PHASE TO PHASE

Thermal loading capacity of cables and transformers

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CONTENTS

1 INTRODUCTION

The increase in Distributed Energy Resources (DERs) coupled with rise in energy demand on an exponential scale needs to be met with heavy infrastructure changes in the grid at a very rapid pace. This is obviously economically expensive and the time frame in which these need to be delivered makes it very difficult to achieve. The network operators are busy expanding the infrastructure but in the meantime, a question lingers if the existing network's hosting capacity is being utilized in a proper manner. This document aims to shed light on how the hosting capacity of components in the grid (cables and transformers) can be determined taking into consideration also their temperature properties proposing the so called **"Dynamic Approach"**.

Guide overview

The report consists of background and the methods used to determine the dynamic thermal loading capacities of transformers and cables in a Medium Voltage (MV) distribution network. The way to use this feature is explained with a small network example towards the end.

2 DYNAMIC APPROACH VS STATIC APPROACH

Traditionally, the loading of the components is determined based on the ratio of the actual current calculated by load flow to the nominal rated current of the component. In the present situation, most of the components are overloaded if this method is considered. This is referred to as **"Static Approach"** in this document.

An important aspect to determine if the component is indeed beyond its hosting capacity is to also look into its temperature state. The static approach pays no heed to this characteristic of the components. Hence, there comes into play the dynamic approach which takes into consideration the temperature properties of the components and determines the dynamic thermal loading also including the effect of the current loading on the component.

3 BRIEF OVERVIEW

The dynamic approach (called Cyclic calculation) is possible to be computed only when profile loadflow or data driven loadflow (DDLF) is performed in Vision Network Analysis since the norms are defined for an extended time series. The Data Driven load flow method is explained in detail in another document on the Phase to Phase website. The thermal loading calculation is based on the IEC norms 60287 [1] and 60853 [2] for cables and IEC norm 60076-7 for the transformers. In the upcoming sections, context is provided on these norms and their implementation in Vision Network Analysis. The norms for cables have been already implemented in Vision Cable Analysis which have been updated as well as improved to also perform MV network analyses in Vision Network Analysis tool.

4 THERMAL LOADING CAPACITY OF A CABLE

The thermal loading of the cables is calculated on the basis of the two IEC norms 60287 and 60853 as previously mentioned. The soil and environment conditions as well as geometric properties of cables need to be taken into account for the calculation. The extensive documentation is available at [1] and [2] which are used to calculate the permissible current of the overloaded cables, cyclic rating factor and the conductor temperature as well as the maximum stationary current for every cable section in the network topology.

Conventionally, the loading of components is determined based on its nominal current. The current in a component varies with time and is typically regulated to be below its nominal value. Thermal time constants of components are large enough to allow short term overloading in terms of current but not above the rated temperature of the component. An in depth explanation of the entire working of this particular case and a few test results is available in [3].

5 THERMAL LOADING CAPACITY OF A TRANSFORMER

In a similar way, thermal loading of oil immersed power transformers can be computed using the norm IEC 60076-7 [4]. A lot of factors like the type of transformer, environmental conditions, thermal constants of the oil and the windings as well as the initial state of the transformer needs to be considered. In a similar way to the previous section, the conventional approach of limiting the hosting capacity only on the basis of nominal current is being challenged with this approach.

6 IMPLEMENTATION IN VISION NETWORK ANALYSIS

The so called Cyclic calculation is an addition to the already existing loadflow and DDLF (state estimation) calculations in Vision Network Analysis. To use this feature, check the **Cyclus** checkbox that is present when profile load flow or DDLF option is selected. The location of the checkbox in the dialog boxes when clicked on them on the ribbon is as shown in Figure 1.

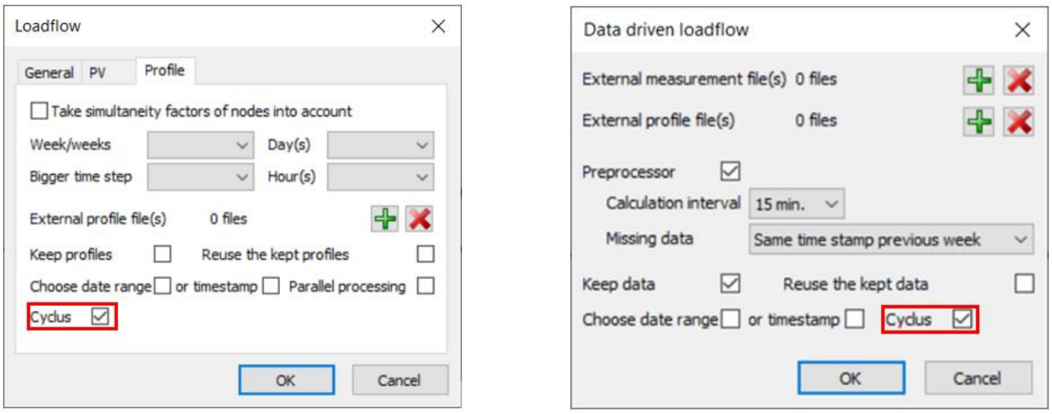

Figure 1 Cyclus checkbox in the dialog boxes (highlighted here)

Note: This functionality is only possible when the calculation is done for a profile of at least a day's duration and hence cannot be replicated for a single instance of load flow.

A default minimum time interval of 1 hour is taken between two timestamps to calculate change in temperature in accordance with the norms. If the profile has duration of less than 1 hour, then the average of the current loading calculated from loadflow over an hour is taken as input for the calculation of the temperature properties.

6.1 Customizing initialisation settings

In the general options tab, the environment variables of the cable and transformer can be adjusted. A snapshot of the available options is shown in Figure 2. The drying type of soil, ground temperature, outer sheath temperature and heat diffusivity of soil can be setup for the cable. For the transformer, the air temperature as well as the hotspot factor of the windings can be initialized.

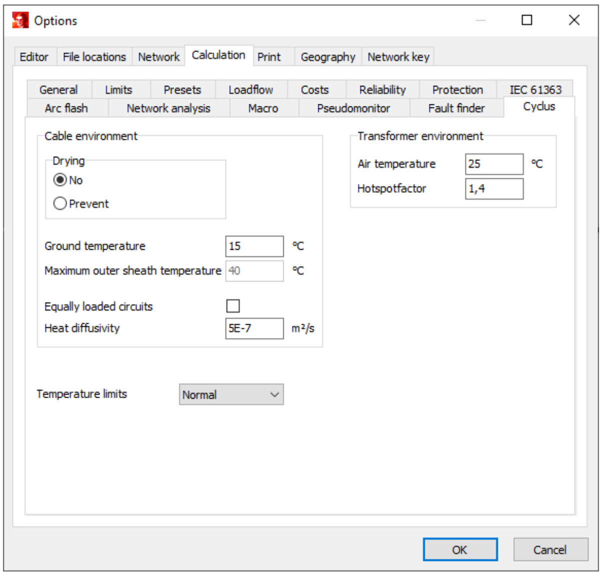

Figure 2 Cyclus options

The temperature limits to be followed can also be adjusted depending on if the loading is normal, short-term emergency or long-term emergency. These indicate various maximum temperature limits depending on the duration of overloading as shown in Table 1. There obviously is an effect on the degradation of the components which needs to be taken into account depending on the loading.

Temperature limits	Hot spot temperature	Top oil temperature
Normal	120	105
Long-term emergency	140	115
Short-term emergency	160	115

Table 1 Temperature limits based on loading

6.1.1 TRANSFORMER COOLING TYPE SETTINGS

The type of cooling for the transformer can be selected from the Connection (Aansluiting in Dutch) tab from the transformer window as shown in Figure 3. The default cooling type is taken as natural cooling for air.

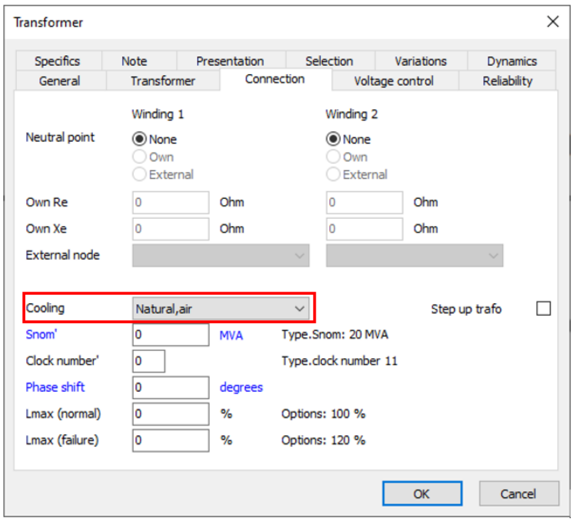

Figure 3 Snap shot of cooling type setting for transformer (highlighted here)

There are seven types of cooling modes defined from the norm [4] shown in Table 2. When an ON- or OF-transformer is zigzag cooled, then the radial spacer thickness if less than 3 mm might cause restricted oil circulation which has an effect on the thermal constants.

Cooling type	Definition
Natural,air	Oil Natural Air Natural (ONAN)
Natural,air,restricted	Oil Natural Air Natural restricted (ONANr)
Forced,air	Oil Natural Air Forced (ONAF)
Forced,air,restricted	Oil Natural Air Forced restricted (ONAFr)
Forced,oil	Oil Forced (OF)
Forced,oil,restricted	Oil Forced restricted (OFr)
Direct,oil	Direct Oil (OD)

Table 2 Transformer cooling types

6.1.2 DETERMINATION OF ‘R’ FOR A TRANSFORMER

R is the ratio of load losses at rated current to the no-load losses at rated voltage. This is needed for the calculation of the temperature of top oil as well as the windings defined as from the norm [4]. In Vision Network Analysis, this can be setup by filling in the values of Pk and Po as seen in Figure 4. Therefore here, R is the ratio of Pk and Po.

If these values are not entered or less than 0.1, then a default value of 20 is taken to proceed with the calculation.

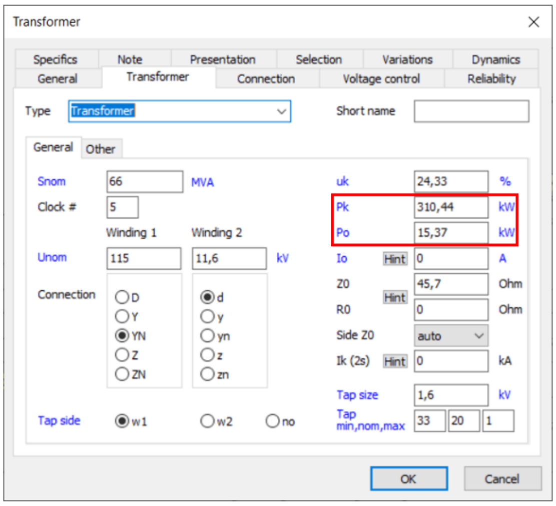

Figure 4 Transformer settings for determination of 'R' (highlighted here)

6.1.3 'G' FOR A CABLE SECTION

The thermal resistivity ***G*** (K·m/W) of a soil for each cable section can be configured taking into account the corresponding nominal current. This can be done by going to the cable properties and selecting the Inom for each cable section which corresponds to a specific thermal soil resistivity.

This can be seen in Figure 5 and has a large impact on the determination of temperature for the cables which makes it important to accurately select the value.

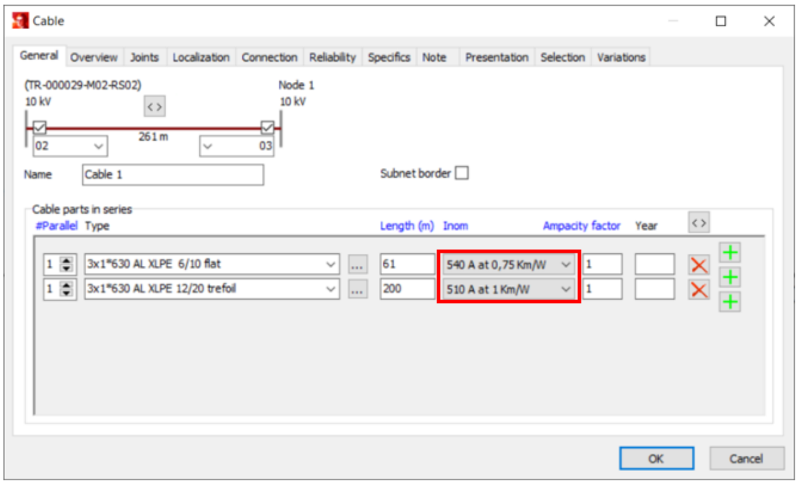

Figure 5 'G' value for cable sections (highlighted here)

6.2 Input format for Excel

The format for input Excel files is described for DDLF as well as profile load flow. The data can be provided as an input in the form of Excel sheets at this moment of time. Considering the bigger picture and practicality that might involve quite a large number of networks, other solutions will be considered for future implementations of these module.

6.2.1 INPUT FORMAT 1 (PROFILE LOAD FLOW)

An easy way to input profiles is name the Excel file same as the element name in the Vision Network Analysis file (.vnf). Then the Excel file format is as shown in Figure 6. The first column is the data and time with the second column being the active power values in **MW**. This format is specifically used to perform the profile load flow studies in Vision Network Analysis.

This format is a bit shorthanded when used for the DDLF module since it is encouraged to have at least two different types of values as inputs to decrease the uncertainty in the calculation.

	A	B	C	D	E
1	01/12/2022 00:00	0,068			
2	01/12/2022 01:00	0,0633			
3	01/12/2022 02:00	0,0601			
4	01/12/2022 03:00	0,0621			

Element Name

Figure 6 Active powers input with Excel

6.2.2 INPUT FORMAT 2 (DDLF)

The format of input profiles facilitated by Vision Network Analysis specifically for DDLF module is described here. The inputs that can be handled by the DDLF module are active/reactive power and current injections at the nodes; active/reactive power flows and currents in branches of the network. This format can also be used when loading profiles for profile load flow.

6.2.2.1 Assigning data to element (MV/LV transformer and industry users)

A particular format needs to be followed for the Excel sheet to recognize and differentiate between the inputs. To connect a profile/measurement with the element in Vision, the format of ***NodeName.ElementName*** needs to be used as shown in Figure 7. Depending on the type of input, the corresponding unit is also entered. For example ***W/kW/MW*** for active power, ***var/kvar/Mvar*** for reactive power, ***A/kA*** for currents and ***V/kV*** for voltages. Additionally, the standard deviations can also be specified through the input, for example ***W_std/kW_std/MW_std*** for active power and ***var_std/kvar_std/Mvar_std*** for reactive powers. This helps in assigning data to the corresponding element. It is advisable to input all parameters in the same class of units. The same process needs to be followed to assign data to industry users too.

Note: Active and reactive power injections at nodes are the most frequently used measurements.

	A	B	C	D	E
1	**datum & tijd**	**NodeName.ElementName**	**NodeName.ElementName**	**NodeName.ElementName**	**NodeName.ElementName**
2		*MW*	*Mvar*	*MW_std*	*Mvar_std*
3	07/02/2022	0,18493071	0,03836006	0,01383925	0,00281018

Figure 7: Data input format for elements

6.2.2.2 Assigning data to branch

In order to assign a profile to a branch, the name of the measuring field ***Name*** needs to be specified instead of the previous format used as shown in Figure 8. The rest of the procedure is similar as to the previous case of assigning to an element but here it is for the branch.

Note: Here, the measuring field represented by ⚲ helps in identifying the branch and cross-referencing it. It is also side specific which means it indicates the side of the branch where the measurement is taken.

	A	B	C
1	**datum & tijd**	**Name**	**Name**
2		*kW*	*kvar*
3	01/01/2021	108	48

Figure 8: Input format for branch element

Note: The units of variables should be uniform in the Excel files throughout the measurement and profile files to avoid computational errors. Refer to the State Estimation document on this module for more details.

6.3 Matching the cable properties

To assess the thermal characteristics of the cables, it is important to also keep track of what its geometric and material properties are. For this, in the types file present in the root folder where Vision is installed there are now two additional sheets. One of them goes over the geometric properties of different kinds of cables (**CABLE GEOMETRY**) and the other one helps to match the names of the existing cables used in Vision Network Analysis in the CABLE sheet to the ones in the CABLE GEOMETRY sheet (**CABLE MAPPING**).

It is imperative that if new cable types which are not from the existing selection provided by Vision Network Analysis are used, then the CABLE GEOMETRY and CABLE MAPPING sheets need to be updated to obtain the results of the cyclic thermal) calculation.

7 EXAMPLE

The usage of this Cyclus feature is explained here with the help of a simple network, and the obtained results are explained.

7.1 Network description

A network with three nodes, one transformer and two loads is taken for the purpose of demonstration as shown in Figure 9. The nominal voltage level of the network is 10 kV. The transformers are rated 50/10 kV.

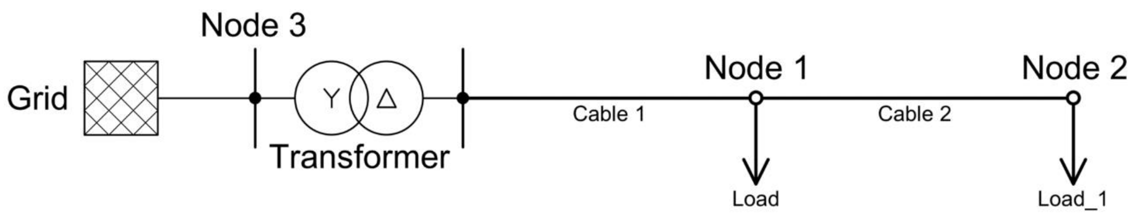

Figure 9: Example of a MV Network

7.2 Input

After selecting the required settings for either the profile load flow or DDLF calculation and also loading in the files in the required manner with the Cyclus checkbox ticked, it is possible to visualize the results of the thermal loading for the components (cables and transformers).

7.3 Viewing the cyclic results

After computation, the cyclus results can be viewed for cable or a transformer by right clicking it and using the Details button to display numerical results, the Graph button for making a plot and the Cyclus button to visualise the temperature outcome. The temperature load rate is also available in the table of the Details button with the rest of the results from the load flow / DDLF calculation.

7.3.1 CABLE

On right clicking the cable, the details panel gives an overview of quite a few variables and there is also an option to view the temperature load rate (minimum and maximum) when the cyclic calculation is performed.

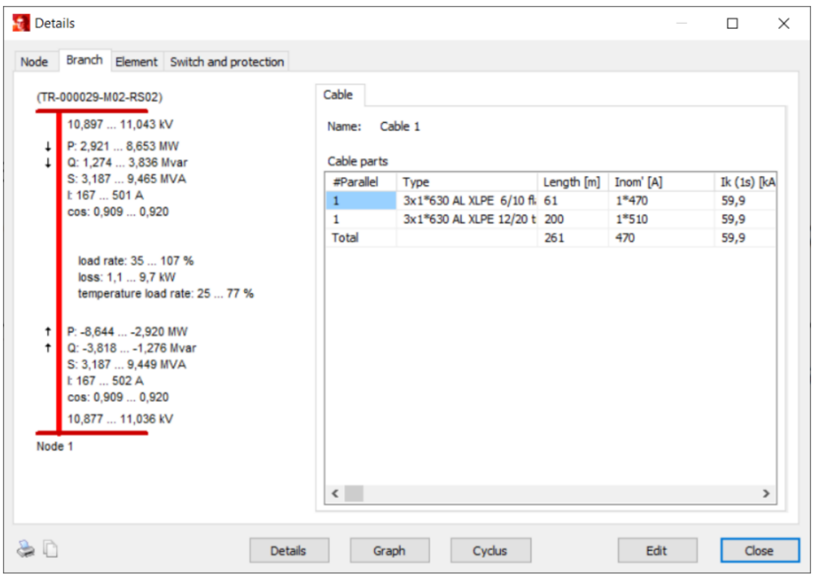

Figure 10: Results in detail form pop-up for a cable

When clicked on the Cyclus option, a detailed visualization can be viewed which shows the conductor temperature with respect to the current profile that is obtained after performing load flow for every cable section as shown in Figure 11. The cable sections can be changed using the drop down menu in the form. The maximum allowed conductor temperature (dependent on the cable type) is plotted as a limit. From the IEC norms, the M- factor and the maximum factor for the current profile is determined as well as the maximum stationary current carrying capacity.

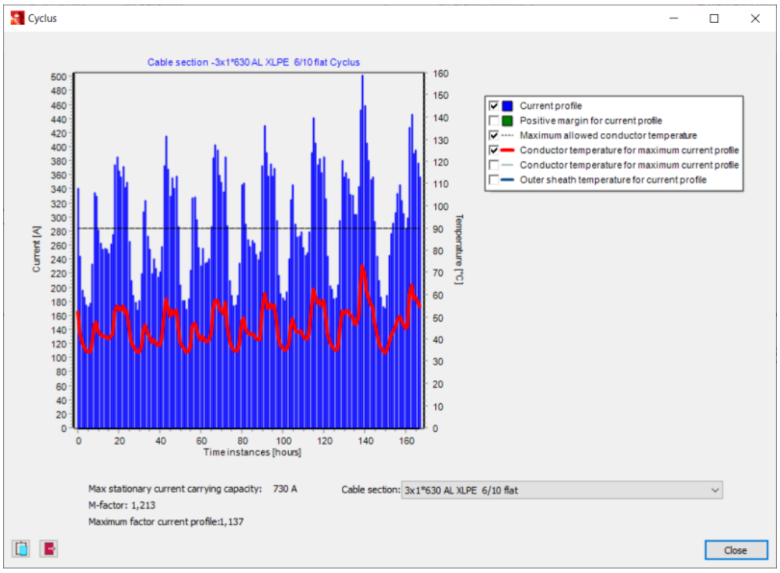

Figure 11 Thermal hosting capacity of cable

The outer sheath temperature can also be visualized by checking on the checkbox in the legend on the right hand side of the form. On the left hand side at the bottom of the form, there are options to export the conductor and outer sheath temperature results along with current profile as excel for every cable section and also to copy the graph to clipboard.

7.3.2 TRANSFORMER

A similar output is also expected from a transformer. The overview is given in the details pane as seen in Figure 12 when right clicked on the transformer with it displaying also the temperature load rate.

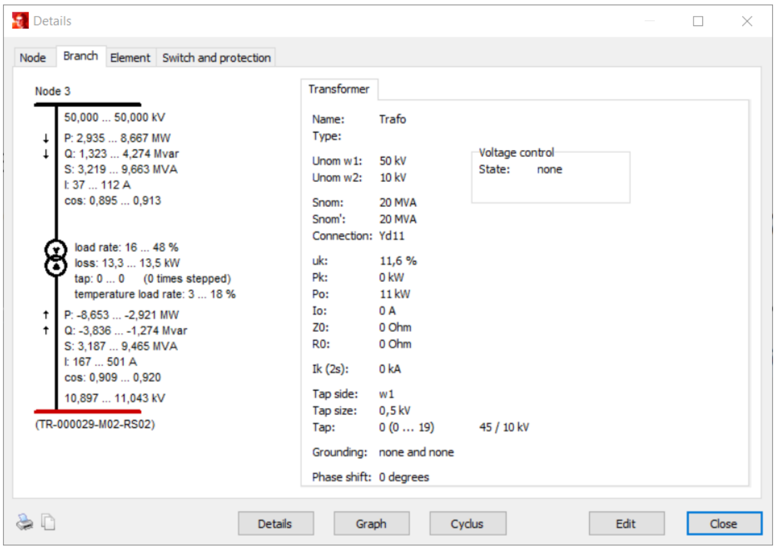

Figure 12 Results in detail form pop-up for a transformer

When clicked on the Cyclus button, Figure 13 pops up which displays the hot spot temperature (in windings of the transformer) against the current profile calculated from the load flow. The top oil temperature can also be viewed by clicking on the option in the legend on the right hand side of the form.

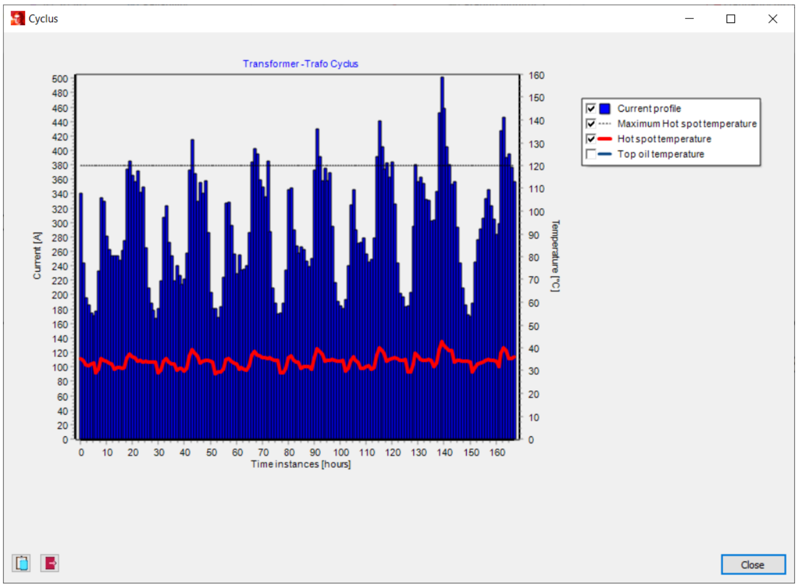

Figure 13 Thermal hosting capacity of transformer

Options to export the hot spot and oil temperatures against the current profile to Excel and to copy the graph to clipboard are available at the left hand side at the bottom of the form.

8 REFERENCES

[1] International Electrotechnical Commission, "Electric cables - Calculation of the current rating," IEC 60287, 2014.

[2] International Electrotechnical Commission, "Calculation of the cyclic and emergency current rating of cables," IEC 60853, 2002.

[3] S.S Nibhanupudi and A. Ishchenko, "Dynamic thermal Loading capacity of underground cables in Medium Voltage Distribution networks," CIRED, Vienna, 2024.

[4] International Electrotechnical Commission, "Power transformers - Part 7: Loading guide for mineral-oil-immersed power transformers," IEC 60076-7, 2018.