



Deliverable D4.3 – C1

Grid Impact studies of electric vehicles

ITRES

Tool for assessing the technical and economic impact of electric vehicles on distribution networks

User Manual

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1 Introduction

This document describes the ITRES¹ tool that Imperial College London has developed in the Green eMotion project as part of D4.3 Grid Impact studies of electric vehicles. As illustrated in Figure 1.1, this user manual together with the calculation tool itself constitutes a part of Deliverable 4.3 denoted as C1 (Tool kit).

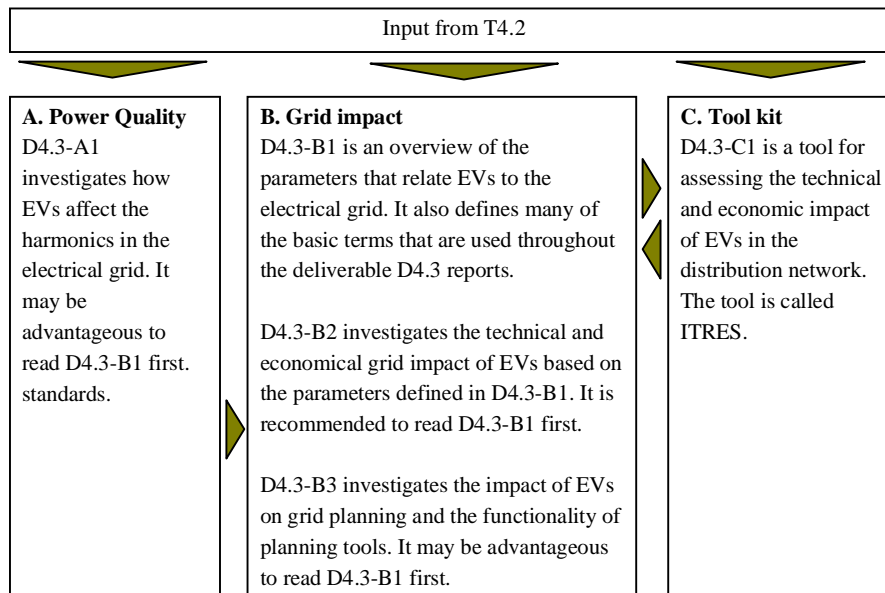


Figure 1.1 Overview of Deliverable 4.3

ITRES tool has been used for calculating the necessary reinforcement of LV distribution networks in Deliverable 4.3 – B2: Grid impact studies of electric vehicles. During their work on D4.3-B2 DEA developed a Calculation Guide to assist future users of the tool in preparing their input data for ITRES calculations. The Calculation Guide and the associated Excel data template are therefore distributed as accompanying documents with ITRES installation file and this manual.

ITRES has been designed to quantify the impact of a significant uptake of electric vehicles (EVs) on the need for reinforcements in a specific LV distribution network, and hence to facilitate the network planning process in the context of accommodating a high number of EVs. The reinforcement needs are quantified over the time-horizon of up to 25 years, with the possibility to consider alternative EV charging strategies.

The key purpose of the tool is to enable the partners in the project to analyse the impact of different EV uptake levels and charging policies on the local LV distribution network, particularly in the demo-regions. Furthermore, this will also enable the benefits of alternative smart charging policies to be evaluated on specific LV networks.

This document describes the functionality of the ITRES tool and provides instructions for its installation and use. It specifies the input requirements and templates for data entry, while

¹ ITRES = Imperial Tool for REinforcement Simulations.

also describing the user interface and the key results and outputs. The organisation of the document is as follows: Section 2 provides an overview of the ITRES tool. Section 3 addresses the installation and system requirements. Input data and the relevant templates are presented in Section 0. Section 0 describes the user interface where the execution of the tool is controlled. Section 0 discusses the methodology and implementation for reinforcement calculation, and Section 0 presents the key outputs of the tool. Finally, the contents of the End-User Licence Agreement for the ITRES tool are presented in the Appendix.

2 Tool overview

The ITRES tool quantifies the impact of alternative charging strategies and different uptakes of EVs on the reinforcement of a specific LV distribution network. The tool is primarily intended to be used in Green eMotion demo-regions.

Reinforcement calculations in ITRES are carried out based on a positive sequence load flow algorithm (i.e. assuming perfectly balanced load), as well as on deterministic projections of future EV load and baseline demand. Therefore, it cannot be directly used to calculate reinforcements in unbalanced load conditions, however with the appropriate adjustments of the input data the model could be extended to run separate phase-by-phase calculations. It also does not explicitly handle uncertainty in its current form (apart from the possibility to run different future scenarios in separate models runs).

Three different modes of operation are available when using the tool for reinforcement calculations. These modes enable the user to select the level of granularity which corresponds to the available data. The modes are as follows:

- (i) **Mode A** requires the user to provide detailed load profiles with hourly values of active and reactive power for the peak day in a given LV network. These profiles should be given for the existing non-EV load, as well as for the user-specified EV charging profiles in every node in the network and for every year considered in the study period of up to 25 years (see Figure 2.1).
- (ii) **Mode B1** requires the user to supply the existing load profiles (hourly active and reactive power for the peak day) in year 1, and then specify their growth rate over the study period. The evolution of EV penetration is input as the number of EVs present in the network in each year of the study period. In this mode three different charging profiles can be associated with the EVs on the network (Figure 2.2). Unlike in Mode A, different possibilities for the allocation of EVs across the network can be analysed, which may be particularly relevant for testing voltage-driven constraints and the impact of feeder-tapered LV network design approaches.
- (iii) **Mode B2** requires the same data for existing load as Mode B1. EV uptake is defined by the total number of vehicles in the network in each year of the study period. EV load patterns are defined through average daily profiles (per vehicle), which vary depending on the number of EVs in the network (Figure 2.3). Similar to Mode B1, different possible allocations of EVs across the network can be analysed.

There are four sets of input data required for using the ITRES tool:

- LV network data, containing the network topology and electric parameters of network elements
- Cost of network assets (differentiating between underground and overhead feeder sections and corresponding asset ratings)
- Existing load profiles for the relevant peak day (hourly active and reactive power)
- EV charging profiles (hourly active and reactive power)

Depending on the granularity of the input data associated with load and EV charging that a user is able to provide, the tool can run in Mode A, Mode B1 or Mode B2. Based on the selected mode and the parameters of the low-voltage distribution network under study, the tool evaluates network power flows and voltage profiles for each hour of the peak day and each year in the time horizon specified. As part of this process the tool identifies any violations of thermal and voltage constraints. If there are constraints that are violated, appropriate network reinforcement solutions will be selected and implemented. In Modes B1 and B2 it may be relevant to consider alternative allocations of EV across the network. The output of the analysis contains the volumes of voltage and thermal-driven network reinforcement required along with the associated costs for each year in the time horizon studied. Inputs and outputs for the three execution modes of the ITRES tool are presented in Figure 2.1 to Figure 2.3.

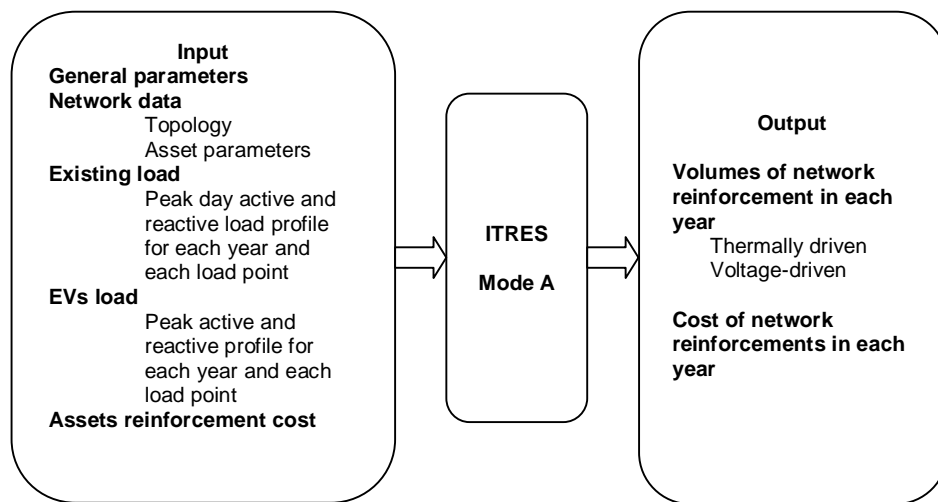


Figure 2.1 Execution Mode A

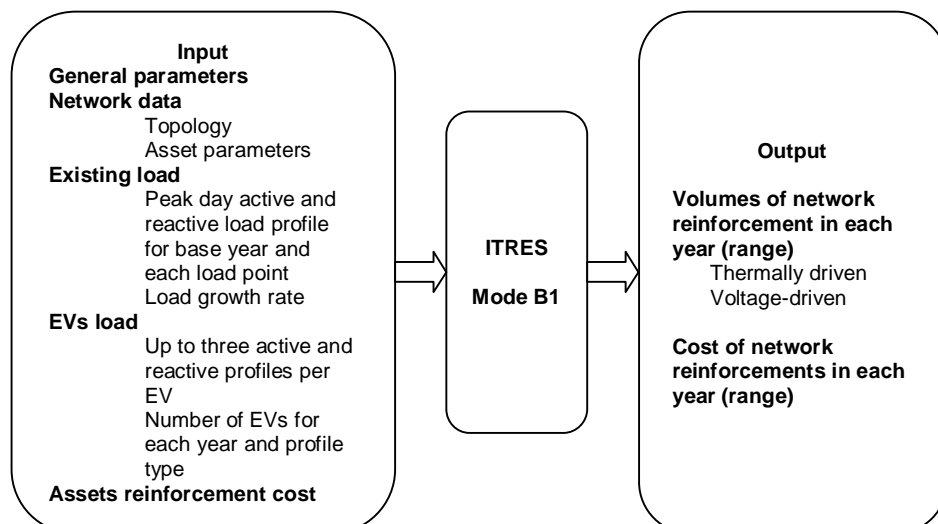


Figure 2.2 Execution Mode B1

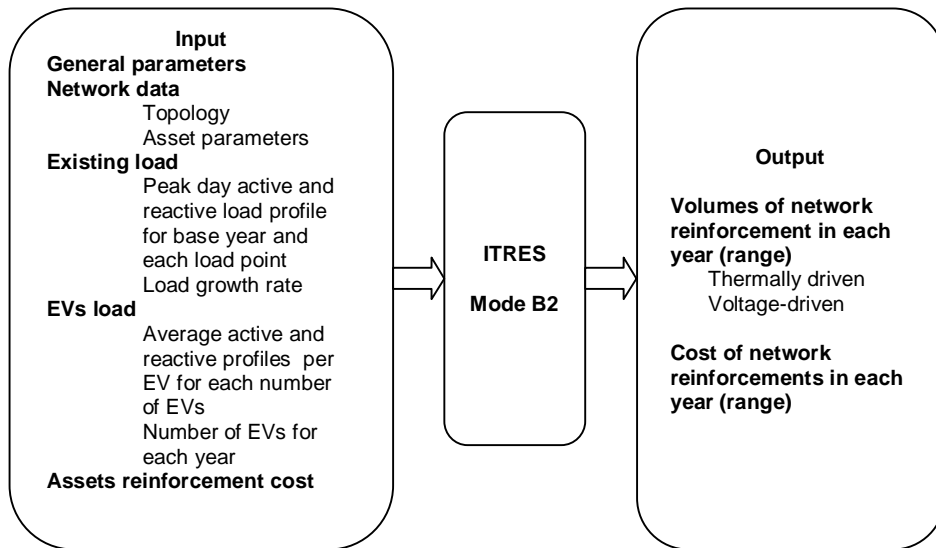


Figure 2.3 Execution Mode B2

The ITRES tool enables the user to understand and quantify the impact of different user-defined EV charging strategies on network reinforcement requirements and the corresponding investment profiles over the time horizon considered. The tool will therefore enable the evaluation of benefits of smart EV charging policies on any LV network of interest. An overview diagram of the ITRES tool is provided in Figure 2.4.

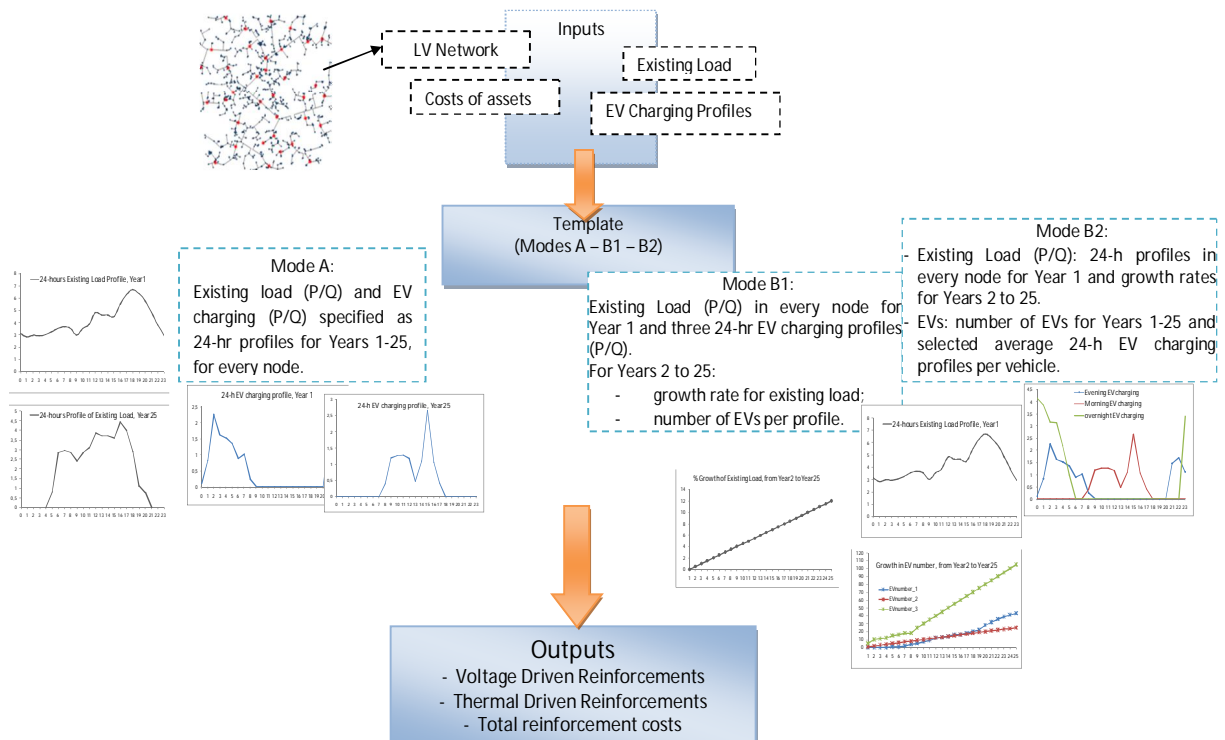


Figure 2.4 Overview of ITRES tool inputs and outputs

3 Installation and system requirements

ITRES software tool is installed by starting the associated executable setup file (“ITRES...setup.exe”) provided by Imperial College London as part of the installation package. The operating system required to install and use the model is Windows, version XP or later (e.g. Vista or Windows 7), and it is also required to have Microsoft Office 2007 or later installed on the computer.

Running ITRES requires that Microsoft .NET Framework Client Profile version 3.5 or higher is installed on the machine. Windows 7 already includes .NET Framework 3.5, while for earlier versions the framework can be freely downloaded from Microsoft’s website.²

The screenshots presented in this chapter are based on the installation onto Windows XP. The actual interface may look slightly different when ITRES is installed on other versions of Windows.

Terms and conditions for installing and using the ITRES software are defined by the Imperial College London’s End User License Agreement (see Appendix), which needs to be accepted by the user before installing the software.

After running the setup file, the ITRES installer shows the “Preparing to Install” dialog box during the initial phase of installation, which is followed by a welcome window (Figure 3.1). The user proceeds by clicking “Next”.



Figure 3.1 ITRES installation – welcome screen

In the next step the user is required to accept the terms of the EULA in order to be able to proceed with the installation of the ITRES tool by clicking “Next” (Figure 3.2).

² Microsoft .NET Framework 3.5 Client Profile can be downloaded from <http://www.microsoft.com/en-gb/download/details.aspx?id=14037>. Alternatively, the latest version of the .NET Framework can be downloaded from <http://www.microsoft.com/net/downloads>.



Figure 3.2 Accepting the ITRES EULA

In the next step the user specifies the installation folder (or continues with the default option), as shown in Figure 3.3. Upon installation, the ITRES folder will contain the executable file ITRES.exe, which starts the user interface described in Section 0. The installation folder will also contain a subfolder named “Templates”, which will contain Excel templates for all three types of input files (i.e. for modes A, B1 and B2), as well as the template for the extended asset data table (see Section 5.2).

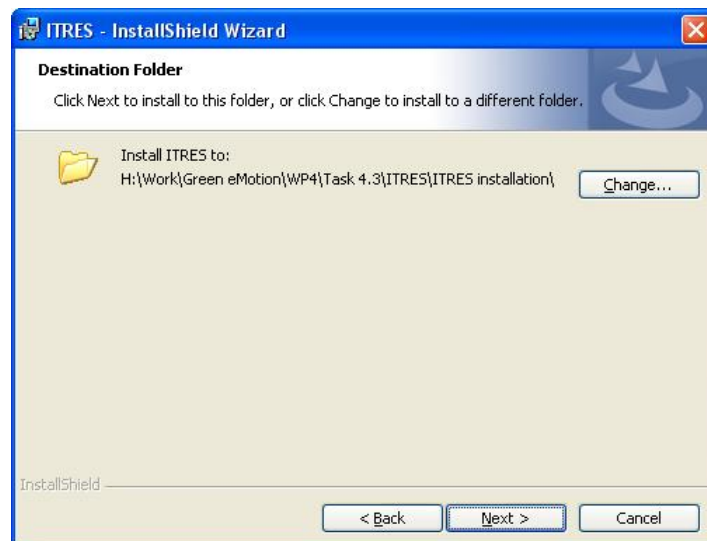


Figure 3.3 Selecting the installation folder

Figure 3.4 shows the “Ready to Install” dialog box that is displayed in the next step. The user should then click “Install” in order to proceed with the installation. If the “User Account Control” dialog box appears (in Windows Vista and later), the user should provide his/her administrative credentials and click Yes.



Figure 3.4 Installing the ITRES tool

The “Setup Progress” dialog box is shown during the installation and at the end the user is informed that the installation is complete, as shown in Figure 3.5. The user should click on “Finish” to complete the installation.



Figure 3.5 Completed installation

Shortcuts for starting ITRES and for uninstalling the software are added to the Start Menu under the “Imperial College” folder. Alternatively, to repair or remove ITRES, one can use the “Add/Remove Programs” or “Programs and Features” section of the Control Panel, depending on the Windows version.

4 Input data templates

This section presents and discusses the input requirements of the ITRES tool. The required inputs include the complete network topology with electrical parameters, non-EV load and EV charging demand, and costs of the individual network assets.

The input data is organised using an MS Excel template with multiple datasheets. Each datasheet contains a specific data set as follows:

1. Main
2. Network
3. Existing load
4. EV
5. Costs

As indicated in the previous section, three different modes of data entry are enabled for the existing load and EV charging – Mode A, Mode B1 and Mode B2.

4.1 Main datasheet

The table in the Main datasheet contains general information needed to execute a case study (Table 4.1). This includes the time horizon of the study (number of years in the study period), reference voltage values at the distribution substation, voltage limits, and power and voltage base values used for converting impedances into per-unit values.³

Table 4.1 Main datasheet table

Parameter	Value	Comment
Time horizon considered (years)	25	Value from 1 to 25
Voltage at transformer LV busbar (p.u.)	1.03	Expected voltage at LV busbar of a transformer
Minimum operating voltage (p.u.)	0.94	Voltage operating range (min) for intact system (and max)
Maximum operating voltage (p.u.)	1.06	
Power base value (MVA)	0.1	Power base value for which resistance (p.u.) and reactance (p.u.) are given; if zero, resistances and reactance are given in Ohms
Voltage base value (kV)	0.4	Voltage base value for which resistance (p.u.) and reactance (p.u.) are given; if zero, resistances and reactance are given in Ohms

4.2 Network datasheet

The Network datasheet contains the data representing the network topology as well as the electrical parameters of the network under study. This is defined by specifying for each network branch: (i) the sending node, (ii) the receiving node, (iii) asset type, (iv) rating, (v) length, (vi) resistance and (vii) reactance. The structure of the Network datasheet table is presented in Table 4.2, and an illustrative example is given in Table 4.3. Maximum number of nodes in ITRES is 200.

³ In addition to the ITRES input datasheets, an additional input template has been created by DEA along with their Calculation Guide that enables the user to automatically generate some of the input data. This template differs from the ITRES input datasheet, as explained in the Calculation Guide.

Table 4.2 Network datasheet table

Sending node ID	Receiving node ID	Asset type	Rating (kVA)	Length (m)	Resistance (p.u.)	Reactance (p.u.)
1	2	GM transformer	800		0.01	0.02
2	3	Underground cable	200	53	0.02	0.005
2	4	Overhead line	120	42	0.03	0.01
...
153	167	Underground cable	100	32	0.01	0.0025

Notes:

- Sending and receiving node IDs are alphanumeric IDs of nodes connected by the asset (not case sensitive)
- Asset type can be Underground cable, Overhead line, PM transformer or GM transformer (not case sensitive)
- Rating (kVA) is the asset thermal cyclic rating relevant for design; if the power flow is found to be above this rating, the asset is to be upgraded
- Length (m) is length of cable or line section in meters; for transformers it is ignored
- Resistance (p.u.) and reactance (p.u.) are branch electrical parameters in per-unit values.⁴

Table 4.3 Network datasheet example

Sending node ID	Receiving node ID	Asset type	Rating (kVA)	Length (m)	Resistance (p.u.)	Reactance (p.u.)
2	45	Underground cable	76	56.0	0.031901	0.002730
3	55	Underground cable	76	71.1	0.040500	0.003466
4	42	Underground cable	76	16.3	0.009259	0.000792
5	48	Underground cable	291	116.1	0.007622	0.005263
6	44	Underground cable	76	18.7	0.002665	0.000228
7	53	Underground cable	76	51.4	0.029307	0.002508
8	52	Overhead line	87	10.3	0.005850	0.001925
9	46	Underground cable	76	17.2	0.002449	0.000210
10	47	Underground cable	76	67.4	0.038382	0.003285
11	59	Underground cable	76	13.5	0.007715	0.000660
12	49	Overhead line	87	28.9	0.016453	0.005416
13	50	Underground cable	76	33.4	0.004751	0.000407
14	51	Underground cable	152	64.5	0.013535	0.002961
15	54	Underground cable	76	24.1	0.013732	0.001175
16	53	Underground cable	76	24.4	0.013911	0.001191
17	54	Underground cable	76	15.0	0.008570	0.000733
18	15	Underground cable	76	24.6	0.013989	0.001197
19	58	Underground cable	76	104.0	0.059261	0.005072
20	12	Underground cable	76	40.3	0.022947	0.001964
21	60	Overhead line	87	10.2	0.005782	0.001903
22	8	Underground cable	76	26.6	0.015155	0.001297
23	55	Underground cable	76	23.1	0.013173	0.001127
24	56	Overhead line	87	31.6	0.018016	0.005930
25	57	Underground cable	76	14.2	0.002022	0.000173
26	18	Underground cable	76	21.2	0.012103	0.001036
27	58	Underground cable	76	10.0	0.001421	0.000122
28	27	Underground cable	76	64.6	0.036817	0.003151
29	14	Underground cable	152	44.3	0.009312	0.002037
30	59	Overhead line	87	18.4	0.010459	0.003443
31	60	Overhead line	87	10.5	0.005955	0.001960
32	61	Overhead line	87	15.3	0.008744	0.002878
33	63	Underground cable	76	36.7	0.020905	0.001789
34	62	Underground cable	222	12.9	0.001388	0.000597

⁴ Resistance and reactance can also be specified in Ohms if Power base value in Table 4.1 is defined as 0.

Sending node ID	Receiving node ID	Asset type	Rating (kVA)	Length (m)	Resistance (p.u.)	Reactance (p.u.)
35	34	Overhead line	87	11.9	0.006795	0.002237
36	29	Underground cable	152	46.0	0.009654	0.002112
37	32	Overhead line	87	23.7	0.013476	0.004436
38	63	Underground cable	76	119.9	0.068294	0.005845
39	64	Underground cable	76	39.8	0.022662	0.001939
40	37	Underground cable	76	37.8	0.021530	0.001843
41	47	Underground cable	222	35.9	0.003864	0.001661
42	46	Underground cable	222	49.6	0.005339	0.002294
43	42	Underground cable	222	20.7	0.002224	0.000956
44	41	Underground cable	76	30.5	0.017387	0.001488
45	49	Underground cable	76	34.5	0.019634	0.001680
46	41	Underground cable	222	34.5	0.003710	0.001594
47	56	Underground cable	222	60.7	0.006536	0.002809
48	43	Underground cable	291	36.4	0.002392	0.001651
49	57	Underground cable	76	73.4	0.041786	0.003576
50	45	Underground cable	76	43.1	0.024542	0.002100
51	64	Underground cable	222	44.7	0.004807	0.002066
52	50	Underground cable	76	13.0	0.007397	0.000633
53	61	Overhead line	87	46.8	0.026635	0.008767
54	52	Overhead line	87	15.0	0.008521	0.002805
55	44	Overhead line	87	83.1	0.047316	0.015575
56	62	Underground cable	222	38.3	0.004124	0.001772
57	43	Overhead line	87	11.3	0.006430	0.002116
58	3	Underground cable	76	45.7	0.026008	0.002226
59	48	Underground cable	76	19.2	0.010955	0.000938
60	4	Underground cable	76	15.9	0.002264	0.000194
61	51	Underground cable	152	21.3	0.001121	0.000245
62	1	Underground cable	76	112.8	0.064231	0.005497
63	7	Underground cable	76	54.3	0.030925	0.002647
64	5	Underground cable	291	21.3	0.000350	0.000241
65	43	GM transformer	500	0.0	0.005190	0.018591

As an illustration, the underlying topology of the network with the parameters specified in Table 4.3 is shown in Figure 4.1.

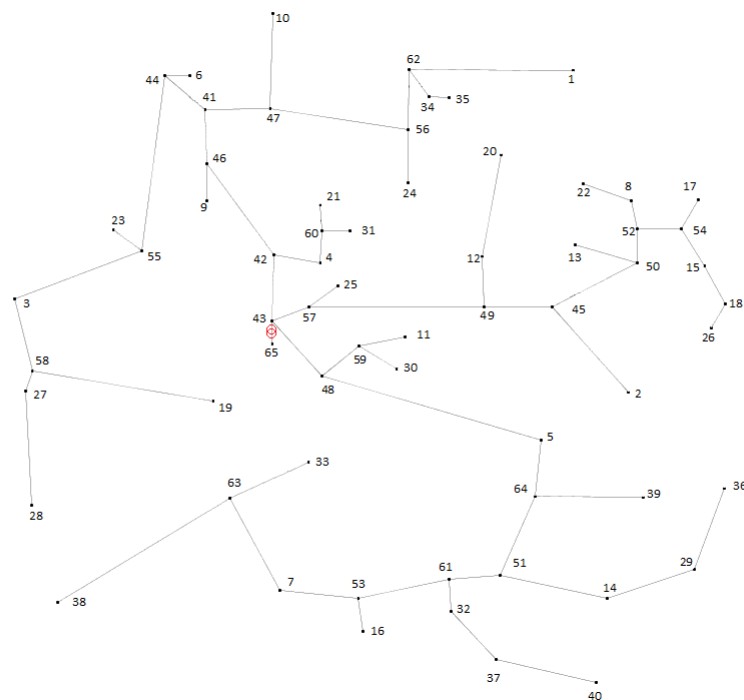


Figure 4.1 Topology of example distribution network

4.3 Existing Load datasheet

The Existing Load datasheet is used for defining the existing (non-EV) network load. According to the description of Modes A and B1/B2:

- Mode A datasheet contains the information about the 24-hour profile of active and reactive load for the peak day, specified for each network node and for every year considered, as shown in Table 4.4 and for an illustrative example in Table 4.6.
- Mode B1 and B2 datasheets include the parameters to identify the 24-hour active and reactive load profiles at each connection node only for the first year under study. For the remaining years of the study period they include the load growth rates, as shown in Table 4.5 and for an illustrative example in Table 4.7. The first table in Table 4.5 contains the projected growth rates, and the second one specifies load profiles for each node.

Table 4.4 Mode A Existing Load table

Node ID	1P1	...	1P24	1Q1	...	1Q24	2P1	...	25Q24
1	3.131	...	2.955	0.992	...	0.925	3.201	...	1.498
2	3.049	...	3.789	0.839	...	0.933	3.109	...	1.488
...
61	2.857	...	3.238	0.792	...	0.862	2.906	...	1.373

Note: yXh is active (P) or reactive (Q) power for year y and hour h.

Table 4.5 Mode B1/B2 Existing Load tables

Year	1	2	...	25
Growth rate	1	1.02	...	1.5

Node ID	P1	...	P24	Q1	...	Q24
1	3.131	...	2.955	0.992	...	0.925
2	3.049	...	3.789	0.839	...	0.933
...
61	2.857	...	3.238	0.792	...	0.862

Note: Xh is active (P) or reactive (Q) power for hour h



Table 4.6 Illustrative example of the Existing Load “Mode A” datasheet (representing 24-hr P and Q values for Year 1)

Node ID	1P1	1P2	1P3	1P4	1P5	1P6	1P7	1P8	1P9	1P10	1P11	1P12	1P13	1P14	1P15	1P16	1P17	1P18	1P19	1P20	1P21	1P22	1P23	1P24
1	3.131	2.848	2.991	2.951	3.03	3.257	3.564	3.691	3.568	3.027	3.556	3.868	4.825	4.65	4.662	4.507	5.547	6.318	6.714	6.387	5.78	4.869	3.847	2.955
2	3.049	2.948	2.5	2.704	3.112	3.491	4.087	4.204	4.743	3.991	3.511	3.099	3.316	3.653	3.739	4.133	5.148	5.665	5.866	5.059	5.064	4.662	4.479	3.789
3	2.365	2.339	2.542	2.543	2.374	2.372	2.748	3.827	3.89	4.14	3.78	4.055	4.208	4.387	4.355	4.856	5.426	5.978	5.917	5.375	5.034	4.436	4.358	3.265
4	2.978	2.686	2.521	2.539	2.475	3.184	3.411	3.426	3.786	3.392	3.867	3.366	3.995	4.161	4.116	4.452	4.239	4.879	5.422	6.035	6.014	5.321	4.243	3.136
5	2.591	2.575	2.69	2.809	2.846	3.08	3.179	3.433	3.499	3.857	3.841	3.298	3.323	3.625	3.807	4.111	4.59	5.43	5.668	5.036	4.22	3.607	3.741	3.505
6	2.969	2.934	2.958	2.896	2.638	2.673	2.941	3.708	4.215	4.388	4.367	3.867	3.994	3.879	4.16	4.295	4.669	5.112	5.667	5.596	5.727	4.94	4.455	3.46
7	2.436	2.124	2.254	2.246	2.948	3.679	4.173	4.396	4.155	3.816	3.472	3.834	4.201	4.024	3.819	3.941	4.678	5.263	5.283	5.285	5.093	4.718	3.938	2.679
8	2.443	2.741	3.059	3.352	3.472	3.494	4.055	4.034	4.065	3.41	3.336	3.314	3.794	3.908	4.117	4.42	5.575	6.486	6.917	6.832	6.11	5.524	4.161	3.025
9	2.362	2.022	2.53	2.295	3.093	3.273	3.807	4.095	4.67	4.673	3.785	3.21	3.469	4.424	4.585	5.299	5.867	6.712	6.565	5.73	5.002	3.95	3.476	2.843
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2.516	2.87	2.621	3.01	2.78	2.915	3.499	3.78	4.039	3.606	3.825	4.035	4.192	4.421	4.517	4.504	4.731	4.935	5.127	4.656	4.732	4.512	4.299	3.077
12	3.034	3.093	3.046	3.184	3.371	3.436	3.963	4.165	4.934	4.134	3.824	3.52	3.807	4.355	4.396	4.86	5.418	6.264	6.053	5.164	4.1	3.73	3.655	3.154
13	2.688	2.432	2.627	2.83	2.994	3.314	3.541	3.464	3.452	3.728	3.727	3.528	3.609	3.887	4.175	4.817	5.568	6.315	6.02	5.356	4.862	4.687	3.845	2.621
...																								
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(continued)

1Q1	1Q2	1Q3	1Q4	1Q5	1Q6	1Q7	1Q8	1Q9	1Q10	1Q11	1Q12	1Q13	1Q14	1Q15	1Q16	1Q17	1Q18	1Q19	1Q20	1Q21	1Q22	1Q23	1Q24	...
0.992	0.955	0.875	0.845	1.003	0.992	0.976	1.005	0.9	0.867	0.935	0.869	0.961	0.846	0.918	0.833	0.857	0.935	0.947	0.83	0.819	0.851	0.866	0.925	
0.839	0.878	0.975	0.949	0.869	0.828	0.942	0.881	0.958	0.922	0.906	0.846	0.827	0.974	0.921	0.879	0.832	0.846	0.867	0.802	0.858	0.866	0.922	0.933	
0.645	0.698	0.656	0.675	0.649	0.662	0.607	0.781	0.591	0.685	0.646	0.758	0.642	0.745	0.771	0.649	0.617	0.643	0.775	0.709	0.7	0.785	0.773	0.711	
0.866	0.939	0.795	0.81	0.856	0.823	0.832	0.848	0.809	0.888	0.903	0.855	0.802	0.942	0.847	0.882	0.852	0.89	0.822	0.925	0.792	0.772	0.863	0.789	
0.781	0.745	0.829	0.762	0.843	0.813	0.668	0.67	0.84	0.671	0.844	0.84	0.8	0.81	0.843	0.839	0.81	0.685	0.691	0.792	0.801	0.84	0.715	0.813	
0.789	0.888	0.949	0.791	0.78	0.773	0.877	0.794	0.786	0.939	0.796	0.828	0.786	0.818	0.956	0.771	0.862	0.926	0.811	0.772	0.959	0.855	0.859	0.946	
0.62	0.631	0.805	0.715	0.73	0.804	0.765	0.731	0.617	0.773	0.701	0.653	0.726	0.698	0.73	0.805	0.715	0.632	0.767	0.633	0.715	0.806	0.728	0.652	
0.736	0.788	0.811	0.723	0.801	0.621	0.627	0.748	0.681	0.675	0.749	0.671	0.656	0.764	0.628	0.79	0.778	0.754	0.656	0.726	0.63	0.656	0.69	0.775	
0.751	0.66	0.594	0.721	0.705	0.748	0.769	0.717	0.691	0.595	0.645	0.638	0.72	0.615	0.661	0.648	0.65	0.655	0.785	0.747	0.629	0.75	0.707	0.659	
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
0.675	0.659	0.655	0.691	0.762	0.737	0.684	0.672	0.773	0.759	0.781	0.822	0.688	0.823	0.73	0.676	0.701	0.659	0.669	0.827	0.771	0.663	0.641	0.784	
0.968	0.817	0.983	0.852	0.855	0.95	0.962	0.799	0.942	0.881	0.817	0.85	0.852	0.877	0.864	0.818	0.966	0.857	0.936	0.805	0.892	0.891	0.859	0.898	
0.766	0.772	0.879	0.782	0.841	0.758	0.859	0.715	0.881	0.687	0.816	0.725	0.705	0.781	0.695	0.78	0.773	0.722	0.694	0.839	0.884	0.694	0.758	0.839	
...																								
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

Table 4.7 Illustrative example of the Existing Load “Mode B1/B2” datasheet (representing the growth rates for Years 1-25 and 24-hr P and Q values for Year 1)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Growth rate	1	1.02	1.04	1.06	1.08	1.1	1.12	1.14	1.16	1.18	1.2	1.22	1.24	1.26	1.28	1.3	1.32	1.34	1.36	1.38	1.4	1.42	1.44	1.46	1.48

Node ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24
1	3.131	2.848	2.991	2.951	3.03	3.257	3.564	3.691	3.568	3.027	3.556	3.868	4.825	4.65	4.662	4.507	5.547	6.318	6.714	6.387	5.78	4.869	3.847	2.955
2	3.049	2.948	2.5	2.704	3.112	3.491	4.087	4.204	4.743	3.991	3.511	3.099	3.316	3.653	3.739	4.133	5.148	5.665	5.866	5.059	5.064	4.662	4.479	3.789
3	2.365	2.339	2.542	2.543	2.374	2.372	2.748	3.827	3.89	4.14	3.78	4.055	4.208	4.387	4.355	4.856	5.426	5.978	5.917	5.375	5.034	4.436	4.358	3.265
4	2.978	2.686	2.521	2.539	2.475	3.184	3.411	3.426	3.786	3.392	3.867	3.366	3.995	4.161	4.116	4.452	4.239	4.879	5.422	6.035	6.014	5.321	4.243	3.136
5	2.591	2.575	2.69	2.809	2.846	3.08	3.179	3.433	3.499	3.857	3.841	3.298	3.323	3.625	3.807	4.111	4.59	5.43	5.668	5.036	4.22	3.607	3.741	3.505
6	2.969	2.934	2.958	2.896	2.638	2.673	2.941	3.708	4.215	4.388	4.367	3.867	3.994	3.879	4.16	4.295	4.669	5.112	5.667	5.596	5.727	4.94	4.455	3.46
7	2.436	2.124	2.254	2.246	2.948	3.679	4.173	4.396	4.155	3.816	3.472	3.834	4.201	4.024	3.819	3.941	4.678	5.263	5.283	5.285	5.093	4.718	3.938	2.679
8	2.443	2.741	3.059	3.352	3.472	3.494	4.055	4.034	4.065	3.41	3.336	3.314	3.794	3.908	4.117	4.42	5.575	6.486	6.917	6.832	6.11	5.524	4.161	3.025
9	2.362	2.022	2.53	2.295	3.093	3.273	3.807	4.095	4.67	4.673	3.785	3.21	3.469	4.424	4.585	5.299	5.867	6.712	6.565	5.73	5.002	3.95	3.476	2.843
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	2.516	2.87	2.621	3.01	2.78	2.915	3.499	3.78	4.039	3.606	3.825	4.035	4.192	4.421	4.517	4.504	4.731	4.935	5.127	4.656	4.732	4.512	4.299	3.077
12	3.034	3.093	3.046	3.184	3.371	3.436	3.963	4.165	4.934	4.134	3.824	3.52	3.807	4.355	4.396	4.86	5.418	6.264	6.053	5.164	4.1	3.73	3.655	3.154
13	2.688	2.432	2.627	2.83	2.994	3.314	3.541	3.464	3.452	3.728	3.727	3.528	3.609	3.887	4.175	4.817	5.568	6.315	6.02	5.356	4.862	4.687	3.845	2.621
...																								
65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

(continued)

Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12	Q13	Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24
0.992	0.955	0.875	0.845	1.003	0.992	0.976	1.005	0.9	0.867	0.935	0.869	0.961	0.846	0.918	0.833	0.857	0.935	0.947	0.83	0.819	0.851	0.866	0.925
0.839	0.878	0.975	0.949	0.869	0.828	0.942	0.881	0.958	0.922	0.906	0.846	0.827	0.974	0.921	0.879	0.832	0.846	0.867	0.802	0.858	0.866	0.922	0.933
0.645	0.698	0.656	0.675	0.649	0.662	0.607	0.781	0.591	0.685	0.646	0.758	0.642	0.745	0.771	0.649	0.617	0.643	0.775	0.709	0.7	0.785	0.773	0.711
0.866	0.939	0.795	0.81	0.856	0.823	0.832	0.848	0.809	0.888	0.903	0.855	0.802	0.942	0.847	0.882	0.852	0.89	0.822	0.925	0.792	0.772	0.863	0.789
0.781	0.745	0.829	0.762	0.843	0.813	0.668	0.67	0.84	0.671	0.844	0.84	0.8	0.81	0.843	0.839	0.81	0.685	0.691	0.792	0.801	0.84	0.715	0.813
0.789	0.888	0.949	0.791	0.78	0.773	0.877	0.794	0.786	0.939	0.796	0.828	0.786	0.818	0.956	0.771	0.862	0.926	0.811	0.772	0.959	0.855	0.859	0.946
0.62	0.631	0.805	0.715	0.73	0.804	0.765	0.731	0.617	0.773	0.701	0.653	0.726	0.698	0.73	0.805	0.715	0.632	0.767	0.633	0.715	0.806	0.728	0.652
0.736	0.788	0.811	0.723	0.801	0.621	0.627	0.748	0.681	0.675	0.749	0.671	0.656	0.764	0.628	0.79	0.778	0.754	0.656	0.726	0.63	0.656	0.69	0.775
0.751	0.66	0.594	0.721	0.705	0.748	0.769	0.717	0.691	0.595	0.645	0.638	0.72	0.615	0.661	0.648	0.65	0.655	0.785	0.747	0.629	0.75	0.707	0.659
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.675	0.659	0.655	0.691	0.762	0.737	0.684	0.672	0.773	0.759	0.781	0.822	0.688	0.823	0.73	0.676	0.701	0.659	0.669	0.827	0.771	0.663	0.641	0.784
0.968	0.817	0.983	0.852	0.855	0.95	0.962	0.799	0.942	0.881	0.817	0.85	0.852	0.877	0.864	0.818	0.966	0.857	0.936	0.805	0.892	0.891	0.859	0.898
0.766	0.772	0.879	0.782	0.841	0.758	0.859	0.715	0.881	0.687	0.816	0.725	0.705	0.781	0.695	0.78	0.773	0.722	0.694	0.839	0.884	0.694	0.758	0.839
...																							
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

4.4 EV (Electric Vehicle) datasheet

The EV datasheet is used to define the EV load integrated in the network selected for study. Similarly to the Existing Load datasheet described earlier, the EV datasheet can be provided in three different modes:

- **Mode A:** the datasheet contains the parameters to identify the 24-hour active power (and reactive power if relevant) of EV charging profiles at each connection node and for every year considered, as shown in Table 4.8 and for an illustrative example in Table 4.11.
- **Mode B1:** three alternative 24-hour EV charging profiles and the corresponding EV penetration levels (specified in terms of the number of EVs) are to be provided, as shown in Table 4.9 and for an illustrative example in Table 4.12. The first table in Table 4.9 contains charging profiles of single EVs with up to three different charging profiles; the second table contains the number of EVs existing in the network in each year, differentiated across the three charging profiles.
- **Mode B2:** a series (e.g. 30) of average 24-hour EV charging profiles and the projection of the EV penetration level (specified in terms of the number of EVs) are, as shown in Table 4.10 and for an illustrative example in Table 4.13. The first table in Table 4.10 contains the number of EVs present in the network in each year; the second table contains average daily EV charging profiles for a given number of EVs.

Table 4.8 Mode A EV charging table

Node ID	1P1	...	1P24	1Q1	...	1Q24	2P1	...	25Q24
1	0	...	0	0	...	0	0	...	0
2	0	...	0	0	...	0	0.087	...	0
...
61	0	...	0	0	...	0	0	...	0

Note: yXh is active (P) power in kW or reactive (Q) power in kVAr for year y and hour h.

Table 4.9 Mode B1 EV charging table

Profile ID	P1	...	P24	Q1	...	Q24
1	0.108	...	1.109	0	...	0
2	1.185	...	1.26	0	...	0
3	2.16	...	2.4	0	...	0

Note: Xh is active (P) power in kW or reactive (Q) power in kVAr for hour h.

Profile ID \ Year	1	2	...	25
1	0	0	...	43
2	0	0	...	40
3	0	0	...	45

Table 4.10 Mode B2 EV charging table

Year	1	2	...	25
Number of EVs	0	0	...	128

Number of EVs	P1	...	P24	Q1	...	Q24
1	3.68	...	3.68	0	...	0
...
30	0.483	...	1.354	0	...	0

Note: Xh is active (P) power in kW or reactive (Q) power in kVAr for hour h.

Table 4.11 Illustrative example of the Mode A EV Load datasheet (displaying 24-hr P values for Year 10)

Node ID	...	10P1	10P2	10P3	10P4	10P5	10P6	10P7	10P8	10P9	10P10	10P11	10P12	10P13	10P14	10P15	10P16	10P17	10P18	10P19	10P20	10P21	10P22	10P23	10P24	...
1		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7		0.084	0.578	1.24	0.903	0.746	0.853	0.95	0.523	0.256	0.779	1.46	1.267	0.852	1.537	0.64	0.56	1.041	1.905	1.28	0.617	1.233	1.634	1.196	0.515	
8		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9		0.068	0.662	1.385	1.06	0.903	1.325	0.416	0.746	0.153	1.502	0.926	0.89	1.192	2.43	0.828	0.534	2.109	2.838	0.728	0.814	0.803	0.713	1.885	1.426	
10		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12		0.094	0.469	2.008	1.932	1.688	0.907	0.409	1.24	0.189	0.954	1.35	0.679	1.004	1.692	1.185	0.571	0.975	1.357	1.17	0.904	1.866	1.83	0.804	1.351	
13		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
...																										
65		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.12 Illustrative example of the Mode B1 EV Load datasheet (displaying 24-hr P and Q values for the three charging profiles and EV numbers for Years 1 to 25)

Profile ID	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	Q1	...	Q24
1	0.108	0.829	2.268	1.631	1.529	1.363	0.886	1.017	0.24	1.438	1.195	1.366	1.594	2.203	1.362	1.042	2.063	2.4	1.068	0.815	1.671	1.462	1.692	1.109	0	0	
2	1.185	1.867	1.607	0.203	2.342	2.35	1.817	0.211	2.4	1.294	1.261	0.496	1.178	0.474	1.916	0.659	2.061	2.121	1.853	0.954	0.631	0.979	1.022	1.26	0	0	
3	2.16	1.871	2.162	1.133	1.204	0.321	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.72	1.089	1.44	2.4	0	0	

Profile ID \ Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	0	0	0	0	1	1	2	4	5	7	9	12	13	14	16	16	18	20	22	28	32	36	39	41	43
2	0	0	0	0	1	2	3	4	5	7	7	7	8	10	12	12	13	16	19	20	26	28	30	32	40
3	0	0	1	1	4	4	4	6	7	8	9	9	10	11	12	13	17	20	23	28	32	36	40	45	45

Table 4.13 Illustrative example of the Mode B2 EV Load datasheet (displaying EV numbers for Years 1 to 25 and 24-hr P and Q values for thirty average EV charging profiles)

Year	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Number of EVs	0	0	1	1	6	7	9	14	17	22	25	28	31	35	40	41	48	56	64	76	90	100	109	118	128

Number of EVs	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14	P15	P16	P17	P18	P19	P20	P21	P22	P23	P24	Q1	...	Q24	
1	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	3.68	0	...	0
2	3.68	3.406	3.35	3.26	3.014	3.079	3.051	3.68	3.68	3.68	3.68	3.68	3.68	3.668	3.68	3.68	3.68	3.406	3.68	3.68	3.68	3.68	3.68	3.406	0	...	0	
3	2.883	2.647	2.611	2.554	2.395	2.438	2.419	3.128	2.931	3.068	3.262	3.68	3.065	2.813	3.68	3.68	2.833	2.647	3.33	3.149	3.349	2.864	2.883	2.647	0	...	0	
...
30	1.369	1.172	1.14	1.089	0.942	0.982	0.965	1.56	1.408	1.515	1.658	2.048	1.512	1.312	1.958	2.176	1.328	1.171	1.707	1.575	1.721	1.354	1.369	1.172	0	...	0	

4.5 Cost datasheet

The Cost datasheet (shown in Table 4.14) contains the information about the unit prices of various network assets considered in the analysis. These costs are required to quantify the impact of EV penetration and alternative charging strategies on the network reinforcement cost.

Table 4.14 Cost datasheet table

Asset type	Unit	Reinforcement cost (€)
Underground cable	m	120
Overhead line	m	40
GM transformer	#	15,500
PM transformer	#	3,400

5 User Interface

Execution of the ITRES tool is controlled via the user interface depicted in Figure 5.1. The interface is started by opening the ITRES.exe file from the installation folder.



Figure 5.1 ITRES user interface

5.1 Input file selection

The path at the top of the user interface form points to the currently selected folder (C:\Documents and Settings\mauned\My Documents\Templates in the above example). The upper drop-down list then contains the list of all Excel spreadsheets in the selected folder. The user selects the LV network to be analysed by selecting the appropriate input file from the list. For convenience, there is also an option to open the input spreadsheets directly from the user interface by clicking the “Open” button to the right of the drop-down list.

5.2 Tool execution options

The “Input data mode” group of options enables the user to choose between the three tool execution modes (A, B1 and B2), which have been explained earlier. The selection of the input mode should be in agreement with the format of the input spreadsheet selected in the first drop-down list.

The “Electric vehicles distribution” group of options is used when mode B1 or B2 is selected (the choice is ignored if mode A is selected). The selection determines how EVs, i.e. their charging profiles are allocated across the network:

- **Random:** EV charging profiles are randomly allocated across the network load nodes.
- **Best case:** EV charging profiles are first allocated to the load nodes with the highest voltages (based on the initial power flow calculation without EVs). When the number of EVs per node reaches the number of loads per that node, the allocation of EVs proceeds to the next node in order. If there are more EVs than loads, the allocation cycle is repeated.
- **Worst case:** EV charging profiles are first allocated to the load nodes with the lowest voltages (analogously to the “Best case” option). Similarly to the “Best case”, when the number of EVs per node reaches the number of loads in that node, the allocation of EVs proceeds to the next node in order. If there are more EVs than loads, the allocation cycle is repeated.

- **Distributed:** EV charging profiles are first allocated to the load node with the lowest voltage, but with only one profile per node. The allocation then cycles through all load nodes until all EVs have been allocated, while ensuring that there are no more EVs per node than the loads connected at that node. If there are more EVs than loads, the allocation cycle is repeated by allocating the next EV to the load node with the lowest voltage.

We illustrate how different options allocate EVs to network nodes using as an example the network denoted by ID129197 (provided by DEA). The network contains 16 customers, and its topology is illustrated in Figure 5.2. Blue numbers placed next to the nodes are node IDs, while red numbers represent the number of customers supplied from a given node in the network.

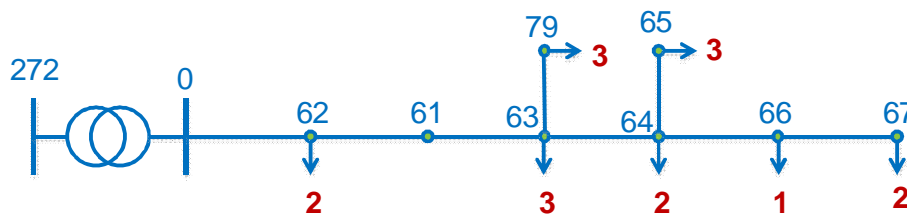


Figure 5.2 Example of a network (ID129197) used for allocating EVs

Assuming there are exactly 16 EVs that need to be placed into the network, and provided that either mode B1 or B2 is selected, the four EV distribution options allocate EVs in the following sequences:

- **Random:**⁵ 63, 65, 66, 79, 65, 79, 63, 64, 62, 67, 62, 67, 64, 63, 65, 79
- **Best case:** 62, 62, 63, 63, 63, 79, 79, 79, 64, 64, 65, 65, 65, 66, 67, 67
- **Distributed:** 67, 66, 65, 64, 79, 63, 62, 67, 65, 64, 79, 63, 62, 65, 79, 63
- **Worst case:** 67, 67, 66, 65, 65, 65, 64, 64, 79, 79, 79, 63, 63, 63, 62, 62

Prior to determining the sequence of nodes for the Best case, Distributed and Worst case options, the nodes are ranked according to their minimum voltage in base year, with only the existing load considered (i.e. without EVs). Using this information, the Best case allocation starts by placing as many EVs as there are customers starting with the nodes with the highest voltage, and then proceeds towards nodes with lower voltage values until all EVs have been allocated. The Worst case allocation works in exactly the opposite fashion, while the Distributed allocation follows the same sequence as the Worst case allocation, but places only one EV into each node before proceeding to the next node (provided that the number of customers at the next node is higher than the number of previously allocated EVs; otherwise it proceeds to the next node in the sequence).

For all EV allocation options, if the number of EVs is higher than the number of customers in the network, then after one vehicle has been assigned to each consumer, the allocation cycle

⁵ The sequence of nodes for the Random option will be the same (i.e. obtained using the same random number seed) in order to obtain repeatable results in multiple runs.

is repeated with the remaining vehicles using the same sequence of nodes until all EVs have been placed in the network.

The “Asset cost mode” group of options controls the way the necessary LV network investment is calculated. If the “Reinforcement” option is selected, the model finds the necessary reinforcement cost based on the information contained in the Cost datasheet of the input spreadsheet. On the other hand, if the “Installation” option is chosen, the asset cost is taken from an extended asset data table, the source file for which is chosen in the lower drop-down list (which becomes enabled upon selecting the “Installation” option). The user interface form also allows for opening the extended asset data file directly by clicking the “Open” button next to the drop-down list. The extended table contains electrical parameters and costs for a range of asset types within each asset class (e.g. several different types of underground cables). An illustrative example of this extended asset data table is given in Table 5.1.

Table 5.1 Extended asset data table

Parameter	Value	Comment						
Power base value (MVA)	0.1	Power base value for which resistance (p.u.) and reactance (p.u.) are given; if zero, resistances and reactance are given in Ohms						
Voltage base value (kV)	0.4	Voltage base value for which resistance (p.u.) and reactance (p.u.) are given; if zero, resistances and reactance are given in Ohms						

Asset type	Asset class	Nominal rating (kVA)	Unit	Resistance (p.u.)	Reactance (p.u.)	Supply cost (€k)	Installation cost (€k)	Total cost (€k)
UG 0.4kV 50AI	Underground cable	113	km	0.4725	0.04625	20.0	100.0	120.0
UG 0.4kV 95AI	Underground cable	162	km	0.24875	0.04625	20.0	100.0	120.0
UG 0.4kV 185AI	Underground cable	232	km	0.128125	0.04625	20.0	100.0	120.0
UG 0.4kV 300AI	Underground cable	301	km	0.07875	0.04625	20.0	100.0	120.0
UG 0.4kV Inf	Underground cable	9999	km	0.03125	0.04625	20.0	100.0	120.0
OH 0.4kV 50AI	Overhead line	113	km	0.4725	0.25	10.0	30.0	40.0
OH 0.4kV 95AI	Overhead line	162	km	0.24875	0.185	10.0	30.0	40.0
OH 0.4kV 185AI	Overhead line	232	km	0.128125	0.185	10.0	30.0	40.0
OH 0.4kV 300AI	Overhead line	301	km	0.07875	0.185	10.0	30.0	40.0
OH 0.4kV Inf	Overhead line	9999	km	0.03125	0.185	10.0	30.0	40.0
GMT 0.4kV 100kVA	GM transformer	100	#	0.0215	0.00086	10.0	5.5	15.5
GMT 0.4kV 200kVA	GM transformer	200	#	0.00672	0.000269	10.0	5.5	15.5
GMT 0.4kV 315kVA	GM transformer	315	#	0.00393	0.00017	10.0	5.5	15.5
GMT 0.4kV 500kVA	GM transformer	500	#	0.002875	0.000115	10.0	5.5	15.5
GMT 0.4kV 800kVA	GM transformer	800	#	0.002116	0.000085	10.0	5.5	15.5
GMT 0.4kV 1MVA	GM transformer	1000	#	0.00135	0.000056	10.0	5.5	15.5
GMT 0.4kV Inf	GM transformer	9999	#	0.000625	0.000031	10.0	5.5	15.5
PMT 0.4kV 50kVA	PM transformer	50	#	0.042	0.001681	2.0	1.4	3.4
PMT 0.4kV 100kVA	PM transformer	100	#	0.0215	0.00086	2.0	1.4	3.4
PMT 0.4kV Inf	PM transformer	9999	#	0.00672	0.000269	2.0	1.4	3.4

As indicated in Table 5.1, fictive assets with very high ratings (those marked with “Inf”) may be added to the Asset Table to allow investment above the highest rated asset. An example is the cable “UG 0.4kV Inf” with the rating of 9,999 kVA. If the resulting investment schedule

suggests that this asset has to be used, the user might wish to add higher-rated assets to the table such as “UG 0.4kV 400Al”, “UG 0.4kV 300Cu” or “UG 0.4kV 2x300Al”. It might also indicate that feeders might need splitting by adding another feeder or secondary substation; however these decisions are out of scope of the tool. The use of “Inf” assets is at the user’s discretion, and is merely a suggestion to ensure a failsafe running of the tool.

If the “Installation” option is selected, the data in the Cost datasheet of the input spreadsheet (Table 4.14) are ignored. Columns in the extended table have the following meaning:

- “Asset type” is the alphanumeric name of the asset type. The “asset type” or “asset class” must be used in the Network table (Table 4.2).
- “Asset class” is the alphanumeric class of an asset. It is used in the asset replacement procedure so that replacement asset is of the same class as original one. In addition, it can be used as asset type in the Network table (Table 4.2).
- “Nominal rating (kVA)” is the asset nominal thermal capacity/rating given in kVA. It should be noted that the Rating specified in the Network table might not be the same as Nominal rating for the same asset type due to the rating factor (derating factor; cyclic rating factor) depending on the installation conditions. The same rating factor will be applied for a newly installed asset.
- “Unit” specifies the volume of the asset for which resistance, reactance and costs are given. It should be noted that the unit for cables and overhead lines here is “km” rather than “m” as in the Costs table (Table 4.14). Transformers in the asset table are detected using the character “#” in the “Unit” column.
- “Resistance (p.u.)” and “Reactance (p.u.)” are electric parameters of the asset type given in per-unit values.
- “Supply cost” and “Installation cost” represent the costs of buying and delivering an asset, and installing it, respectively, with “Total cost” being equal to the sum of the two cost categories. Note that only total cost is used for reinforcement calculations. It should also be noted that the cost here is specified in €k rather than in € as in the Costs table (Table 4.14).

In the Investment mode the assets in the Network table (Table 4.2) may be specified as either “Asset type” or “Asset class” column of the Assets table. If an asset is specified as an asset class, the asset type is selected as the one with the lowest nominal rating that is still greater than or equal to the specified installed cyclic rating specified in the Network table. This enables that the Investment mode can use the same Network data file as the Reinforcement mode. However, if the above assumption is not correct, the assets type has to be explicitly specified in the Network table.

It needs to be mentioned that in the ITRES tool there are no checks for internal data consistency, such as e.g. whether existing load is connected to a node which exists in the Network table. The user should therefore ensure that the data inputs used are mutually consistent before running the calculation.

Finally, once all options have been selected and input files specified, the calculation is started using the “Run” button on the user interface.

6 Methodology and implementation outline

This section provides a description of how the reinforcement calculations are carried out within the ITRES tool. Individual calculation steps are illustrated in the block diagram in Figure 6.1.

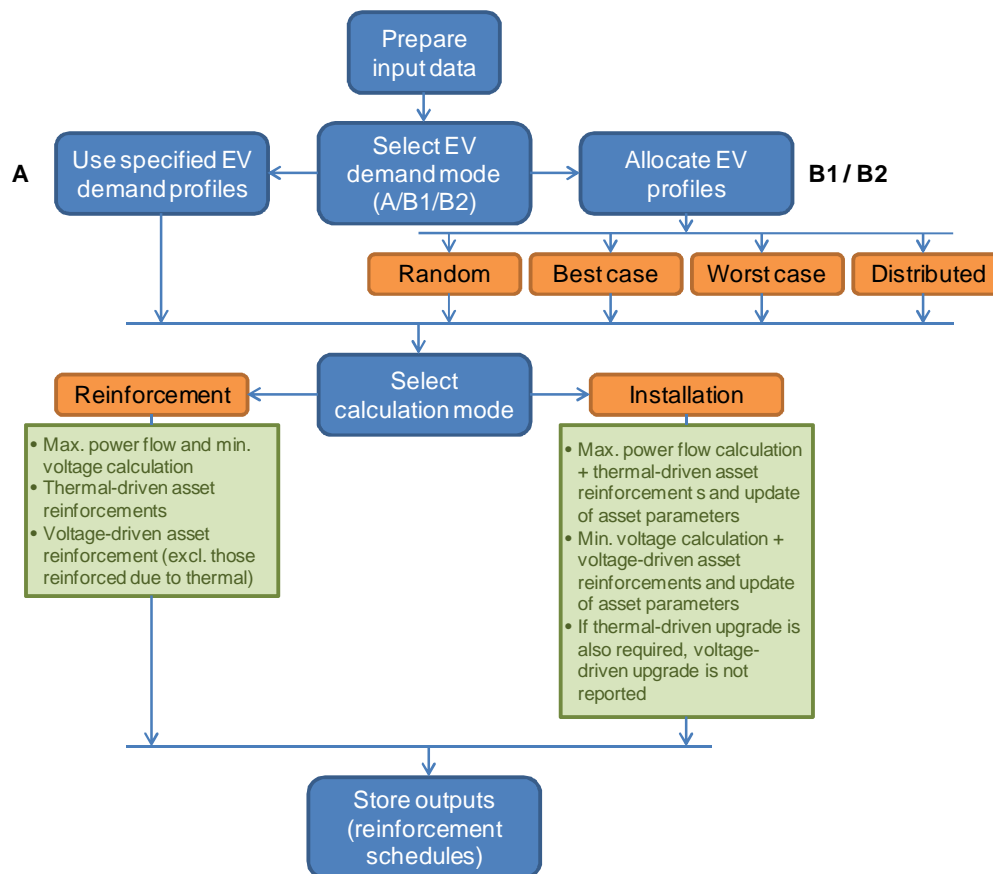


Figure 6.1 Block diagram of ITRES execution

6.1 Reinforcement mode

The Reinforcement mode of ITRES estimates the cumulative reinforcement cost, assuming that the assets existing in the network are those defined in the base year. For each year of the study horizon, the tool calculates the annual maximum power flow for each asset and annual minimum voltage for each node in the network. Power flow calculations are performed based on standard positive sequence load flow algorithms, assuming balanced load across the phases.⁶

Given that each year is assessed separately (i.e. there is no memory effect between the years), a drop in demand at some point during the study period can potentially result in a

⁶ The literature on power flow calculations in power systems is extensive. Two examples include: (i) B. Stott, "Review of Load-Flow Calculation Methods", *Proceedings of the IEEE*, Vol. 62, No. 7, pp. 916-929, July 1974; (ii) B. M. Weedy, B. J. Cory, N. Jenkins, J. B. Ekanayake, G. Strbac, *Electric Power Systems* (5th edition), Wiley-Blackwell, 2012.

drop in cumulative investment. This can be used as an indication to the user that other short-term mitigation measures might be considered in the short term in order to defer network investment. This is not the case in the Installation mode where assets upgraded in previous years are assumed to be in place in all subsequent years.

The resulting reinforcement schedule contains the list of upgraded assets indicating the year of the first upgrade either due to thermal constraints violation or because of inadequate voltage levels (if not already upgraded due to thermal constraints violation).⁷ It may therefore occur that an element is first designated for voltage-driven replacement, while a few years afterwards it becomes selected for thermal-driven replacement, when compared to the base year rating. In real life, obviously, if the actual element is indeed replaced when a voltage-driven requirement first emerges, this might eliminate or postpone the necessity to replace the same asset later in the study period due to thermal constraints violation.

6.2 Installation mode

The Installation mode of the ITRES tool performs an evaluation of reinforcement cost for each individual year within the study period, taking into account any upgrades or replacements carried out in all previous years. A common occurrence in these calculations is that, if an element is upgraded in a given year, this will lead to reduced network losses in subsequent years, which may postpone the reinforcement of other assets when compared to the results of the Reinforcement mode. In addition, the node voltages might be back within limits when compared to the results of the Reinforcement mode, due to investments in previous years (either thermal- or voltage-driven), thus not requiring investment on sections where voltage drop becomes greater than the specified threshold.

When calculating asset replacements, the Installation mode makes two evaluations of line flows and node voltages in each year. The first run is used to determine the necessary asset upgrades due to thermal limit violations. The second calculation assumes that upgrades indicated in the first run have been implemented, and then finds any further replacements or upgrades that are required due to voltage limit violations.

Installation mode captures possible multiple upgrades of the same asset throughout the study period, so that an asset replaced in a given year due to either of the two upgrade drivers (thermal and voltage) may become upgraded again at a later point due to both of these drivers. Therefore, two (or theoretically more) upgrades of the same asset could be required during the study period, which cannot be detected in the Reinforcement mode.

The derating factor, representing the ratio between the installed asset cyclic rating specified in the Network table and the nominal asset rating specified in the Assets table, is preserved after an asset is upgraded. This feature is not relevant for the Reinforcement mode (where it could not be calculated in the first place as nominal asset ratings are not specified).

⁷ Any voltage-driven reinforcements occurring in the same year or after a thermal-driven reinforcement will not be reported, while in the opposite case both reinforcements are reported.

6.3 Further assumptions

Transformers

The HV side of the transformer has to be specified in the sending end column of the Network table (Table 4.2). It is assumed that the voltage set point on the HV side is 0.02 p.u. greater than on the LV side of the transformer, where the voltage is set to the desired value specified in the Main worksheet (Table 4.1).

Voltage-driven reinforcement

The trigger for considering asset upgrades due to voltage constraint violation is when a node voltage drops below the Minimum operating voltage specified in Main worksheet (Table 4.1). All assets on the supply path from the detected node to the LV side of a transformer are upgraded if the asset's maximum normalised voltage drop per kilometre is greater than the specified threshold. The supply path is determined based on the active power flow in hour 17 of the base year.

7 Tool Outputs

Depending on the granularity of the input data associated with load and EV charging that the user is able to provide, the tool will run in Mode A, B1 or B2. For the mode chosen, and for a given LV distribution network under study, the tool evaluates network power flows and voltage profiles for each hour of the peak day and each year in the specified study period. Any violations of thermal and voltage constraints are identified in this process. In case there are violations, appropriate network reinforcements are selected and implemented. Key outputs of the analysis include:

- Volumes (capacities) of voltage-driven network reinforcements in each year
- Volumes (capacities) of thermally driven network reinforcements in each year
- Cost of network reinforcements in each year

Once the tool execution is complete, the results of the calculation are stored in a new worksheet named "Result" which is placed in the original input Excel file. The information reported in the output worksheet includes:

- Length of cables and overhead lines that need to be replaced in each year of the study period
- Number of transformers that need to be replaced in each year of the study period
- Total cost of reinforcement during the study period
- Cost of reinforcement as percentage of total network installation cost
- Summary results of power flow calculations during the study period:
 - Nodes: minimum hourly voltage found for each year of the study period (in p.u.); maximum hourly magnitude of apparent power consumption found for each year of the study period (in kVA)
 - Lines: maximum hourly magnitude of apparent power flow found for each year of the study period (in kVA)
- Charts depicting the volumes and cost of reinforced or replaced network elements

As explained in Section 6, the reinforcement calculation can be performed with two different approaches:

- *Reinforcement mode* – finding the necessary reinforcement for each year separately by comparing it to the base year, and
- *Installation mode* – finding incremental reinforcements needed in each year while taking into account reinforcements selected in previous years.

Figures presented in this chapter describe the outputs produced in both of these calculation modes. All results are based on the example network specified in Table 4.3, and the assumption that the baseline demand grows 2.3 times in the 25-year period, while the number of EVs in the same time interval increases from 0 to 128. Figure 7.1 shows the evolution of peak network demand and EV penetration assumed in this example.

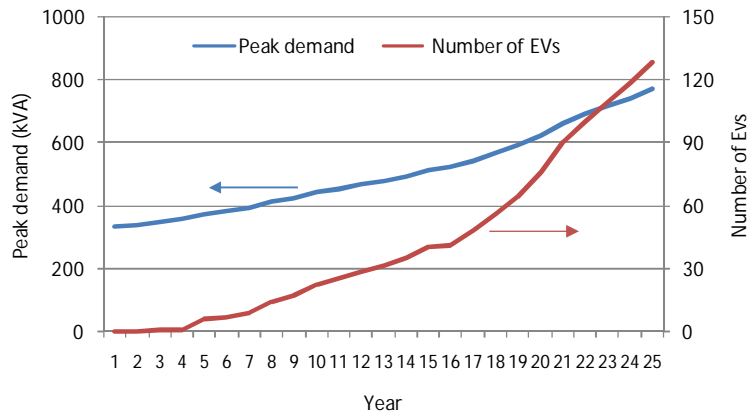


Figure 7.1 Total peak demand and EV penetration during the calculation period

Figure 7.2 to Figure 7.4 illustrate the graphic output provided in the output worksheet in the Reinforcement mode. Figure 7.2 displays the length of reinforced underground cables and overhead lines, disaggregated with respect to the line type and to the driver for line reinforcement (voltage or thermal constraint). For instance, UG-I denotes the length of reinforced underground cables due to thermal violations, while UG-V refers to cable reinforcements driven by voltage constraints. In a similar manner, OH-I and OH-V refer to overhead line reinforcements. It has to be noted that for each year depicted the reinforced length refers to the reinforcements needed between the network design associated with the base year and the one required in the observed year, rather than the reinforcement required in that particular year only.⁸

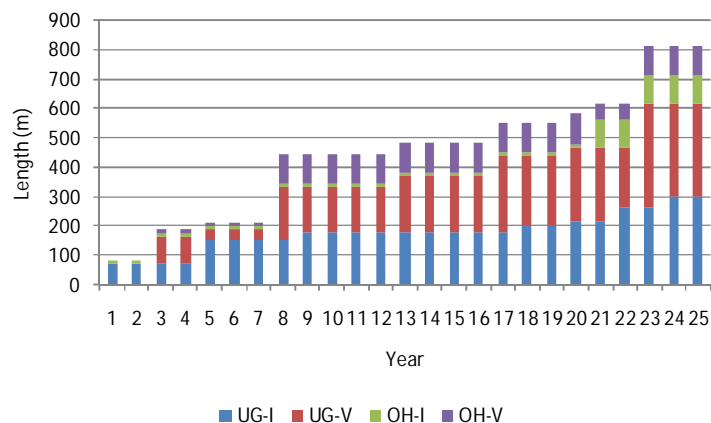


Figure 7.2 Length of reinforced lines during the study period (Reinforcement mode)

Figure 7.3 shows when the distribution transformer in the example LV network needs replacing to accommodate the projected demand growth and the increasing penetration of EVs. The distinction is made between ground-mounted (GMT) and pole-mounted (PMT) transformers.

⁸ This means that if there is a sudden increase in peak demand in one year of the study period followed by a decline in the demand in the next year, the reinforcements selected for the later year (with lower peak) would not take into account the reinforcements selected to accommodate the demand in the earlier year (with higher peak). In other words, the reinforcements in the later year may be lower than those in the earlier year.

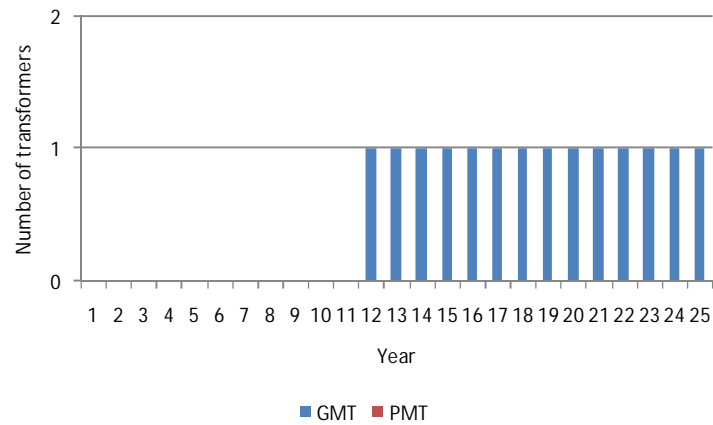


Figure 7.3 Number of replaced transformers during the study period (Reinforcement mode)

Figure 7.4 presents the total cost of reinforcement during the 25-year period disaggregated into different asset types (cables, lines, transformers) and different reinforcement drivers (voltage and thermal limits). Similar to Figure 7.2, the reinforcement cost values in Figure 7.4 refer to network investments required between base year and each given year.

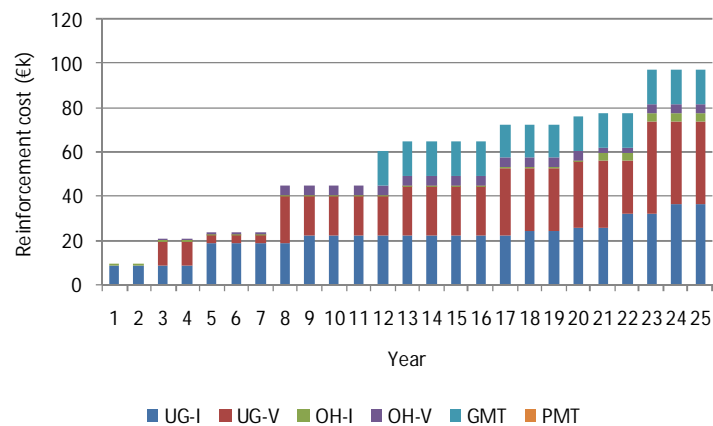


Figure 7.4 Reinforcement cost components (Reinforcement mode)

Unlike the Reinforcement mode, the results of the Installation mode are presented as discrete investments occurring in individual years over the study period, taking into account the chronology of investments taking place in previous years. Figure 7.5 represents the reinforced line length in each year over the study period, while Figure 7.6 shows when (and if) the distribution transformer is replaced during the same period (as in Figure 7.3, the transformer needs to be replaced around the middle of the 25-year study period).

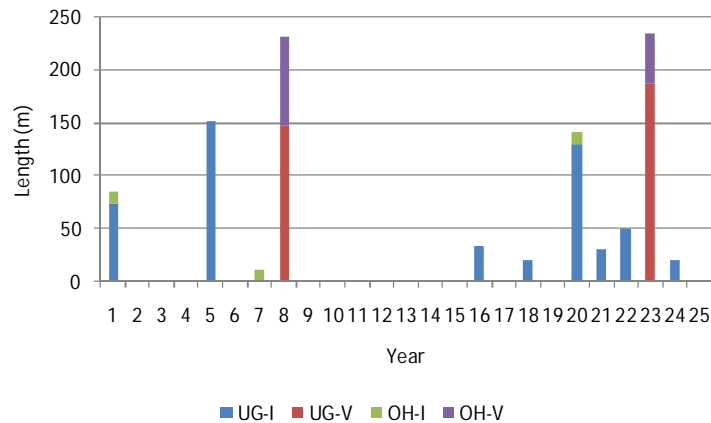


Figure 7.5 Length of reinforced lines during the study period (Installation mode)

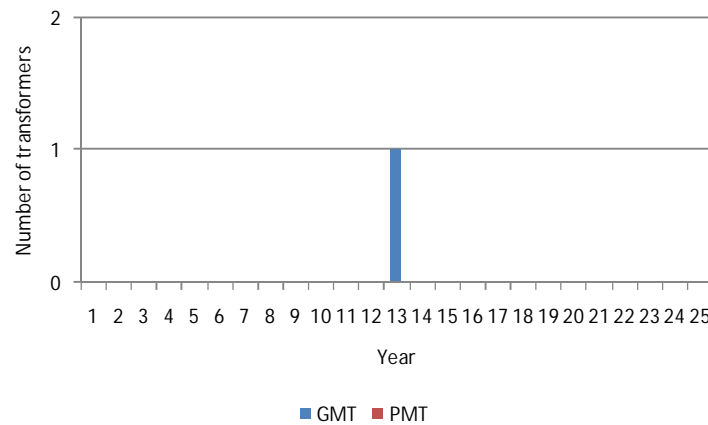


Figure 7.6 Number of replaced transformers during the study period (Installation mode)

Figure 7.7, finally, shows the investment cost associated with reinforcements occurring in individual years over the study period. As before, cost categories distinguish between types of assets (cable, overhead line or transformer) and reinforcement triggers (voltage or thermal issues).

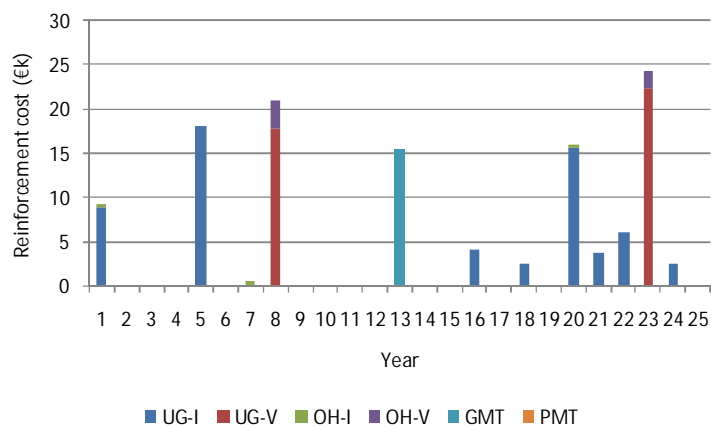


Figure 7.7 Reinforcement cost components (Installation mode)

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