# Validity Report for Short-Circuit and Loadflow

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# 1 Introduction

This is the validity report for the power system planning software NEPLAN®, modules Short circuit calculation and Loadflow.

NEPLAN® is a software package for the analysis, planning and optimization of electrical networks, gas- , water- and heating networks. The system works object-oriented, fully graphical supported and fully integrated and runs on different windows systems (Windows 2008 and higher). This software offers the world's first full web based power system analysis tool on the market and therefore has all the advantages of cloud computing based on client-server architecture technology. It consists of several calculation modules, such as Loadflow, Short circuit, Harmonic analysis, Motor starting, Dynamic analysis, Protection setting and analysis, etc. It is available in German, English, French, Italian, Spanish, Croatian, Slovenian, Bulgarian, Persian, Danish, Hungarian and Polish.

NEPLAN® has been developed by Busarello+Cott+Partner Inc, Erlenbach (Switzerland) in cooperation with the Swiss Federal Institute of Technology ETH in Zurich, Institutes of Prof. Dr. K. Reichert and Prof. Dr. H. Glavitsch, and the ABB Utilities GmbH.

Formerly Busarello+Cott+Partner Inc., now PSI Neplan AG is a specialized company for designing and developing power system software tools.

NEPLAN® is on the market since 1988, the Windows version since 1991. Therefore it is a very stable program. NEPLAN® has a very high quality and is very reliable. NEPLAN® is a high-end power system analysis tool for applications in transmission, distribution, generation, industrial, renewable energy systems, Smart Grid application and is used in more than 110 countries.

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# 2 Short circuit calculation

The short circuit calculation in NEPLAN® can be made according to

- IEC 60909-0:2016 [1] and
- superposition method [2], [3].

The short circuit calculation has been validated with calculations by hand. A comparison with the calculation in IEC 60909-0:2016, Appendix A gives excellent results. The superposition method is based on the same models (without correcting factors) and algorithm as the calculation according to IEC 60909-0:2016. Therefore a special test result for the superposition method is not given here. Furthermore, the calculation methods ANSI C37.010 and ANSI C37.013, IEC61363-1 and IEC61660-1 (DC) as well as according to G74 recommendation can be selected. However, these methods are not considered here.

The example below gives a comparison with the test example in IEC TR 60909-4:2021.

*The following test network (380 kV/ 110 kV/30 kV) with data of electrical equipment and results for the short-circuit currents in accordance with IEC 60909-0 shall offer the possibility to the designers and users of digital programs to check the results found with their program in comparison to the results given.*

*The results should be reached, to declare a good correspondence between the calculated results and the given results. This is a necessary but not an overall sufficient condition for the program, because even if this test is fulfilled, other procedures within the program may lead to incorrect results. If there are deviations, they should be smaller than ± 0,02 %.*

*Maximum three-phase short-circuit currents shall be calculated at the busbars ① to ⑧ with* $c = c_{\max} = 1{,}1$ *in accordance with (table 1 of IEC 60909-0:2016) and, in addition, maximum line-to-earth short-circuit currents at the busbars ② to ⑤ only. In any case, the short-circuit impedance is to be related to the voltage level where the short-circuit location is situated.*

The complex impedance of network feeders at the connection point shall be calculated with

$$\boldsymbol{X}_{\mathrm{Q}} = \frac{\boldsymbol{Z}_{\mathrm{Q}}}{\sqrt{\mathbf{1} + \left(\boldsymbol{R}_{\mathrm{Q}}/\boldsymbol{X}_{\mathrm{Q}}\right)^2}},$$

*if the ratio* $\boldsymbol{R_Q}/\boldsymbol{X_Q}$ *is given (see Formula (5) of IEC 60909-0:2016) because the approximation* $\boldsymbol{X_Q} = 0{,}995\,\boldsymbol{Z_Q}$ *is offered only for the special case* $\boldsymbol{R_Q}/\boldsymbol{X_Q} = 0{,}1$ *(6.2 of IEC 60909-0:2016). A similar procedure should be chosen for asynchronous motors if the ratio* $\boldsymbol{R_M}/\boldsymbol{X_M}$ *is given (6.10 of IEC 60909-0:2016). Line capacitances are not taken into account because the earth fault factor is smaller than 1,4 (5.2 f) of IEC 60909-0:2016).* $K_{\mathrm{T}}$ *is calculated with Formula (12a) of IEC 60909-0:2016 because load flow conditions are not known for the test network. It is anticipated for the calculation of the impedance correction factor* $K_{\mathrm{S1}}$ *for the power station unit S1 that the generator is operated only in the overexcited region (Figure 7 of IEC 60909-1:2002).*

*In the case of negative values for the reactances of three-winding transformers in the positive-sequence or the negative-sequence system, these should not be interpreted as capacitances, especially in the case of the calculation with the equivalent frequency method (8.1.2 c) of IEC 60909-0:2016. The negative sign may occur for the equivalent reactance (see Figure 6b of IEC 60909-0:2016) of the winding which is situated in between the other two windings in the case of a three-winding transformer (see Table 3 of IEC TR 60909-2:2008, for instance no. 6).*

*When using the 20 Hz or the 24 Hz method respectively to find the factor $\kappa$ in meshed networks, the impedance correction factors $K_{\mathrm{G}}$, $K_{\mathrm{S}}$ and $K_{\mathrm{T}}$ shall be used in the form given (IEC 60909-0).*

*Figure 1 gives the topology of the three-phase a.c. test network, 50 Hz, with the busbars ① to ⑧ and the electrical equipment. The busbars ① to ⑧ shall be the short-circuit locations in the case of three-phase short circuits and the busbars ② to ⑤ in the case of line-to-earth short circuits. There are three earthing points in the 110-kV-part of the network: transformer T4, power-station unit S1 (G1 + T1) and feeder Q2.*

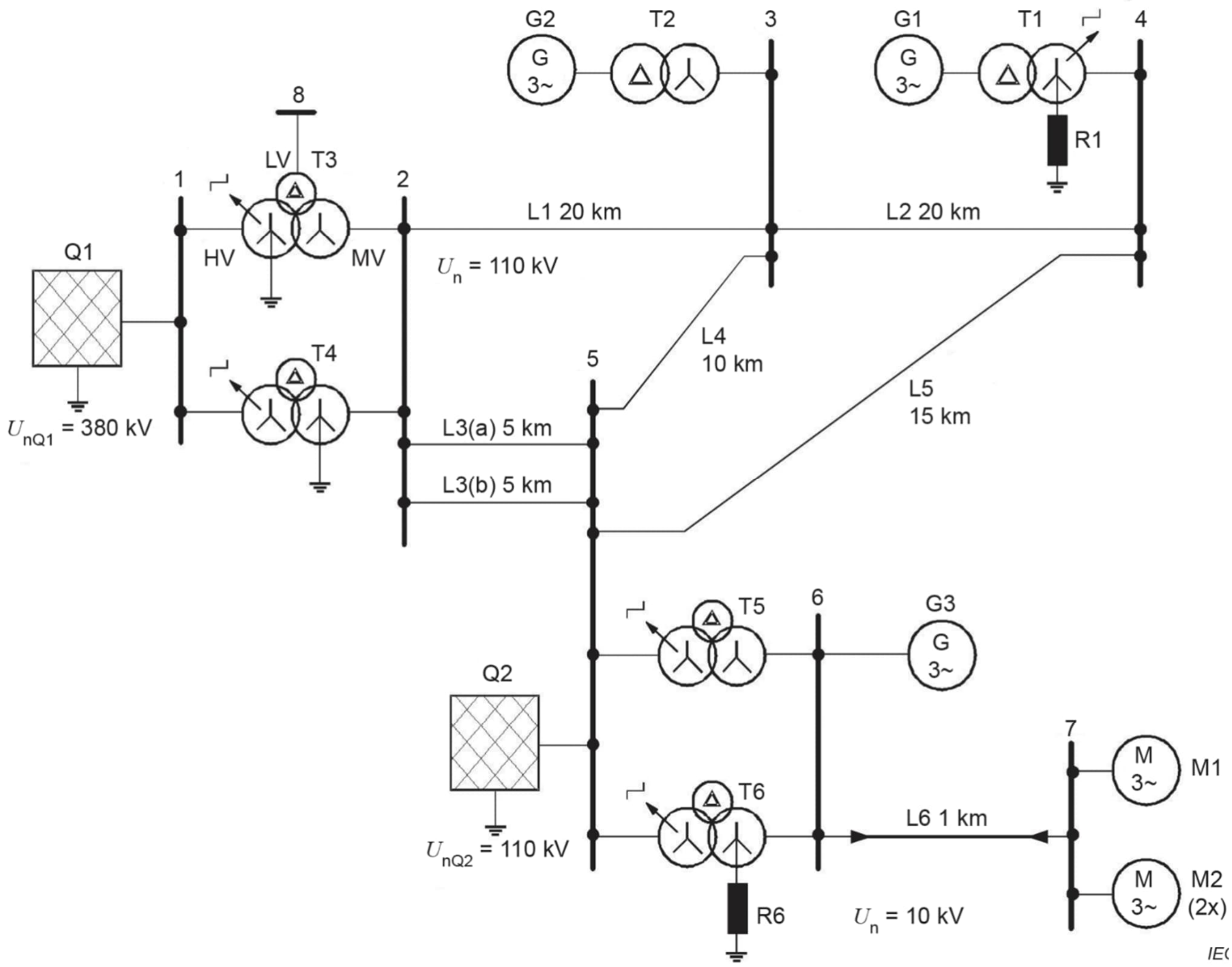


Figure 1: High-voltage a.c. test network 380 kV/110 kV/30 kV/10 kV

Results: Three-phase short-circuit currents

| F | $U_n$ | $I''_k$ [a] | $i_p(50)$ [b] | $i_p(20)$ [c] | $I_b$ [d] | $I_k$ [e] |
|---|---|---|---|---|---|---|
| | kV | kA | kA | kA | kA | kA |
| ① | 380 | 40.6447 | 100.5766 | 100.5677 | 40.645[f] | 40.635 |
| ② | 110 | 31.7831 | 80.5120 | 80.6079 | 31.570 | 31.663 |
| ③ | 110 | 19.6730 | 45.8249 | 45.8111 | 19.388 | 19.623 |
| ④ | 110 | 16.2277 | 36.8041 | 36.8427 | 16.017 | 16.196 |
| ⑤ | 110 | 33.1894 | 83.6265 | 83.4033 | 32.795 | 32.997 |
| ⑥ | 10 | 37.5629 | 99.1910 | 98.1434 | 34.028 | 34.356 |
| ⑦ | 10 | 25.5895 | 51.3864 | 51.6899 | 23.212 | 22.276 |
| ⑧ | 30 | 13.5778 | 36.9201 | 36.9227 | 13.578[g] | 13.573 |

a) $c = c_{max} = 1.1$;

b) Calculated without the factor 1.15 (see 8.1.2 b) of IEC 60909-0:2016), the cable L6 is connected in series with the asynchronous motors and forms a common branch, the overhead lines have a ratio of $R/X \approx 0.3$. In the case of a short circuit in 7, L6 represents a branch and the factor 1,15 shall be used. Take $i_{p50}$ multiplied by 1,15.

c) Calculated with the 20 Hz method (8.1.2 c) of IEC 60909-0:2016).

d) Calculated with Formula (77) of IEC 60909-0:2016 and $t_{min} = 0.1\,s$.

e) $I_k = I''_{kM0}$ (11.2.7 of IEC 60909-0:2016)

f) Far-from-generator and far-from-motor short circuit $I_b = I''_k$ (Formula (76) of IEC 60909-0:2016)

g) Far-from-motor short circuit $\mu_{Mj} = 1 \rightarrow (1 - \mu_{Mj} q_{Mj}) = 0$ (9.1.7 of IEC 60909-0:2016).

Table 1: IEC-Results

| F | $U_n$ | $I''_k$ | $i_p(20)$ | $I_b$ | $I_k$ |
|---|---|---|---|---|---|
| | kV | kA | kA | kA | kA |
| ① | 380 | 40.645 | 100.568 | 40.642 | 40.635 |
| ② | 110 | 31.783 | 80.609 | 31.570 | 31.663 |
| ③ | 110 | 19.673 | 45.811 | 19.388 | 19.623 |
| ④ | 110 | 16.228 | 36.843 | 16.017 | 16.196 |
| ⑤ | 110 | 33.189 | 83.403 | 32.795 | 32.997 |
| ⑥ | 10 | 37.564 | 98.161 | 34.027 | 34.356 |
| ⑦ | 10 | 25.588 | 51.706 | 23.211 | 22.276 |
| ⑧ | 30 | 13.578 | 36.923 | 13.578 | 13.573 |

Table 2: NEPLAN®-Results

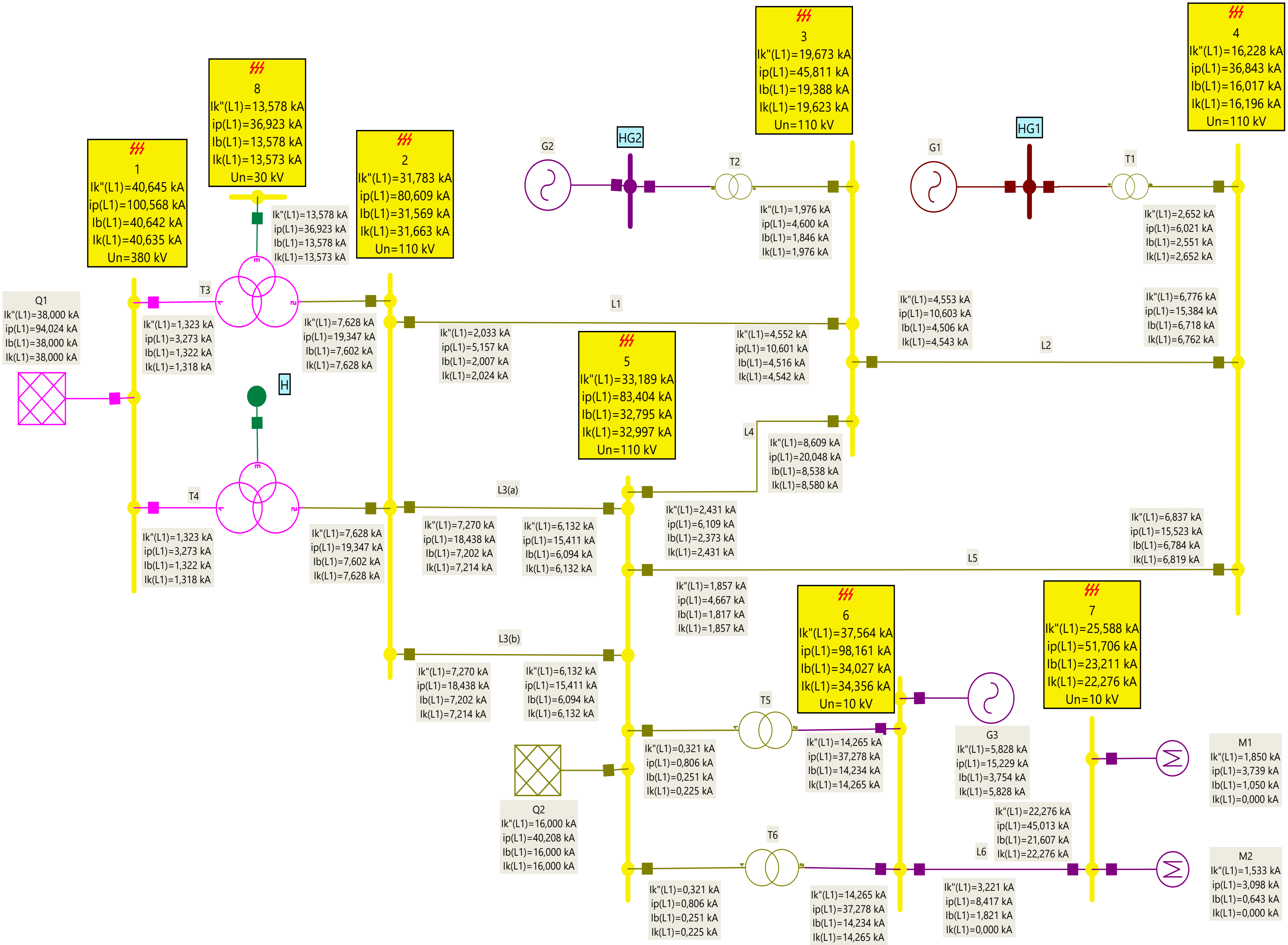




Figure 2: NEPLAN Results for three-phase short-circuit

Results: Line-to-earth short-circuit currents

| F | $U_n$ | $I''_{k1}$ [a)] | $i_{p1}$ [b)] | $i_{p1}$ [c)] | $X_{(0)}/X_{(1)}$ |
|---|---|---|---|---|---|
| | kV | kA | kA | kA | - |
| ② | 110 | 15.9722 | 40.5086 | 39.9641 | 3.961 |
| ③ | 110 | 10.4106 | 24.2424 | 24.2635 | 3.666 |
| ④ | 110 | 9.0498 | 20.5463 | 21.0415 | 3.394 |
| ⑤ | 110 | 17.0452 | 42.8337 | 41.4303 | 3.823 |

a) $I''_{k1} = I_b = I_{k1}$ (see 9.2 and 11.3 of IEC 60909-0:2016), $c = c_{max} = 1.1$;

b) Calculated with the 20 Hz method for the impedances of the positive-sequence system at the short-circuit location (see 8.1.2 c) of IEC 60909-0:2016).

c) Calculated with the 20 Hz method taking into account the zero-sequence, the positive-sequence and the negative-sequence impedances in series at the short-circuit location.

Table 3: IEC Results

| F | $U_n$ | $I''_{k1}$ | $i_{p1}(20)$ | $X_{(0)}/X_{(1)}$ |
|---|---|---|---|---|
| | kV | kA | kA | - |
| ② | 110 | 15.971 | 40.506 | 3.961 |
| ③ | 110 | 10.41 | 24.241 | 3.667 |
| ④ | 110 | 9.049 | 20.545 | 3.395 |
| ⑤ | 110 | 17.043 | 42.823 | 3.825 |

Table 4: NEPLAN®-Results

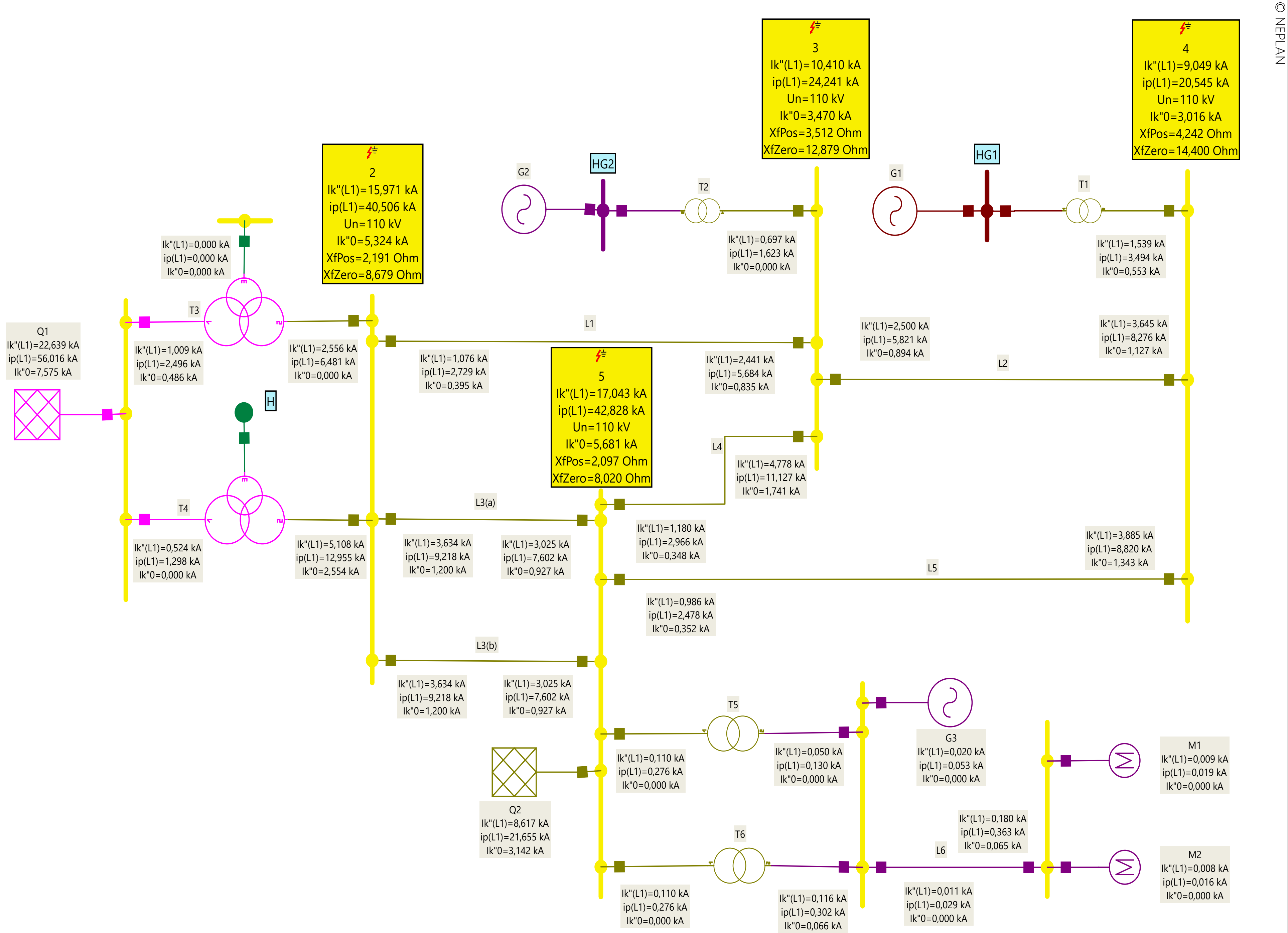


Figure 3: NEPLAN Results for single-phase to ground short-circuit in 110-kV-network

# 3 Loadflow Calculation

The loadflow calculation in NEPLAN® can be made according to the

- current iteration method at the factorized and reduced Y-Matrix
- Newton-Raphson method
- Extended Newton-Raphson method.

Furthermore, the calculation methods Voltage Drop and DC Load Flow can be selected. However, these methods are not considered here.

The methods are described in references [2] and [3]. The current iteration method shows good convergence behavior for networks without PV-nodes. In this case it is much faster than the Newton-Raphson method.

The Extended Newton-Raphson method is basically the same as the normal Newton Raphson method. In the Extended Newton-Raphson method, the modeling equations of the elements are formulated in a different way. Additionally, FACTS devices and Area/Zone control are considered by this calculation method.

The state-of-the-art for loadflow calculation is the Newton-Raphson method. Both methods can be started with

- flat start ($U$ = 0.1 pu) or
- predefined node voltages and transformer taps

and have been validated with calculations by hand. In case of convergence they will get the same results.

In NEPLAN® there is a special algorithm, which checks the Kirchhoff equations

$$[\boldsymbol{Y}]\bullet[\boldsymbol{U}] - [\boldsymbol{I}] = \boldsymbol{\varepsilon}$$

If there is an error greater than $\varepsilon$ a message appears.

### Example 1: Simple Network

The network in Figure 4 can be calculated by hand:

From the equations

$$\boldsymbol{U}_{\mathbf{K1}} = \boldsymbol{R} \cdot \boldsymbol{I} + \boldsymbol{U}_{\mathbf{K2}}; \qquad \boldsymbol{I} = {\boldsymbol{P}_{\mathbf{K2}}}/{\boldsymbol{U}_{\mathbf{K2}}}$$

the solution will be obtained as

$$\boldsymbol{U}_{\mathbf{K2}} = {\boldsymbol{U}_{\mathbf{K1}}}/{\mathbf{2.0}} + \sqrt{\left({\boldsymbol{U}_{\mathbf{K1}}}/{\mathbf{2.0}}\right)^2 - \boldsymbol{R} \cdot \boldsymbol{P}}$$

With the values $\boldsymbol{U}_{\mathbf{K1}} = 10\ \mathrm{kV}, R = 0.5\ \Omega$, $P_{\mathrm{K2}} = 10\ \mathrm{MW}, \boldsymbol{U}_{\mathbf{K2}}$ will be:

$$\boldsymbol{U}_{\mathbf{K2}} = \mathbf{9.472\ kV}$$

The same solution will be obtained by NEPLAN®.

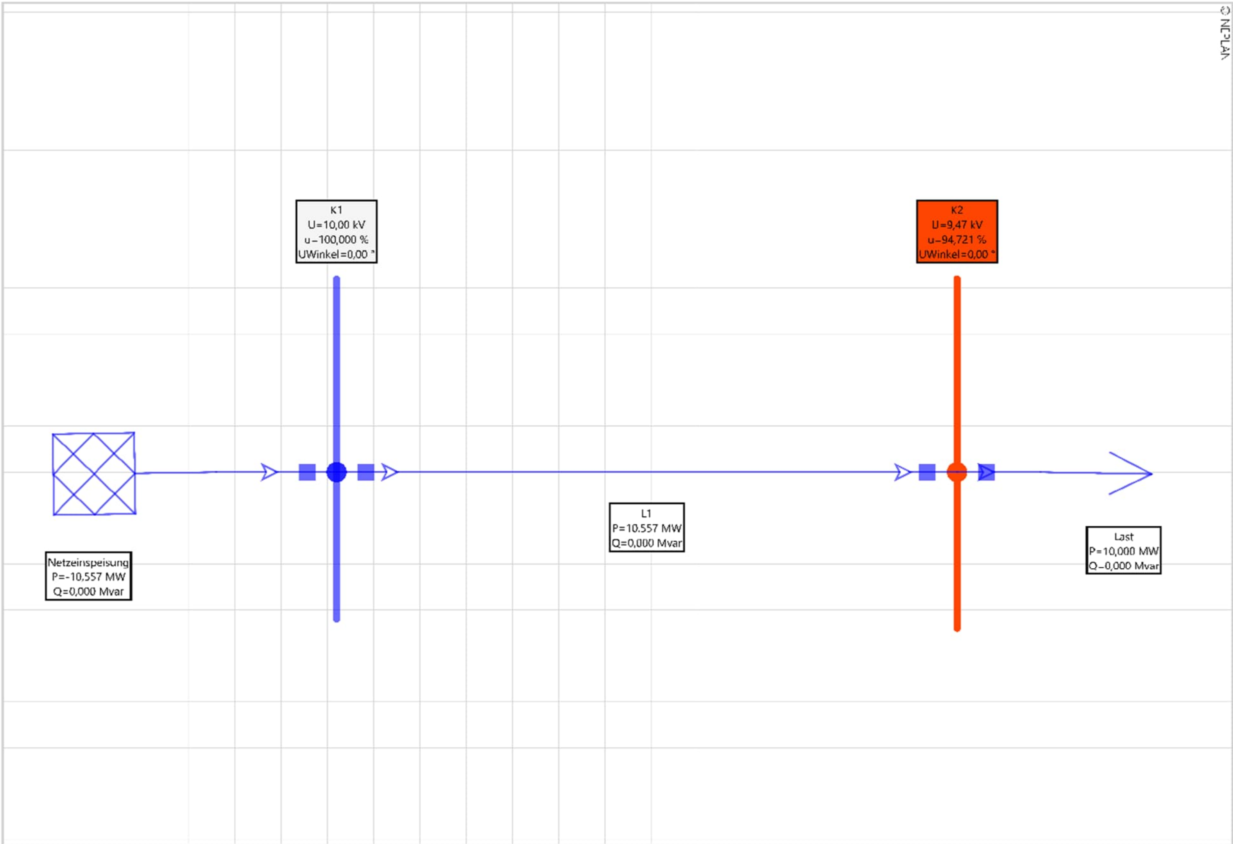


Figure 4: Print-out of NEPLAN®, Loadflow example 1

### Example 2: IEEE 14-Bus System

The IEEE 14-Bus test case is a simplified approximation of the American transmission grid as of February 1962 which has been worked out from the University of Illinois, United States of America and is published in the reference [4].

In the reference the loadflow calculation data is provided for comparison.

The table below shows the results obtained by NEPLAN®. A comparison with the reference shows very small differences, which comes from the input data, different calculation method and the convergence criteria.

| | NEPLAN®, Extended Newton-Raphson | | | Reference | |
|---|---|---|---|---|---|
| | Slackpower:<br>-232.58 MW 16.32 Mvar<br>Total Mismatch:<br>0.0 MW 0.0 Mvar | | | Slackpower:<br>-232.4 MW 16.9 Mvar<br>Total Mismatch:<br>0.0 MW 0.0 Mvar | |
| | Voltages | | | Voltages | |
| Node Names | Volts in % | Angle | | Volts in % | Angle |
| Bus 1 | 106.0 | 0.0 | | 106.0 | 0.0 |
| Bus 2 | 104.5 | -4.98 | | 104.5 | -4.98 |
| Bus 3 | 101.0 | -12.73 | | 101.0 | -12.72 |
| Bus 4 | 101.58 | -10.27 | | 101.9 | -10.33 |
| Bus 5 | 101.86 | -8.78 | | 102.0 | -8.78 |
| Bus 6 | 107.0 | -14.42 | | 107.0 | -14.22 |
| Bus 7 | 105.09 | -13.26 | | 106.2 | -13.37 |
| Bus 8 | 108.97 | -13.26 | | 109.0 | -13.36 |
| Bus 9 | 103.43 | -14.84 | | 105.6 | -14.94 |
| Bus 10 | 103.3 | -15.05 | | 105.1 | -15.10 |
| Bus 11 | 104.77 | -14.85 | | 105.7 | -14.79 |
| Bus 12 | 105.35 | -15.27 | | 105.5 | -15.07 |
| Bus 13 | 104.72 | -15.31 | | 105.0 | -15.16 |
| Bus 14 | 102.17 | -16.07 | | 103.6 | -16.04 |

Table 5: Comparison of NEPLAN Results with Reference for Loadflow Example 2

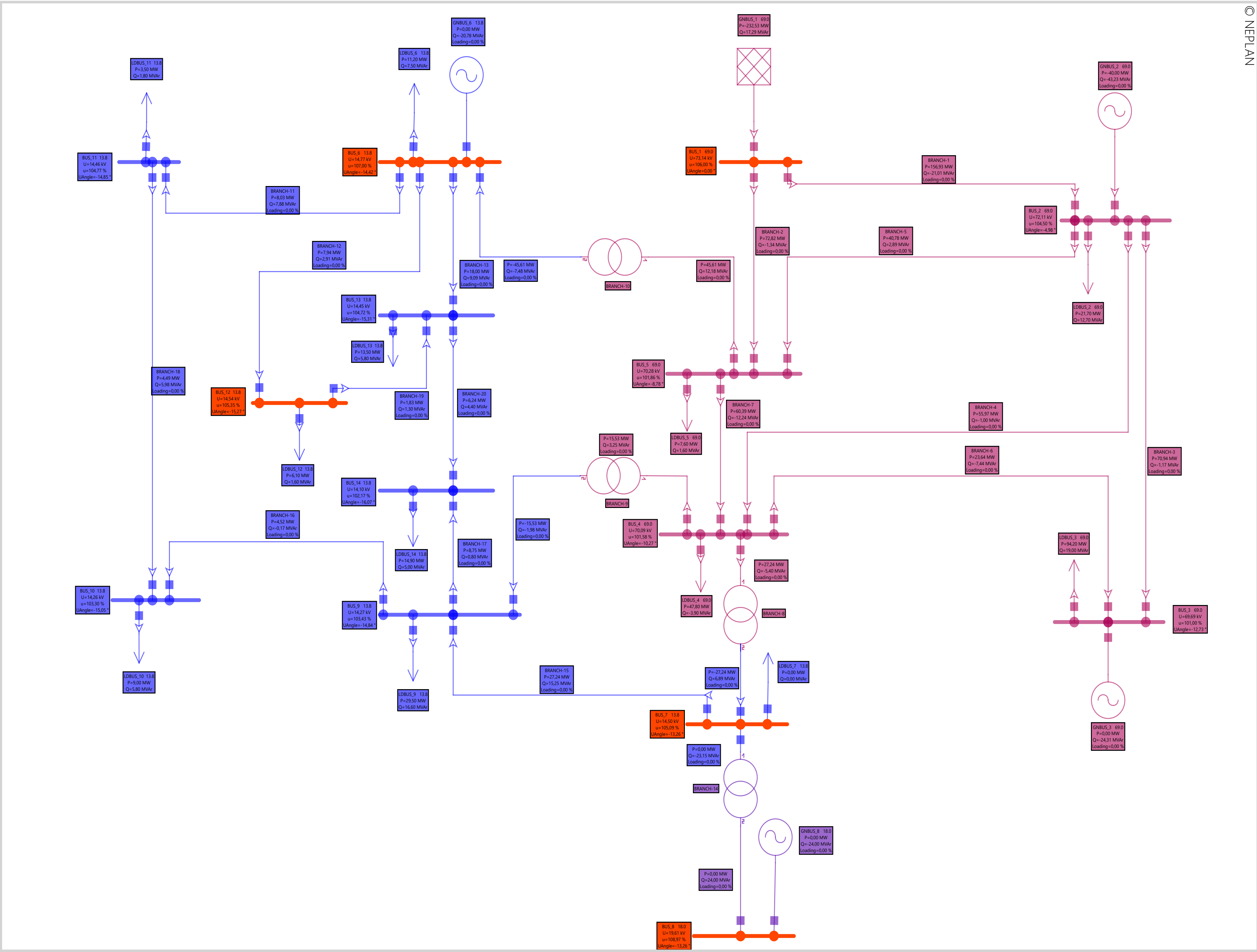


**Figure 5**: NEPLAN Loadflow Results Example 2

# 4 References


[1] IEC, *International Standard 60909-0:2016, Short-circuit currents in three-phase a.c. systems,* 2016.

[2] L. Busarello, *Über die Entwicklung eines Programmsystems zur Analyse und Planung elektrischer Energieversorgungsnetze für Arbeitsplatz-Computer,* Dissertation Nr. 8319 ed., Eidgenössische Technische Hochschule Zürich, 1987.

[3] C. A. J. Arrillaga, Computer Analysis of Power Systems, Baffins Lane, Chichester West Sussex PO19 1DU, England: John Wiley & Sons Ltd., 1990.

[4] U. o. Illinois, *IEEE 14-Bus System Power Flow Test Case,* Illinois: University of Illinois, 1962.