Generic Test Network Model for Scalability and Replicability Analysis on the DeCAS Project

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Abstract. *The main aim of this paper is to present test network model to be used within European project DeCAS by individual pilot sites to demonstrate replicability and scalability of proposed solutions and results. The main objective of the DeCAS project is to research and analyse the coordination of ancillary services such as, aggregated demand response, individual voltage control and reactive power management concepts over traditional boundaries from high voltage (HV), medium voltage (MV) to low voltage (LV).*

1 Simulation Model Description

The simulation model is one of the results of an European project DeCAS (Demonstration of Coordinated Ancillary Services covering different Voltage Levels and the Integration in Future Markets) [1, 2].

The simulated test network covers all elements between the transmission (220 kV) level, distribution (110 kV and 20 kV) level and the LV connection points. A 110 kV looped grid is supplied from two sides, with two three-winding 220/110 kV transformers.

At the MV level, two feeders (rural and urban) were modelled in details, representing the generic model of two typical feeders. The consumption of other MV feeders was determined by appropriate scaled equivalent loads.

At the LV level, several LV (radial) feeders were modelled in details to represents the situation in rural and urban LV networks. The consumption of other LV networks that were not modelled in details was determined by scaled equivalent LV loads.

1.1 HV Network

Modelled HV network is supplied with a slack bus. In order to observe the variables in the HV net-work, one 110 kV loop has been modelled. Underlying MV networks are supplied through this HV loop. Topology of the proposed HV network is presented in Figure 1.

1.2 MV Network

To illustrate a typical situation in the MV network, the transformer station was modelled with two generic radial feeders:

– Rural (OH) feeder and
– Urban (cable) feeder.

The following line parameters have been considered:

Rural line	Urban line
Type: Al/Fe 70/12	Type: NA2XS(F)2Y 1x150RM
U_r = 20 kV	U_N = 12/20 kV
I_r = 290 A	I_N = 309 A
r = 0,413 Ω/km	r = 0,210 Ω/km
x = 0,362 Ω/km	x = 0,122 Ω/km
	b = 79,796 S/km

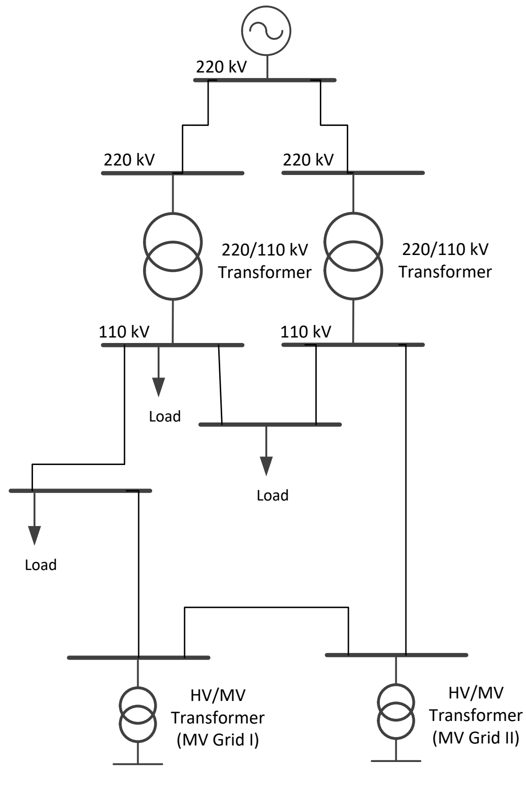

Figure 1: Modelled HV network single-line diagram.

U_r being the nominal voltage, Ir the nominal current, r series resistance per km, x series reactance per km and b parallel susceptance.

The length of the rural feeder is 8 km, which represents a typical length of a rural feeder, where larger (400 kVA) transformers (5 in total) are uniformly distributed along the beginning of the feeder, followed by 13 transformers of 250 kVA and 4 transformer with a nominal power of 160 kVA. Transformers towards the end of the feeder are supplying remote small settlements, with low consumption.

The length of the urban feeder is 2 km, with 400 kVA transformers (10 in total) uniformly distributed along the feeder.

Rural feeder mainly supplies household consumers, while a portion of industrial or business consumers is attached to the urban feeder (approximately 30% of total consumption).

The MV network modelled in DIgSILENT PowerFactory v.2017 software is shown in Figure 2.

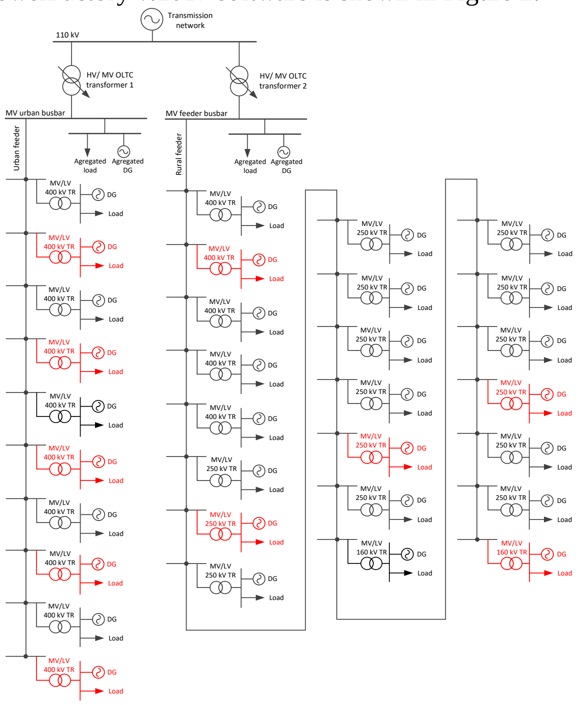

Figure 2: Single-line diagram of a MV distribution network with two feeders. At the point, where the transformer stations are reddish, LV networks are modelled in details.

1.3 LV Rural Network

Individual LV radial feeders are supplying 70 customers and are connected to the rural MV network at different points along the feeder.

The main conductors have a cross-section of 70 mm^2, more distant conductors are 35 mm^2 and 16 mm^2. The total lengths of conductors of all feeders are as follows:

- 3.000 m conductors with a cross-section of 70 mm2,
- 1.000 m conductors with a cross-section of 35 mm2,
- 1.500 m conductors with a cross-section of 16 mm2.

The following line parameters have been considered:

X00/0-A 70 (NFA2X)	X00/0-A 35 (NFA2X)	X00/0-A 4x16 (NFA2X)
U_N = 0,6/1 kV	U_N = 0,6/1 kV	U_N = 0,6/1 kV
I_N = 223 A	I_N = 142 A	I_N = 91 A
r = 0,496 Ω/km	r = 0,972 Ω/km	r = 2,139 Ω/km
x = 0,100 Ω/km	x = 0,100 Ω/km	x = 0,100 Ω/km

In contrast to the MV network, the loading of lines vary considerably over time. The rural network supplies only household consumers.

1.4 LV Urban Network

Individual radial feeders of urban LV (cable) network are connected to the MV urban feeder at different points along the feeder. Consumption is more concentrated than in the rural case, and the feeders are shorter and amount to about 400 m. The following data has been used:

Type: PP 00-A 4x70 (NAYY)

U_r = 0,6/1 kV

I_r = 175 A

r = 0,444 Ω/km

x = 0,075 Ω/km

b = 254,5 S/km

The network supplies both, household and business customers.

In both cases, with the rural and urban LV networks, the transformers tap positions are set so that the nominal voltage at the LV busbar in the transformer station is always achieved, thus allowing a 10 % voltage drop in the LV network.

2 Generation of Load and DG Profiles

For modelling the loads, real measured 15-minute load data of LV customers were used. The measurement data contains 1 year load profiles of 3000 consumers. For each transformer station, the required number of consumers is set in such a way that in winter times, when a peak in demand is reached, the transformer is loaded with approximately 75 %.

The aggregated household consumption differs from the business or industrial load especially in a clear eveningpeak (see Figure 3). In the case of other types of loads, the peak demand occurs during working hours. As mentioned, in the urban network, 70 % of the consumption is modelled as household loads and the rest 30 % as a combination of business and industrial loads.

In terms of voltage dependence, loads are modelled as constant power type of load and operate with cosφ = 0,95.

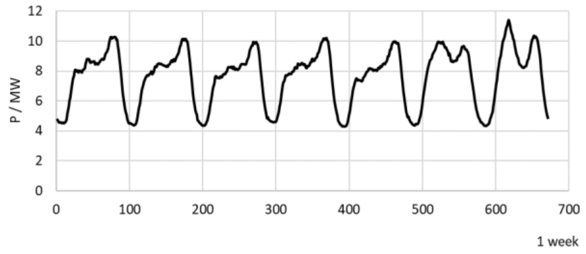

Figure 3: Week diagram of 3000 household loads.

Simulations can be performed for different days of the week (or for several days) and for different seasons. Household consumption is higher during the weekends, whereas industrial consumption is generally lower during the weekends. There are also some other differences.

The time of the year for which we are preforming the simulations is also important. In winter, consumption is high and production from solar power plants (PV system) is low, and in the summer it is the opposite, consumption is lower, and production from DG is higher. An example of one-week production of a 10 kW

solar power plant is shown in Figure 4, where we can see how production can vary within one week.
Similarly to load diagrams, measured data was also used to model the PV sources. Diagrams for the production of solar power plants are based on yearly measured production diagrams with appropriate scaling of power. In the analysis, only PV sources were taken into account, since they represent the majority of DG in distribution networks, taking into account that the rated power of each PV source is 10 kW.

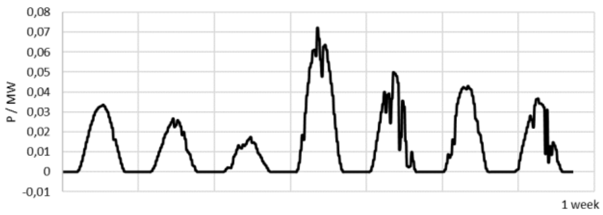

Figure 4: Example of a one-week production diagram from a solar power plant

3 Simulation Procedure

Load flow simulations can be performed on the network model presented in previous chapters. Several loads are connected to the MV network, which represent the consumption of individual transformer stations. In order to analyse the situation on the LV level, at different locations along the MV feeder, several LV feeders (urban and rural) were modelled in details. One- or several-days simulations of all networks (MV and LV) are carried out simultaneously.
The process of calculating the LF simulations roughly follows the following steps:
1. A network model is developed in a simulation program.
2. Load consumption and PV production diagrams for one or several days with a resolution of 15 min are generated with Matlab file LoadPVGenerator.m.
a. Randomly, but with certain limitations, the consumption of loads is determined and the PV units are placed in the network.
3. The load flow is calculated for all the operation points.
4. The simulation results (voltages, power flow etc.) for every simulation time step are saved into an excel file.
Simulations can be made for different days of the week and for different seasons. The results below represent the situation for a winter day, as the most severe season.

4 One-Day Simulation Results

4.1 MV feeders

The maximum voltage drop that occurs on the MV rural feeder is about 4 % and maximal power consumption of the feeder about 3 MVA. Both number represent a realistic situation on the MV level.
The maximum voltage drop occurring on the MV urban feeder is about 0,8%, with a maximal power flow of 2 MVA.
Despite the fact that permitted voltage drop in the MV network is 7.5 %, in reality, such high values normally do not occur. In reality, 5% drop in voltage is already a very high value.
In the MV transformer station there is also a generic load and generation connected to the MV busbars. The power of the generic load on the rural feeder is about 10,5 MVA, and on the urban feeder 14,5 MVA.
The 20 kV network is connected to the 110 kV level via a 31,5 MVA OLTC transformer, with ± 12 taps of 1,33% U_n each. The reference voltage on the secondary side of the OLTC transformer is 1,03 p.u.

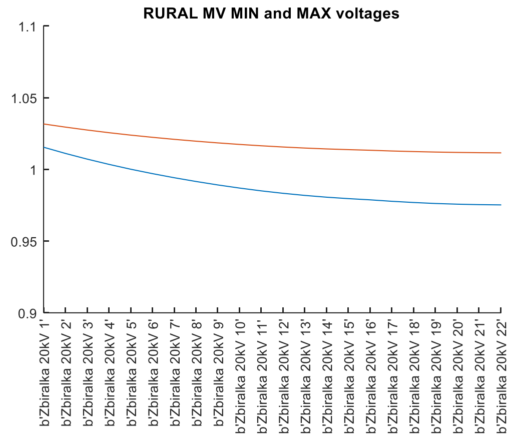

Figure 5: MIN and MAX voltages of individual MV busbars – rural feeder.

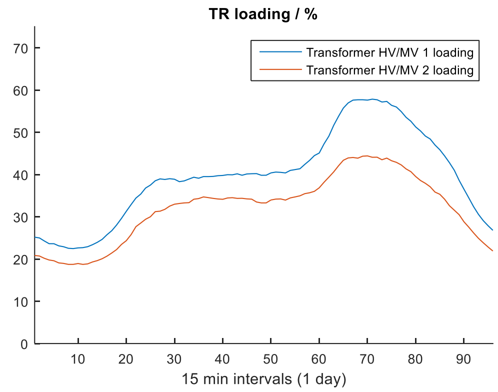

Figure 6: Loading of HV/MV transformers.

4.2 LV rural feeders

Below in Fig. 7 are power flow results for transformer station no. 19 on the rural MV feeder. The maximum power flowing through the transformer is about 125 kVA, which means 78 % of the peak load. The highest voltage drop is app. 6,9 % (Fig. 3.9).

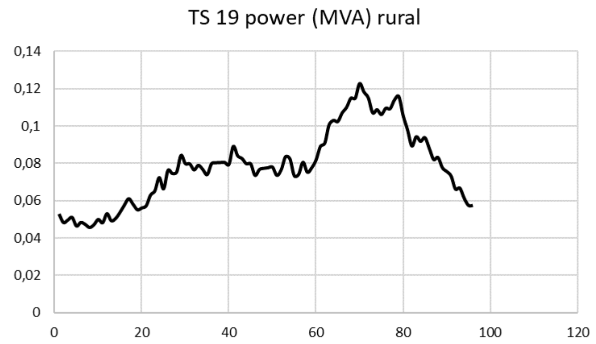

Figure 7: MV/LV transformer no. 19 (rural feeder) load flow data.

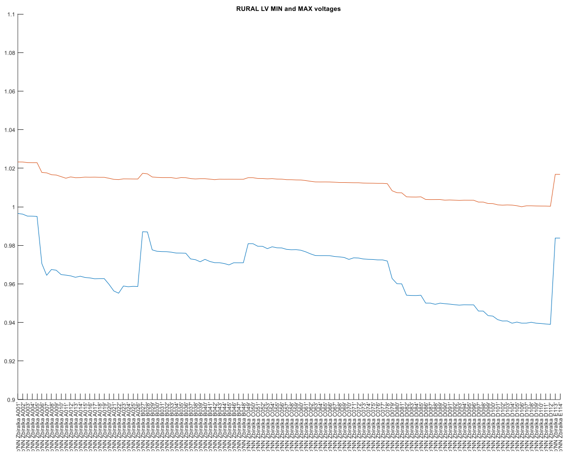

Figure 8: MIN and MAX voltages of individual LV busbars – rural feeder.

4.3 LV urban feeders

Below in Fig. 9 are power flow results for transformer station no. 10 on the urban MV feeder. The maximum power flowing through the transformer is about 226 kVA, which means 57 % of the peak load. The highest voltage drop is app. 1,8 %.

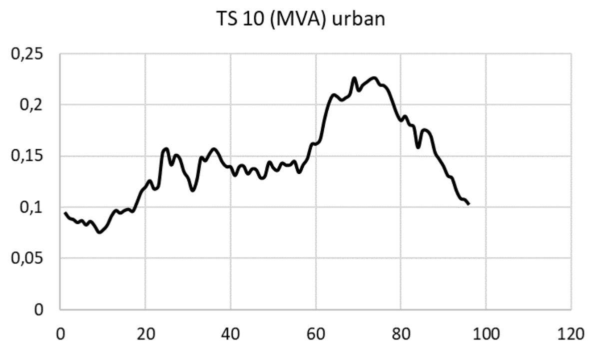

Figure 9: MV/LV transformer no. 10 (urban feeder) load flow data.

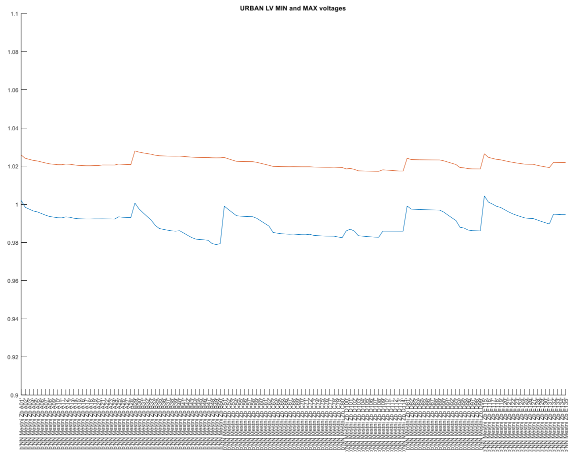

Figure 3.10: MIN and MAX voltages of individual LV busbars – urban feeder.

5 Conclusions

In this paper a generic test network model was presented, which was used within the DeCAS project for scalability and replicability analysis of individual pilot action's outputs.

Literature

[1] Fingrid, 'Supply of Reactive Power and Maintenance of Reactive Power'. .

[2] 'DeCAS project'. [Online]. Available: decas-project.eu. [Accessed: 05-Dec-2017].