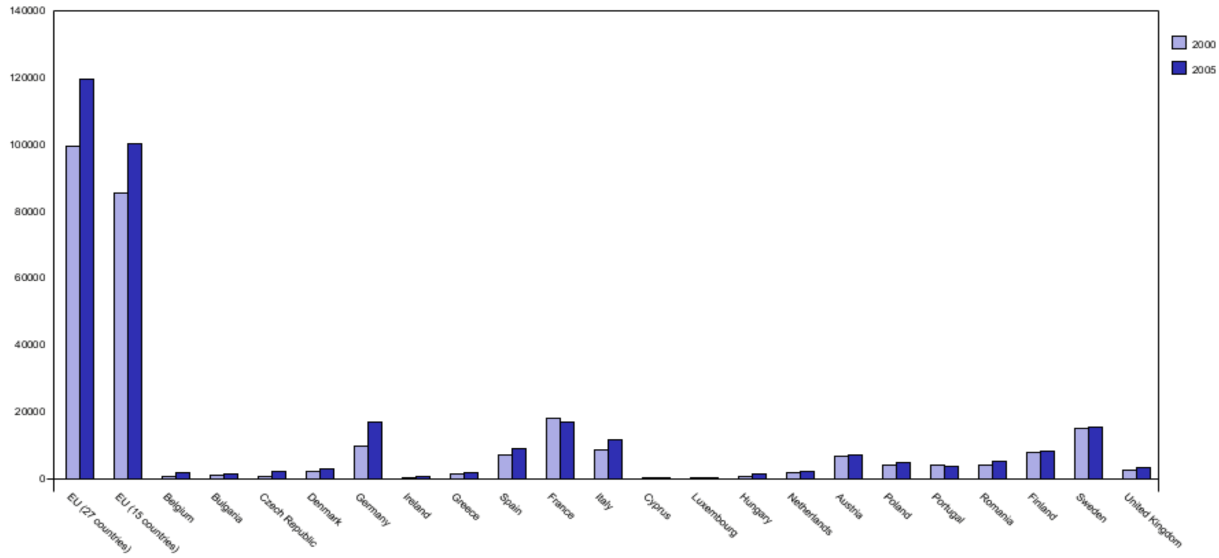


Figure 11 – Primary production of RES (1000 toe) in Europe (source Eurostat)

The share of renewable generation differs all over Europe, leading to different impacts on network operation.

However, in order to fully exploit the advantages provided by RES, coordinated control of microgeneration units – as suggested by the Microgrids approach - is required. This is not done so far, apart from some test sites/installations and applications on islands. But at least some approaches based on virtual power plant (VPP) concept exist that could make use of energy aggregation.

4.5.2 Microgrid simulation scenarios

The further development of Microgrid scenarios strongly depends on both the benefits that can be provided by this kind of operation as well as supporting regulatory and political framework conditions.

Nevertheless, future generation scenarios must be developed concerning the microgeneration technologies most likely to appear in each network. The technologies should reflect the type of network they are included in, for instance, CHP will be concentrated mainly in urban areas.

For each type of network and each load profile, different microgeneration penetration scenarios will be developed considering different types and penetration level of generation technology, namely:

- Micro-CHP generation;
- Micro-Hydro generation;
- Micro-PV generation;
- Micro-Wind generation.

Nevertheless, other technologies may be considered, according to what is expected to be developed for each typical network. Several situations should be explored, namely considering that the percentage of microgeneration penetration can, for instance, account for 0% (base case) 10%, 20% and 30% of the total simultaneous peak load of each network.

PV generation levels can be considerably high during a large period of the year in the southern European countries while they can be smaller in the northern European countries. On the other hand, CHP contribution can be quite relevant in northern European countries, especially during winter time, while CHP microgeneration levels can be smaller in southern European countries.

It must be stressed that the main aim of the analysis is to evaluate the impact of microgeneration in the distribution grid. Consequently, only the impact of microgeneration penetration is being considered. Additional microgeneration connected directly to the MV and HV level are treated in separate considerations.

A scenario is defined for each network considering typical load and generation profiles. For illustration purposes realistic Microgrid scenarios in each country with average percentage of each microsource technology for each distribution network is presented in Table 16 for year 2015.

Network	Generation Technology	**Penetration level per technology in %**								
		PT	PL	IT	NL	DE	GR	DK	MC	UK
HV	CHP	42	5		5	5	5		-	30
	Hydro	16	5		10	5	3		-	
	PV	26	-		5	5	2		-	
	Wind	16	20		80	85	90		-	70
RMV	CHP	-	5		50	30	5		-	40
	Hydro	40	5		-	15	30		100	
	PV	20	-		10	5	5		-	
	Wind	40	10		40	50	60		-	60
UMV	CHP	70	8		50	45	30		-	100
	Hydro	-	-		-	-	-		-	
	PV	30	-		20	15	20		-	
	Wind	-	5		30	30	50		-	
RLV	CHP	-	20		40	30	15		-	70
	Hydro	40	2		-	5	-		-	
	PV	20	1		50	50	80		-	20
	Wind	40	5		10	15	5		-	10
ULV	CHP	70	20		50	50	30		-	90
	Hydro	-	-		-	-	-		100	
	PV	30	1		50	50	70		-	10
	Wind	-	-		-	-	-		-	30

Table 16 - Typical penetration level in Microgrid Scenario 2015

4.6 Economic aspects

Economic impact of Microgrid operation is calculated as the economic benefits provided to the customers and producers forming the Microgrid compared to the operating situation without Microgrid.

4.6.1 Costs of Microgeneration Technologies

To perform the evaluations of WPG, microgeneration cost data as median values are taken from seven published sources of literature, whose origins are respectively German [2], Austrian [3], Belgian [4], UK [6], Siemens internal calculations, US [9], and Canadian [10]. By specifying 8 existing generator-fuel combinations as study cases, Table 17 describes the basic economic and technical data required for further calculations. Each item (listed in the first column to the left) is described by a minimum value (given in the upper row of each two) and a maximum one (given in the lower row of each two); when they are equal in amount, the item is assumed to have a constant value. Lifetime of all generation technologies is assumed to be 15 years.

Tech-Type	Dispatchable (CHP)						Undispatchable	
Fuel-Type	Fossil Fuels			Renewables (RES)				
Cases	1	2	3	4	5	6	7	8
Tech-Fuel Correlation	Steam Turbine	Recip. Engine	Micro-turbine	Gas Turbine	Stirling Engine	Fuel Cell	Wind Turbine	PV Array
	Coal	Diesel	Natural Gas	Bio-mass	Solar-thermal	Metha-nol	Wind	Solar
Rated Power (kW)	500	200	30	100	1	1	10	1
	10000	10000	500	5000	100	1000	5000	5000
Investment Cost (€/kW)	900	600	1200	2600	6700	4000	1000	4000
	1250	1000	2000	4200	10000	12000	2500	8500
Operation and maintenance Cost (€/MWh)	8	14	10	8	12	10	4	4
Fuel Cost (€/MWh)	16	22	24	18	0	34	0	0
Energy-specific Cost (€/MWh)	34	43,5	38,5	26	12	44	4	4
Full-load Hours (h/a)	1500	2500	3000	4500	1500	3000	1500	800
	4500	6000	5000	6000	2500	5000	3500	1500
Feed in tariff / Premium (€/MWh)	5,8	5,8	7,5	33	312,6	18,3	20	312,6

Table 17 - Economic and Technological Data for Selected Microgeneration Scenarios (2007)

For all CHP generation technologies, the power- and energy-specific costs are electrically based, which means thermal-related costs and revenues are subtracted from total values and are assumed to be independent from the operation mode (heat-driven or electricity-driven) of the plant.

Currently, cost efficiency of different microsources is primarily determined by different support schemes described in detail in Annex 3.

Evaluations done in WPG will consider scenarios without any support as well as operation strategies according to current legislation.

4.6.2 Energy market data

An increasing share of electricity is traded on European spot markets; their interrelation for European UCTE network is shown in Figure 12, with strong correlations in energy prices as shown in Figure 13. UK Electricity market is not separately considered.

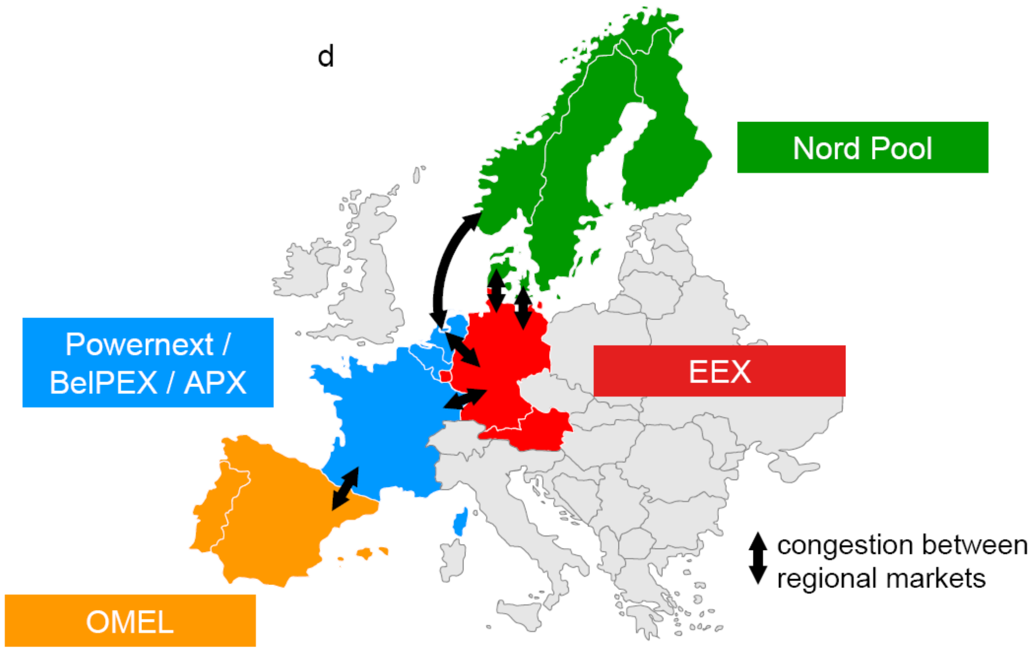


Figure 12 – Connection of regional energy markets in Europe, source EEX

Due to this high correlation cost and market data are assumed to be consistent on EU level for evaluations in WPG. It is possible to calculate with average European market prices; i.e. data from EEX are available for 2006 and 2007 as for day ahead and intraday market.

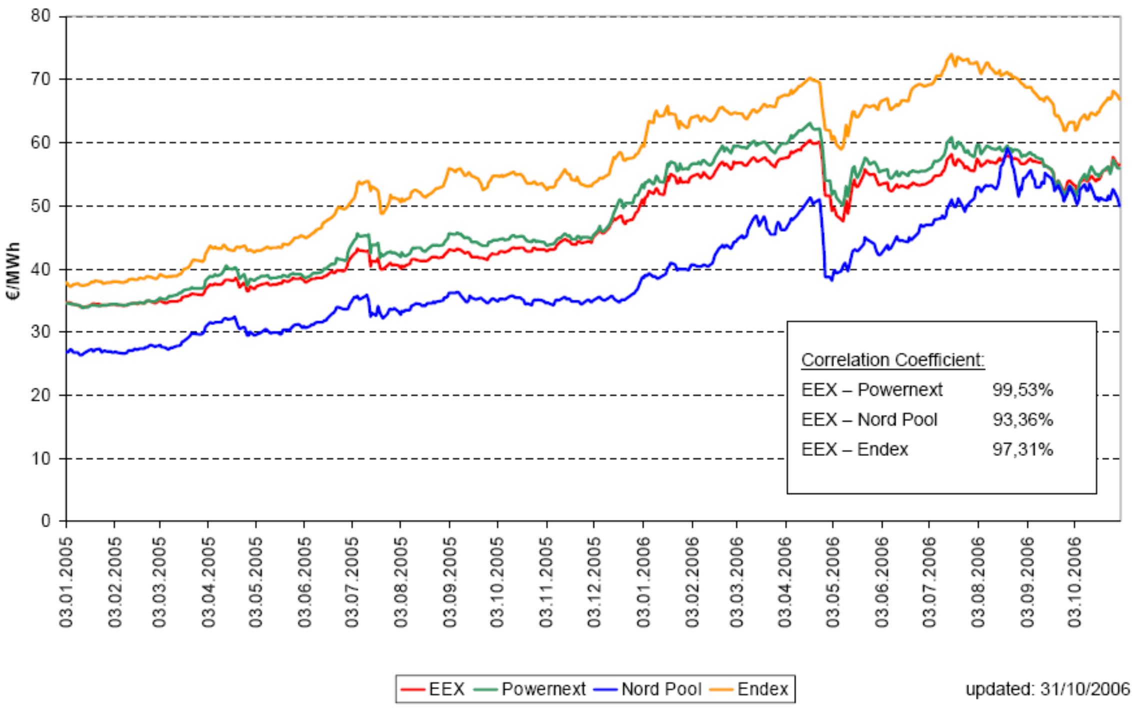


Figure 13 – Connection of regional energy markets in Europe, source EEX

4.6.3 Electricity tariffs

Average European electricity tariff for household in 2007 was 11.87 Ct/kWh (without taxes), for industry customers it was 8.22 Ct/kWh (Assumption for households: yearly consumption 3500 kWh, 1300 kWh of it during night; for industry: total energy demand 2000 MWh, with a maximum of 500 kW).

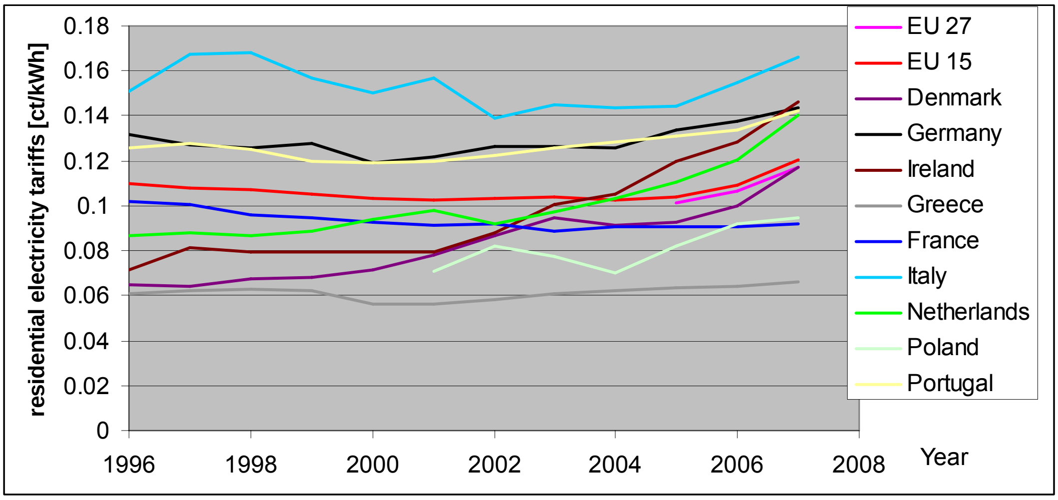


Figure 14 – Development of residential electricity tariffs, source Eurostat

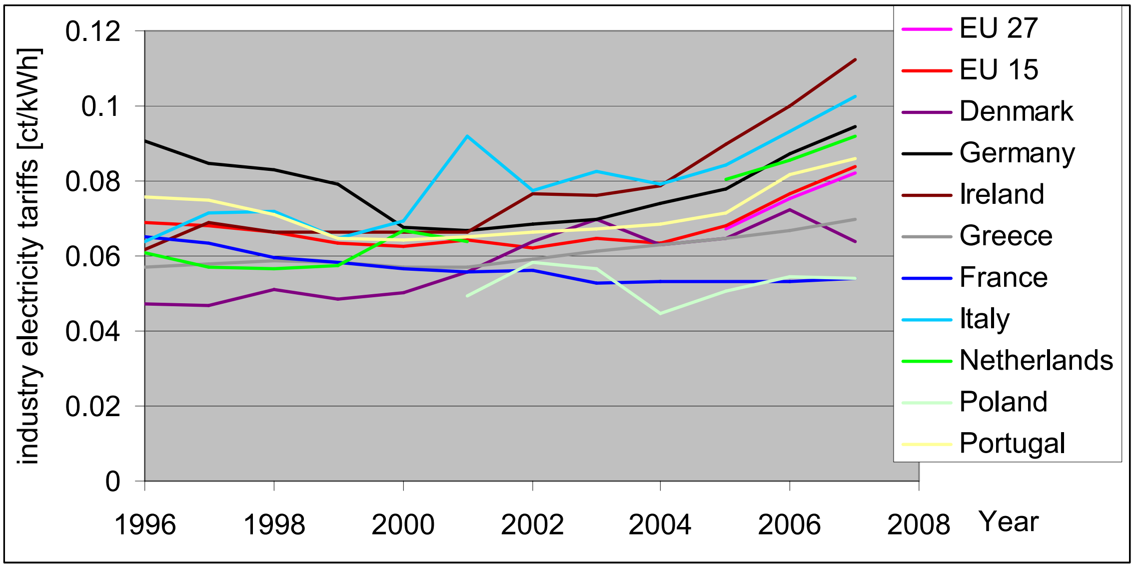


Table 18 - Development of industrial electricity tariffs, source Eurostat

Additional taxes, components for renewable support schemes, congestion levy, etc. may increase final tariff paid by consumers, i.e. in Germany for households up to 20.12 ct/kWh in average.

4.7 Environmental aspects

CO2-emissions strongly depend on the efficiency of the generation technology and the fuel used. While the basics to determine emissions can be found in Annex 5 summarises Table 19 average emissions per country and Table 20 the total yearly emissions in the country due to electricity supply.

gr/kWh	PT	PL	IT	NL	DE	GR	DK	MC	UK
CO_2 equivalents	544.4	847.0	456.6	506	470.9	688.6	526.0	1344.9	495.3
SO_2	2.91	5.6	1.64	1.53	2.71	4.32	2.77		2.10
NO_x	1.61	2.81	1.08	1.24	1.47	2.17	1.71		1.32
Particulate Matter		0.663				0.501			

Table 19 - Average emissions in gram/kWh per country

Mio. tonnes/year	PT	PL	IT	NL	DE	GR	DK	MC	UK
CO_2 equivalents	25.36	132.92	138.67	50.71	292.10	41.33	19.08	6.54	198.38
SO_2	0.14	0.88	0.50	0.15	1.68	0.26	0.10		0.84
NO_x	0.07	0.44	0.33	0.12	0.91	0.13	0.06		0.53
Particulate Matter		2				0.03			

Table 20 - Average total yearly emissions per country in Mio. tonnes

CO_2 equivalents are considered as they are assigned in national allocation plans to industry and electricity generation units in each country. EEA (European Emission Allowances) that equal 1 tonne CO_2 equivalents are traded on forward markets such as EEX, or APX. Settlement prices and trading volumes are given as example from EEX in Figure 15 and Figure 16.

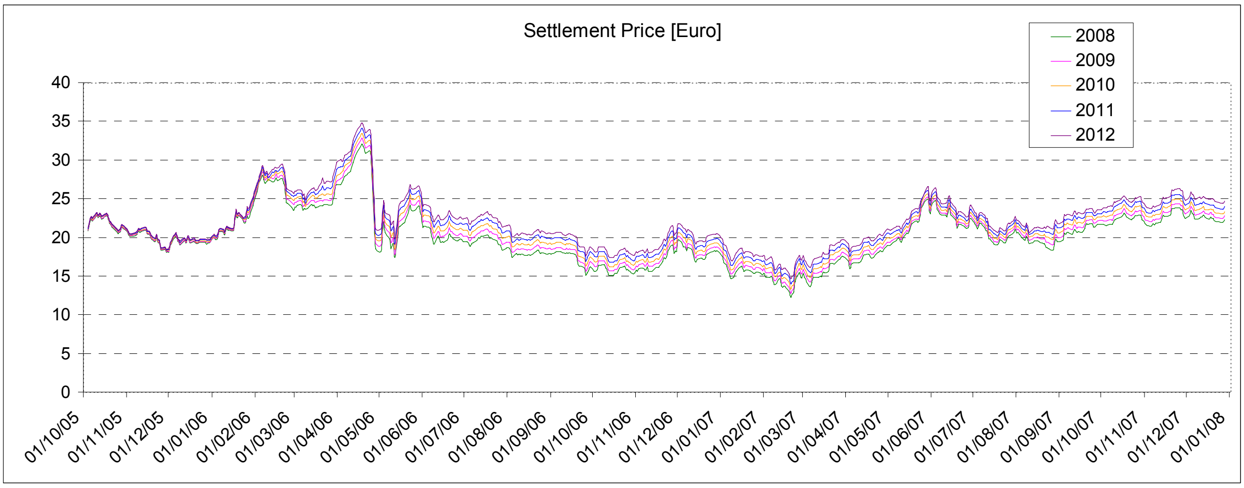


Figure 15 – Settlement prices per EEA for 2008 – 2012 futures, EEX

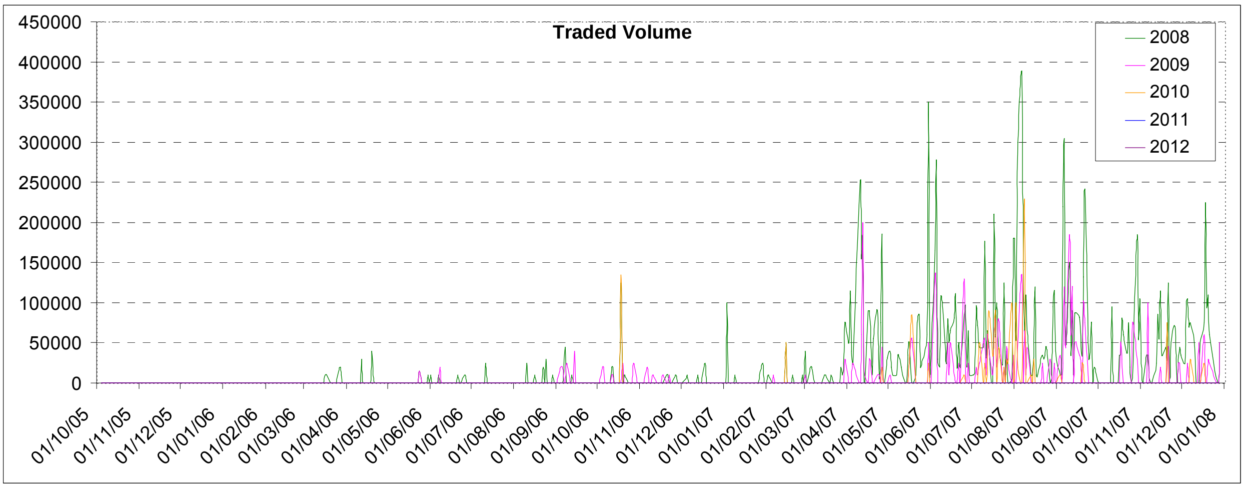


Figure 16 – Traded volumes for EEA, EEX

It is possible to determine the reduction in GHG emissions based on the average consumption per country only as long as the reduction is significantly low in comparison to total GHG emission. As soon as certain power plants have to be switched off due to a more widespread microgeneration average emission levels per country will change and thus need to be recalculated.

5 Conclusions

This deliverable describes the results of extensive investigations that have been performed in WPG, task 1 to collect all information required for further analysis in WPG for the countries Portugal, Poland, the Netherlands, Italy, Germany, UK and Greece. Based on this information it is possible to perform evaluations of technical, economic and environmental Microgrid benefits at regional and at European level.

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Annex 1 Reliability indices in Europe

CEER [1] gives an interesting overview about reliability indices in Europe. The main information is summarized in this Annex 1.

Because of different measurement practices in European countries, available data on actual levels of continuity of supply are not always comparable. It is important to consider the country specific conditions. In particular the following should be noted:

- First, whilst the scope of benchmarking interruptions has been extended to include short interruptions as well as long interruptions, not all countries separate their interruptions data into these two categories. I.e. interruptions shorter than three minutes are (separately) measured in only a few countries (Finland, France, Hungary, Great Britain, and Italy).
- Second, there are different ways of measuring supply interruptions. Continuity data may be collected at all voltage levels or may exclude some voltage levels. Furthermore, continuity indicators may refer to all customers or be split between customers at different voltage levels (Figure 17).
- The final and perhaps most important factor to take into consideration is that continuity indicators are not always defined in a comparable way. Continuity indicators can be weighted by three different methods; by customer, transformer or contracted power. This can give rise to differences depending on which weighting method is used (Figure 18).

SAIDI, SAIFI and MAIFI per voltage level (H, M, L)	GB, HU, IT, NO (from 2006)
SAIDI and SAIFI per voltage level (H, M, L)	CZ, GR, PT, FR, LT, NO (from 2006)
SAIDI and SAIFI per voltage level (H, M)	SI (some data only), BE_Wallonia
SAIDI and SAIFI all voltages	SE, EE, IE (SAIFI from 2006)
Average duration (D) and frequency (F) per contracted power or other	AT (average D and F weighted on MV power affected, MV/MV, MV/LV), ES (average D and F weighted on MV power affected: TIEPI, NIEPI) FI (Average D and F weighted on yearly energy consumption) FI (Interruptions are weighted by the yearly energy consumption of the distribution area that one distribution transformer feeds). PT (TIEPI, ENS, excluding LV) NO (ENS, excluding LV: ≤1kV)
Other/No indicators	LV (number of interruptions), PL (no indicators)

Figure 17 – Continuity indicators for distribution

USER	Belgium-Wallonia, Czech Republic (from January 2007) Estonia, France (LV and T networks), Great Britain, Hungary, Ireland, Italy, Lithuania, Portugal, Sweden,
TRANSFORMER	Finland[10] , Norway
POWER	Austria (MV-networks, MV/MV, MV/LV), Czech Republic (until January 2007), France (MV networks), Spain
None used/no answer	Belgium, Greece, Latvia, Netherlands, Slovenia, Poland

Figure 18 – Weighting methods used for continuity indicators

Figure 19 to Figure 29 demonstrate the most important indices in Europe.

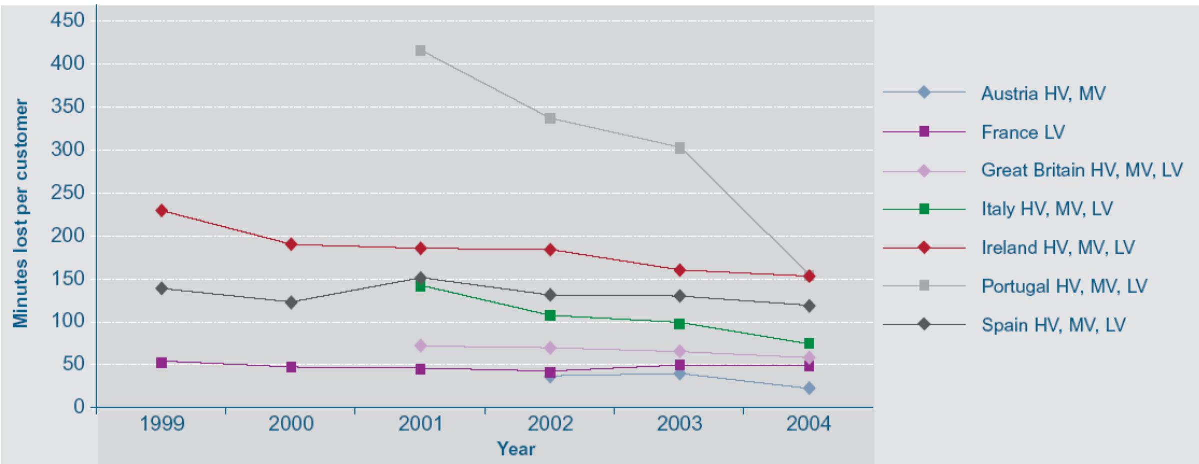


Figure 19 – Unplanned interruptions excluding exceptional events (SAIDI)

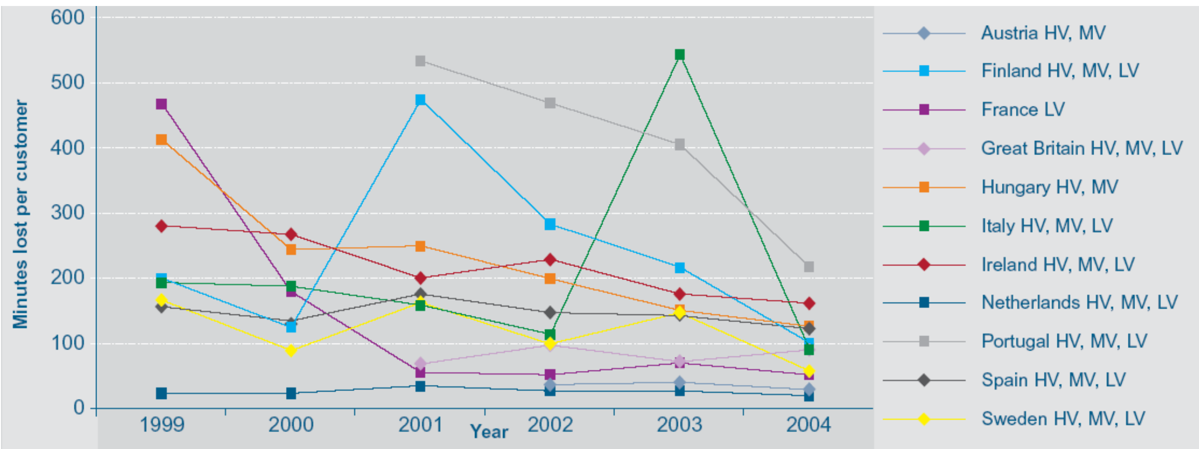


Figure 20 – Unplanned interruptions (SAIDI)

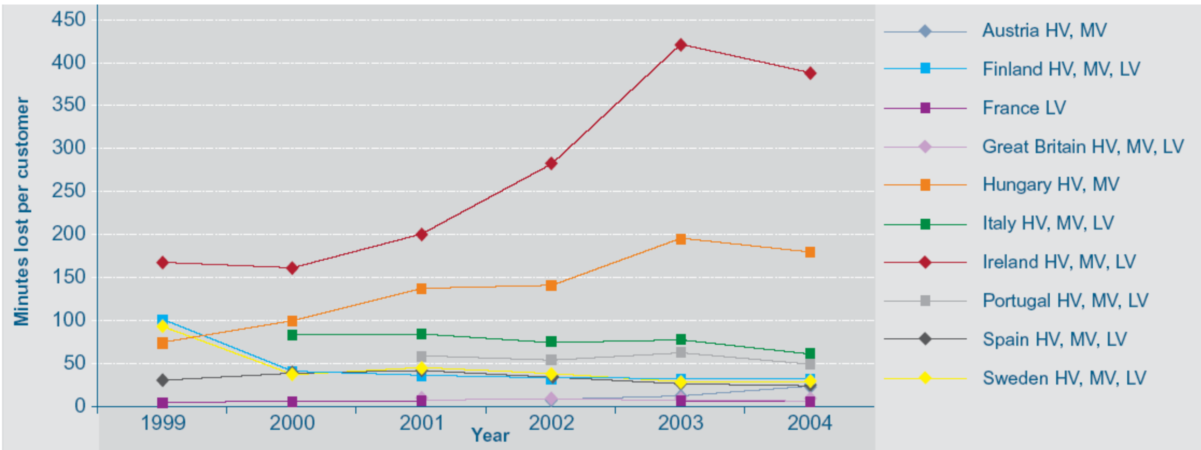


Figure 21 – Planned interruptions (SAIDI)

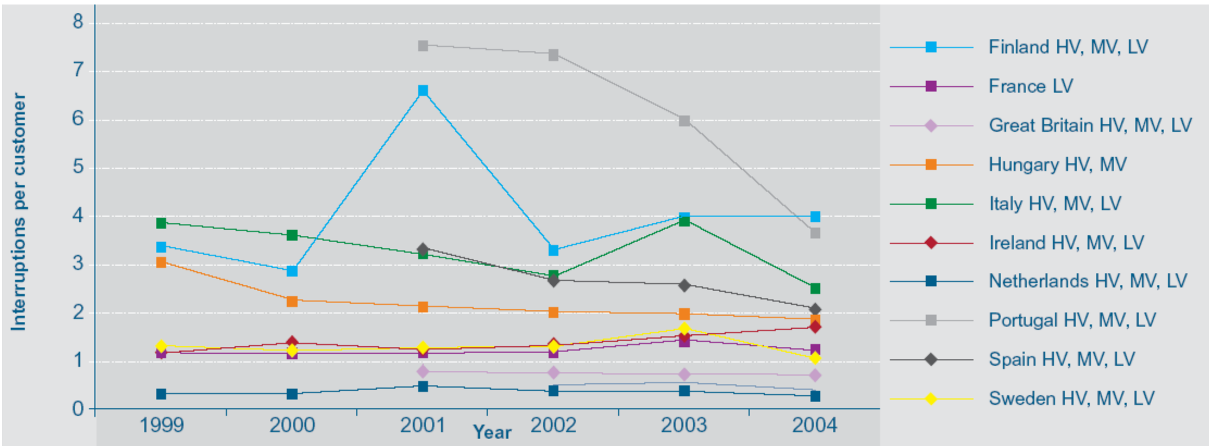


Figure 22 – Unplanned interruptions SAIFI

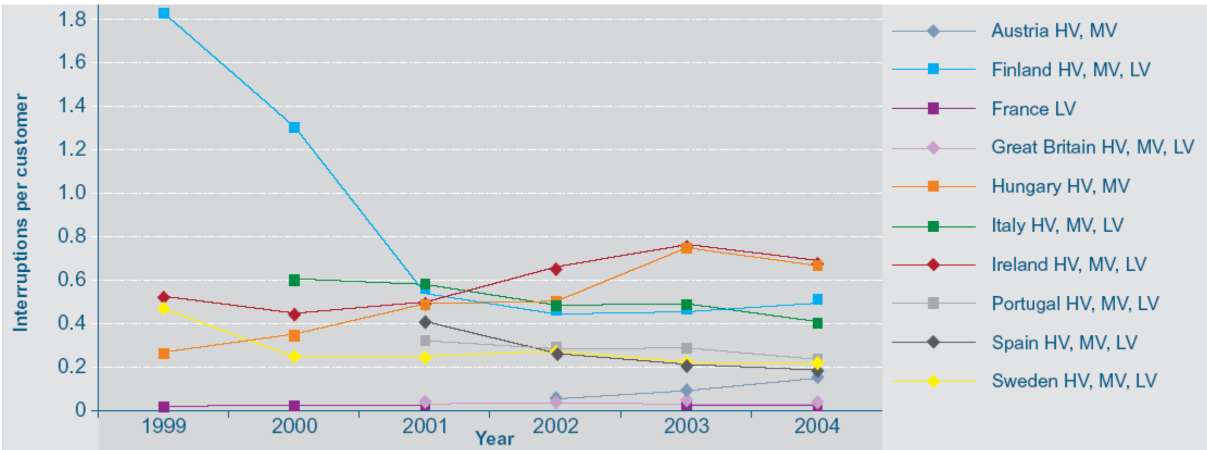


Figure 23 – Planned interruptions SAIFI

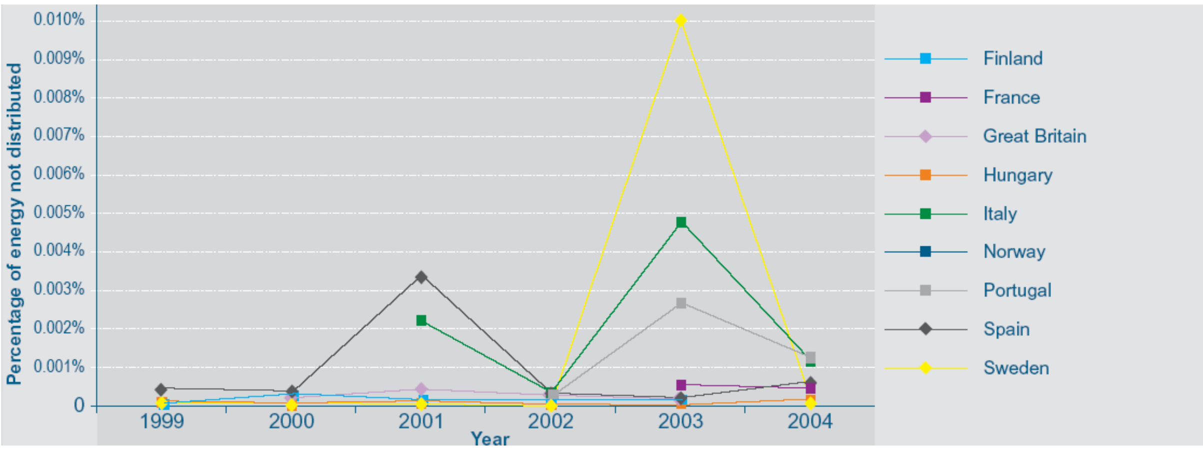


Figure 24 – ENS as percentage of distributed energy

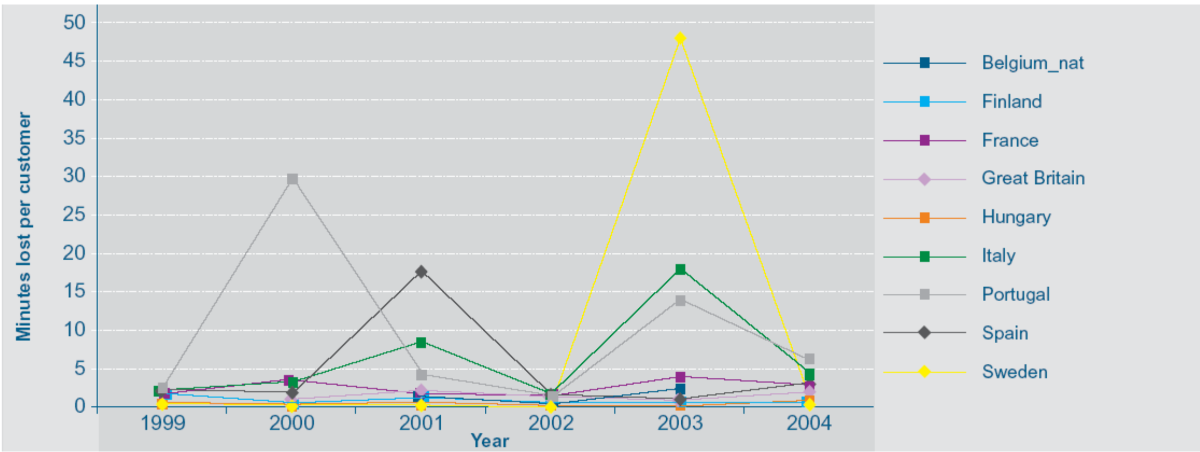


Figure 25 – Minutes lost per year, transmission, all interruptions

Country	1999	2000	2001	2002	2003	2004
Finland	198.00	129.60	468.00	284.40	212.40	103.00
France	459.00	176.00	59.00	52.00	69.30	57.10
Great Britain			75.84	101.33	72.68	87.33
Hungary	411.00	241.20	250.20	196.80	155.40	137.40
Italy	191.77	187.40	149.09	114.74	546.08	90.53
Ireland	273.60	257.90	199.30	230.20	171.90	162.80
Netherlands	26.00	27.00	34.00	28.00	30.00	24.00
Portugal			530.74	467.98	406.18	217.79
Spain	156.37	145.41	179.69	142.56	141.91	123.60
Sweden	165.77	89.17	162.90	101.84	148.05	59.73
Latvia					14.00	8.50
Lithuania						190.00

Figure 26 – Unplanned interruptions, minutes lost per customer/year

Country	1999	2000	2001	2002	2003	2004
Austria				7.40	12.79	20.69
Finland	103.20	38.00	33.00	32.00	32.00	30.00
France	4.00	6.00	6.00		5.30	6.60
Great Britain			7.85	9.04	8.43	6.95
Hungary	75.00	99.60	139.80	142.80	199.80	178.80
Italy		82.62	84.82	77.97	80.67	62.62
Ireland	172.00	164.70	202.00	284.10	422.30	390.70
Portugal			57.37	52.21	62.39	49.16
Spain	31.96	37.05	36.57	30.66	24.79	22.80
Sweden	90.07	34.53	42.28	37.12	25.41	29.59
Estonia					24.38	
Greece					87.00	
Lithuania						122.45

Figure 27 – Planned interruptions, minutes lost per customer/year

Country	1999	2000	2001	2002	2003	2004
Finland	3.32	2.89	6.61	3.34	3.97	4.00
France	1.22	1.20	1.20	1.20	1.43	1.30
Great Britain			0.84	0.82	0.79	0.75
Hungary	3.09	2.29	2.13	2.03	2.05	1.90
Italy	3.81	3.59	3.29	2.76	3.96	2.48
Ireland	1.15	1.49	1.31	1.37	1.50	1.70
Netherlands	0.40	0.40	0.40	0.30	0.40	0.30
Portugal			7.51	7.35	5.96	3.66
Spain			3.30	2.65	2.60	2.06
Sweden	1.38	1.23	1.34	1.32	1.64	1.05
Latvia					0.04	0.04
Lithuania						1.58

Figure 28 – Unplanned interruptions (per customer and year)

Country	1999	2000	2001	2002	2003	2004
Austria				0.07	0.13	0.17
Finland	1.83	1.30	0.55	0.46	0.47	0.50
France	0.03	0.04	0.04		0.04	0.05
Great Britain			0.04	0.04	0.04	0.03
Hungary	0.29	0.34	0.50	0.52	0.75	0.68
Italy		0.61	0.59	0.49	0.49	0.40
Ireland	0.51	0.43	0.49	0.66	0.76	0.67
Portugal			0.32	0.29	0.30	0.23
Spain			0.42	0.26	0.20	0.19
Sweden	0.45	0.25	0.23	0.26	0.22	0.22
Estonia					0.49	
Greece					0.44	
Lithuania						0.40

Figure 29 – Unplanned interruptions (per customer and year)

Annex 2 Network Data Requirements

Load Flow analysis

Interconnected system

Rated voltage	Ur	kV
Voltage range of operation (max./min. load)	± ΔU	
Max. active power infeed	Pmax	MW
Reactive power infeed range	±Q	MVAr

Overhead lines

Single-circuit lines		
Multiple-circuit lines		
Length	l	km
Positive-sequence resistance	r1’	Ω/km
Positive-sequence reactance	x1’	Ω/km
Positive-sequence capacitance	c1’	nF/km

Cables

Rated voltage	Ur	kV
Number of parallel cables	n	
Cable type		
Cable size		
Diameter	q	mm2
Length	l	km
Positive-sequence resistance	r1’	Ω/km
Positive-sequence reactance	x1’	Ω/km
Positive-sequence capacitance	c1’	nF/km

Transformers

Two-winding transformers

Rated power	Sr	MVA	
Rated voltage HV-side (main tap position)	U_{r1}	kV	
Rated voltage LV-side	U_{r2}	kV	
Main tap	U_1 / U_2		
Tap band	n steps with ± ΔU		
Impedance voltage at rated power	z_r	%	
Resistance voltage at rated power or	r_r	%	
Total winding losses	P_r	kW*)	
Total no-load losses	V_m	kW*)	
Vector group			
Magnetizing current as a percentage of the rated current		i_m	%)
Tap changing under load; Range of regulation		±ΔU	%)
Tap changing under load; Number of steps			
Impedance voltage dependant on the tap position		z	%)
On load / off load tap changer			

*) not essential

Three-winding transformers

Rated power	S_{r12}	MVA
Rated power	S_{r23}	MVA

Rated power	S_{r13}	MVA	
Impedance voltage on three-phase-MVA of circuit 1		z_{12}	%
Impedance voltage on three-phase-MVA of circuit 2		z_{23}	%
Impedance voltage on three-phase-MVA of circuit 3		z_{13}	%
Resistance voltages	r_{r12} / r_{r13} / r_{r23} %		
Rated voltage HV-side (main tap position)	U_{r1}	kV	
Rated voltage MV-side	U_{r2}	kV	
Rated voltage LV-side	U_{r3}	kV	
Vector group			
Tap changing under load; On load / off load tap changer			

Current-limiting reactors

Rated voltage	U_r	kV
Rated current	I_r	kA
Rated reactor reactance	x_r	%

Shunt capacitors

Rated voltage	U_r	kV
Positive-sequence capacitance	C_l	μF
Rated power	Q_r	kVAr
Switched step (3-phase)	ΔQ	kVAr

Synchronous generators and motors

Rated voltage	$U_r \pm \Delta U$	kV ± %
Rated power	P_r	MVA
Rated current	I_r	kA
Rated power factor	PF_r	
Generator diagram		
Operating point of generator		
Active power	P	MW
Reactive power or	Q	MVar
Operating voltage	U	kV
Power factor	PF	
Load data		
Design of load connection point		
Voltage level	U_r	kV
Size of load	S_r	MVA
Rated power	P_r	MW
Active power demand	P_{op}	MW
Reactive power demand of	Q_{op}	MVAr
Load type		
Static type load (impedance, heating, etc.)	I, H etc.	
AC-motor load (ASM, SRM, SM)		
Converter load (type of converter)	I-Converter, V-Converter	
Power factor	PFop	
Compensation (for induction motors	Qcomp	MVAr

Further typical network components

Type, Connection diagram + relevant information		
Rated voltage	U_{rC}	kV

Optimization

Range of voltage profile ± ΔU %
Transformer tap range ± ΔU %
Number of tap steps
Range of reactive power infeed (interconnected system) Qmin (grid) MVAr
Range of reactive power of generators Q_{min} (grid) MVAr
Size and steps of shunt compensator Q_{shunt} MVAr
ΔQ MVAr

Short-Circuit-Study

Data requirements are similar to load flow analysis. Additional information required is:

For 3-phase and line-to-line short circuits

Interconnected system

Rated voltage U_r kV
Maximal initial short-circuit power at the connection point SK“max MVA
Minimum initial short-circuit power at the connection point SK“min MVA
$SK'' = \sqrt{3} \bullet Ik'' \bullet Ur$

Synchronous generators

Rated voltage U_r kV
Rated power S_r MVA
Rated power factor cos Φr
Subtransient direct-axis reactance (saturated) x“d %
Transient direct-axis reactance (saturated) x’d %
Stator resistance r_a %
Negative-sequence reactance (saturated) x_2 %
Steady-state short circuit current I_k kA
Type of excitation system

HV-asynchronous motors

Rated voltage U_r kV
Rated power P_r kW
Rated current I_r kA
Ratio of locked-rotor to rated current I_{lr} / I_r
Rated speed n_r 1/min
Efficiency %
Loading factor %
Compensation Q_{comp} KVAr

Static converter fed drives

Rated voltage of the static converter transformers on the network side or rated voltage of the static converter if no transformer is present Ur kV
Rated current of the static converter of the network side or rated current of the static converter if no transformer is present Ir kA
Probability how the drive is in reverse operation, when the short-circuit occurs %

LV-asynchronous motor groups

Designation of motor group connection point
Rated power of the motor group in operation $P_{r\ group}$ kW
Relation transformer size - rated power of motor group $P_{r\ group} / S_{rT}$

Power consumption of the group	P_{op}, Q_{op}	KW, KVAr
Power factor (estimated)	PF_{op}	

Line-to-earth short circuit

Additional data to three-phase short circuits are:

Overhead lines

Zero-sequence resistance	r'_0	Ω/km
Zero-sequence reactance or ratios r'0 / r'1 , x'0 / x'1	x'_0	Ω/km
Zero-sequence capacitance	c'_0	nF/km

Cables

Type (construction)		
Zero-sequence resistance	r'_0	Ω/km
Zero-sequence reactance or r'0 / r'1 , x'0 / x'1	x'_0	Ω/km
Zero-sequence capacitance	c'_0	nF/km

Transformers

Ratio of zero-sequence impedance to positive-sequence impedance;	z_0 / z_1	
for three winding transformers	z_{01}, z_{02}, z_{03} and z_{0m}	
Connection of neutral point		
Neutral grounding impedance	R_{NE} , X_{NE}	Ω

Synchronous generators (if neutral grounded)

Zero-sequence reactance (saturated)	x_0	%
Neutral grounding impedance/resistance	R_{NE} , X_{NE}	Ω

Annex 3 Current European Microsources Support Schemes

Due to increasing environmental concerns on a global scale—especially in Europe [11], policy interventions are widely implemented in this market sector to bolster technologies that could contribute to GHG (Green House Gas) reduction and energy saving effects. Currently a number of different RES- and CHP-supporting schemes are carried out on a country-to-country basis in Europe, which can be summarized as Figure 9 (source [12]):

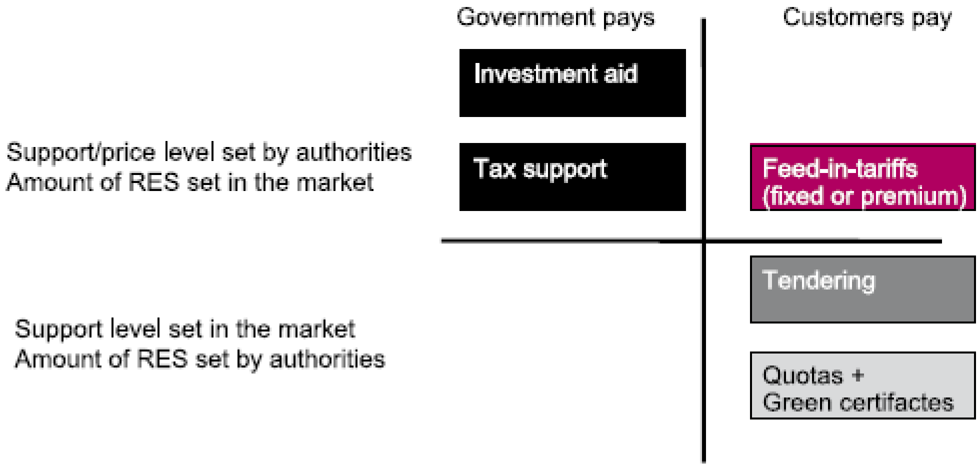


Figure 30 – Types of RES/CHP Supporting Mechanism

As Figure 9 suggests, direct government support for RES/CHP could appear in the form of investment subsidy or tax reduction [14]. However, such measures can be viewed as mainly case-specific (subsidy) or approximately negligible in a simplified market environment (tax incentive). This leaves three major types of customer-paid supporting scheme under examination, which can be defined respectively as:

1. Feed-in-Tariff (FIT) method (for RES/CHP)

An FIT system either sets (annually) fixed prices for RES/CHP generated electricity according to the type of used technology, or adds technology-specific bonuses on top of market price for RES/CHP sources of electricity—the latter is also known as a premium system [12]. Under an FIT environment, utilities are often required to provide maximum support for grid connection of microgeneration [11] and are even demanded to buy all electricity generated from a RES/CHP unit [13]. Past experience has shown that a high-pricing FIT system can be extremely effective for increasing microgeneration penetration [15] [16], although FIT systems are also consistently doubted to repress competition in the electricity market and hence curtail technology innovations [11]. With a proper schedule for price reduction over years [13], however, sufficient incentives for microgeneration -related cost reduction could be achieved, which should be able to compensate for the deficiencies in an FIT system.

2. Quota obligation plus TGC (Tradable Green Certificate) method (for RES)

In a quota-based TGC system, electricity generated from a RES unit is sold in a competitive free market and thus receives no direct financial support from its sales revenue [14]. This free-market competition, however, is complemented by annually-fixed quota (i.e. percentage of RES-based electricity in annual consumption) set by local authorities. The quota has to be met by a predefined market actor such as energy supplier or end customer [11] [14], which means the liable entity has to purchase a minimum amount of TGC from RES-E producers. Failure of meeting the preset annual quota will infer a per-MWh penalty determined by the amount of TGC deficit [14]. The quota system has been designed to promote competition among RES-E producers and drive least-cost solutions through a market incentive [17]; but since the non-discriminative nature of TGC trading does not differentiate one microgeneration technology from another and neglects the size of microgeneration units, proper specification of technology- and size-dependent quotas will have to be implemented if RES market evolutions towards a single most cost-effective technology and large microgeneration unit sizes are to be avoided [14] [15] [16].

3. Tendering method (for RES)

Formerly also implemented in UK and France [11], the tendering approach is now only applied in Ireland under a European context. In a tendering system, the local municipality offers a number of technology-specific tenders to RES-E bidders on a long-term contract basis [18]. Competition among the bidders should (theoretically) lead to efficient cost reduction of RES technologies, but the execution of tendering approach has proved the system could have difficulties in meeting preset RES quota and stimulating high-cost RES (such as PV) markets [11].

Based on the descriptions above, a brief comparison of three existing RES/CHP supporting schemes is shown in Table A-21.

Support Scheme	Feed-in-Tariff	Quota Obligation	Tendering
Number of EU Countries	17	6	1
Typical Example	Germany, Spain	Sweden, UK	Ireland
Advantages	Effective Incentives Flexibility of Policy	Market Initiative Least-Cost Driver	Pro-Competition Pro-Cost reduction
Disadvantages	Low Competition Costly to Society	Volatile TGC Price Costly Transaction	High Bidding Cost Insufficient Motive

Table A-21 - Comparison of RES/CHP Supporting Schemes

Study [16] shows that current supporting schemes among European nations mostly fall into FIT or quota categories, and notably a number of counties choose to use a mixture of both approaches to keep maximum flexibility [14]. In scope of this report, since wholesale electricity price is assumed to be a constant annual average value, the impact of electricity market on final calculation results can be seen as negligible. Therefore, the FIT approach is adopted in this report to suit previous assumptions.

Annex 4 Results of data collection for typical LV, MV and HV networks in Europe

Annex 4.1 Portugal

In order to be able to evaluate technical, economical and environmental benefits that may result from the presence of microgeneration in the electrical grids, an evaluation approach was developed with the following objectives:

- To identify overall loss reduction energy in all network voltage levels (distribution and transmission) at a national level;
- To identify the overall avoided CO_2 emissions that result from the avoided active losses in the electrical networks;
- To evaluate the investment deferral in network reinforcements, identifying the number of years that corresponds to postponing investments;
- To evaluate the annual energy that can be produced locally at the microgeneration level.

The development of this approach requires a first step where typical distribution networks must be identified. In order to obtain a European evaluation of the benefits described previously, the utilities involved in the project should provide data on typical, representative, distribution networks for their countries, considering several voltage levels and present and future operational scenarios of microgeneration penetration, including different generation technologies.

The methodology for identifying typical networks within the framework of WPH was used here.

A 4.1.1 Typical Networks

Each utility should identify typical grids for each country at the distribution level, concerning all distribution voltage levels: High Voltage, Medium Voltage and Low Voltage networks.

Apart from the distribution network data, data from the transmission network should also be gathered in order to evaluate technical and economical benefits that will appear at this level. This includes information related to typical load levels and generation profiles that may occur during a 1 year period of operation.

INESC Porto in collaboration with EDP has identified typical networks for HV, MV and LV distribution grids, considered as representative for Portugal.

The 5 typical networks identified in Portugal are presented next:

- 1 typical HV distribution network
- 2 typical MV distribution networks (Urban MV network, Rural MV network)
- 2 typical LV distribution networks (Urban LV network, Rural LV network)

For these networks, the following information was obtained:

- Single-line diagram;
- Base voltage;
- Line/cable data – branch resistance, reactance and susceptance, line/cable length, nominal rating, status;
- Transformer data (HV/MV and MV/LV) – leakage reactance/short-circuit impedance, rated power, transformer ratio, status;

The network data was obtained in accordance to the Methodology and the Data Request Form developed by INESC Porto for Work Package H, Task TH1.

The topologies for a typical HV network and for MV distribution networks for urban and rural areas in Portugal are shown in Figure 31, Figure 32, and Figure 33, respectively. The topologies for the typical LV networks for urban and rural areas in Portugal are shown in Figure 34 and Figure 36.

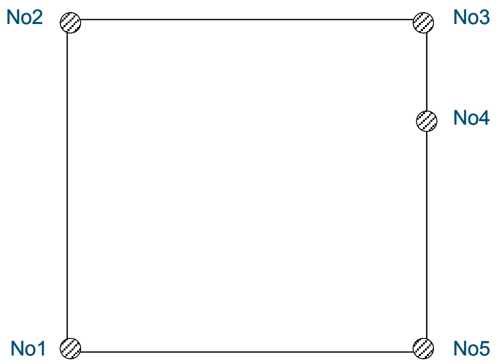


Figure 31 – Typical distribution HV network, Portugal

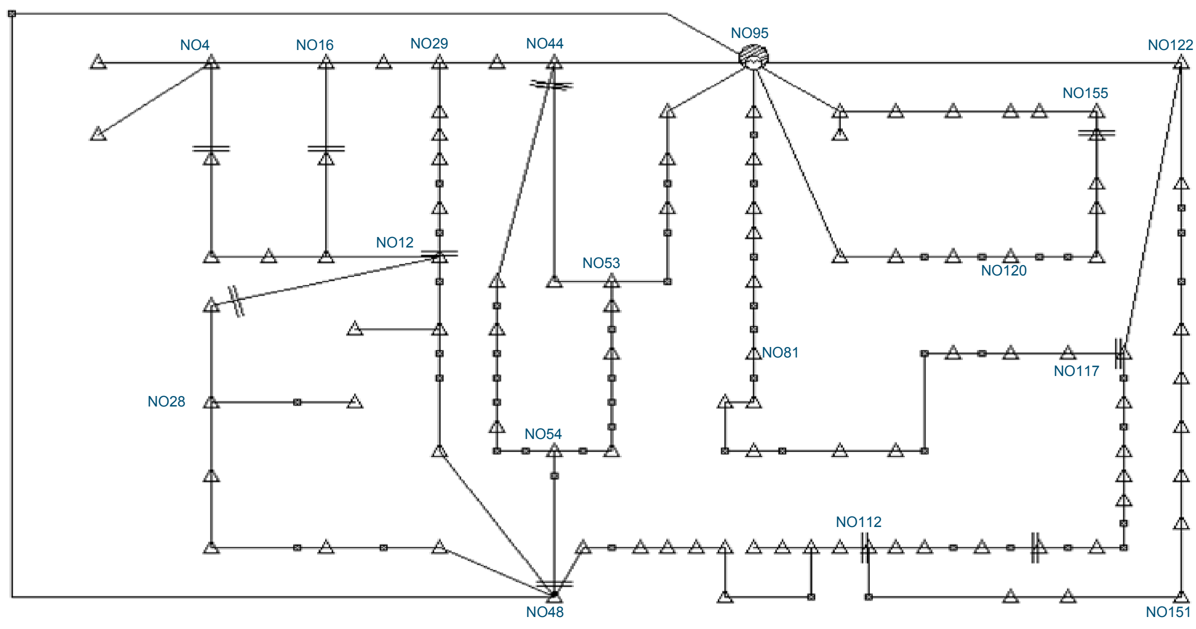


Figure 32 – Typical urban distribution MV network, Portugal

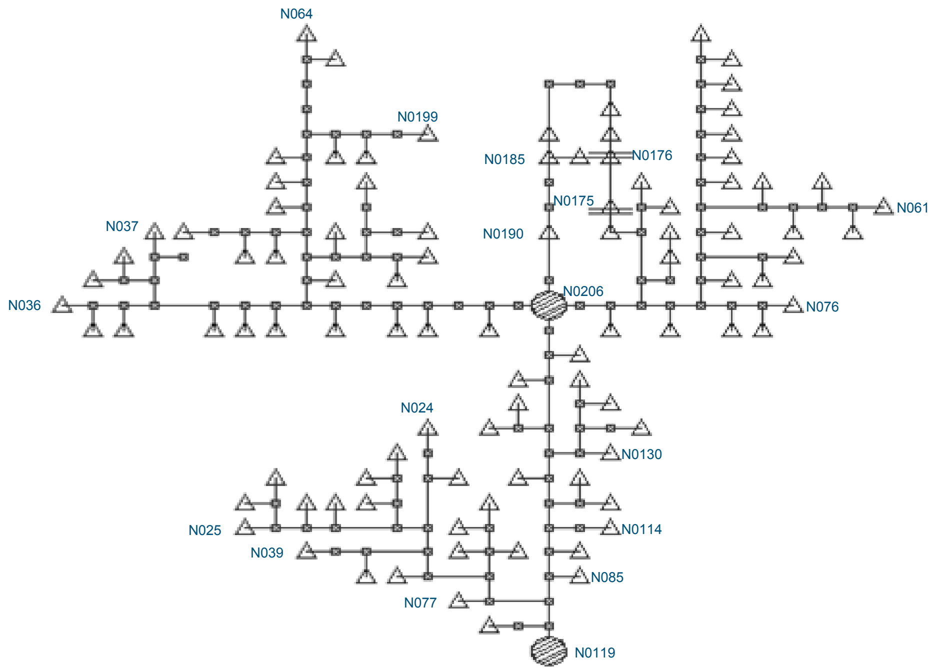


Figure 33 – Typical rural distribution MV network, Portugal

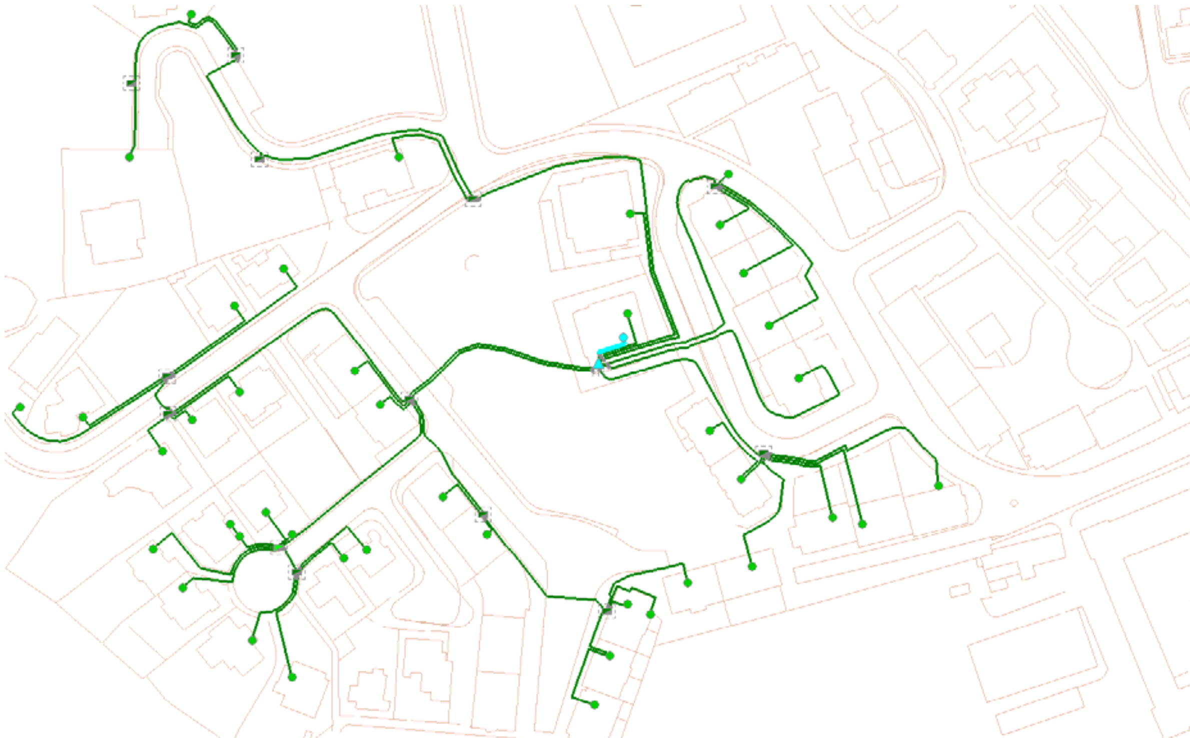


Figure 34 – Typical urban distribution LV network, Portugal

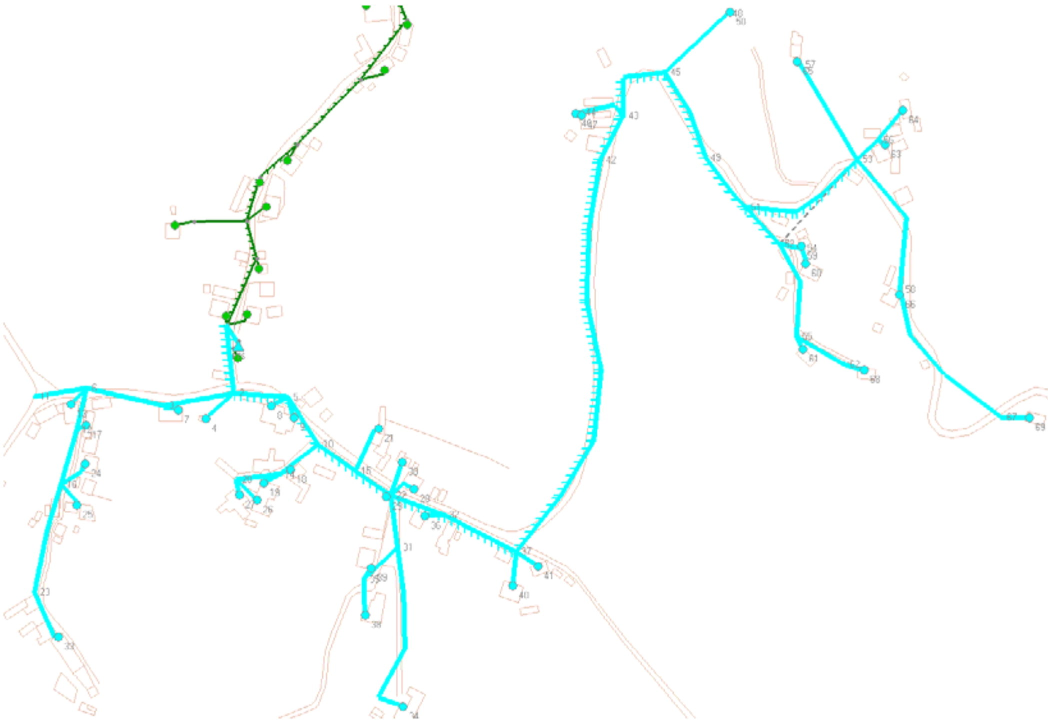


Figure 35 – Typical rural distribution LV network (feeder 1), Portugal

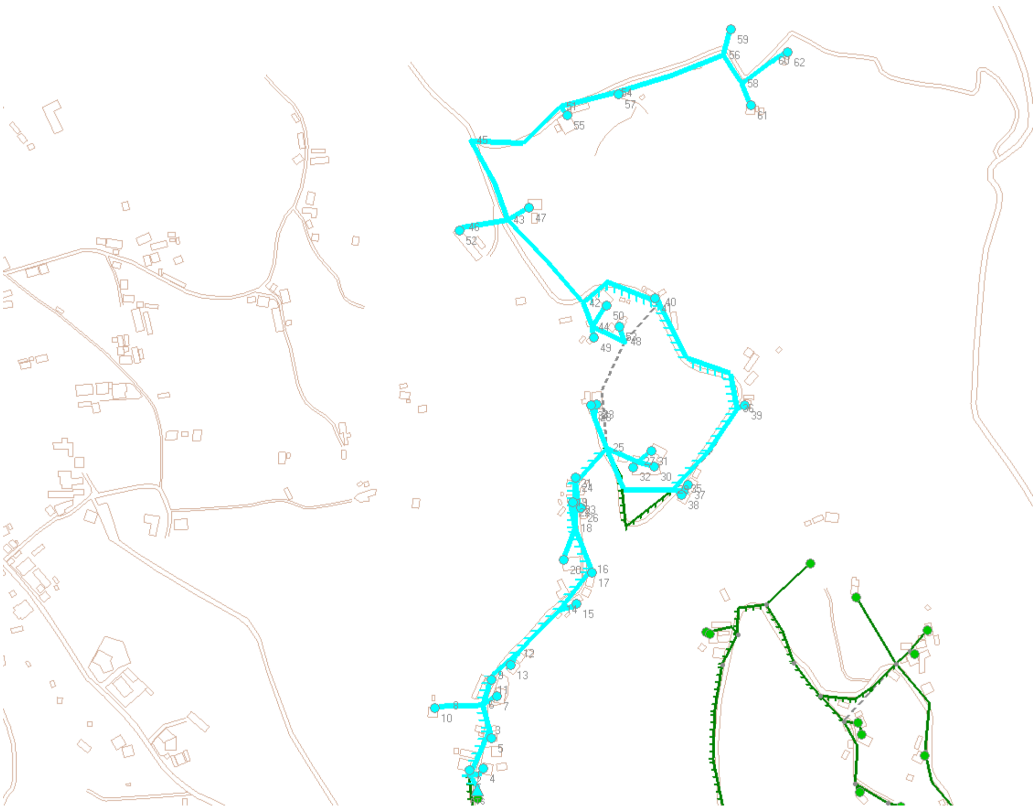


Figure 36 – Typical rural distribution LV network (feeder 2), Portugal

Figure 37 and Figure 38 show two feeder of the LV distribution network which integrates the Microturbine analysed in the WP F – Portuguese test site on EDP site. Concerning this LV network several data have been collected in order to support a detailed characterization. The data collection includes supply reliability, design characteristics, automation level and power quality analysis.

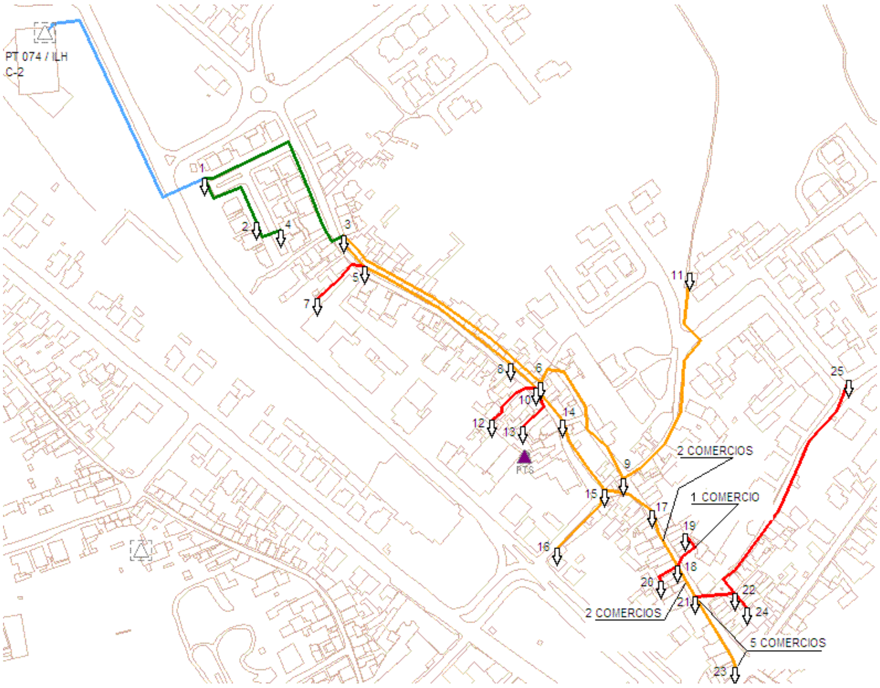


Figure 37 – Feeder 1 of Ilhavo LV distribution network (WP F - Portuguese test site)

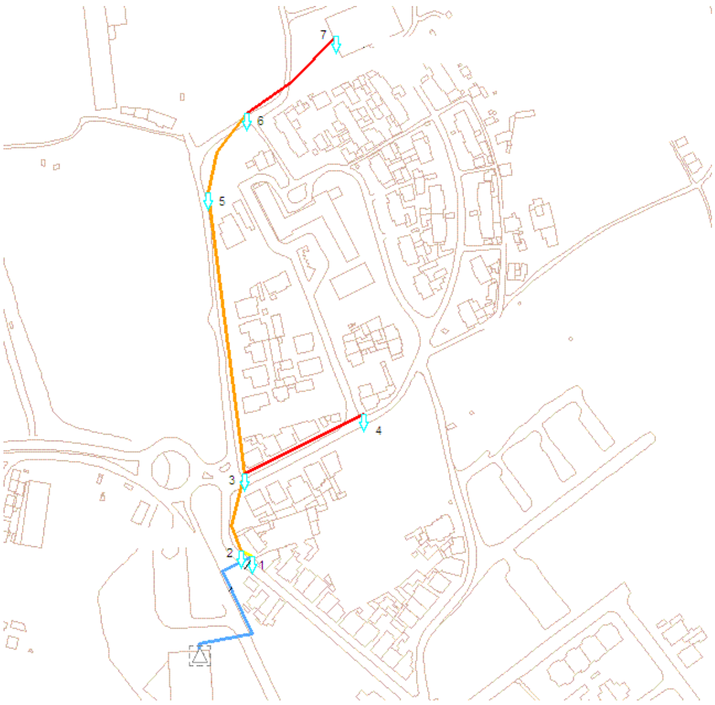


Figure 38 – Feeder 2 of Ilhavo LV distribution network (WP F - Portuguese test site)

Figure 39 to Figure 42 show the results of a power quality monitoring campaign performed at the Power Transformer (PT) of the Ilhavo LV distribution network.

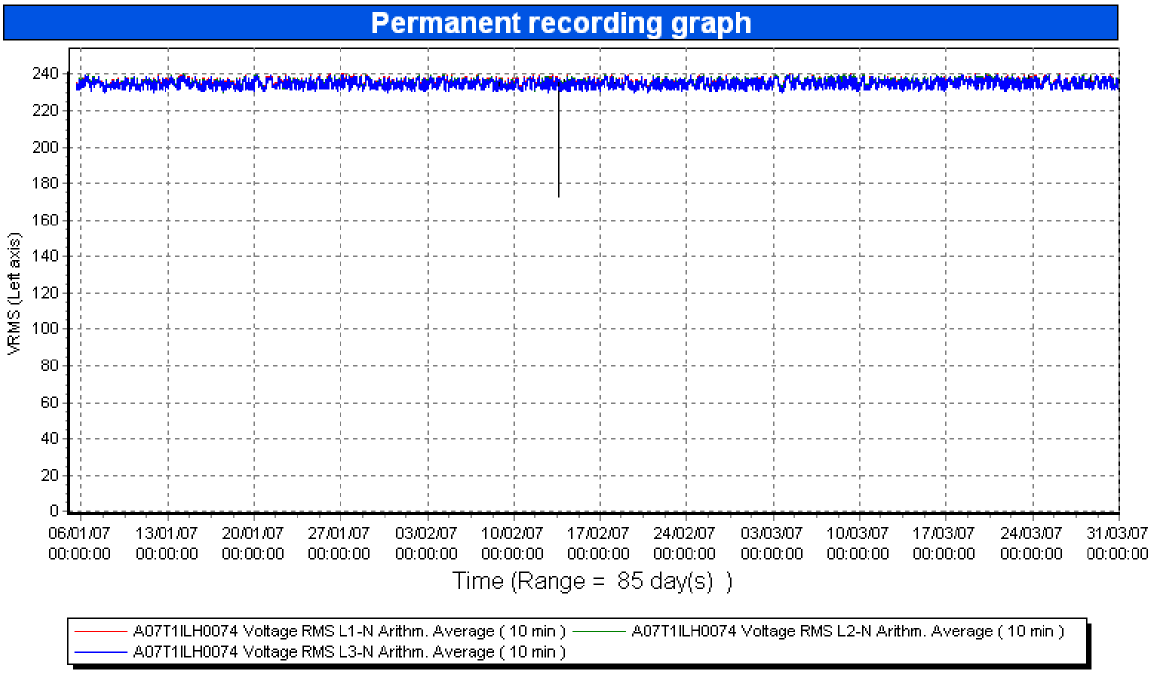


Figure 39 – Voltage RMS values at the LV busbar of PT – Ilhavo LV network

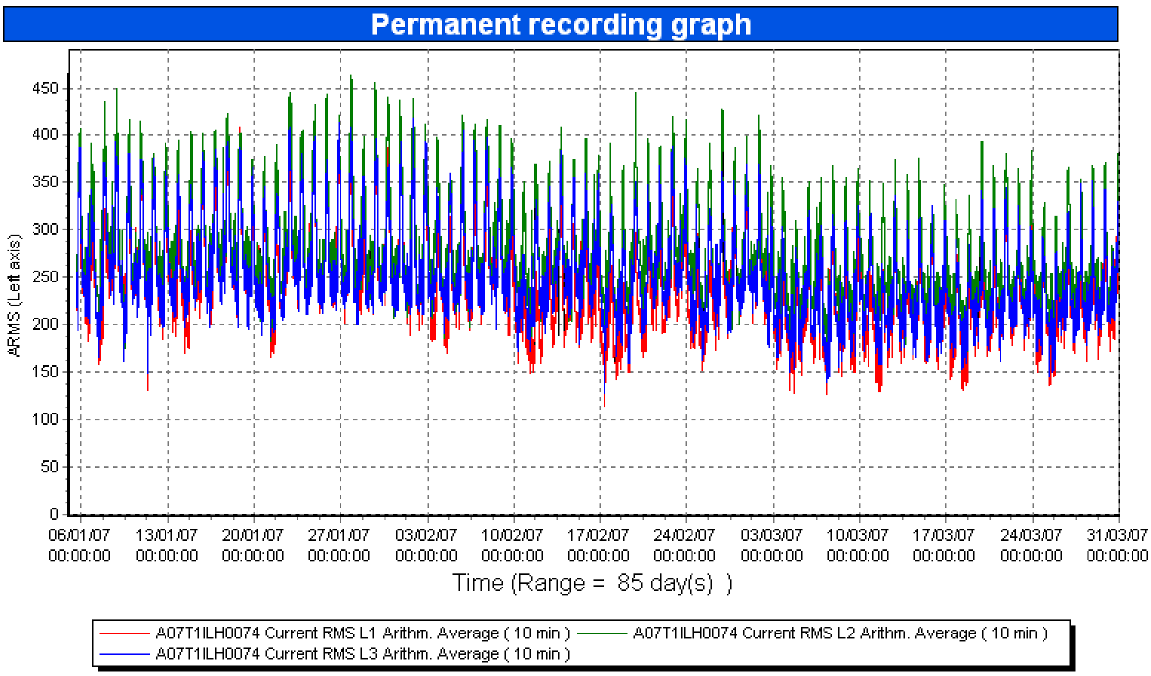


Figure 40 – Current RMS values at the LV busbar of PT – Ilhavo LV network

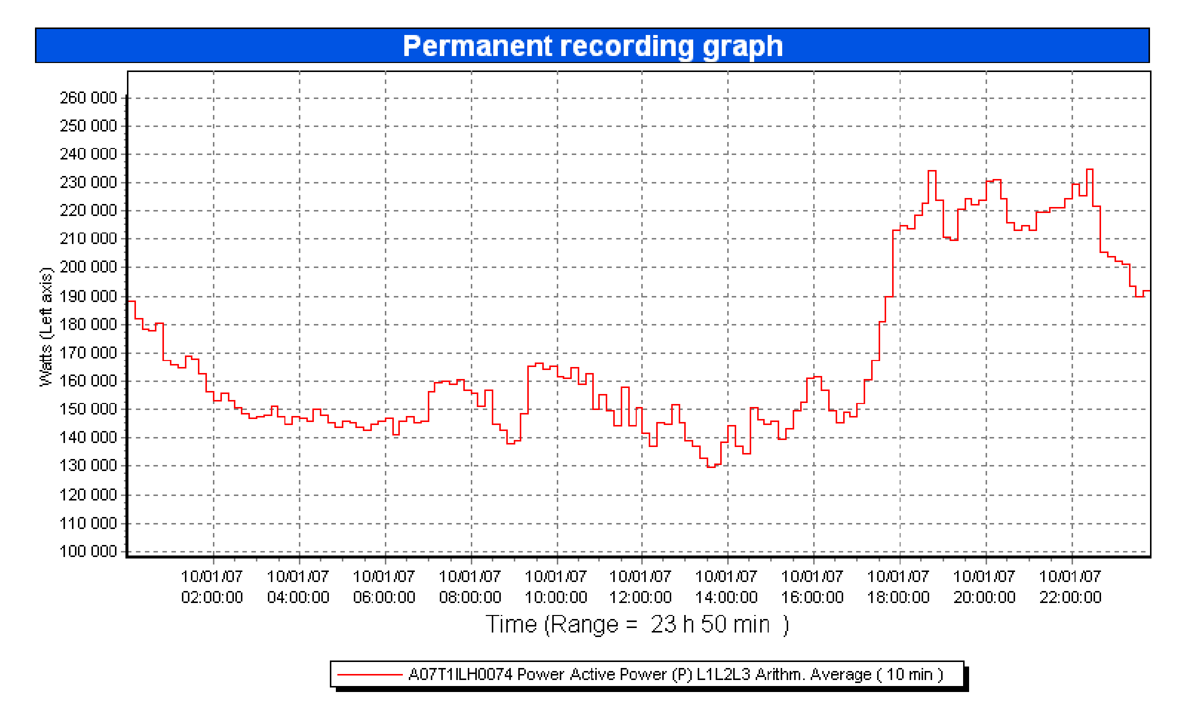


Figure 41 – Load during a weekday at the LV busbar of PT – Ilhavo LV network

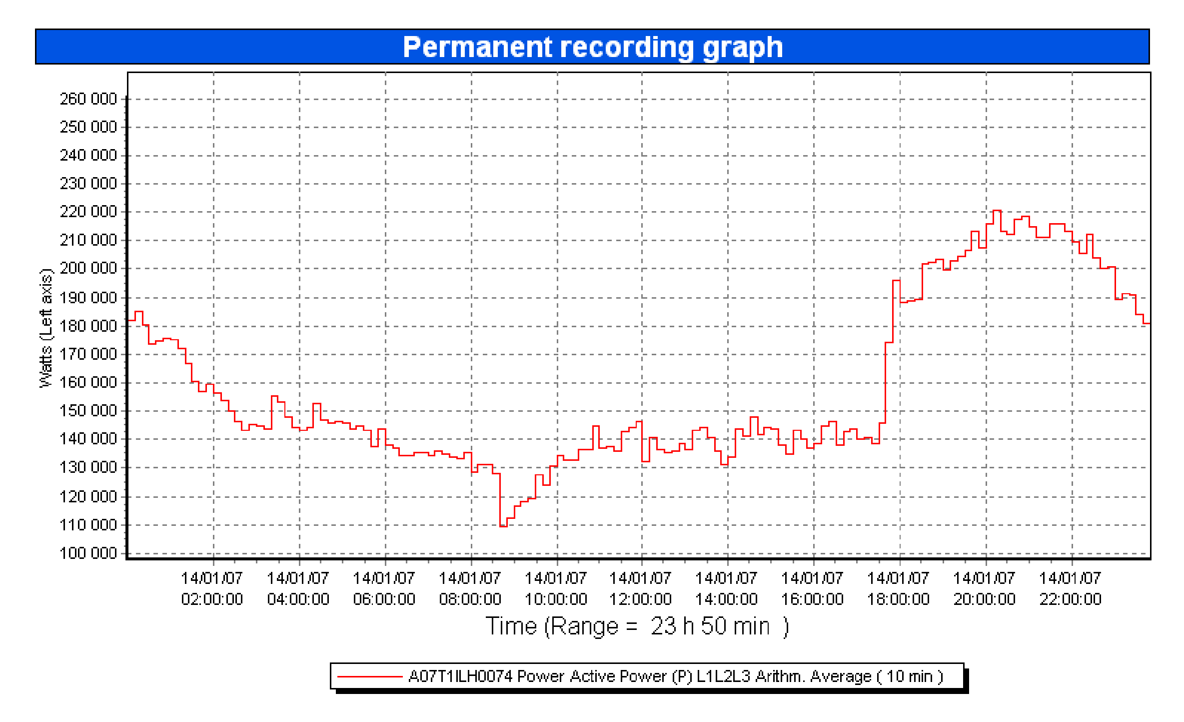


Figure 42 – Load during the weekend at the LV busbar of PT – Ilhavo LV network

A 4.1.2 Load Scenarios

For each of the networks, the peak load at each node for a given time span (typically concerning a recent one year period) should be obtained. The sum of all load values will reflect a "simultaneous peak load". This simultaneous peak load is obviously unrealistic, as the peak in each node will not occur at the same time. Hence, a reduction will be applied through a "simultaneity factor".

In order to build the load scenarios, consumer load curves concerning a 24-hour period must be identified and provided. These load diagrams can be divided into 3 different types, according to the type of network considered:

- Residential consumers;
- Commercial consumers;
- Industrial consumers.

A load curve resulting from the combination of these 3 load diagrams must also be derived, and shall be expressed as a percentage of the simultaneous peak load value.

In addition to daily load variations, seasonality must also be considered. Thus a simultaneity factor (referred above) must be established for winter and summer scenarios in order to affect the simultaneous peak load for each of the networks.

For illustration purposes, Figure 43 presents an aggregated (considering residential and commercial consumers) typical load diagram for Portugal. The simultaneity factor considered is 0,8 for winter and 0,7 for summer (because in Winter time there is typically more load than in summer, despite the growing use of air-conditioning devices in Portugal).

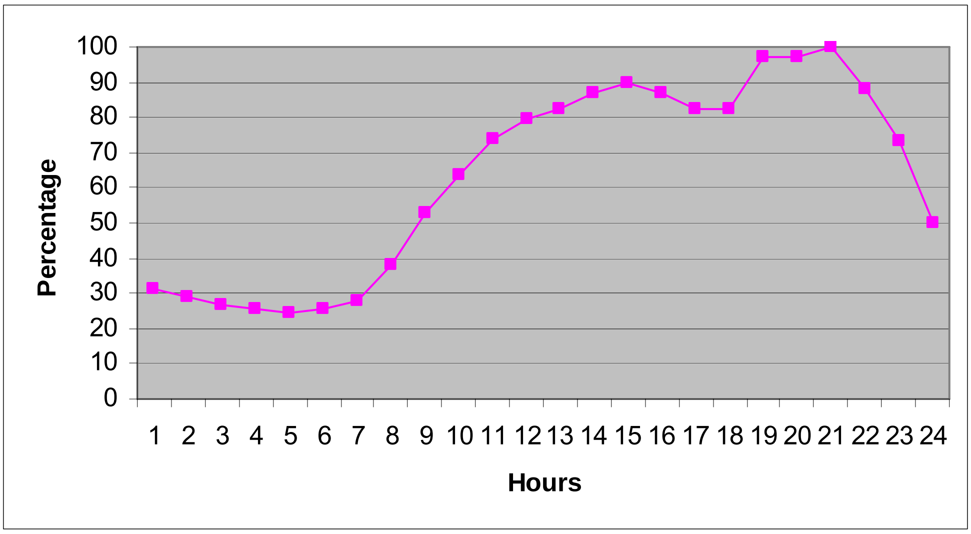


Figure 43 – Typical Aggregated Daily Load Diagram, Portugal (% of peak value)

It must be stressed that this load profile is assumed to be the same at all LV load buses.

A 4.1.3 Generation Scenarios

Future generation scenarios must be developed concerning the microgeneration technologies most likely to appear in each network. The technologies should reflect the type of network they are included in, for instance, CHP will be concentrated mainly in urban areas.

For each type of network and each load profile, different microgeneration penetration scenarios will be developed considering different types of generation technology, namely:

- Micro-CHP generation;
- Micro-Hydro generation;
- Micro-PV generation;
- Micro-Wind generation.

Nevertheless, other technologies may be considered, according to what is expected to be developed for each typical network.

Several situations should be explored, namely considering that the percentage of microgeneration penetration can, for instance, account for 0% (base case) 10%, 20% and 30% of the total simultaneous peak load of each network. Consequently, for this approach, microgeneration penetration can be defined as in equation (2).

Daily generation diagram profiles, for each season, must be identified and be available for each of the microgeneration technologies. This information is quite relevant since PV generation levels can be considerably high during a large period of the year in the southern European countries while they can be smaller in the northern European countries. On the other hand, CHP contribution can be quite relevant in northern European countries, especially during winter time, while CHP microgeneration levels can be smaller in southern European countries.

It must be stressed that the main aim of this analysis is to evaluate the impact of microgeneration in the distribution grid. Consequently, only the impact of microgeneration penetration is being considered; no Distributed Generation (DG) is considered to be connected directly to the MV and HV level.

Some other initial assumptions include:

- The LV networks connected to the MV level are all considered to be Microgrids;
- A given percentage for each type of networks should be defined initially for each country to be analysed. For Portugal, 60% of the MV networks connected to the HV level are considered to be of the urban type and 40% are considered to be rural type.

The inclusion of microgeneration is simulated by **reducing the load at all load nodes** according to the load reduction at each node covered by microgeneration, which involves tackling properly with microgeneration contribution across the daily load diagram.

A scenario is defined for each network and each season (winter and summer), considering typical load and generation profiles.

In order to calculate the load reduction due to the inclusion of microgeneration, the following formula was applied to all LV and MV buses.

For a single typical day of each scenario, for each of the 24 hours (h):

$$P_{load}^{red} = p_{\mu G} \cdot \sum_{i=1}^{4} P_{i,h}^{\mu G} \cdot p_i$$

Where:

P_{load}^{red} is the active power load reduction due to the inclusion of microgeneration

$p_{\mu G}$ is the percentage of microgeneration penetration (0%, 10%, 20% or 30%)

i is the microgeneration technology (1 – µCHP, 2 – µHydro, 3 – µPV, 4 – µWind)

$P_{i,h}^{\mu G}$ is the active power provided by microgeneration technology *i* at hour *h*, according to the available generation profile

p_i is the percentage of the contribution of generation technology *i*.

Although the extension of this microgeneration penetration to the MV loads may be questionable, such an assumption tries to include the fact that a considerable amount of MV loads (large commercial and service buildings, apartment buildings and small industries) would join microgeneration formula in their installations.

For the HV distribution network, the same formula is used twice to determine a weighted average, considering, that X% of the MV networks connected to the HV level are Urban and Y% are Rural (X + Y = 100%). These percentages can be parameterized according to the system under analysis. For the Portuguese study case it was assumed that 60% of these MV networks are of urban type, being the remaining 40% of the rural type.

At the HV distribution level it is also important to admit that a percentage of the HV loads can be of the industrial type, without the presence of any local generation. In order to tackle with this issue, a few load buses can be randomly considered as “only load type”, assuming that such labelling is defined after a uniform distribution (for the number of busses in the HV grid). In this way only a certain number of load buses are considered as connected to MV grids that have a given microgeneration participation, as previously defined.

For illustration purposes the percentage for each generation technology P_i for each distribution network is presented in the next table, considering the study-case defined for Portugal.

Network	Generation Technology	Percentage per Technology
HV	CHP	42,00%
	Hydro	16,00%
	PV	26,00%
	Wind	16,00%
RMV	CHP	
	Hydro	40,00%
	PV	20,00%
	Wind	40,00%
UMV	CHP	70,00%
	Hydro	
	PV	30,00%
	Wind	
RLV	CHP	
	Hydro	40,00%
	PV	20,00%
	Wind	40,00%
ULV	CHP	70,00%
	Hydro	
	PV	30,00%
	Wind	

Note that these percentages were estimated taking into account not only the expected future scenarios for generation for Portugal but also the different technologies available for each type of network.

Concerning each microgeneration technology available, also a typical daily generation diagram for each technology and for each season must be developed and expressed as a percentage of its installed capacity.

For illustration purposes, Figure 44 presents the typical generation diagram for a micro-PV microgenerator in winter time for Portugal and Figure 45 shows the typical generation diagram for a micro-PV microgenerator in summer time for Portugal. Figure 46 presents the typical generation diagram for a micro-CHP installation for Portugal (considered equal for winter and summer time).

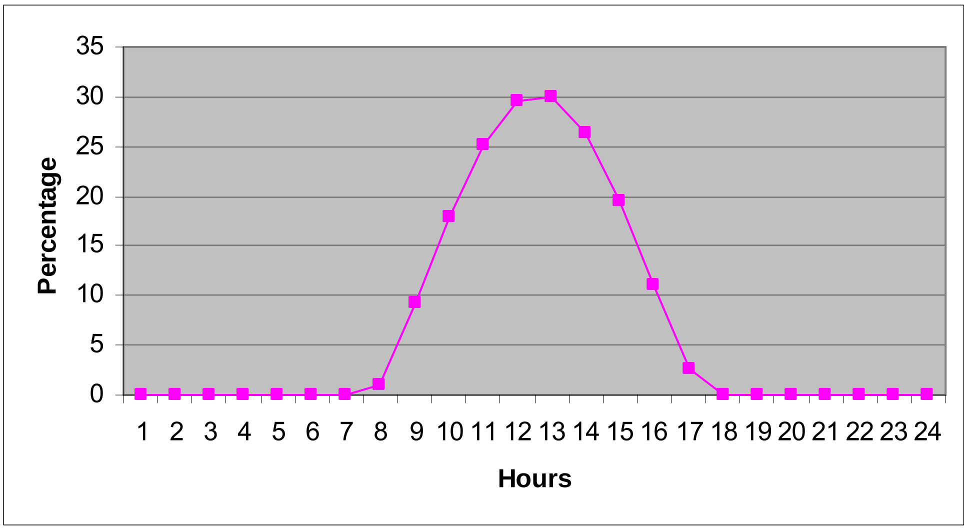


Figure 44 – Typical Daily micro-PV Generation Diagram for Winter, Portugal (% of installed capacity)

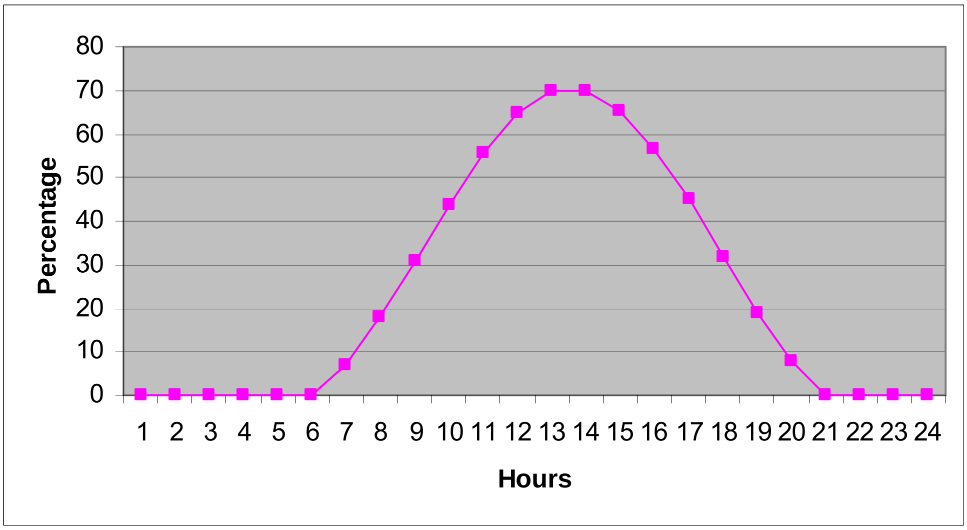


Figure 45 – Typical Daily micro-PV Generation Diagram for Summer, Portugal (% of installed capacity)

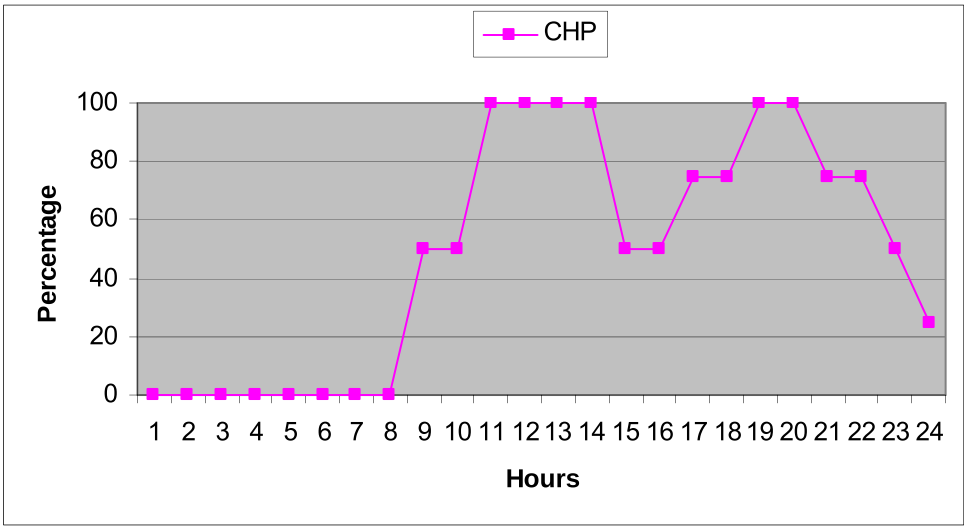


Figure 46 – Typical Daily micro-CHP Generation Diagram (% of installed capacity), Portugal

The results obtained will be described in a future report concerning Task TG2.

Annex 4.2 Poland

Technical parameters of the distribution network and of components of network connected to one grid supply point are determined by the templates given in WPH. In addition, we enclose additional data for distribution networks which are extension to methodology in WPH.

A 4.2.1 Typical Networks

LRPD has identified 5 typical networks for HV, MV and LV distribution grids considered as representative for central Poland. Data include area about 18.000 km^2 where about 600000 customers are supplied.

1 typical HV distribution network

2 typical MV distribution networks (urban MV network, rural MV network)

Structure of urban MV networks is presented as:

- network normally operated radially with disconnectors installed in nodes (or in last time there are used switches wireless controlled) (normally open are represented by bold lines),
- mostly underground, potentially – overhead,
- MV/LV transformer substations are as indoor substations with one transformer, (MV/LV transformer parameters are presented in Table A-23),
- Schema of MV/LV indoor substation is presented in Figure 48.
- disconnectors and load switches are used as switching equipments in transformer substations.

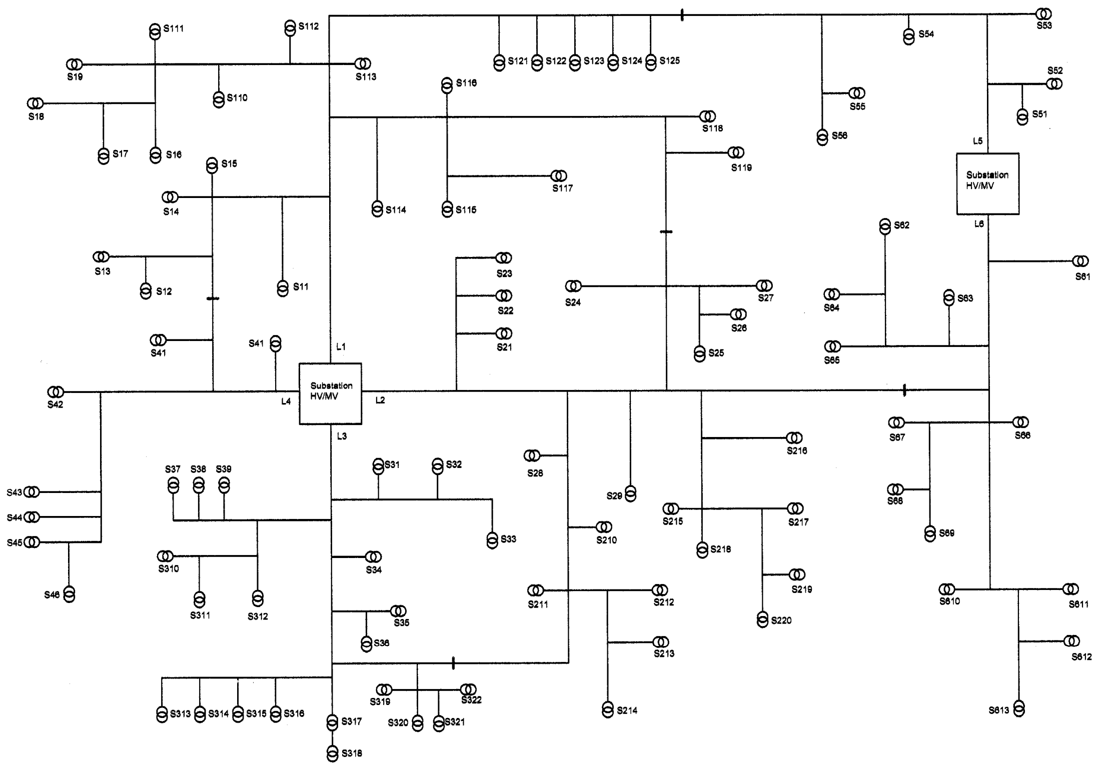
This type of network is usually situated in city centres, in suburbs networks are similar to rural lines.

Structures of rural MV networks are presented as:

- radial,
- overhead,
- MV/LV transformer substations exist as pole-mounted substations,
- disconnectors and load switches are used as switching equipments in transformer substations, disconnector is installed in front of each pole-mounted substation.

Urban and rural MV network is presented in Figure 47.

Schema of MV/LV pole-mounted substation and of an indoor substation is shown in Figure 48.



- normally open

Figure 47 – Generic structure of urban and rural MV network, Poland

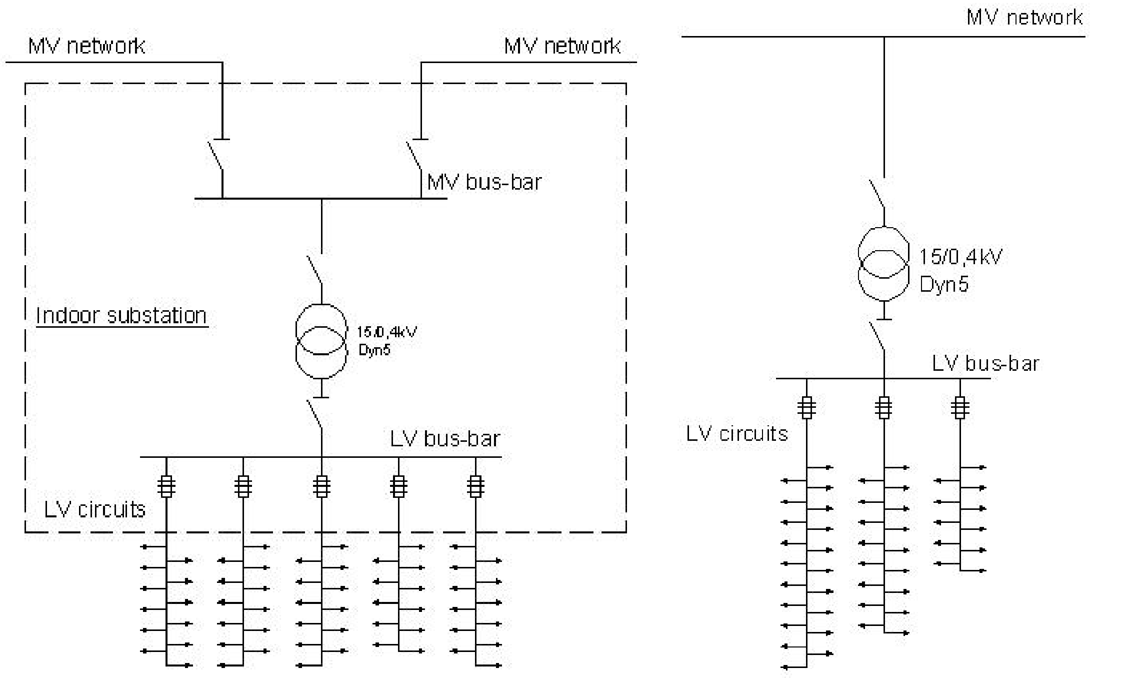


Figure 48 – Schema of MV/LV indoor and a MV/LV pole-mounted substation, Poland

2 typical LV distribution networks (urban LV network, rural LV network)

Structure of urban LV networks is presented as:

- radial,
- mostly underground, sometimes overhead in peripheral part of city.

Structure of rural LV networks is presented as:

- radial,
- overhead.

A 4.2.2 Transformer substations

Transformers HV/MV

Table A-22 presents HV/MV transformers technical data

- rated voltage,
- rated power,
- no-load losses,
- load losses,
- short-circuit impedance,
- no-load current,
- voltage control.

Transformers HV/MV 110/15 kV				
rated power [MVA]	**V_{cc} [%]**	**I_o [%]**	**No-load losses [kW]**	**Load losses [kW]**
10	10,7	0,32	9,17	63,1
16	11	0,38	16,42	85,56
25	16,9	0,25	17,4	161
Automatic voltage control through on-load tap changer: (± 8×1,2 5%)				

Table A-22 - HV/MV transformers technical data, Poland

Majority of the transformer substations works as two-transformer substation with 5 HV circuit breakers, though nowadays in new-built substations there are normally 4 HV circuit breakers only. Each transformer feeds an individual MV bus-bar section.

Transformers MV/LV

Table A-23 presents MV/LV transformers technical data

- rated voltage,
- rated power,
- no-load losses,
- load losses,
- short-circuit impedance,
- voltage control.

Transformers MV/LV			
Rated power [kVA]	**V_{cc} [%]**	**No-load losses [W]**	**Load losses [W]**
40	4,2	160	870
63	3,7	210	1270
100	4,6	290	1740
160	4,4	410	2560
250	4,3	618	3470
400	4,4	940	4580
630	5,8	1240	6950
Manual no load tap changer: (+2×2,5%; –2×2,5%)/400V			

Table A-23 - MV/LV transformers technical data, Poland

A 4.2.3 Protections used in transformer substations

HV/MV transformer substations

HV feeder protections

- distance protection – main,
- earth fault protection – back-up.

HV bus-bar coupler protections

- distance protection.

HV transformer protections

- differential protection,
- overcurrent time-lag protection,
- overcurrent instantaneous protection,
- Buchholtz protection.

MV feeder protections

- overcurrent time-lag protection,
- overcurrent instantaneous protection,
- earth fault protection.

MV bus-bar coupler protections

- overcurrent time-lag protection,
- overcurrent instantaneous protection.

Bus-bar protections

- distribution substations (more than one system bus-bar) are equipped in distance protection,
- HV and MV busbar in H-type substation are protected by mutual redundancy circuit breakers.

HV/MV transformer substations automatics

- loss-of-voltage tripping automatics,
- autoreclosing,
- load shedding protection,
- automatic load restoration.

MV/LV transformer substations

MV/LV transformer substations are protected by fuses both MV and LV.

Fuses applied for MV voltage winding:

4A, 6A, 10A, 15A, 20A, 30A, 40A, 50A, 60A

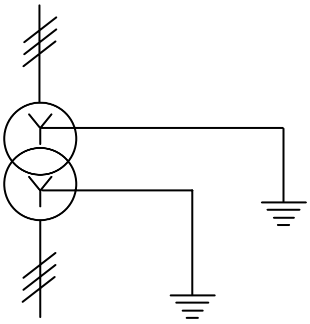
Fuses applied for LV voltage winding:

32A, 63A, 80A, 100A, 160A, 200A, 250A, 315A, 400A, 630A, 1000A

A 4.2.4 Transformer neutral grounding

HV distribution network

HV distribution network operates with an effectively grounded transformer.

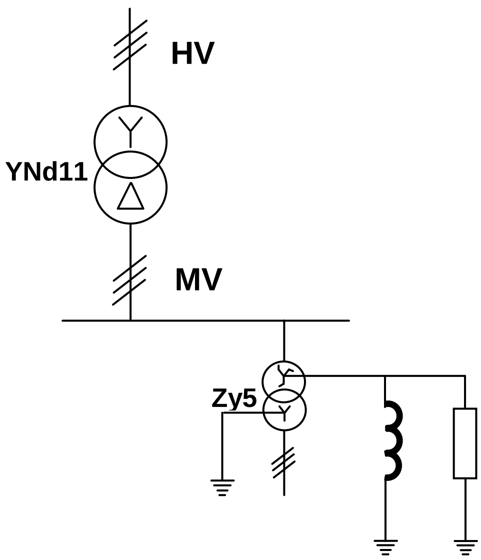


HV

For safety reasons, grid parameters would assure $R_0/X_1 \leq 0.5$, by suitable dimension of transformers working with earthing neutral point of winding. Additionally, keeping correct relation between R_0 and X_0 can guarantee correct activity earth fault protection.

MV distribution network

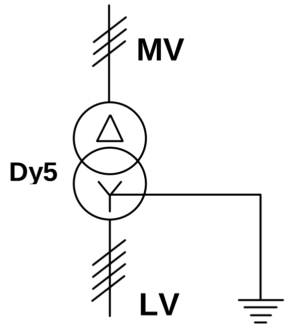
MV distribution network operates with reactance grounded transformer.



Triangle connection low voltage winding of the transformer implies necessity to create artificial earthing neutral point using the transformer connected to MV bus-bar with an arc-suppression coil together with resistor.

LV distribution network

LV distribution network operates with an effectively grounded transformer.



A 4.2.5 Quality parameters

Measuring systems record about 20% MV/LV transformer substations every year analyzing to determine LV distribution network parameters. Measurements cover 15100 km^2 area where 11130 MV/LV transformer substations and 32262 LV circuits exist.

	Total number of MV/LV transformer substations	Total number of LV circuits	Total number of customers	$U<U_n$ [%]	Approximate number of customer with incorrect voltage parameters
Urban area	2188	10333	297426	0,84	6420
Rural area	8942	21929	297629	2,51	15400
Totality	11130	32262	595070	3,35	21820

Table A-24 - Amount of LV circuits contain lowered voltage

MV reliability indices

MV reliability indices equals to CAIDI = 4

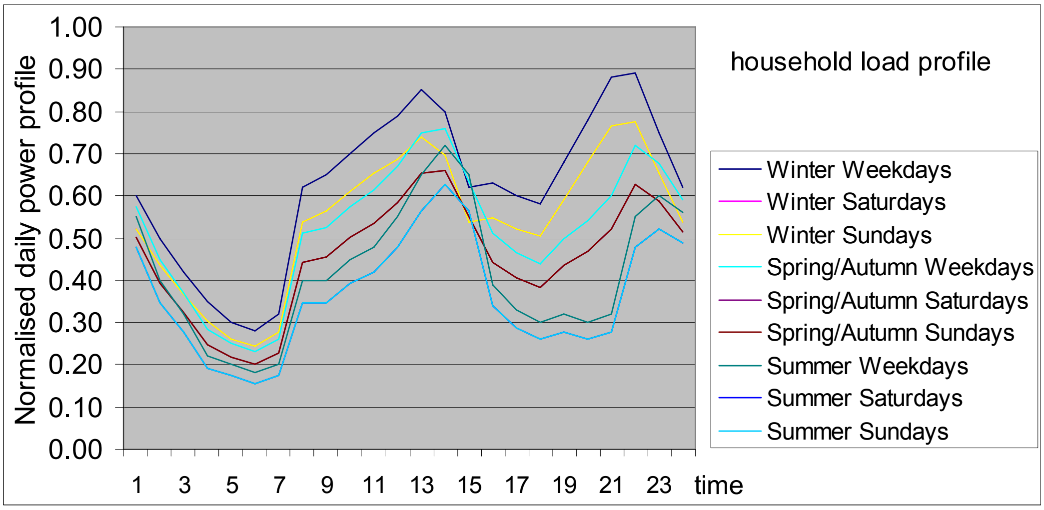
LV reliability indices

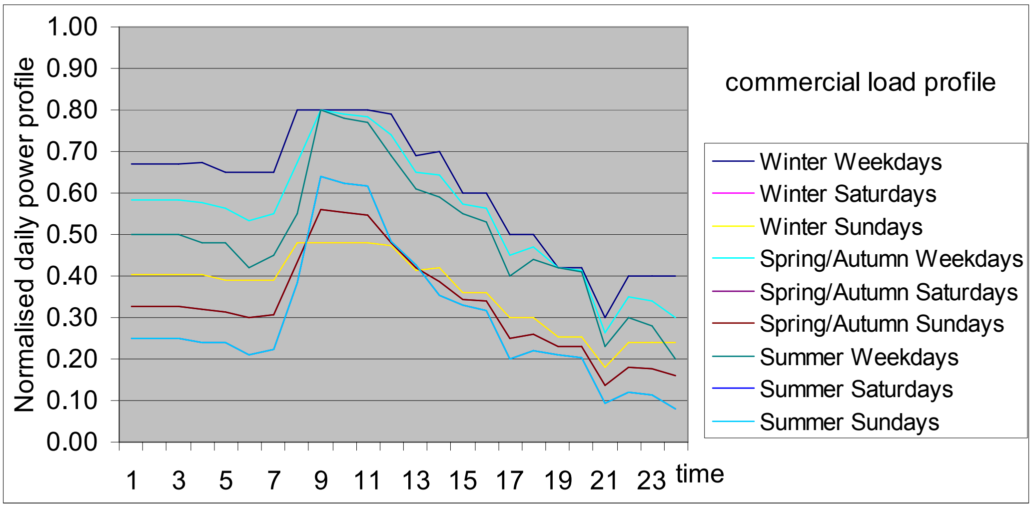
LV reliability indices are presented in Table A-25.

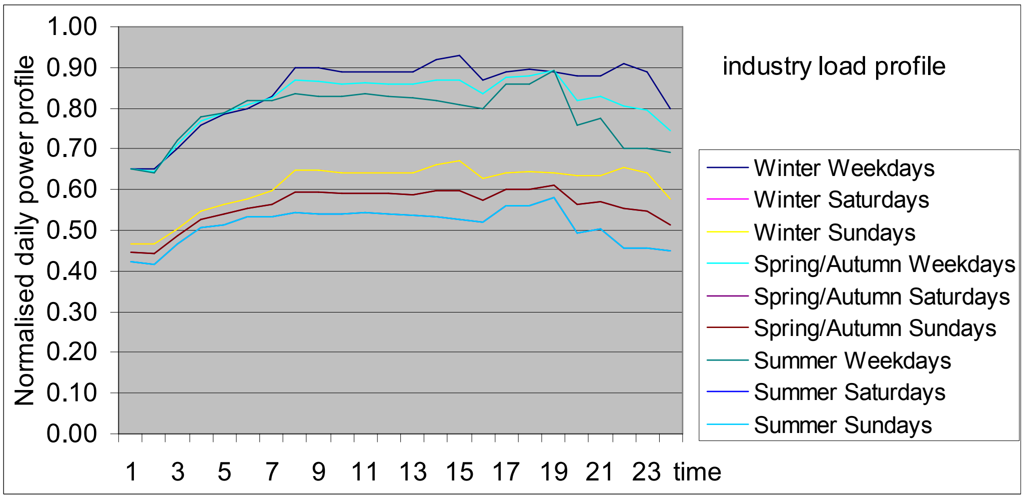
Type of area	SAIFI [1/a]	SAIDI [h/a]	CAIDI
Urban	1,4	-	-
Rural	6,7	-	-
Totality	4	10,8	2,7

Table A-25 - LV reliability indices

A 4.2.6 Load Scenarios







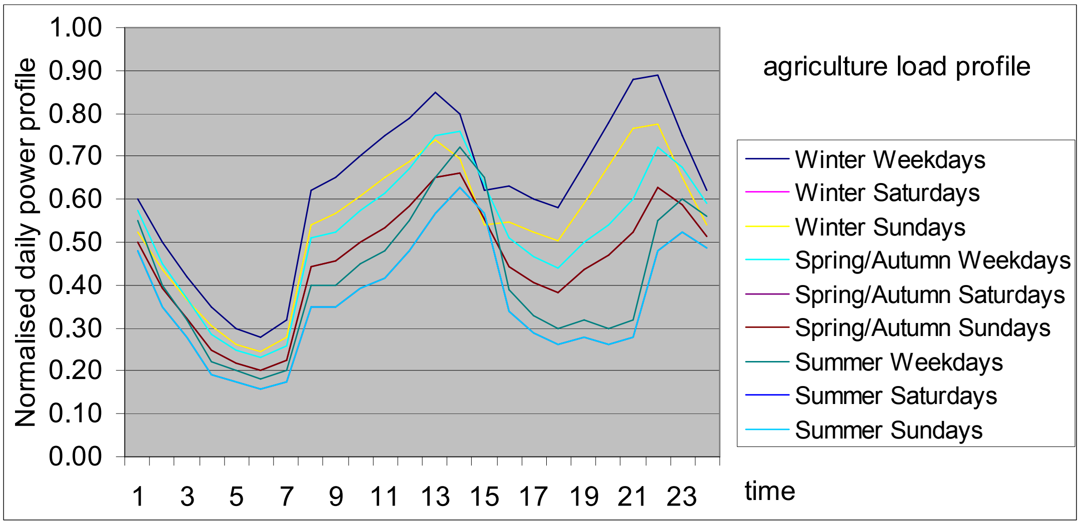


Figure 49 – Normalised daily load profiles, Poland

A 4.2.7 Generation Scenarios

Energy system in Poland is based on huge coal power plants and minority share hydro power plants. In the last time there is intensive development in wind-generation and bio-gas generation. Wind-generations and bio-gas generations are connected to existing distribution network, currently with little share on total Polish electricity generation.

Table A-26 presents sorts of generation installed in LRPD.

Type of generation	Capacity
Small hydro generation	1.6 MW
Wind generation	2 MW
Biogas generation	4.8 MW
Hydro generation	7.4 MW
Large CHP	24 MW
Total share RES in consumption LRPD	5.9 %

Table A-26 - Microgeneration installed in LRPD

Microgeneration development in Poland has a chance with a view to radial MV/LV network and many of vast rural areas, where security of power supply mainly depends on weather conditions. Improving certainty power supply for customer, microgeneration could provide an option to meet growing demand for electric energy.

Typical microgeneration could be installed on rural area e.g. in north or east Poland where transmission and HV distribution networks are poorly extended.

A 4.2.8Tariffs

System charges are divided into

- Distribution charge,
- Energy supplied charge.

Settlement of customers is realized using created energy tariffs, which differentiate customers depending on:

- voltage level of connection,
- power connection, defined in distribution agreement,
- settlement of time zones (single-zone, double-zone, peak-zone, outside-peak zone, day-zone, night-zone).

Type of customers	Unit	Distribution tariffs	Energy tariffs	Electricity charges
Household	[€/kWh/month]	11.34	0.22	0.04
Commercial	[€/kWh/month]	99.30	0.66	0.04
Industrial	[€/MWh/month]	625.97	66.39	47.22

Table A-27 - Typical tariffs, Poland

Annex 4.3 Italy

The activity of CESI RICERCA has consisted of the collection of typical data and information (where available) about the structure and operation of the Italian MV and LV distribution network.

Data collection has involved contacts with Distribution Network Operators, consulting of technical documents, reports and databases (both public and reserved).

In particular, the following items have been investigated (at present, data collection has not yet been completed):

- Network topology: number of conductors, number of lines, section/branch length;
- Network operation: radial/open-loop/meshed, type of grounding, allowed component loading, voltage drop, power factor, voltage regulation, cost figures for components and upgrading (transformer cost, switchgear cost, circuits cost);
- Protection devices: principles of operation (directional, over current), tripping time and settings;
- Substation transformers: winding connection, sizes, load real losses, no-load real losses, short circuit voltage, voltage regulation (on-load or no-load tap changer);

A 4.3.1 Typical networks

Examples of typical Italian distribution network configurations (LV rural network, LV urban network, MV rural network, MV urban network) have been identified and described in terms of schematic single line diagram, transformers and lines data, and loads characteristics (Figure 50 - Figure 52).

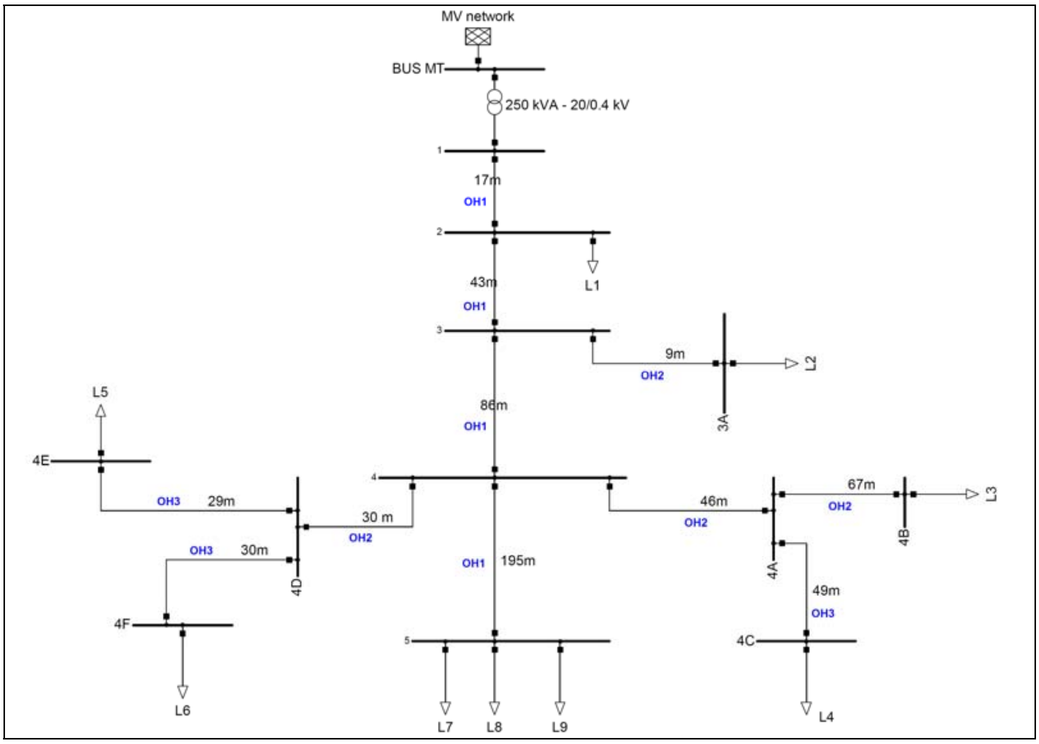


Figure 50 – Example of rural LV network, Italy

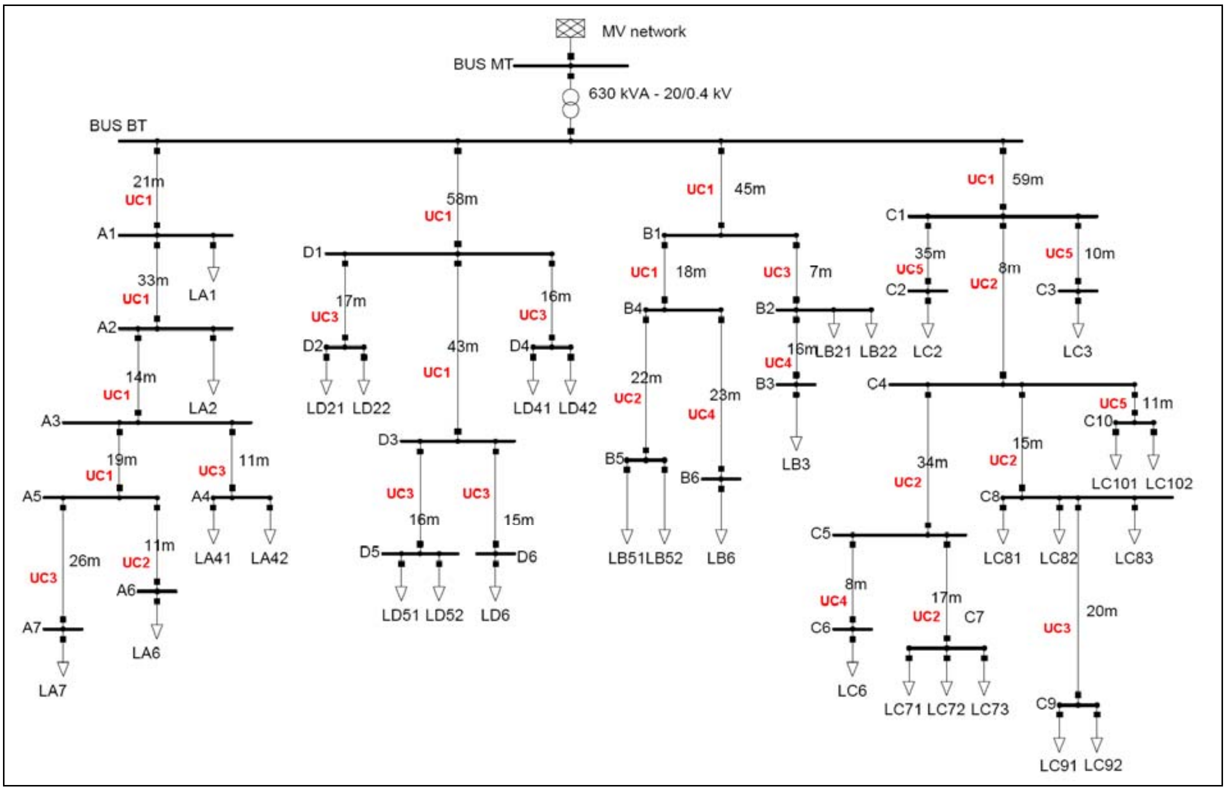


Figure 51 – Example of urban LV network, Italy

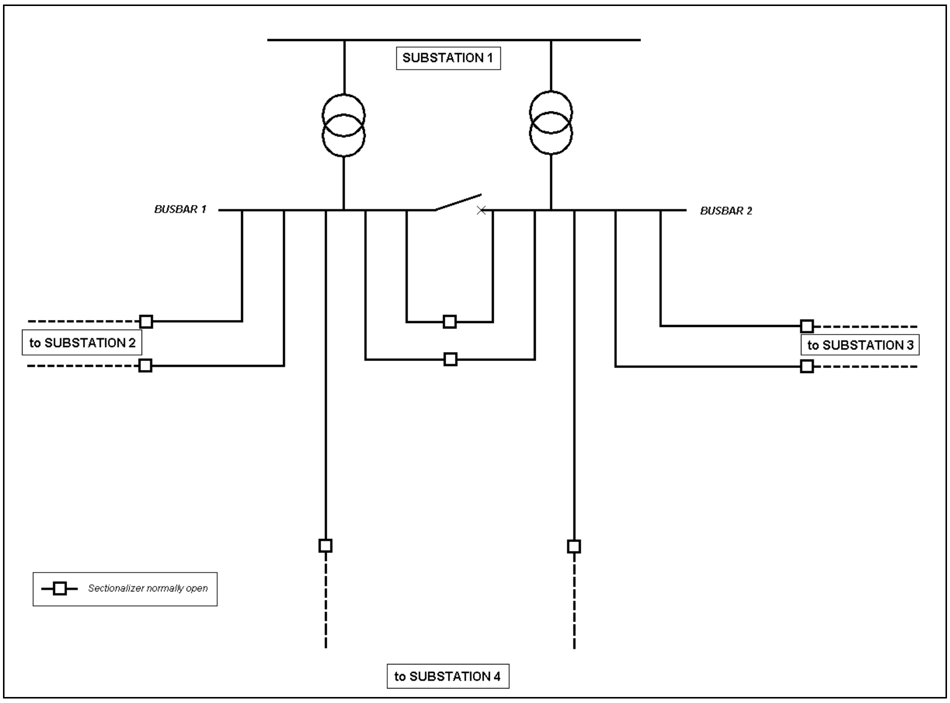


Figure 52 – Typical structure of urban MV underground network, Italy

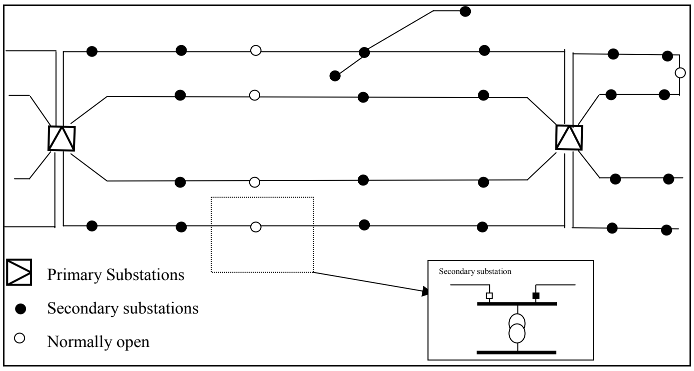


Figure 53 – Typical network structure, Italy

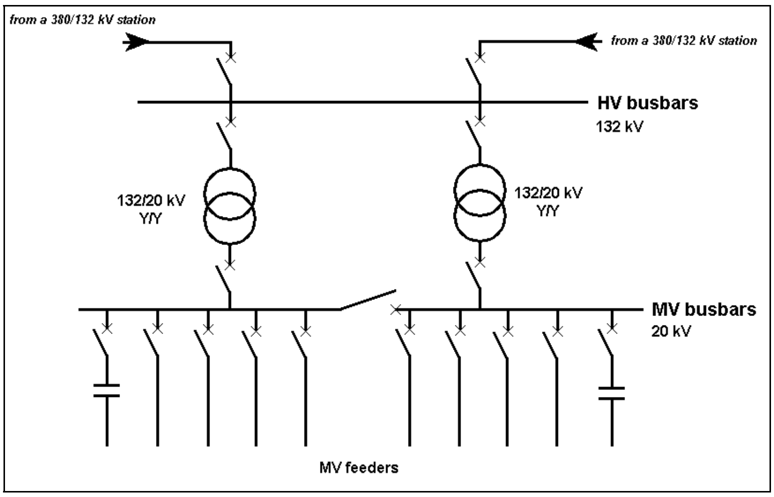


Figure 54 – Electrical schema for primary substation, Italy

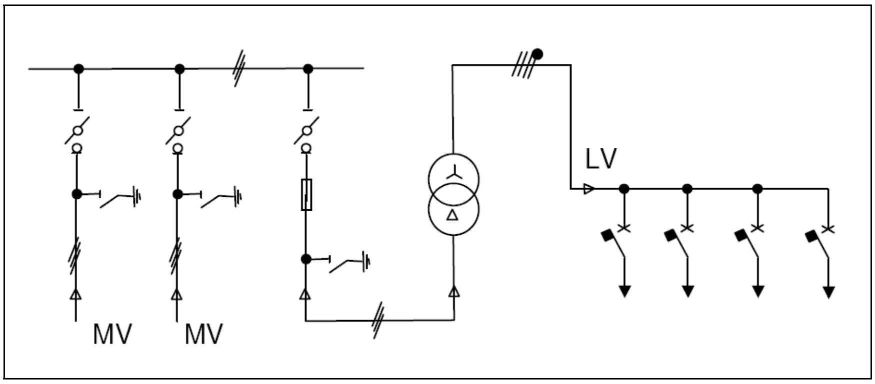


Figure 55 – Electrical schema for secondary substation, Italy

HV/MV transformers			
Size [MVA]	***V_{cc} %***	***No-load losses [kW]***	***Load losses [kW]***
16	13.0%	12	88
25	14.6%	16	122
40	15.5%	23	186
63	18.3%	32	282
100	16.8%	40	210
Voltage regulation: automatically control through on-load tap changer (±12×1.5%); control techniques: constant voltage at the MV busbar or current compound.			
MV/LV transformers			
Size [kVA]	***V_{cc} %***	***No-load losses [W]***	***Load losses [W]***
50	4%	150	850
100	4%	250	1400
160	4%	360	1850
250	4%	520	2600
400	4%	740	3650
630	6%	900	5600
Voltage regulation: manual no load tap changer: V_{MN} (+2×2.5%; –3×2.5%)/400 V (V_{MN} = nominal voltage of MV grid).			

Table A-28 - HV/MV, MV/LV transformers technical data, Italy

HV lines parameters						
Type	**Conductors**	**Section** [mm²]	**Operating Voltage** [kV]	**Current limit** [A]	**Resistance R** [Ω/km]	**Reactance X** [Ω/km]
Overhead lines	Copper	109	132	406	0.164	0.439
	Copper	134	132	463	0.133	0.432
	Aluminum-Steel	308	132	570	0.107	0.401
	Aluminum-Steel	428	132	686	0.081	0.389
	Aluminum-Steel	585	132	860	0.055	0.381

MV lines parameters						
Type	Conductors	Section [mm^2]	Current limit [A]	Resistance R [Ω/km]	Reactance X [Ω/km]	Capacitance C [μF/km]
Underground cables	Aluminum paper insulated ARC4HLRX	95	200	0.320	0.125	0.350
	Aluminum paper insulated ARC4HLRX	150	280	0.206	0.117	0.420
	Aluminum paper insulated ARC4HLRX	240	360	0.125	0.110	0.500
Overhead lines	Copper	25	140	0.720	0.400	0.008
	Copper	35	190	0.520	0.430	0.009
	Copper	70	280	0.270	0.400	0.010
	Aluminum -Steel	150	350	0.230	0.340	0.010

LV lines parameters				
Type	Conductors	Current limit [A]	Resistance R [Ω/km]	Reactance X [Ω/km]
Underground cables	Aluminium 3 X 150 + 50 N	305	0.206	0.075
	Copper 3 X 50 + 25 N	208	0.391	0.078
	Copper 3 X 25 + 25 N	145	0.734	0.081
	Copper 3 X 16 + 16 N	114	1.160	0.082
	Copper 1 X 6 + 6 N	78	3.060	0.090
Overhead lines - cables	Aluminium 3 X 70 + 54.6 N	191	0.443	0.100
	Aluminium 3 X 35 + 54.6 N	123	0.868	0.110
	Copper 4 X 10	80	1.900	0.120
	Copper 2 X 10	88	1.900	0.110
Overhead lines - bare conductors	Copper 1 X 35	180	0.519	0.313
	Copper 1 X 25	140	0.719	0.323
	Copper 1 X 16	105	1.117	0.345

Table A-29 – HV, MV and LV Line Parameters, Italy

A 4.3.2 Load Scenarios

Unplanned interruptions excluding exceptional events						
	voltage level	2000	2001	2002	2003	2004
minutes lost per customer per year (min/a)	T	2,72	8,00	0,82	0,94	1,68
	HV	2,63	2,12	1,46	1,66	2,81
	MV	124,31	102,63	80,59	73,85	55,87
	LV	29,56	25,82	26,01	20,38	15,5
number of interruptions per customer per year (1/a)	T	0,13	0,18	0,07	0,07	0,09
	HV	0,12	0,14	1,10	0,09	0,11
	MV	2,97	2,69	2,41	2,35	2,05
	LV	0,24	0,18	0,16	0,17	0,14
interruption duration (min)	T	20,9	44,4	11,7	13,4	18,7
	HV	21,9	15,1	1,3	18,4	25,5
	MV	41,9	38,2	33,4	31,4	27,3
	LV	123,2	143,4	162,6	119,9	110,7

Unplanned interruptions		2000	2001	2002	2003	2004	2005	2006
minutes lost per customer per year (min/a)	*all*	187,40	149,09	114,74	103,69	90,77	79,86	63,80
	excluding exceptional events	159,22	138,57	108,88	96,83	75,86	---	---
number of interruptions per customer per year (1/a)	*all*	3,60	3,29	2,76	2,72	2,48	2,42	2,39
	excluding exceptional events	3,46	3,19	3,74	2,68	2,39	---	---
interruption duration (min)	*all*	52,1	45,3	41,5	38,1	36,6	33,0	26,7
	excluding exceptional events	46,0	43,4	29,1	36,1	31,7	---	---

Table A-30 - Reliability Indices, Italy

ELECTRICITY DEMAND FORECAST - ITALY				
year	ENERGY DEMAND GROWTH		POWER DEMAND GROWTH	
	Low-growth scenario	High-growth scenario	Low-growth scenario	High-growth scenario
2008 – 2010	1,3%	2,3%	2,4%	2,8%
2010 – 2020	1,3%	2,3%	2,4%	2,8%
2020 – 2030	1,3%	2,3%	2,4%	2,8%

Table A-31 – Electricity Demand Forecast, Italy

A 4.3.3 Generation Scenarios

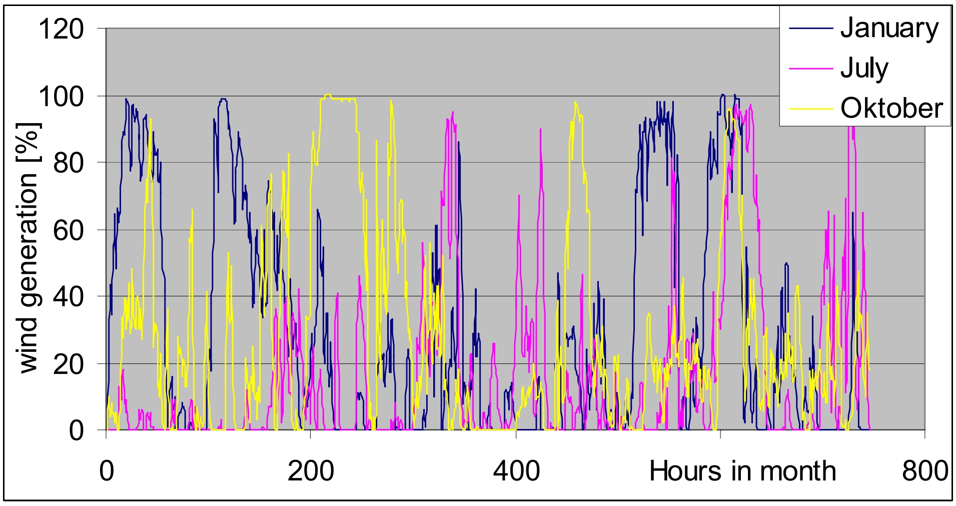
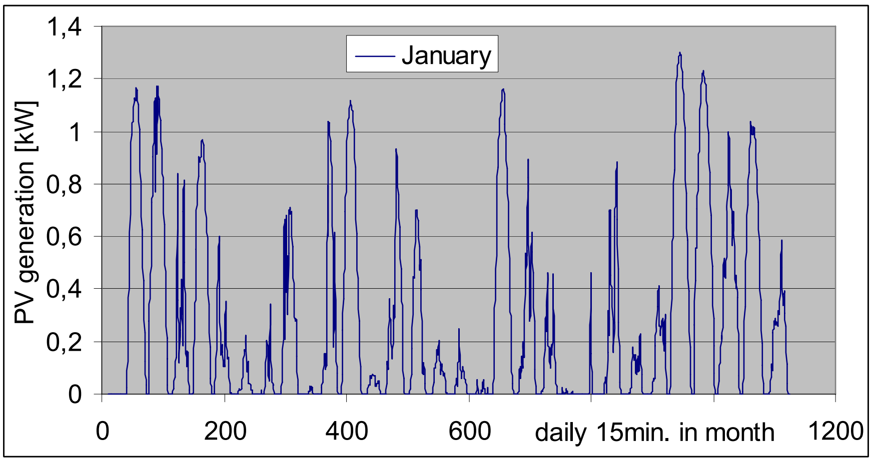


Table A-32 – Wind generation profiles, Southern Italy



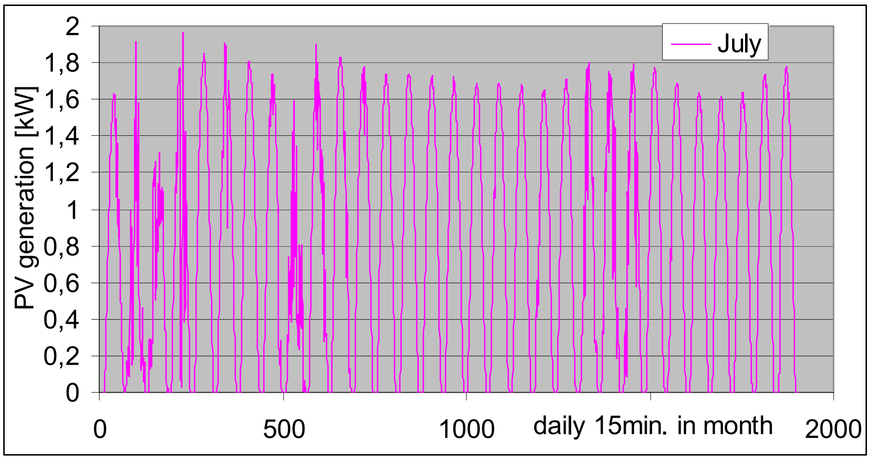


Table A-33 – PV generation profiles, Northern Italy

Annex 4.4 Netherlands

A 4.4.1 Typical networks

Single line diagrams with typical network structures are presented in Figure 56 - Figure 58.

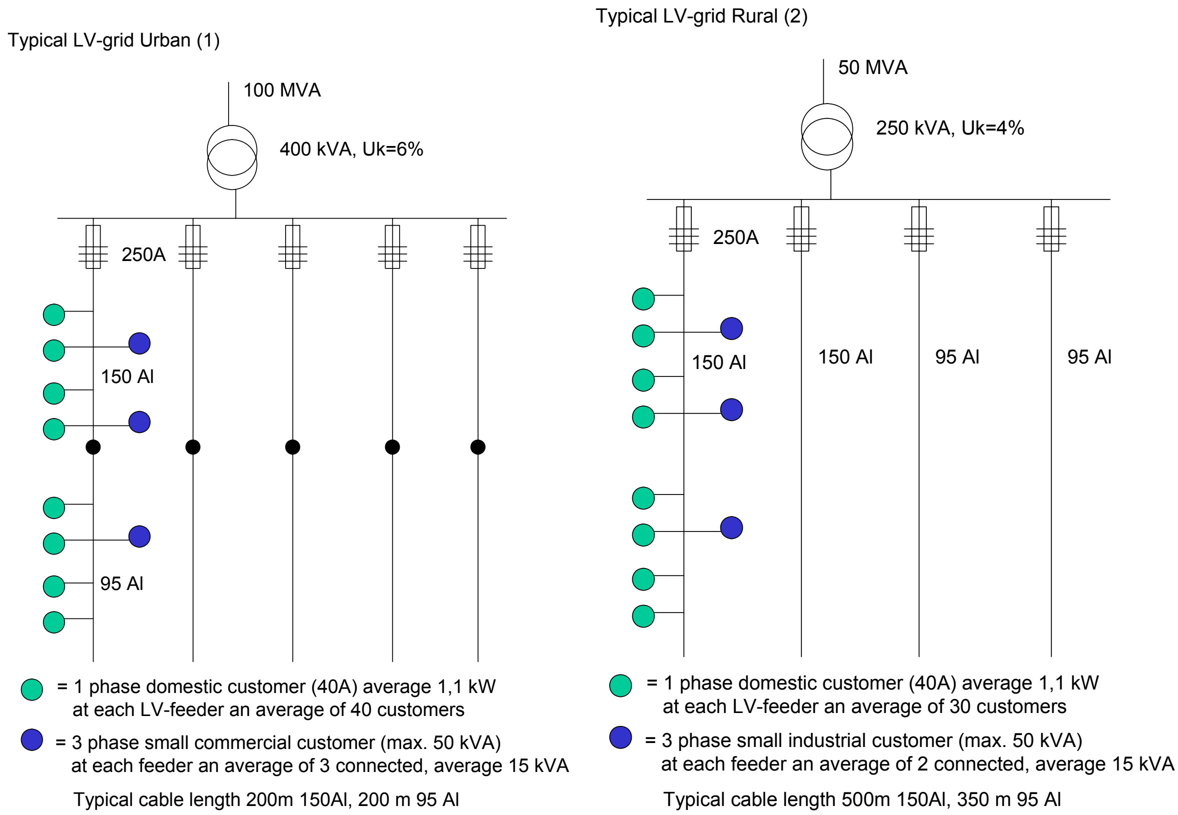


Figure 56 – Typical structure of urban and rural LV network, the Netherlands

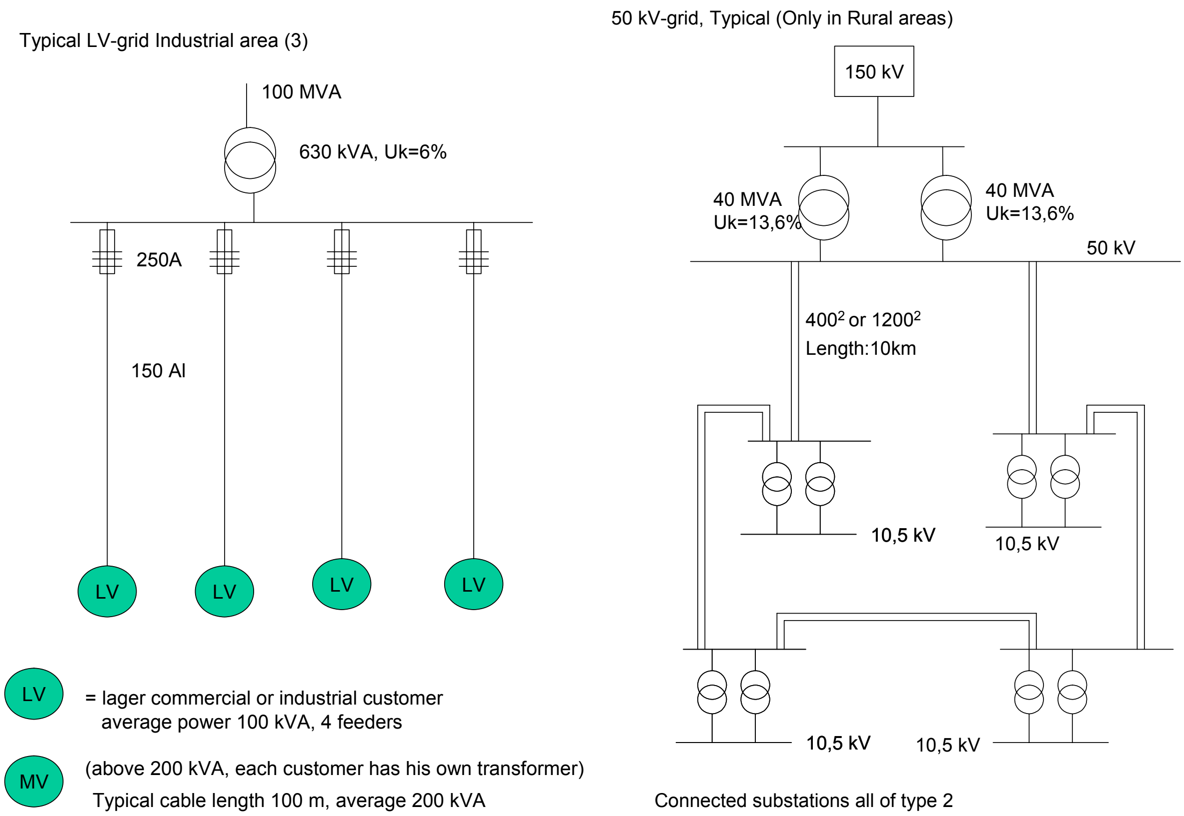


Figure 57 – Typical structure of Industrial LV network and rural 50 kV network

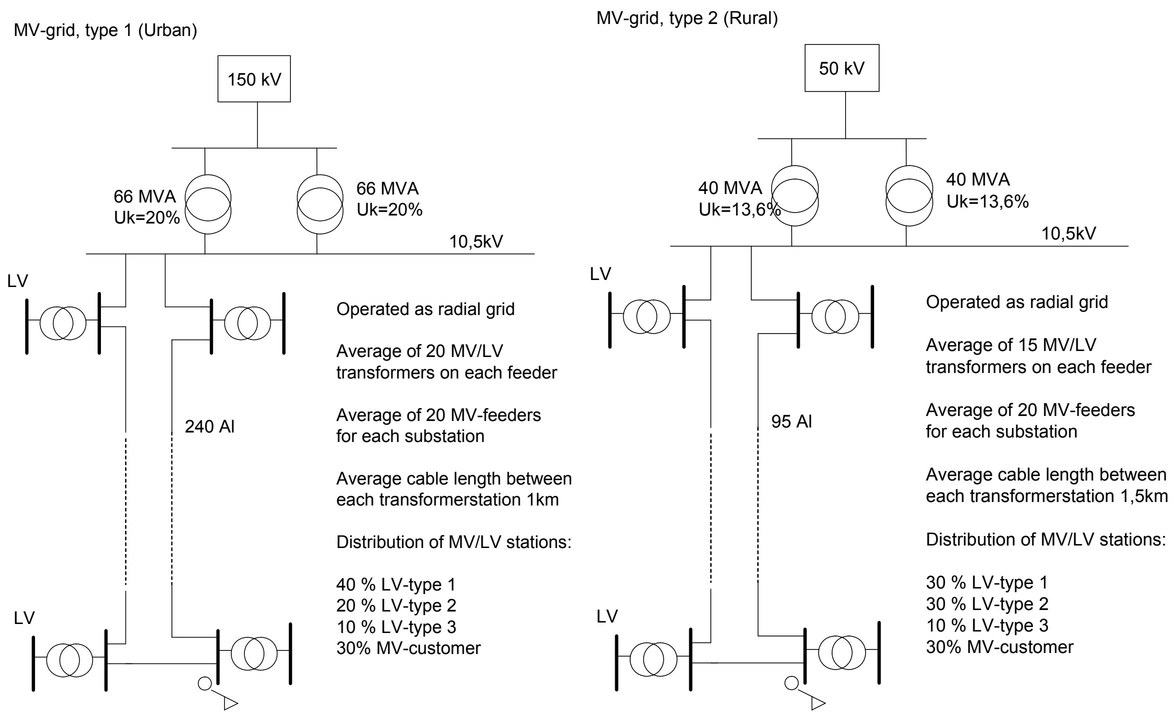
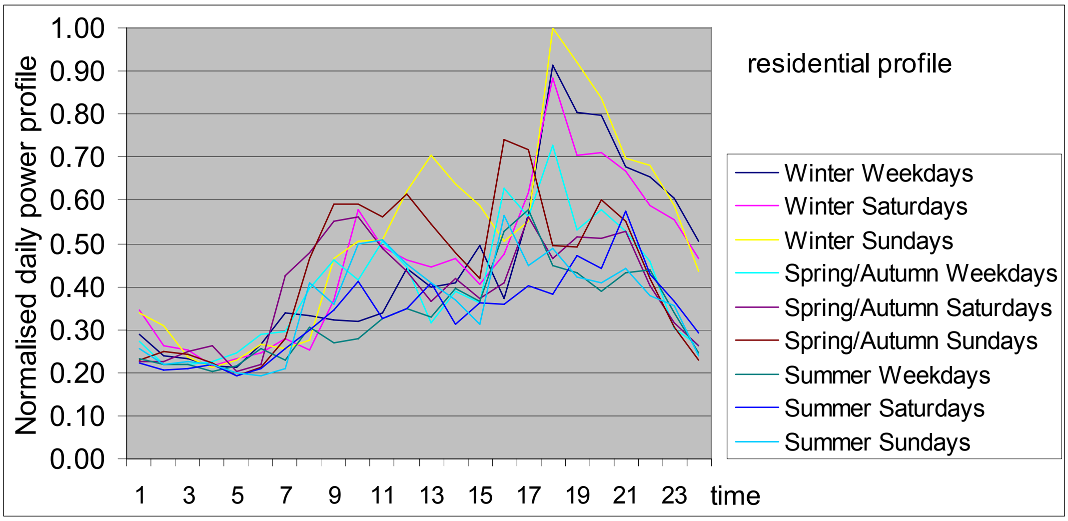
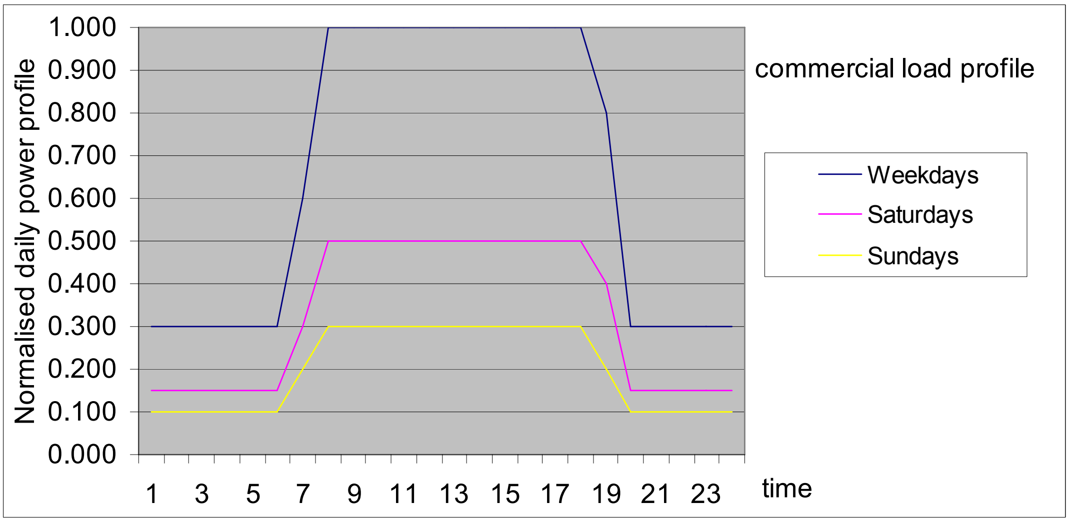


Figure 58 – Typical structure of urban and rural MV network, the Netherlands

A 4.4.2 Load Scenarios





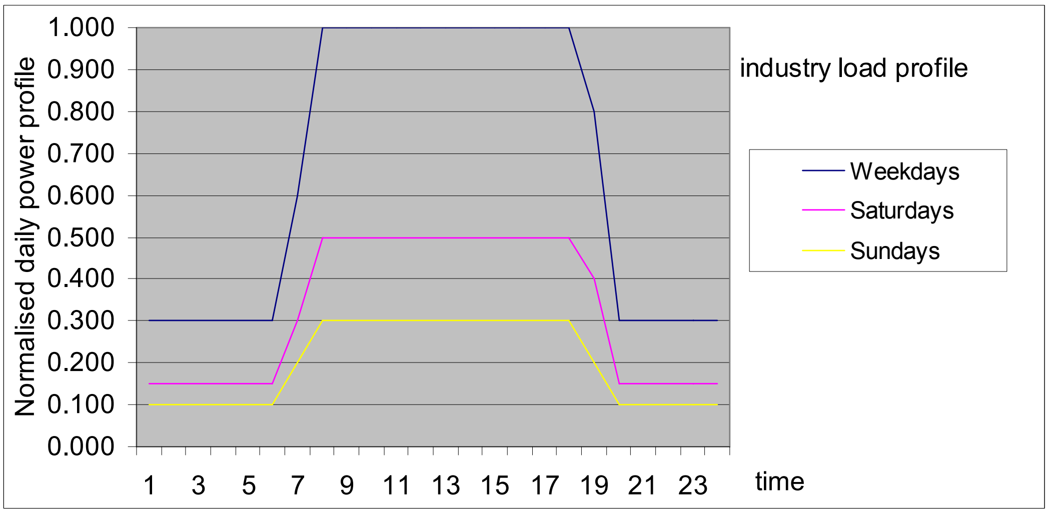
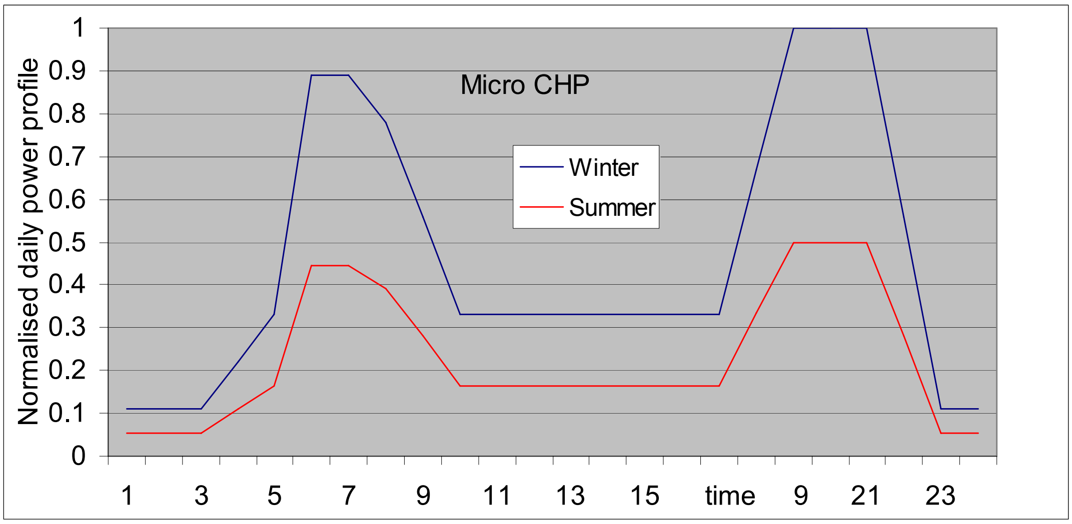
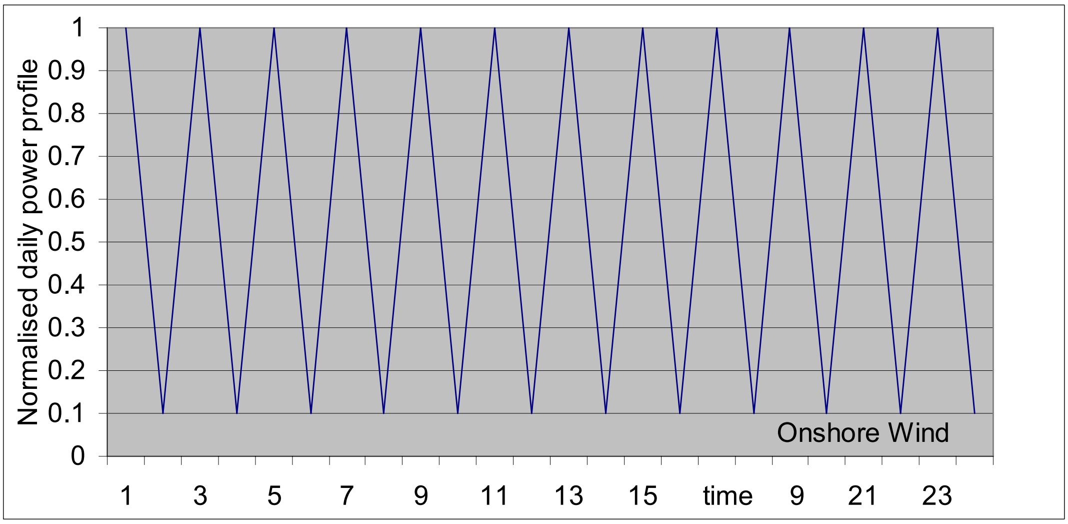


Figure 59 – Normalised daily load profile, the Netherlands

A 4.4.3 Generation Scenarios





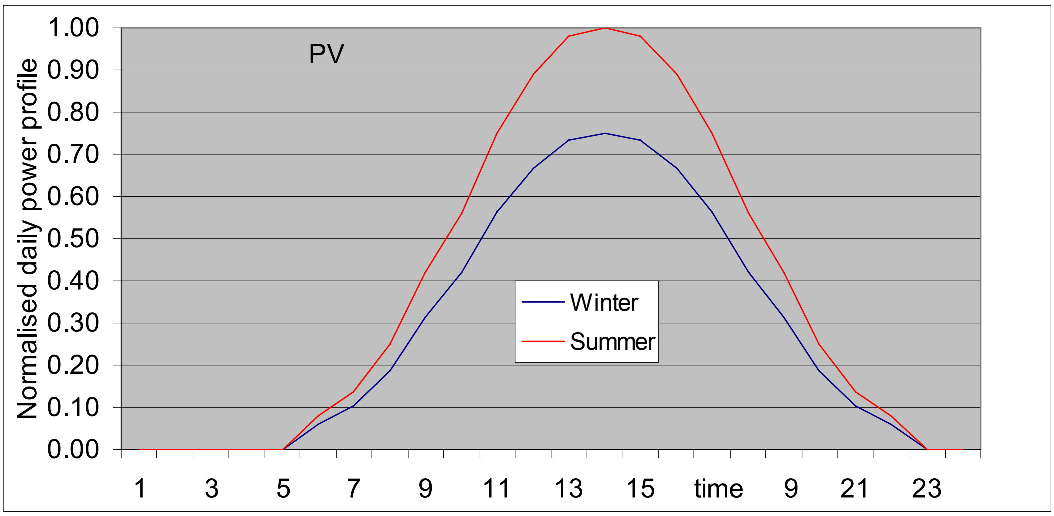


Figure 60 – Typical Daily Generation Profiles, the Netherlands

Annex 4.5 Germany

A 4.5.1 Typical network structure

In Germany there are around 800 distribution utilities each with different operation philosophies with meshed and (open) ring network structure (Figure 61); thus it is difficult to give a typical network. Therefore from the variety of existing network structures some existing MV examples are taken that can be considered to be typical (shown in Figure 62 and Figure 63). For LV an artificial network is created with different structures for different load segments (Figure 64).

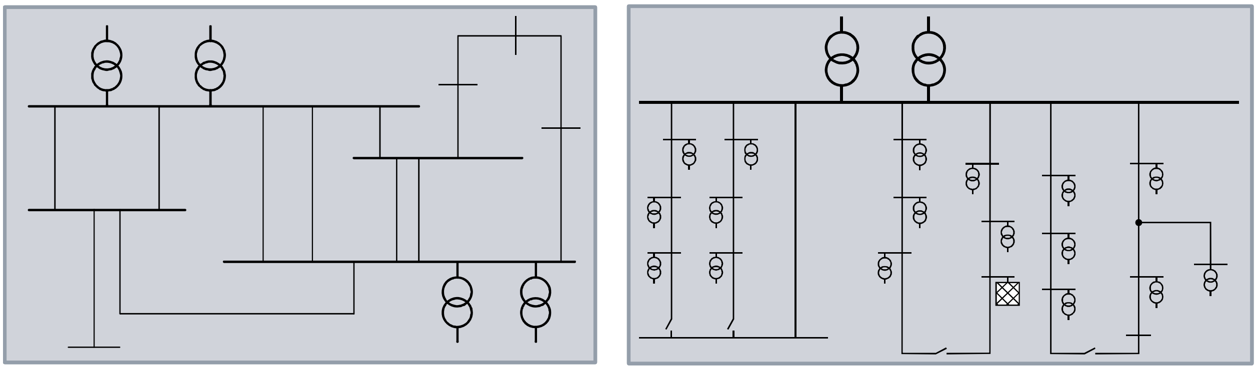


Figure 61 – a) Meshed network b)(Open) ring network structure

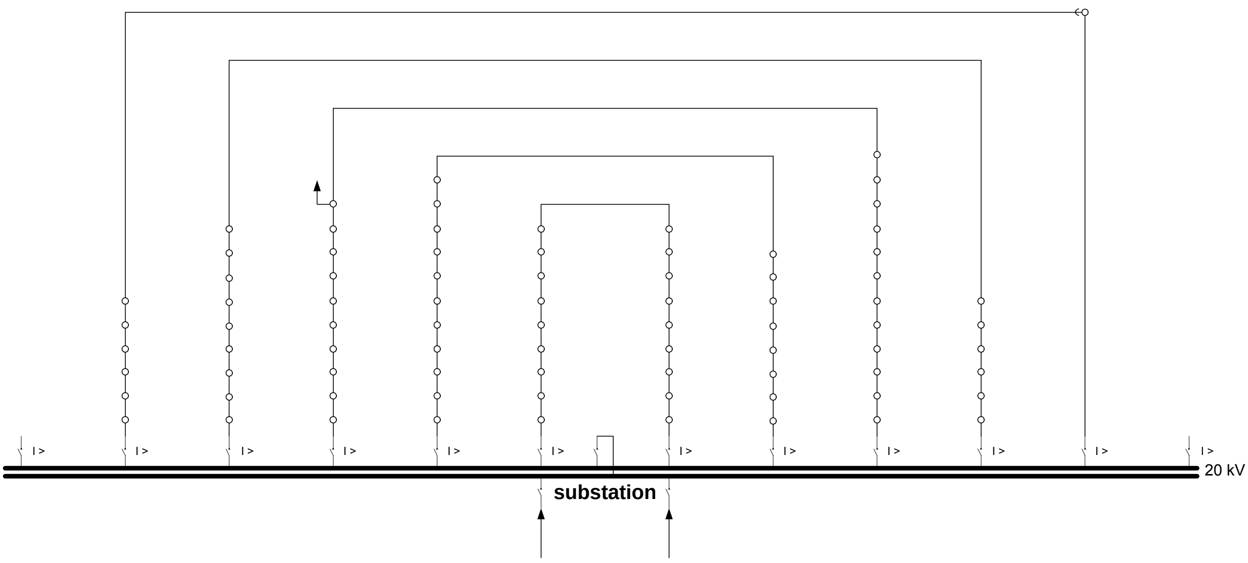


Figure 62 – Typical urban MV network, Germany

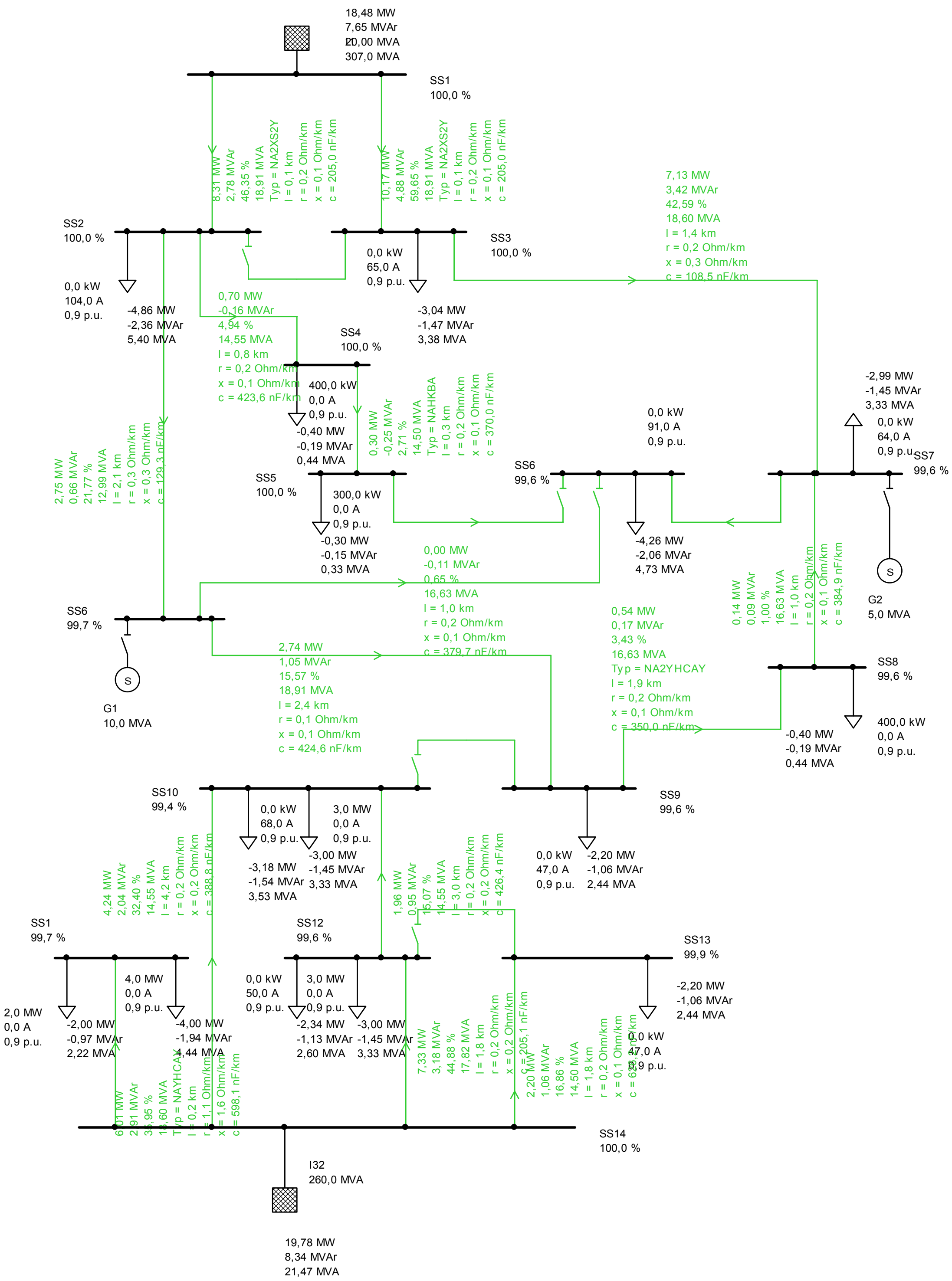


Figure 63 – Typical rural MV network (20 kV), Germany

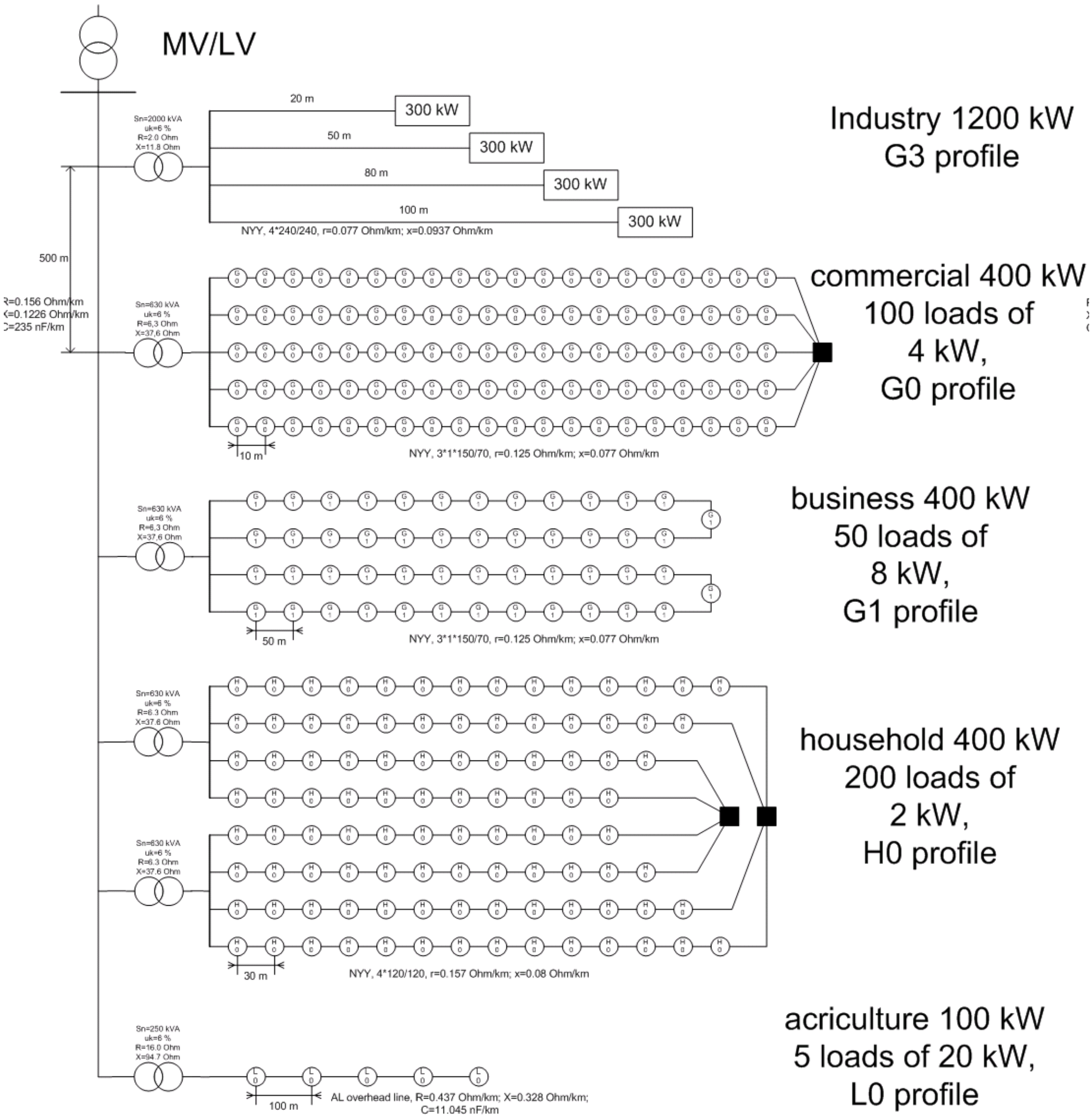


Figure 64 – Typical LV network, Germany

		R1 Ohm/km	X1 Ohm/km	C1 nF/km	R0 Ohm/km	X0 Ohm/km	C0 nF/km
400 kV	overhead line	0,03	0,25	14	0,33	1,44	6,5
110 kV	overhead line	0,07	0,41	10	0,35	1,65	4,7
	cable	0,04	0,11	400	0,50	0,28	400
20 kV	overhead line	0,31	0,4	10	0,40	1,50	5,0
	cable	0,20	0,13	300	0,50	0,30	300

Table A-34 - Typical line parameter, Germany

Figure 65 gives an overview of the German LV network of the MVV test site. Calculations will be performed with this network as well to validate results obtained in field test.

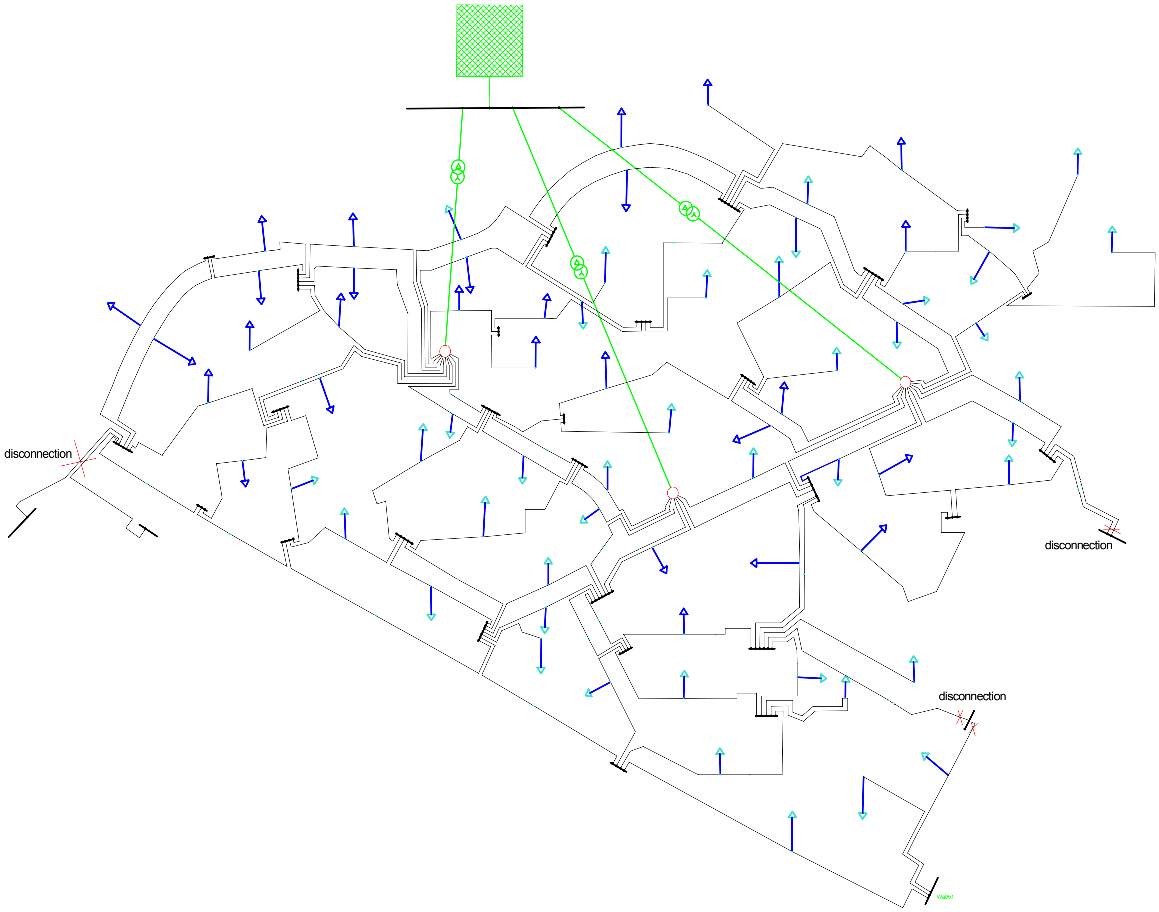


Figure 65 – Example for modelling of LV networks, MVV test site, Germany

Cable type for all lines is 4X150 NA2XY-J with:

r [Ohm/km]	x [Ohm/km]	c [nF/km]	I_{th} [kA]
0,202	0,08	570	290

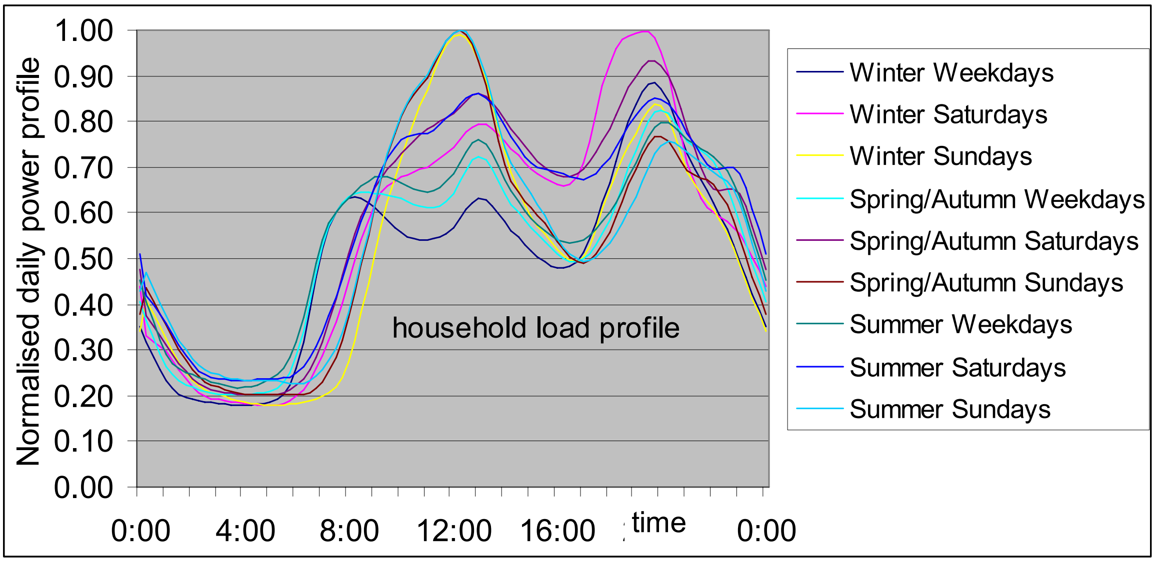
Cable lengths vary between 10 metres and 500 metres.

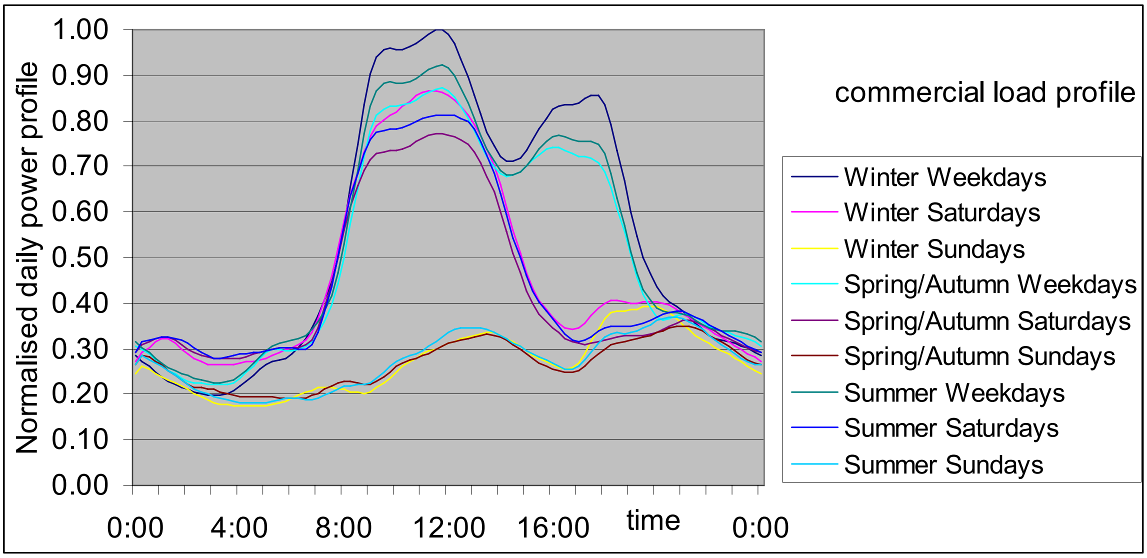
The development of the network is considered in different variants. While the current load is P = 0.7 MW and Q = 0.032 MVAr in the final structure there will be a total load of P = 1.12 MW and Q = 0,367 MVAr corresponding to cosphi = 0.95.

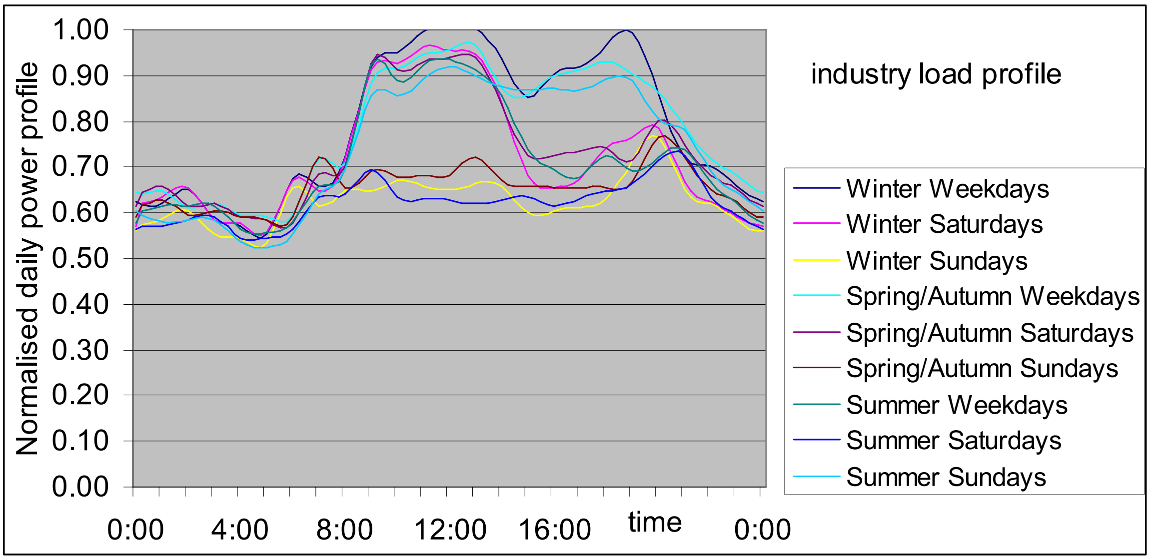
A 4.5.2 Load Scenarios

Load profiles correspond to German standard load profiles from.

German standard load profiles for households (H0), for industry (G0), for business (G3) and for agriculture (L0) are demonstrated as example in Figure 66.


Normalised daily power profile
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0:00
4:00
8:00
12:00
16:00
time
0:00
household load profile
Winter Weekdays
Winter Saturdays
Winter Sundays
Spring/Autumn Weekdays
Spring/Autumn Saturdays
Spring/Autumn Sundays
Summer Weekdays
Summer Saturdays
Summer Sundays


Normalised daily power profile
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0:00
4:00
8:00
12:00
16:00
time
0:00
commercial load profile
Winter Weekdays
Winter Saturdays
Winter Sundays
Spring/Autumn Weekdays
Spring/Autumn Saturdays
Spring/Autumn Sundays
Summer Weekdays
Summer Saturdays
Summer Sundays


Normalised daily power profile
1.00
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
0:00
4:00
8:00
12:00
16:00
time
0:00
industry load profile
Winter Weekdays
Winter Saturdays
Winter Sundays
Spring/Autumn Weekdays
Spring/Autumn Saturdays
Spring/Autumn Sundays
Summer Weekdays
Summer Saturdays
Summer Sundays

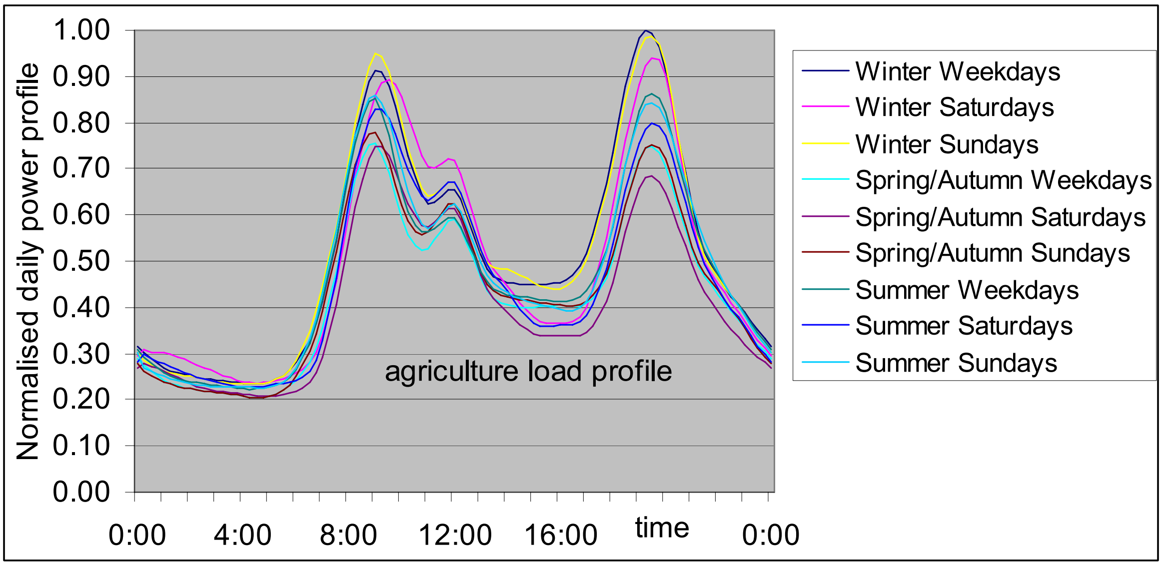


Figure 66 – Normalised daily load profiles, Germany

Typical reliability indices for Germany according to VDN (German Network operation association) statistics are printed in Table A-35.

	Stochastic Outages caused by failures in		**DISQUAL indices** LV	MV	HV	EHV	Ges.
2004	Interruption frequency	1/a	0,018	0,370	0,027	0,008	**0,422**
	Interruption duration	min	155,5	49,3	19,4	190,0	**54,3**
	Supply unavailability	min/a	2,8	18,2	0,5	1,4	**22,9**
2005	Interruption frequency	1/a	0,023	0,293	0,020	0,000	**0,336**
	Interruption duration	min	145,6	52,8	24,1	5,0	**57,5**
	Supply unavailability	min/a	3,3	15,5	0,5	0,0	**19,3**
					including "Münsterland outage"		
ø	Interruption frequency	1/a	0,020	0,331	0,024	0,004	**0,379**
	Interruption duration	min	149,9	50,9	21,1	186,7	**55,7**
	Supply unavailability	min/a	3,05	16,85	0,50	0,70	**21,10**

Table A-35 - Typical reliability indices, Germany

A 4.5.3 Generation Scenarios

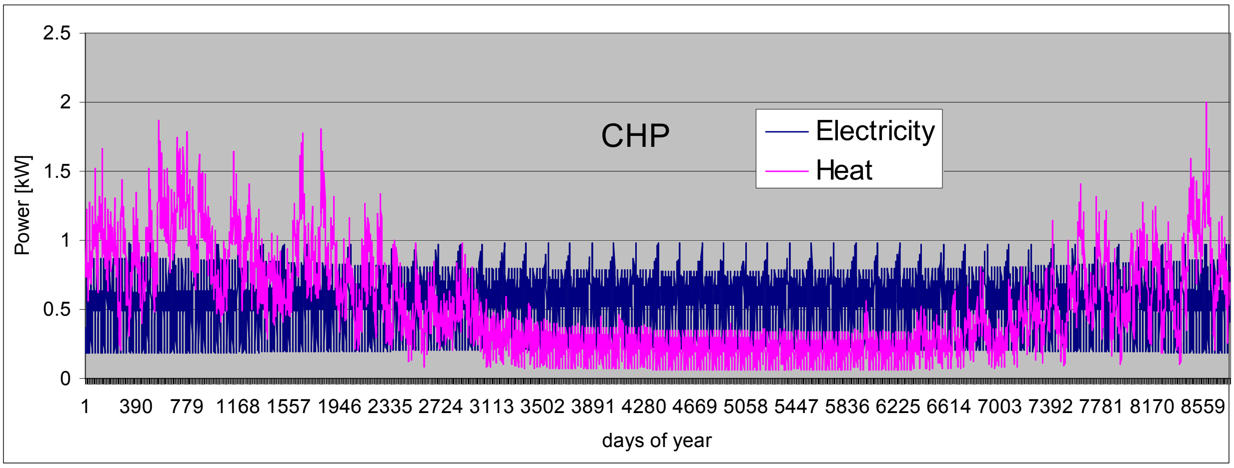


Figure 67 – Typical Daily CHP Generation Profiles, Germany

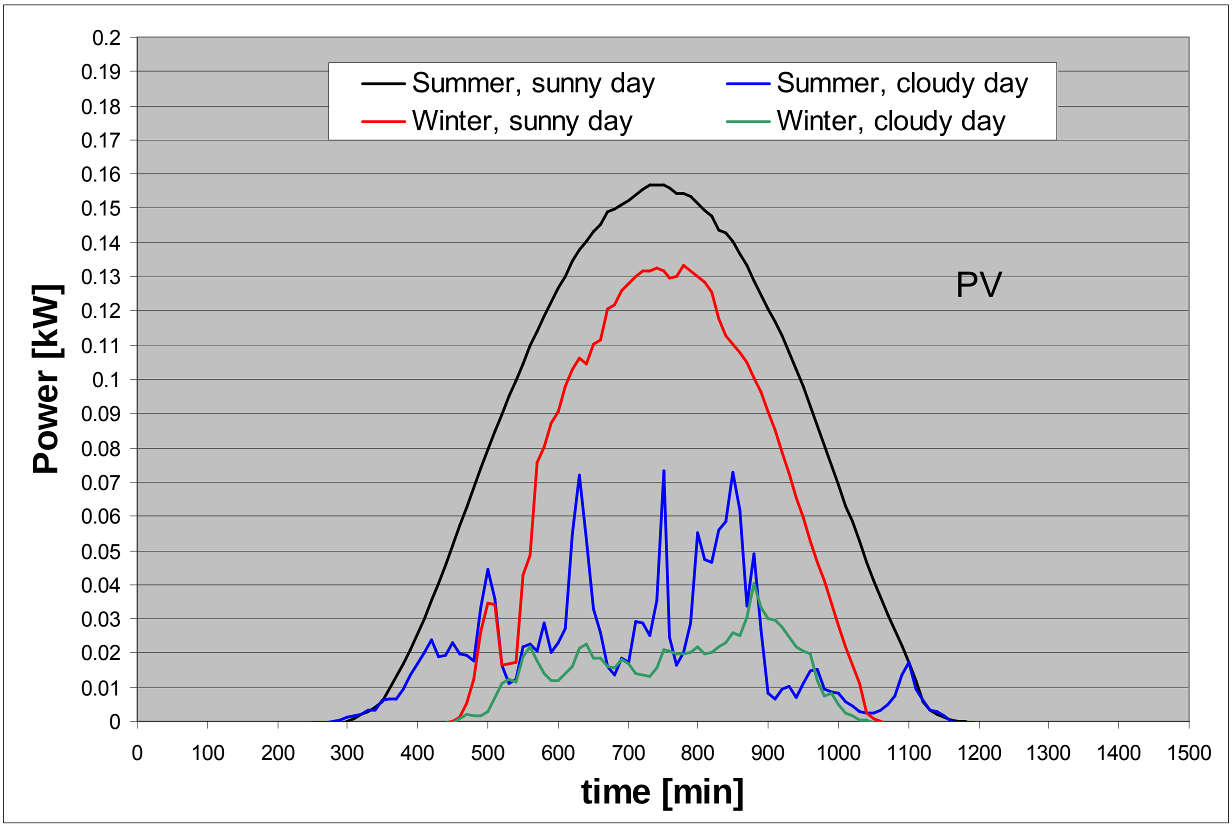


Figure 68 – Typical Daily PV Generation Profiles, Germany

Yearly wind profiles in 15 – min resolution metered in Germany are available for further analysis. There is a strong intermittency in generation depending on weather conditions without any seasonal peculiarities (Figure 69).

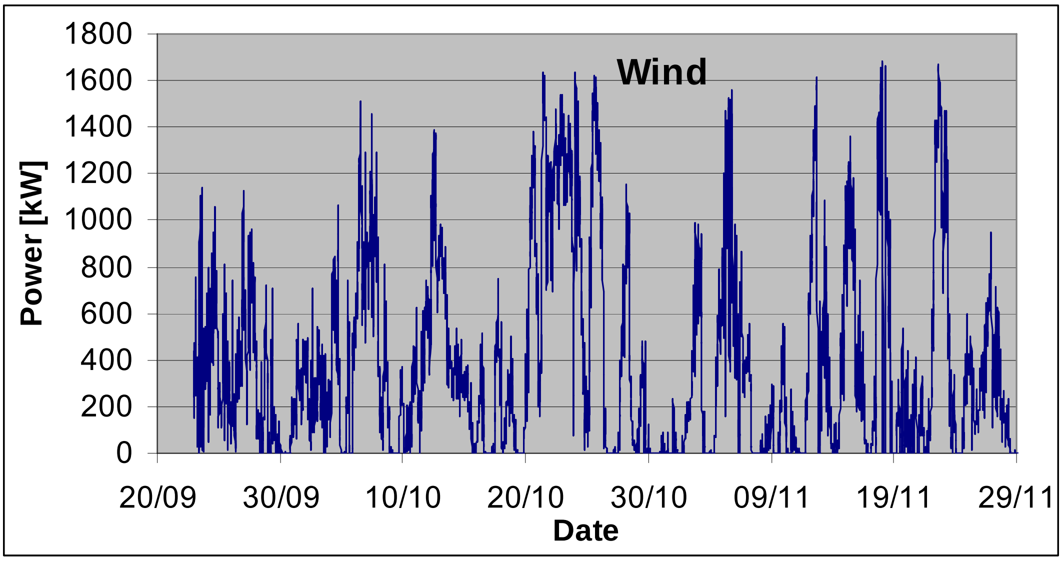


Figure 69 – Typical Daily Wind Generation Profiles, Germany

It is agreed in WPG to develop the scenarios based on existing forecasts for typical microgeneration in different countries. Figure 70 serves as an example for expected development of RES in Germany.

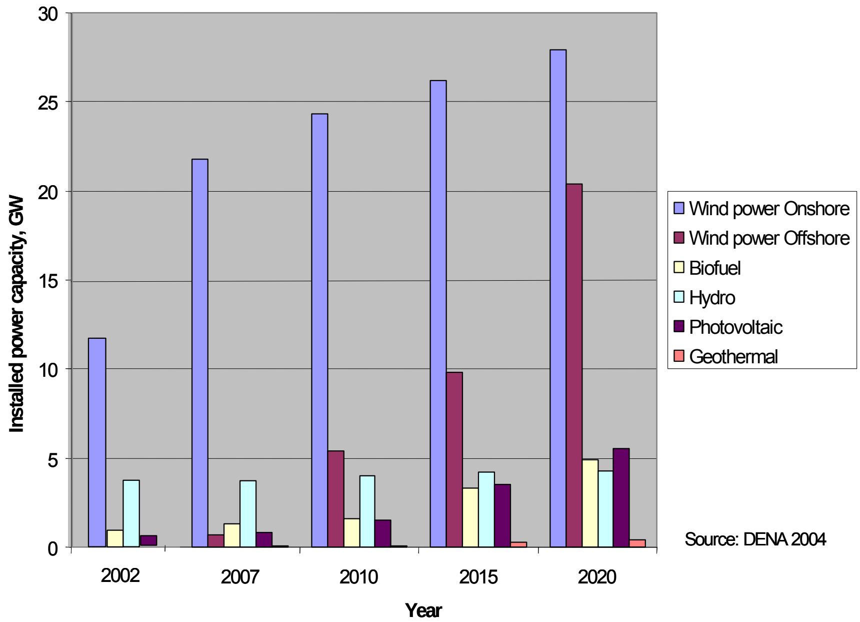


Figure 70 – Development of renewables' installed capacity in Germany

A 4.5.4 Tariffs

Main components of electricity prices are energy rates, use of system charges and ca. 40 % supplement due to governmental charges (different taxes, concession levy and the additions due to Renewable Energy and CHP support schemes) (Figure 71).

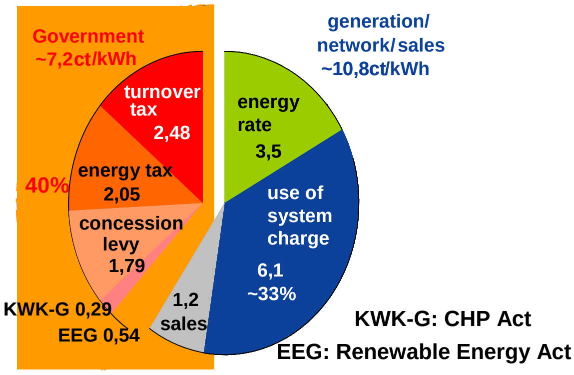


Figure 71 – German tariff structure (source VDN, 2004)

While in 2007 use of system charge decreased, electricity prices for household and commercial consumer increased compared to 2006 (Table A-36).

	average electricity price	average use of system charge
Household (0,4 kV, 3500 kWh/a)	20,12 ct/kWh (18,89 ct/kWh)	6,34 ct/kWh (7,30 ct/kWh)
Commercial (0,4 kV, 50 MWh/a, Pmax = 50 kW)	19,75 ct/kWh (19,35 ct/kWh)	5,49 ct/kWh (6,38 ct/kWh)
Industry (24 GWh/a, Pmax = 4000 kW, 20 kV)	11,95 ct/kWh (12,14 ct/kWh)	1,53 ct/kWh (1,70 ct/kWh)

Table A-36 - German average electricity prices 2007 (and 2006)
(Source Bundesnetzagentur, Monitoringbericht 2007)

Annex 4.6 Greece

A 4.6.1 Typical network structure

Three typical networks in Greece are presented in this chapter. For these networks, the following information is obtained:

- Network topology and one line diagram;
- Base Voltage;
- Line/Cable data – branch resistance, reactance, length of lines/cables etc.
- Transformers data (HV/MV and MV/LV);

The topologies for the typical HV, MV, and LV networks are shown in Figure 72 - Figure 76.

Typical data and information (where are available) about the MV and LV networks are given in the following tables.

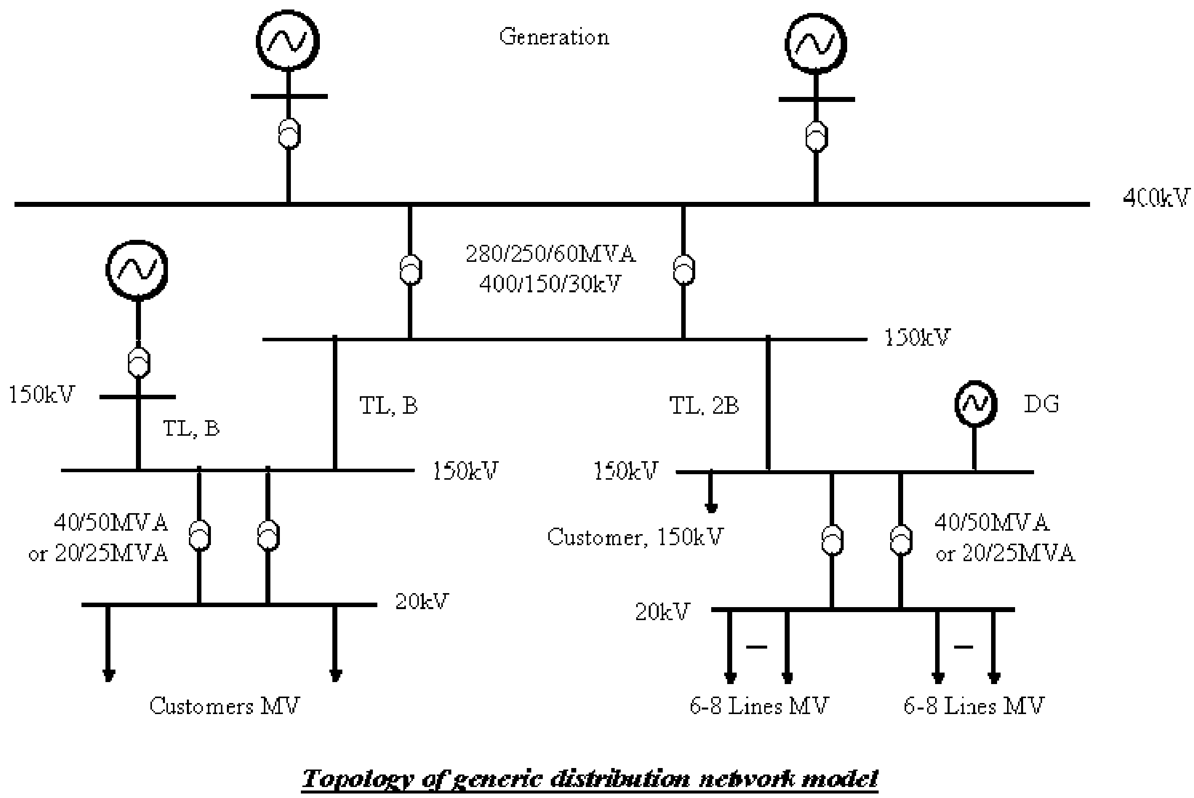


Figure 72 – Typical network structure, Greece

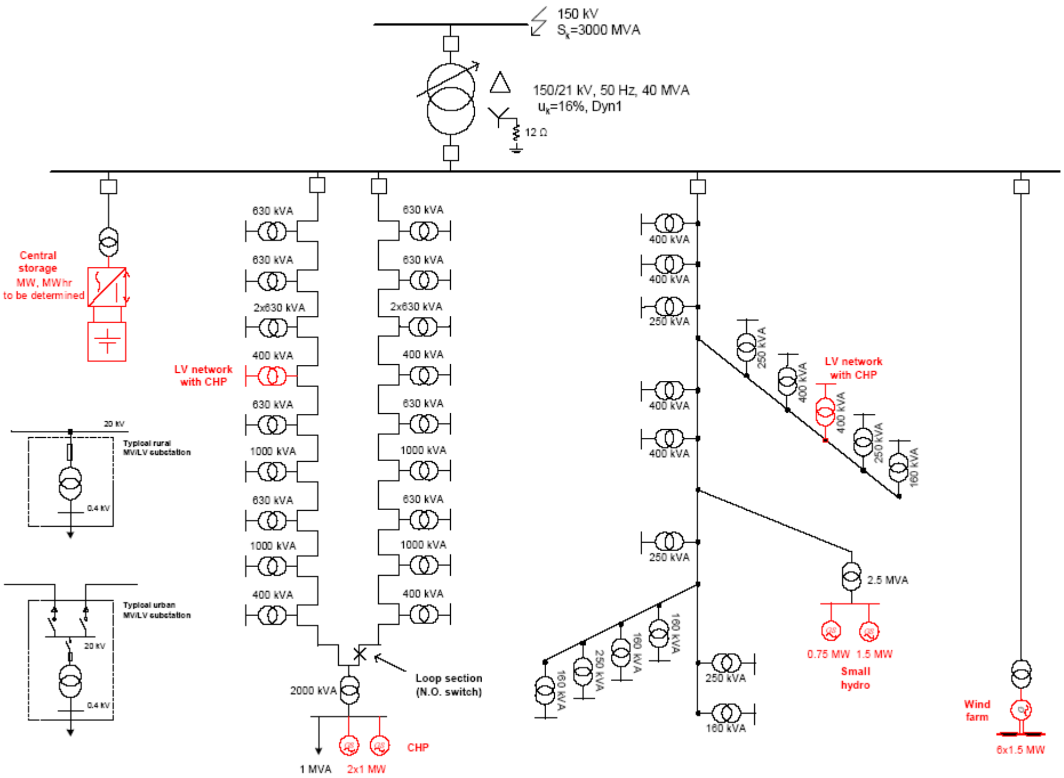


Figure 73 – Specific MV network, Greece

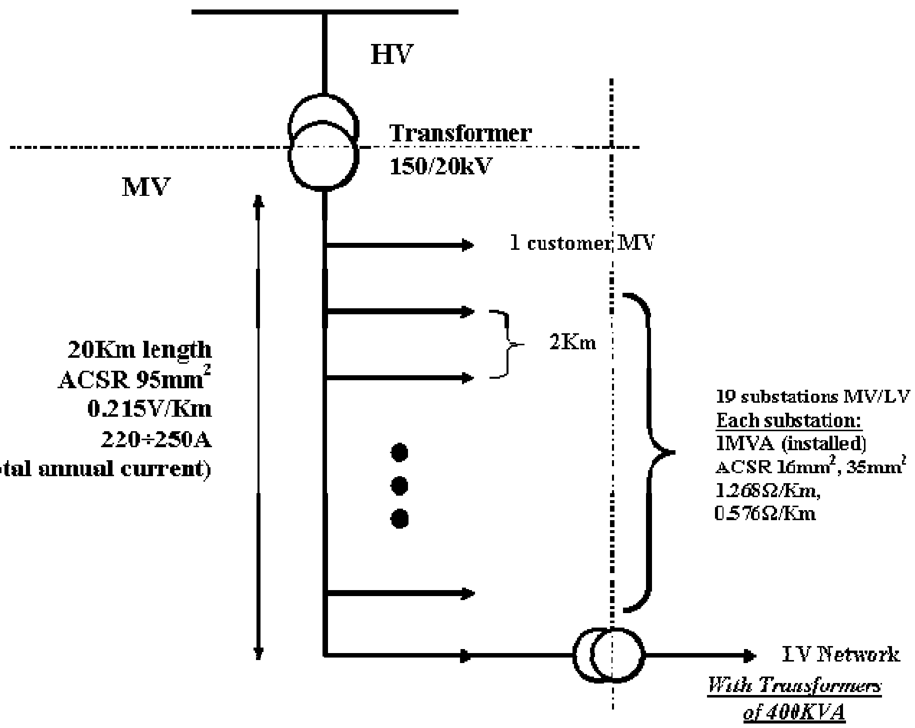


Figure 74 – Typical Rural Distribution MV network, Greece

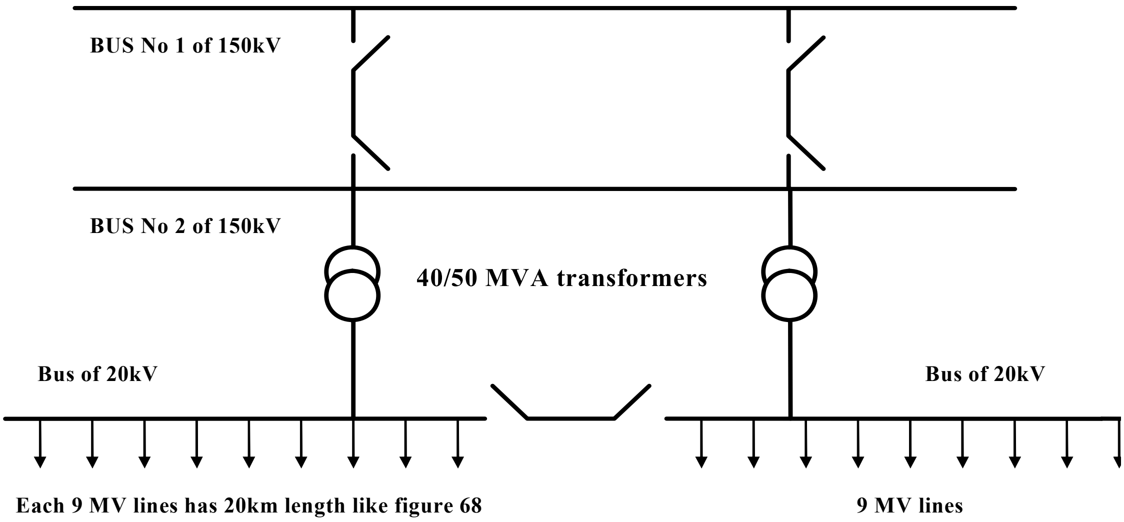


Figure 75 – Typical Urban Distribution MV network, Greece

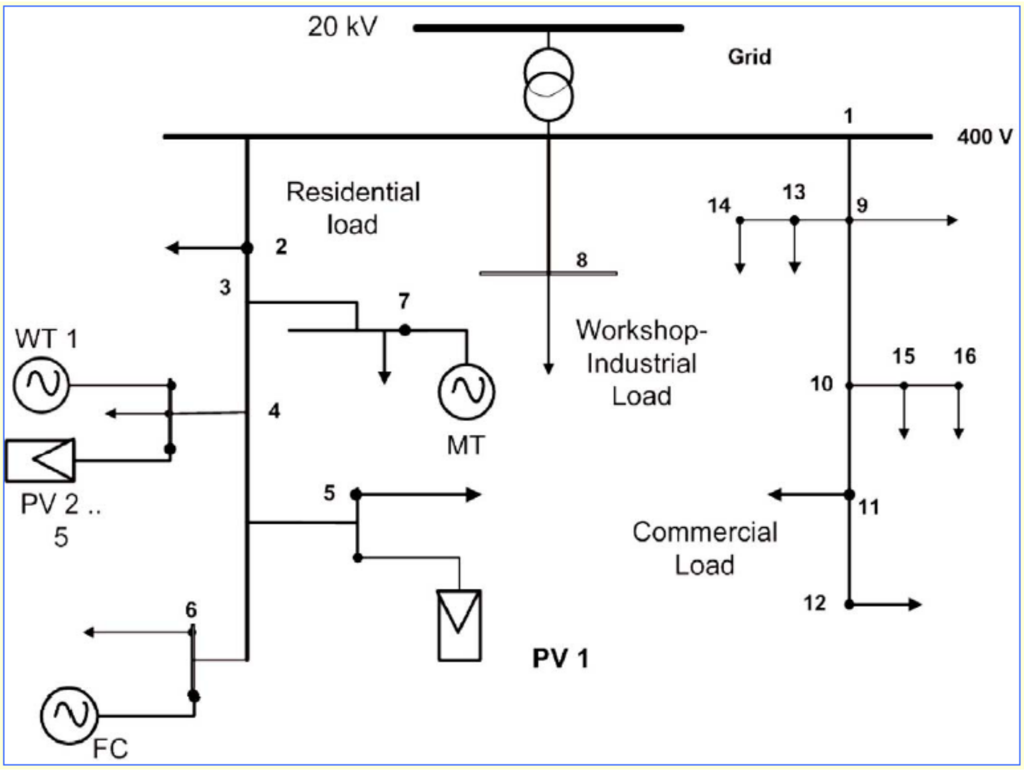


Figure 76 – Typical Rural LV network, Greece

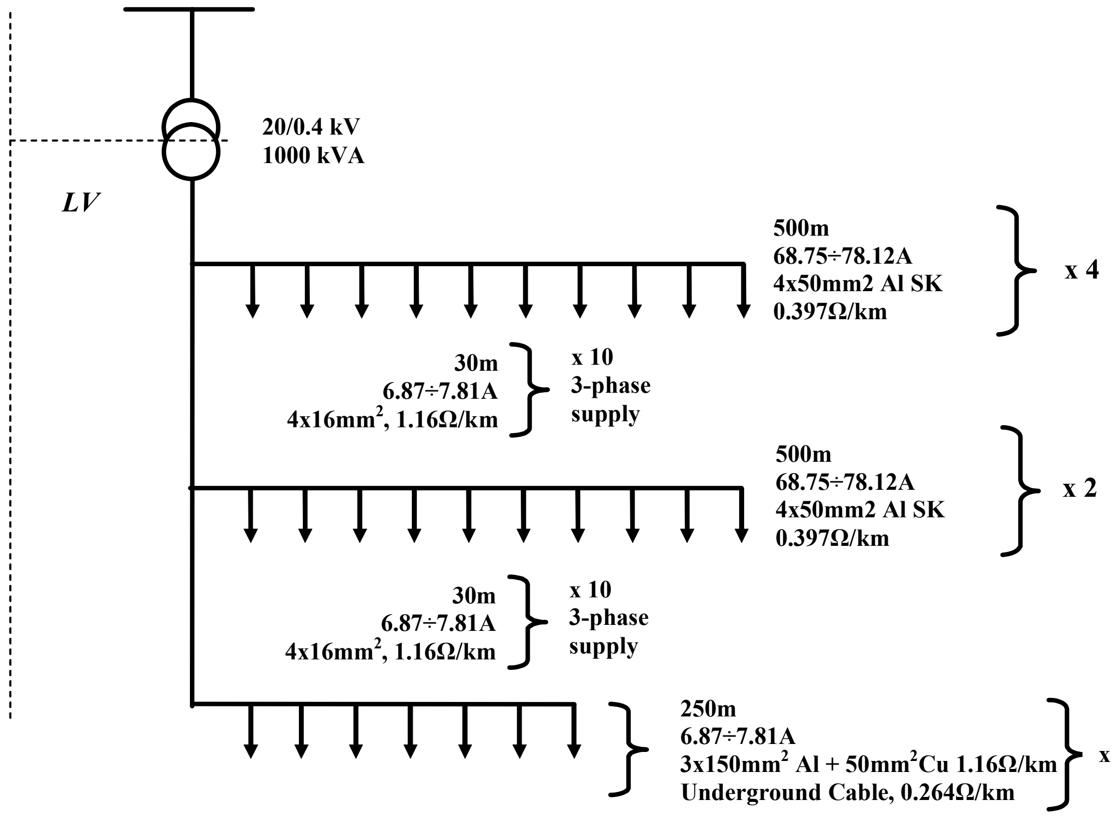


Figure 77 – Typical Urban LV network (radial), Greece

	TYPES OF CABLES			
	B	2B	B'B'' (400kV)	2B'B'' (400kV)
Cross Section per phase – ACSR (mm^2)	1x322	1x322	2x484	2x484
Thermal Limit under Rated Condition (MVA)	202	2x202	1400	2x1400
Thermal Limit under Bad Condition, 40^0C (MVA)	169	2x169		
R_1 (Ω/km)	0.0974	0.0971	0.031	0.033
X_1 (Ω/km)	0.4219	0.3914	0.337	0.318
Admittance1 (μS/Km)	2.7318	2.9190		
R_0 (Ω/km)	0.3599	0.4968	0.295	0.485
X_0 (Ω/km)	1.3090	2.3492	1.035	1.931
Admittance0 (μS/km)	2.0724	1.2864		
Cost (thousand)€/km (5km<l<10km)	105	138		
Cost (thousand)€/km (5km<l<10km)	88	115		

Table A-37 – Characteristics of typical overhead HV transmission lines, Greece

	TYPES OF CABLES		
	16 ACSR	**35 ACSR**	**95 ACSR**
R_1+jX_1 (Ω/km)	1.268+j0.422	0.576+j0.397	0.215+j0.334
B_1 ($Y_1=Y_2=jB_1$) (μS/km)		3.109	3.421
R_0+jX_0 (Ω/km)	1.416+j1.620	0.724+j1.595	0.363+j1.556
B_0 ($Y_0=jB_0$) (μS/km)		1.419	1.480
Imax (A)	136	224	448
Costs (€/km)		12,000	20,000

Table A-38 – Characteristics of typical overhead MV transmission lines, Greece

	LINE TYPE	R (Ω/km)	X (Ω/km)	R_n (Ω/km)
1	Overhead-Twisted cable 4x120mm² Al (***1-2, 2-3, 3-4, 4-5, 5-6 buses***)	0.284	0.083	0.284
2	Overhead-Twisted cable 3x70mm² Al+54.6 mm² AAAC (***3-7 buses***)	0.497	0.100	0.630
3	Overhead–Conductors 4x50mm² Al (***1-9, 9-10 buses***)	0.397	0.279	
4	Overhead–Conductors 4x35mm² Al (***9-13, 13-14, 10-11, 11-12 buses***)	0.574	0.294	
5	Overhead–Conductors 4x16mm² Al (***10-15, 15-16 buses***)	1.218	0.318	
6	Underground–XLPE cable 3x150mm² Al+50mm² Cu (***1-8 buses***)	0.264	0.071	0.387

Table A-39 – LV lines characteristics, Greece (1)

Node i	Node j	R (pu)	X (pu)	Length (km)
1	**2**	0.000010	0.00001	0.035
1	**8**	0.033125	0.00875	0.200
1	**9**	0.007500	0.00500	0.030
17 (Slack Bus)	**1**	0.001150	0.00383	0.000
2	**3**	0.012500	0.00375	0.035
3	**4**	0.012500	0.00375	0.035
3	**7**	0.021870	0.00438	0.035
4	**5**	0.012500	0.00375	0.035
5	**6**	0.012500	0.00375	0.035
9	**10**	0.015000	0.01063	0.030
9	**13**	0.010630	0.00563	0.030
10	**11**	0.021250	0.00563	0.030
10	**15**	0.023130	0.00625	0.030
11	**12**	0.021250	0.00563	0.030
13	**14**	0.010630	0.00563	0.030
15	**16**	0.023130	0.00625	0.030

Table A-40 – Characteristics of LV lines, Greece (2)

	RATED POWER (MVA)	
	20/25	40/50
Rated Secondary Current (A)	916/688	1833/1375
Short-Circuit Voltage u%=z% (%)	≥15% (20MVA)	≥15% (40MVA)
Losses of Fe (kW)	27	42
Losses of Cu (kW)	100	174
Cost (€)	700,000	780,000
Connection: Dy1, Transformer Tabs: -12.5%÷7.5% (17 steps of 1.25%)		

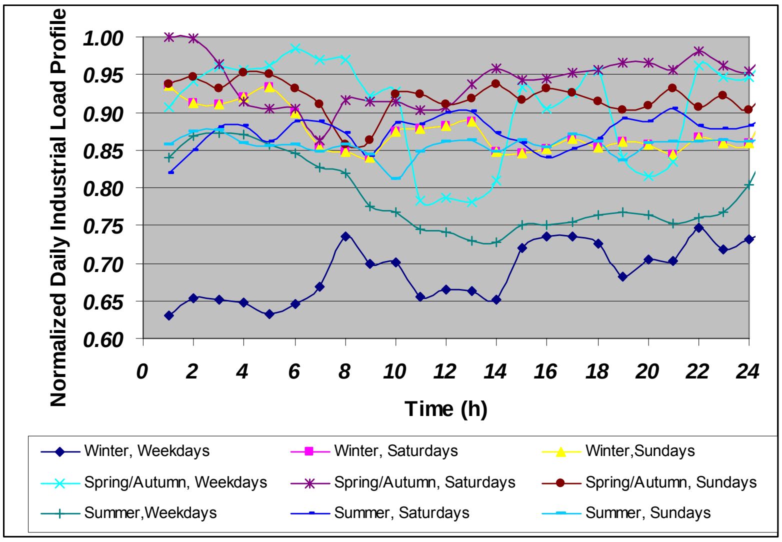
Table A-41 – Characteristics of typical HV/MV (150/20 kV) transformer, Greece

		RATED POWER (KVA)				
		160	250	400	630	1000
Rated Secondary Current (A)		231	361	577	909	1443
Short-Circuit Voltage u%=z% (%)		4	4	4	4	5
R	%	1.47	1.30	1.15	1.03	1.05
	Ω	36.72	20.80	11.50	6.55	4.20
X	%	3.72	3.78	3.83	3.86	4.89
	Ω	93.01	60.53	38.31	24.54	19.55
Losses of Fe (W)		315	450	640	890	1200
Losses of Cu (W)		2350	3250	4600	6500	10500
Connection: Dyn11, Transformer Tabs: -5%, -2.5%, 0%, 2.5%, 5%						

Table A-42 – Characteristics of typical MV/LV (20/0.4kV) transformers, Greece

A 4.6.2 Load Profiles

Consumer load curves concerning a 24-hour period must be identified and provided. The following figures present typical load diagrams for Greece.



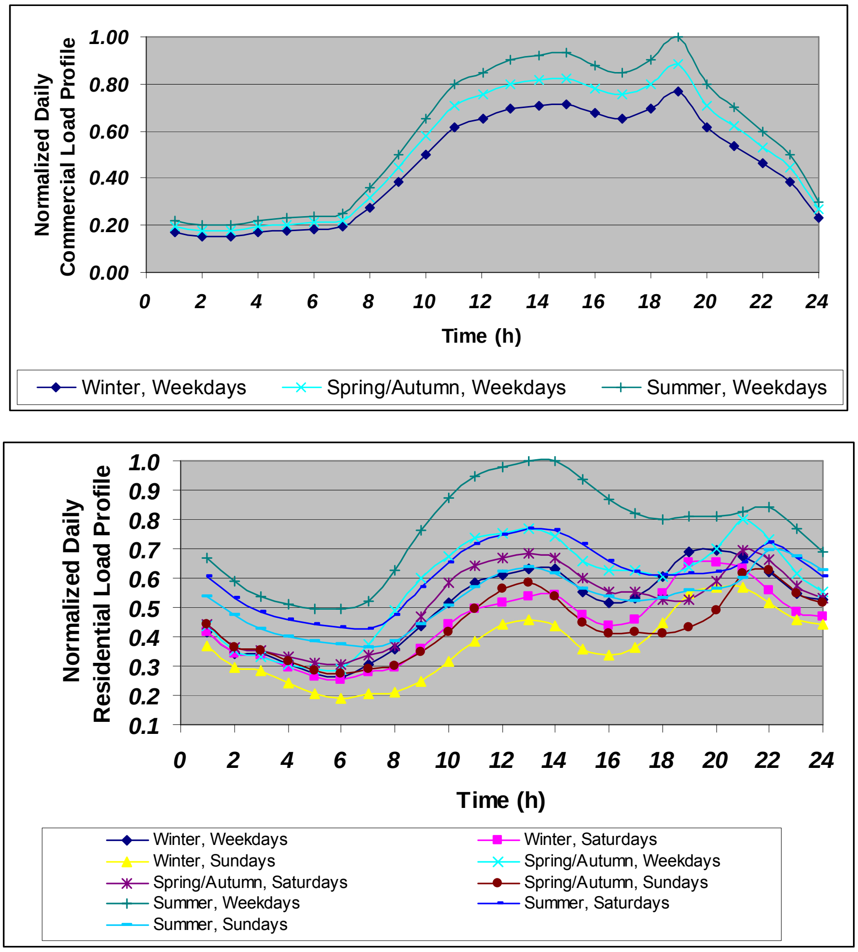


Figure 78 – Normalised Daily Load Profiles in Greece

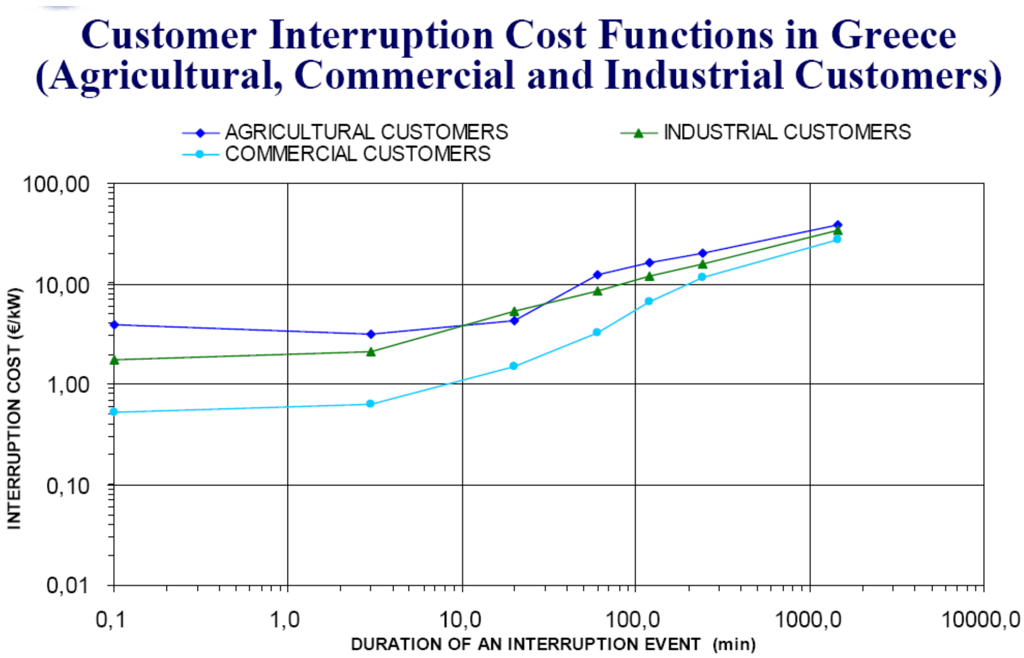


Figure 79 – Customer interruption costs, Greece

A 4.6.3 Generation Scenarios

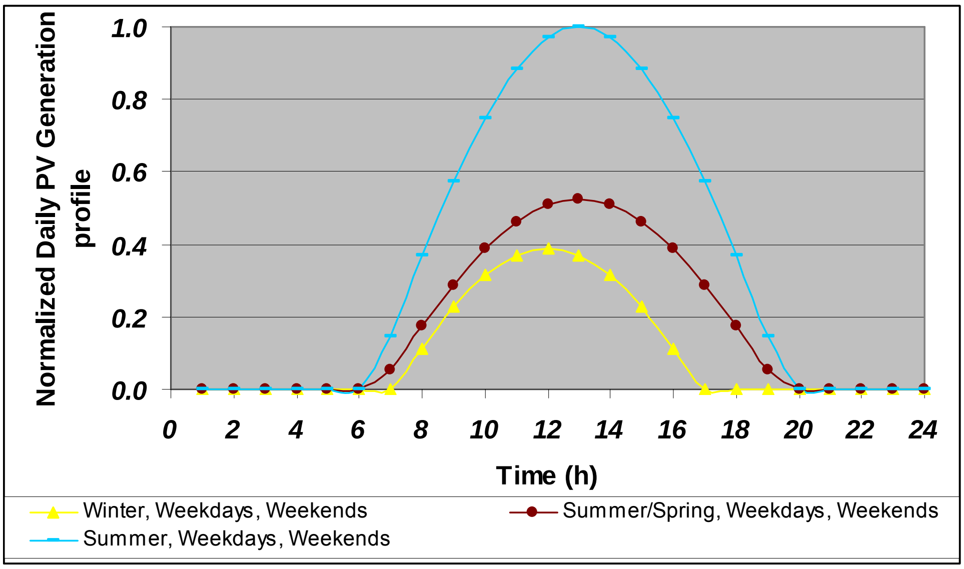


Figure 80 – Typical Daily PV Generation Profile, Greece

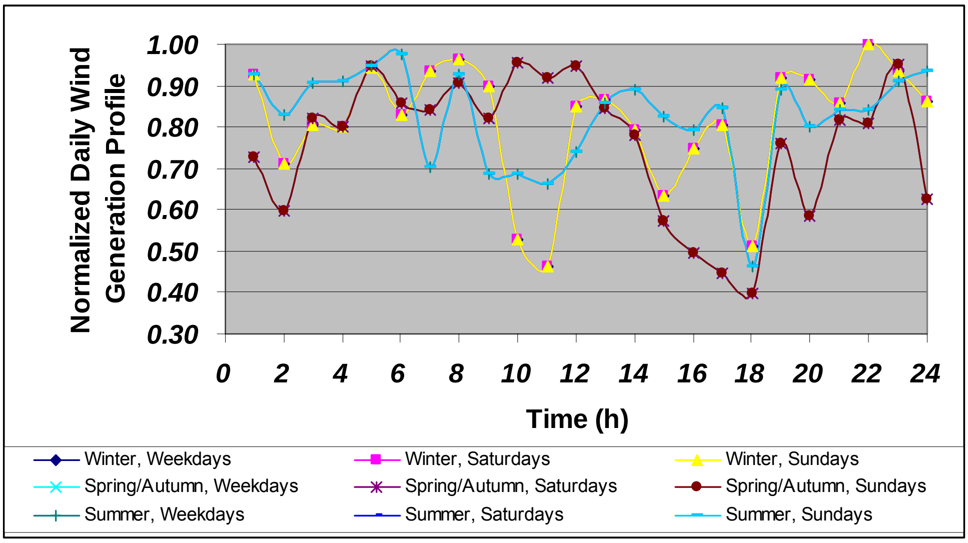


Figure 81 – Typical Daily Wind Generation Profile, Greece

Typical CHP generation in Greece is assumed to follow a daily profile as demonstrated in Figure 82.

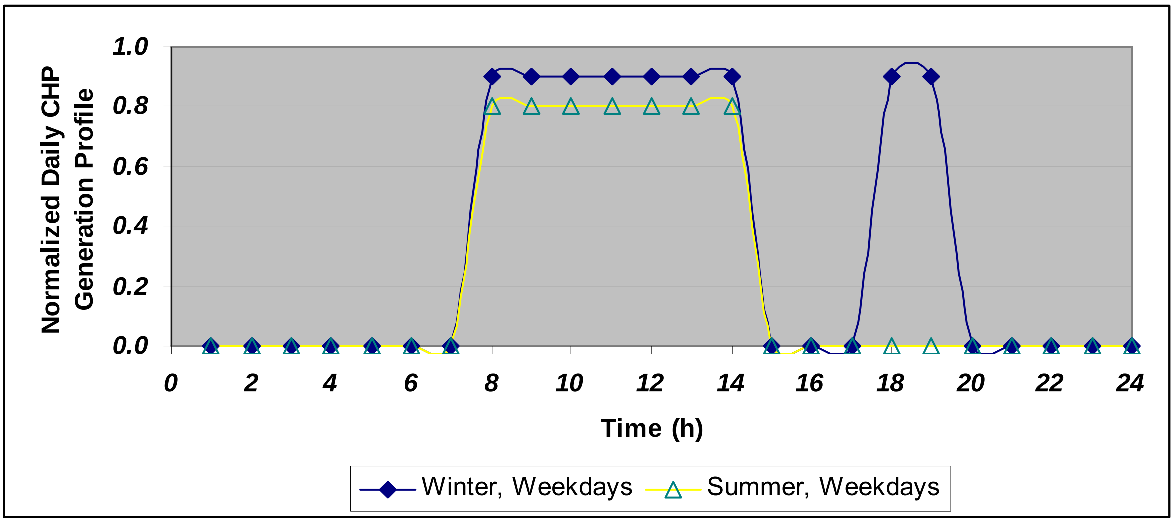


Figure 82 – Typical Daily micro-CHP Generation Diagram, Greece

Annex 4.7 Denmark

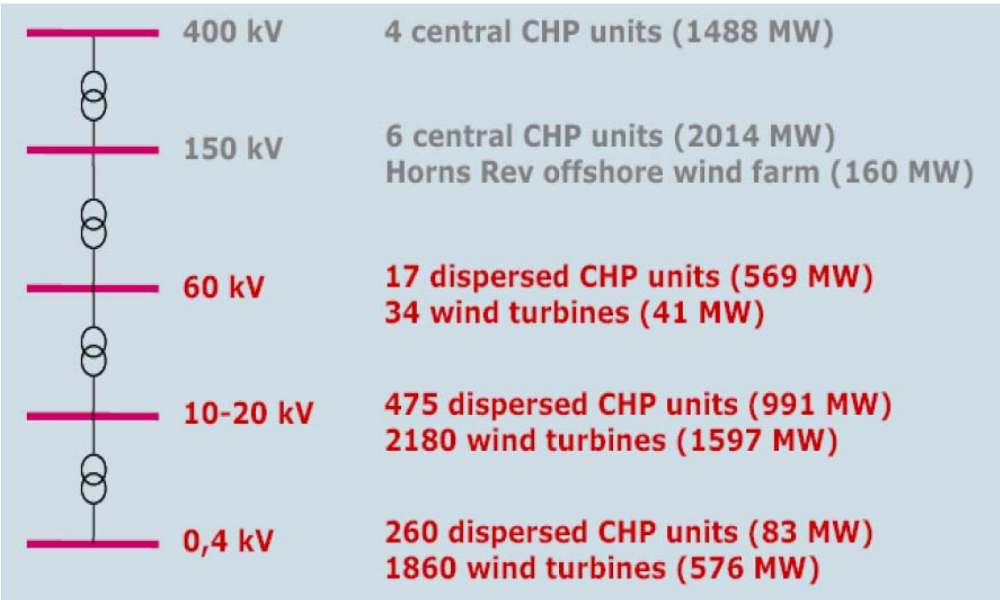


Figure 83 – Generators connected at different voltage levels, Denmark

Figure 84 – Development of capacity and load, Denmark

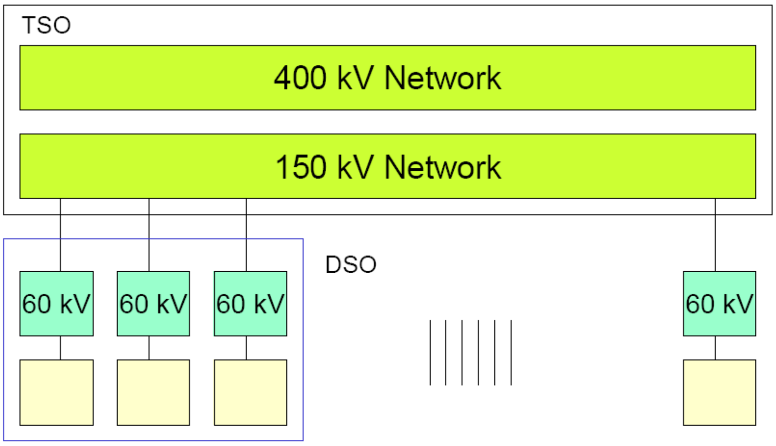


Figure 85 – Typical network structure, Denmark

Detailed analysis of Danish Microgrids is done with help of the Bornholm test site.

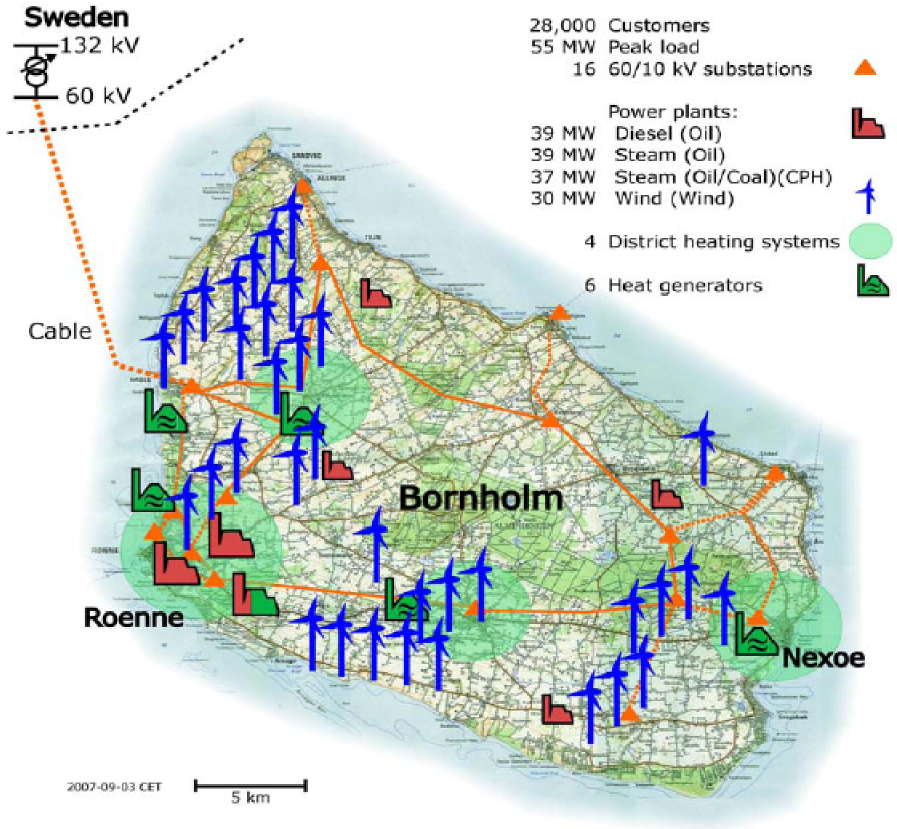


Figure 86 – The Bornholm test and analysis site, Denmark

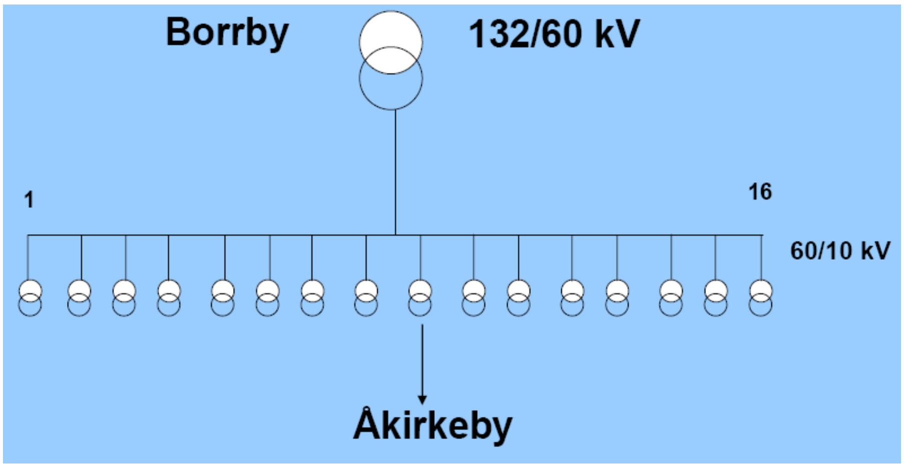


Figure 87 – Typical network structure, Bornholm, Denmark

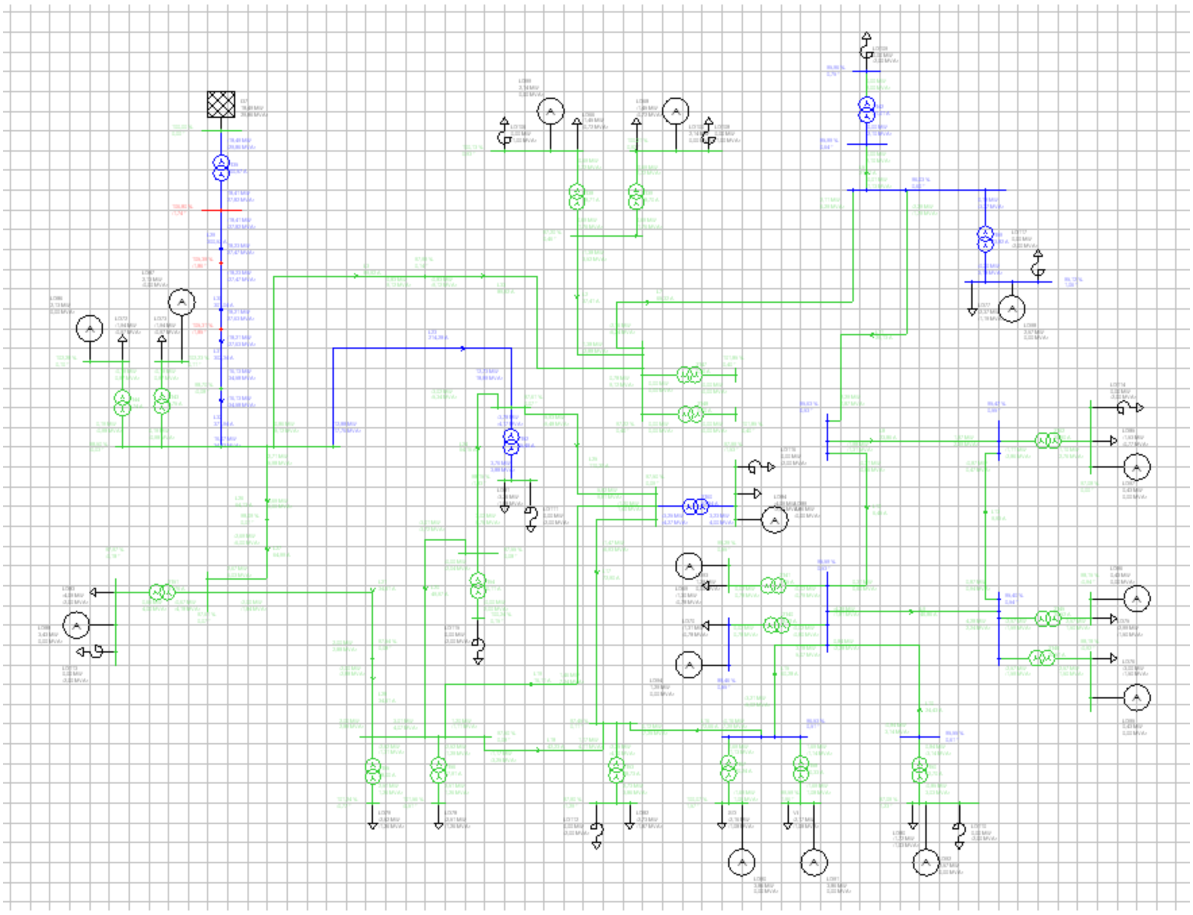


Figure 88 – Typical MV (60 kV) Danish network, Bornholm, Denmark

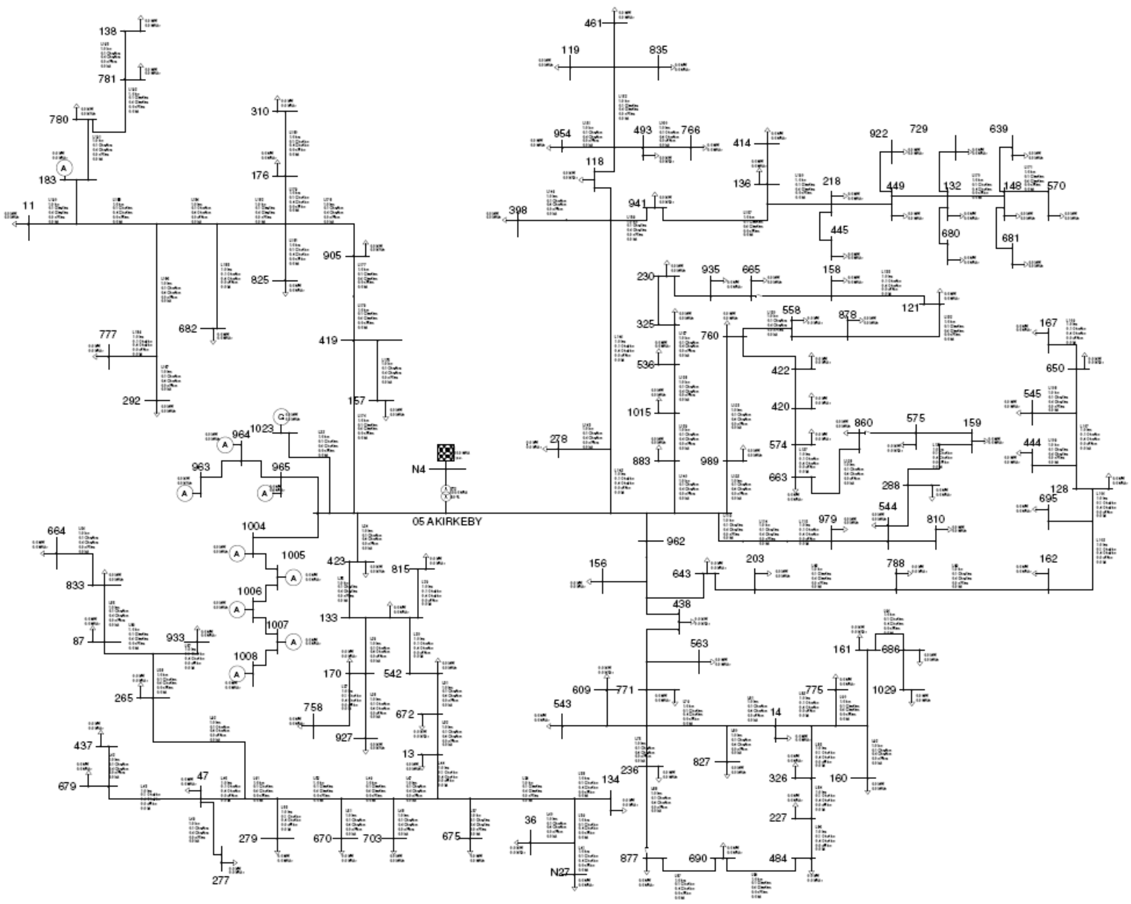


Figure 89 – Typical MV (10 kV) network in Bornholm, Denmark

Annex 4.8 Macedonia

UKIM and ICEIM-MANU have identified typical HV, MV and LV networks and network elements for Macedonia. The data is obtained form different sources, mainly the electricity companies in the country.

A 4.8.1 Typical networks

The examples of typical HV, MV and LV grids are presented in this section. The single line diagrams and the data in the tables (Table A-43 to Table A-50) give basic information of the different voltage levels and the most frequently used equipment in these networks.

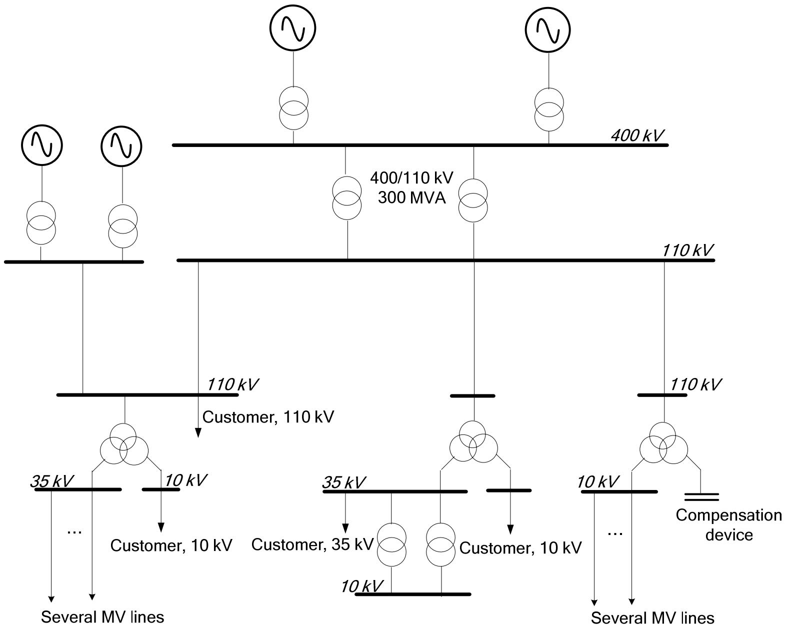


Figure 90 – Typical network, Macedonia

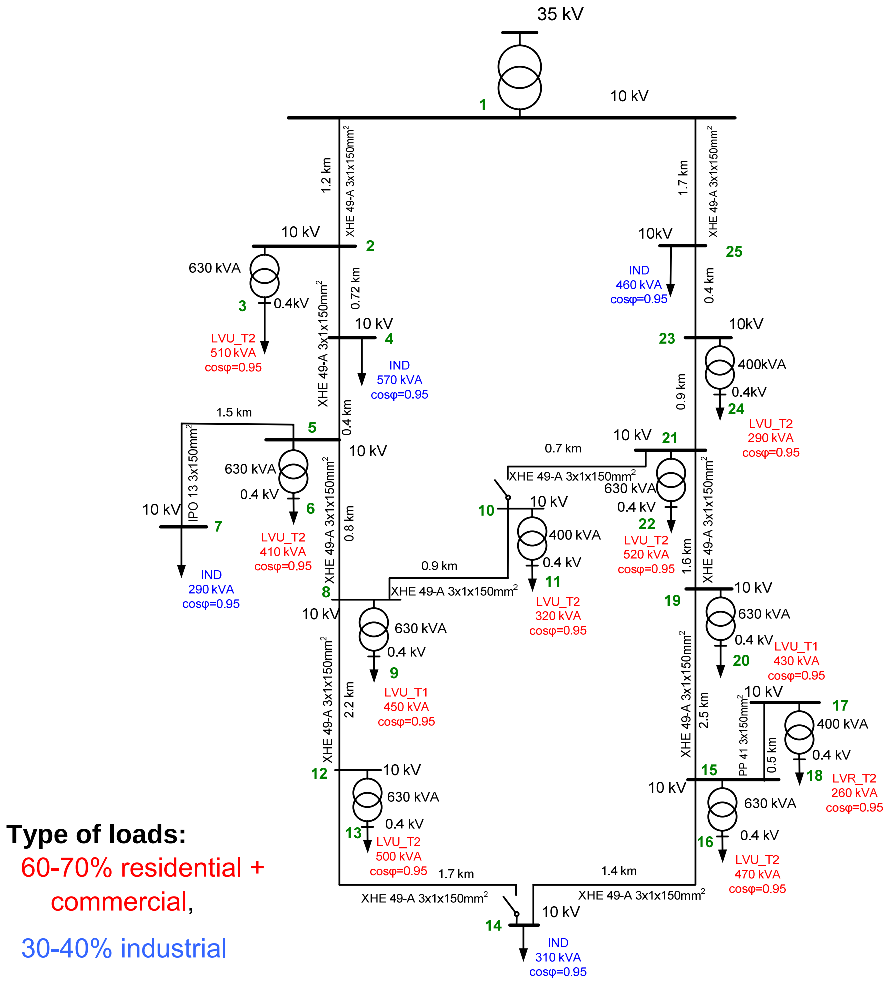


Figure 91 – Typical MV urban network, Macedonia

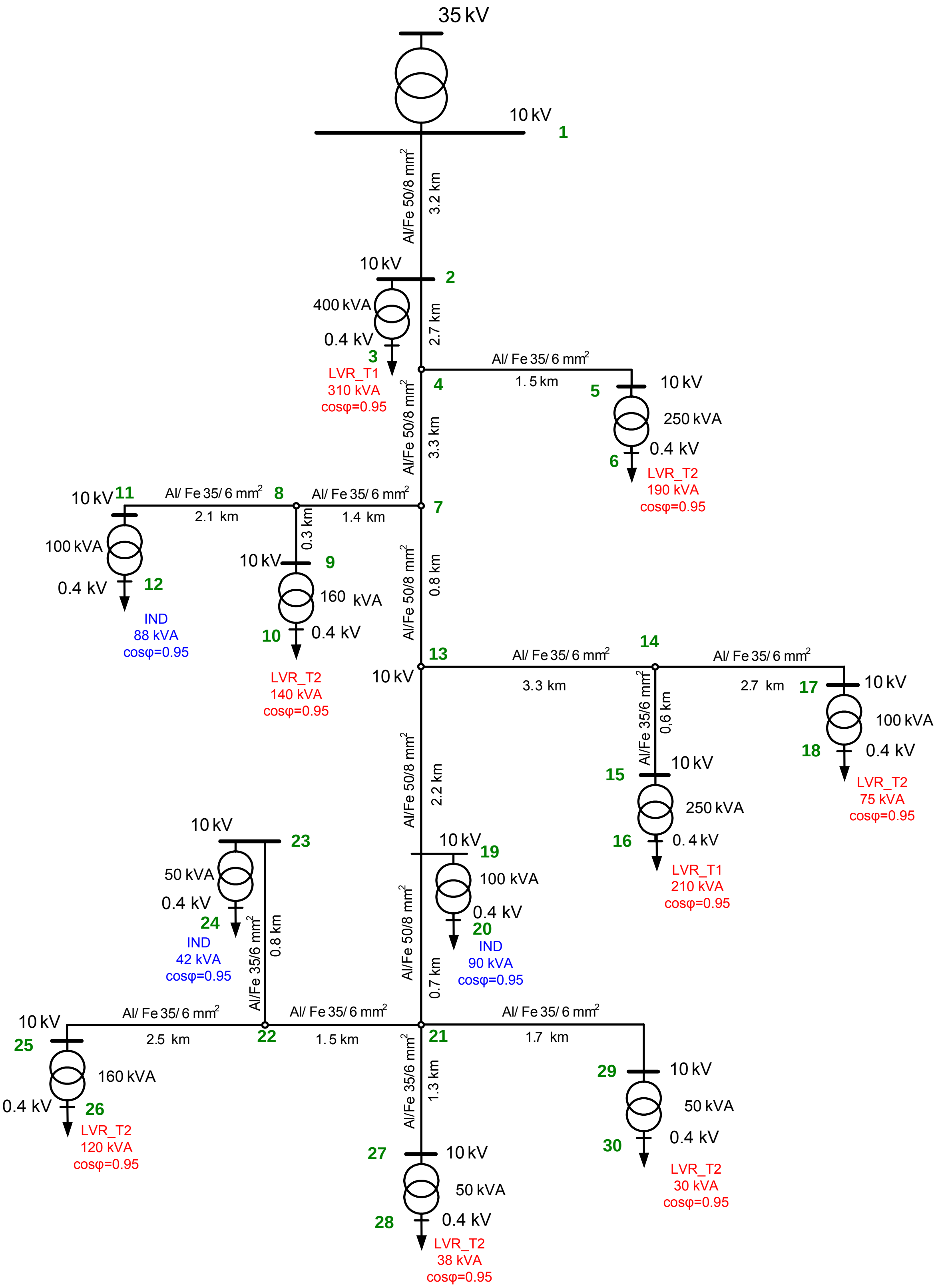


Figure 92 – Typical MV rural network (overhead lines), Macedonia

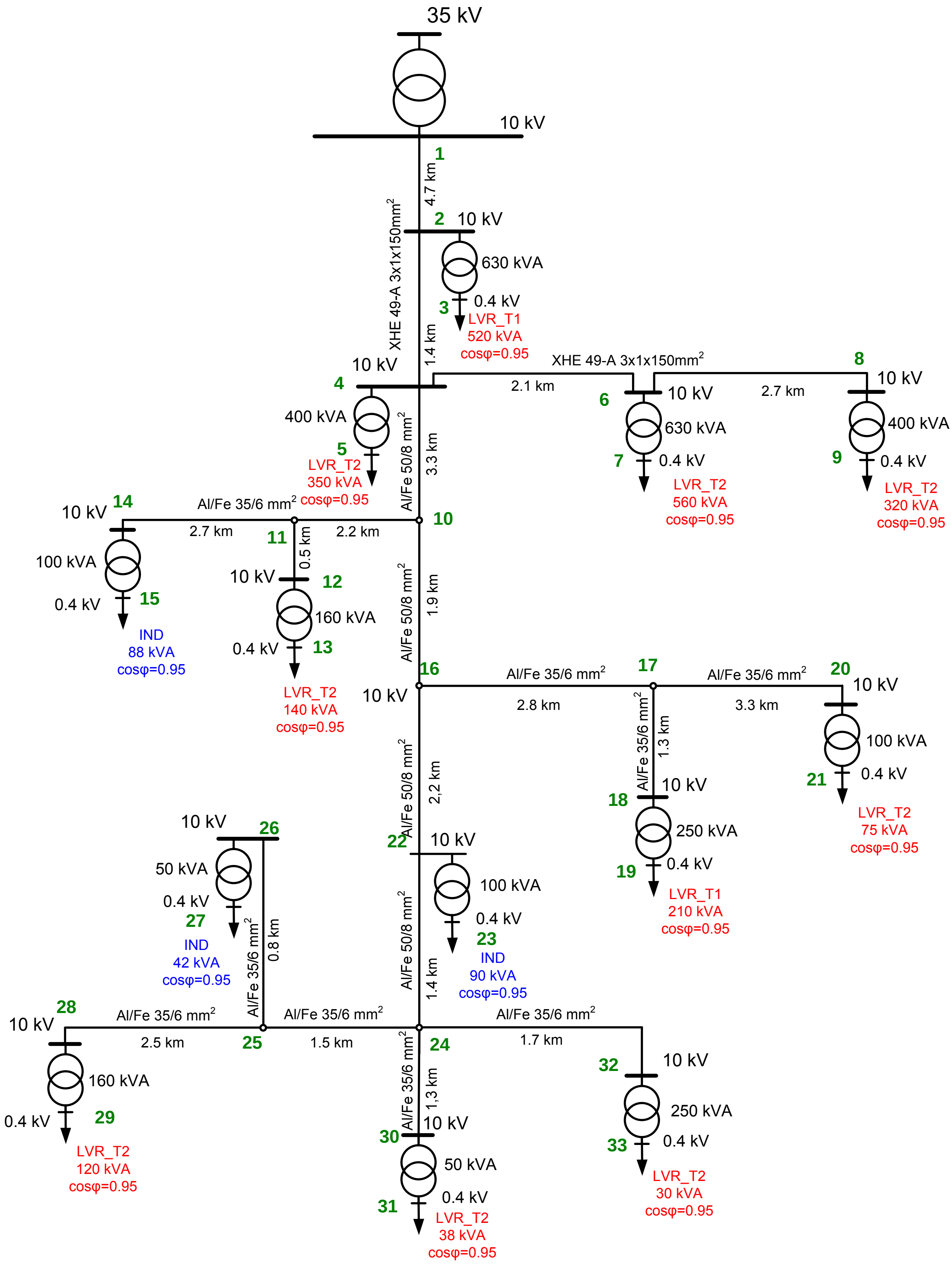


Figure 93 – Typical MV rural network (mix overhead lines and underground cables)

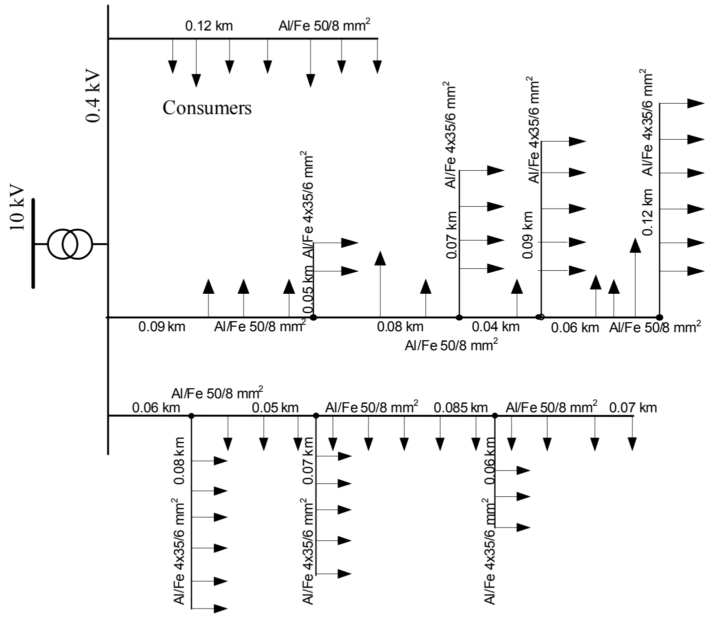


Figure 94 – Typical LV rural network, Macedonia

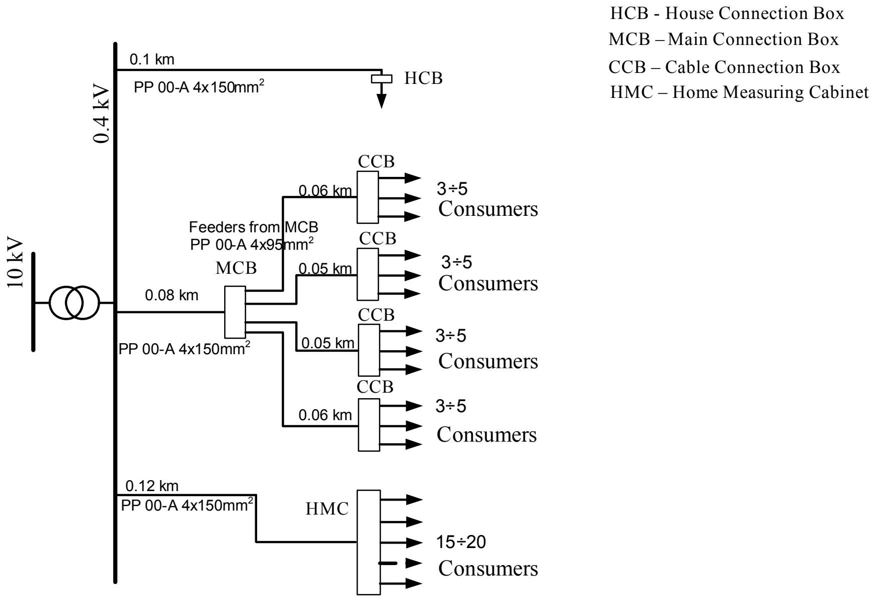


Figure 95 – Typical LV urban network, Macedonia

Transformers

Table A-43 and Table A-44 present data for the most frequently used two and three-winding HV/MV transformers, respectively. Concerning the two-winding transformers, the largest share have the transformers with ratio 35/10 kV, most of which have rated power of 8 MVA. The share of transformers with ratio 110/10.5 kV is quite low, while the share of transformers with ratio 110/35 kV is negligible. Concerning the three-winding transformers, in most of the cases, the tertiary winding of the transformers with ratio 110/10.5/10.5 is used for connection of compensation devices.

Rated power (MVA)	*Rated voltage* (kV)	*Short circuit voltage u_k* (%)	*Copper losses P_{Cu}* (kW)	*Iron losses P_{Fe}* (kW)	*Connection type*
2.5	35/10.5	6	24	3.8	YNd5
4		6	33	5.5	
8		7	54	9.4	
31.5	110/10.5	11	178	30.5	
300	400/115	12.5	700	150	YYd

Table A-43 - HV/MV two-winding transformers technical data, representing most frequent transformer sizes, Macedonia

Rated power $S_1/S_2/S_3$ (MVA)	*Rated voltages* $U_1/U_2/U_3$ (kV)	*Short circuit voltage* $u_{k12}/u_{k13}/u_{k23}$ (%)	*Copper losses* P_{Cu} (kW)	*Iron losses* P_{Fe} (kW)
31.5/31.5/10.5	110/10.5/10.5[1]	11/11/7	178	30.5
20/20/6.67	110/10.5/10.5 110/36.75/10.5	11/11/7	130	22
20/13.4/13.4	110/36.75/10.5	8.5/11/7	90	22
40/40/13.4	110/36.75/10.5	11/11/7	211	36

Table A-44 - HV/MV three-winding transformers technical data, representing most frequent transformer sizes

The following section represents technical data for the **MV/LV** transformers. Transformation ratio 35/0.4 kV is rarely used. The data for the typical representative is shown in Table A-45. Most of the transformers have the transformation ratio 10/0.4 kV. The most frequent types and the share of each type in the distribution network are presented in Table A-46.

Rated power (kVA)	*Rated voltage* (kV)	*Short circuit voltage u_k* (%)	*Copper losses P_{Cu}* (kW)	*Iron losses P_{Fe}* (kW)	*Connection type*
1000	35/0.4	6	11.2	1.95	Yyn0

Table A-45 - MV/LV (35/0.4) transformers technical data, Macedonia

Rated power (kVA)	*Rated voltage* (kV)	*Short circuit voltage u_k* (%)	*Copper losses P_{Cu}* (kW)	*Iron losses P_{Fe}* (kW)	*Share of each type*	*Connection type*
30	10/0.4	4	0.85	0.15	2%	Yzn5
50	10/0.4	4	1.05	0.19	13%	
100	10/0.4	4	1.75	0.32	13%	
160	10/0.4	4	2.35	0.46	11%	
250	10/0.4	4	3.25	0.65	15%	Dyn5
400	10/0.4	4	4.60	0.93	15%	
630	10/0.4	4	6.50	1.30	26%	
1000	10/0.4	4	13.50	1.75	5%	
Other types (from 10 kVA to 2500 kVA)					1%	

Table A-46 - MV/LV (10/0.4) transformers technical data, with share of each type

[1] usually, the tertiary winding of the three winding transformers with ratio 110/10.5/10.5 is used for connection of compensation devices

Transmission and distribution lines

The following section represents the data for the most frequently used HV, MV and LV lines. Table A-47 shows the characteristics of the HV overhead lines. Table A-48 presents the parameters of the MV overhead and underground lines. In the last column, the share of each conductor type in the total length of OHL or UC on each MV level is presented. On 10 kV level, the ratio OHL/UC is about 3.3, on 20 kV level, the same ratio has the value of 2.1 and on 35 kV level, the OHL/UC ratio is 24.8.

Type	***Operating voltage* (kV)**	***Conductor***	***Section* (mm^2)**	***Current limit* (A)**	***Resistance* (ohm/km)**	***Reactance* (ohm/km)**
Overhead lines	400	Aluminum-steel	3x2x490/65	840	0.03	0.32
	110		3x240/40	530	0.119	0.409
	110		3x150/25	400	0.194	0.424

Table A-47 - HV lines parameters, Macedonia

Type	***Operating voltage*(kV)**	***Conductors***	***Section* (mm^2)**	***Current limit* (A)**	***Resistance* (ohm/km)**	***Reactance* (ohm/km)**	***Share* (%)**
Overhead lines	10	Aluminium-steel	25/4	125	1.203	0.38	31.3
			35/6	145	0.835	0.37	26.3
			50/8	170	0.595	0.36	35.6
			With different sections				6.8
	20	Aluminium-steel	35/6	145	0.835	0.39	25.1
			50/8	170	0.595	0.38	37.9
			70/12	235	0.413	0.36	16.7
			With different sections				20.3
	35	Aluminium-steel	50/8	170	0.595	0.40	22.2
			95/15	290	0.306	0.38	59.4
			With different sections				18.4
Under-ground cables	10	Copper, PVC insulation	150	345	0.124	0.105	10
		Copper, paper insulation		325	0.124	0.080	30
		Aluminium, meshed PVC insulation		340	0.206	0.092	16
		Copper with various insulation	With different sections (mostly paper insulated with sections 70 and 120 or Aluminium with PVC insulation with various sections)				44
	20	Aluminium, meshed PVC insulation	120	400	0.253	0.115	35
			150	450	0.206	0.110	43
		Aluminium, meshed PVC or PVC insulation	With different sections (mostly Copper PVC insulated 150)				22
	35	Copper, paper insulation	95	240	0.193	0.138	22
			150	305	0.124	0.130	45
		Copper, meshed PVC	185	440	0.124	0.120	19

Table A-48 - MV lines parameters, Macedonia

Type	*Conductors*	*Section* (mm²)	*Current limit* (A)	*Resistance* (ohm/km)	*Reactance* (ohm/km)
Overhead lines	Aluminium-steel	25/4	125	1.203	0.38
		35/6	145	0.835	0.37
		50/8	170	0.595	0.36
	Aluminium	35	150	0.833	0.33
		70	225	0.437	0.30
Underground cables	Copper, PVC insulation	70	230	0.268	0.082
	Aluminium, PVC insulation	35	125	0.876	0.083
		95	215	0.320	0.082
		120	245	0.253	0.080
		150	275	0.206	0.080

Table A-49 - LV lines parameters, Macedonia

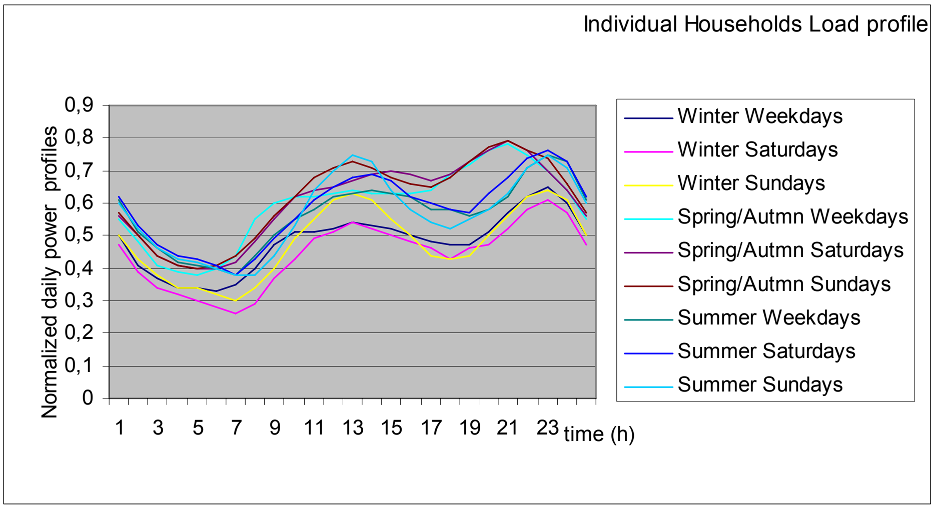
Protection

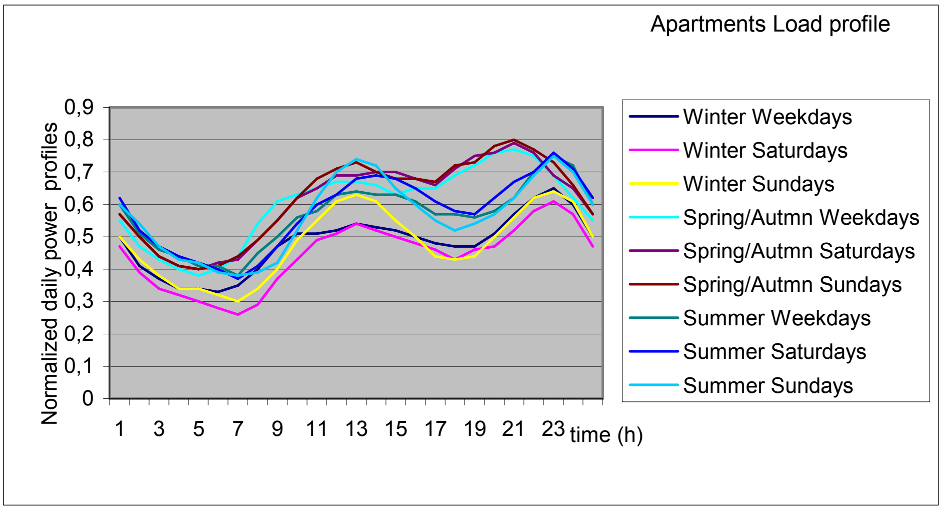
Element	*Rated voltage* (kV)	*Type*
Overhead line	110	distance protection, HV fuses
	35, 10	over-current and earth-fault protection, HV fuses
Transformer	110/35/10	differential and over-current protection, Buchholz protection, thermal protection, HV fuses
	35/10	differential and over-current protection, Buchholz protection, thermal protection, HV fuses
	10/0.4	Buchholz and thermal protection, fuses
Compensation devices (batteries)		over-current protection, over-voltage and under-voltage protection, differential protection

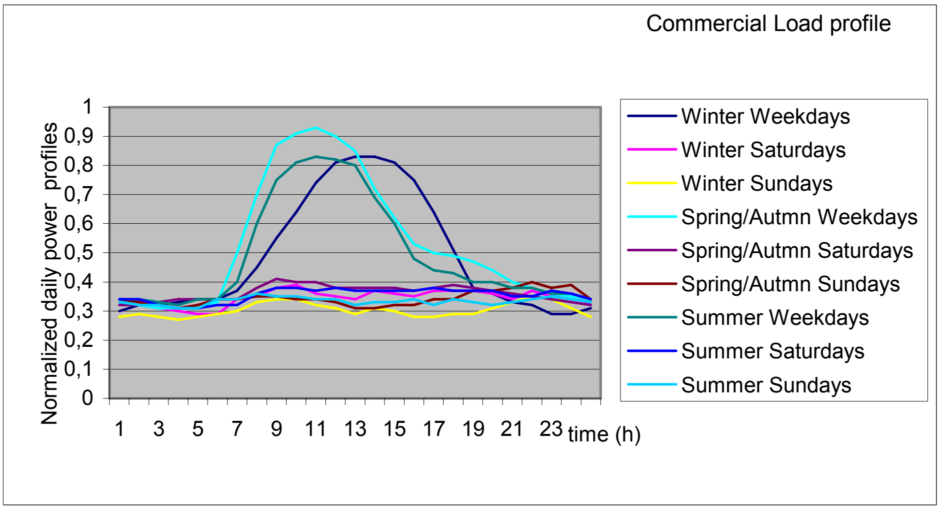
Table A-50 – Overview typical protection units, Macedonia

A 4.8.2 Load Profiles

The load profile for individual house includes electrical heating, while the load **profile for apartments represents typical profile with centralized heating**.







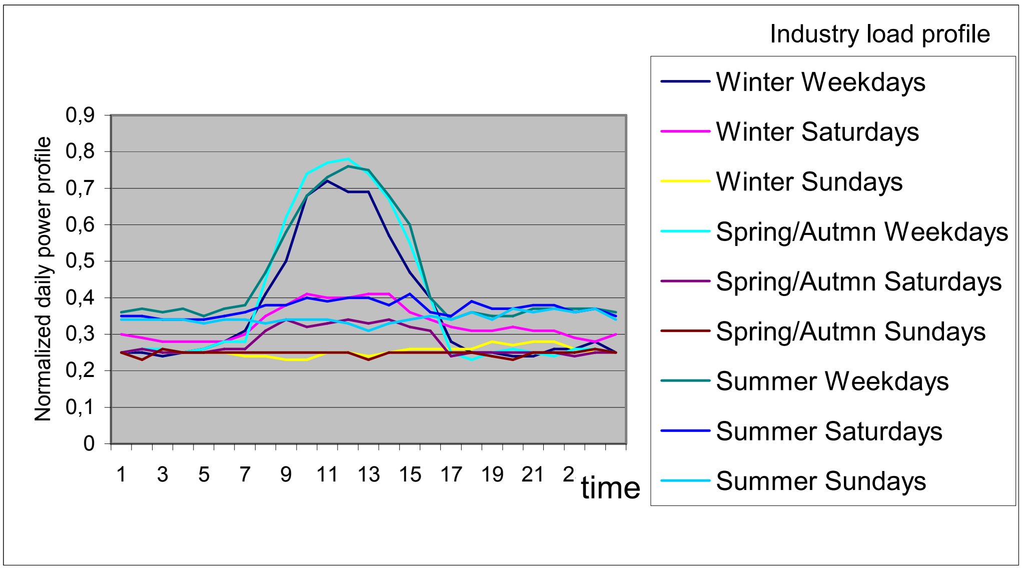


Figure 96 – Normalized daily load profiles, Macedonia

A 4.8.3 Generation Profiles

Electricity production is based on large thermal and hydro power plants. However, there is certain share of small hydro power plants (SHPPs) which comprise the RES in the country. The total installed capacity of all small hydro plants is 40.36 MW. The average yearly production is about 110 GWh. Figure 97 shows the average annual electricity production from all SHPPs for the period 1992 to 2003. Additional 35 MW is planned as the Government has tendered out for concession 60 sites for SHPPs.

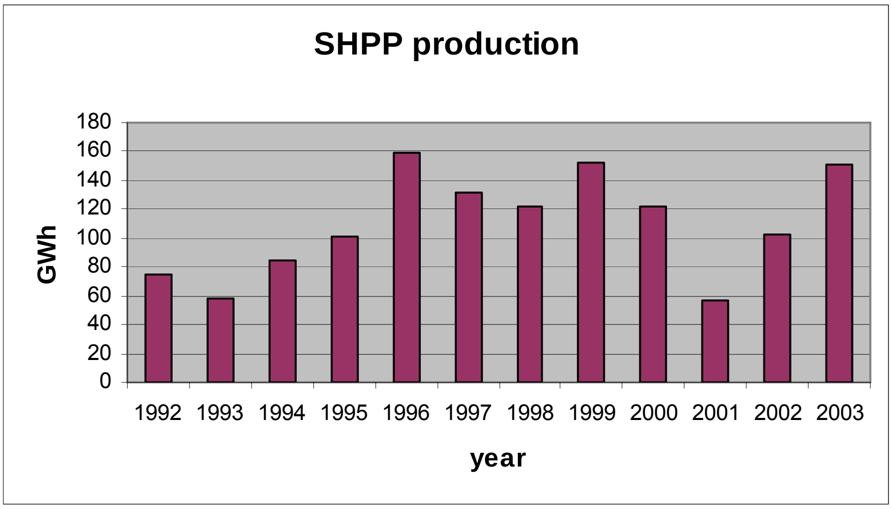


Figure 97 – SHPPs production 1992-2003, Macedonia

The use of solar energy is limited only to solar water heating, although it is estimated that solar energy radiation is among the highest in Europe. There is an ongoing programme aiming to examine sites with best wind energy potential in the country. Only few cogeneration plants exist, all of them function within several industrial facilities and most of them are oil fired.

A 4.8.4 Tariffs

The price of electricity is determined by the Energy Regulatory Commission of the Republic of Macedonia. The tariff rates for high voltage and low voltage users are given in Table A-51 and Table A-52, respectively.

Measure	*Unit*	*Tariff time*	*Tariff costs (EUR) (18% VAT not included)*	
			High voltage users	
			35 kV	**10 kV**
Power	kW		10.42	8.04
Energy	kWh	HT	0.0306	0.0338
		LT	0.0159	0.0166
	kVArh	HT	0.0078	0.0075
		LT	0.0039	0.0046

Table A-51 - Tariffs for high voltage users, Macedonia

Measure	*Unit*	*Tariff time*	*Tariff costs (EUR) (18% VAT not included)*				
			Low voltage users (0.4 kV)				
			Households		*Other consumers*		
			One tariff measurement	Two tariffs measurement	I Tariff degree	II Tariff degree	Public Lightening
Power	kW		(*)	(*)	7.81	(*)	
Energy	kWh	HT	0.0350	0.0436	0.0374	0.0678	0.0582
		LT		0.0218	0.0184		
	kVArh	HT			0.0093	0.0172	
		LT			0.0047		

(*) The power for these consumers is calculated by increasing the consumed active energy (in kWh) for 33.33%

Table A-52 - Tariffs for low voltage users, Macedonia

In 2007 the Energy Regulatory Commission published Rulebooks on the method and procedures for establishing and approving the use of feed-in tariffs for purchase of electricity produced from small hydro power plants, wind power plants and by power facilities using biomass as fuel.

The approved feed-in tariffs for purchasing electricity produced and delivered from small hydro power plants and from power facilities that use biomass as a fuel are presented in Table A-40 and Table A-41, respectively. The feed-in tariff for the sale of electricity produced and delivered from wind power plants is **8.9 €cents/kWh.** All feed-in tariffs do not include VAT.

Group	***Monthly amounts of delivered electricity (kWh)***	***Annual amounts of delivered electricity (kWh)***	***Feed-in tariff (€cents/kWh)***
I	1-85,000	1-1,020,000	12.00
II	85,001-170,000	1-2,040,000	8.00
III	170,001-350,000	2,040,001-4,200,000	6.00
IV	350,001-700,000	4,200,000-8,400,000	5.00
V	over 700,001	over 8,400,001	4.50

Table A-53 - Feed in tariffs for electricity from small hydro power plants, Macedonia

Group	***Installed Power***	***Feed-in tariff (€cents/kWh)***
I	≤500 kW	13.00
II	>500 kW	11.00

Table A-54 - Feed in tariffs for electricity produced by power facilities using biomass as fuel

Group	***Installed Power***	***Feed-in tariff (€cents/kWh)***
I	***≤50 kW***	***46.00***
II	***>50 kW***	***41.00***

Table A-55 - Feed in tariffs for electricity produced by photovoltaics

A 4.8.5 Reliability Indices

At the moment, the total number of unplanned interruptions is not available. Figure 98 presents the ratio of planned and unplanned interruptions and the distribution of the unplanned interruptions within different voltage levels (in %).

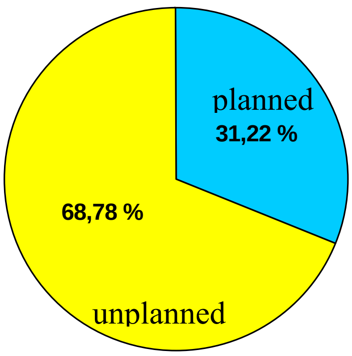
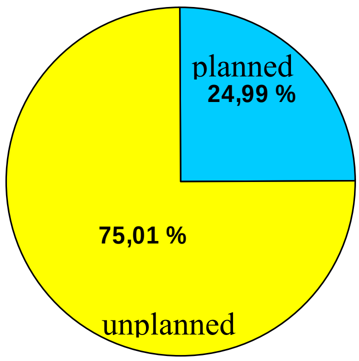
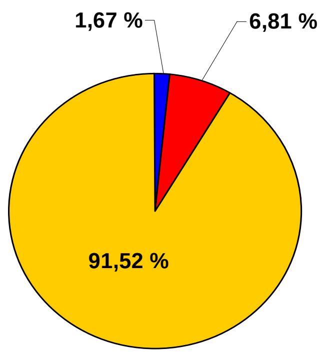
Ratio of planned and unplanned interruptions in the distribution network	Ratio of interruption duration of planned and unplanned interruptions in the distribution network	Distribution of the unplanned interruptions by voltage levels
		 110 kV; 35 kV; 10(20)kV

Figure 98 – Planned and unplanned interruptions, Macedonia

Annex 4.9 United Kingdom

A 4.9.1 Typical Networks

Imperial College has identified typical UK networks, described in the sequel. Further data are also available in WPH.

Urban LV network

A typical urban LV network is shown in Figure 99, corresponding to an area of about 0.25 km^2. Typical network characteristics and loads are described below.

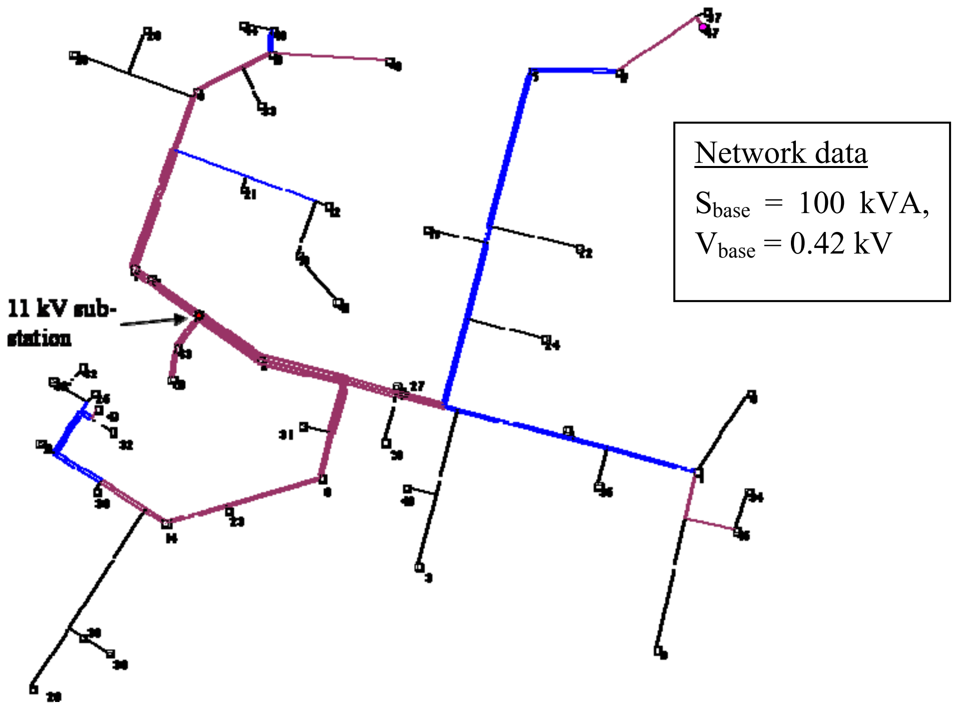


Figure 99 – Typical urban low voltage network in the UK

Sending end	Receiveing end	Cable size (mm^2)	R (p.u.)	X (p.u.)	Capacity (A)	Capacity (kVA)	length (m)
2	54	5x300	0.00069	0.00046	1680	1222	61.26
3	79	95	0.00935	0.00201	220	160	51.57
4	52	35	0.00256	0.00170	110	80	5.21
5	63	2x185	0.00520	0.00217	576	419	111.83
6	1	95	0.01193	0.00257	220	160	65.76
7	59	2x300	0.00024	0.00016	756	550	12.92
8	72	2x300	0.00092	0.00061	756	550	32.37
9	67	2x300	0.00014	0.00009	756	550	4.84
10	55	95	0.01682	0.00362	220	160	92.73
11	56	35	0.00251	0.00166	110	80	5.09
12	60	35	0.00406	0.00270	110	80	8.26
13	58	95	0.00774	0.00166	220	160	42.66
14	64	2x300	0.00127	0.00085	756	550	44.68
15	59	35	0.00098	0.00065	110	80	2.00
16	66	35	0.00625	0.00415	110	80	12.70
17	5	2x185	0.00279	0.00116	576	419	59.94
18	60	95	0.00711	0.00153	220	160	39.19
19	74	2x300	0.00063	0.00042	756	550	22.10
20	76	95	0.00897	0.00193	220	160	49.45
21	62	35	0.00414	0.00275	110	80	8.42
22	63	95	0.01136	0.00244	220	160	62.60
23	64	35	0.00172	0.00114	110	80	3.50

Sending end	Receiveing end	Cable size (mm^2)	R (p.u.)	X (p.u.)	Capacity (A)	Capacity (kVA)	length (m)
24	65	95	0.01015	0.00218	220	160	55.93
25	71	35	0.00415	0.00275	110	80	8.44
26	69	95	0.00753	0.00162	220	160	41.53
27	68	35	0.00098	0.00065	110	80	2.00
28	69	95	0.00599	0.00129	220	160	33.03
29	70	95	0.00623	0.00134	220	160	34.35
30	80	35	0.00631	0.00419	110	80	12.82
31	72	95	0.00391	0.00084	220	160	21.54
32	82	35	0.00851	0.00565	110	80	17.29
33	74	95	0.00531	0.00114	220	160	29.28
34	45	95	0.00520	0.00112	220	160	28.67
35	75	95	0.00488	0.00105	220	160	26.92
36	76	95	0.00189	0.00040	220	160	10.39
37	77	35	0.00371	0.00246	110	80	7.53
38	36	95	0.00388	0.00083	220	160	21.40
39	78	35	0.00360	0.00238	110	80	7.31
40	79	95	0.00390	0.00084	220	160	21.51
41	18	95	0.00766	0.00165	220	160	42.21
42	80	35	0.00958	0.00636	110	80	19.48
43	81	2x300	0.00077	0.00052	756	550	27.26
44	46	95	0.00385	0.00082	220	160	21.20
45	55	300	0.00201	0.00136	420	306	35.54
46	19	2x185	0.00078	0.00032	576	419	16.87
47	77	300	0.00045	0.00030	420	306	7.99
48	19	300	0.00463	0.00312	420	306	81.65
49	82	300	0.00043	0.00029	420	306	7.61
50	43	2x300	0.00063	0.00042	756	550	22.15
51	52	2x185	0.00354	0.00147	576	419	76.18
52	75	2x185	0.00146	0.00061	576	419	31.43
53	51	2x185	0.00045	0.00018	576	419	9.75
54	56	2x300	0.00066	0.00044	756	550	34.82
55	1	300	0.00194	0.00130	420	306	34.18
56	70	2x300	0.00004	0.00002	756	550	2.00
57	7	2x300	0.00164	0.00110	756	550	86.67
58	65	2x185	0.00249	0.00104	576	419	53.60
59	81	2x300	0.00083	0.00056	756	550	44.04
60	62	185	0.00477	0.00199	320	233	51.36
61	14	2x300	0.00047	0.00031	756	550	16.44
62	57	185	0.00497	0.00207	320	233	53.49
63	58	2x185	0.00063	0.00026	576	419	13.48
64	8	2x300	0.00192	0.00129	756	550	67.80
65	53	2x185	0.00294	0.00123	576	419	63.34
66	78	2x185	0.00177	0.00073	576	419	38.00
67	57	2x300	0.00114	0.00077	756	550	40.24
68	53	2x300	0.00056	0.00038	756	550	29.92
69	67	95	0.00861	0.00185	220	160	47.44
70	68	2x300	0.00008	0.00005	756	550	4.15
71	73	185	0.00068	0.00028	320	233	7.34
72	54	2x300	0.00071	0.00048	756	550	37.63
73	66	2x185	0.00158	0.00066	576	419	34.03
74	9	2x300	0.00101	0.00068	756	550	35.56
75	1	2x185	0.00298	0.00124	576	419	64.07

Sending end	Receiveing end	Cable size (mm^2)	R (p.u.)	X (p.u.)	Capacity (A)	Capacity (kVA)	length (m)
76	61	95	0.01769	0.00381	220	160	97.53
77	17	300	0.00380	0.00256	420	306	67.06
78	61	2x300	0.00103	0.00069	756	550	36.31
79	51	95	0.01103	0.00237	220	160	60.83
80	71	95	0.00292	0.00063	220	160	16.11
81	2	5x300	0.00059	0.00039	1680	1222	51.78
82	73	2x185	0.00037	0.00015	576	419	7.99
83	81	Transformer	0.00118	0.00461	-	1000	-

Table A-56 – Typical urban LV network data in the UK

<u>Load data</u>

The load density is about 2.77 MW/km^2.

The customers can be typically classified into 4 types as follows.

Type no.	Type of consumers	Total number	Peak load (kW)
1	Domestic Unrestricted	40	11
2	Domestic Economy 7	4	30
3	Non-Domestic Unrestricted	4	52
4	Non-Domestic Economy 7	2	86

Table A-57 – Typical urban LV customer category in the UK

For simulation purposes, it is possible to allocate the different types of customers as from the table below.

Bus no	Type	Bus no	Type	Bus no	Type	Bus no	Type	Bus no	Type
1	1	11	1	21	1	31	1	41	2
2	1	12	1	22	1	32	1	42	2
3	1	13	1	23	1	33	1	43	2
4	1	14	1	24	1	34	1	44	2
5	1	15	1	25	1	35	1	45	3
6	1	16	1	26	1	36	1	46	3
7	1	17	1	27	1	37	1	47	3
8	1	18	1	28	1	38	1	48	3
9	1	19	1	29	1	39	1	49	4
10	1	20	1	30	1	40	1	50	4

Table A-58 – Allocation of customer typologies in a typical urban LV network in the UK

<u>Network load profile</u>

Power factor can be assumed to be 0.85 p.f. lagging.

Typical electrical loads are given in Figure 100 for wintertime. In summer, they can be modified according to the further load models provided below.

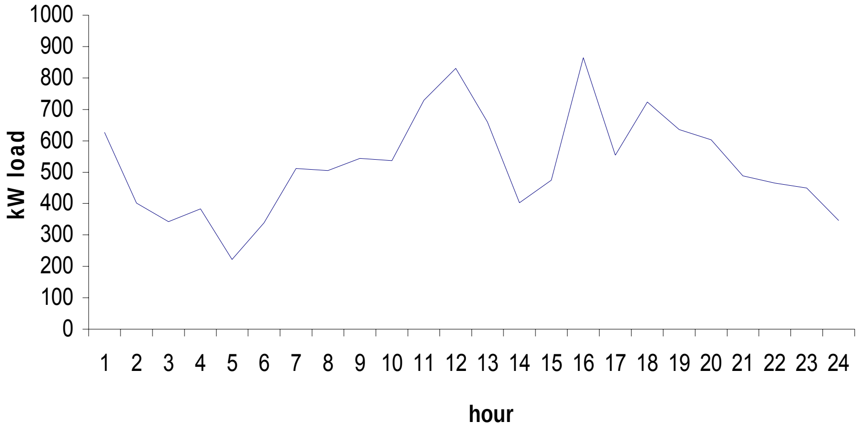


Figure 100 – Typical load profile for the urban LV network in the UK, wintertime

	kW load at hour 1 - 24											
Bus no	1	2	3	4	5	6	7	8	9	10	11	12
1	4.08	0.00	0.00	4.21	3.75	1.87	3.03	8.80	0.00	13.60	0.00	14.73
2	4.16	4.17	5.34	1.88	2.77	4.47	0.63	0.00	6.92	3.73	2.81	5.78
3	0.94	0.72	0.00	6.94	7.55	1.13	1.07	4.76	0.00	3.32	5.63	7.13
4	0.00	0.00	1.67	0.00	5.13	1.31	0.00	3.35	5.08	8.04	5.49	14.10
5	2.89	3.86	0.00	2.01	3.43	0.00	1.80	4.48	0.00	7.28	3.87	8.16
6	6.07	2.20	3.13	0.00	2.22	1.52	2.11	0.00	6.79	0.30	10.45	4.50
7	3.72	5.12	0.56	4.56	4.09	5.07	9.30	2.62	8.59	11.48	5.28	9.59
8	4.55	0.00	2.95	3.81	0.30	7.04	7.56	9.55	12.23	4.09	8.53	11.66
9	1.90	0.00	1.83	3.73	4.71	8.83	0.00	3.06	0.02	0.82	5.26	8.31
10	0.00	0.00	0.00	2.58	0.00	0.00	1.46	10.17	0.00	0.00	8.44	6.60
11	1.20	3.95	6.75	5.78	0.00	4.74	4.83	3.41	9.42	8.12	5.39	2.33
12	5.25	1.00	0.00	0.97	2.13	3.67	0.00	13.56	15.73	7.86	2.14	1.16
13	2.87	5.45	8.04	1.59	0.92	3.88	2.35	5.41	6.01	0.00	9.12	5.14
14	5.46	0.00	3.22	1.02	3.37	0.00	7.30	8.44	2.56	3.03	0.00	6.77
15	0.00	0.00	2.81	0.00	0.00	0.00	4.04	12.95	6.40	5.43	2.38	0.00
16	2.06	2.94	3.91	0.00	0.00	4.92	3.75	20.32	7.71	0.00	4.40	1.98
17	3.83	1.26	3.74	0.83	0.00	6.47	2.30	16.89	0.00	0.00	9.43	1.69
18	8.49	3.97	3.99	0.11	1.22	6.67	4.25	5.98	3.93	14.58	4.15	9.31
19	0.00	0.00	0.00	0.00	6.65	0.00	5.10	10.88	2.42	5.42	5.18	0.00
20	6.14	3.26	2.81	0.77	1.05	0.32	11.79	7.56	2.71	0.00	1.82	17.81
21	0.00	3.67	0.00	6.70	0.00	0.24	5.81	17.69	1.10	5.81	8.25	0.00
22	7.08	9.46	0.00	2.21	0.81	0.00	0.00	0.00	8.07	10.15	18.95	8.36
23	4.49	0.00	0.00	2.84	2.99	2.85	6.80	12.85	10.01	4.09	4.52	5.36
24	0.00	0.73	0.23	3.64	0.99	0.00	6.23	15.79	0.87	2.16	0.00	6.90
25	0.04	0.00	0.00	4.44	2.85	1.22	0.00	8.11	2.52	8.51	4.14	1.82
26	5.31	4.40	1.13	2.11	3.36	5.98	2.82	11.82	17.50	3.43	3.18	13.58
27	0.27	2.03	0.84	6.85	2.99	0.00	6.10	13.21	14.41	6.65	2.47	2.72
28	0.00	0.00	2.17	0.00	5.81	5.98	4.00	9.91	1.77	4.17	0.00	5.50
29	6.96	3.11	6.50	0.24	7.00	0.00	1.06	10.11	9.56	0.00	13.18	5.78
30	0.00	2.28	1.05	3.08	2.46	1.95	0.00	15.27	20.78	4.23	0.00	10.61
31	1.06	0.06	0.00	4.12	0.49	4.45	0.00	0.10	9.37	0.00	0.00	4.92
32	6.23	1.63	3.97	4.22	3.61	0.00	1.71	8.58	8.36	5.48	0.00	9.32
33	0.00	0.69	1.52	0.72	2.35	3.21	0.00	1.07	9.99	2.92	8.93	0.00
34	0.86	0.00	0.00	0.00	0.00	3.32	4.12	9.29	12.37	10.37	11.32	11.74

	kW load at hour 1 - 24											
Bus no	1	2	3	4	5	6	7	8	9	10	11	12
35	6.23	4.66	0.50	5.34	0.00	3.00	5.38	5.47	0.91	10.59	2.61	0.00
36	1.46	0.27	1.68	0.82	3.85	0.96	2.00	0.00	9.23	6.28	12.23	2.81
37	0.00	9.00	2.00	3.84	5.34	7.43	0.00	10.83	5.70	0.56	0.00	2.41
38	7.29	0.77	1.53	3.66	0.00	5.98	0.00	1.72	6.75	0.00	5.53	7.62
39	9.13	0.00	5.92	1.65	0.59	2.36	0.00	7.00	3.72	9.94	5.50	5.51
40	2.07	1.52	2.60	5.73	0.00	0.00	5.00	9.46	11.05	4.79	0.00	5.69
41	38.55	1.02	49.77	50.60	59.39	8.67	26.76	30.33	7.50	0.00	17.90	2.12
42	37.94	0.00	0.00	54.78	0.00	40.45	25.92	5.93	17.49	3.22	6.49	7.86
43	47.41	14.95	8.70	0.00	0.76	29.35	37.67	0.00	15.18	4.02	9.12	7.12
44	20.53	22.66	40.81	30.14	0.00	0.00	40.70	33.06	17.92	0.57	3.07	3.84
45	9.37	26.05	0.34	0.00	11.66	0.00	24.77	27.19	50.63	0.00	17.46	56.25
46	11.16	30.09	0.00	30.02	24.64	0.00	0.00	0.00	0.00	123.38	92.50	155.22
47	22.96	2.52	0.00	33.12	20.13	0.00	5.43	0.00	17.76	80.86	96.30	153.20
48	15.74	0.70	0.00	23.02	0.00	25.56	34.83	23.59	65.99	0.00	31.76	76.53
49	63.69	38.32	129.42	0.00	0.00	0.00	0.00	22.80	90.82	78.78	137.45	47.85
50	237.44	183.56	31.39	58.68	10.76	124.55	191.79	42.10	0.00	49.13	116.97	73.16
Total	626.90	402.03	342.84	383.35	222.13	339.42	511.59	505.44	543.83	537.15	729.60	830.51

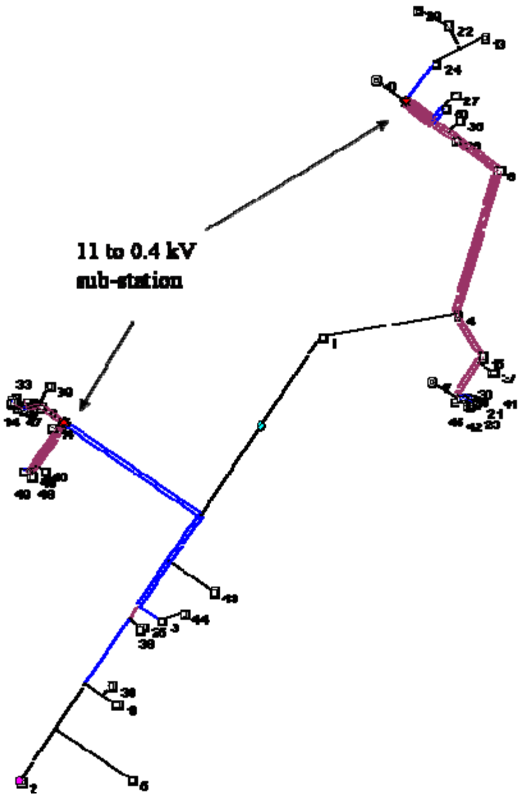
	kW load at hour 1 - 24											
Bus no	13	14	15	16	17	18	19	20	21	22	23	24
1	3.66	2.21	8.77	3.45	15.85	0.00	14.98	11.53	6.35	8.66	5.39	2.46
2	14.89	8.78	3.12	0.00	15.38	20.58	21.53	17.81	14.66	0.00	8.25	2.42
3	5.65	6.25	10.88	7.99	13.95	0.00	11.36	0.00	9.98	19.88	6.73	11.38
4	12.84	1.46	0.00	3.29	9.54	3.13	9.04	9.39	12.22	8.65	11.90	0.79
5	1.06	0.00	0.65	2.49	14.12	6.86	12.84	10.42	8.77	15.06	9.73	0.00
6	11.62	0.29	11.33	12.32	6.50	17.18	9.96	5.35	6.42	5.23	9.82	15.98
7	4.01	0.41	0.54	6.52	1.54	9.07	12.77	7.95	9.88	13.84	13.88	0.96
8	0.00	0.00	10.26	0.46	0.00	5.79	8.44	3.11	2.94	0.76	1.63	14.06
9	3.57	0.00	13.30	3.01	9.43	3.85	18.03	8.00	14.90	0.00	2.50	3.84
10	2.28	0.60	8.84	0.00	13.67	0.28	5.33	11.80	8.74	6.78	4.14	6.45
11	9.45	1.57	11.02	13.59	2.40	10.56	15.16	10.19	6.80	1.80	3.20	7.53
12	3.40	12.45	12.24	3.18	0.85	12.49	10.75	23.42	2.80	15.57	11.41	7.17
13	10.83	11.26	6.50	4.16	11.92	7.05	18.90	6.40	11.48	15.87	5.97	1.97
14	10.61	1.11	4.44	5.88	8.68	14.74	9.75	1.31	7.13	13.02	7.49	2.57
15	5.19	8.64	13.29	3.21	14.39	9.63	20.21	10.27	6.71	4.00	7.01	6.98
16	4.30	11.11	10.82	13.61	4.34	5.42	5.44	8.19	2.09	10.91	0.00	7.24
17	1.18	6.64	2.65	12.16	13.52	4.12	1.79	12.82	8.51	11.34	10.11	9.04
18	9.06	1.68	2.70	11.53	4.15	9.73	5.06	8.22	8.41	0.00	6.65	0.00
19	1.99	5.92	3.25	9.49	7.01	10.06	17.30	17.59	9.14	4.11	7.60	7.31
20	3.96	2.40	2.89	0.05	7.34	12.16	7.02	14.90	8.38	16.86	3.95	12.51
21	5.93	5.56	4.39	11.87	20.77	1.13	14.99	14.48	1.46	10.69	6.11	0.54
22	0.94	12.88	4.42	0.00	1.25	4.25	8.99	5.62	0.00	15.74	8.62	1.84
23	1.29	6.57	14.07	4.82	0.00	9.80	6.70	15.14	5.00	1.86	9.29	4.83
24	4.94	8.85	7.67	12.04	2.34	16.05	24.99	1.78	2.17	11.34	9.67	0.00
25	1.64	4.97	5.71	9.09	7.10	21.73	4.27	10.24	15.76	7.93	0.20	3.23
26	10.66	9.72	7.51	0.30	1.75	20.75	6.30	18.63	9.47	6.58	1.06	4.31
27	0.00	5.05	11.78	0.00	11.10	15.72	16.70	14.39	9.71	19.46	2.53	0.67
28	9.78	1.65	1.05	3.20	9.52	14.80	17.07	9.55	13.53	13.10	8.42	2.58

	kW load at hour 1 - 24											
Bus no	13	14	15	16	17	18	19	20	21	22	23	24
29	8.81	15.26	2.99	1.50	7.01	0.00	7.84	9.10	13.56	10.10	5.75	5.20
30	9.75	7.79	3.91	14.86	12.65	3.06	15.37	15.13	9.31	3.77	0.00	0.28
31	12.33	6.79	4.36	0.00	3.54	9.60	15.27	13.52	6.12	5.16	8.78	6.60
32	14.87	9.26	0.77	0.00	3.43	7.44	7.93	13.23	18.89	0.00	18.47	5.72
33	3.59	8.81	1.44	13.76	0.06	10.72	7.88	8.80	5.25	1.13	10.94	9.23
34	6.84	0.00	0.00	0.00	7.65	5.50	7.51	6.69	4.67	2.40	8.56	0.00
35	5.16	2.98	0.00	18.51	0.33	20.23	3.81	8.54	13.88	12.23	15.27	1.94
36	5.71	0.00	1.32	4.37	12.89	11.17	12.17	10.60	4.40	14.55	12.08	3.49
37	2.66	11.24	1.83	10.67	0.06	16.16	12.65	0.00	11.81	6.71	15.60	9.89
38	2.11	7.16	0.00	9.51	0.00	18.83	12.83	7.62	7.52	6.61	4.52	3.18
39	0.00	3.97	3.94	5.35	13.63	7.34	12.57	14.16	5.28	7.74	4.15	11.75
40	6.84	3.55	2.72	9.16	16.05	2.58	19.21	0.00	2.26	8.80	15.21	0.00
41	2.85	3.93	1.52	10.65	0.00	24.73	16.33	2.87	18.79	5.14	13.78	0.00
42	12.11	6.20	7.05	5.81	19.81	11.32	15.82	9.59	4.29	13.21	17.55	16.16
43	1.61	1.63	12.96	0.00	0.00	10.71	11.75	14.34	6.27	8.15	9.18	5.53
44	5.44	9.70	8.46	2.29	0.00	15.44	11.60	8.90	21.44	10.17	6.56	12.61
45	41.63	14.29	12.24	76.49	88.22	50.65	26.69	13.37	10.26	15.08	15.90	12.55
46	75.21	46.34	9.46	98.42	31.87	0.00	17.91	15.55	19.36	8.54	17.68	0.00
47	88.59	4.98	0.00	94.02	23.44	24.24	12.22	21.03	15.25	13.44	19.07	7.38
48	86.52	5.60	0.00	79.02	23.59	64.21	21.35	52.52	16.82	13.47	16.16	2.36
49	46.98	16.05	0.00	35.84	57.51	65.30	9.26	30.06	35.66	40.12	12.94	44.57
50	66.01	79.25	205.56	216.90	4.05	77.62	21.74	39.16	13.75	0.00	17.58	49.32
Total	660.35	402.81	474.63	864.81	554.19	723.79	635.39	603.28	488.24	465.56	449.02	346.37

Table A-59 – Typical winter load models for 24 hours, urban LV network in the UK

Rural LV network

A typical urban LV network is shown in Figure 101, corresponding to an area of about 4 km^2. Typical network characteristics and loads are described below.



Network data
S_{base} = 100 kVA
V_{base} = 0.42 kV

Figure 101 – Typical rural low voltage network in the UK

Sending end	Receiving end	Cable size (mm^2)	R (p.u.)	X (p.u.)	Capacity (A)	Capacity (kVA)	length (m)
2	52	95	0.02853	0.00615	220	160	157.27
3	51	185	0.00597	0.00249	320	233	64.22
4	1	95	0.06153	0.01326	220	160	339.19
5	52	95	0.04064	0.00876	220	160	224.00
6	55	2x300	0.00207	0.00139	756	550	72.91
7	72	2x185	0.00047	0.00019	576	419	10.11
8	4	2x300	0.00703	0.00474	756	550	371.83
9	7	300	0.00104	0.0007	420	306	18.40
10	54	95	0.0173	0.00373	220	160	95.36
11	9	300	0.00066	0.00044	420	306	11.73
12	75	2x185	0.00009	0.00003	576	419	2.00
13	61	95	0.01147	0.00247	220	160	63.25
14	56	95	0.00411	0.00088	220	160	22.64
15	4	2x300	0.00342	0.00231	756	550	120.74
16	57	35	0.00527	0.0035	110	80	10.72
17	57	95	0.01345	0.0029	220	160	74.15
18	58	2x300	0.00032	0.00021	756	550	11.40
19	60	95	0.00685	0.00147	220	160	37.79
20	62	2x185	0.00045	0.00018	576	419	9.64
21	20	2x185	0.00069	0.00028	576	419	14.80
22	61	95	0.01256	0.0027	220	160	69.22

Sending end	Receiving end	Cable size (mm^2)	R (p.u.)	X (p.u.)	Capacity (A)	Capacity (kVA)	length (m)
23	62	35	0.00098	0.00065	110	80	2.00
24	54	185	0.01139	0.00475	320	233	122.48
25	71	35	0.00098	0.00065	110	80	2.00
26	64	35	0.00137	0.00091	110	80	2.78
27	66	95	0.00732	0.00157	220	160	40.34
28	67	35	0.00587	0.0039	110	80	11.94
29	22	95	0.01539	0.00331	220	160	84.82
30	21	2x185	0.00029	0.00012	576	419	6.29
31	68	95	0.00065	0.00014	220	160	3.57
32	31	35	0.00418	0.00277	110	80	8.49
33	11	35	0.00165	0.00109	110	80	3.36
34	68	35	0.00151	0.001	110	80	3.07
35	69	95	0.00767	0.00165	220	160	42.27
36	60	95	0.00584	0.00126	220	160	32.21
37	70	95	0.00783	0.00168	220	160	43.14
38	71	35	0.00364	0.00241	110	80	7.39
39	6	95	0.00999	0.00215	220	160	55.05
40	73	95	0.00426	0.00091	220	160	23.50
41	30	300	0.00022	0.00015	420	306	3.95
42	41	35	0.00495	0.00328	110	80	10.06
43	74	95	0.02378	0.00512	220	160	131.10
44	3	95	0.01049	0.00226	220	160	57.84
45	41	185	0.00062	0.00026	320	233	6.70
46	12	300	0.00033	0.00022	420	306	5.86
47	72	300	0.00113	0.00076	420	306	19.91
48	75	2x300	0.0003	0.0002	756	550	10.69
49	48	2x185	0.00039	0.00016	576	419	8.45
50	66	2x185	0.00009	0.00003	576	419	2.00
51	74	2x185	0.00619	0.00258	576	419	133.18
52	59	95	0.0242	0.00521	220	160	133.38
53	1	95	0.09644	0.02079	220	160	531.65
54	65	4x300	0.0012	0.00081	1344	978	85.01
55	53	2x185	0.01892	0.0079	576	419	406.97
56	55	2x300	0.00052	0.00035	756	550	27.59
57	58	95	0.00101	0.00021	220	160	5.58
58	70	2x300	0.00267	0.0018	756	550	94.22
59	63	185	0.01807	0.00754	320	233	194.36
60	59	95	0.00916	0.00197	220	160	50.49
61	24	95	0.01285	0.00277	220	160	70.82
62	18	2x185	0.00009	0.00003	576	419	2.00
63	51	300	0.00225	0.00151	420	306	39.60
64	8	2x300	0.00244	0.00164	756	550	129.13
65	69	2x300	0.00087	0.00058	756	550	45.86
66	65	2x185	0.00207	0.00086	576	419	44.54
67	11	185	0.00049	0.0002	320	233	5.31
68	67	95	0.00068	0.00014	220	160	3.77
69	64	2x300	0.00042	0.00028	756	550	22.40
70	15	2x300	0.00056	0.00037	756	550	19.63
71	63	95	0.00593	0.00128	220	160	32.71
72	6	2x300	0.00091	0.00061	756	550	32.16
73	56	2x300	0.00187	0.00126	756	550	98.87
74	53	2x185	0.00641	0.00267	576	419	137.78
75	73	2x300	0.00045	0.0003	756	550	23.82

Sending end	Receiving end	Cable size (mm^2)	R (p.u.)	X (p.u.)	Capacity (A)	Capacity (kVA)	length (m)
76	55	Transformer	0.00274	0.00727	-	630	-
77	54	Transformer	0.00205	0.00911	-	500	-

Table A-60 – Typical rural LV network data in the UK

Load data

The load density is about 0.17 MW/km^2.

The customers can be typically classified into 4 types as follows.

Type no.	Type of consumers	Total number	Peak load (kW)
1	Domestic Unrestricted	40	11
2	Domestic Economy 7	4	30
3	Non-Domestic Unrestricted	4	52
4	Non-Domestic Economy 7	2	86

Table A-61 – Typical rural LV customer category in the UK

For simulation purposes, it is possible to allocate the different types of customers as from the table below.

Bus no	Type	Bus no	Type	Bus no	Type	Bus no	Type	Bus no	Type
1	1	11	1	21	1	31	1	41	2
2	1	12	1	22	1	32	1	42	2
3	1	13	1	23	1	33	1	43	2
4	1	14	1	24	1	34	1	44	2
5	1	15	1	25	1	35	1	45	3
6	1	16	1	26	1	36	1	46	3
7	1	17	1	27	1	37	1	47	3
8	1	18	1	28	1	38	1	48	3
9	1	19	1	29	1	39	1	49	4
10	1	20	1	30	1	40	1	50	4

Table A-62 – Allocation of customer typologies in a typical rural LV network in the UK

Network load profile

Power factor can be assumed to be 0.85 p.f. lagging.

Typical electrical loads are given for wintertime. In summer, they can be modified according to the further load models provided below.

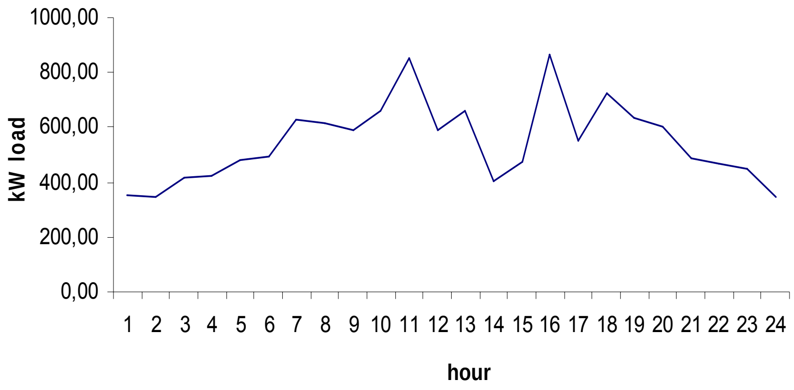


Figure 102 – Typical load profile for the rural LV network in the UK, wintertime

	kW load at hour 1 - 24											
Bus no	1	2	3	4	5	6	7	8	9	10	11	12
1	0.55	5.70	0.58	2.09	0.00	1.81	5.89	9.94	13.16	16.41	2.03	4.62
2	2.74	2.36	3.17	2.65	5.87	6.84	5.45	0.00	11.79	0.00	13.10	10.17
3	0.00	0.00	0.72	0.32	5.81	1.39	11.09	10.62	5.11	6.85	10.24	10.59
4	0.00	4.36	5.64	2.05	0.00	0.00	6.43	9.39	3.19	5.46	16.69	0.72
5	0.59	4.88	1.29	1.96	1.86	0.64	8.67	0.00	5.78	0.00	15.69	7.81
6	3.85	0.54	2.47	1.92	7.93	1.01	5.93	3.24	2.30	4.42	0.06	6.52
7	3.22	0.00	0.00	0.36	0.00	6.23	0.00	0.00	9.60	0.00	9.03	12.66
8	0.00	1.47	1.40	4.46	0.00	3.62	6.27	15.44	7.89	0.00	7.26	12.01
9	5.03	1.64	0.00	0.00	0.59	2.16	8.67	0.32	14.21	5.33	2.37	0.00
10	2.04	1.09	0.00	0.00	1.69	0.00	9.52	0.09	4.90	15.96	16.09	13.99
11	12.30	6.36	1.65	0.00	1.10	3.50	4.59	16.95	1.30	2.47	2.61	6.52
12	9.60	0.00	0.00	4.62	0.00	0.00	0.00	9.60	7.41	6.18	8.53	7.16
13	5.20	2.56	6.53	1.92	0.00	6.63	1.27	20.03	7.43	0.00	1.93	6.87
14	1.93	3.00	4.14	2.01	0.00	0.00	2.57	0.00	7.36	9.06	9.78	11.92
15	4.79	7.45	1.82	4.19	2.40	0.00	0.00	20.91	8.75	12.89	9.95	9.91
16	0.94	2.62	0.49	0.00	0.00	2.76	10.20	8.57	2.19	12.79	0.00	0.38
17	5.18	1.48	3.43	4.36	6.13	0.00	4.84	10.47	6.17	0.00	7.87	2.62
18	3.57	4.50	1.72	5.68	2.94	1.66	7.65	15.27	4.82	9.92	4.18	8.22
19	7.96	2.65	1.02	2.75	3.78	4.46	0.00	0.00	9.80	11.09	9.49	1.98
20	0.00	4.74	2.40	1.36	2.02	6.59	9.32	0.00	10.68	9.08	3.86	5.15
21	8.47	0.00	5.42	3.93	2.88	4.75	7.96	14.44	9.69	6.17	1.01	9.14
22	2.76	0.00	0.00	2.88	2.73	1.54	2.47	12.91	4.54	4.48	11.72	13.22
23	0.00	3.53	4.66	4.98	7.42	0.58	6.35	8.97	6.01	8.59	8.75	3.15
24	2.88	0.00	0.00	0.00	0.00	0.00	0.00	14.54	7.58	4.03	4.48	0.00
25	7.93	4.98	1.81	1.96	5.01	4.97	0.00	3.65	3.17	6.94	15.91	5.09
26	0.00	7.58	0.00	3.14	0.00	2.15	5.28	8.05	5.57	7.85	0.00	4.65
27	0.00	3.08	0.00	0.00	5.19	2.15	14.47	9.20	12.44	0.00	10.14	11.45
28	6.94	0.50	0.37	0.82	2.84	5.51	8.59	1.87	3.86	3.43	3.64	9.32
29	2.17	5.26	7.50	1.23	0.00	0.00	6.12	9.12	6.21	8.28	7.41	1.31
30	5.92	0.00	1.51	0.00	0.00	0.00	4.61	12.63	7.14	10.90	0.00	9.05
31	7.04	1.88	2.72	0.00	4.92	0.00	0.00	3.02	7.26	9.01	1.92	5.29
32	0.00	1.72	2.32	0.00	5.06	0.00	0.94	5.88	5.60	4.75	13.23	14.57
33	1.71	1.19	4.60	5.51	1.13	8.18	1.46	4.34	24.73	7.13	16.85	13.35
34	0.00	5.39	5.33	0.93	5.69	4.51	13.02	2.82	2.99	1.54	10.30	6.50
35	2.56	1.60	0.63	5.56	0.00	0.56	7.87	4.87	4.56	6.45	2.87	6.01
36	5.25	1.01	0.00	0.00	7.62	2.95	7.78	0.00	11.64	7.54	8.77	15.82
37	2.81	5.05	0.00	0.00	7.76	5.45	9.73	15.47	10.62	3.93	0.71	0.00
38	0.44	2.76	0.00	4.47	1.32	8.87	2.26	0.79	8.95	6.29	4.34	10.26

	kW load at hour 1 - 24											
Bus no	1	2	3	4	5	6	7	8	9	10	11	12
39	4.22	5.26	2.16	0.00	0.00	0.00	0.00	0.00	8.99	9.81	3.66	7.20
40	2.86	4.86	0.89	3.73	0.61	2.06	3.62	13.41	5.43	16.62	0.00	9.76
41	29.06	18.37	11.43	67.76	31.83	2.29	18.28	23.11	12.50	9.99	0.00	0.24
42	31.41	33.45	0.00	49.53	58.73	0.00	0.00	21.35	8.50	7.04	0.00	0.00
43	30.32	31.41	47.35	34.44	20.69	0.00	41.91	41.90	8.80	11.37	9.68	10.45
44	18.92	69.46	73.96	22.31	15.41	14.47	18.76	10.75	4.06	5.65	11.37	5.61
45	6.16	4.59	19.16	18.26	16.95	11.01	30.17	19.70	83.48	40.49	56.47	46.96
46	0.00	24.81	20.71	25.19	21.38	10.90	10.77	30.56	7.88	129.07	150.64	46.25
47	0.00	27.19	21.81	23.34	7.69	19.53	0.00	47.28	67.01	120.95	85.44	28.91
48	5.93	0.00	19.40	1.21	7.35	28.51	27.62	0.00	20.55	0.00	74.26	38.55
49	0.00	0.00	5.94	33.41	81.30	125.68	144.79	71.51	5.36	3.75	103.12	0.69
50	98.66	22.85	116.66	66.09	119.50	177.37	125.17	53.51	69.65	67.31	86.09	117.00
Total	353.91	345.20	414.80	423.39	483.14	493.30	628.38	616.49	588.61	657.23	853.54	589.62

	kW load at hour 1 - 24											
Bus no	13	14	15	16	17	18	19	20	21	22	23	24
1	8.98	0.55	0.33	1.15	4.83	20.10	1.46	13.62	5.72	18.36	13.10	7.11
2	16.06	9.58	4.80	12.53	5.11	23.19	6.40	7.78	3.89	11.23	9.67	8.63
3	13.36	1.72	9.26	6.87	15.50	12.47	13.43	16.18	11.71	17.52	1.81	4.15
4	4.55	5.44	1.31	12.11	12.39	16.01	17.47	3.59	6.25	4.48	15.90	9.10
5	8.93	13.56	2.27	14.28	10.37	10.25	15.05	30.28	19.06	13.76	9.97	7.70
6	2.68	3.70	11.28	15.79	13.51	8.91	1.78	9.51	12.43	5.13	1.98	8.32
7	8.78	7.17	0.00	3.96	5.51	0.00	9.87	18.64	16.51	15.48	13.67	9.59
8	0.00	6.06	9.98	3.12	17.01	3.45	6.59	19.63	30.30	10.94	7.68	13.08
9	7.29	19.81	11.68	12.11	0.00	19.74	10.32	21.74	8.02	13.17	14.85	8.68
10	6.08	0.00	5.13	7.36	9.10	3.38	16.63	19.98	8.43	9.80	5.22	7.25
11	7.96	5.74	6.09	17.15	11.27	16.01	15.80	16.73	9.07	5.38	14.99	5.37
12	12.92	2.93	0.00	4.85	16.83	16.39	23.32	18.39	0.54	5.77	9.63	9.87
13	3.68	5.16	6.11	0.82	4.97	9.27	3.38	10.51	15.00	19.05	8.38	12.49
14	0.68	8.71	5.35	9.68	4.90	17.47	11.35	0.00	8.81	0.00	8.17	4.25
15	0.00	0.85	0.00	4.07	6.39	20.85	7.47	9.33	11.69	10.82	0.00	8.89
16	13.65	16.67	1.46	0.64	14.22	17.28	11.22	17.17	5.11	2.95	4.55	5.31
17	10.62	10.96	13.78	4.16	0.00	17.52	15.53	19.46	17.85	10.63	0.00	6.06
18	10.69	6.11	0.00	5.93	13.28	17.95	7.28	17.16	6.31	12.92	3.95	10.14
19	5.87	6.95	5.36	7.90	15.21	16.22	12.45	9.93	9.91	22.28	11.72	12.41
20	9.09	7.30	11.14	0.00	0.00	11.09	18.90	11.43	9.51	6.93	5.12	6.39
21	11.07	8.83	11.96	7.08	20.45	24.95	1.70	7.38	21.58	18.64	10.91	13.68
22	3.00	4.73	7.53	4.66	11.41	0.00	10.06	2.37	13.29	8.30	18.32	6.79
23	0.95	7.36	6.64	6.10	9.49	20.71	16.84	0.00	3.57	1.77	7.88	6.48
24	13.29	0.00	9.47	0.00	21.36	11.58	21.26	13.83	17.47	5.36	7.09	1.24
25	11.79	5.49	0.00	1.28	9.36	5.96	3.37	13.24	5.93	14.13	0.00	8.74
26	8.88	8.72	0.53	4.37	4.56	4.95	7.65	17.19	15.32	1.82	5.20	11.00
27	6.50	4.81	0.00	10.26	14.14	18.97	17.66	0.00	16.97	0.00	10.88	1.42
28	17.83	3.72	0.98	7.48	12.02	7.21	3.54	6.75	11.44	2.10	14.63	9.58
29	0.00	0.00	13.89	14.60	15.32	14.36	9.86	1.78	15.97	2.99	10.95	11.37
30	5.05	3.01	6.09	10.94	0.00	0.10	12.15	15.11	10.39	8.40	12.85	7.14
31	5.67	10.46	0.00	0.00	5.05	11.22	11.06	10.22	17.98	12.47	15.24	13.61
32	10.80	2.59	7.38	3.19	0.00	12.53	6.22	10.82	13.59	8.24	11.87	0.00
33	5.17	16.60	4.42	0.00	14.56	31.72	6.79	6.16	10.22	13.41	2.43	3.07
34	11.70	9.33	0.00	4.73	5.02	27.76	5.43	9.60	13.81	5.21	3.81	9.25

	kW load at hour 1 - 24											
Bus no	13	14	15	16	17	18	19	20	21	22	23	24
35	10.98	9.04	0.30	0.21	22.75	15.87	10.53	1.01	5.37	11.18	1.05	0.00
36	17.88	0.00	8.08	7.71	19.74	9.06	14.09	12.12	12.75	6.31	8.47	6.03
37	2.08	1.95	4.64	0.00	0.42	4.18	5.30	24.52	3.60	11.10	7.65	6.86
38	8.79	2.09	6.72	8.21	14.54	0.13	12.06	3.96	7.16	13.95	2.63	9.40
39	12.55	0.00	8.80	7.09	11.86	14.68	15.37	8.43	10.78	8.38	12.40	0.00
40	0.00	0.00	4.88	2.34	2.10	5.68	19.27	3.44	17.17	4.31	9.32	12.74
41	0.32	6.26	5.46	0.00	6.23	16.89	11.85	0.00	6.79	7.05	6.33	4.36
42	8.30	6.62	9.32	0.43	16.69	24.40	16.99	0.00	7.84	6.41	2.45	0.00
43	6.39	0.97	12.14	7.30	1.33	10.19	4.87	22.54	0.00	5.72	0.00	0.00
44	2.15	12.04	14.87	19.62	15.52	11.13	20.42	0.00	7.83	11.53	8.73	7.02
45	0.00	8.91	65.74	0.00	42.25	47.60	5.90	5.56	12.99	11.38	6.97	6.26
46	57.83	135.18	49.81	44.61	91.19	34.96	16.83	30.08	30.86	15.14	0.00	18.90
47	10.20	19.12	67.41	84.93	89.60	17.50	48.41	0.00	42.73	25.53	19.37	18.84
48	111.36	44.86	105.83	0.00	55.12	5.31	44.40	20.32	19.88	10.02	4.92	10.73
49	137.79	173.82	152.54	130.38	55.19	83.22	42.22	40.94	24.28	41.95	89.52	2.01
50	0.00	146.75	112.40	104.90	51.19	103.70	81.56	0.00	14.49	32.58	30.79	63.43
Total	660.35	402.81	474.63	864.81	554.19	723.79	635.39	603.28	488.24	465.56	449.02	346.37

Table A-63 – Typical winter load models for 24 hours, rural LV network in the UK

Urban MV network

The topology of a typical underground urban network in the UK is strongly radial with conventional 132/33 kV and 33/11 kV transformation. Such a network is typically characterized by short circuit length, high customer density, and an overall large area.

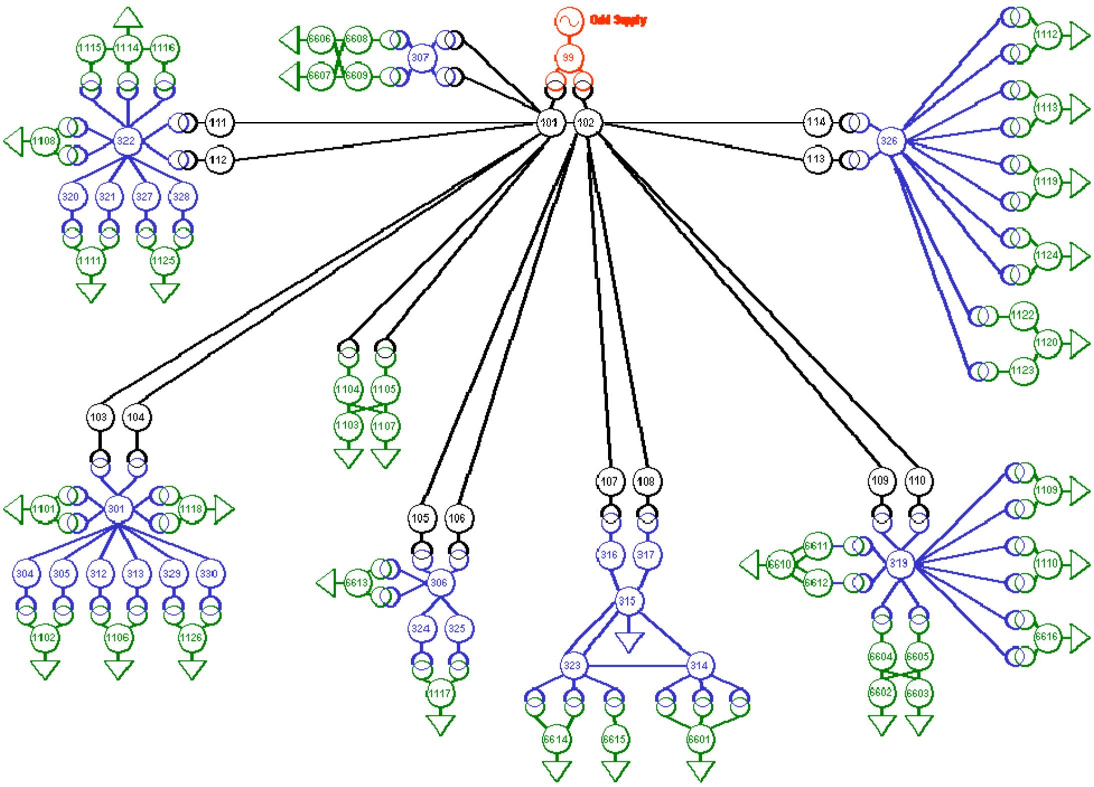


Figure 103 – Typical urban radial MV network in the UK

Rural MV network

The model of a typical UK 33 kV overhead rural network fed from a 132 kV supply point is presented below. The topology is radial, with long lines, low customer density, and small overall size.

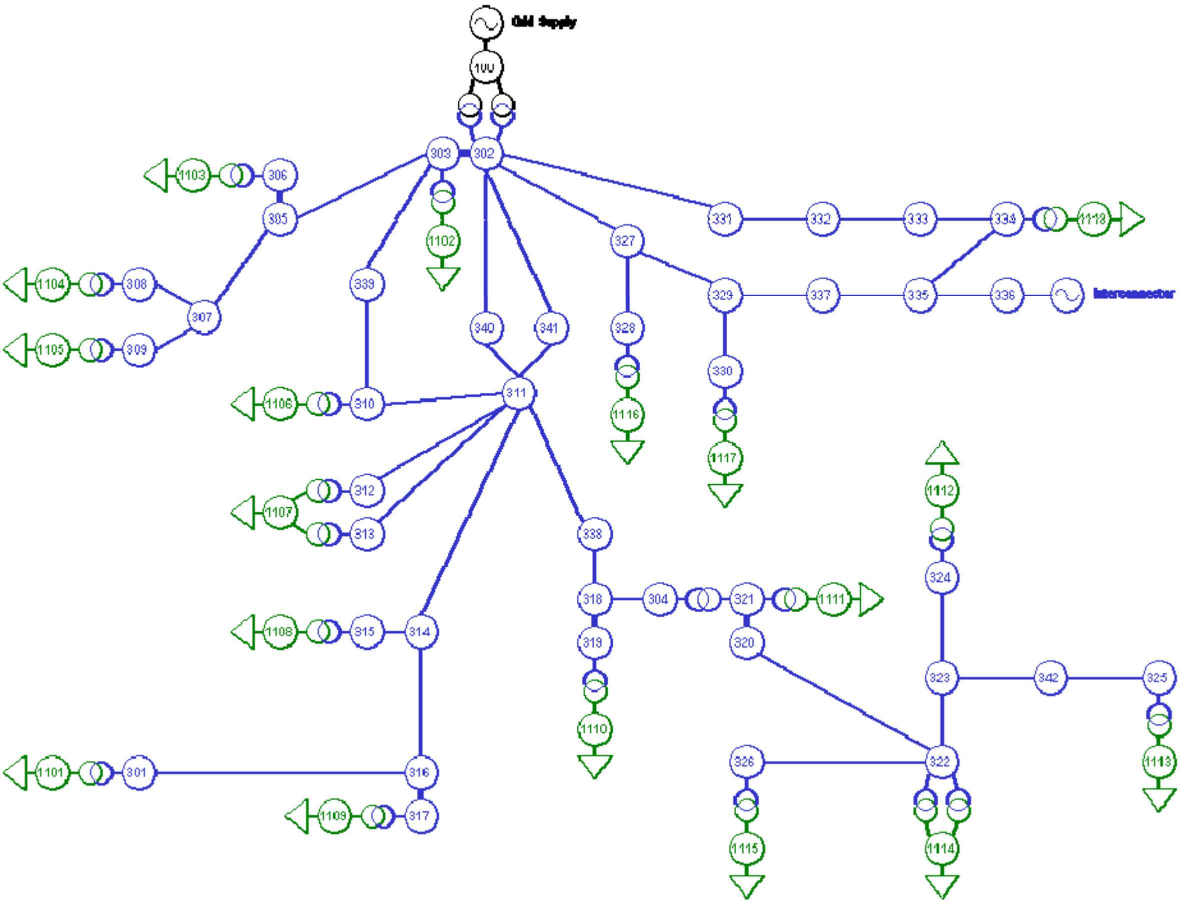


Figure 104 – Typical rural radial MV network in the UK

A 4.9.2 Typical Equipment data

Typical equipment data (transformers, and HV, MV, and LV circuits) are provided below with reference to average characteristics it is possible to encounter in UK networks and according to the models developed in WPH.

Voltage level	Number × capacity of transformers			
	Model 1	Model 2	Model 3	Model 4
11kV/0.4kV	200 x 100kVA	250 x 250kVA	250 x 250kVA	250 x 630kVA
33kV/11kV	12 x 2 x 7.5MVA	12 x 2 x 17.5MVA		
132kV/33kV	4 x 2 x 66MVA			
GSP substation	1 × 2 × 240MVA			

Table A-64 – Typical number and capacity of transformers at different voltage levels, UK

0.4kV Module	Circuit	Type	Size (mm²)		Length(km)		% of load		Load distribution[1]	
			Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Module 1	Circuit 1	UG	50	70/50	0.5	0.1	25	40	L.I.	U.D.
	Circuit 2	UG	185/95	95/50	1	0.4	75	60	U.D.	U.D.
Module 2	Circuit 1	UG	95	185/95	0.5	0.1	25	45	L.I.	U.D.
	Circuit 2	UG	300	300/95	1	0.4	75	55	U.D.	U.D.
Module 3	Circuit 1	UG	50	50	0.5	0.1	10	15	L.I.	U.D.
	Circuit 2	UG	185/95	95/50	1	0.4	20	20	U.D.	U.D.
	Circuit 3	UG	185/95	185/50	0.5	0.1	30	30	L.I.	U.D.
	Circuit 4	UG	300/95	185/95	1	0.4	40	35	U.D.	U.D.
Module 4	Circuit 1	UG	185/50	185/70	0.5	0.1	10	15	L.I.	U.D.
	Circuit 2	UG	300/95	300/95	1	0.4	20	20	U.D.	U.D.
	Circuit 3	UG	300/95	300/95	0.5	0.1	30	30	L.I.	U.D.
	Circuit 4	UG	300	185/95	1	0.4	40	35	U.D.	U.D.

[1] U.D. Uniformly Distributed, L.I. Linearly Increasing

Table A-65 – Typical circuit parameters for LV (0.4 kV) networks, UK

11kV module	Circuit	Type		Size(mm²)		Length(km)		% of load		Load distribution	
		Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban	Rural	Urban
Module 1	Circuit 1	OH	UG	50	70/50	40	5	5	14	L.I.	U.D.
	Circuit 2	OH	UG	300/95[2]	50	40	5	20	11	L.I.	U.D.
	Circuit 3	OH	UG	50	70/50	30	5	5	14	U.D.	U.D.
	Circuit 4	OH	UG	300/95	50	30	5	20	11	U.D.	U.D.
	Circuit 5	OH	UG	50	70/50	15	2.5	5	14	L.I.	U.D.
	Circuit 6	OH	UG	300/50	50	15	2.5	20	11	U.D.	U.D.
	Circuit 7	OH	UG	50	70/50	10	2.5	5	14	U.D.	U.D.
	Circuit 8	OH	UG	300/50	50	10	2.5	20	11	L.I.	U.D.
Module 2	Circuit 1	OH	UG	95/50	185/50	40	5	5	14	U.D.	U.D.
	Circuit 2	OH	UG	300	185/50	40	5	20	11	U.D.	U.D.
	Circuit 3	OH	UG	95/50	185/50	30	5	5	14	L.I.	U.D.
	Circuit 4	OH	UG	300/95	185/50	30	5	20	11	U.D.	U.D.
	Circuit 5	OH	UG	95/50	185/50	15	2.5	5	14	L.I.	U.D.
	Circuit 6	OH	UG	300/95	185/50	15	2.5	20	11	L.I.	U.D.
	Circuit 7	OH	UG	95/50	185/50	10	2.5	5	14	U.D.	U.D.
	Circuit 8	OH	UG	300/50	185/50	10	2.5	20	11	U.D.	U.D.

Table A-66 – Typical circuit parameters for MV (11 kV, "HV") networks, UK

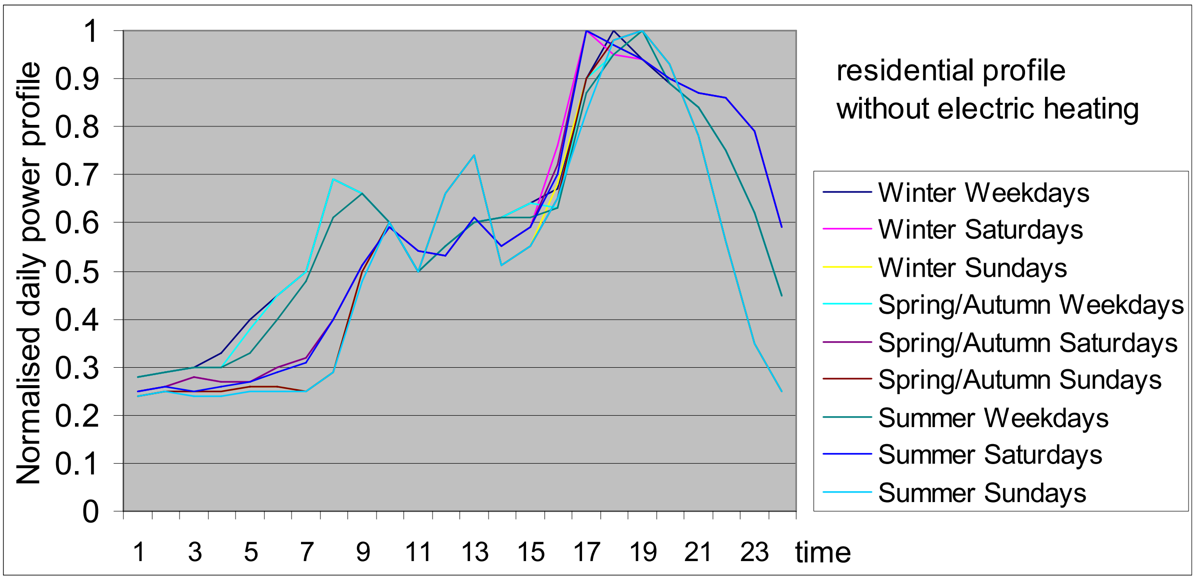
33kV Module	Type	Size(mm^2)		Length(km)	
		Rural	Urban	Rural	Urban
Circuit 1	OH	300	300/185	20	7
Circuit 2	OH	185	185	20	7
Circuit 3	OH	300	300/185	14	5
Circuit 4	OH	185	185^2	14	5
Circuit 5	OH	300	185	8	3
Circuit 6	OH	185	185	8	3

Table A-67 – Typical circuit parameters for MV (33 kV, "EHV") networks, UK

132kV Module	Type	Size(mm^2)		Length (km)	
		Rural	Urban	Rural	Urban
Circuit 1	OH	300	300	17	5
Circuit 2	OH	300	300	17	5
Circuit 3	OH	300	300	17	5
Circuit 4	OH	300	300	17	5

Table A-68 – Typical circuit parameters for HV (132 kV) networks, UK

A 4.9.3 Typical Load Scenarios



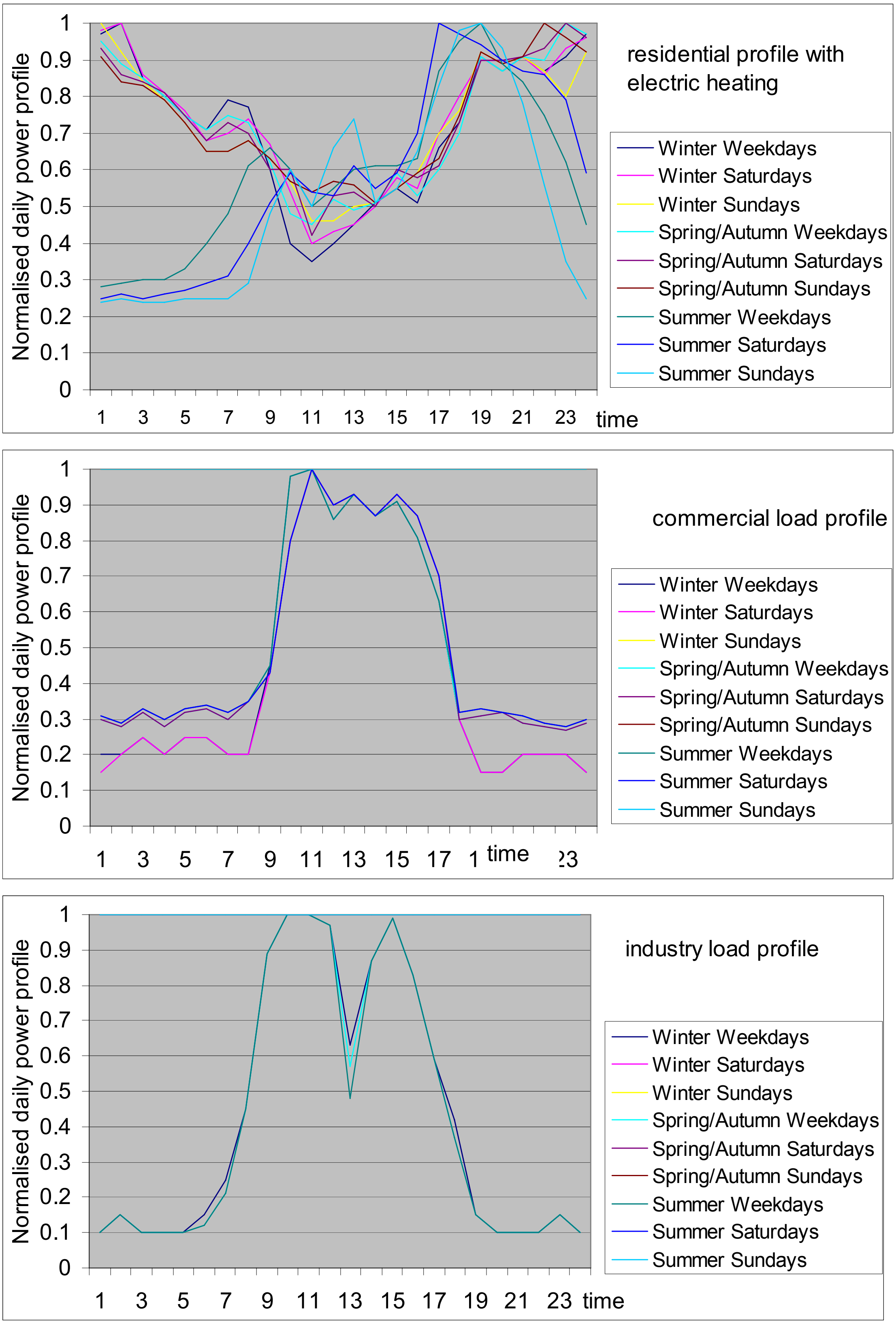


Figure 105 – Normalised daily load profiles, UK

A 4.9.4 Generation Scenarios

For network simulation purposes, typical micro-CHP generation in UK can be assumed to follow a daily profile identical for winter and intermediate seasons, and for week and weekend days (Figure 106). The CHP unit is switched off in the summertime. A typical PV generation profile is also provided. Further generation models for UK are discussed in WPH.

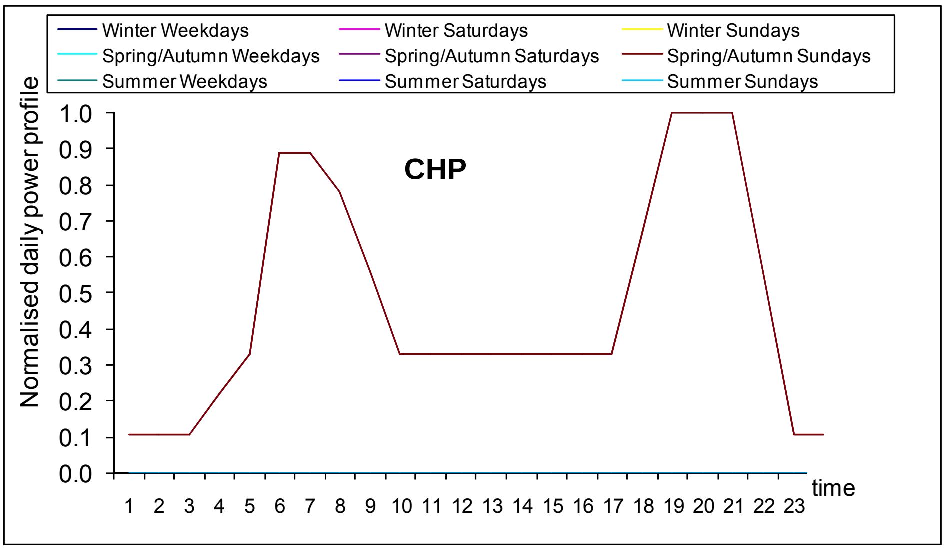


Figure 106 – Typical Daily micro-CHP Generation Diagram, UK

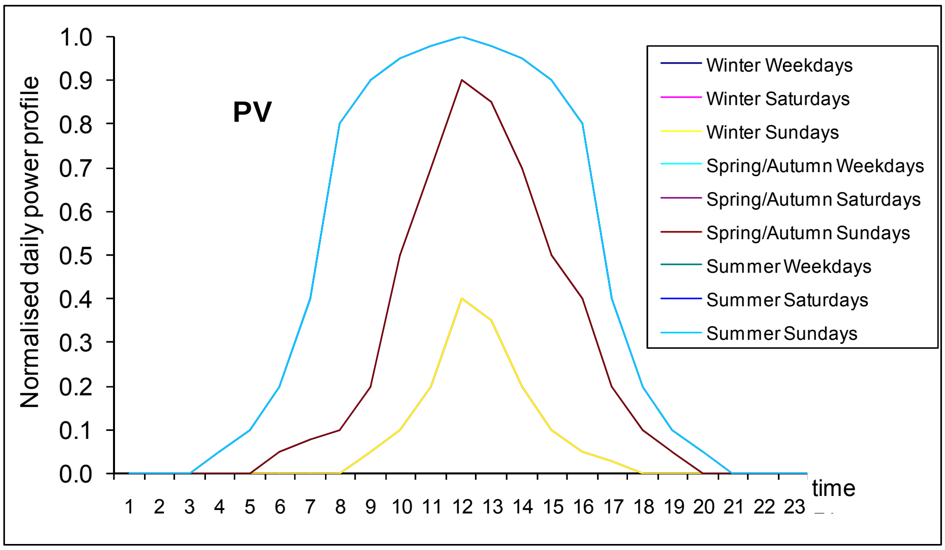


Figure 107 – Typical Daily PV Generation Diagram, UK

A 4.9.5 Reliability information

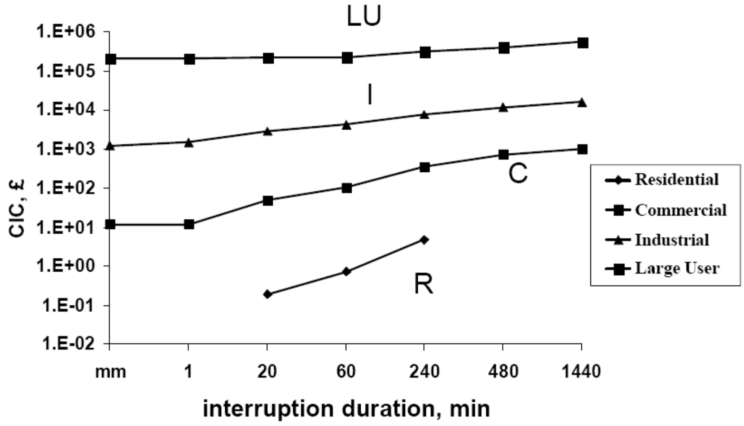


Figure 108 – Customer interruption costs, UK

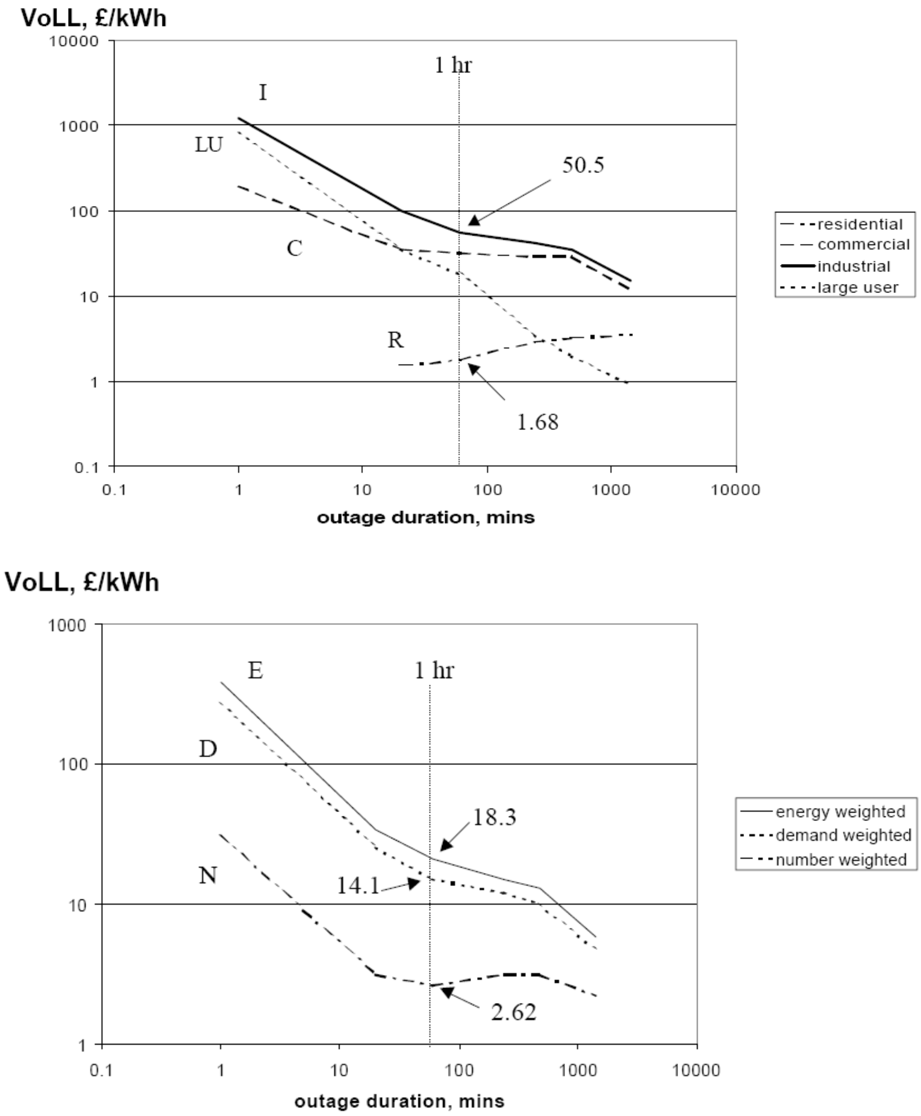


Figure 109 – VoLL Curves, UK

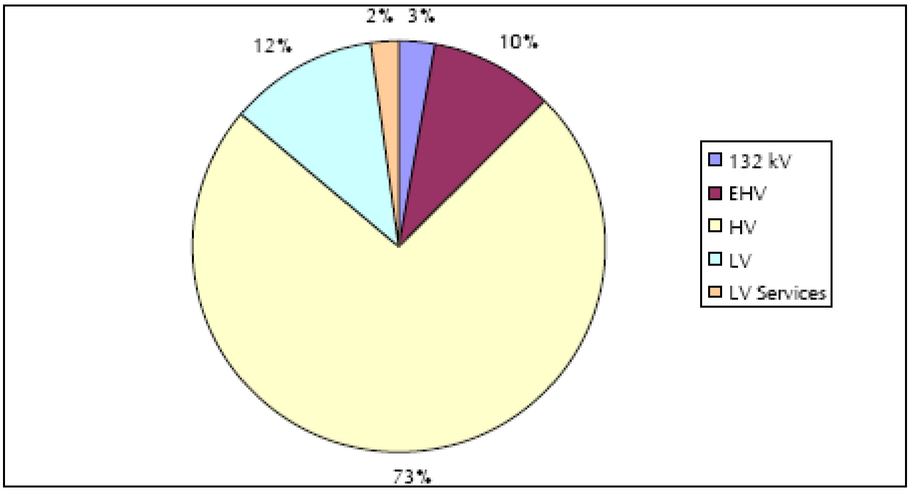


Figure 110 – Proportion of customer interruptions by voltage, UK

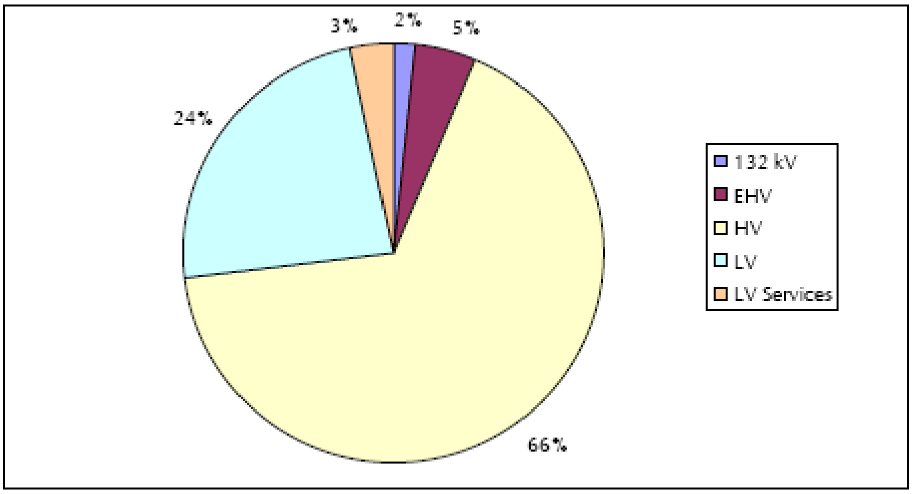


Figure 111 – Proportion of customer minutes lost by voltage, UK

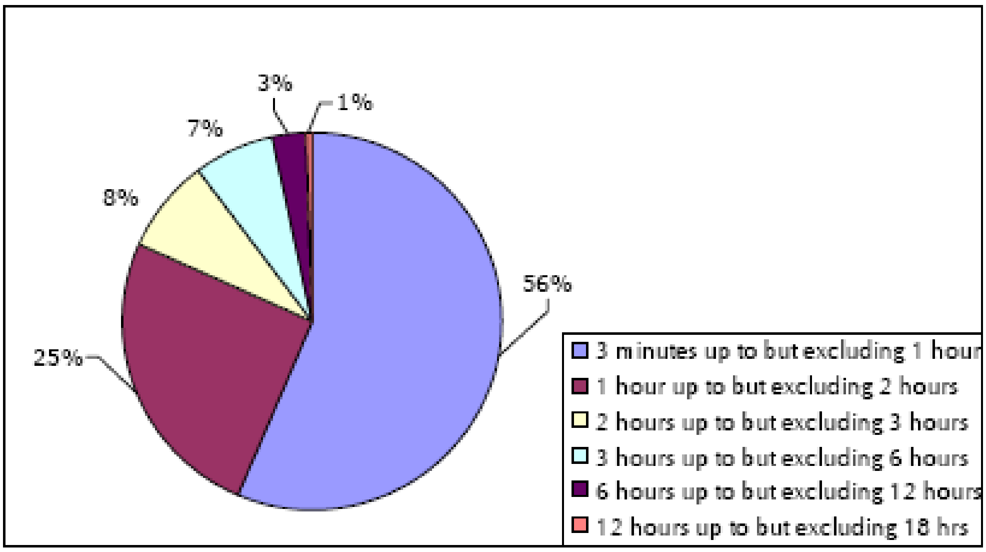


Figure 112 – Interruption breakdown by duration band, UK

Annex 5 Electricity statistics in Europe

The content of this annex is based on statistics provided by Eurostat.

Average energy dependency of final consumption (Figure 113) strongly varies all over Europe, with a surplus in Denmark up to a dependency of 87 % in Italy. Thus, it is one aim of a Microgrid operation to increase the share of renewable energy sources that currently differs between 3 % and 78 %. Figure 114 demonstrates the electricity generated from renewable sources - from hydro plants (excluding pumping), wind, solar, geothermal and electricity from biomass/wastes - in % of gross national electricity consumption, forecasted for 2010. Figure 115 indicates the share of renewables on net production in 2007.

Denmark	-36.8
Germany	61.3
Greece	71.9
Italy	86.8
Netherlands	38.0
Poland	19.9
Portugal	83.1
United Kingdom	21.3
EU (27 countries)	53.8
EU (15 countries)	56.9

Figure 113 – Energy dependency in Europe, 2006

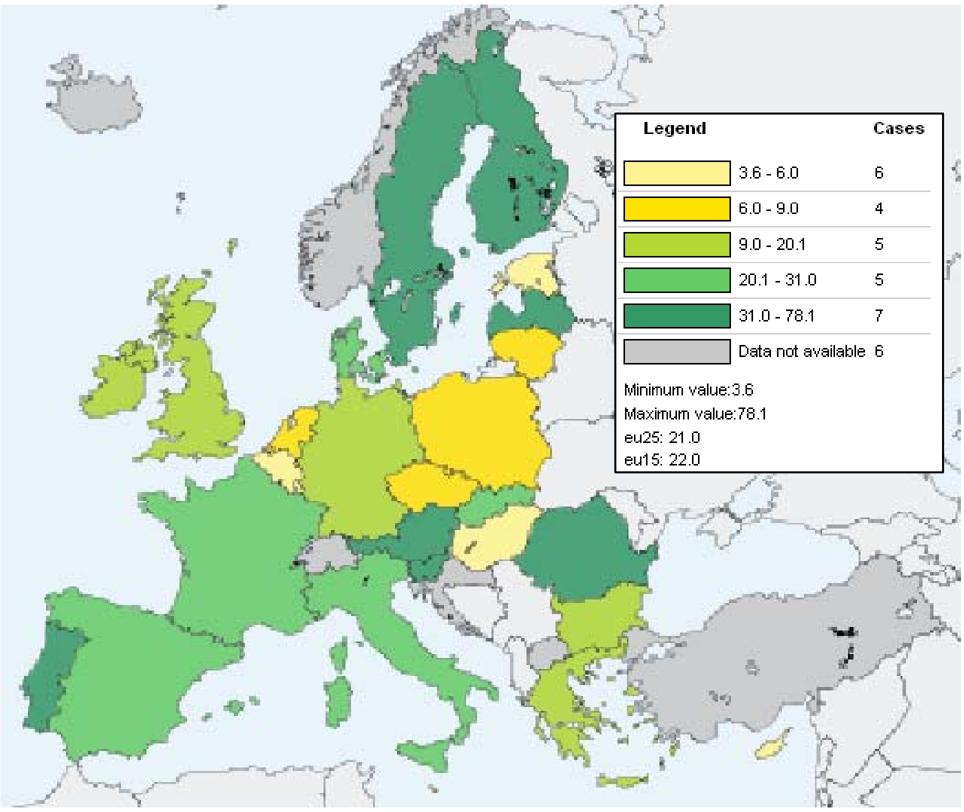


Figure 114 – Electricity generated from renewable energy sources (forecast 2010) (Eurostat)

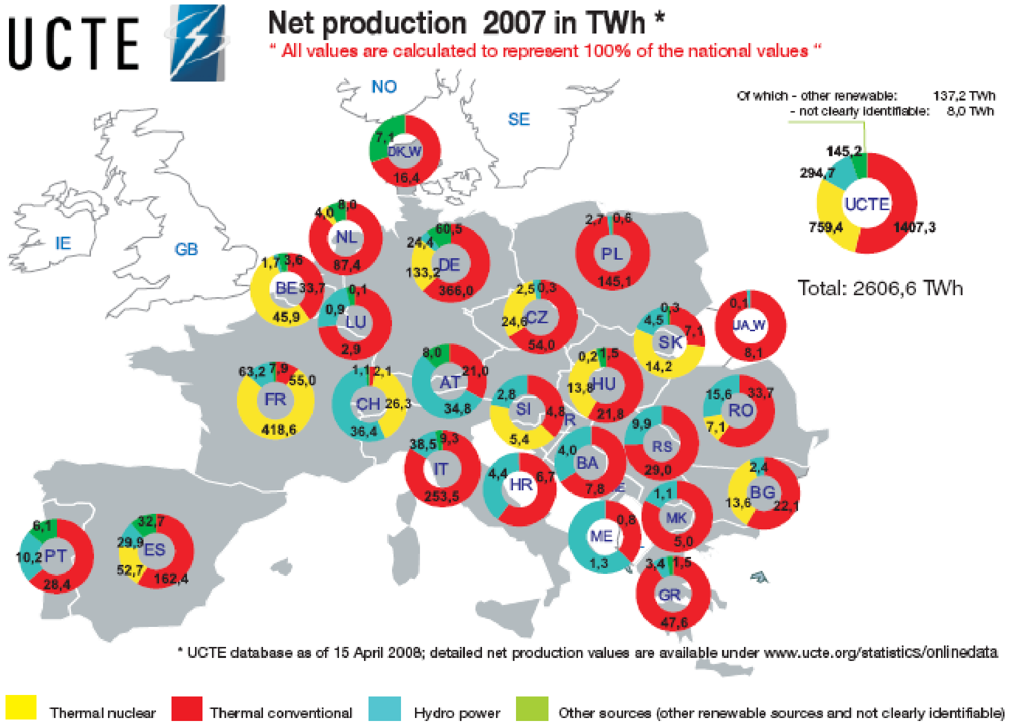


Figure 115 – Share of renewables on net electricity production [24]

Also the share of combined heat and power generation varies between 0 and 42 % in the year 2006 (Figure 116).

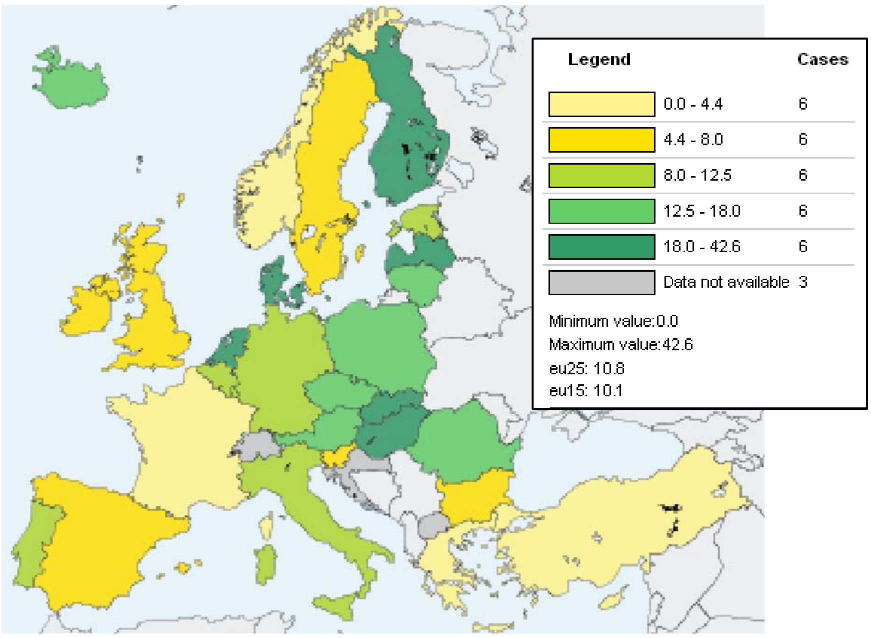


Figure 116 – CHP generation - Percentage of gross electricity generation (2006)

Figure 117 presents European average electricity prices in Euro per kWh without taxes charged to final industry consumers (annual consumption of 2 000 MWh, maximum demand of 500 kW and annual load of 4 000 hours), Figure 118 these for households (annual consumption of 3 500 kWh).

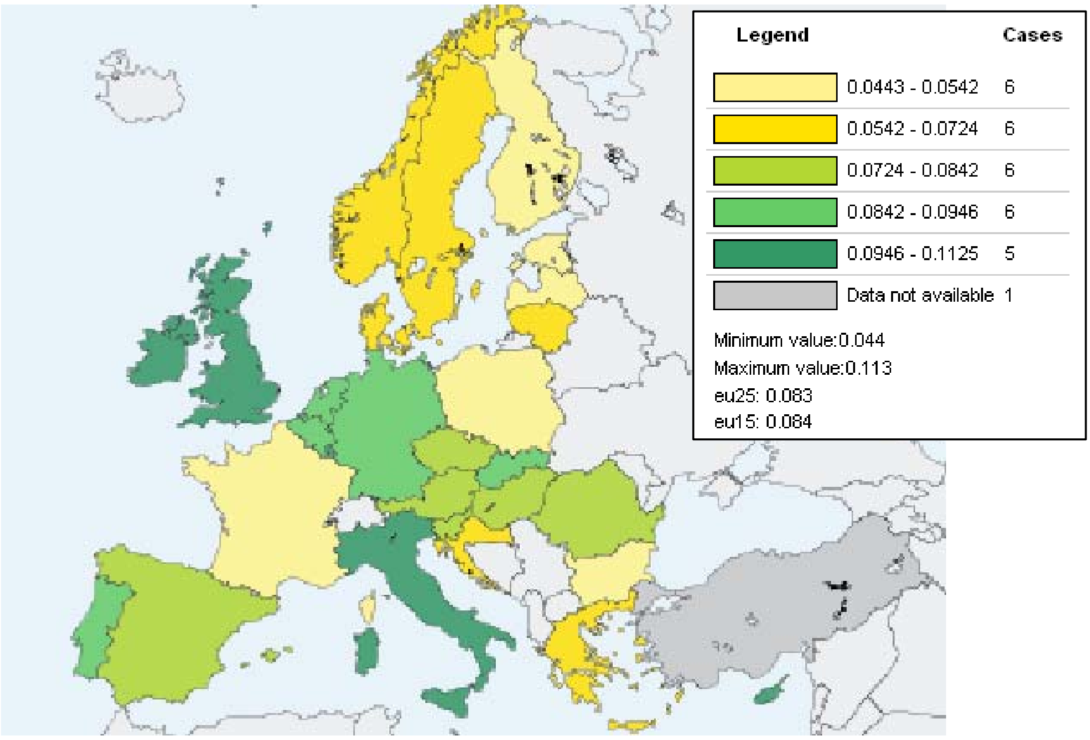


Figure 117 – Electricity prices by type of user - Euro per kWh (2007), Industry

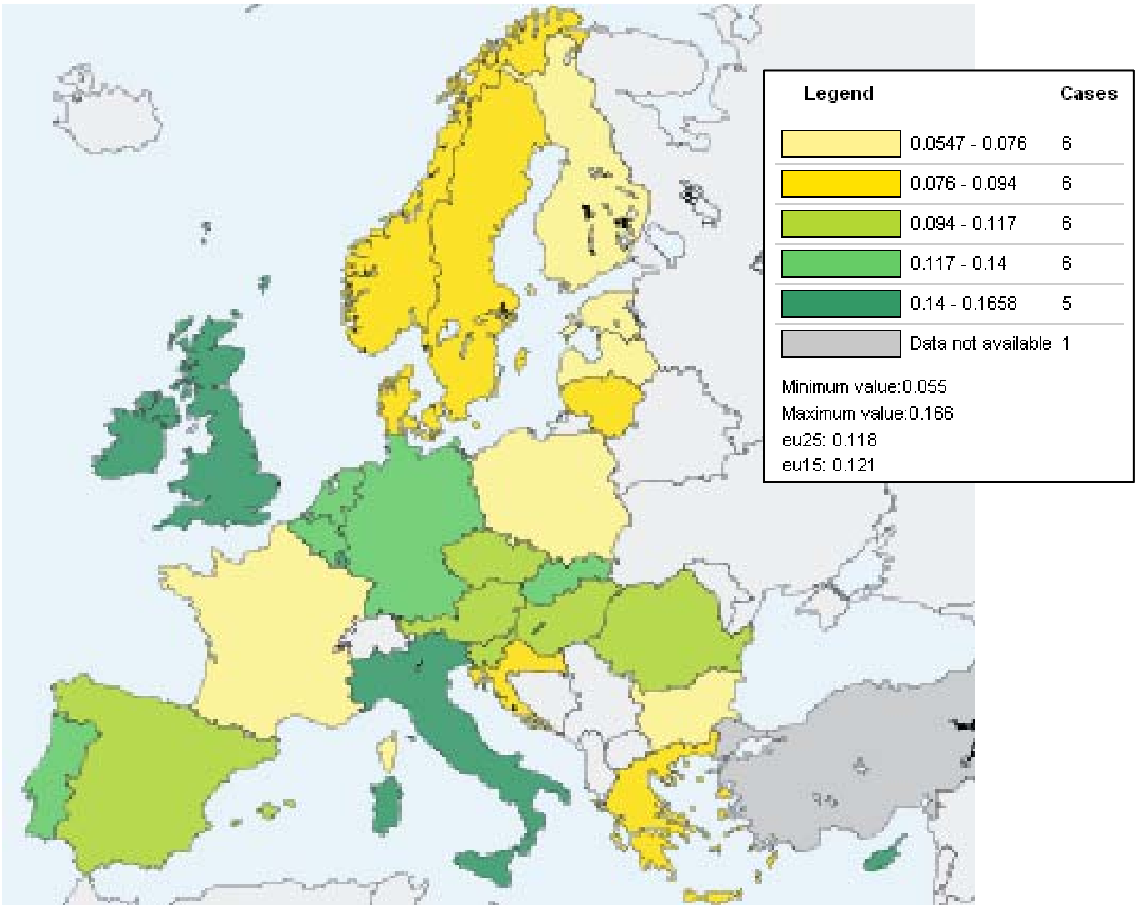


Figure 118 – Electricity prices by type of user - Euro per kWh (2007), Households

Annex 6 Environmental Impact of Microgrid Operation

Conventional central thermal power plants have long been seen as a major threat to environment due to their emissions of greenhouse gases (GHG) as well as toxic and harmful wastes. Up to now, air emission from electricity generation is mainly covered on four aspects: (1) CO_2 and other greenhouse gases; (2) SO_2, which causes acid rain and human health problems; (3) NO_x, which aggregates into toxic hazes in the atmosphere; (4) PM (particulate matter), which poses a considerable threat to human respiratory systems. Due to limitations of data availability, only the first three types of waste gases are considered in this report.

During burning of fossil fuels, CO_2 normally represents the largest share in the air emission of thermal power plants. Thus under the imminent global warming context, CO_2 and other GHG reduction becomes more and more important for the electricity generation industry. According to UNFCC (United Nations Framework Convention on Climate Change) and E-PRTR (European Pollutant Release and Transfer Register), major greenhouse gases include CO_2, CH_4, N_2O, SF_6, HFCs and PFCs etc [24]. Since the latest (4th) IPCC (Intergovernmental Panel on Climate Change) assessment report on climate change points out that CO_2, CH_4, and N_2O respectively accounts for 76.7%, 14.3% and 7.9% of GHG emissions (totaling 98.9%), consideration of these three gas types should be sufficient for modeling purposes.

In order to accurately evaluate potential global warming effect of different generation technologies, the concept of CO_2-equivalent emission can be used as per IPCC definition:

CO_2-equivalent emission is the amount of CO_2 emission that would cause the same time-integrated radioactive forcing, over a given time horizon, as an emitted amount of a long-lived GHG or a mixture of GHGs. The equivalent CO_2 emission is obtained by multiplying the emission of a GHG by its Global Warming Potential (GWP) for the given time horizon. For a mix of GHGs it is obtained by summing the equivalent CO_2 emissions of each gas. Equivalent CO_2 emission is a standard and useful metric for comparing emissions of different GHGs but does not imply the same climate change responses. [26]

According to the technical summary of fourth IPCC assessment report [27], Global Warming Potentials (GWP) of CO_2, CH_4, and N_2O are respectively 1, 25, and 298, which means equivalent CO_2 emission of electricity generation can be approximately calculated as:

$$kgCO_2\_eq \cong kgCO_2 + 25 \cdot kgCH_4 + 298 \cdot kgN_2O$$

An IEA (International Energy Agency) study [28] suggests that the energy sector accounts for about 36% of global CH_4 emission and 4% of global N_2O emission. In addition, it points out that the majority of energy-related CH_4 emissions can be attributed to production and transportation of coal and gas, while N_2O mainly arises from direct combustion or burning of fossil fuels. Thus it can be derived that CH_4 and N_2O emissions during the electricity generation process itself are comparatively small in comparison with CO_2 (even after multiplication of GWP), but CH_4 emission from electricity production will be considerably higher under a life-cycle analysis.

In order to determine CO_2 equivalent, SO_2, and NO_x emissions from different energy resources, data from 7 existing publications [29] [30] [31] [32] [33] [34] [35] are compared and summarized in Table A-69.

kg / MWh	Kg Emission per MWh Generated Electricity								
	CO_2_eq			SO_2			NO_x		
	Min	Max	Taken	Min	Max	Taken	Min	Max	Taken
Coal	740	960	900	0.5	12	6	0.5	4.5	3
Diesel	550	850	650	1	14	8	1	12	8
Natural Gas	400	680	500	0.001	0.003	0.003	0.5	0.8	0.6
Nuclear	10	45	40	0.01	0.03	0.03	0.01	0.03	0.03
Biomass / Biogas	20	80	60	0.1	0.2	0.12	1	2	1.8
Wind Turbine	10	30	20	0.01	0.05	0.05	0.01	0.04	0.04
Photovoltaic	30	150	100	0.1	0.25	0.25	0.1	0.22	0.22
Hydro	5	30	20	N/A	N/A	0	N/A	N/A	0
Geothermal	23	41	30	N/A	N/A	0	N/A	N/A	0

Table A-69 - Waste Gas Emissions by Different Energy Resources

It should be noted that general data inconsistency and discrepancy are prevalent in current power plant emission studies due to three major facts:

1. Emission levels depend on both fuel type and the technology of prime mover, thus emission data from a certain energy source (as shown in Table A-69) are generally not uniform with different generator technologies (especially for fossil or biomass fuels). [36]
2. Current studies on CO_2 equivalent emission generally do not provide detailed contributions from CO_2, CH_4, and N_2O, thus it is difficult to identify whether a study is conducted with life-cycle approach or not (which could lead to large differences in CH_4 emission levels).
3. As pointed out in [36], emission level of a power plant varies with its generation status, thus hour-wise emission data might be a better reflection of real-life running conditions when combined with hourly energy output of the plant.

In order to simplify analysis, however, uniform emission levels are adopted in this report (shown as ‘Taken’ values in Table A-69) for specified energy resources. Based on European- and country-wise portfolios of electricity generation summarized in [37], Figure 119 provides a general picture of energy mixes for generation of electricity under a European framework.

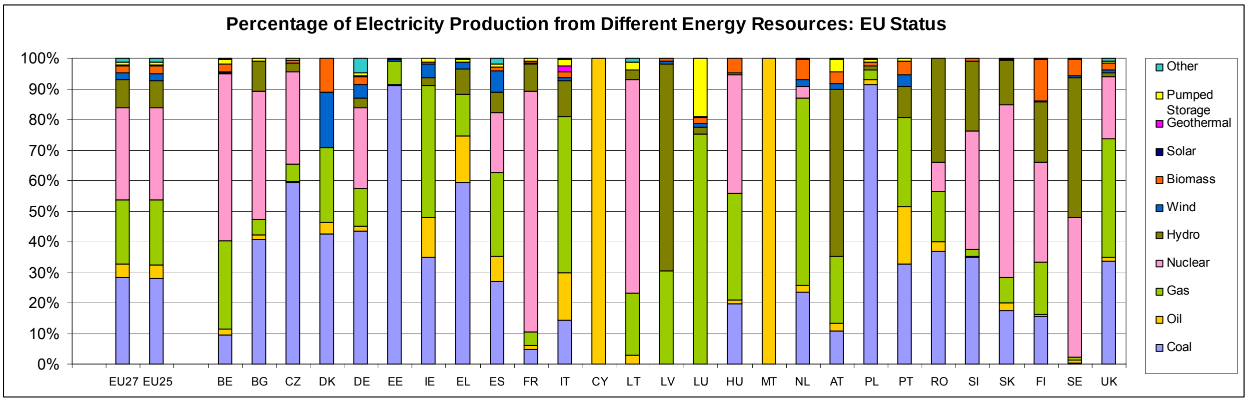


Figure 119 – General EU and Country-Wise Electricity Generation Portfolios

with

Belgian	BE	France	FR	Austria	AT
Bulgaria	BG	Italy	IT	Poland	PL
Czech Republic	CZ	Cyprus	CY	Portugal	PT
Denmark	DK	Lithuania	LT	Romania	RO
Germany	DE	Latvia	LV	Slovenia	SI
Estonia	EE	Luxembourg	LU	Slovak	SK
Ireland	IE	Hungary	HU	Finland	FI
Greece	EL	Malta	MT	Sweden	SE
Spain	ES	Netherland	NL	United Kingdom	UK

Now that general emission status of EU and national levels can be obtained via emission data of Table A-69 and energy makeup ratios of Table A-70 the environmental impact of Microgrid operation in a specified region can be estimated once the energy portfolio of a Microgrid is known. Assuming a Microgrid relies entirely on its own microgeneration units for energy supply, its environmental impact will then depend on the proportions of different technologies within it. In Table A-70, four scenarios of Microgrid constitution are assumed respectively with dominating fossil, biomass, renewable and balanced energy portfolios for comparison purposes.

Microgrid Modes	Percentage of Energy Production			
	Nat. Gas	Biomass	Wind	Solar
1. Scenario Gas	60%	10%	20%	10%
2. Scenario Bio	10%	60%	20%	10%
3. Scenario RES	10%	10%	50%	30%
4. Scenario Mix	20%	30%	30%	20%

Table A-70 - Energy Resources in Microgrid Scenarios

By summarizing weighted (according to resource proportion in the energy portfolio) emission levels of different energy resources, the total emission data of current EU status and potential Microgrid scenarios can be compared on a case-to-case basis. In Figure 120, Figure 121, and

Figure 122, comparison results for CO_2 equivalent, SO_2, and NO_x emissions are respectively shown.

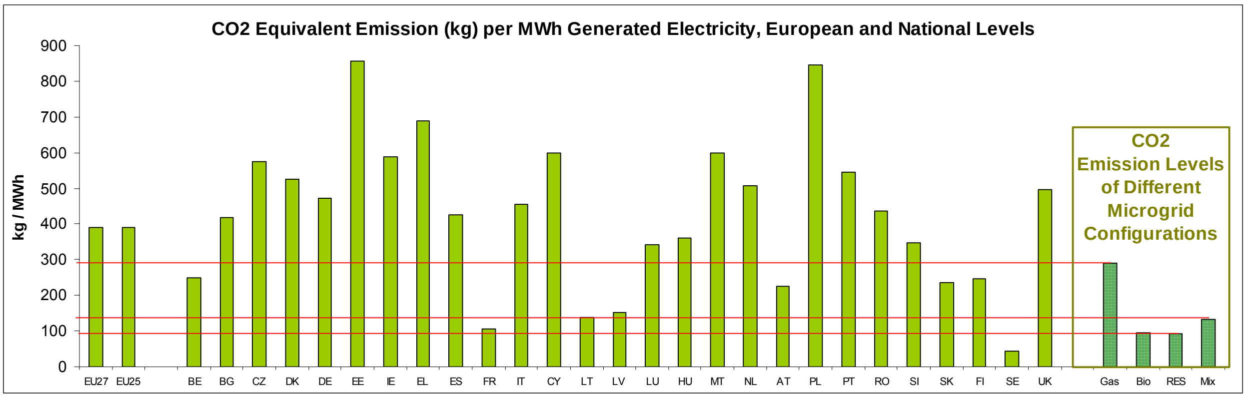


Figure 120 – Comparison of CO_2 Emission from EU Status Quo and Microgrid Scenarios

Figure 119 shows that even a fossil (natural gas) -dominant Microgrid could prove to be an effective CO_2-equivalent reduction measure for the majority of European countries except for those that meet most energy demands via hydro, nuclear, biomass, and/or natural gas resources (i.e. BE, AT, SK, FI, FR, LT, LV, SE). Microgrids with higher energy ratios of biomass or RES resources might be an appealing option for some of these low-carbon countries (e.g. Belgian, Austria, Slovak, and Finland), but countries that rely almost entirely on nuclear and/or hydro resources (e.g. France and Sweden) will still have sufficient reasons to keep existing generation structure.

Comparison of CO_2-equivalent emission for different Microgrid scenarios in Figure 120 reveals a relatively close performance result between biomass- and RES-dominated Microgrids, which appears to be inconsistent with general identification of RES units as more 'environmentally friendly'. This is caused by the high emission level during the production stage of concurrent photovoltaic (PV) units—with further technology innovations, however, PV emission should be reduced to a more competitive level.

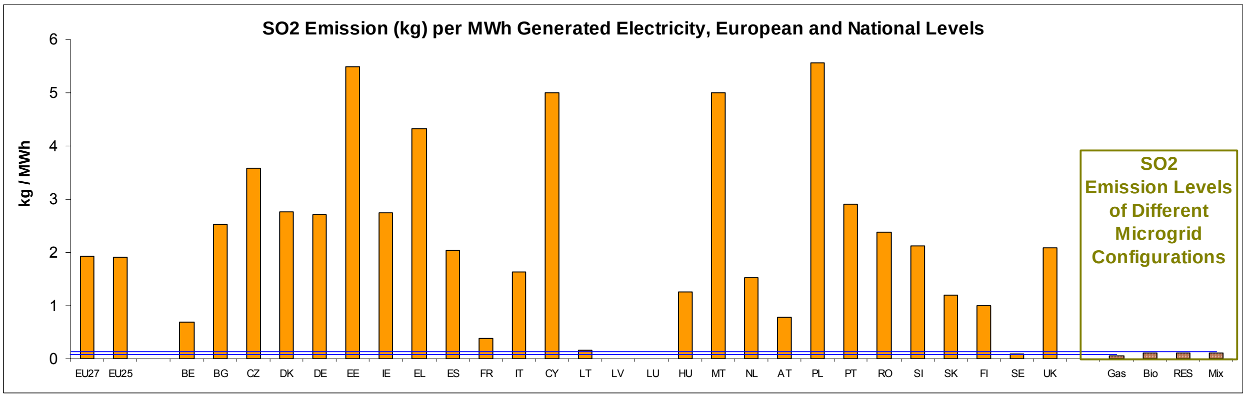


Figure 121 – Comparison of SO_2 Emission from EU Status Quo and Microgrid Scenarios

In Figure 121, SO_2 reduction effects can be seen as significant for virtually all Microgrid scenarios, and only hydro-, nuclear-, and/or natural gas-dominated European countries (e.g. Latvia, Lithuania, Luxembourg and Sweden) might find insignificant or no SO_2 reduction credits from adoption of Microgrids. This is due to the extremely high SO_2 emission levels of coal and oil in comparison with all other energy resources.

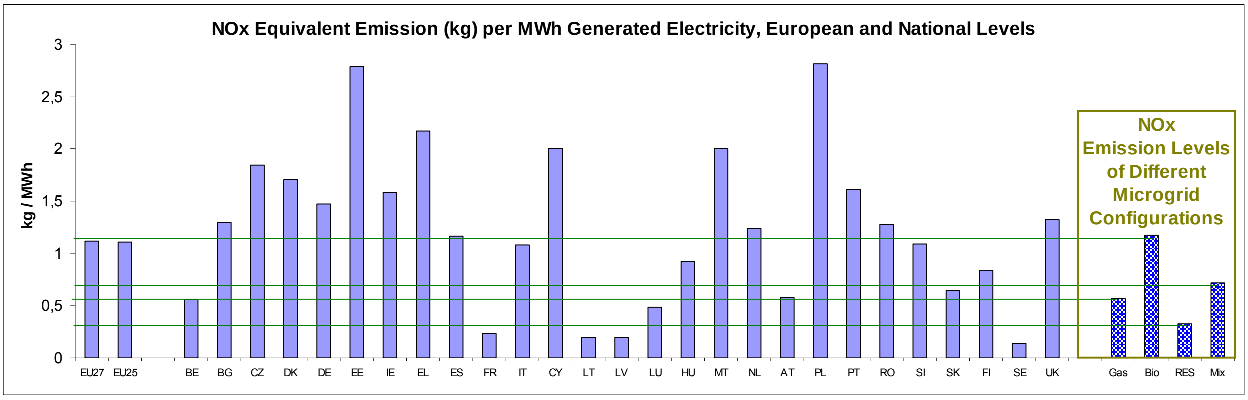


Figure 122 – Comparison of NOx Emission from EU Status Quo and Microgrid Scenarios

Figure 122 suggests that NO_x emission from a biomass-dominated Microgrid proves to be even higher than a natural gas-dominated Microgrid, which makes NO_x reduction prospect of a Microgrid under 'Bio' scenario only appealing for EU countries with large coal or oil energy proportions (such as Poland and Estonia etc.). Increasing natural gas or RES ratios in a Microgrid could lead to higher NO_x reduction credits and thus boost applicability of Microgrid to more EU countries in turn. NO_x emission level of a RES-dominated Microgrid proves to be the lowest among all four scenarios, which means Microgrid of this type could reduce NO_x emission level for most EU countries except for those dominated by hydro, nuclear, and/or natural gas resources (e.g. France, Latvia, Lithuania and Sweden).

As a conclusion, emission reduction credit of a Microgrid depends heavily on both its constitution and physical location. In addition, CO_2 equivalent, SO_2, and NO_x (plus PM if applicable) emission levels should be analyzed separately to evaluate the total environmental impact of a Microgrid.

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