

Impact of Electrical Vehicle Charging in Low Voltage Grid Structures

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Summary

The project sMobilityCOM [1] aims for reduction of plugin electrical vehicles (PEV) operating cost in the field of mobile nursing services by providing services of efficient routing as well as optimized charging strategies. The project work includes the impact analysis in low voltage grid structures. This paper presents analysis results based on the combination of the load flow simulation tool OpenDSS [2] and Matlab® scripts for preparation and evaluation of the calculated results.

Keywords: plugin electrical vehicle (PEV), simulation, power flow calculation

1 Introduction

The market for PEVs is slowly but continuously growing. This will also increase the penetration rates of PEV in local grid areas. Violation of security and quality aspects can be expected, since existing grids have not been considered PEVs during the planning phase. sMobilityCOM is investigating this influences, considering the application of mobile nursing services with centralized charging infrastructure. sMobilityCOM stands for “smart mobility in Thuringia commercial” and is founded by the German ministry of Commerce and Energy (BMWi) within the research framework “ICT for electric mobility III” [3].

Risk evaluations are necessary to estimate maximum numbers of various PEV types before a local grid structure have to be enforced. Previous works using OROP “Open Research on Operation Prototype” present an evaluation approach for analyzing the risk with the help of a Monte Carlo (MC) simulation [4, 5, 6]. One major shortcoming of the presented work is the evaluation of one PEV type at the time. Therefore this paper focusses on the extension of this approach of analyzing heterogeneous PEV fleets in low voltage grids [7, 8]. Chapter 2 describes the methodical extension of Monte Carlo simulation. Chapter 3 explains the modelling of test cases. Chapter 4 presents preliminary results and concludes with chapter 5.

2 Methodology

The OROP MC simulation as well as the MC algorithm in the Matlab® prepare scripts approach can be summarised as followed. The MC algorithm places a random number of homogenous PEVs within a modelled grid structure. A simulation and evaluation process executes after each placement. The algorithm ensures that each drawn situation occurs only once in the simulation. All MC methods work with equal distributions. A detailed description of the original algorithm is given in [4, 5].

The simulation evaluates the power flow within the grid according to DIN EN 50160 [9] and regulations in [10, 11]. Test criteria are:

- the maximum voltage range limit of $\pm 10\%$ at each node,
- the maximum positive/negative sequence ration of 2 % at each node,
- the thermal load of the cable and
- the thermal load of the transformer.

The approach aims to receive an answer to the question of “How many PEVs fit into a grid structure, for a given allocation of miscellaneous PEV types?” The algorithmic extension includes one additional step within the algorithm, referenced as Fig. 1. Firstly, a routine verifies the model for its structural correctness. Secondly, the model precomputes the ratio for each possible drawn number of PEVs to meet the given allocation as close as possible. Thirdly, a seed determines the number of PEV randomly. Fourthly, an algorithm selects the PEV type according to the ratio for the PEV number. Fifthly, another seed determines the connection point within the grid. Sixthly, a third seed determines the phase randomly. Evaluation steps ensure that no connection is selected twice or that more PEV as well PEV types are placed. Seventhly, OpenDSS runs the power flow calculation. Finally, the analysis evaluates the power flow results for given test criteria.

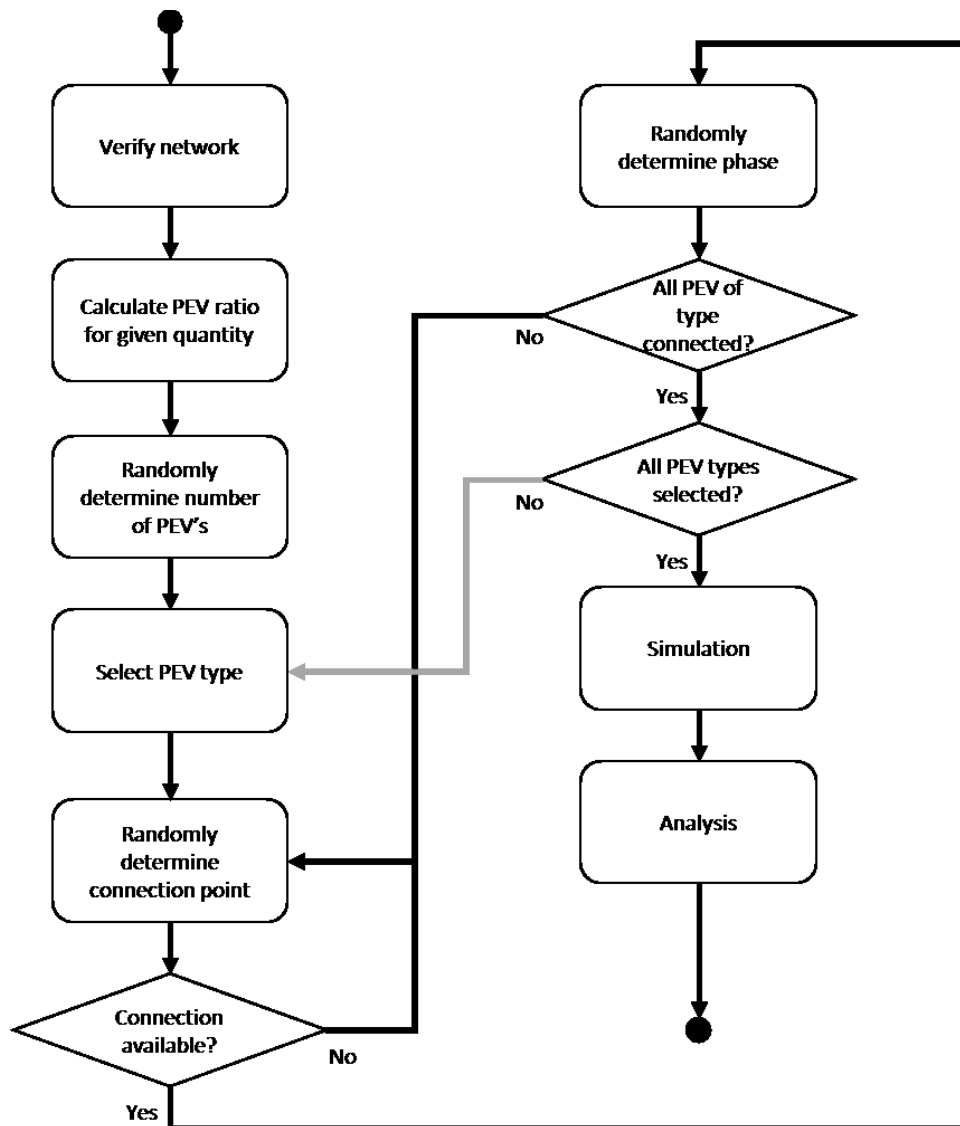


Figure 1: Algorithm visualization

The preparation algorithm integrates additional rules to match practical problems. First, a PEV is always an undividable entity. Second, the user has to choose the priority in terms of lower or higher PEV load. The later one is more important if the simulation focusses on asymmetric load behaviours or on thermal behaviours. The following PEV fleet example shall match the given allocation:

- PEV type 3,7 kVA with 1 charging phase is 40 % of all PEV,
- PEV type 4,6 kVA with 1 charging phase is 20 % of all PEV,
- PEV type 7,4 kVA with 2 charging phase is 10 % of all PEV,
- PEV type 11 kVA with 3 charging phase is 20 % of all PEV and
- PEV type 22 kVA with 3 charging phase is 10 % of all PEV.

Table 1 lists the results for one to eleven PEV. The focus is on asymmetric load behaviour.

Table 1: calculated absolute numbers and relative probabilities for the given allocation

No. PEVs	3.7 kVA		4.6 kVA		7.4 kVA		11 kVA		22 kVA	
	abs. No.	prob. [%]	abs. No.	prob. [%]	abs. No.	prob. [%]	abs. No.	prob. [%]	abs. No.	prob. [%]
1	1	100	0	0	0	0	0	0	0	0
2	1	50	1	50	0	0	0	0	0	0
3	1	33.33	1	33.33	0	0	1	33.33	0	0
4	2	50	1	25	0	0	1	25	0	0
5	2	40	1	20	1	20	1	20	0	0
6	2	33.33	1	16.67	1	16.67	1	16.67	1	16.67
7	3	42.86	1	14.29	1	14.29	1	14.29	1	14.29
8	3	37.5	2	25	1	12.5	1	12.5	1	12.5
9	3	33.33	2	22.22	1	11.11	2	22.22	1	11.11
10	4	40	2	20	1	10	2	20	1	10
11	5	45.45	2	18.18	1	9.09	2	18.18	1	9.09

3 Modelling

3.1 Grid modelling

The investigations use a reference grid structure, the IEEE European test feeder [12], referenced Fig. 2. It consists out of a transformer, which reduces the voltage from 11 kV to 0.4 kV, and 69 loads, which are connected to the grid. The modelling of the grid is built as dss files and the load flow calculations are done with OpenDSS through a Matlab® API.

The load case and installed cable types have been close to its maximum capacity. With the original parameterization, almost no PEV could be integrated. Therefore, the installed load of the 69 connected house nodes and structural parameters have been adopted. Every house load is set to 0.4 kVA and a $\cos(\varphi)$ of 0.9. The standard consumption profile of electric power serves as base to model the load level of the connected houses [13]. This profile is characterized by an average electrical power consumption of 0.25 kVA per 15-minute interval. The load was increased to 0.4 kVA because the standard consumption profile describes a medium load case over the 15-minute interval. The power flow simulation calculates a current value. In order to match the power load distribution, the higher load value was chosen. The grid model uses the following cables:

- NYY-J 3X4 SW,
- NAYY-J 4X25 SW,

- NAYY-J 1X25 SW,
- NAYY-J 1X35 SW,
- NAYY-J 1X70 SW,
- NYY-J 3X70 SW,
- NAYY-J 4X35 SW,
- NAYY-J 4X185 SW and
- NAYY-J 4X70 SW.

The cable in the main feeder is modelled with the NAYY-J 4x185. These cables are replacements compared to the original grid by IEEE European test feeder [9]. The other cables are connections to houses or other feeders except the main feeder. These cables are not replaced and bare same as in the given test feeder.

The 800 kVA in the original test feeder is not representative for a typical low voltage feeder with this number of connected houses. Therefore, it is changed into a transformer with a rated power of 250 kVA.

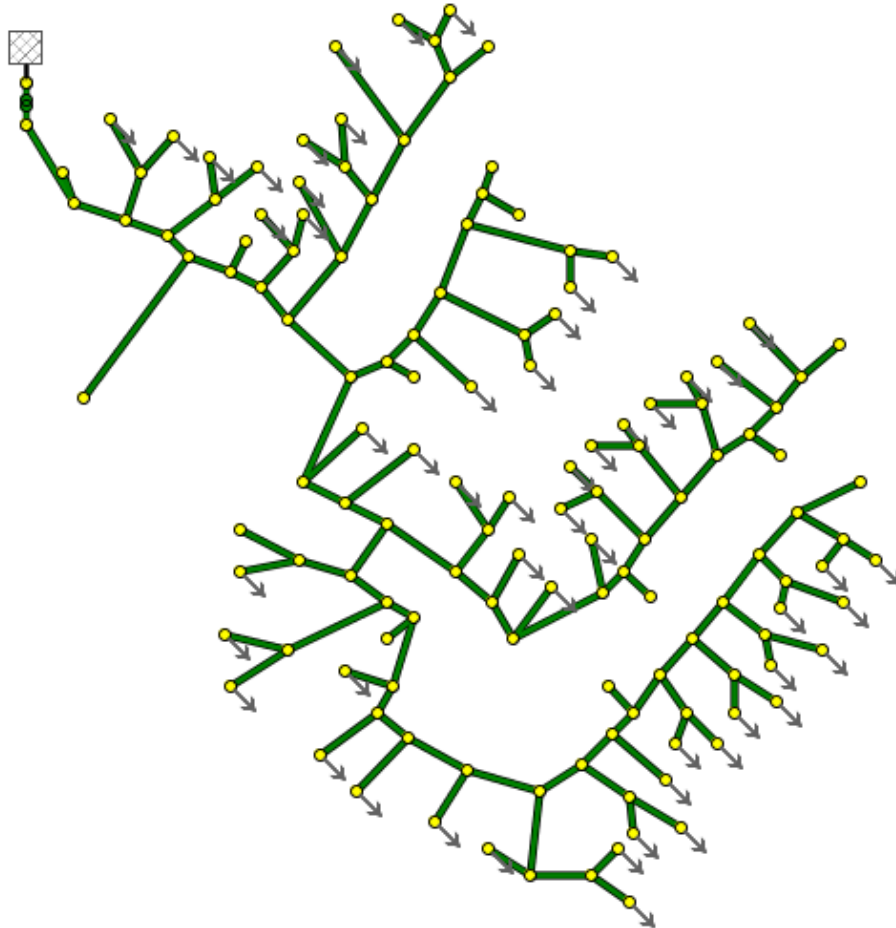


Figure 2: IEEE European low voltage test feeder [9]

3.2 Scenario modelling

There are five different PEV load type configurations possible in low voltage grids:

- single phase: 3.7 kVA and 4.6 kVA,
- two phase: 7,4 kVA,
- three phase: 11 kVA and 22 kVA.

Ten scenarios are defined. Scenario one to five calculates the integration potential of each single PEV type as homogenous scenario. Scenario six focusses on only asymmetric loads including one and two phase charging PEV. Furthermore the 7.4 kVA is not considered, since it has no significant market share. Scenarios seven to ten are combined scenarios, which move the focus from asymmetric load problems to thermal load problems, referenced in table 2. The authors also expect a similar development in market penetration. In the beginning, mainly PEV with smaller battery capacity and dominate the market. With a continuing development of advanced battery systems prices will drop as well capacities and loads will raise. PEV with higher load capacities will not apply, because the connection takes place at voltage levels above 0.4 kV.

Table 2: scenario definitions

Scenario No.	3.7 kVA [%]	4.6 kVA [%]	7.4 kVA [%]	11 kVA [%]	22 kVA [%]
1	100	0	0	0	0
2	0	100	0	0	0
3	0	0	100	0	0
4	0	0	0	100	0
5	0	0	0	0	100
6	50	0	50	0	0
7	80	0	0	10	10
8	60	10	0	10	20
9	40	10	0	20	30
10	20	20	0	20	40

4 Results

Between 66,139 and 68,207 simulations with up to 69 PEV where run for each scenario. Table 3 gives a summary of all simulation results and a graphical evaluation represents Fig. 3. The summary contains the number of cars at the error probabilities of 0 %, 30 % and 100 %. These values describe the expected occurrence of any error types. The figure lists the relative error ratios as well. The accumulated error attains values above 100 %. This behaviour results from the analysis algorithm, in which each alternative is checked for the occurrence of each type of error. This causes errors which contain the simultaneous appearance of types of errors.

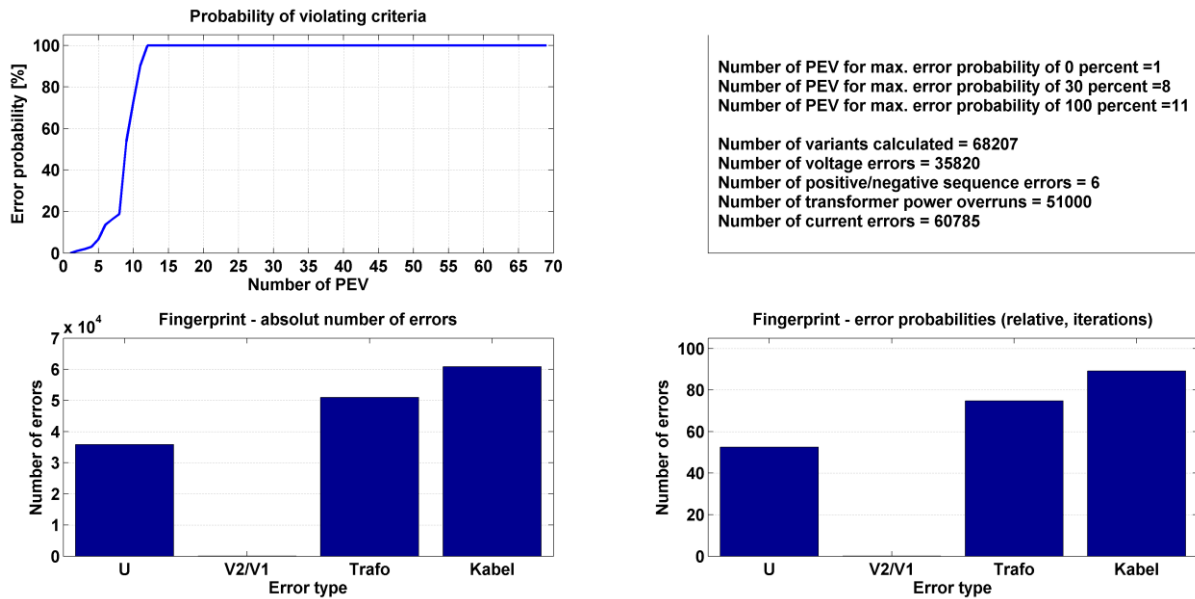


Figure 3: simulation results of scenario 9

The results show that for a fault probability of 0 %, 1 to 5 PEVs are loaded in all scenarios. The error probability of 30 % is reached from 5 to 22 PEVs and the error probability of 100% from 5 to 31 PEVs. The positive/negative sequence ration is not significant in all scenarios. Mostly often, thermal defects occur in the cables of the grid, followed by the thermal loads of the transformer and then the voltage. The number of PEV that can be integrated does not increase with an increasing error probability of scenarios four and five. Accordingly ten respectively five PEV are unable to integrate with an increasing error probability from 30 % to 100 %. The effect causes a hard cut of integrable PEV by the power of the transformer or the cables.

Table 3: simulation results

Scenario No.	Error Probability 0 % [No,]	Error Probability 30 % [No,]	Error Probability 100 % [No,]	Error of voltage boundary [%]	Error of pos./neg. sequence ration [%]	Error of thermal load of the cable [%]	Error of thermal load of the transformer [%]
1	4	22	31	0,55	0,01	66,55	21,35
2	1	14	25	6,72	0,00	77,97	37,15
3	3	13	18	35,27	0,01	81,56	54,26
4	3	10	10	46,82	0,00	86,60	74,20
5	1	5	5	75,21	0,00	94,70	87,97
6	5	17	27	12,53	0,01	75,26	41,63
7	4	14	18	21,05	0,01	80,31	52,88
8	1	11	14	39,25	0,01	86,37	64,87
9	1	8	11	52,52	0,01	89,12	74,77
10	1	7	9	59,69	0,01	90,37	79,33

5 Conclusion

All the results of the scenarios underline that the greatest probability of occurrence is the thermal overload of cables, followed by the thermal overloading of the transformer. If this error occurs, the network operator

has only two choices to expand the power grid or to act with an active control. The results are consistent with the investigations in the publications [4, 5] with homogeneous PEV fleets.

There was no significant difference between the key figures. Using a heterogeneous PEV fleets, more absolute vehicles can be integrated into the grid than in scenario 5. A limitation to 11 kW peak load of PEV in the 0.4 kV grid would be a possible compromise solution to achieve relatively high integration numbers with simultaneous high-energy transfer.

The small occurrence of voltage errors and counter-system errors has several causes. On the one hand the main cables were reinforced in the network construction. This reduces voltage errors. On the other hand, the models calculates only a reduced variant number of 1,000 per PEV. Thus, not all possible error event variants are detected. However, earlier simulations have shown that the error behaviour changes into a saturation behaviour with increasing number of variants. Thus, higher variants would not lead to any new basic findings.

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