Three-phase Power Flow Calculation Tool

Introduction

Within the work of the CIRED working group “LOAD MODELLING AND DISTRIBUTION PLANNING IN THE ERA OF ELECTRIC MOBILITY”, an unbalanced power flow tool was developed in Excel. Especially, it is useful to investigate the effect of unbalanced charging of electric vehicles in low voltage grids. It is open-source and can be adapted to individual applications.

Many professional power flow tools exist already. They can be used to model low voltage grids in a high level of detail. Disadvantages are that they are complicated to use and a lot of input data is needed. The tool presented here can be used in Excel, so no extra software has to be installed. Additionally, it is easy to use and the level of complexity can be chosen by the user. In the following sections, the simulation framework is presented and basic instructions for the tool are given. Furthermore, an example to determine the effect of EV charging is shown.

Simulation Framework

The program code for the tool was written in Visual Basic for Application (VBA). VBA was developed to adapt Microsoft Office applications to the user’s need. The tool was mainly developed by Pit Maier [1].

To solve the load flow problem, the simulation framework uses the Newton-Raphson method or Gauss-Seidel method. If no settings are changed, the Gauss-Seidel method is used automatically as it was faster during performance tests. The used algorithm is described in [1]. The calculations are performed in the per-unit system. For modelling the grid, a transformation of the grid data to symmetrical components is used to solve load flow problem. Loads can be modelled as constant-power or constant-impedance loads.

The tool consists of simulation core and a graphical user interface (GUI). The following sections focus on the GUI and possible applications in the context of this working group. Nevertheless, the simulation core can also be adapted to further purposes and additional settings can be changed there. Using the unhide function of excel, additional sheets can be shown to where the input data is processed.

The load flow tool has been validated using the commercially available tool DIgSILENT PowerFactory.

Instructions

The graphical user interface of the tool is divided in three areas. With an increasing number of the area, more detailed input data can be entered into the tool. All input data fields are already prefilled with realistic data, which can be modified according to the user's needs.

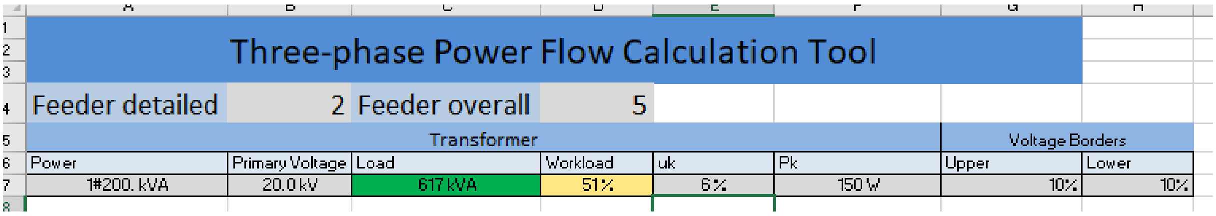
Area 1

A screenshot of Area 1 is given in Figure 1. At first, the number of detailed considered feeder as well as the total number of feeders in the regarded low voltage grid can be defined. For a detailed feeder, Aria 2 & 3 are available to enter more detailed data especially for this feeder. The input data for all feeder that are not considered detailed will be entered in a common form of Aria 2 & 3.

Additionally, data for the MV/LV-transformer can be entered here as well as calculation result for the transformer (Load and Workload) are shown in Aria 1.

Besides that, voltage limits for all points in the grid are defined here. The voltage limits affect the coloured highlighting of the calculation results.

Grey coloured fields are input data and green to red coloured fields are for simulation results.



Three-phase Power Flow Calculation Tool							
Feeder detailed	2	Feeder overall	5				
Transformer						Voltage Borders	
Power	Primary Voltage	Load	Workload	uk	Pk	Upper	Lower
1#200. kVA	20.0 kV	617 kVA	51 %	6 %	150 W	10%	10%

Figure 1: Screenshot of Area 1

Area 2

A screenshot of Area 2 is given in Figure 2. Input data in Area 2 are the predefined line type for the whole feeder, the total number of knots in the feeder and the feeder length. Additionally, data of equipment can be entered for an automatic calculation of the power of the equipment. This includes the number of charging points and their respective charging power. Further input data is the number of households in the feeder. This data is used the calculate the concurrency of charging processes. At the end of Area 2 is a summary of the assumed power for households, EV charging and PV generation. All values are added to calculate the total power. As PV systems generate energy, this is considered through subtraction.

Input data in grey fields is used to calculate the input data for light blue fields. However, the data in light blue fields can still be modified by the user if necessary. In green to red coloured fields simulation results are shown.

1		Low voltage knots	Feeder length	Lines(Typ, Number parallel lines)			
		20	500 m	N(A)YY 4x150		1	
Charging power of EV		3.7 kW	11.0 kW	22.0 kW	Number households	Peak Power [kVA]	Concurrency
Number EV		3	2	1	10	30	0.23
Concurrency		1.00	1.00	1.00	Power per household	6.938073745	
Power							
Households		E-Mobility		PV		Additional	
S	cos(φ)	S	cos(φ)	S	cos(φ)	S	cos(φ)
69.38 kVA	0.95	55.10 kVA	1	0.00 kVA	0.95	0.00 kVA	0.95
		Max ΔU		Current			
		-3.20%		177.97 A			

Figure 2: Screenshot of Area 2

<u>Area 3</u>

A screenshot of Area 3 is given in Figure 3. For each knot in the feeders that are regarded in detail exists a data area as in Figure 4. The power of loads and generators is displayed here for each phase independently. Each power can be modified and the total sum will then be updated automatically.

For each line segment, the line type and length can be chosen independently in Area 3. In the field Max ΔU, the voltage drop between each point and the MV/LV transformer is given. In the field Unbalanced, it is shown if the loads and generators at these points generate a balanced or unbalanced power flow. In the field Max Current, the maximum current flowing on a phase is shown.

All fields for input data are light blue. Grey coloured fields from Area 2 are used for the calculation of the light blue input data. Nevertheless, input data in light blue coloured fields can be modified by the user manually. In green to red coloured fields simulation results are shown. The field of the maximum current is grey coloured as no review of the utilization is given here.

Knoten					Lines		
Nr.	S	cos(φ)	Max ΔU	Unbalanced	Max Current	Length	Linetype
1	6.15 kVA	0.98	-0.74%	No	177.97 A	25.00	N(A)YY 4x150
2	6.15 kVA	0.98	-0.99%	No	169.07 A	25.00	N(A)YY 4x150
3	6.15 kVA	0.98	-1.22%	No	160.17 A	25.00	N(A)YY 4x150
4	6.15 kVA	0.98	-1.44%	No	151.26 A	25.00	N(A)YY 4x150
5	6.15 kVA	0.98	-1.65%	No	142.36 A	25.00	N(A)YY 4x150
6	6.15 kVA	0.98	-1.84%	No	133.46 A	25.00	N(A)YY 4x150
7	6.15 kVA	0.98	-2.03%	No	124.56 A	25.00	N(A)YY 4x150
8	6.15 kVA	0.98	-2.19%	No	115.66 A	25.00	N(A)YY 4x150
9	6.15 kVA	0.98	-2.35%	No	106.76 A	25.00	N(A)YY 4x150
10	6.15 kVA	0.98	-2.49%	No	97.86 A	25.00	N(A)YY 4x150
11	6.15 kVA	0.98	-2.62%	No	88.97 A	25.00	N(A)YY 4x150
12	6.15 kVA	0.98	-2.74%	No	80.07 A	25.00	N(A)YY 4x150
13	6.15 kVA	0.98	-2.84%	No	71.17 A	25.00	N(A)YY 4x150
14	6.15 kVA	0.98	-2.93%	No	62.27 A	25.00	N(A)YY 4x150
15	6.15 kVA	0.98	-3.01%	No	53.38 A	25.00	N(A)YY 4x150
16	6.15 kVA	0.98	-3.07%	No	44.48 A	25.00	N(A)YY 4x150
17	6.15 kVA	0.98	-3.12%	No	35.58 A	25.00	N(A)YY 4x150
18	6.15 kVA	0.98	-3.16%	No	26.69 A	25.00	N(A)YY 4x150
19	6.15 kVA	0.98	-3.19%	No	17.79 A	25.00	N(A)YY 4x150
20	6.15 kVA	0.98	-3.20%	No	8.90 A	25.00	N(A)YY 4x150

Figure 3: A screenshot of Area 3

Nr.	S	cos(φ)	Max ΔU	Unbalanced	Max Current	Length	Linetype
1	6.15 kVA	0.98	-0.74%	No	177.97 A	25.00	N(A)YY 4x150
	L1		L2		L3		N
	S	cos(φ)	S	cos(φ)	S	cos(φ)	
Households	1.16 kVA	0.95	1.16 kVA	0.95	1.16 kVA	0.95	
E-Mobility	0.92 kVA	1.00	0.92 kVA	1.00	0.92 kVA	1.00	
PV	0.00 kVA	0.95	0.00 kVA	0.95	0.00 kVA	0.95	
Additional	0.00 kVA	0.95	0.00 kVA	0.95	0.00 kVA	0.95	
Sum	**0.92 kVA**	**1.00**	**0.92 kVA**	**1.00**	**0.92 kVA**	**1.00**	
ΔU	-0.74%		-0.74%		-0.74%		
I	177.97 A		177.97 A		177.97 A		0.00 A

Figure 4: Detailed view of the input data for a specific knot

Exemplary simulation

The setting used for this exemplary simulation is the standard setting, which is chosen automatically, when the tool is started.

No EV

The setting consists of five low voltage feeders that are identical. They are 500 metres long (NAYY 4x150), consists of 20 knots and ten households are connected to each feeder with a peak power of 30 kVA. As concurrency is considered, the real power demand of each household is 6.15 kVA. This leads to a maximum current of 98.58 A and a maximum voltage drop of 2.06% of the nominal voltage.

Balanced charging

To determine the effect of EV charging, it is assumed that six EV (3x3.7kW, 2x11kW, 1x 22kW) are connected. This setting is the standard setting that is assumed automatically when the Excel file is opened. As no further input data is entered, the additional load by the EV is distributed equally between all points and phases in the feeder. This leads to a maximum current of 177.97 A and a maximum voltage drop of 3.2% of the nominal voltage. Hence, a significant effect of the EV charging can be regarded.

Unbalanced charging

For a third scenario, the EV charging is now considered more detailed. The same amount of EV and the same charging powers are assumed than in the previous scenario. At Point 4,5,6, a charging point for 3.7 kW at Phase A is considered. Furthermore, at Point 8 and 11, a 11 kW charging point is installed. Finally, a 22 kW charging point is considered at Point 15. In this scenario, the maximum current is on Phase A with 210.63 A (Phase B: 162.01 A, Phase C: 161.85 A). The maximum voltage drop can also be regarded on Phase A with 3.71% of the nominal voltage (Phase B: 2.82%, Phase C: 3.17%). Assuming unbalanced charging as in this scenario for the 3.7 kW charging points leads to significant different results as for balanced charging.

[1] Pit Maier, “Integration der Ladeinfrastruktur von Elektroautos in die Verteilnetze und deren Auswirkung auf den Netzausbau“, Bachelor thesis, Hochschule Karlsruhe, 2020

[2] M. Abdel-Akher, K. Mohamed Nor and A. Abdul-Rashid, "Development of unbalanced three-phase distribution power flow analysis using sequence and phase components," *2008 12th International Middle-East Power System Conference*, Aswan, 2008, pp. 406-411, doi: 10.1109/MEPCON.2008.4562347.