SmartNetics

Transformer analysis

Tutorial - July 2025

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Introduction

SmartNetics is a software for the design and analysis of magnetic devices: inductors and transformers.

In previous tutorials (available at www.powersmartcontrol.com) we have shown how to design a dedicated magnetic component. In this case, we will showcase another capability our tool provides: the **analysis of a component**.

This tutorial aims to illustrate how to tackle the analysis of a magnetic component that was already manufactured and for which many of the parameters are unknown. On top of getting the main parameters, SmartNetics gives the user the chance to know if that device will be able to operate in different conditions, to check how far it will be from saturating or burning and even to simulate it in third party software.

This time we are going to analyze a transformer, that was already manufactured for an old project, which data is totally unknown. Once characterized, we will try to find out if we can use it for new projects and what are the expected performance and use limits. The transformer to test is shown in Figure 1.

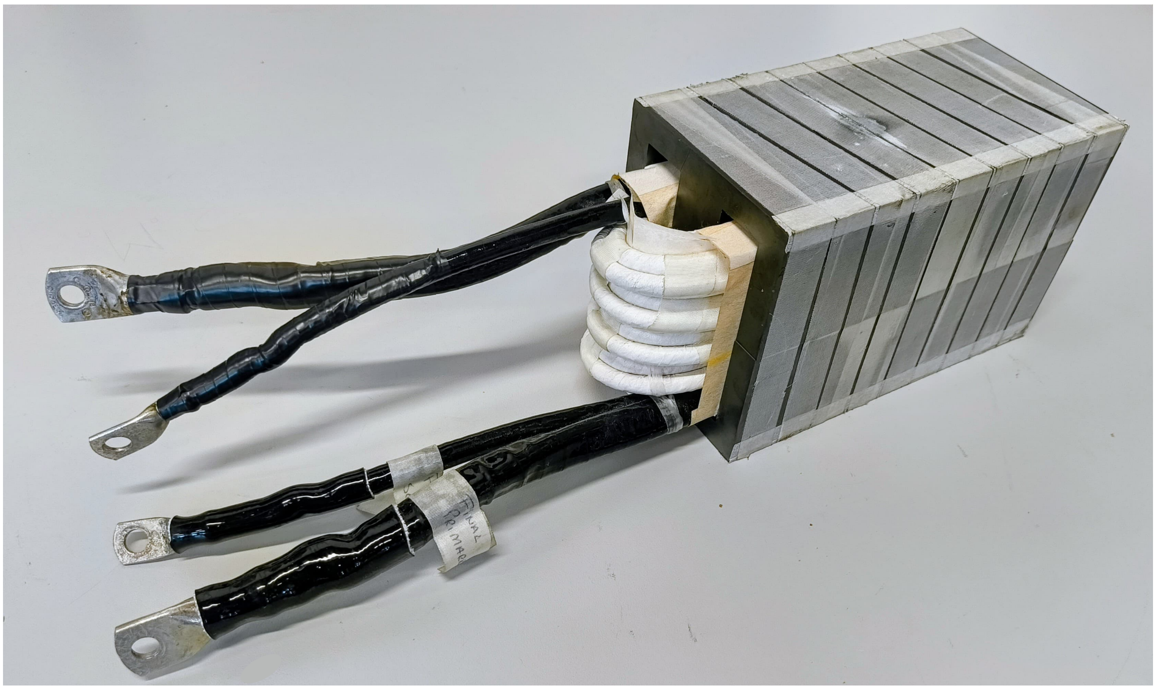


Figure 1: Transformer under analysis

Physical Measurements

Although the original specifications, purpose and manufacturer of the transformer are unknown, there are several parameters that can be obtained by a simple inspection of the geometry. The ones we are going to obtain in this analysis are:

- Core geometry
- Conductor geometry
- Primary turns
- Secondary layers
- Bobbin

Core geometry

First of all, the dimensions of the core can be easily measured.

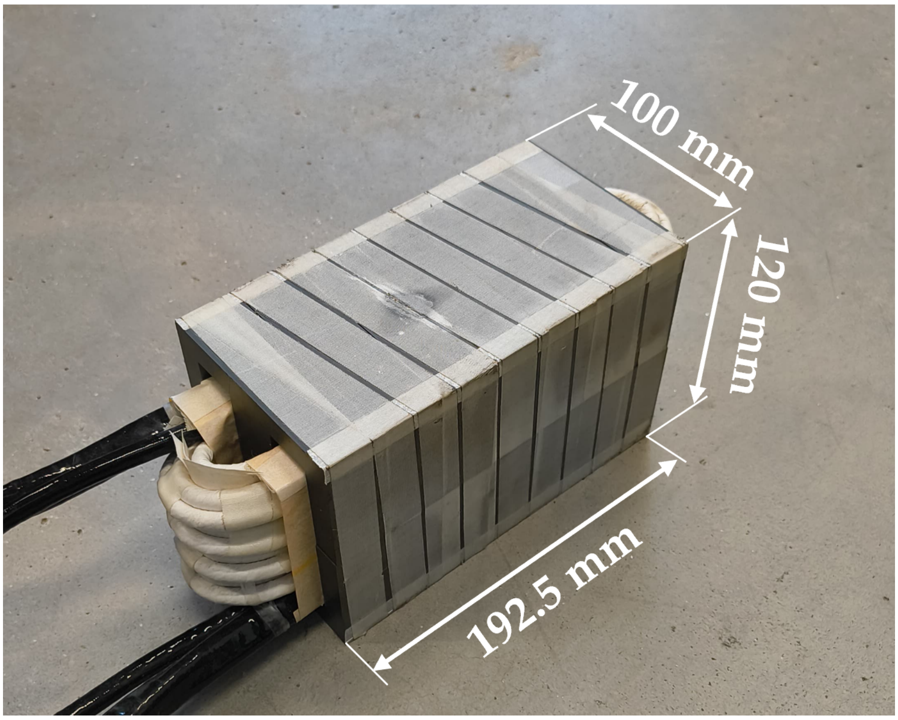


Figure 2: Core dimensions

For the transformer under study, the approximate width, height and length are:

- Width ≈ 100 mm
- Height ≈ 120 mm
- Length ≈ 192.5 mm

From the width and height we can get the core geometry used and select it in the database. In this case, the dimensions correspond to an E100/60/28, so that is the only core geometry we will allow in the database (accessed through "Configuration" - "Databases" - "Core geometry"), as shown in Figure 3.

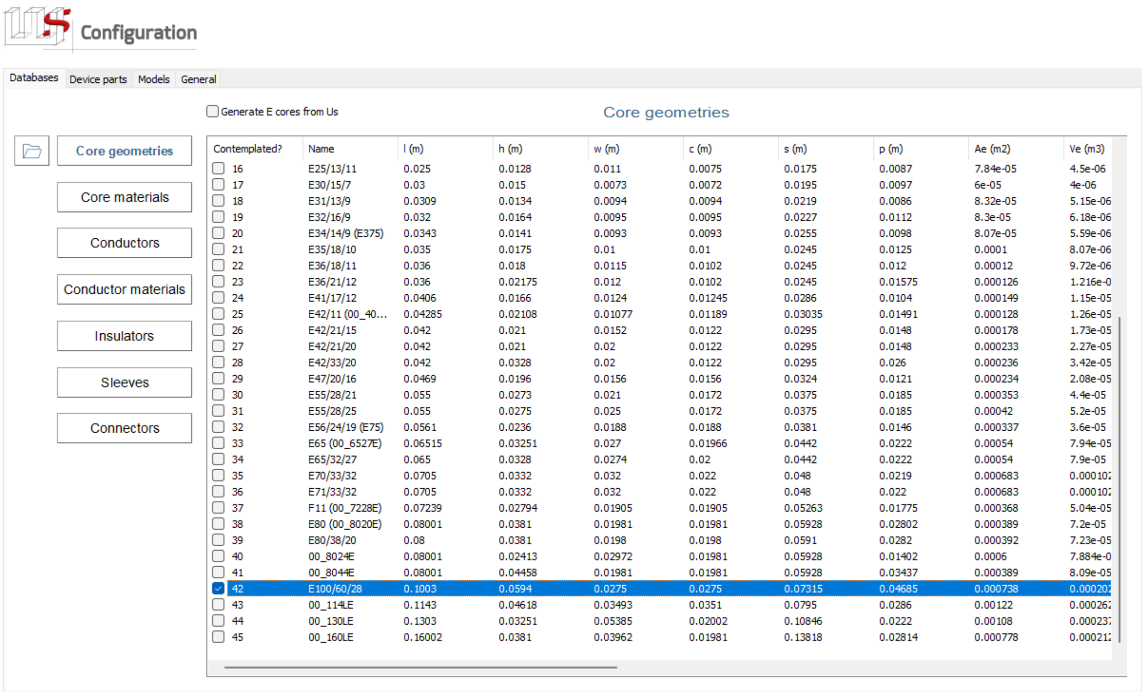


Figure 3: Core geometry

As can be seen, in the database we have selected a geometry that matches the measured width (defined by the parameter "l (m)" in SmartNetics) and height (2 times the parameter "h (m)"), which corresponds to the E100/60 core. The remaining dimension (length) is much bigger than the one shown in the database ("w (m)"), which means there is more than one core, stacked in parallel. The original length of an E100/60/28 core is 27.5 mm, so this means the number of stacked cores in this case is:

$$\frac{192.5}{27.5} = 7$$

To avoid the use of a different number, we will set the minimum and maximum number of staked cores to 7 at "Configuration" - "Device parts" - "Minimum stacked cores"/"Minimum stacked cores", as shown in Figure 4.

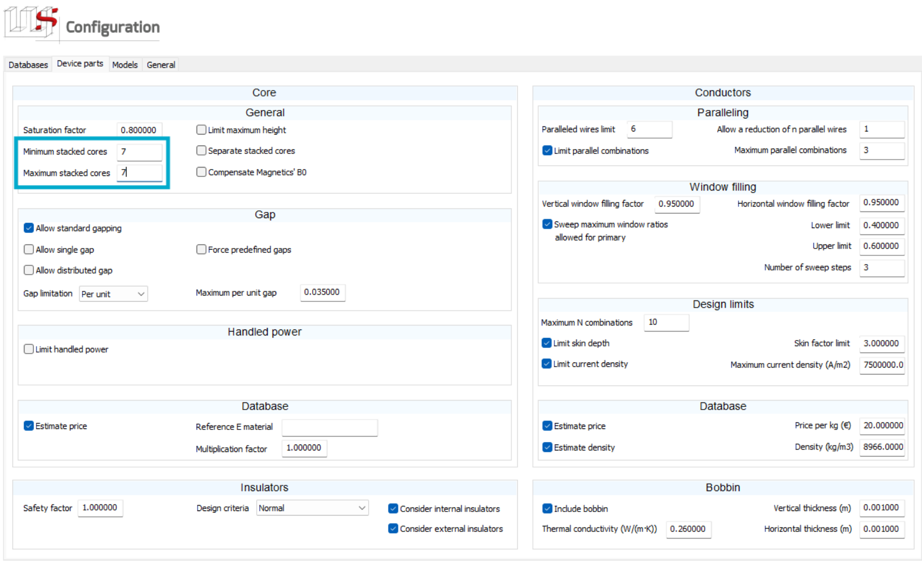


Figure 4: Maximum and minimum stacked cores

Once the core geometry is defined, the next step is to analyze the conductors.

Conductor geometry

The windings are easily accessed by the front and back. As shown in Figure 5, the same wire is used for primary and secondary. The wire has some insulation that seems added ad-hoc but, nevertheless, the approximate external diameter can be measured with a caliper.

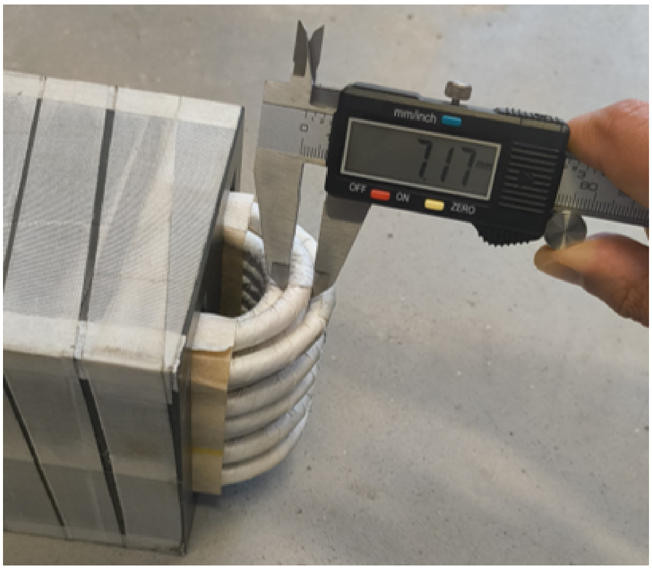
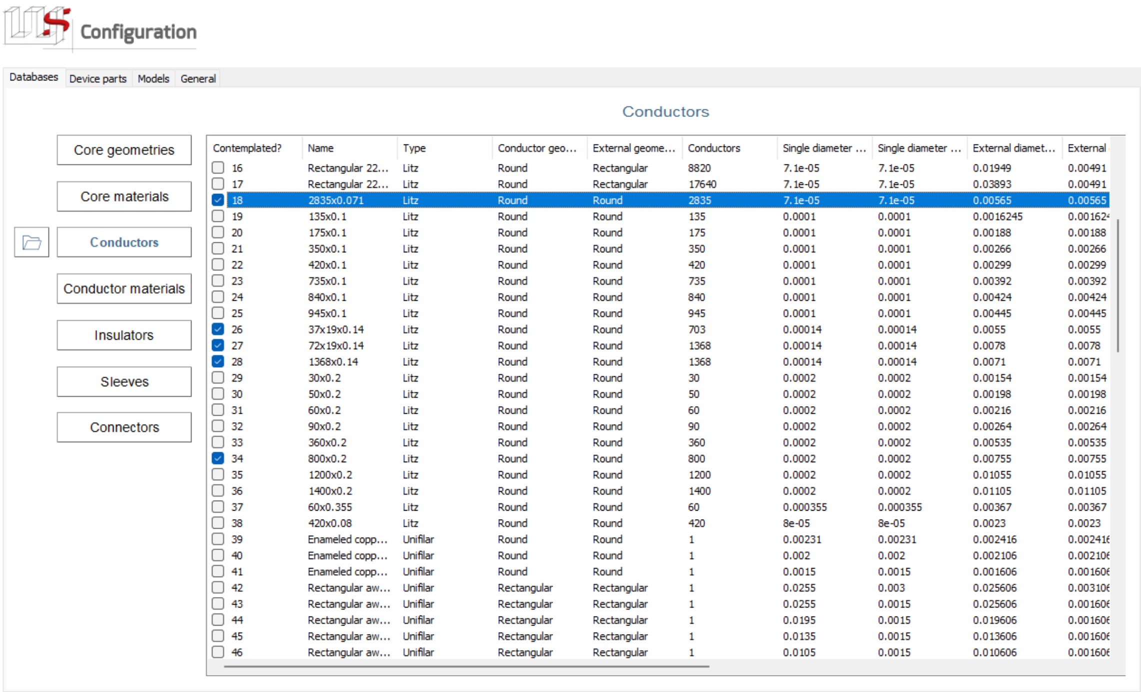


Figure 5: Wire diameter measurement

The approximate external diameter of the wire is 7.17 mm, but there are some uncertainties regarding the thickness of the extra insulation or the grip strength when measuring the dimension. Instead of a single option, every wire that is close to the measurement (from 5 to 8 millimeters) is going to be selected as a possibility in the database (accessed through “Configuration” - “Databases” - “Conductors”):



Contemplated?		Name	Type	Conductor geo...	External geome...	Conductors	Single diameter ...	Single diameter ...	External diamet...	External
☐	16	Rectangular 22...	Litz	Round	Rectangular	8820	7.1e-05	7.1e-05	0.01949	0.00491
☐	17	Rectangular 22...	Litz	Round	Rectangular	17640	7.1e-05	7.1e-05	0.03893	0.00491
☑	18	2835x0.071	Litz	Round	Round	2835	7.1e-05	7.1e-05	0.00565	0.00565
☐	19	135x0.1	Litz	Round	Round	135	0.0001	0.0001	0.0016245	0.00162
☐	20	175x0.1	Litz	Round	Round	175	0.0001	0.0001	0.00188	0.00188
☐	21	350x0.1	Litz	Round	Round	350	0.0001	0.0001	0.00266	0.00266
☐	22	420x0.1	Litz	Round	Round	420	0.0001	0.0001	0.00299	0.00299
☐	23	735x0.1	Litz	Round	Round	735	0.0001	0.0001	0.00392	0.00392
☐	24	840x0.1	Litz	Round	Round	840	0.0001	0.0001	0.00424	0.00424
☐	25	945x0.1	Litz	Round	Round	945	0.0001	0.0001	0.00445	0.00445
☑	26	37x19x0.14	Litz	Round	Round	703	0.00014	0.00014	0.0055	0.0055
☑	27	72x19x0.14	Litz	Round	Round	1368	0.00014	0.00014	0.0078	0.0078
☑	28	1368x0.14	Litz	Round	Round	1368	0.00014	0.00014	0.0071	0.0071
☐	29	30x0.2	Litz	Round	Round	30	0.0002	0.0002	0.00154	0.00154
☐	30	50x0.2	Litz	Round	Round	50	0.0002	0.0002	0.00198	0.00198
☐	31	60x0.2	Litz	Round	Round	60	0.0002	0.0002	0.00216	0.00216
☐	32	90x0.2	Litz	Round	Round	90	0.0002	0.0002	0.00264	0.00264
☐	33	360x0.2	Litz	Round	Round	360	0.0002	0.0002	0.00535	0.00535
☑	34	800x0.2	Litz	Round	Round	800	0.0002	0.0002	0.00755	0.00755
☐	35	1200x0.2	Litz	Round	Round	1200	0.0002	0.0002	0.01055	0.01055
☐	36	1400x0.2	Litz	Round	Round	1400	0.0002	0.0002	0.01105	0.01105
☐	37	60x0.355	Litz	Round	Round	60	0.000355	0.000355	0.00367	0.00367
☐	38	420x0.08	Litz	Round	Round	420	8e-05	8e-05	0.0023	0.0023
☐	39	Enameled copp...	Unifilar	Round	Round	1	0.00231	0.00231	0.002416	0.002416
☐	40	Enameled copp...	Unifilar	Round	Round	1	0.002	0.002	0.002106	0.002106
☐	41	Enameled copp...	Unifilar	Round	Round	1	0.0015	0.0015	0.001606	0.001606
☐	42	Rectangular aw...	Unifilar	Rectangular	Rectangular	1	0.0255	0.003	0.025606	0.003106
☐	43	Rectangular aw...	Unifilar	Rectangular	Rectangular	1	0.0255	0.0015	0.025606	0.001606
☐	44	Rectangular aw...	Unifilar	Rectangular	Rectangular	1	0.0195	0.0015	0.019606	0.001606
☐	45	Rectangular aw...	Unifilar	Rectangular	Rectangular	1	0.0135	0.0015	0.013606	0.001606
☐	46	Rectangular aw...	Unifilar	Rectangular	Rectangular	1	0.0105	0.0015	0.010606	0.001606

Figure 6: Selected conductor geometries

Primary turns

From the front we can see that only the external winding is easily accessible. We will define it as the primary winding and, as shown in the next figure, we can see that it is composed by 5 turns consistent of three wires in parallel each.

Figure 7: Primary winding

Those restrictions to the design can be imposed in "Configuration" - "General" - "Parameters set" - "Transformer". Only the known parameters are set, while the remaining ones are left empty (or as 0) since they are still unknown and we need the tool to calculate them. The resulting configuration is displayed in Figure 8.

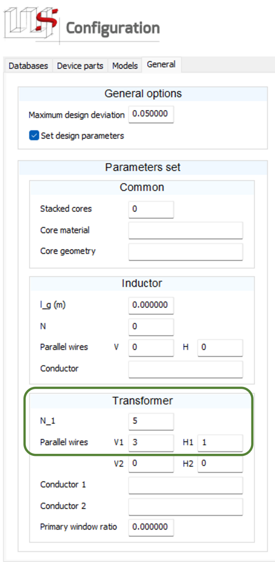


Figure 8: Set parameters

Notice that, although the real transformer does not strictly have 3 wires in vertical in its winding, in SmartNetics only rectangular packaging is currently supported, so this serves as a good approximation.

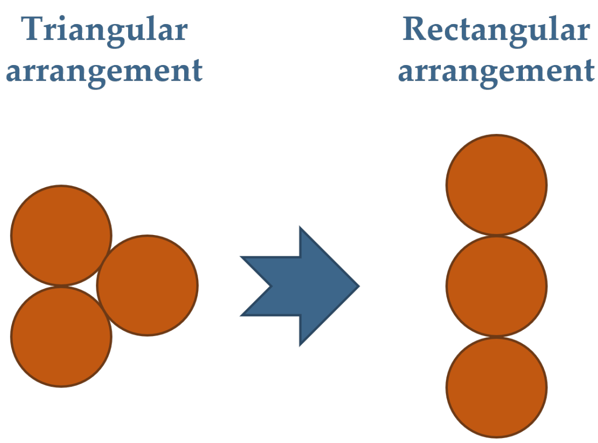


Figure 9: Supported wire arrangement

Secondary layers

The secondary winding lays between the core and the primary side, so we have very limited access to it, as can be seen in Figure 10.

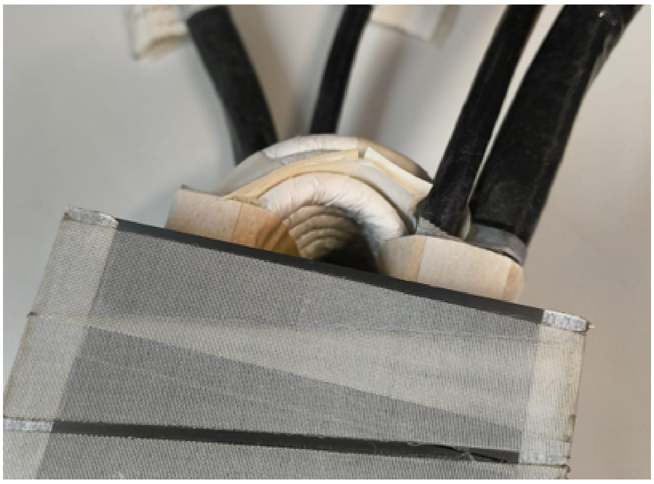


Figure 10: Secondary winding enclosed by the primary

Although we cannot see how many wires are in parallel at the secondary winding, we can identify that there is a single layer of wires, which will help us discard some combinations later.

Bobbin

As can also be seen, no bobbin has been used in this transformer, so we will deactivate that option in SmartNetics, in “Configuration” - “Device parts” - “Include bobbin”, as shown in the next figure:

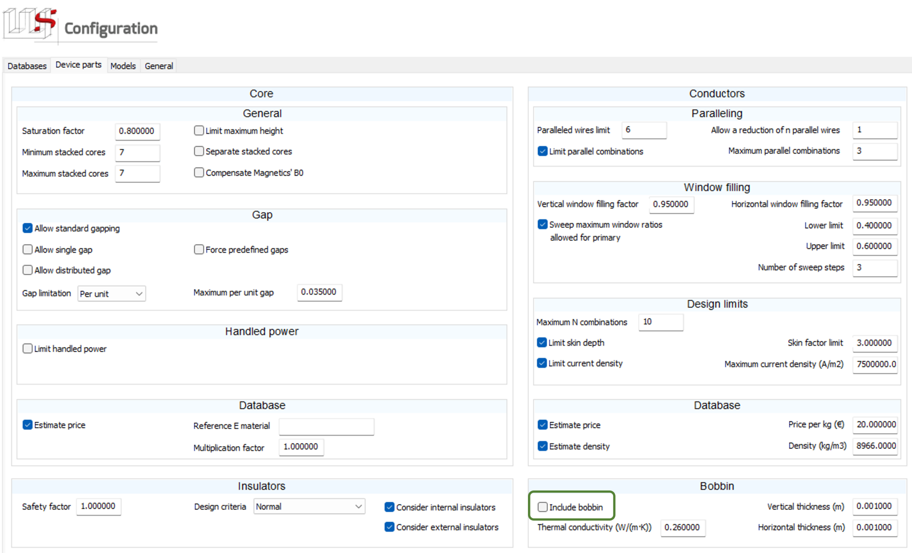


Figure 11: Unchecked bobbin option

These are the parameters that can be physically measured. There are some remaining unknowns that can be determined without dismantling or damaging the device, by some easy electrical measurements that we will carry out as well.

Electrical Measurements

By using specific, expensive equipment, there are many parameters that can be extracted from the device. With the aim to keep the approach presented here as general as possible, we will restrict ourselves to measure a very low number of properties and to use equipment as cheap and generally available as possible. With those restrictions in mind we can measure:

- Turns ratio
- DC resistance

Turns ratio

The only parameter it is compulsory to input in SmartNetics when designing a transformer is the turns ratio, defined as the number of turns of the primary over the number of turns of the secondary. Since we can see the primary, we know it is a 5 turns winding, but we have no way to visually extract that value from the secondary. We don't need to know the number of turns, since we only need the ratio, and that we can easily find out by injecting a small perturbation at the primary side and measuring the resulting value at the secondary.

There are many ways to do this with very little equipment, like using a signal generator to inject a pure sinusoidal signal and measuring the AC value at the secondary with a multimeter. In this case, to graphically show the relationship between both windings, we are going to use an oscilloscope to record the primary and secondary voltages, and its internal signal generator to generate the sinusoidal perturbation. The probes connected to primary and secondary side and the signal generator output attached to the primary side are shown in Figure 12.

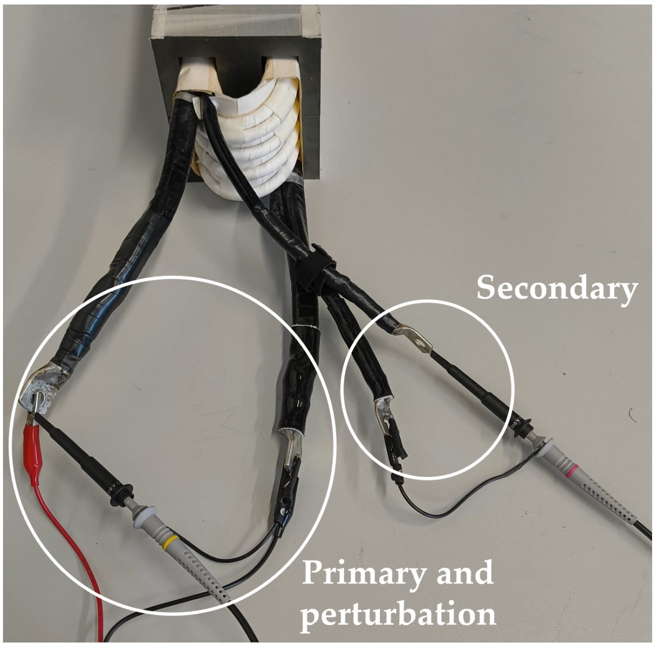


Figure 12: Probed device

The voltages at primary (yellow) and secondary (orange) windings are shown in Figure 13.

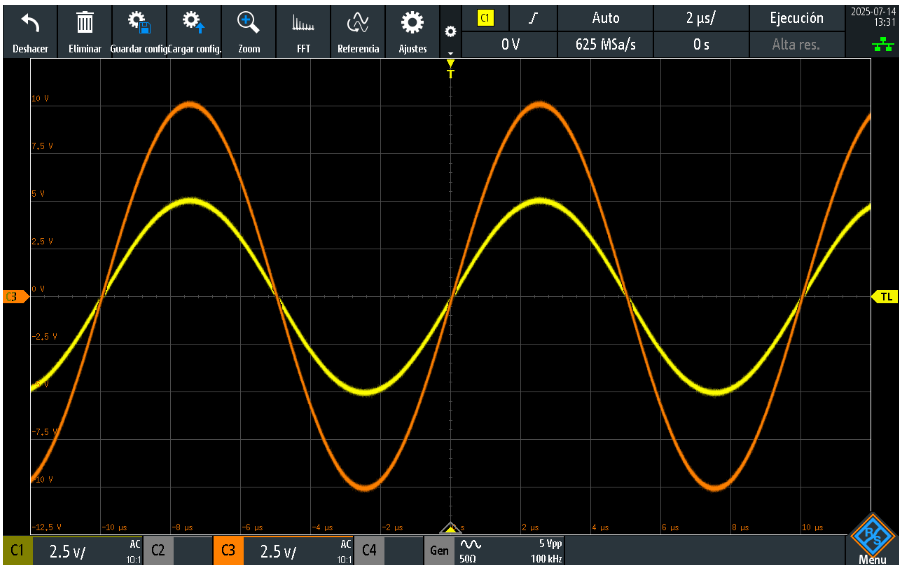


Figure 13: Oscilloscope waveforms

From the peak value of those signals, we can extract the turns ratio:

$$n = \frac{V_{1,peak}}{V_{2,peak}} = \frac{5}{10} = 0.5$$

This value must be set in the first dialog of SmartNetics ("Input data"), as shown in Figure 14:

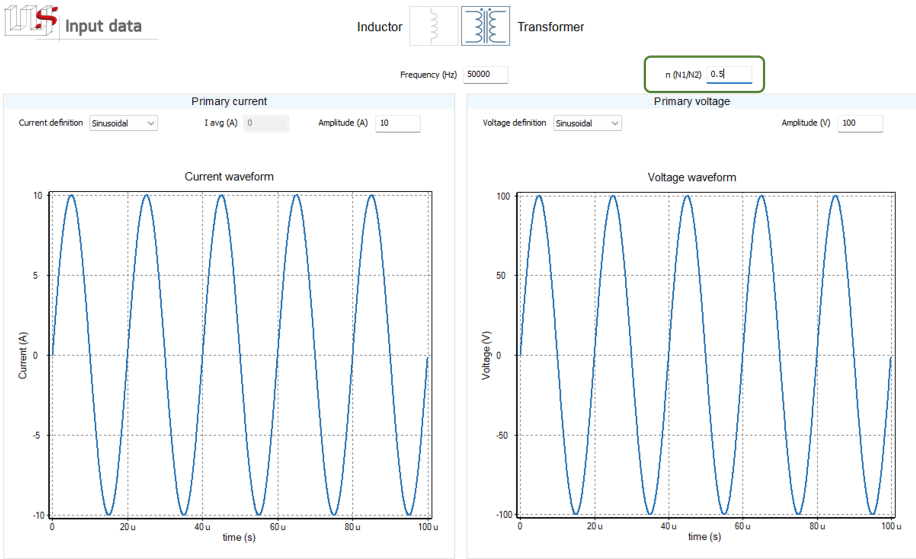


Figure 14: Turns ratio value

DC resistance

By means of an advanced impedance measurement we could get a very detailed description of the winding but, with the aim of keeping the number of measurements as low as possible and to ensure they are fast and cheap (so they can be done with easily accessible equipment), we will only measure the DC resistance.

The primary side is composed by a number of turns lower than the secondary ($n < 1$) and uses 3 wires in parallel, so we can assume its resistance is very low. Since we are limited in our capacity to measure low resistance values, we choose to measure the secondary resistance instead.

The cheapest way to measure a very low resistance is to impose a high current on the winding and measure its voltage drop. This can easily be done by means of a multimeter and a DC voltage source.

Figure 15: Voltage and current measurement

From this measurement the secondary DC resistance can be calculated. Its value will help us find out the conductor used for the construction of the device.

$$R_{DC,2} = \frac{V}{I} = \frac{15.702 \cdot 10^{-3}}{3.1014} = 5.06\, m\Omega$$

* Ideally, the DC source itself would be enough to take these measurements but, as shown, only the current has a value high enough to be correctly measured by it, and an external voltmeter is usually needed for such low values.

SmartNetics Configuration

We don't know the prior use of this particular device, so we don't know the current, voltage or frequency, whether or not it complies with a restricted number of wires in parallel, if skin depth was considered or even if a maximum temperature restriction was used, etc. In order to avoid accidentally discarding the real device configuration, we will eliminate all of those restrictions before finding every combination of parameters that can reproduce the real transformer. To do so we will configure:

- Input data
- Device parts
- Models

Input data

Since we don't know the real values, we will use very small ones so we can ensure the device is not discarded due to a possible over-temperature or saturation. To do so, we will select current and voltage waveforms with an amplitude of 1 amp and 1 volt, respectively (this device is big enough to assume it will not have any issue at such values):

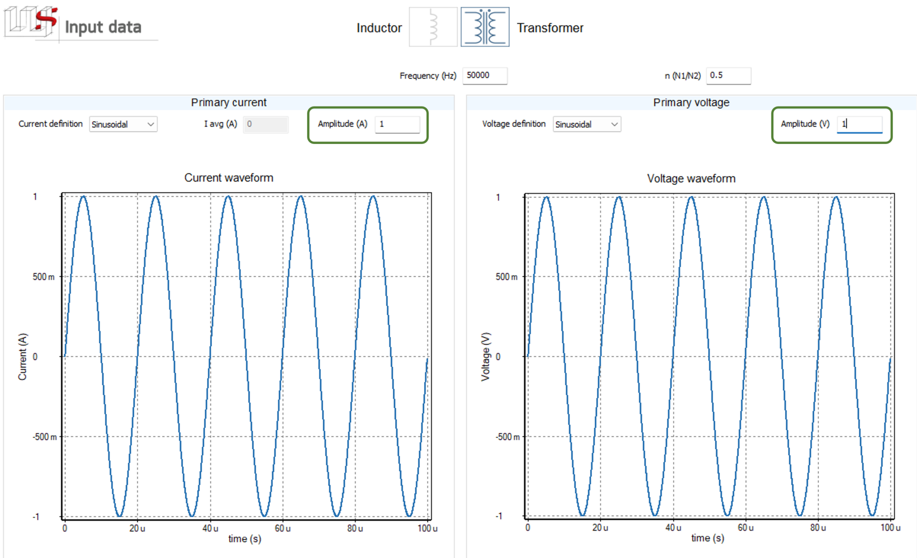


Figure 16: Voltage and current values

Device parts

In order to avoid discarding the real device due to any restriction that we didn't know if was taken into account during the design, we will take out most of them. In this case, we have:

- Set "Saturation factor" to 0.95.
- Set the "Paralleled wires limit" to 20 (any big value would do).
- Set the "Allow a reduction of n parallel wires" to 20 (any big value would do).
- Unchecked "Limit parallel combinations".
- Set the "Vertical window filling factor" to 0.95.
- Set the "Horizontal window filling factor" to 0.95.
- Set the "Lower limit" of the window ratio allowed for primary to 0.1.
- Set the "Upper limit" of the window ratio allowed for primary to 0.9.
- Set the "Number of sweep steps" to 100 (any big value would do).
- Set the "Maximum N combinations" to 50 (any big value would do).
- Unchecked "Limit skin depth".
- Unchecked "Limit current density".

The applied restrictions are shown in the next figure.

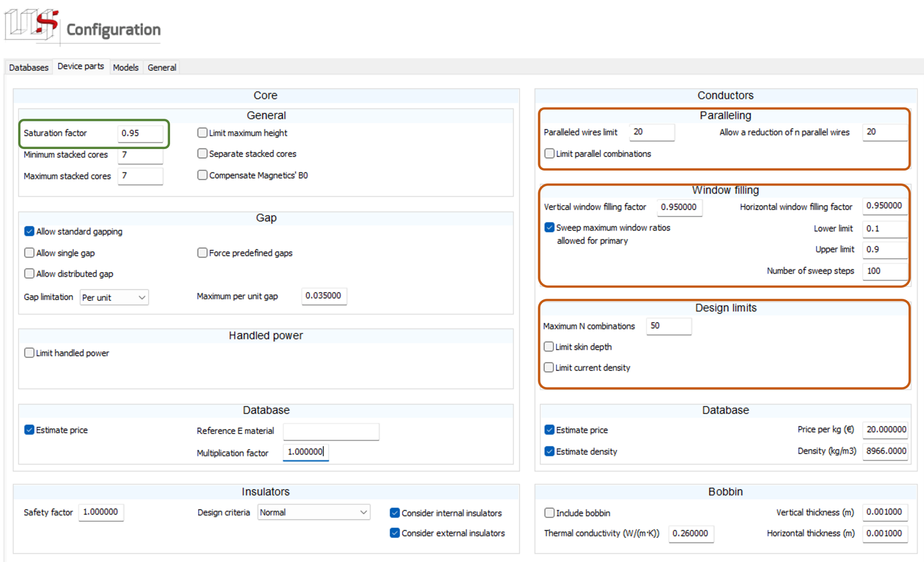


Figure 17: Device parts restrictions

Models

To avoid discarding the real design due to an excess of temperature, we will deactivate its calculation as well, as shown in Figure 18.

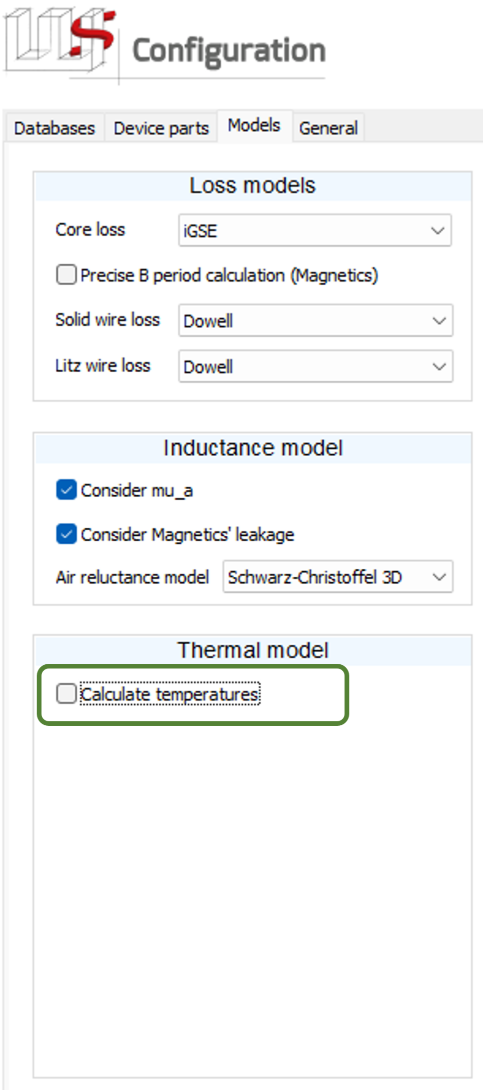


Figure 18: Thermal calculation deactivation

Once the restrictions have been lifted, we can get all the possible combinations that can produce a transformer similar to the one under study, to find out which one is the correct one.

Possible Devices

Once all the available information has been set and the restrictions have been eliminated, the user can begin the "Design" process to find out the possible combinations of parameters that would yield a transformer similar to the one under analysis.

To run the design, the user must press on "Begin magnetic design", under "Design". Once it runs, every combination of the parameters of the databases (including materials, geometries, wire arrangement, etc.) is displayed in the 4 axes below, as shown in the next figure:

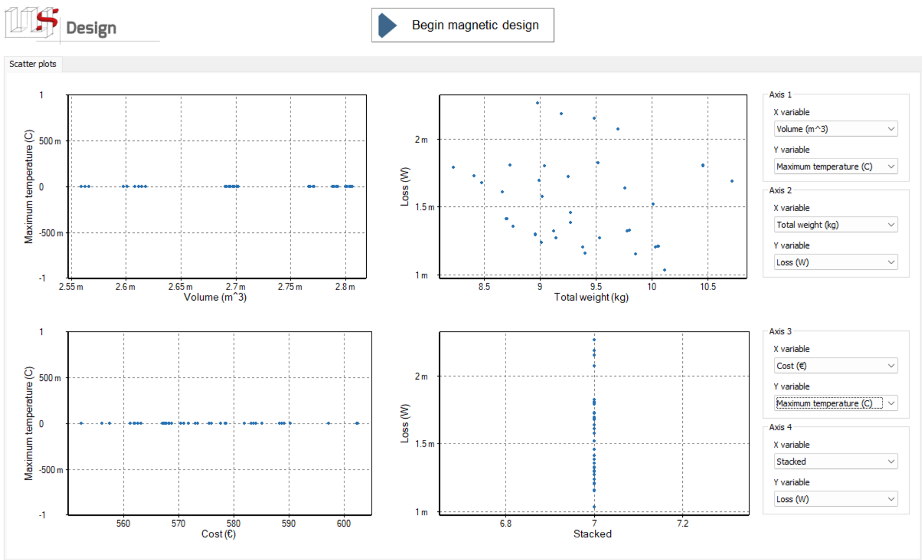


Figure 19: Possible devices (default axes)

The default configuration for the variables shown usually fits the design procedure. In this case, however, since there are so many parameters that are set to a given value, more convenient variables can be chosen. That can be done by means of the panels at the right side and, in this case, we have changed:

- Axis 1, Y variable: N_2
- Axis 3, X variable: $R_{DC,2}$
- Axis 3, Y variable: $Secondary\, layers$
- Axis 3, X variable: $Total\, weight\, (kg)$

The same results, but using the new variables, are shown in Figure 20.

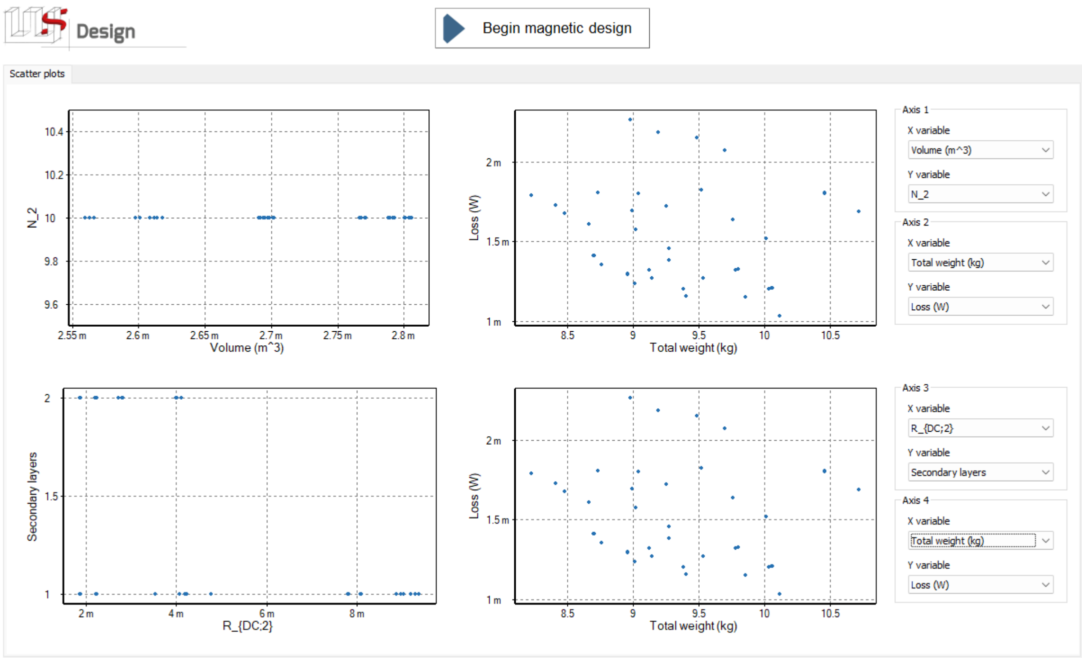


Figure 20: Possible devices (selected axes)

Now we can filter the designs even further thanks to the measurements we did before. We measured a resistance of around 5 mΩ, but that included the additional resistance imposed by the terminals and the measurement setup, so we can expect the winding to be a bit lower than that. We will select all the devices with a secondary winding DC resistance between 3.5 and 5 mΩ. Also, when carrying out the visual inspection, we found out that there is a single layer of secondary wires, so we will only select the ones corresponding to that value. Both variables were selected for the third axis, so we will use it, as shown in Figure 21.

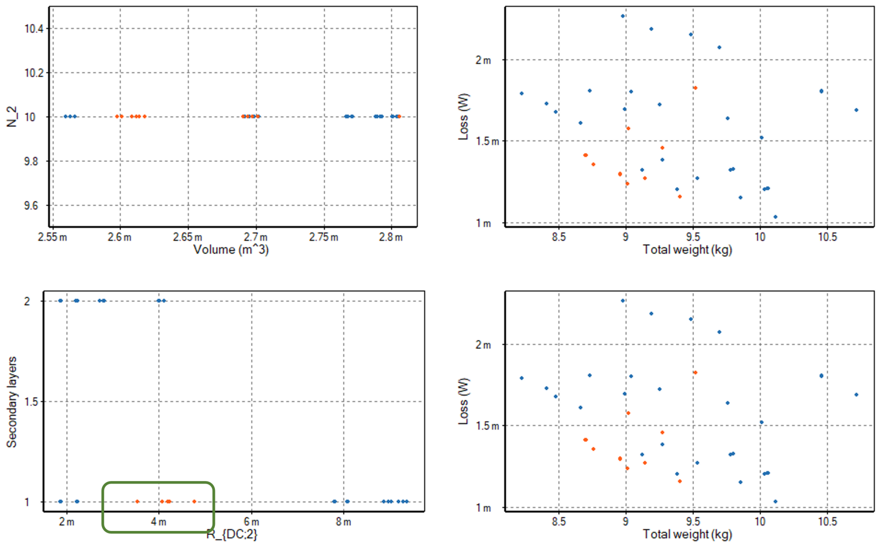


Figure 21: Possible devices (filtered)

Once we have reduced the options to a small number, we can proceed to the next dialog, “Selection”, for an even finer tune. In this new dialog, every detail of the devices is shown:

Selection

	Cores	Material	Stacked	l_g (m)	Stacked cores d...	Insulator	Wiring	Inner winding	N_1	N_2	Window filling	Primary w
1	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.749179	0.26228
2	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.736035	0.26228
3	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.595838	0.26228
4	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.56517	0.26228
5	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.584885	0.26228
6	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.742607	0.25532
7	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.729463	0.25532
8	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.589266	0.25532
9	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.558598	0.25532
10	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.578313	0.25532
11	E100/60/28	3C94	7	0	0	NOMEX	Central	Primary	5	10	0.94195	0.6592

Figure 22: Selection dialog

During the visual inspection we found out that primary and secondary windings were done using the same conductor (even though we still do not know which one), so we will select only the options that have the same value under the “Primary wire” and “Secondary wire” variables:

Selection

Stacked	l_g (m)	Stacked cores d...	Insulator	Wiring	Inner winding	N_1	N_2	Window filling	Primary window...	Primary wire	Secondary wire
7	0	0	NOMEX	Central	Primary	5	10	0.749179	0.262287	2835x0.071	2835x0.071
7	0	0	NOMEX	Central	Primary	5	10	0.736035	0.262287	2835x0.071	37x19x0.14
7	0	0	NOMEX	Central	Primary	5	10	0.595838	0.262287	2835x0.071	72x19x0.14
7	0	0	NOMEX	Central	Primary	5	10	0.56517	0.262287	2835x0.071	1368x0.14
7	0	0	NOMEX	Central	Primary	5	10	0.584885	0.262287	2835x0.071	800x0.2
7	0	0	NOMEX	Central	Primary	5	10	0.742607	0.255324	37x19x0.14	2835x0.071
7	0	0	NOMEX	Central	Primary	5	10	0.729463	0.255324	37x19x0.14	37x19x0.14
7	0	0	NOMEX	Central	Primary	5	10	0.589266	0.255324	37x19x0.14	72x19x0.14
7	0	0	NOMEX	Central	Primary	5	10	0.558598	0.255324	37x19x0.14	1368x0.14
7	0	0	NOMEX	Central	Primary	5	10	0.578313	0.255324	37x19x0.14	800x0.2
7	0	0	NOMEX	Central	Primary	5	10	0.94195	0.6592	1368x0.14	1368x0.14

Figure 23: Devices with same conductors

Although we don’t know yet if the secondary winding has more than one wire in parallel in vertical, during the visual inspection we saw that there is only one wire in horizontal. From the still available options there is a single one that matches such specifications, so that is the one we are going to select, like shown in Figure 24.

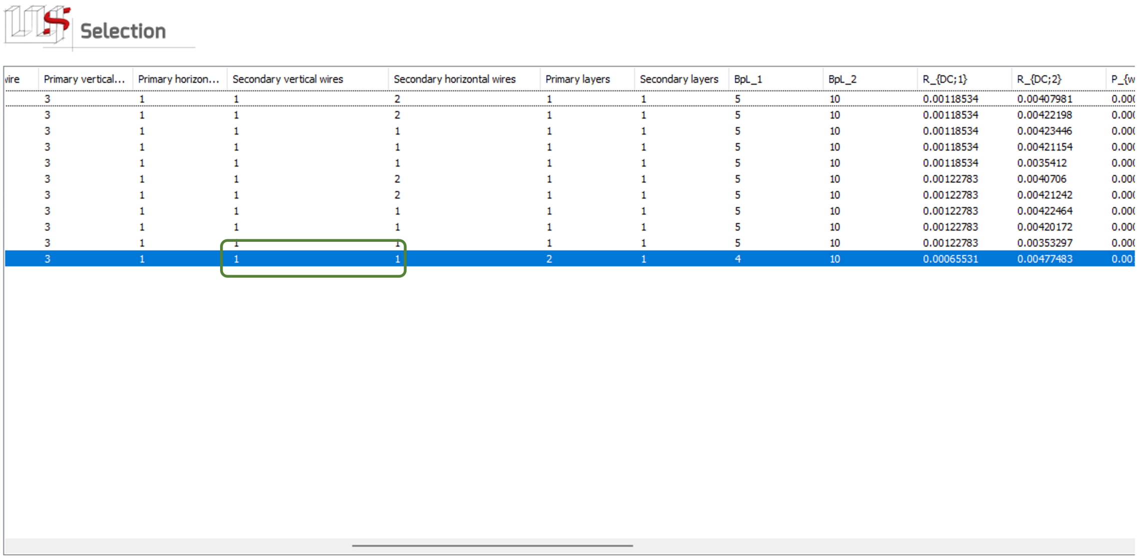


Figure 24: Selected device

Once a single device is identified, the user can click on the "Select design" button below, to carry on a more detailed analysis of that particular device. Once the user does, the data of said device is replicated at the bottom and the last step ("Device") is enabled, as shown in the next figure.

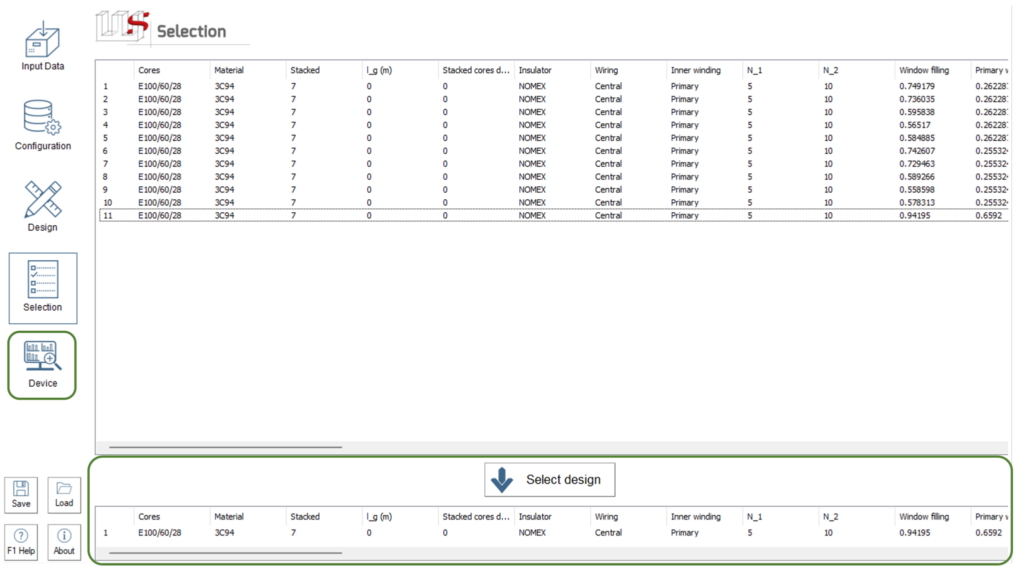


Figure 25: Selected device (analyzed)

To visually check the differences between the selected device and the one we want to reproduce, the user can go to the last dialog "Device" and compare both geometries. The representation of the full device, and the wires and cores used to manufacture it are shown in the first tab, as displayed in Figure 26.

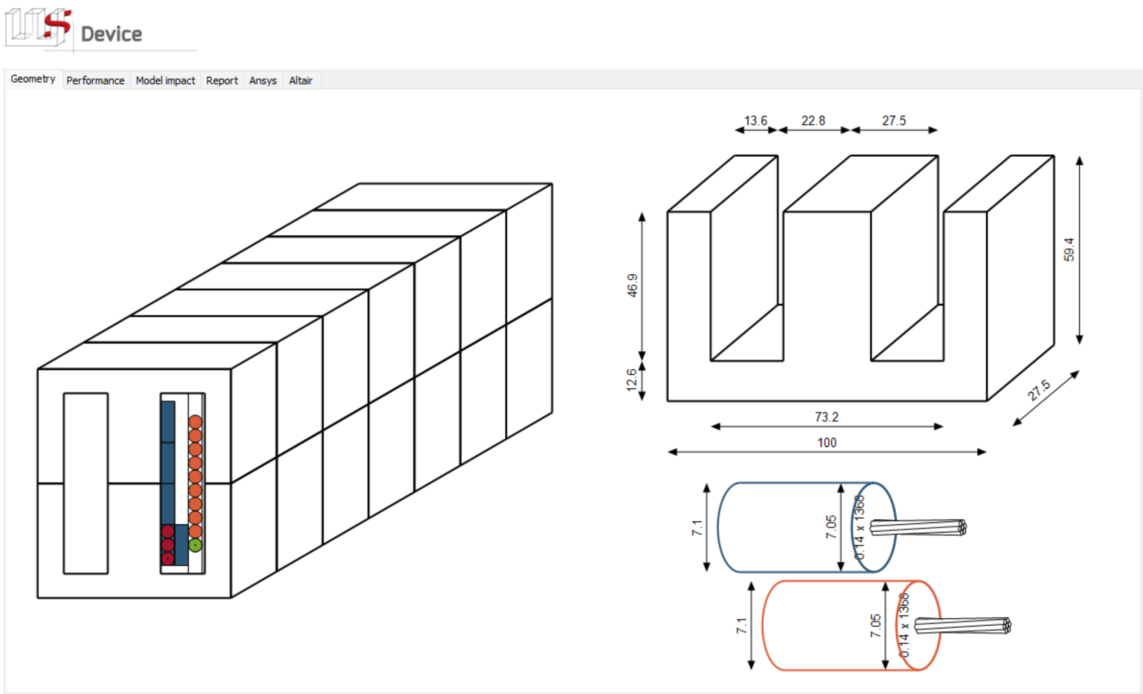


Figure 26: Geometry of the selected device

Reproduced device

At this point, we have been able to analyze and get all the information needed to use and reproduce a transformer for which every parameter was unknown.

Thanks to SmartNetics, we can do even more. In the next section, we will show how to find out if this same device can be reused for a different project, with currents and voltages that do not necessary match the ones it was designed for (since they are unknown) and how it is going to perform (in terms of saturation, temperature, etc.).

As can be seen by comparing the device in the previous figure to the one shown at the beginning, in Figure 1, there are still some differences. They are due to the restrictions in the design space (only rectangular paralleling of wires in SmartNetics versus a triangular stacking in the real device) and to the uncertainties still present (the conductor selected may not be exactly the one used for the real device, since the possibilities are almost infinite). Also, to keep the measurements as easy as possible, we have omitted the core material selection, which will have an impact on loss and temperature later on. In this tutorial we will assume it is a ferrite and select any of the ones present in the database.

Device Usage

Since now every parameter is known, the user can set all of them to reduce the design space to a single device (the one we have already reproduced). The remaining parameters can be set under "Configuration" - "General" - "Parameters set" - "Transformer", as shown in the next figure.

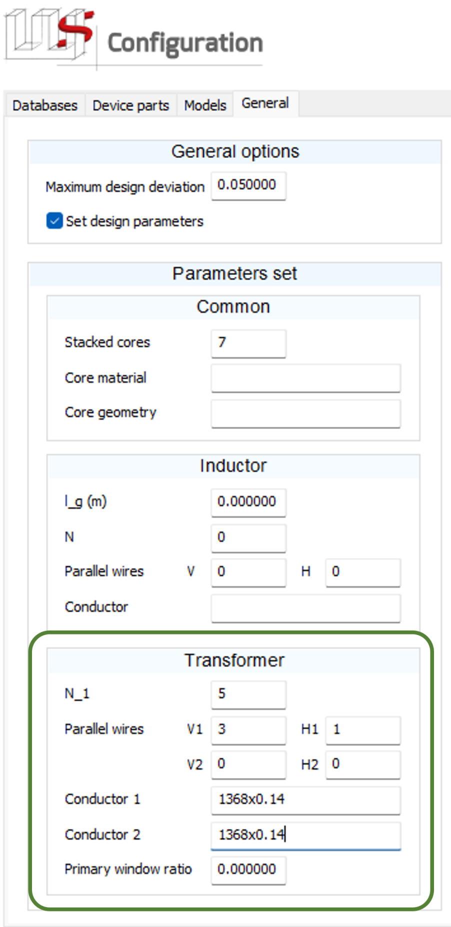


Figure 27: Device parameters set

Now, if the user carries out the design, there is a single possible solution. That can be seen by pressing the "Begin magnetic design" button in the "Design" dialog. The single solution is shown in Figure 28.

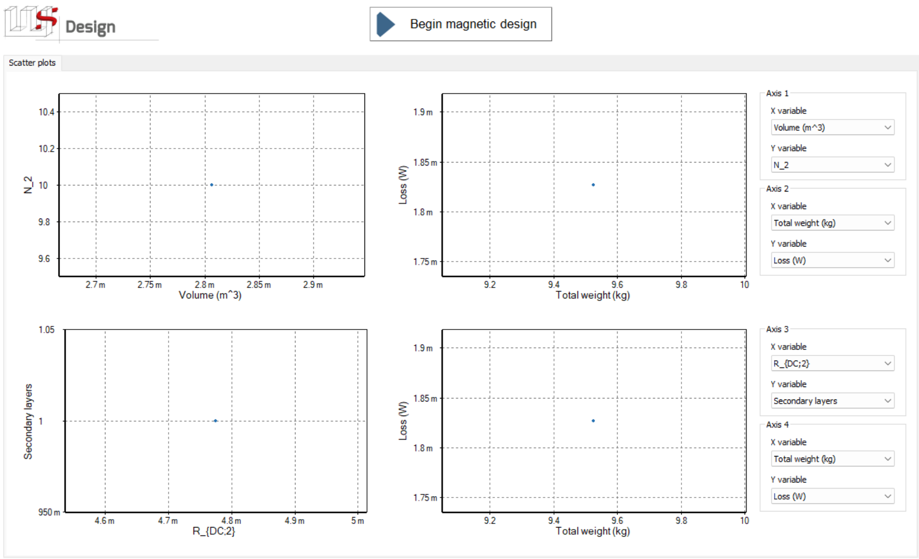


Figure 28: Single result

Up until now, we have not set any requirement for the transformer. If we want to use it for our real design we have to ensure, at least, two things:

- It does not saturate
- It does not reach an excessive temperature

Saturation

To check whether it saturates or not, we have to input our real voltage waveform, which can be selected in "Input data". For our project we need a ±400 V square waveform with a 25 kHz frequency, like the one shown in Figure 29.

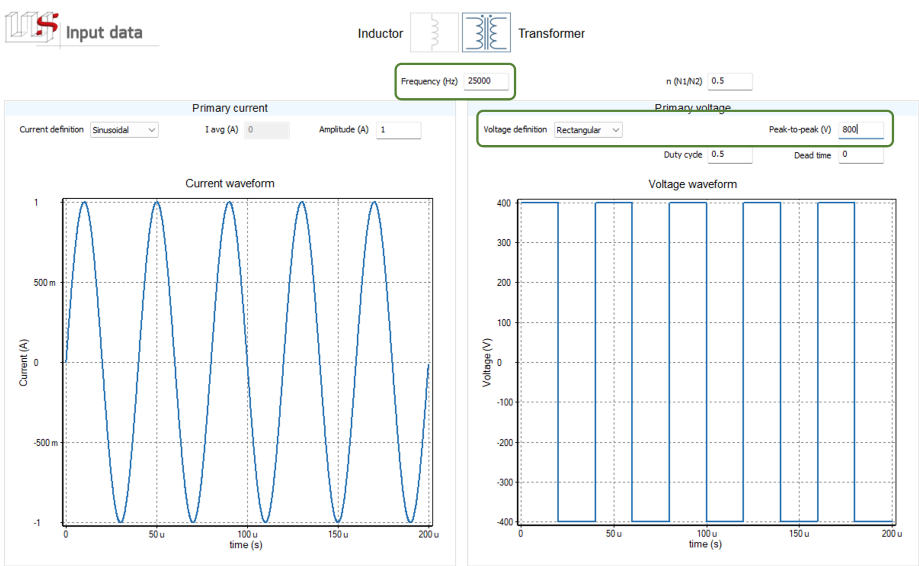


Figure 29: Voltage target

If we carry out the design again, we can see the Flux density ripple in the core. To do so, in the "Design" dialog, we have changed the Y variable in Axis 3 to Delta Bpp (ΔBpp):

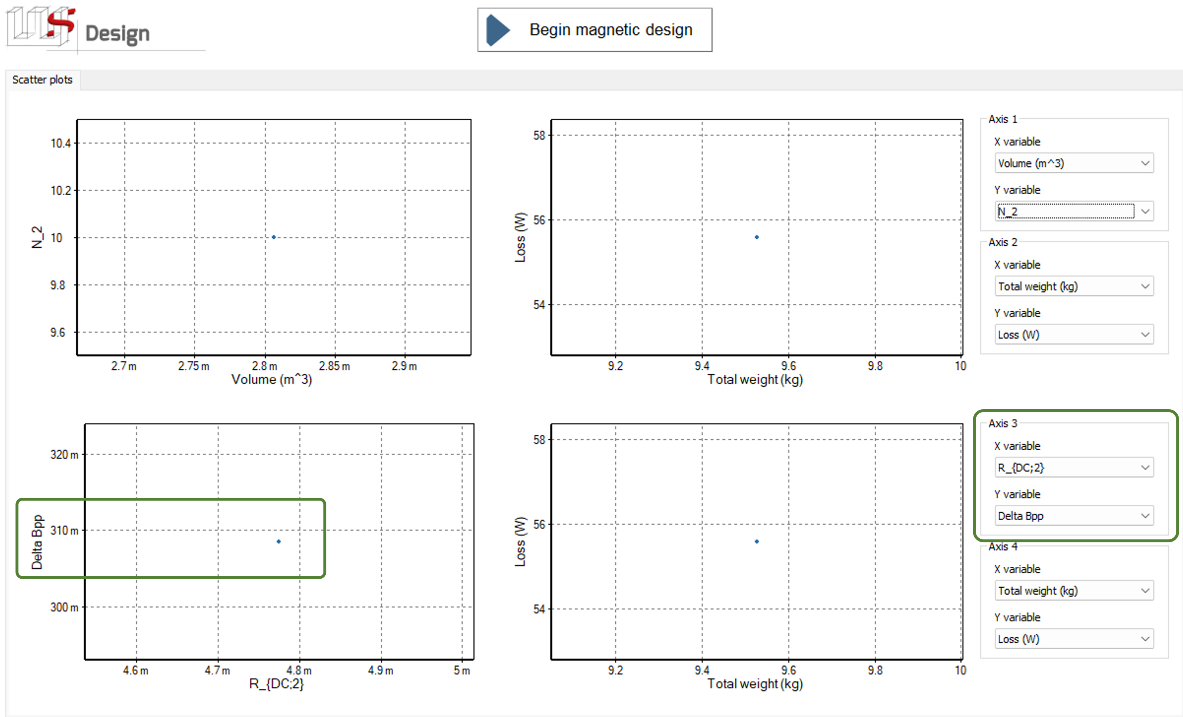


Figure 30: Saturation check (axes)

As can be seen, the ripple is around 310 mT, which means the peak value is around 165 mT, far enough from saturation. The exact numeric value can be seen in the next dialog, "Selection", as show in Figure 31.

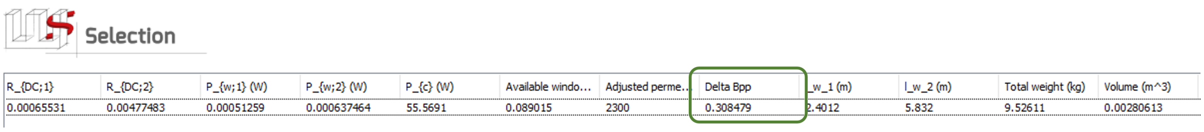


Figure 31: Saturation check (value)

Temperature

To check the temperature behavior, first we need to reactivate the temperature calculation in "Configuration" - "Models" - "Thermal model". The selected values are shown in Figure 32.

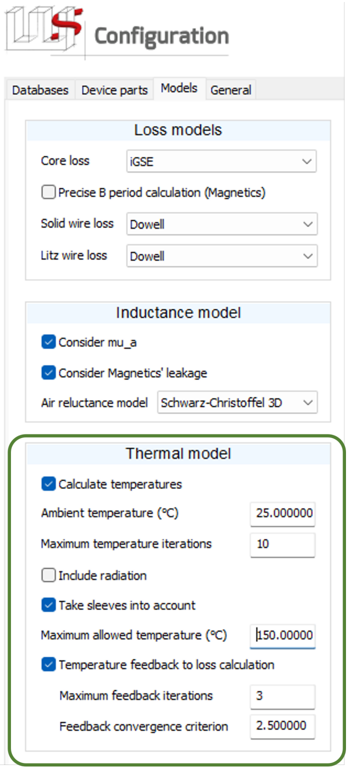


Figure 32: Thermal model

To estimate a real value for temperature we need to estimate the losses, so we need to input the real current the device is going to handle. We aim to drive a triangular current with a 150 A peak-to-peak value. We can set those values the same way we set the voltage waveform before, in the "Input data" dialog:

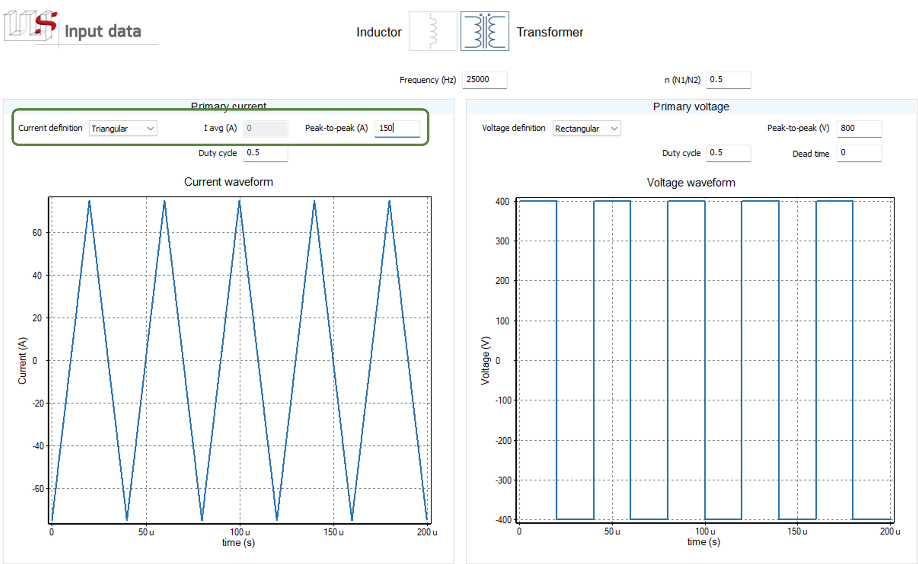


Figure 33: Current target

Now we can carry out the design process once again to see the expected temperature. The results are shown in the Figure 34.

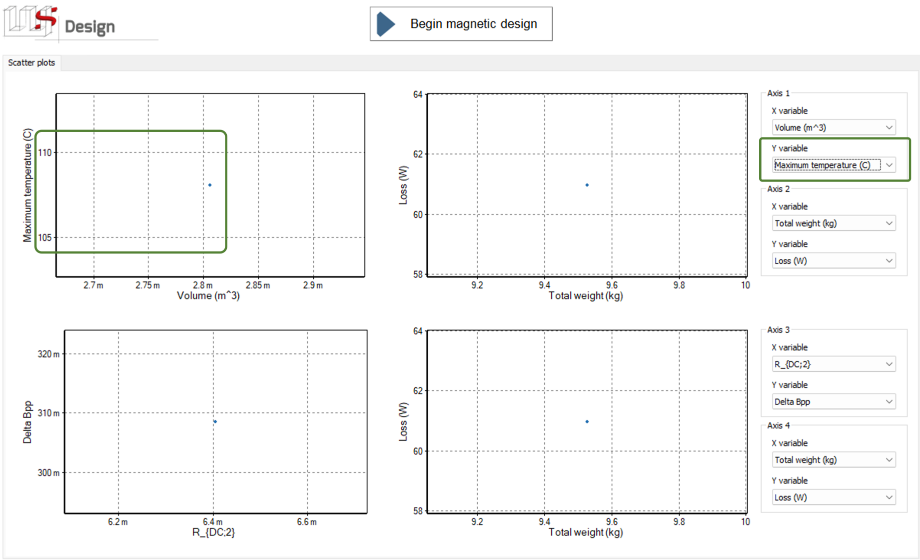


Figure 34: Temperature check (axes)

As can be seen, the maximum temperature is expected to lay between 105 a 110 ºC, which is acceptable for this particular project.

As we did before, the numeric value can be seen in the "Selection" dialog:

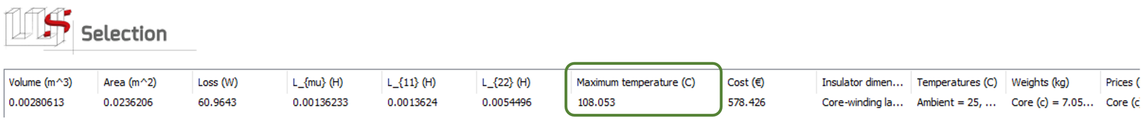


Figure 35: Temperature check (value)

A finer temperature distribution is displayed in the "Device" dialog, in the "Performance" tab, like shown in Figure 36.

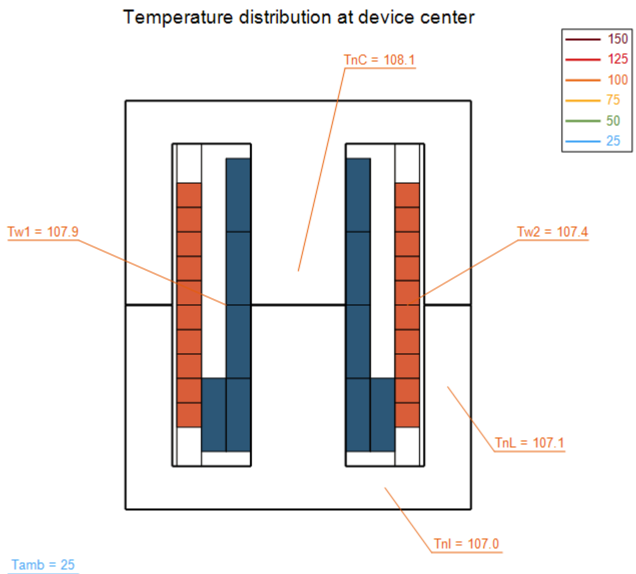


Figure 36: Temperature distribution

If the user needs a further check of the results, they can automatically reproduce the real device in Ansys or Flux, as shown in Figures 37 and 38, respectively.

In Ansys, both electromagnetic and thermal simulations can be carried out, by means of Maxwell and IcePack.

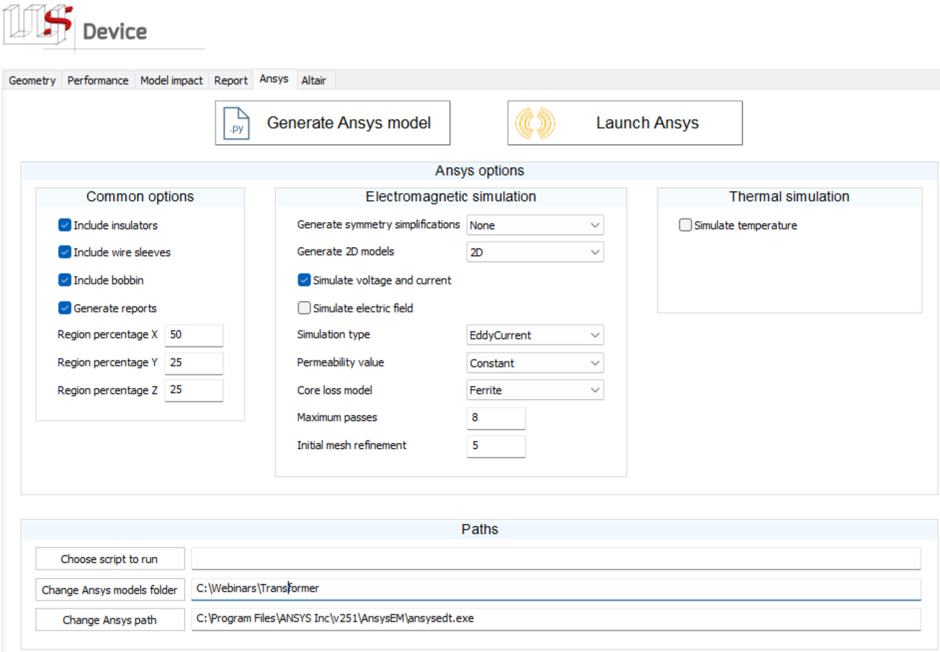


Figure 37: Ansys export

In Flux, only electromagnetic simulation is currently supported for its automatic export.

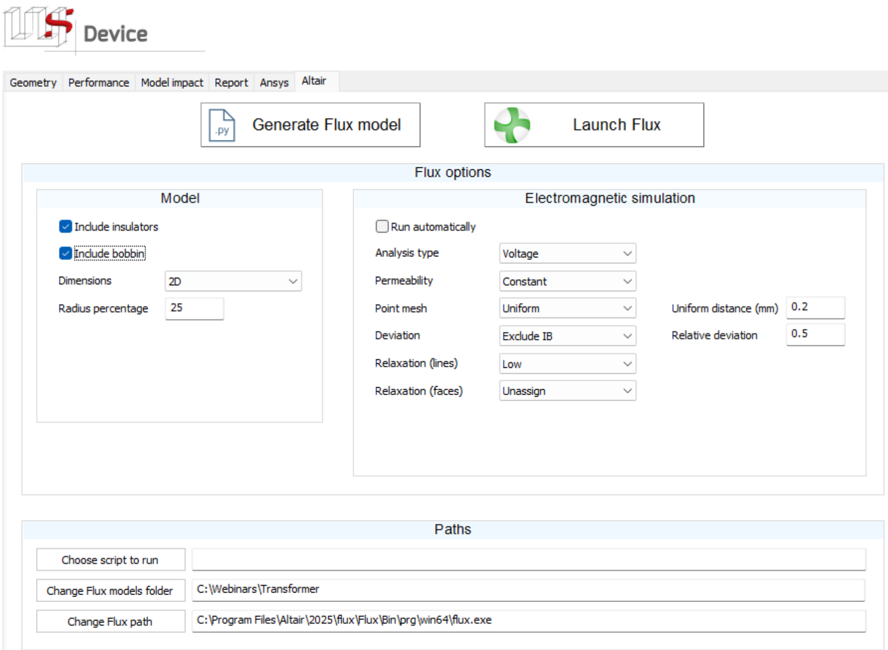


Figure 38: Flux export

Conclusions

In this tutorial we have shown how to analyze and extract every unknown parameter of a transformer that was already built for a different project.

On top of that, thanks to the SmartNetics capabilities, the user can check if the device will be able to comply with new specifications, allowing the reuse of it. Furthermore, thanks to the availability of every possible combination of parameters that provide a valid solution, the user can improve the current design, selecting wires, cores, etc. that are more convenient for its new needs.

Last but not least, the user can automatically export the full model to third party tools for its simulation, including Ansys (Maxwell or IcePack) and Altair-Flux.

In this example we have not studied the specific core material to be used in order to keep the measurements as easy as possible. By means of an impedance analyzer the user could get an idea of the magnetizing inductance, from which the core material could be deduced.

This tutorial is intended as an example, so the user is encouraged to try different configurations to find the one that is best suited for their particular project. Please, keep in mind that the images shown in this document may not exactly coincide with the options and distribution shown in the application, since different updates may incur in slight changes.