BASIC DESIGN HALSTEREN 380 KV SUBSTATION

Magnetic Field Zones and Optimisation of the Lines

TenneT TSO B.V.

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1 EXECUTIVE SUMMARY

TenneT TSO B.V. intends to integrate a new 380 kV substation into the existing 380 kV transmission line from Geertruidenberg to Rilland (GT-RLL380). The loop-in will occur on the section between towers 125 (HB+0) and 128 (S+0).

The Geetruidenberg – Rilland 380 kV line will also beF upgraded with Warsaw ACCC conductors and new insulators to facilitate a 4000 A nominal load current. As part of the BO stage calculations, TenneT has requested DNV to undertake a magnetic field analysis for the new configuration pertaining to the integration of the new Halsteren substation.

DNV has calculated the specific magnetic field zones where the new HST380 substation is planned to be integrated into the double circuit GT-RLL380 overhead line. For the calculation of the specific magnetic field zones, the guidelines from the RIVM document 'Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen', version 5.0 of 01 April 2023, were applied.

EFC400, a 3rd party verified software program that is used to calculate magnetic fields, was used to calculate the 0.4uT contours, at a height of 1m above ground, around the Geertruidenberg – Halsteren 380 kV line and the Halsteren – Rilland 380 kV line. The contours were processed to calculate the specific magnetic field zone widths around the lines. There are no new sensitive destinations near the location where the proposed Halsteren substation lines connect to the existing Geertruidenberg – Rilland 380 kV circuits. The results outlined in this report are not formatted according to the RIVM formatting or language requirements, as this report relates to the BO design stage of the Halsteren substation. The full RIVM submission will only be compiled during the DO stage.

The phase configuration of the Geertruidenberg – Halsteren 380 kV line is optimized to result in the smallest specific field zone. However, the Halsteren – Rilland 380 kV line phase configuration can still be optimized to reduce the specific field zone width by 10m – 15m.

2 INTRODUCTION

The planned 380 kV Halsteren substation is to be integrated into the 380 kV double circuit overhead line between substations Geertruidenberg and Rilland. The geographic location of this line is illustrated in the grip map in Figure 2-1.

The Geetruidenberg – Rilland 380 kV line will also be upgraded with Warsaw ACCC conductors and new insulators to facilitate a 4000 A nominal load current. As part of the BO stage calculations, TenneT has requested DNV to undertake a magnetic field analysis for the new configuration pertaining to the integration of the new Halsteren substation.

DNV has calculated the specific magnetic field zones where the new HST380 substation is planned to be integrated into the double circuit GT-RLL380 overhead line. For the calculation of the specific magnetic field zones, the guidelines from the RIVM document ‘Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen’, version 5.0 of 01 April 2023, were applied. The results outlined in this report are not formatted according to the RIVM formatting or language requirements as this report relates to the BO design stage of the Halsteren substation. The full RIVM submission will only be compiled during the DO stage.

The structure of this report is organized as follows:

Section 3 describes the starting points used for this investigation.

Section 4 presents the details of the EM field analysis, including the assessment of the new sensitive destinations which will fall within the specific magnetic field zone when the Halsteren substation is integrated.

Section 5 gathers the conclusions drawn and provides further recommendations.

2.1 Overview

The Haslteren 380 kV substation will be integrated into the existing Geertruidenberg – Rilland 380 kV double circuit line, by the loop-in-loop-out (LILO) configuration outlined in Figure 2-1.

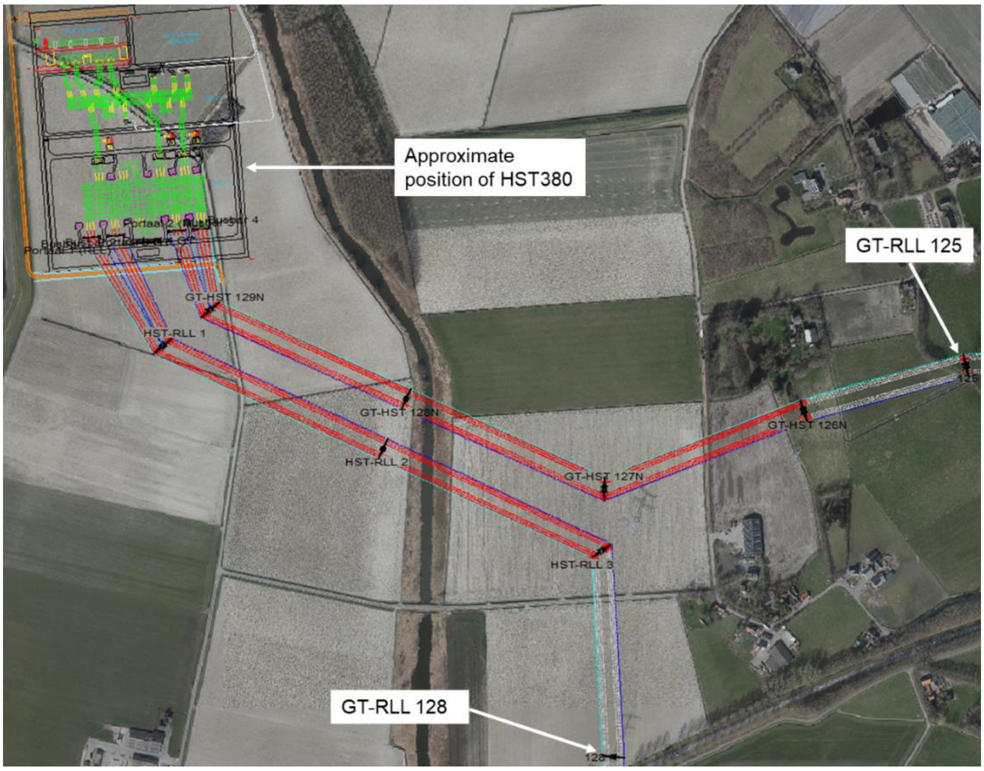


Figure 2-1 Overview of the transmission line GT-HST 380 and HST- RLL 380, with respect to the changed tower near the new Halsteren substation

The new LILO line sections will transmit the same load current as the rest of the line. These lines will therefore also emit magnetic fields which have some design implications on the configuration of the substation and the lines.

Currents transmitted through circuits create magnetic fields. Near transmission lines, as those considered in this report, these circuits conduct AC current resulting in oscillating magnetic fields with a frequency of 50 Hz. If 50 Hz fields are very strong, then nerves can be stimulated, allowing muscles to move uncontrollably. These oscillating magnetic fields can lead to discomfort, if the fields are strong enough, but it does not lead to rreversible health effects. These very strong fields do not occur in the normal living or working environment. In the case where magnetic fields exceed a certain threshold, this can lead to acute effects, such as 'seeing' flashes of light. For magnetic field strength, the European Commission has recommended a reference level for members of the population of 100 micro-Tesla at 50 Hz. Below this reference level, the magnetic field does not cause acute effects. The 100uT field zone is very localized around the current carrying conductors and does not reach to 1m above ground level under the transmission lines. Based on the geometry of the transmission lines and the attachment height of the conductors, there is no possibility of the general public being exposed to the 100uT zone.

The effects of prolonged exposure to even lower field strengths, less than a few micro-Tesla, is not very clear. Some research has identified a weak correlation between children living near overhead power lines and a low increased risk of childhood leukemia. This involves long-term exposure to magnetic field strengths that are on average higher than about 0.4 micro-Tesla. However, a causal relationship between magnetic fields and childhood leukemia has not been demonstrated.

Taking a precautionary approach, the Ministry of Infrastructure and Water Management has issued guidelines for the high-voltage line policy to municipalities, grid operators and provinces. The guidelines recommend that, as far as reasonably possible, the magnetic field strengths due to new, or upgraded power lines, should not increase above 0.4 micro-Tesla on average per year.

The Ministry of I&M drew up a clarification of the opinion; It explains in more detail definitions and concepts from the opinion e.g. what is meant by 'long-term residence' and 'sensitive destination'. The calculation in this memo has been carried out according to the ‘Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen’, version 5.0 of 01 April 2023.

3 INPUT DATA AND STARTING POINTS

The calculations of the magnetic field zones are based on the following starting points:

- The calculation in this memo has been carried out according to the 'Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen', version 5.0 of 01 April 2023.
- A value of 30% of the design flow is used for the calculation flow (in accordance with the RIVM guide)
- The magnetic field strengths are calculated at a height of 1m above ground level, in accordance with the above-mentioned guide.

EFC-400, version 2017, "Magnetic and Electric Field Calculation, Telecommunication, Power Lines and Stations - According to EN 50413, IEC 62226-1, ICNIRP, EU", was used for the calculations of the magnetic field contours. EFC400 is a 3rd party verified software tool.

According to the RIVM-Handreiking, version 5.0, sensitive destinations are classified as:

a. Homes

b. Schools, crèches, or other childminding facilities

c. Areas where children under the age of 15 can stay for prolonged periods.

Other facilities, even if children stay there, are not sensitive destinations within the definition of the policy guideline of the central government. To determine which destination rests on a location, the zoning plan is used as starting point. In the RIVM-Handreiking, version 5.0 a property is only considered a sensitive destination if the specific magnetic field zone intersects the respective buildings, and no longer considers the property boundary as a whole.

The calculation is executed with the following two future lines sections taken into consideration:

- GT-HST380 (Zwart/Wit)
- HST-RLL380 (Zwart/Wit)

The line and tower design documented in "23-0305 Rev.1 DNV Memo TenneT - Halsteren Loop-In.pdf" have been used for the calculation of the magnetic field zones. No additional mitigation measures are considered to further reduce the magnetic field zones widths. It is possible to reduce the magnetic field strength by optimizing the phasing of the lines. This possible optimisation is described in Section 5.1 of this report, but has not been implemented in the calculations, as TenneT has confirmed that the phasing provided for this study should be used in the calculation.

The geometric line information, pertaining to the conductor attachment points, is imported from the PLS CADD model prepared for BO stage of this Halsteren substation project. The PLS CADD data contains the X, Y and Z coordinates, as well as the phasing information used in the EM field calculations.

3.1 Tower Types

The tower types employed along the loop-in lines are summarised in Table 3-1 below. The new towers are similar to those used along the existing line, as shown in the Figure 2-1. The tower types concerning for this study are given in the Table 3-1.

Table 3-1 Tower types for the changed line section

Tower Type	Tower Number(s)
HA+0	GT-HST 126N
HC+0	GT-HST 127N
S+0	GT-HST 128N
HC+0	GT-HST 129N
HC+0	HST-RLL 1
S+0	HST-RLL 2
HC+0	HST-RLL 3

The outlines of these towers are given in Figure 3-1, Figure 3-2 and Figure 3-3.

In addition to the integration of the Halsteren substation, it is understood that the GT-RLL 380 line will also be upgraded with some new insulators and conductors. For this BO submission is understood that the new transmission lines will be designed to conduct a nominal load current of 4000 A.

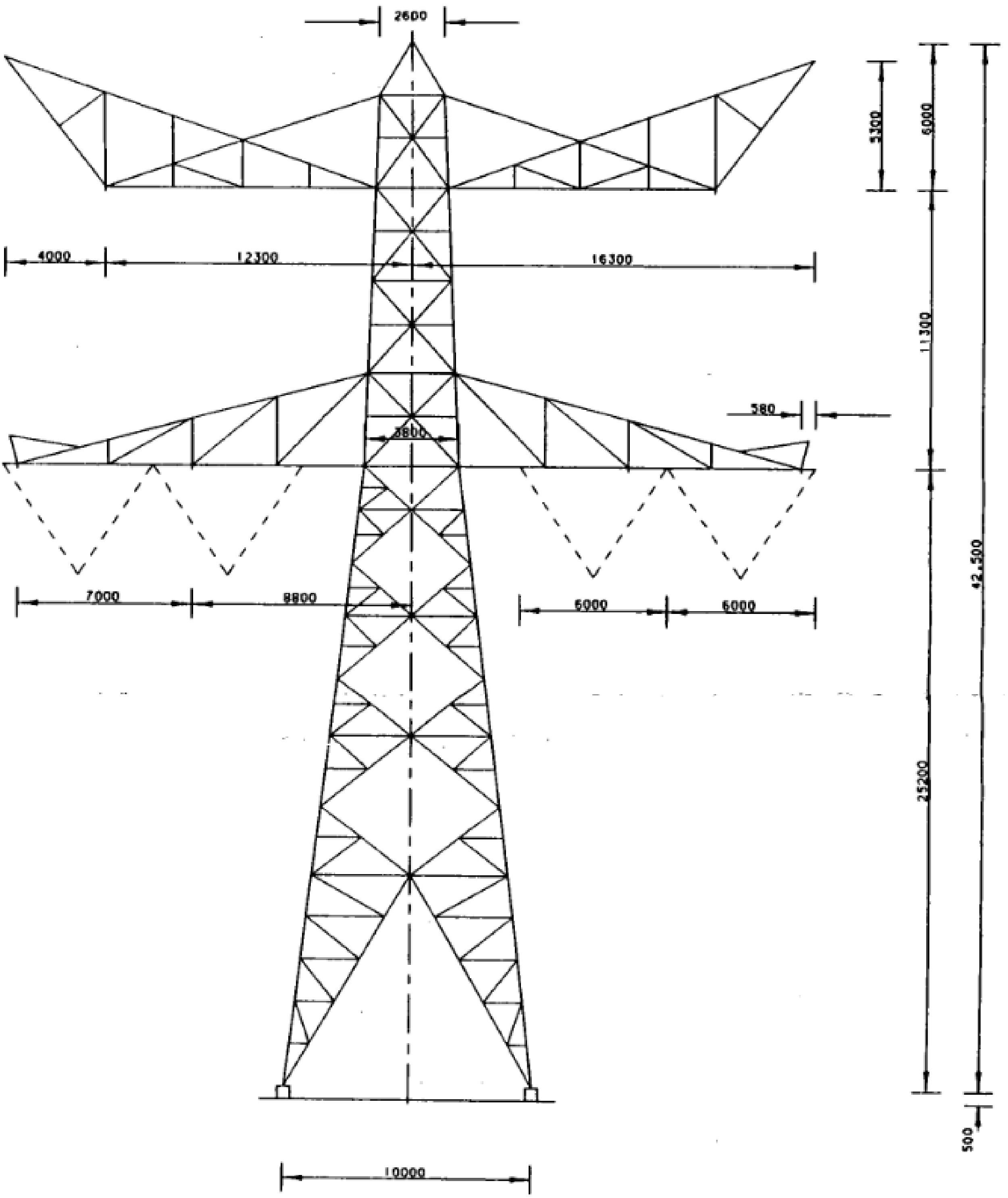


Figure 3-1 Outline of tower type HA

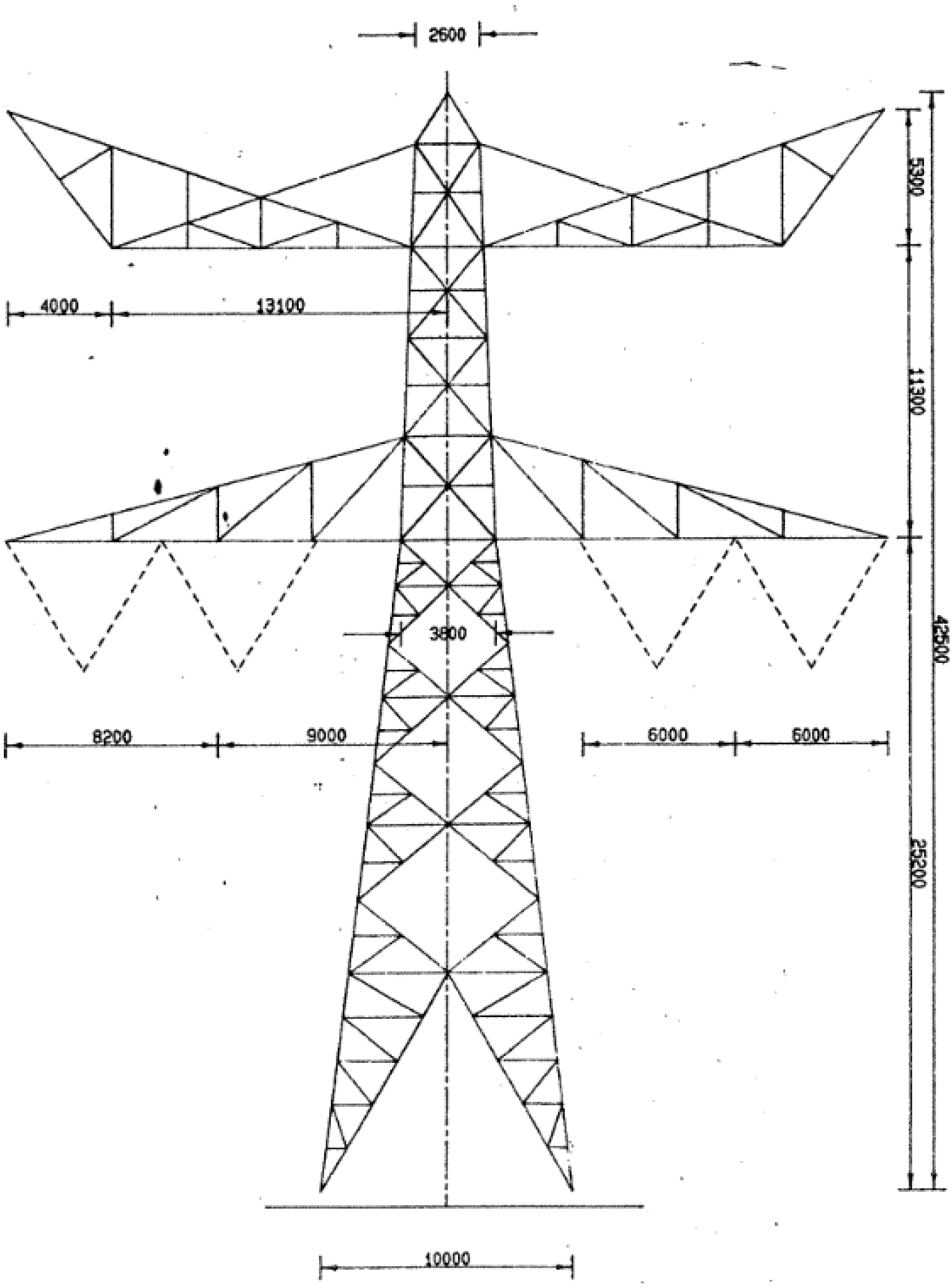


Figure 3-2 Outline of tower type HC

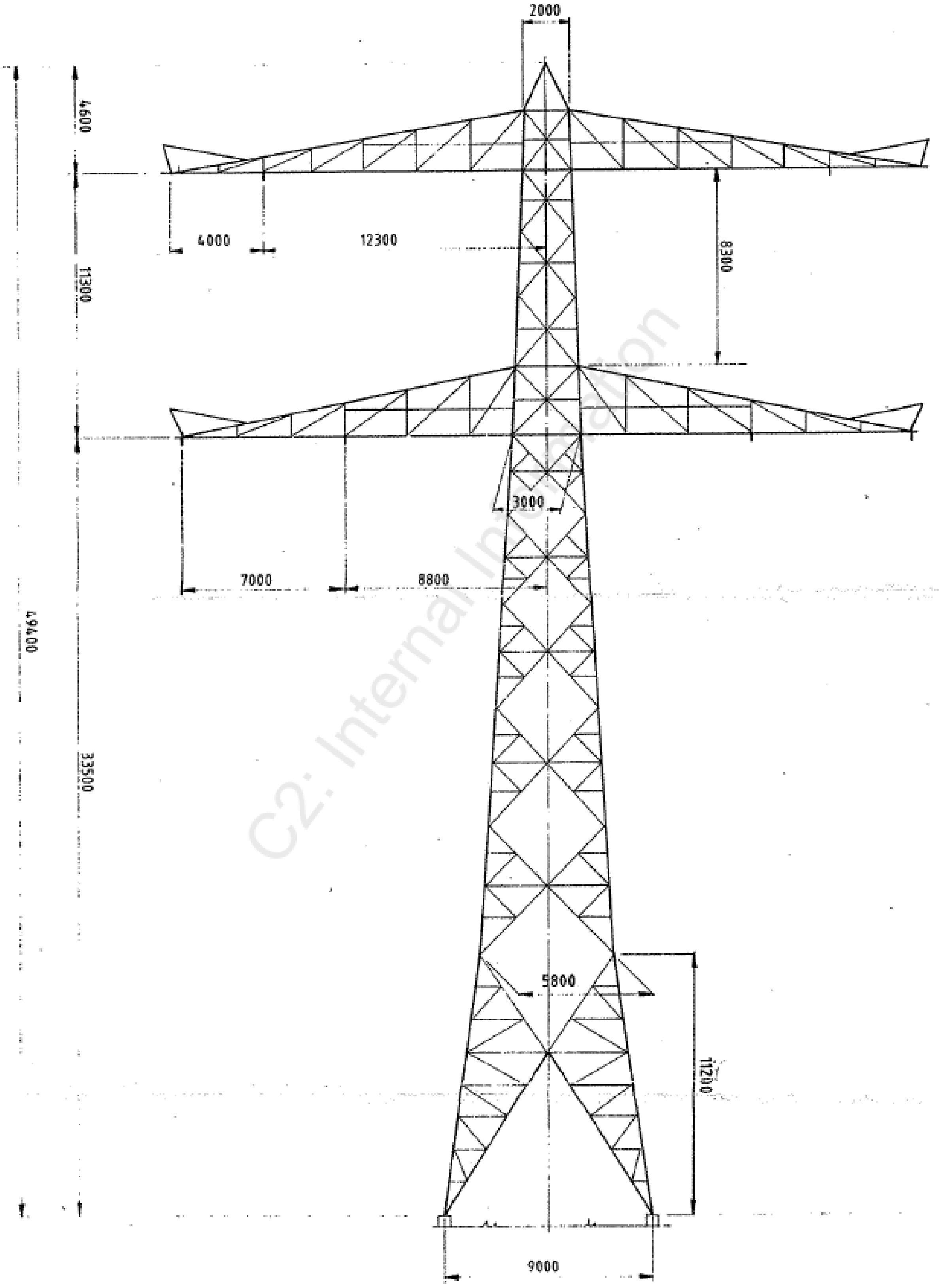


Figure 3-3 Outline of tower type S+0

3.2 Circuit Currents

The currents used in the electro-magnetic field simulation are determined from the design transmission capacity for the two circuits integrating the HST380 substation. The transmission capacity for each of the circuits is 2635 MVA. The long-term current, calculated as 30% of the design current, is summarized in Table 3-2.

Table 3-2: Magnetic field calculation current consideration

Circuit	Voltage level [kV]	Design current [A]	Long-term average current [A]
GT-HST380 (W/Z)	380	4000	1200
HST-RLL380 (W/Z)	380	4000	1200

The magnetic fields are calculated for the assumption that the currents in the two parallel circuits always flow in the same direction, as both circuits terminate at the same substations. According to the “Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen”, version 5.0 of 01 April 2023, the magnetic fields around the two lines are calculated independently, and therefore do not consider any interactions between the magnetic fields of the two lines. It is therefore also not necessary to consider different current directions in the two lines.

3.3 Phase configurations

Table 3-3 and Table 3-4 show the phasing on the connections to Rilland viewed from Rilland towards HST380.

Table 3-3: Phasing on the gantries connecting to Rilland

Gantry – Tower HST-RLL 1					
	Zwart			Wit	
12	4	8	12	4	8

Table 3-4: Phasing on HST-RLL1 towards Rilland.

Tower HST-RLL 1 - Rilland					
	Zwart			Wit	
	4			4	
12		8	12		8

Table 3-5 and

Table 3-6 show the phasing on the connections to Geertruidenberg viewed from Geertruidenberg towards Halsteren 380.

Table 3-5: Phasing on the gantries connecting to Geertruidenberg.

Tower GT-HST 129 N – Gantry Halsteren					
	Wit			Zwart	
8	4	12	12	4	8

Table 3-6: Phasing on GT-HST 1.

Tower GT-HST 129 N - Geertruidenberg			
	Wit		Zwart
	12		4
8	4	12	8

The double circuit line between Halsteren and Geertruidenberg has an “optimized” phase configuration, resulting in the lowest magnetic field widths along the length of the line.

The double circuit line between Halsteren and Rilland is not optimized to reduce the magnetic field width along the length of the line.

3.4 Line configuration

The dimensions of the spans comprising the Loop-In-Loop-Out (LILO) 380 kV double circuit sections are summarised in Table 3-7 and Table 3-8.

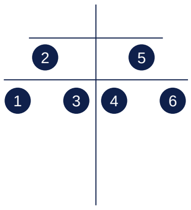
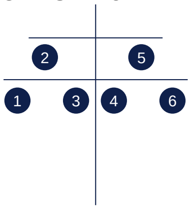
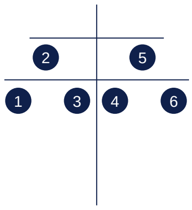
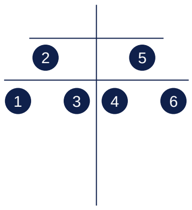
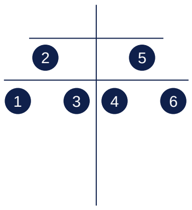
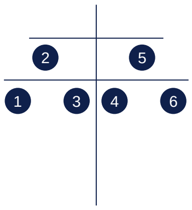
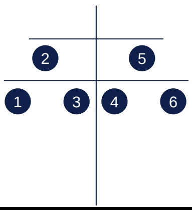
Table 3-7: GT-HST380 Line: Tower numbers, coordinates, types, span length and sag.

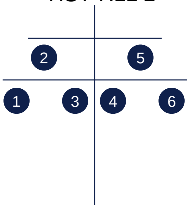
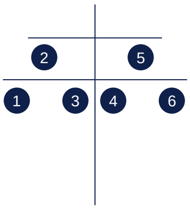
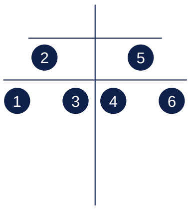
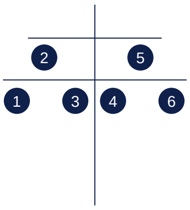
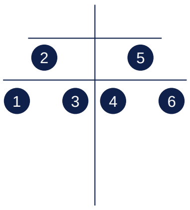
Tower Number [-]	X - coordinate [m]	Y- coordinate [m]	Tower type [-]	Angle [°]	Span length [m]	Sag [m]
GT-HST 129N	75734.88	395587.84	HC+0	-39.9	343.5	11.5
GT-HST 128N	76053.55	395443.09	S+0	-65.6	273.6	6.4
GT-HST 127N	76375.69	395296.77	HC+0	-88.5	345.8	10.3
GT-HST 126N	76699.72	395424.08	HA+0	-108.5	345.2	10.1
125	76963.43	395497.44	HB+0	-105	341.4	12.2
124	77297.46	395521.65	S+0	85.8		

Table 3-8: HST-RLL380 Line: Tower numbers, coordinates, types, span length and sag.

Tower Number [-]	X - coordinate [m]	Y- coordinate [m]	Tower type [-]	Angle [°]	Span length [m]	Sag [m]
HST-RLL 1	75657.64	395529.09	HC+0	320.1	386.7	12.84
HST-RLL 3	76371.17	395196.16	HC+0	145.8	396.7	15.14
HST-RLL 2	76015.83	395361.96	S+0	115.0	326.7	9.44
128	76390.41	394861.53	S+0	-175.3	372.8	12.81
129	76359.98	394489.88	S+0	-175.3	320.0	9.38
130	76333.86	394170.95	S+0	-175.3	353.0	11.54
131	76305.14	393819.11	S+0	-175.3	370.8	12.67

3.5 Condcutor attachment points

Tower name	Tower Type	Conductor number	Horizontal Distance [m]	Height [m]
GT-HST 129N 	HC+0	1	-17.5	26.9
		2	-13.2	38.2
		3	-9.0	26.9
		4	9.0	26.9
		5	13.3	38.2
		6	17.5	26.9
GT-HST 128N 	S+0	1	-8.0	33.5
		2	-5.0	33.5
		3	-3.9	33.5
		4	3.9	33.5
		5	5.0	33.5
		6	8.0	33.5
GT-HST 127N 	HC+0	1	-10.9	13.8
		2	-7.4	13.8
		3	-3.9	13.8
		4	3.9	13.8
		5	7.4	13.8
		6	10.9	13.8
GT-HST 126N 	HA+0	1	-8.0	25.7
		2	-5.0	29.2
		3	-3.9	25.7
		4	3.9	25.7
		5	5.0	29.2
		6	8.0	25.7
125 	HB+0	1	-9.0	18.6
		2	-6.1	18.6
		3	-3.3	18.6
		4	3.3	18.6
		5	6.1	18.6
		6	9.0	18.6
124 	S+0	1	-9.2	35.5
		2	-6.3	35.5
		3	-3.3	35.5
		4	3.3	35.5
		5	6.3	35.5
		6	9.2	35.5
HST-RLL 1 	HC+0	1	-9.2	27.7
		2	-6.3	27.7
		3	-3.3	27.7
		4	3.3	27.7
		5	6.3	27.7
		6	9.2	27.7

Tower name	Tower Type	Conductor number	Horizontal Distance [m]	Height [m]
HST-RLL 2 	HC+0	1	-10.8	54.0
		2	-7.1	54.0
		3	-3.7	54.0
		4	3.7	54.0
		5	7.1	54.0
		6	10.8	54.0
HST-RLL 3 	S+0	1	-10.6	31.8
		2	-7.1	31.8
		3	-3.6	31.8
		4	3.6	31.8
		5	7.1	31.8
		6	10.6	31.8
128 	S+0	1	-9.2	15.1
		2	-6.4	15.1
		3	-3.5	15.1
		4	3.5	15.1
		5	6.4	15.1
		6	9.2	15.1
127 	S+0	1	-10.6	31.8
		2	-7.1	31.8
		3	-3.6	31.8
		4	3.6	31.8
		5	7.1	31.8
		6	10.6	31.8
126 	S+0	1	-9.2	15.1
		2	-6.4	15.1
		3	-3.5	15.1
		4	3.5	15.1
		5	6.4	15.1
		6	9.2	15.1

4 RESULTS

The simulation results, in terms of the specific field zone widths, are summarized in Table 4-1 and Table 4-2.

Table 4-2 for the future grid situation with HST380 substation integrated into the 380 kV grid. The contour width is the maximum distance between the centre line and the contour at the lowest point of the line, between the respective spans. The contours are rounded to 5m specific field zones, as per 'Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen', version 5.0 of 01 April 2023.

It should be noted that the results are for the line configuration and phasing outlined in the BO design document /1/. These results are not formatted according to the RIVM standard as this report relates to the BO design stage of the Halsteren substation. The phasing configuration for the HST-RLL380 line is not optimized for the smallest magnetic field widths. The magnetic field zones are also displayed graphically in Figure 4-1.

Table 4-1: Specific magnetic field zone: GT-HST380 double circuit OHL

Span		Specific Magnetic Field Zone [m]				
From Tower	To Tower	Calculated 0,4 µT Magnetic Field contours (not rounded) [m]		Calculated 0,4 µT Specific Field Zone (rounded) [m]		New sensitive destinations
		(-) Side	(+) Side	(-) Side	(+) Side	
GT-HST 129N	GT-HST 128N	86.8	87.9	85	90	0
GT-HST 128N	GT-HST 127N	89.0	88.5	90	90	0
GT-HST 127N	GT-HST 126N	89.4	89.2	90	90	0
GT-HST 126N	125	86.9	87.2	85	85	0
125	124	87.6	87.5	90	85	0
124	123	86.2	86.3	85	85	0

Table 4-2: Specific magnetic field zone: HST-RLL380 double circuit OHL

Span		Specific Magnetic Field Zone [m]				
From Tower	To Tower	Calculated 0,4 µT Magnetic Field Zone (not rounded) [m]		Calculated 0,4 µT Specific Field Zone (rounded) [m]		Sensitive Destinations
		(-) Side	(+) Side	(-) Side	(+) Side	
HST-RLL 1	HST-RLL 2	120.5	122.4	120	120	0
HST-RLL 2	HST-RLL 3	121.6	124.9	120	125	0
HST-RLL 3	128	120.3	126.4	120	125	0
128	129	122.2	123.1	120	125	0
129	130	121.6	121.7	120	120	0
130	131	122.1	122.1	120	120	0

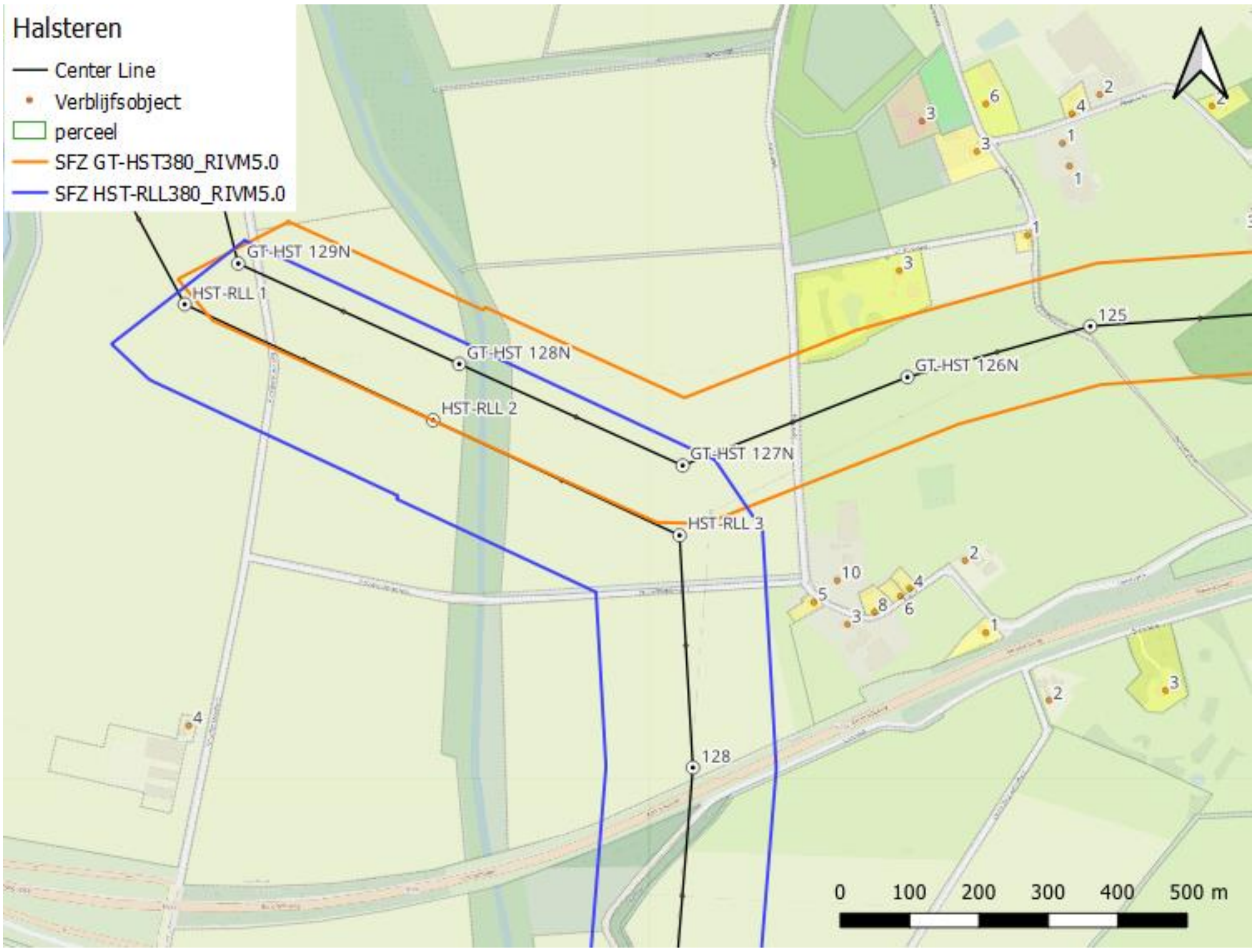


Figure 4-1: Specific magnetic field zone: HST380 substation integration.

It should be noted that the proposed phasing configuration of the HST-RLL380 double circuit line, increases the magnetic field zone width by 15m – 25m along the length of the line. The specific field zones have not been calculated for the line beyond tower 130, but it is likely that the change in phasing, from the existing situation, could incur further sensitive destinations further towards Rilland substation.

5 PHASE OPTIMISATION

Phase optimization (changing the phase sequence) is a way to narrow the magnetic field zone of overhead power lines in specific cases. The narrower zones outside the lines are achieved by positioning the phase conductors on one side of the Tower relative to the phase conductors on the other side of the Tower in such a way that the resulting magnetic field is reduced. The magnetic fields of the circuits cancel each other as much as possible, making the magnetic field zone narrower on both sides of the line.

For electricity transmission based on three-phase alternating voltage, at least three conductors are required. Each of the three conductors has a phase denoted by a clock number. The three conductors together are called a circuit. In the Netherlands, most overhead high-voltage connections consist of two circuits; one on each side of the Tower.

Figure 5-2 shows the non-optimized situation while Figure 5-3 shows the optimized situation. Compared to the current situation, 2 phases in circuit II have changed places. As a result, the magnetic fields of both circuits will have shifted slightly in time (phase). As a result, the sum of all the magnetic fields becomes smaller and thus the magnetic field zone of the span becomes narrower.

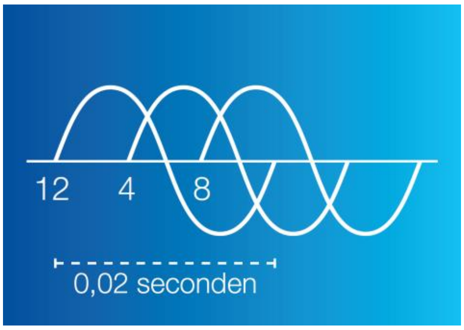


Figure 5-1: Phase numbers and voltage waveform of a 3-phase circuit

The three phases are designated with clock numbers 12, 4 and 8. This designation is derived from the dial of a clock whose hand would go around in 0.02 seconds, if all three phases would start at a zero point in that time frame.

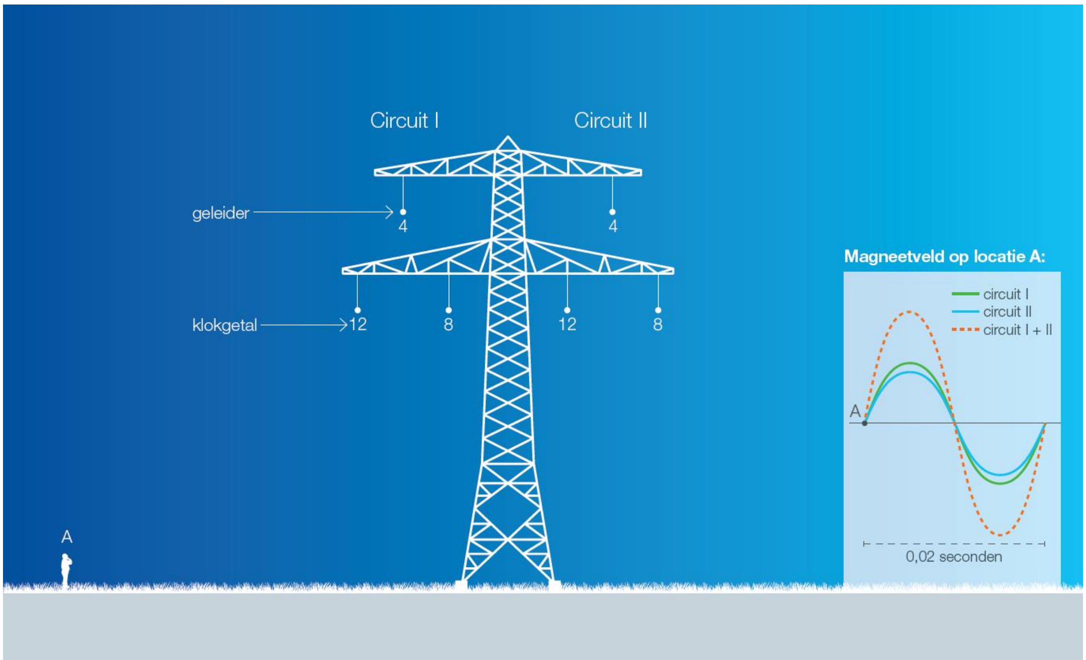


Figure 5-2: Non-optimized situation

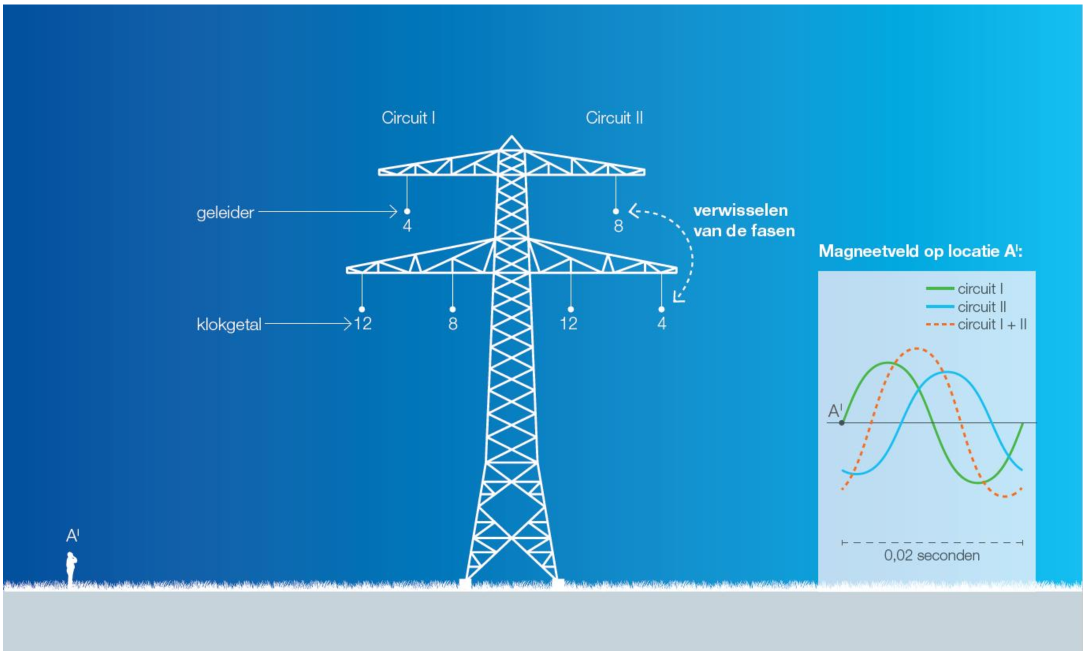


Figure 5-3: Optimized situation

By adjusting the position of the clock numbers (phases), it is possible to find the situation in which the magnetic fields of the individual circuits attenuate each other the best, thereby minimizing the magnetic field zone of the line.

5.1 Optimized Phase configurations

Table 5-1 and Table 5-2 show the optimized phasing on the connections to Rilland viewed from Rilland towards HST380. The portal phasing is not adjusted, as this corresponds to the busbar interconnector layout.

Table 5-1: Phasing on the portals connecting to Rilland

Gantry – Tower HST-RLL 1					
	Zwart			Wit	
12	4	8	12	4	8

Table 5-2: Phasing on HST-RLL1 towards Rilland.

Tower HST-RLL 1 - Rilland					
	Zwart			Wit	
	4			12	
12		8	8		4

Table 5-3 and Table 5-4 show the optimized phasing on the connections to Geertruidenberg viewed from Geertruidenberg towards Halsteren 380. The phasing configuration of the GT-HST380 line is already optimized and does not require any changes to reduce the magnetic field zone along the length of the line.

Table 5-3: Phasing on the portals connecting to Geertruidenberg.

Tower GT-HST 129 N – Gantry Halsteren					
	Wit			Zwart	
8	4	12	12	4	8

Table 5-4: Phasing on GT-HST 1.

Tower GT-HST 129 N - Geertruidenberg					
	Wit			Zwart	
	12			4	
8		4	12		8

Optimizing the Halsteren - Rilland line phase configuration will reduce the field zone width by between 10m and 15m on either side. The optimised situation has not been considered in the calculation.

6 CONCLUSIONS AND RECOMMENDATIONS

The planned 380 kV Halsteren substation is to be integrated into the 380 kV double circuit overhead line between substations Geertruidenberg and Rilland.

The Geetruidenberg – Rilland 380 kV line will also be upgraded with Warsaw ACCC conductors and new insulators to facilitate a 4000 A nominal load current. As part of the BO stage calculations, TenneT has requested DNV to undertake a magnetic field analysis for the new configuration pertaining to the integration of the new Halsteren substation.

DNV has calculated the specific magnetic field zones where the new HST380 substation is planned to be integrated into the double circuit GT-RLL380 overhead line. For the calculation of the specific magnetic field zones, the guidelines from the RIVM document 'Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen', version 5.0 of 01 April 2023, were applied

EFC400, a 3rd party verified software program that is used to calculate magnetic fields, was used to calculate the 0.4uT contours around the Geertruidenberg – Halsteren 380 kV line and the Halsteren – Rilland 380 kV line. The contours were processed to calculate the specific magnetic field zone widths around the lines. From these, a new sensitive destination has been identified, which falls within the specific field zone, as a result of the integration of the Halsteren substation. The results outlined in this report are not presented in line with the RIVM formatting or language requirements as this report relates to the BO design stage of the Halsteren substation. The full RIVM submission will only be compiled during the DO stage.

The phase configuration of the Geertruidenberg – Halsteren 380 kV line is optimized to result in the smallest specific field zone. However, the Halsteren – Rilland 380 kV line phase configuration can still be optimized to reduce the specific field zone width by 15m – 25m. Since the magnetic field zones were only calculated for the towers close to Halsteren, it is not known what the effect is of the non-optimized line along the rest of the 15 km long line, in terms of the number of new sensitive destinations.

7 REFERENCES

/1/ 23-0305 Rev.1 DNV Memo TenneT - Halsteren Loop-In.pdf.

/2/ Handreiking voor het berekenen van de specifieke magneetveldzone bij bovengrondse hoogspanningslijnen, version 5.0 of 01 April 2023.

About DNV

DNV is the independent expert in risk management and assurance, operating in more than 100 countries. Through its broad experience and deep expertise DNV advances safety and sustainable performance, sets industry benchmarks, and inspires and invents solutions.

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