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DG3. Report on the technical, social, economic, and environmental benefits provided by Microgrids on power system operation

Annex 5 – Study performed by INESC Porto

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Content

1 Benefits to the Distribution System

1.1 Methodology

This section addresses the overall benefits (technical, economical and environmental) resulting from the large-scale integration of micro-generation and Microgrids in typical Portuguese distribution networks. A total of four networks were analysed considering rural and urban environments in both Low Voltage and Medium Voltage grids.

These networks have been identified within Task TG1 and are described in Deliverable DG1.

1.1.1 CAMC functionalities – MMG optimization procedure

Potential cost-benefit approach is central to the MMG impact evaluation by addressing the real benefits (and costs) that micro-generation in form of MMG can bring to the distribution networks in order to find out the right incentives to encourage the Distribution System Operator (DSO), micro-generation owners and consumers to be involved in the MMG concept deployment.

Therefore, the MMG impact assessment will be addressed through a multi-attribute decision making problem where the decision is about choosing the amount of controllable load or micro-generation, to be actively managed within the MMG, to account for the technical problem resolution in terms of high congestion level or high voltage drops.

The distribution network is assumed to be operating in two operating modes:

- Normal operating mode referring to a situation when the network technical constraints, in terms of congestion levels and voltages are not violated;
- Stressed operating mode followed by violation of any technical constraint.

Moreover, periods of high electricity market prices in normal operating mode, will account for indirect benefits attributed to the DSO, in terms of:

- LV and MV active losses reduction;
- Emissions' reduction caused by active losses reduction;
- Emission's reduction due to displacement of central thermal generation units by micro-generation production with less emissions;
- Network investment deferral (in years),

due to price responsiveness of the controllable micro-sources and controllable load within each MG.

Besides the benefits passed to the DSO, the minimization of the operational cost of each MG leads to lower energy price for the MG consumers in respect to the upstream market prices, power quality improvement, local reliability enhancement, etc. These benefits should be separately treated and included further on in the analysis, since both, the DSO and the MMG consumers are profiting from the MG and MMG concepts [7].

Furthermore, in periods of low electricity market price, the local micro-generation production is not economically attractive and thus, no micro-generation is expected to be dispatched at MG level under Micro-Grid Central Controller (MGCC) control level. Moreover, consideration of a certain load growth will lead to potentially high congestion levels and/or voltage drops resulting in network reinforcement (network investment due to load growth). Traditionally, the electric utilities have satisfied customer demand by generating electricity centrally and distributing it through transmission and distribution networks. When demand increases beyond a certain level, however, the capacity of the generation, transmission and distribution systems can become constrained and the traditional utility response to these constraints is to expand or reinforce existing circuits.

An alternative option to the network reinforcement is introduced by exploiting a specific optimization procedure – a new functionality to be installed at the CAMC level in order to deal with the so called stressed operating condition. This functionality defines the amount of available controllable micro-generation to be produced and/or controllable load to be curtailed, subjected to predefined curtailment contracts when network physical restrictions arrive for a given time interval. The benefits, coming out of the MMG optimization procedure are assigned as direct benefits attributed to the DSO.

The impact that the MMG concept may have on the distribution network may be evaluated through definition of different control levels and management strategies at all distribution network levels to address the real benefits and costs which may come out of the MMG control structure. Moreover, potential costs and benefits coming out of the MG and MMG concept deployment are identified by modelling the impact that large scale integration of micro-generation in form of MG and MMG may have on the LV and MV distribution network as multi-attribute decision making problem. Therefore, a careful choice of relevant attributes should be made, addressing the impact of the large scale integration of micro-generation operated and managed under the MMG concept deployment. The hierarchical structure of such a control system allows evaluation of the local decision performed at each MGCC level, at MV level by carrying out another successive decision at more centralized level, namely the CAMC.

As already mentioned, the MMG may operate in two modes of operation: normal and stressed operating conditions, under responsibility of the CAMC, by dealing with different contracts and constraints. Therefore, CAMC communicating through each MGCC at local level will have information for each of the micro-generation controllable units, not being dispatched locally, at LV level, due to not being financially attractive. This can usually occur in low market prices period when is more beneficially for the MG to satisfy the MG demand by buying energy from the upstream network, thereby minimizing the total MG operational cost, as shown in equation (1-1) in the main document. Hence, what is assumed to take place in periods of stressed MV operating conditions, is activation of special contractual agreements between the DSO and the controllable micro-generation units within each MG defining the maximum amount of controllable micro-generation available (not being dispatched locally) for the respective hour, as well as curtailment contracts between the DSO and the controllable loads, for curtailing their noncritical part of the demand (the same subjected to shift bidding option at MG level due to market price responsiveness), thereby being compensated for their service. Each curtailment contract determines the upper limit of the curtailable load, the cost of curtailing, and optionally agreed time intervals for curtailing. Both, the production level of each controllable micro-generation unit available at CAMC level, as well as the maximum controllable load associated with the curtailment contracts, are subjected to the following optimization procedure, performed at CAMC level.

$$\min C_{operation} = \min\left\{\sum_{i=1}^{N} C_{1i} + \sum_{j=1}^{L} C_{2j} + CP_{losses}\right\} \tag{1}$$

$$s.t.$$

$$g(X,U)=0 \tag{2}$$

$$I_{ij} \le I_{ij\max} \tag{3}$$

$$U_i \ge U_{\min} \tag{4}$$

$$P_{Gc_i}^{\min} \le P_{Gc_i} \le P_{Gc_i}^{\max} \tag{5}$$

$$0 \le P_{Lc_i} \le P_{Lc_i}^{\max} \tag{6}$$

Where

$$C_{1i} = \left(a_i \cdot P_{Gc_i} + b_i\right) \cdot \Delta t \qquad (7)$$

$$C_{2j} = c_j \cdot P_{Lcj} \cdot \Delta t \qquad (8)$$

where C_{1i} [€cent] is the cost associated with the activation of the contractual agreement of the i controllable micro-source being dispatched at MMG level, whereas C_{2j} [€cent] is the cost of curtailing the controllable load aggregated at j node, assigned under curtailment contract and C stands for the cost associated with the MV active power losses. P_{Gci} [€cent/kW] and P_{Lcj} [€cent/kW] as control variables of the minimization problem (1), stand for the upper limit of controllable micro-generation and controllable load under contractual agreements and curtailment contracts respectively, activated in stressed operating periods. In order to introduce different importance levels of the controllable load, c_j [€cent/kWh] is defined for three groups of controllable load within the LV network, randomly chosen, assigning highest value to the one considered of highest importance.

However, different DSM options and price responsive mechanisms at LV level, is subject to future research. The terms a_i [€cent/kWh] and b_i [€cent/h] in (7) present the cost coefficients of each controllable micro-generation, where the value of C_{1i} is defined within the contractual agreement between the DSO and the micro-generation owner, activated in stressed operating hours. The term CP_{losses} stands for cost associated with the MV active losses.

Equation (2) includes the power flow equality constraints where X stands for the vector of state variable, such as slack bus power, bus voltage magnitudes and phase angles, network power flows, line parameters, network power flows, generator reactive power output, whereas U denotes the vector of control variables like real and reactive power generation, generator bus voltages, transformers tap ratios, VAR sources (capacitor banks, static var compensators – SVC, static synchronous compensators – STATCOM), (3) and (4) stand for the technical constraints, in terms of current and voltage limits, whereas (5) and (6) present the upper and lower limit of each controllable micro-generation unit and controllable load subjected to contractual agreements and curtailment contract between the DSO and the micro-generation owner/MMG consumer, respectively.

In order to simulate the MMG control and management strategy under (1), an optimization procedure was created in MATLAB environment for emulation of the MGCC and CAMC behaviour using Sequential Quadratic Programming (SQP) methods [8]. Such assessment requires a monitoring of MV technical constraints violation and thereby, sending set-points or/and load change commands to each MGCC locally. Hence, it was assumed that each MGCC communicates with the available controllable sources and controllable loads within the MG through the local MC and LC and sends information back to the CAMC about the controllable micro-generation production availability/controllable load willing to be contracted for load curtailment in stressed operating hours.

1.1.2 Multi-attribute assessment of the MMG impact deployment

The impact of large scale micro-generation in form of MG and MMG is modelled as multi-attribute problem, where the attributes of the criteria defined are calculated externally using the optimization procedures described in (1).

Four criteria/attributes have been identified from the MMG impact evaluation in both modes of operation:

- Total investment cost, annualized, consisted of MMG installation cost involving hardware and software costs of MCs, LCs, MGCCs and CAMC as well as communication infrastructure, and MMG operational cost;

- Total (LV and MV) annualized active losses reduction in terms of energy;
- Distribution network investment deferral due to MMG concept deployment for the peak hour(s) at the year of investment (evaluated through the number of years of deferral);
- Annualized CO_2 emissions reduction (in tons of CO_2) due to:
  - micro-generation production within the MMG and displacement of the marginal upstream network units;
  - LV and MV active losses reduction.

The three attributes regarding the benefits expected to be reported at LV and MV level will be assessed and described further on in the report. Extensive results regarding the adoption of this approach, as well different decision aid techniques will be presented within deliverable DH3, "Business case for Microgrids".

1.1.2.1 Evaluation of the investment deferral attribute

Expected yearly load growth would yield at a certain moment a technical constraint violation resulting in reinforcement of the most congested distribution network line or transformer where the voltage drops below the allowable technical limit. An alternative approach is introduced by the Multi-Microgrid (MMG) concept deployment expected to defer the distribution network upgrade for a certain time (years) before the technical limit will be reached or the technical constraint violated. The investment deferral will be evaluated for the worst MV branch or (MV/LV transformer) due to congestion level or voltage drop for the peak hour in the year when the MV network reinforcement needs to take place.

The investment deferral criterion in our analysis is evaluated using the voltage drop criterion for rural networks and congestion level for urban networks. The idea is to evaluate how much (in years) the voltage level can be kept within the technical limits or congestion level can be decreased in the MV network and the network upgrade can be postponed by setting up the MMG, for a given scenario and each alternative considered. Two different criteria are used for investment deferral evaluation in respect to the type of network under study and therefore two independent analyses will take place:

- In typical urban networks, the investment deferral is assessed by time deferral (in years) until the congestion level limit is reached due to MMG concept deployment for the most congested MV line.
- In the rural study case networks, the highest voltage drop limit for the bus (MV/LV transformer) present the criteria of the investment deferral due to MMG deployment.

Moreover, the investment deferral will be assessed in both modes of operation, namely normal and under stressed conditions.

High electricity market prices would yield micro-generation dispatch from the controllable units within each MG and potential controllable load shifting, performed under (1), and thus, contribute for deferring the network upgrade for a certain time (years) due to MMG concept deployment.

Likewise, dispatching controllable micro-generation units and activation of curtailment contracts for controllable load shedding in stressed operating hours, likely to occur in low electricity market prices period will account for investment deferral for the hours when some of the technical constraints are being violated and network reinforcement needs to take place.

Therefore, the investment deferral has been defined as a period of time (years) between the first and i-th year when network reinforcement need to take place due to highly congested MV line. The first year corresponds to the initial year of activation of curtailment contracts and micro-generation dispatch under CAMC to account for the congestion problem (usually common in urban networks), whereas i-th year relates to the year when dispatching the whole controllable micro-generation and curtailment of the controllable load under CAMC does not lead to resolution of the congestion problem. Put it in another words, the investment deferral (in years) corresponds to the number of years when activation of (1) and can account for a resolution of the problem of technical constraint violation.

1.1.2.2 Evaluation of the technical (economic) attribute

Strategically located micro-generation sources in form of MMG may systematically reduce the distribution network losses, beneficial to the DSO as entity mandated to keep the losses at minimum level and therefore minimizing the operational cost. Nevertheless, the technical benefit of loss reduction due to MMG can be translated into an economic benefit as avoided cost due to avoided active losses as well as environmental benefit of emissions reduction due to active losses reduction, introducing one of the criteria of the multi-criteria decision making problem attributed to the DSO.

The active losses criterion will be evaluated through active losses reduction in terms of energy for normal and stressed operating period during the year of study. Therefore, the active losses may be reported as direct benefit coming out of the global optimization procedure (1), performed at the stressed operating hours and/or indirect benefits due to micro-generation dispatch and load shifting under MGCC in (1) in high market prices period. The concept of technical constraint violation is related to the network reinforcement (upgrade) and therefore, exploitation of the functionality described in (1) in stressed operating conditions appears as an alternative approach to network investment. This will also result in reduction of active losses due to activation of curtailment contracts and dispatching controllable micro-generation under (1). In that sense, the active losses reduction have to be evaluated for each time interval (hour) of normal and/or stressed operating conditions during the whole period (in years) of investment deferral.

Furthermore, the total active losses reduction needs to be annualized for the initial year of study when a load growth related network investment needs to take place (due to technical constraint violation).

1.1.2.3 Evaluation of the environmental benefit/attribute

Taking into account the emission's level of all micro-sources within the MMG as well as emission's level from the upstream network units, potential benefits are expected to be reported regarding emissions' reduction of several pollutants, such as CO_2, NOx, SO_2, due to the dispatch of the micro-sources within the MMG and upstream network production displacement. From the above mentioned pollutants, due to high concern of CO_2 emissions' level, CO_2 will be taken as representative pollutant in our analysis. Moreover, additional CO_2 emission's reduction can be detected due to avoided active losses.

The production from the micro-generation units within the MMG reduces injection from the upstream grid and thus the corresponding emissions from central units. The micro-generation units within the MMG may have their own emissions, which should be taken into account in order to evaluate their environmental impact [9].

High micro-generation penetration level of the MMG units could affect central unit commitment, i.e. it is possible that central units might need to switch off to accommodate increased micro-generation production. What is assumed in our analysis is relatively low global micro-generation penetration level so that only the most expensive units of the system are expected to be affected, so-called marginal units. Therefore, only the emissions of these units should be taken into account, when evaluating the environmental impact of micro-generation in form of MG and MMG.

Regarding emissions data, three possibilities (methods) exist in practice, which also determine the methods used when detailed time-series of the system under study are not available.

(1) Average annual emissions available in kg/kWh;

(2) Monthly emissions available;

(3) Monthly 24 hour emission curve different from month to month according to the type of marginal units.

The simplest type is 1, frequently directly available by utilities or obtained from the annual energy production by type of unit usually available by Transmission System Operators (TSO). If not directly available, the annual emissions for the power system can be estimated by the emission level of each unit using (9):

$$sys\_em\_lev = \frac{\sum_{i=1}^{N} emmision\_level_i \cdot energy_i}{\sum_{i=1}^{N} energy_i} \tag{9}$$

Where:

sys_em_lev is the emissions of the upstream network of the MG, i is the type of unit, energyi is the energy produced by unit type i for the studied period, *emission_level* $_i$ is the emission unit type i and N is the number of different types of units.

Analysis based on average annual data does not take into account the seasonality of production from the upstream network and the MMG units. This seasonality is important, in case different types of units are installed in the upstream network, since peaking units, like gas turbines, during some months operate for very few hours. Moreover, some micro-generation units like PV and CHP units, provide significantly higher production during summer and winter, respectively, and should be taken into account in the emission analysis performed.

A more detailed analysis than in method 1 can be performed, if data about monthly emissions are available, or the monthly production of each unit usually made available by TSOs and utilities are known. Monthly analysis can provide increased information compared to annual average data, providing more realistic results especially for high penetration of micro-generation. However, for low level of micro-generation penetration like the one assumed in the analysis, the operation of micro-generation does not change central unit commitment, but only the units' set points.

The base units of the power system are neglected in the analysis under method 3, because their operation is very rarely affected by the micro-generation operation and therefore only the emissions of the marginal units are taken into account when evaluating the environmental impact of micro-generation within the MMG. .

The distinction between peaking and base units is especially important in the analysis of power systems with significantly diversified generation mix. For systems based on nuclear or hydro-units, like the systems of France and Norway, respectively, the operation of the base units reduces the overall CO_2 emissions, while in such systems the production of peaking units with significantly higher emissions is replaced by micro-generation. Neglecting this fact and applying methods 1 and 2, significantly underestimates micro-generation benefits. On the other hand, in power systems with coal units operating as base units and oil- or gas-fired units covering load peaks, micro-generation production reduces the output of units with lower CO_2 emissions. In this case, 1 and 2 might overestimate the environmental benefits coming out from the micro-generation in form of MMG.

In our analysis, the value of 0.47 kg/kWh average annual emissions for the Portuguese system has been used as a reference factor for annual CO_2 emissions avoided due to the RES dispatched and load curtailed by activation of the curtailment contracts under (1), whereas reference factor of 0.202 kg/kWh has been used for the fuel-consuming units (Micro-Turbines) within the MMG, dispatched under (1) [10].

Likewise with the active losses reduction, the total CO_2 emissions reduction needs to be evaluated in normal and/or stressed, annualized for the initial year of a network investment required due to load growth.

1.2 Definition of study cases

The impact assessment of the adoption of the approach described before is performed at LV and MV distribution voltage level in typical Portuguese distribution networks through the different management and control strategies described above, assumed to be developed in real market environment.

Several data are needed for performing the analysis, provided by the Portuguese utility (EDP):

- Identification of typical distribution urban and rural networks;
- Typical LV and MV load profiles for summer and winter;
- RES production curves for summer and winter;
- Identification of typical day of low and typical day of high market prices (using OMEL data).

Real LV and MV networks have been used in this analysis. Two independent study cases have been considered due to different potential technical constraint violation in each of the network. Namely, in rural networks due to the wires length, what is expected to take place is significant voltage drop considering certain annual load growth, whereas in typical urban network, high congestion levels are assumed as a common technical issue.

Figure A-1 and Figure A-2 present typical Portuguese LV urban and rural networks used in the analysis. Figure A-3 and Figure A-4 show typical MV urban and rural network, respectively with several Micro-sources placed as shown below. The ten worst nodes regarding the voltage drop are designated in black in Figure A-3, whereas the ten most congested lines in Figure A-4 are shown in bold.

Figure A-1 Typical LV urban network

Figure A-2 Typical LV rural network

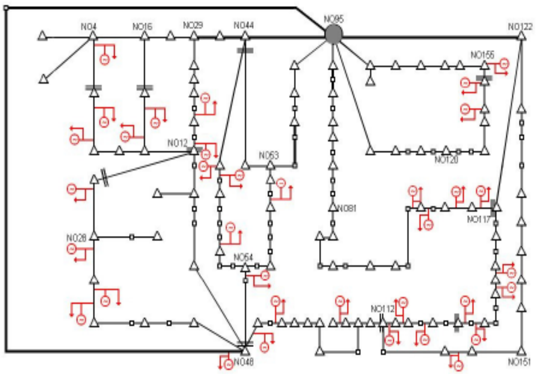

Figure A-3 Typical MV urban network

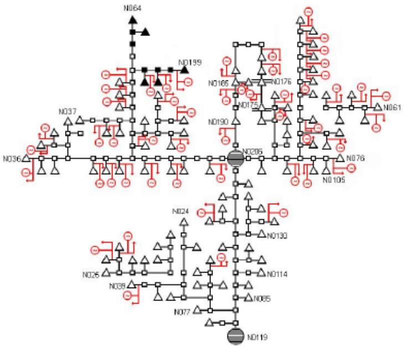

Figure A-4 Typical MV rural network

Starting at a single MG level, in different scenarios, different micro-generation production level is expected to take place, due to electricity market price responsiveness, which would decrease the MV load profile at the MMG level for the hours of micro-generation production. Therefore, since the reduction of MV hourly load profile depends on the amount of micro-generation produced locally and the micro-generation installed capacity is a certain percentage of respective MV/LV substation or particular MG peak demand, the same percentage reduction in the 24-hours load profile is applied to each LV/MV node where MG is placed. Thus, our analyses are based on the real demand at each MV/LV substation level where a MG is placed. Figure A-5 and Figure A-6 present typical LV and MV load profiles for Portuguese distribution networks. Figure A-7 and Figure A-8 depict the typical PV and wind profile for Portugal [11]. Figure A-9 illustrates the electricity market prices used in the analysis [12].

Moreover, it is relevant to mention that the RES generation mix share depends on the type of network:

- Urban distribution network comprises 100% PV in the mix of RES generation installed;
- 20% wind and 80% PV in the generation mix of RES installed in rural distribution network.

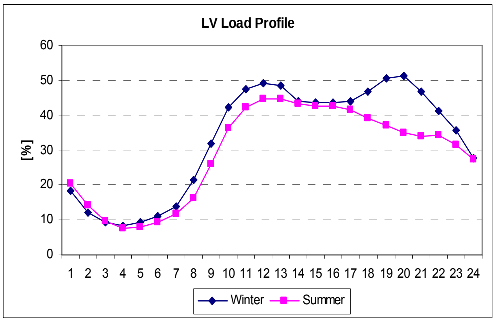

Figure A-5 Typical aggregated daily LV load profile

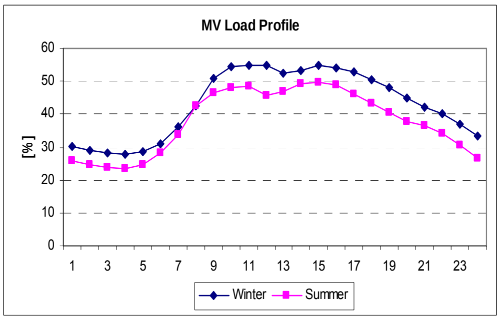

Figure A-6 Typical aggregated MV load profile Typical aggregated daily

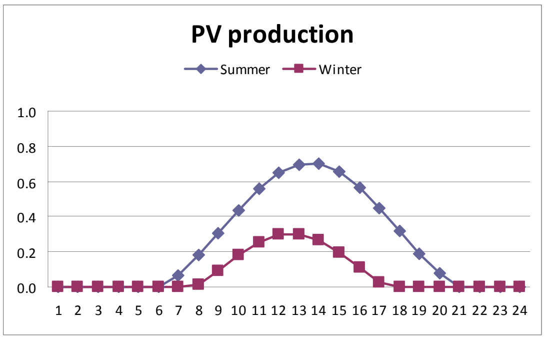

Figure A-7 PV production profile

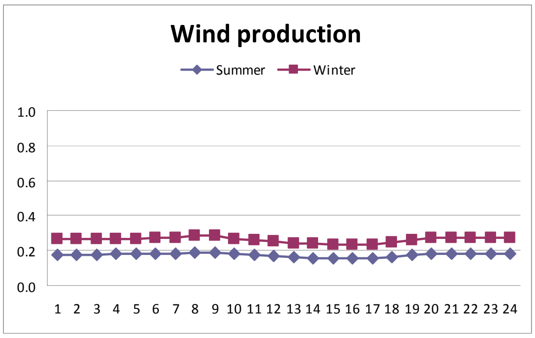

Figure A-8 Wind production profile

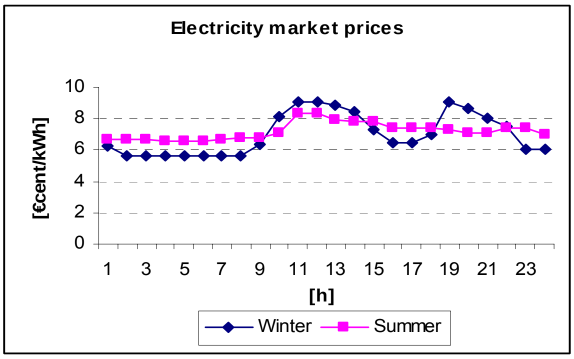

Figure A-9 OMEL electricity market prices

1.3 Definition of set of alternatives (options)

Seven (7) alternatives are presented to the Decision Maker, where the DSO may decide to do nothing or to take some actions exploiting the control and management infrastructure of the MMG concept in respect to a reference option of 20 % non-controllable micro-generation installed capacity. This reference value was defined due to the Portuguese legislation, allowing 25% of micro-generation installed capacity regarding a respective MV/LV transformer's peak load to be installed causing no technical problems in terms of overvoltages and reverse power flows. Being on the safe side, 20 % of micro-generation will be taken as a reference option in this study work. The alternatives selection has been done due to exploitation of the controllability and management of the MMG concept through active micro-generation/load management in respect to already existing non-controllable micro-generation (20% in respect to a corresponding MV/LV transformer's peak load).

A. No active network management (20% non-controllable micro-generation installed capacity (coming from RES);
B. 20% non-controllable micro-generation together with 10% controllable micro-generation and 10% controllable load within each MG of the MMG;
C. 20% non-controllable micro-generation together with 20% controllable micro-generation and 20% controllable load within each MG of the MMG;
D. 30% non-controllable micro-generation together with 10% controllable micro-generation and 10% controllable load within each MG of the MMG;
E. 30% non-controllable micro-generation together with 20% controllable micro-generation and 20% controllable load within each MG of the MMG;
F. 40% non-controllable micro-generation together with 10% controllable micro-generation and 10% controllable load within each MG of the MMG;
G. 40% non-controllable micro-generation together with 20% controllable micro-generation and 20% controllable load within each MG of the MMG.

Annex 1.1 Definition of scenarios

The uncertainties regarding the electricity market prices and load growth levels are captured by definition of scenarios. Moreover, LV and MV load and RES generation profiles are taken into account by consideration of additional scenarios (situations) regarding two principal seasons.

I. Typical day of low electricity market prices and 2% load growth during winter;

II. Typical day of low electricity market prices and 2% load growth during summer;
III. Typical day of high electricity market prices and 2% load growth during winter;
IV. Typical day of high electricity market prices and 2% load growth during summer;
V. Typical day of low electricity market prices and 3% load growth during winter;
VI. Typical day of low electricity market prices and 3% load growth during summer;
VII. Typical day of high electricity market prices and 3% load growth during winter;
VIII. Typical day of high electricity market prices and 3% load growth during summer.

Typical days of low and high electricity market prices using OMEL have been identified. Since the analysis are performed on annual basis, the benefits in terms of active losses reduction and micro-generation are multiplied by the number of days with low and high electricity market prices during each season for each scenario of load growth during the year of study. Stressed operating conditions will include also the number of years of investment deferral due to activation of curtailment contracts and/or controllable micro-generation dispatch under (1).

In line with the load growth, 2% and 3% annual growth of RES is considered in the scenarios of 2% and 3% load growth, respectively.

1.4 Construction of distribution network impact indices

Most of the benefits of employing micro-generation under the Microgrid and More Microgrid concepts in existing distribution networks have economic, technical and environmental implications and they are interrelated. While all the benefits can be ultimately valuated in terms of money, some of them have a strong technical flavour than others. As such, it is proposed to classify the benefits into two groups—technical and economic benefits with the environmental benefit being interrelated between both [13], [14].

The major technical benefits are:

- Reduced line losses;
- Voltage profile improvement;
- Increased overall energy efficiency;
- Enhanced system reliability and security;
- Improved power quality;
- Relieved T&D congestion.

The major economic benefits are:

- Deferred investments for upgrades of facilities;
- Enhanced productivity;
- Reduced emissions of pollutants;
- Reduced health care costs due to improved environment;
- Reduced fuel costs due to increased overall efficiency;

- Reduced reserve requirements and the associated costs;
- Lower operating costs due to peak shaving;
- Increased security for critical loads.

In this report, a general approach is presented to quantify the technical benefits of micro-generation. It is then applied to assess three major technical benefits, namely line-loss reduction, congestion relief (and/or voltage profile improvement) and environmental impact reduction.

The technical benefits of introducing micro-generation in form of Microgrid and More Microgrid can accrue in one of two broad categories.

1) Improvement of a certain attribute such as voltage profile, reliability, power quality, etc.
2) Reduction of an attribute such as line losses, emissions, congestion, etc.

By comparing and taking the ratio of a measure of an attribute with and without micro-generation in form of Microgrids an index can be derived for each of the attributes. If the introduction of micro-generation is beneficial, indices corresponding to the attributes in category 1 will be greater than unity and indices corresponding to the attributes in category 2 will be less than unity. Due to the fact that the analysis presented in this report are made for a typical urban LV and MV Portuguese network, where it is probable to face congestion levels problems rather than low voltage profiles, all the benefits due to Microgrids concepts deployment belong to category 2. Therefore, the indices presented below are signals of the network performance, where values that are close to unity indicate better network performance.

1.4.1 Losses Reduction Index (LRI)

Although reliability is the primary concern for utilities, network losses are a key consideration particularly given the twin drivers for efficiency given environmental and economic concerns. While large scale penetration of micro-generation may unload lines and reduce losses, the reverse power flows from larger penetration of micro-generation can give rise to excessive losses. Consequently, the first and second indices (IL_p and IL_q) express real and reactive line power losses, respectively. Thus, a beneficial micro-generation location would decrease total network losses, which means near unity values of IL_p and IL_q

$$LRI\ p = 1 - \frac{\mathrm{Re}\left\{Losses_{wMMG}\right\}}{\mathrm{Re}\left\{Losses_{woMMG}\right\}} \tag{10}$$

$$LRI\ q = 1 - \frac{\mathrm{Im}\left\{Losses_{wMMG}\right\}}{\mathrm{Im}\left\{Losses_{woMMG}\right\}} \tag{11}$$

where $Losses^{k}$ is the total complex power losses for the k-th distribution network configuration, and $Losses^{0}$ is the total complex power losses for the distribution network without micro-generation in form of Microgrids.

1.4.2 Congestion Relief Index (CRI)

As a consequence of supplying power near to loads, current flows may diminish in some sections of the network, thus releasing more capacity, but they could also increase to levels beyond distribution line limits. This index gives important information about the level of currents through the network regarding the maximum capacity of conductors for the worst hour of high congestion level. Values of this index close to unity mean reserve capacity for demand growth.

$$CRI^{h} = 1 - \frac{\max\left(\frac{I^{h}_{m/wMMG}}{CC_m} \right)_{m=1}^{NL}}{\max\left(\frac{I^{h}_{m/woMMG}}{CC_m} \right)_{m=1}^{NL}} \tag{12}$$

where $I^{k}_{m/wMMG}$ and $I^{k}_{m/woMMG}$ is the current through the branch m for the h-th worst hour due to high congestion level for the cases with and without micro-generation in form of (More) Microgrids respectively, CC_m is the current capacity of the line conductor m and NL is the number of lines.

1.4.3 Environmental Impact Reduction Index (EIRI)

Another great potential benefit of micro-generation in form of (More) Microgrids is the production of energy with minimal greenhouse gas emissions and other pollutants as compared to conventional technologies. Concerns about greenhouse effect are growing rapidly in the public's view. Greenhouse effect is a result of rising carbon dioxide and other greenhouse gas emissions.

Introduction of micro-generation under (More) Microgrids concepts will result in a reduction of capacity needs of conventional plants due to two reasons:

- The real power generated by micro-generation units within each Microgrid will directly reduce the output requirements;
- The resulting line-loss reductions will further decrease the output needs from conventional plants.

The basic idea behind the proposed EIRI is to compare the emission of a particular pollutant with and without the employment of micro-generation in form of (More) Microgrids; it can be expressed as:

$$EIRI_i^{k} = 1 - \frac{PE_{iw/MMG}}{PE_{iwo/MMG}} \tag{13}$$

for the *i*th pollutant (CO_2, SO_2, NO_x, etc.)

where $PE_{iw/MMG}$ and $PE_{iwo/MMG}$ are the amount of emissions with and without micro-generation in form of (More) Microgrids, respectively, for the i-th pollutant and they are expressed as:

$$PE_{iw/MMG} = \sum_{j=1}^{B} (EG)_{Aj} (AE)_{ij} + \sum_{k=1}^{H} (EDG)_k (AE)_{ik} \tag{14}$$

$$PE_{iw0/MMG} = \sum_{j=1}^{B} (EG)_j (AE)_{ij} \tag{15}$$

Where $(EG)_{Aj}$ and $(EG)_j$ are the amount of electrical energy generated by the j th conventional power plant with and without the employment of micro-generation in form of (Multi) Microgrids, respectively in kWh, $(AE)_{ij}$ is the amount of emission of the i-th pollutant for the j-th conventional plant per kWh of energy generated, $(AE)_{ik}$ is the amount of emission of the i-th pollutant for the k-th micro-generation unit within the (Mulit-) Microgrid per kWh of energy generated, $(EDG)_k$ is the amount of energy generated by the k-th micro-generation unit within the (More) Microgrid, B is the total number of conventional generators in the system, and H is the total number of micro-generation unit within the (More) Microgrid.

These impact indices are intended to give the corresponding importance to each technical issue due to the presence of micro-generation in form of (More) Microgrids and depend on the required analysis (e.g., planning, regular operation, emergency operation).

Table A-1 Impact indices shows indicative values for the three impact factors defined above, for the case of highest micro-generation installed capacity (alternative G) and the first four scenarios defined in Annex 1.1.

Table A-1 Impact indices

Impact Index	Scenario I	Scenario II	Scenario III	Scenario IV
LRI	0.14	0.28	0.2	0.32
CRI	0.07	0.11	0.09	0.12
EIRI	0.09	0.35	0.13	0.38

1.5 Results

1.5.1 (More) Microgrids control and management under MGCC and CAMC

The results that follow present the outcome of the optimization procedure at CAMC level for scenario I and III for a typical urban LV and MV distribution network as shown in Figure A-1 and Figure A-3 respectively. Figure A-10 depicts the congestion level for the most congested line under the local optimization procedure, at MGCC level as well as at CAMC level during winter and low market prices period and load growth of 2% (scenario I). Likewise, Figure A-11 shows the energy losses for the whole MV distribution network. Both figures present the year of investment when all the available controllable micro-generation is dispatched and controllable load curtailed under CAMC. Therefore, they present the last year before the line reinforcement need to take place, assuming no increase of controllable micro-generation.

The middle curve in Figure A-10 depicts the congestion level after performing the local optimization procedure, within each Microgrid (at each MGCC level). Due to low electricity market prices there are no favourable economic conditions for the controllable micro-generation units to be dispatched under MGCC. Therefore, insignificant congestion reduction can be seen in Figure A-10, presented by the middle curve, due to the dispatch of the non-controllable micro-generation units, namely PV units, whose production during winter is not that significant. Therefore, the global optimization under CAMC needs to be performed for the stressed hours of congestion (hour 11, 12, 14, 15, 16, and 17), thereby calculating the amount of controllable micro-generation to be dispatched and controllable load to be curtailed under curtailment contracts to account for the congestion relief (the lowest curve in Figure A-10).

Figure A-11, respectively illustrates the total active losses for the whole MV distribution network presented in Figure A-3.

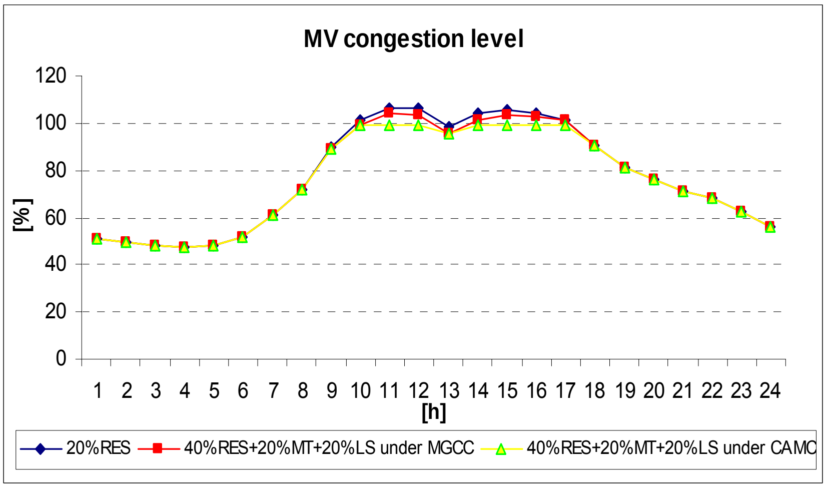

Figure A-10 Congestion level for the most congested MV line under MGCC and CAMC control level in periods of low market prices

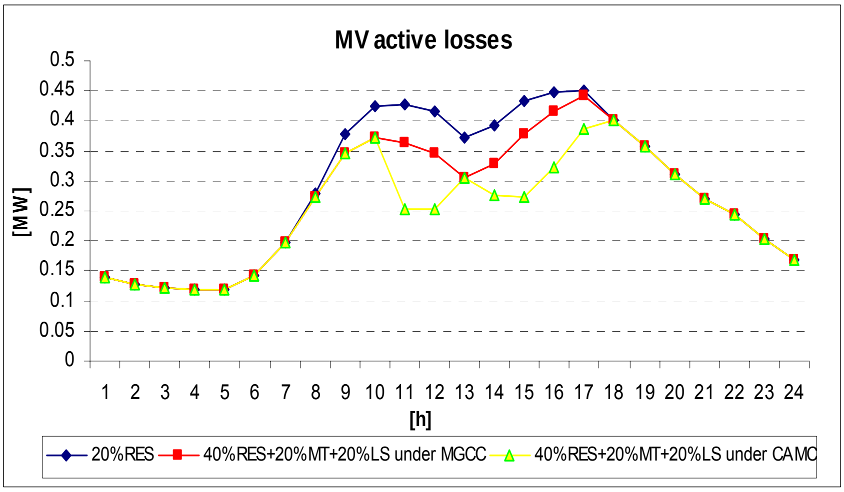

Figure A-11 MV active losses under MGCC and CAMC control level in periods of low market prices

Unlike the low electricity market prices period, high market prices yield controllable micro-generation dispatch under MGCC and controllable load responsiveness to the electricity market prices by shifting the controllable load to the next hour of acceptable electricity price (hour 16 and 17 in Figure A-12 and Figure A-13). Low electricity prices at these hours lead to reconnection of the controllable load (load shifting under MGCC, as presented in (1)) at those hours and therefore, what may occur is MV high congestion level for those hours. Thus, the optimization procedure (1) under CAMC is required to be activated in order to account for the congestion relief for the respective hours.

Figure A-13 illustrate the active losses for the whole MV distribution network. Likewise, reconnection of the controllable load at hour 16 and 17 accounts for losses increase (middle curve), whereas the bottom curves depicts the MV active losses after performing the optimization (1) under CAMC.

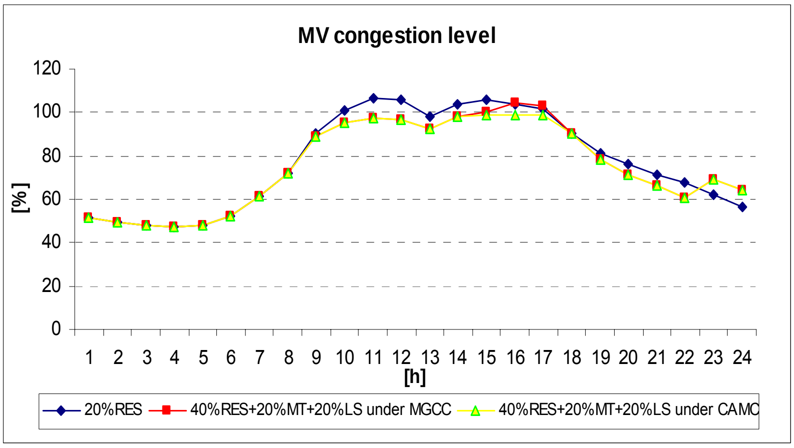

Figure A-12 Congestion level for the most congested MV line under MGCC and CAMC control level

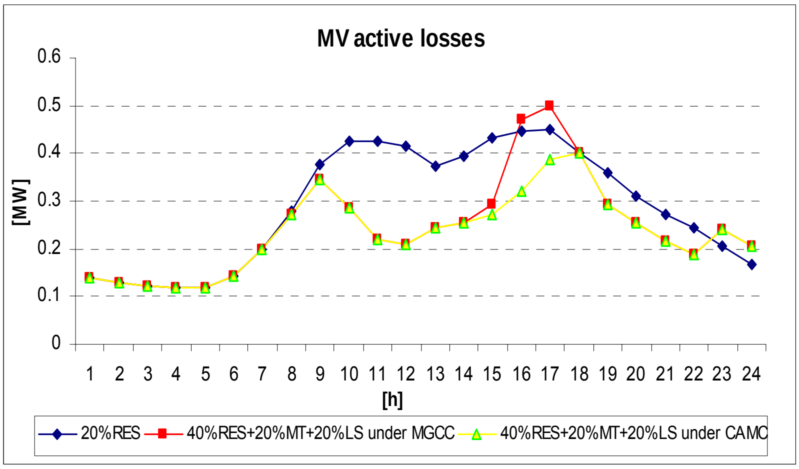

Figure A-13 Congestion level for the most congested MV line under MGCC and CAMC control level

1.5.2 Multi attribute assessment of the MMG impact deployment – evaluation of technical, economic and environmental benefits

The following section presents the attributes in terms of benefits of the multi attribute problem considered assessed using (1) for the scenarios and alternatives described previously.

Table A-2 Assessment of the attributes related with the benefits of MMG impact deployment for scenario I-IV

Scenario	Alternative	Investment Deferral(C2) [years]	Losses reduction(C3) [MWh]	CO_2 reduction(C4) [t]
Scenario I	A	0	0	0
	B	2	15.1	110.5
	C	3	31.0	186.1
	D	2	32.5	321.9
	E	4	64.5	540.2
	F	3	61.0	647.1
	G	4	77.4	741.7
Scenario II	A	0	0	0
	B	1	3.7	52.7
	C	3	21.4	183.5
	D	3	74.4	1128.6
	E	5	93.9	1413.3
	F	5	146.6	2422.8
	G	6	157.3	2642.6
Scenario IIII	A	0	0	0
	B	2	43.5	235.6
	C	4	103.0	620.3
	D	3	72.1	548.5
	E	4	119.9	869.7
	F	3	89.3	788.2
	G	4	137.1	1123.1
Scenario IV	A	0	0	0
	B	2	41.9	317.5
	C	4	84.8	721.6
	D	3	116.0	1563.9
	E	6	168.4	2180.4
	F	5	193.6	3089.2
	G	7	236.0	3691.0

Table A-3 Assessment of the attributes related with the benefits of MMG impact deployment for scenario V- VIII

Scenario	Alternative	Investment Deferral(C2) [years]	Losses reduction(C3) [MWh]	CO_2 reduction(C4) [t]
Scenario V	A	0	0	0
	B	1	12.2	64.7
	C	2	33.4	201.6
	D	1	22.3	249.0
	E	3	70.6	596.7
	F	2	59.9	628.1
	G	3	83.3	790.8
Scenario VI	A	0	0	0
	B	1	8.7	69.0
	C	2	22.2	185.3
	D	2	72.2	1090.9
	E	3	84.1	1213.4
	F	3	135.4	2260.2
	G	4	147.4	2413.7
Scenario VII	A	0	0	0
	B	1	36.8	202.6
	C	2	87.7	502.0
	D	2	68.4	528.1
	E	3	120.3	864.0
	F	2	86.0	759.5
	G	3	137.1	1113.4
Scenario VIII	A	0	0	0
	B	1	34.6	248.2
	C	2	70.2	567.9
	D	2	112.1	1512.3
	E	3	144.7	1865.9
	F	3	179.4	2880.5
	G	5	223.8	3493.4

Higher percentage of micro-generation (controllable and non-controllable) accounts for higher economical, technical and environmental benefits, in terms of investment deferral, LV and MV active losses reduction and CO2 reduction due to the displacement of upstream network units' production by the micro-generation units (controllable and non-controllable) within the Multi-Microgrid. Moreover, additional environmental benefits (in terms of CO2 reduction) can be reported due to active losses reduction. Winter time period (Scenarios I, III, V and VII) favours higher percentage of controllable micro-generation installed capacity (in low and high electricity prices periods) over the non-controllable (PVs) due to poor sun radiation during winter.

Deliverable DH3 within WPH presents results related with Multi-Microgrid installation and operational cost and use different MCDA techniques for capturing different Decision Maker's preference structures.

1.6 Conclusions

This deliverable deals with the evaluation of potential economic, technical and environmental benefits by deployment of the Multi-Microgrid concept at different distribution network control levels. Therefore, several control and management procedures need to be built at different distribution network dealing with different functions and constraints. Thus, a global optimization procedure has been built at Multi-Microgrid (MV) level to account for technical constraint violations, in terms of congestion levels and voltage drops at so called, stressed MV operating hours. A certain load growth and periods of low electricity market prices lead to a moment (hour) of high congestion level (above the allowable limit) for the typical urban LV and MV network (Figure 4 and 6, respectively) and therefore a need of performing an optimization procedure at CAMC control level (Multi-Microgrid network level). Activation of curtailment contracts for the controllable load within each Microgrid, and micro-generation dispatch under special contractual agreements between the DSO and the micro-generation owners accounts for the congestion relief for the worst branch at the worst hour during the year of study. Moreover, it leads to economical implication in terms of years of network investment deferral due to large scale integration of micro-generation under the control and management concept of Multi-Microgrids.

Furthermore, high electricity market prices yield controllable micro-generation dispatch and controllable load shifting at each MG network level (MGCC control level) due to price responsiveness and detection of overall benefits due to a local optimization procedure at each MGCC control level. Moreover, activation of load curtailment contracts for the controllable load within each MG and controllable micro-generation dispatch under CAMC may account for the technical constraint resolution (congestion relief) as well as in high market prices periods, due to a significant controllable load reconnection to an hour of low electricity market price (within the shift option, at each MGCC level).

In general, as it can be seen from Table II and III, higher percentage of micro-generation, controllable or not, leads to higher overall benefits. Moreover, winter time periods favours higher percentage of controllable micro-generation installed capacity (in low and high electricity prices periods) over the non-controllable (PVs) due to poor sun radiation during winter.

Identification and evaluation of costs due to Multi-Microgrids concept deployment is the next relevant task towards potential cost-benefit evaluation using MCDA techniques, described within DH3.

1.7 References

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2 Benefits to the Transmission System

2.1 The Portuguese Transmission System and Methodology of Analysis

This section describes several studies that were developed in order to assess the technical benefits for the Portuguese transmission system that may result from the integration of microgeneration at the distribution level. For this purpose a scenario of the year 2030 was considered. This study was developed with the concern to address namely active power losses reduction.

The main characteristics of the Portuguese transmission and generation systems are summarized in Table A-4 and Table A-5 and a scheme of the network is shown in Figure A-14.

Table A-4 Main Characteristics of the Portuguese Transmission Network

	Number
Buses	693
Loads	105
AC lines	754
Plants	201
Generation Units	296[1]
Transformers	419
Fixed shunts	41
AC Interconnections	9

(1) Each wind park was considered as one single generation unit

Table A-5 Generation Scenarios for the Portuguese Transmission System for the Year of 2030 and Corresponding Voltage Levels[1]

	2030	Target Network Level
Large Hydro	8 937	EHV/HV
Thermal	9 049	EHV
Coal	2 730	EHV
Oil	0	EHV
Oil/ Natural Gas	0	EHV
Diesel	0	EHV
Natural Gas	6 319	EHV
Special Regime Generation	16 879	EHV/HV/MV
Small Hydro	1 540	HV/MV
Co-generation	3 614	HV/MV
Biogas/Biomass	820	HV/MV
Urban Waste to Energy	405	HV/MV
Wind	9 000	EHV/HV
Photovoltaics	700	HV/MV/LV
Concentrating Solar Power	700	HV
Wave Power	100	HV
TOTAL	34 865	

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[1] Based on a Report on Security of Supply for Electricity Generation by REN, the Portuguese TSO, from April 2009 (in portuguese)

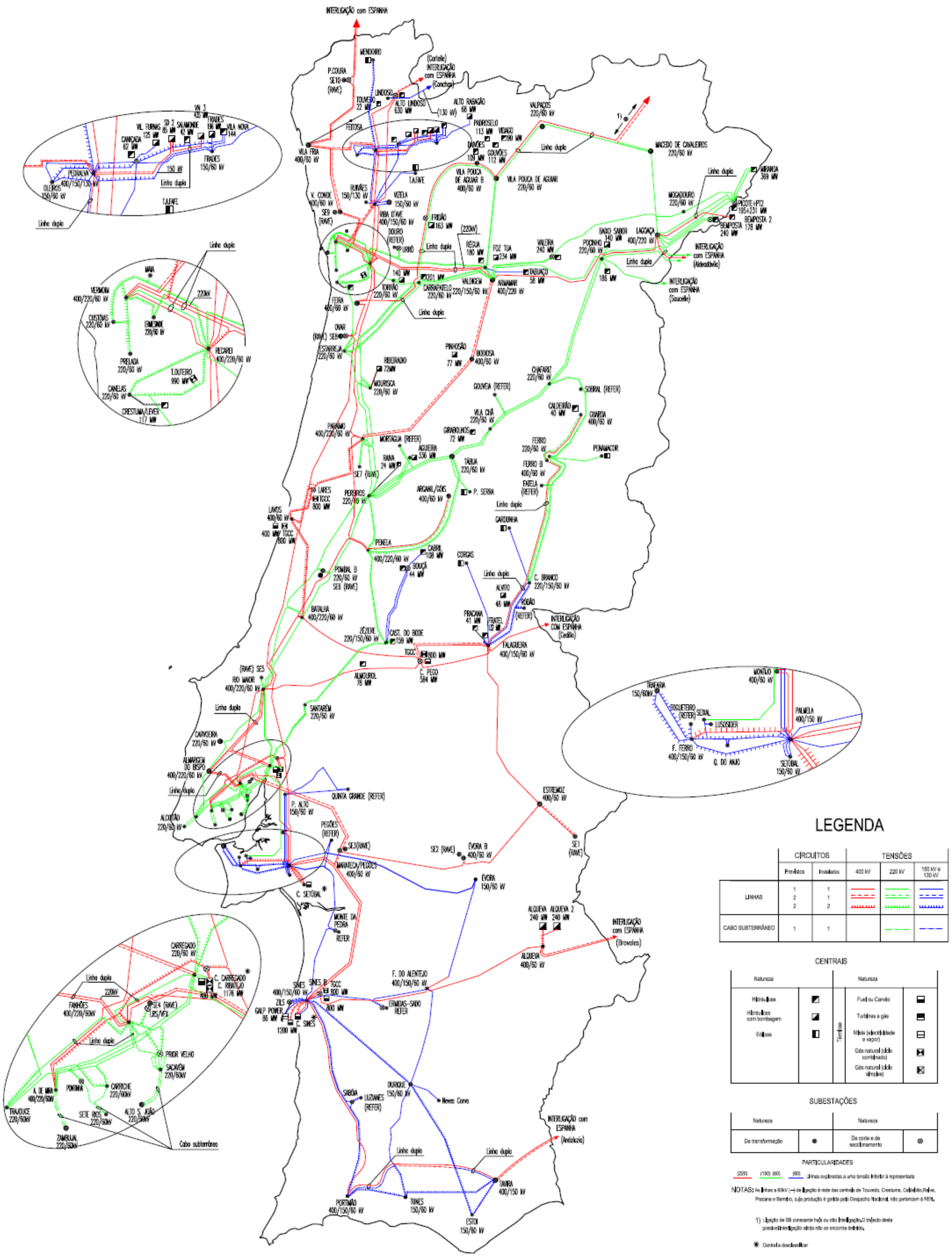

Figure A-14 Foreseen Structure for the Portuguese Transmission Network[2]

2.2 Definition of Scenarios

In order to evaluate these impacts, four operation scenarios representing typical operating conditions of the Portuguese transmission system for 2030 were considered as reference situations (base case considering no microgeneration

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[2] According to the Development and Investment Plan for the Transmission Network by REN, Portuguese TSO, from July 2008 (in portuguese)

penetration, *i.e.* µG = 0%). These scenarios are presented in Table A-6, and reflect foreseen scenarios for both Summer and Winter valley and peak load.

Table A-6 Base Scenarios for the Portuguese Transmission System for the Year 2030

Reference Scenarios	Active Power Load (MW)	Active Power Generation (MW)	Active Power Losses (MW)
Average Winter Peak Load	17 260.8	17 552.5	291.7
Average Winter Valley	6 852.6	6 929.0	76.4
Average Summer Peak Load	14 402.0	14 628.7	226.7
Average Summer Valley	5 491.0	5 552.5	61.5

In addition, these reference conditions were used to define new intermediate operating scenarios, to help reflecting the daily load diagram. Therefore, from both the Winter and Summer peak load, intermediate load scenarios (considering 50% and 75% of the Winter and Summer peak load, respectively) were also developed. Each year was then characterized by a typical Winter and by a Summer load profile with each one of these profiles characterized by 4 load values: valley, 50 % of peak load, 75 % of peak load and peak load.

The load conditions characterizing the Portuguese transmission system in 2030 were then used to create scenarios considering different levels of microgeneration integration. Hence, 4 different levels of penetration were considered: 0% 10%, 20% and 30%, as shown in Table A-7. The resulting 32 operation scenarios were simulated in order to evaluate the impact from the penetration of microgeneration in the Portuguese system.

Regarding microgeneration integration in the transmission grid, it was assumed that:

- In transmission distribution substations, the load can be generally divided into industrial (40%) and residential load (60%), being the microgeneration integration considered only regarding the residential load level;
- Microgeneration integration was simulated through a reduction in the residential load for each one of the previously defined scenarios;
- Each load scenario can be characterized by a certain time duration, which will allow the estimation of the overall annual benefit in terms of avoided energy losses.

Table A-7 Total Number of Scenarios for the Portuguese Transmission System 2030

Simulated Scenarios	Initial Active Power Load (MW)	Available µGeneration (MW)	Final Active Power Load (MW)
Average Winter Peak Load µG 0%	17 260.8	0.0	17 260.8
Average Winter Peak Load µG 10%	17 261.8	231.4	17 030.4
Average Winter Peak Load µG 20%	17 262.8	462.9	16 799.9
Average Winter Peak Load µG 30%	17 263.8	694.3	16 569.5
Average Winter Valley µG 0%	6 929.0	0.0	6 929.0
Average Winter Valley µG 10%	6 929.0	106.7	6 822.3
Average Winter Valley µG 20%	6 929.0	213.5	6 715.5
Average Winter Valley µG 30%	6 929.0	320.2	6 608.8
Average Summer Peak Load µG 0%	14 628.7	0.0	14 628.7
Average Summer Peak Load µG 10%	14 628.7	357.1	14 271.6
Average Summer Peak Load µG 20%	14 628.7	714.3	13 914.4
Average Summer Peak Load µG 30%	14 628.7	1 071.4	13 557.3
Average Summer Valley µG 0%	5 552.5	0.0	5 552.5
Average Summer Valley µG 10%	5 552.5	46.9	5 505.6
Average Summer Valley µG 20%	5 552.5	93.8	5 458.7
Average Summer Valley µG 30%	5 552.5	140.7	5 411.8

The values of available microgeneration presented in Table A-7 were obtained from the average Winter peak load scenario, assuming that the overall installed microgeneration capacity corresponds to 10% of the system's residential consumption which, in its turn, corresponds to 60% of the system's active power load directly connected to the transmission/distribution substations, as it can be seen in Table A-8.

Table A-8 Installed Microgeneration Capacity

	Active Power Load (MW)	Active Power Load 63 kV(MW)	Residential Consumption (MW)	Installed µGeneration (MW)
µG 0%	17 260.8	16 626.4	9 975.8	0.0
µG 10%	17 260.8	16 626.4	9 975.8	997.6
µG 20%	17 260.8	16 626.4	9 975.8	1 995.2
µG 30%	17 260.8	16 626.4	9 975.8	2 992.7

Table A-9 shows the contribution of each microgeneration technology (values in MW). The total installed microgeneration capacity was obtained considering different microgeneration mixes in typical rural and urban LV and MV networks. It was then assumed that 60% of the MV networks connected to the HV network were of the urban type and the remaining 40% were of the rural type in order to assess the influence of microgeneration penetration at the transmission system level.

In addition, it was considered the presence of Distributed Generation (DG) at the MV and HV level and the estimated levels of each DG technology for the year of 2030.

Table A-9 Technology Breakdown for Microgeneration Installed Capacity (MW)

	µG 10%	µG 20%	µG 30%
Total µG	997,6	1 995,2	2 992,7
CHP	179,6	359,1	538,7
Hydro	99,8	199,5	299,3
PV	618,5	1 237,0	1 855,5
Wind	99,8	199,5	299,3

In these simulations, it was assumed that each microgeneration technology has different contributions for each load period (peak and valley) and for Winter and Summer periods, according to the microgeneration daily production diagrams presented in the Deliverable DG1. As an example, the daily diagram for PV microgeneration is presented in Figure A-15.

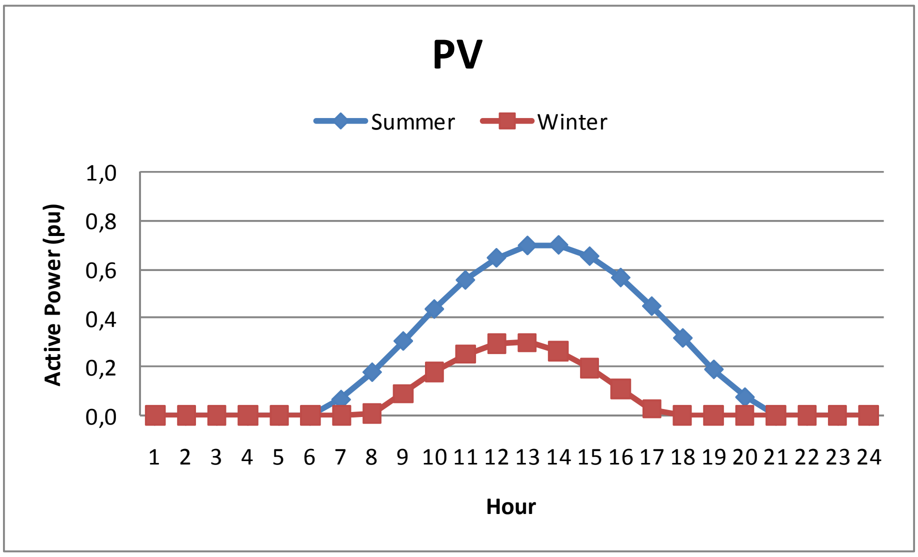

Figure A-15 Daily Generation Diagram for PV Microgeneration

Therefore, the contribution of each microgeneration technology was obtained by multiplying the percentage of microgeneration penetration by one hour of the daily diagrams for each technology corresponding to each of the periods of the day that are analysed: Peak, 75% Peak, 50% Peak and Valley.

2.3 Results

The main results obtained regarding active power losses in the network are presented in the following tables (results with values in MW).

Table A-10 Active Power Losses for Winter Peak Scenario

	µG Penetration			
Average Winter Peak Load	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	17 552,5	17 312,8	17 073,2	16 829,9
Total Active Power Load	17 260,8	17 029,4	16 797,9	16 566,5
Active Power Losses (2)	291,7	283,4	275,3	263,4
CHP Gen	,0	143,7	287,3	431,0
Hydro Gen	,0	59,9	119,7	179,6
PV Gen	,0	,0	,0	,0
Wind Gen	,0	27,9	55,9	83,8
TOTAL µGen	,0	231,4	462,9	694,3
(2) / (1)	1,69%	1,66%	1,64%	1,59%
Active Losses Reduction (%)		2,85%	5,62%	9,70%

Table A-11 Active Power Losses for Average Winter 75% Peak Load Scenario

	µG Penetration			
Average Winter 75% Peak Load	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	13 107,7	12 897,8	12 690,8	12 481,9
Total Active Power Load	12 945,6	12 740,7	12 535,8	12 330,9
Active Power Losses (2)	162,1	157,1	155,0	151,0
CHP Gen	,0	107,7	215,5	323,2
Hydro Gen	,0	59,9	119,7	179,6
PV Gen	,0	12,4	24,7	37,1
Wind Gen	,0	24,9	49,9	74,8
TOTAL µGen	,0	204,9	409,8	614,7
(2) / (1)	1,25%	1,23%	1,24%	1,22%
Active Losses Reduction (%)		3,08%	4,38%	6,85%

Table A-12 Active Power Losses for Average Winter 50% Peak Load Scenario

	µG Penetration			
Average Winter 50% Peak Load	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	8 762,3	8 476,1	8 187,7	7 899,0
Total Active Power Load	8 630,4	8 346,1	8 061,8	7 777,5
Active Power Losses (2)	131,9	130,0	125,9	121,5
CHP Gen	,0	71,8	143,7	215,5
Hydro Gen	,0	59,9	119,7	179,6
PV Gen	,0	123,7	247,4	371,1
Wind Gen	,0	28,9	57,9	86,8
TOTAL µGen	,0	284,3	568,6	852,9
(2) / (1)	1,53%	1,56%	1,56%	1,56%
Active Losses Reduction (%)		1,44%	4,55%	7,88%

Table A-13 Active Power Losses for Winter Valley Scenario

		µG Penetration		
Average Winter Valley	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	6 929,0	6 821,6	6 710,9	6 602,8
Total Active Power Load	6 852,6	6 745,9	6 639,1	6 532,4
Active Power Losses (2)	76,4	75,7	71,8	70,4
CHP Gen	,0	18,0	35,9	53,9
Hydro Gen	,0	59,9	119,7	179,6
PV Gen	,0	,0	,0	,0
Wind Gen	,0	28,9	57,9	86,8
TOTAL µGen	,0	106,7	213,5	320,2
(2) / (1)	1,11%	1,12%	1,08%	1,08%
Active Losses Reduction (%)		0,92%	6,02%	7,85%

Table A-14 Active Power Losses for Summer Peak Scenario

		µG Penetration		
Average Summer Peak Load	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	14 628,7	14 258,4	13 889,3	13 520,2
Total Active Power Load	14 402,0	14 044,9	13 687,7	13 330,6
Active Power Losses (2)	226,7	213,5	201,6	189,6
CHP Gen	,0	143,7	287,3	431,0
Hydro Gen	,0	10,0	20,0	29,9
PV Gen	,0	185,6	371,1	556,7
Wind Gen	,0	18,0	35,9	53,9
TOTAL µGen	,0	357,1	714,3	1 071,4
(2) / (1)	1,57%	1,52%	1,47%	1,42%
Active Losses Reduction (%)		5,82%	11,07%	16,37%

Table A-15 Active Power Losses for Average Summer 75% Peak Load Scenario

		µG Penetration		
Average Summer 75% Peak Load	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	10 930,4	10 660,1	10 390,6	10 122,4
Total Active Power Load	10 801,5	10 537,1	10 272,8	10 008,4
Active Power Losses (2)	128,9	123,0	117,8	114,0
CHP Gen	,0	107,7	215,5	323,2
Hydro Gen	,0	5,0	10,0	15,0
PV Gen	,0	123,7	247,4	371,1
Wind Gen	,0	27,9	55,9	83,8
TOTAL µGen	,0	264,4	528,7	793,1
(2) / (1)	1,19%	1,17%	1,15%	1,14%
Active Losses Reduction (%)		4,58%	8,61%	11,56%

Table A-16 Active Power Losses for Average Summer 50% Peak Load Scenario

		µG Penetration		
Average Summer 50% Peak Load	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	7 276,7	6 921,2	6 566,6	6 215,4
Total Active Power Load	7 201,0	6 850,8	6 500,7	6 150,5
Active Power Losses (2)	75,7	70,4	65,9	64,9
CHP Gen	,0	71,8	143,7	215,5
Hydro Gen	,0	5,0	10,0	15,0
PV Gen	,0	247,4	494,8	742,2
Wind Gen	,0	25,9	51,9	77,8
TOTAL µGen	,0	350,2	700,3	1 050,5
(2) / (1)	1,05%	1,03%	1,01%	1,06%
Active Losses Reduction (%)		7,00%	12,95%	14,27%

Table A-17 Results for Active Power Losses for Summer Valley Scenario

		µG Penetration		
Average Summer Valley	**0%**	**10%**	**20%**	**30%**
Total Generation (1)	5 552,5	5 504,9	5 457,1	5 409,3
Total Active Power Load	5 491,0	5 444,1	5 397,2	5 350,3
Active Power Losses (2)	61,5	60,8	59,9	59,0
CHP Gen	,0	18,0	35,9	53,9
Hydro Gen	,0	10,0	20,0	29,9
PV Gen	,0	,0	,0	,0
Wind Gen	,0	19,0	37,9	56,9
TOTAL µGen	,0	46,9	93,8	140,7
(2) / (1)	1,12%	1,12%	1,11%	1,10%
Active Losses Reduction (%)		1,14%	2,60%	4,07%

From the previous tables, it can be seen that increasing microgeneration integration at the LV level can have a considerable impact on the Portuguese transmission system in terms of active losses reduction. In the most favourable case – Summer Peak scenario, shown in Table A-12 – more than 15% of active power losses reduction can be achieved.

In general, Peak scenarios lead to a bigger reduction in active power losses. Of course, this depends heavily on the technology mix considered for microgeneration and on the load profiles.

Finally, an analysis of the overall energy losses within a full year was made. In order to calculate the total annual energy losses, it was considered that 50% of the year corresponded to Winter scenarios (182,5 days) and the remaining 50% of the year corresponded to Summer scenarios (again 182,5 days).

In addition, the scenarios presented for both Winter and Summer (corresponding to Peak load, 75% Peak load, 50% Peak load and Valley) were distributed according to the hours of a full day as shown in Table A-18.

Table A-18 Hours for each Scenario in a Day

Periods of the Day (hours)			
Valley	50% Peak	75% Peak	Peak
8,0	7,0	6,0	4,0

Therefore, the total annual energy losses were estimated in the transmission system considering the base case with no microgeneration and 10%, 20% and 30% of microgeneration penetration as defined previously.

Table A-19 shows the values in MWh of annual energy losses considering the different levels of microgeneration integration.

Table A-19 Total Annual Energy Losses

	μG Penetration			
	0%	10%	20%	30%
Energy (MWh)	1163 620,0	1124 747,5	1084 159,5	1047 915,0

Figure A-16 illustrates the reduction in percentage of the annual energy losses according to the microgeneration penetration level.

Assuming that the losses in the Portuguese transmission system are around 2%, considering 30% of microgeneration penetration this figure can be reduced to 1,8%.

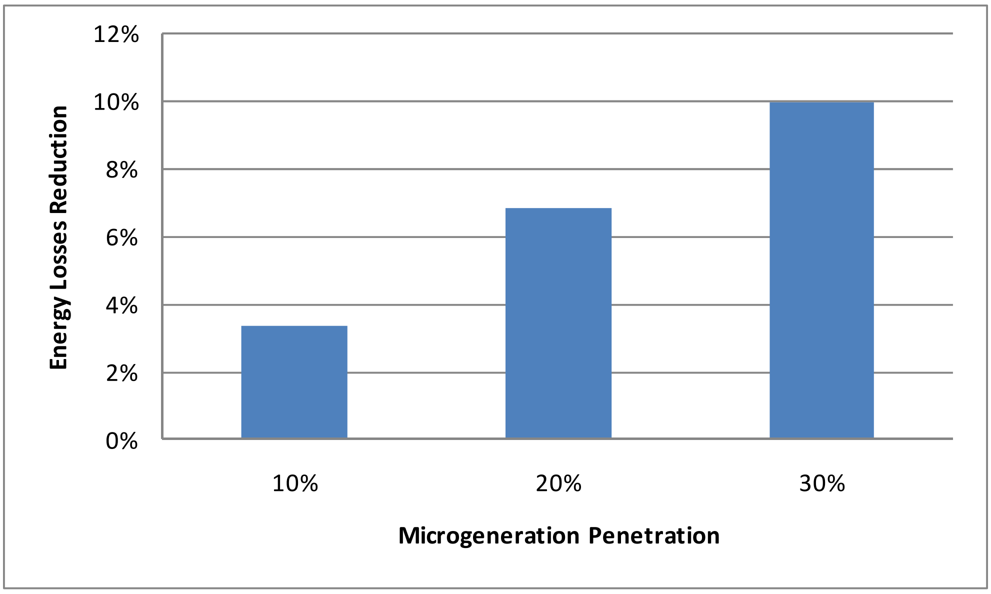

Figure A-16 Annual Energy Losses Reduction

2.4 Conclusions

From the results obtained, it can be seen that the influence on active power losses resulting from the presence of microgeneration at the distribution level is significant and grows with the percentage of microgeneration. In terms of annual energy losses in the transmission system can be reduced up to 10%, namely when the microgeneration penetration reaches 30% of the peak load of the domestic consumption. Such benefits clearly demonstrate the positive effects that microgeneration might bring to the transmission system resulting from the effect of load reduction at the distribution level.