Transformer design example

Tutorial - November 2025

How to Contact:
info@powersmartcontrol.com
www.powersmartcontrol.com

Notice

Power Smart Control tutorials or other design advice, services or information, including, but not limited to, reference designs, are intended to assist designers who are developing applications that use SmartNetics; by downloading, accessing or using any particular Power Smart Control resource in any way, you (individually or, if you are acting on behalf of a company, your company) agree to use it solely for this purpose and subject to the terms of this notice. Power Smart Control reserves the right to make corrections, enhancements, improvements and other changes to its resources. You understand and agree that you remain responsible for using your independent analysis, evaluation and judgment in designing your applications and that you have full and exclusive responsibility to assure the safety of your applications and compliance of your applications with all applicable regulations, laws and other applicable requirements.

Disclaimer

Power Smart Control S.L. (PSC) makes no representation or warranty with respect to the adequacy or accuracy of this documentation or the software which it describes. In no event will PSC or its direct or indirect suppliers be liable for any damages whatsoever including, but not limited to, direct, indirect, incidental, or consequential damages of any character including, without limitation, loss of business profits, data, business information, or any and all other commercial damages or losses, or for any damages in excess of the list price for the license to the software and documentation.

Contents

Introduction

SmartNetics is a software application for the design and analysis of magnetic devices: inductors and transformers. Although these devices can be designed to comply with any specification, SmartNetics is specially suited for magnetics to be used in medium power (10 kW - 100 kW), high frequency (10 kHz - 100 kHz) power converters.

Our approach is not to offer a single one-fits-all solution, but to provide every possible design to have all the available information and, at the same time, an intuitive graphical interface that allows the user to easily assess the impact of every value.

In every part of the software, the user can select whether to input only the minimum amount of data and use the predefined configuration, or to manually adjust every little design parameter. With this approach, whether it is your first time designing a magnetic device or you are a seasoned expert, you can design the device that best suits your needs.

This tutorial aims to illustrate the complete design procedure for a magnetic device. In this particular case, a transformer for a 25kW, 50kHz Dual Active Bridge (DAB) refrigerated by natural convection. The main design parameters are shown in Table 1:

Topology	Power	Frequency	Turns ratio	Max Temp	Refrigeration
DAB	25 kW	50 kHz	1:1	90 °C	Natural convection

Table 1: Main design parameters

Design

In SmartNetics, the design procedure is divided into 5 steps:

1. **Input data:** enter the minimum required data for the design (inductance and current for inductors; turns ratio, primary voltage and current for transformers).
2. **Configuration:** use the default configuration or modify any little aspect of the design procedure.
3. **Design:** find every possible combination of parameters that, complying with the restrictions, provide a suitable device. From those devices, select any number that are potential candidates.
4. **Selection:** analyze in detail the selected subset and select the best device.
5. **Device:** graphically access every property of the selected device, generate a report, or export it to third-party software.

The aim of this tutorial is to guide the user through the 5 steps, from the definition of input signals to the simulation and validation of the device in third-party software.

By default, SmartNetics opens with the first step active. The user can navigate through steps using the 5 buttons at the left side, as shown in Figure 1. Notice how some steps are not available until some previous requirement is met, for example, the user can not select a design until they have generated at least one.

Figure 1: Lateral menus

1 Input data

The first step is to define the target magnetic device. There are two options:

- Inductor: Defined by its inductance and current.
- Transformer: Defined by its turns ratio (n=N1/N2), current and voltage (both referred to the primary side).

The device to design can be selected with the top switch, as shown in Figure 2.

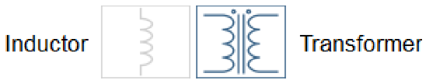


Figure 2: Inductor or transformer switch

For this example, we are going to design a transformer. Once it is selected, the default values for the needed inputs are displayed, as shown in Figure 3. For a transformer, the turns ratio and the voltage and current of the primary side are needed.

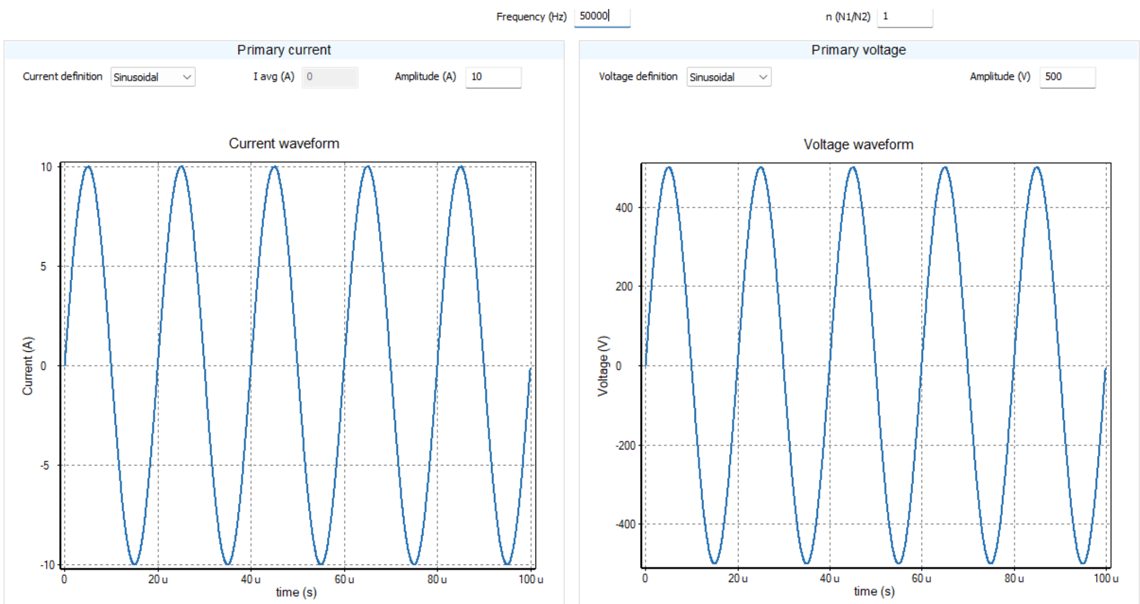


Figure 3: Default transformer parameters

The turns ratio is defined in its own field. In this case, we are designing a 1:1 transformer, so the turns ratio, defined as N1/N2 equals 1. We can input that value in the dialog box, as shown in Figure 4:

Figure 4: Turns ratio value

The user can define the current and voltage waveforms using the predefined shapes: sinusoidal, triangle, or rectangular; or use a generic waveform, that can be taken from a previous measurement or simulation, loading a .csv file.

In this case, we are going to design the transformer for a Dual Active Bridge and, to use the actual waveforms the converter is going to produce, we are going to import voltage and current from a simulation results file. That is done by selecting "File" in the "Current definition" and "Voltage definition" drop-downs and clicking on "Load file" to select a previously saved signal (as .csv). Once loaded, the values are displayed and the main frequency is automatically extracted, as shown in Figure 5.

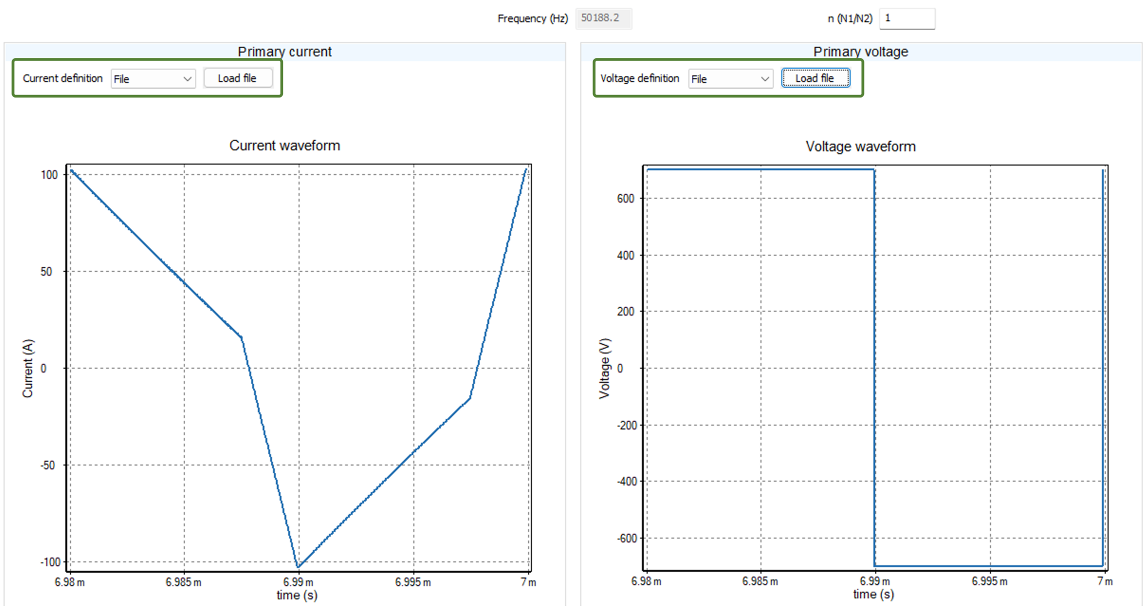


Figure 5: Loaded waveforms

Notice how, for a waveform defined in a file, the frequency field can not be modified (edit box turns gray), since it is extracted from the values of said file.

Once the desired parameters have been defined, the user can configure the design procedure in the next step, "Configuration".

2 Configuration

This step is accessed by the second button of the lateral menus ("Configuration") and is divided into 4 parts:

- Databases
- Device parts
- Models
- General

By default, "Databases" is selected, but the user can navigate them using the tabs on top, as shown in the next figure:

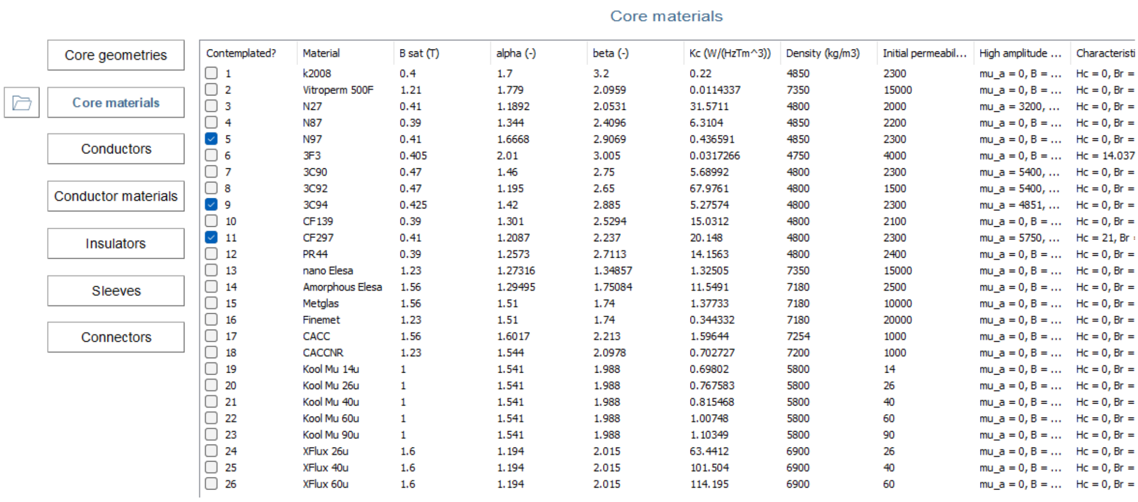
Figure 6: Configuration tabs

In general, the default configuration can produce good results for many applications, but the user is free to use any prior knowledge to achieve an even better result. In this particular case we are going to modify a few aspects as part of the example.

2.1 Databases

We are designing a 50 kHz transformer, so we are limiting the core materials to only ferrites. To allow a wider range of qualities, costs, and suppliers, we are going to select several materials from different manufacturers.

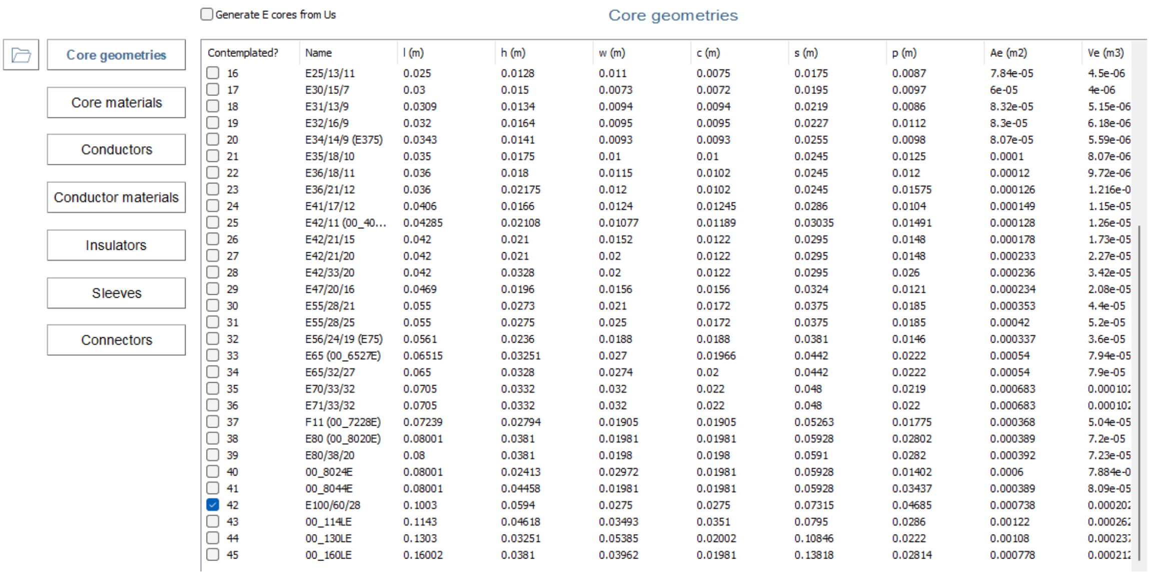
In this example, we are going to consider: N97 from TDK, 3C94 from Ferroxcube, and CF297 from Cosmo Ferrite. Said materials are selected by activating their "Contemplated?" fields in the database, as shown in the next figure.



Contemplated?	Material	B sat (T)	alpha (-)	beta (-)	Kc (W/(HzTm^3))	Density (kg/m3)	Initial permeabil...	High amplitude ...	Characteristi
☐ 1	k2008	0.4	1.7	3.2	0.22	4850	2300	mu_a = 0, B = ...	Hc = 0, Br =
☐ 2	Vitroperm 500F	1.21	1.779	2.0959	0.0114337	7350	15000	mu_a = 0, B = ...	Hc = 0, Br =
☐ 3	N27	0.41	1.1892	2.0531	31.5711	4800	2000	mu_a = 3200, ...	Hc = 0, Br =
☐ 4	N87	0.39	1.344	2.4096	6.3104	4850	2200	mu_a = 0, B = ...	Hc = 0, Br =
☑ 5	N97	0.41	1.6668	2.9069	0.436591	4850	2300	mu_a = 0, B = ...	Hc = 0, Br =
☐ 6	3F3	0.405	2.01	3.005	0.0317266	4750	4000	mu_a = 0, B = ...	Hc = 14.037
☐ 7	3C90	0.47	1.46	2.75	5.68992	4800	2300	mu_a = 5400, ...	Hc = 0, Br =
☐ 8	3C92	0.47	1.195	2.65	67.9761	4800	1500	mu_a = 5400, ...	Hc = 0, Br =
☑ 9	3C94	0.425	1.42	2.885	5.27574	4800	2300	mu_a = 4851, ...	Hc = 0, Br =
☐ 10	CF139	0.39	1.301	2.5294	15.0312	4800	2100	mu_a = 0, B = ...	Hc = 0, Br =
☑ 11	CF297	0.41	1.2087	2.237	20.148	4800	2300	mu_a = 5750, ...	Hc = 21, Br
☐ 12	PR44	0.39	1.2573	2.7113	14.1563	4800	2400	mu_a = 0, B = ...	Hc = 0, Br =
☐ 13	nano Elesa	1.23	1.27316	1.34857	1.32505	7350	15000	mu_a = 0, B = ...	Hc = 0, Br =
☐ 14	Amorphous Elesa	1.56	1.29495	1.75084	11.5491	7180	2500	mu_a = 0, B = ...	Hc = 0, Br =
☐ 15	Metglas	1.56	1.51	1.74	1.37733	7180	10000	mu_a = 0, B = ...	Hc = 0, Br =
☐ 16	Finemet	1.23	1.51	1.74	0.344332	7180	20000	mu_a = 0, B = ...	Hc = 0, Br =
☐ 17	CACC	1.56	1.6017	2.213	1.59644	7254	1000	mu_a = 0, B = ...	Hc = 0, Br =
☐ 18	CACCNR	1.23	1.544	2.0978	0.702727	7200	1000	mu_a = 0, B = ...	Hc = 0, Br =
☐ 19	Kool Mu 14u	1	1.541	1.988	0.69802	5800	14	mu_a = 0, B = ...	Hc = 0, Br =
☐ 20	Kool Mu 26u	1	1.541	1.988	0.767583	5800	26	mu_a = 0, B = ...	Hc = 0, Br =
☐ 21	Kool Mu 40u	1	1.541	1.988	0.815468	5800	40	mu_a = 0, B = ...	Hc = 0, Br =
☐ 22	Kool Mu 60u	1	1.541	1.988	1.00748	5800	60	mu_a = 0, B = ...	Hc = 0, Br =
☐ 23	Kool Mu 90u	1	1.541	1.988	1.10349	5800	90	mu_a = 0, B = ...	Hc = 0, Br =
☐ 24	XFlux 26u	1.6	1.194	2.015	63.4412	6900	26	mu_a = 0, B = ...	Hc = 0, Br =
☐ 25	XFlux 40u	1.6	1.194	2.015	101.504	6900	40	mu_a = 0, B = ...	Hc = 0, Br =
☐ 26	XFlux 60u	1.6	1.194	2.015	114.195	6900	60	mu_a = 0, B = ...	Hc = 0, Br =

Figure 7: Core materials selected for the design

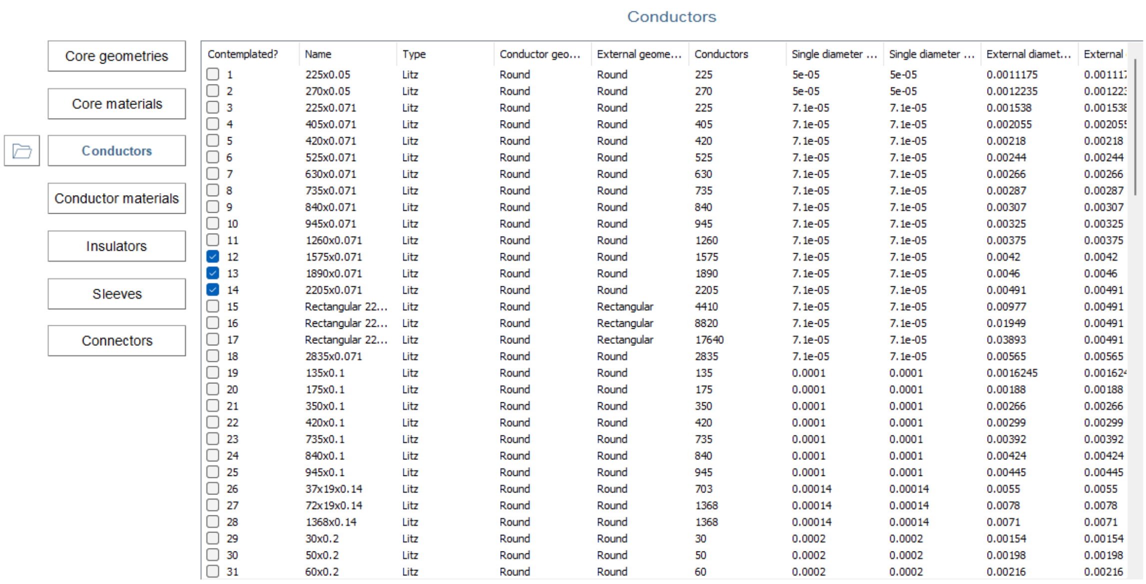
Since the transformer is intended for a 25 kW prototype, only the biggest cores would provide valid solutions. For core geometries, we will leave the database as given by default, with the E100/60/28 geometry selected, as shown in Figure 8.



Contemplated?	Name	l (m)	h (m)	w (m)	c (m)	s (m)	p (m)	Ae (m2)	Ve (m3)
☐ 16	E25/13/11	0.025	0.0128	0.011	0.0075	0.0175	0.0087	7.84e-05	4.5e-06
☐ 17	E30/15/7	0.03	0.015	0.0073	0.0072	0.0195	0.0097	6e-05	4e-06
☐ 18	E31/13/9	0.0309	0.0134	0.0094	0.0094	0.0219	0.0086	8.32e-05	5.15e-06
☐ 19	E32/16/9	0.032	0.0164	0.0095	0.0095	0.0227	0.0112	8.3e-05	6.18e-06
☐ 20	E34/14/9 (E375)	0.0343	0.0141	0.0093	0.0093	0.0255	0.0098	8.07e-05	5.59e-06
☐ 21	E35/18/10	0.035	0.0175	0.01	0.01	0.0245	0.0125	0.0001	8.07e-06
☐ 22	E36/18/11	0.036	0.018	0.0115	0.0102	0.0245	0.012	0.00012	9.72e-06
☐ 23	E36/21/12	0.036	0.02175	0.012	0.0102	0.0245	0.01575	0.000126	1.216e-0
☐ 24	E41/17/12	0.0406	0.0166	0.0124	0.01245	0.0286	0.0104	0.000149	1.15e-05
☐ 25	E42/11 (00_40…	0.04285	0.02108	0.01077	0.01189	0.03035	0.01491	0.000128	1.26e-05
☐ 26	E42/21/15	0.042	0.021	0.0152	0.0122	0.0295	0.0148	0.000178	1.73e-05
☐ 27	E42/21/20	0.042	0.021	0.02	0.0122	0.0295	0.0148	0.000233	2.27e-05
☐ 28	E42/33/20	0.042	0.0328	0.02	0.0122	0.0295	0.026	0.000236	3.42e-05
☐ 29	E47/20/16	0.0469	0.0196	0.0156	0.0156	0.0324	0.0121	0.000234	2.08e-05
☐ 30	E55/28/21	0.055	0.0273	0.021	0.0172	0.0375	0.0185	0.000353	4.4e-05
☐ 31	E55/28/25	0.055	0.0275	0.025	0.0172	0.0375	0.0185	0.00042	5.2e-05
☐ 32	E56/24/19 (E75)	0.0561	0.0236	0.0188	0.0188	0.0381	0.0146	0.000337	3.6e-05
☐ 33	E65 (00_6527E)	0.06515	0.03251	0.027	0.01966	0.0442	0.0222	0.00054	7.94e-05
☐ 34	E65/32/27	0.065	0.0328	0.0274	0.02	0.0442	0.0222	0.00054	7.9e-05
☐ 35	E70/33/32	0.0705	0.0332	0.032	0.022	0.048	0.0219	0.000683	0.00010
☐ 36	E71/33/32	0.0705	0.0332	0.032	0.022	0.048	0.022	0.000683	0.00010
☐ 37	F11 (00_7228E)	0.07239	0.02794	0.01905	0.01905	0.05263	0.01775	0.000368	5.04e-05
☐ 38	E80 (00_8020E)	0.08001	0.0381	0.01981	0.01981	0.05928	0.02802	0.000389	7.2e-05
☐ 39	E80/38/20	0.08	0.0381	0.0198	0.0198	0.0591	0.0282	0.000392	7.23e-05
☐ 40	00_8024E	0.08001	0.02413	0.02972	0.01981	0.05928	0.01402	0.0006	7.884e-0
☐ 41	00_8044E	0.08001	0.04458	0.01981	0.01981	0.05928	0.03437	0.000389	8.09e-05
☑ 42	E100/60/28	0.1003	0.0594	0.0275	0.0275	0.07315	0.04685	0.000738	0.00020
☐ 43	00_114LE	0.1143	0.04618	0.03493	0.0351	0.0795	0.0286	0.00122	0.00026
☐ 44	00_130LE	0.1303	0.03251	0.05385	0.02002	0.10846	0.0222	0.00108	0.00023
☐ 45	00_160LE	0.16002	0.0381	0.03962	0.01981	0.13818	0.02814	0.000778	0.00021

Figure 8: Core geometries selected for the design

With the aim of reducing high frequency conductor losses and to ease manufacture in case several wires need to be used in parallel (since the selected cores are very big), only some Litz wires have been selected (1575x0.01, 1890x0.01 and 2205x0.01, corresponding to items 12, 13 and 14 in the current database, as shown in Figure 9).



Contemplated?	Name	Type	Conductor geo…	External geome…	Conductors	Single diameter …	Single diameter …	External diamet…	External
☐ 1	225x0.05	Litz	Round	Round	225	5e-05	5e-05	0.0011175	0.00111
☐ 2	270x0.05	Litz	Round	Round	270	5e-05	5e-05	0.0012235	0.00122
☐ 3	225x0.071	Litz	Round	Round	225	7.1e-05	7.1e-05	0.001538	0.00153
☐ 4	405x0.071	Litz	Round	Round	405	7.1e-05	7.1e-05	0.002055	0.00205
☐ 5	420x0.071	Litz	Round	Round	420	7.1e-05	7.1e-05	0.00218	0.00218
☐ 6	525x0.071	Litz	Round	Round	525	7.1e-05	7.1e-05	0.00244	0.00244
☐ 7	630x0.071	Litz	Round	Round	630	7.1e-05	7.1e-05	0.00266	0.00266
☐ 8	735x0.071	Litz	Round	Round	735	7.1e-05	7.1e-05	0.00287	0.00287
☐ 9	840x0.071	Litz	Round	Round	840	7.1e-05	7.1e-05	0.00307	0.00307
☐ 10	945x0.071	Litz	Round	Round	945	7.1e-05	7.1e-05	0.00325	0.00325
☐ 11	1260x0.071	Litz	Round	Round	1260	7.1e-05	7.1e-05	0.00375	0.00375
☑ 12	1575x0.071	Litz	Round	Round	1575	7.1e-05	7.1e-05	0.0042	0.0042
☑ 13	1890x0.071	Litz	Round	Round	1890	7.1e-05	7.1e-05	0.0046	0.0046
☑ 14	2205x0.071	Litz	Round	Round	2205	7.1e-05	7.1e-05	0.00491	0.00491
☐ 15	Rectangular 22…	Litz	Round	Rectangular	4410	7.1e-05	7.1e-05	0.00977	0.00491
☐ 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

Figure 9: Conductor geometries selected for the design

The remaining databases are left as default for this example, but the user is free to configure which entries to use, referring to Conductor materials, Insulators, Wire sleeves, and Connectors.

2.2 Device parts

The next step is to configure the rules that apply to every part of the device. Here, the user can leave everything as it is, which will be enough for most designs, or can fine-tune any parameter. There are 4 parts to be configured:

- Core
- Conductors
- Insulators
- Bobbin

Every configuration parameter is accessible (and a comprehensive definition is provided in the help installed along SmartNetics, accessed by pressing *'f1'* in any part of the tool). If the designer has some particular requirements or some previous knowledge about the design output, they can use this configuration to reduce simulation time, by only allowing designs that they know are going to match the desired result. As an example, we have modified 2 fields for this particular design:

- Even though the selected cores are already pretty big, "Maximum stacked cores" has been increased from 2 to 8.
- Even though Litz wire is easier to handle than rigid wire, the maximum number of parallel wires, set by "Paralleled wires limit" has been reduced from 6 to 4 to ensure an easy winding.

The full configuration, once those fields have been modified, is shown in Figure 10.

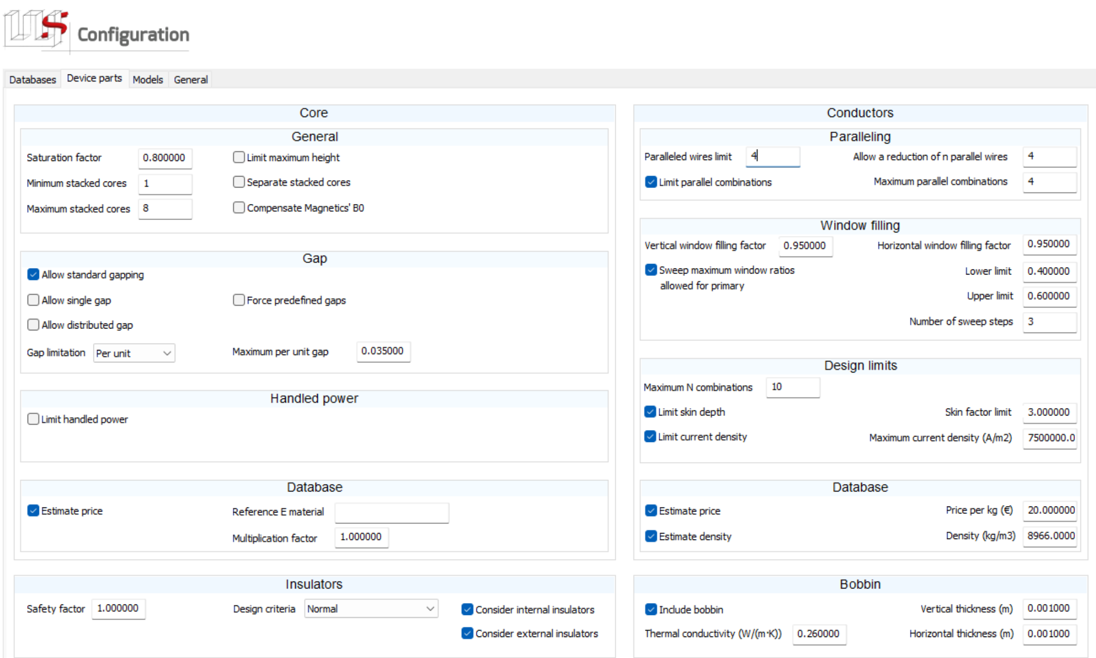


Figure 10: Device parts configuration

The remaining options have been left as in the default configuration. As in every part of the tool, the user is free to use any prior knowledge or information coming from the future manufacturer to adapt the design to the particular needs of a given project.

2.3 Models

In the next tab, "Models", the user can select the model to be used for the calculation of every parameter of the device, including losses, inductance and temperature. By default the most precise models are used for the design, so we will not modify them; the configuration is shown in Figure 11.

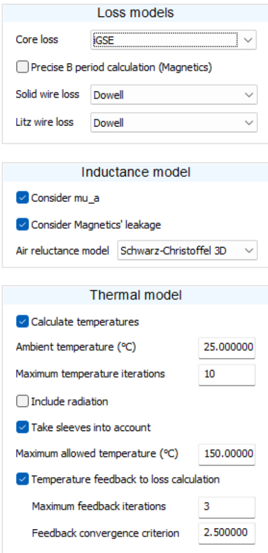


Figure 11: Models configuration

Using the most precise models yields more accurate results, though at the cost of longer design time. To reduce simulation time, a simpler model can be used; for example, if the user knows that core losses are not relevant for the design or that the regular Steinmetz approximation is enough, they can select that model for "Core loss"; or if a rough estimation is enough, the "Maximum temperature iterations" can be reduced. For this example, assuming no prior knowledge of the desired results, high-precision models are used.

2.4 General

In the last step the user can set any parameter of the design to a desired value. Since we don't have any restriction in that regard, let's leave everything as is, including a maximum difference between wanted and achieved inductance of 5% ("Maximum design deviation" = 0.05). The default configuration is shown in Figure 12.

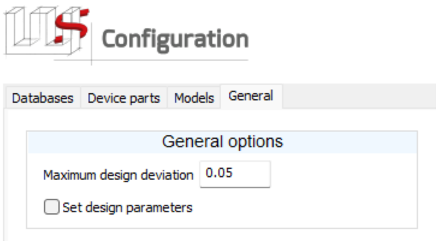


Figure 12: General configuration

Having set every configuration parameter, the user can proceed to the next available step, “Design”, using the lateral menu.

3 Design

Once everything has been configured, the design process can begin, and every parameter combination that produces a valid result is displayed. Any numeric variable that has any impact in the design can be selected at the right-side selectors to be used for comparison.

To choose the most convenient design, we are going to use the variables that are most important for this particular project:

- Axis 1: Temperature vs volume
- Axis 2: Temperature vs loss
- Axis 3: Temperature vs weight
- Axis 4: Loss vs stack

The results with the configured axes are shown in Figure 13.

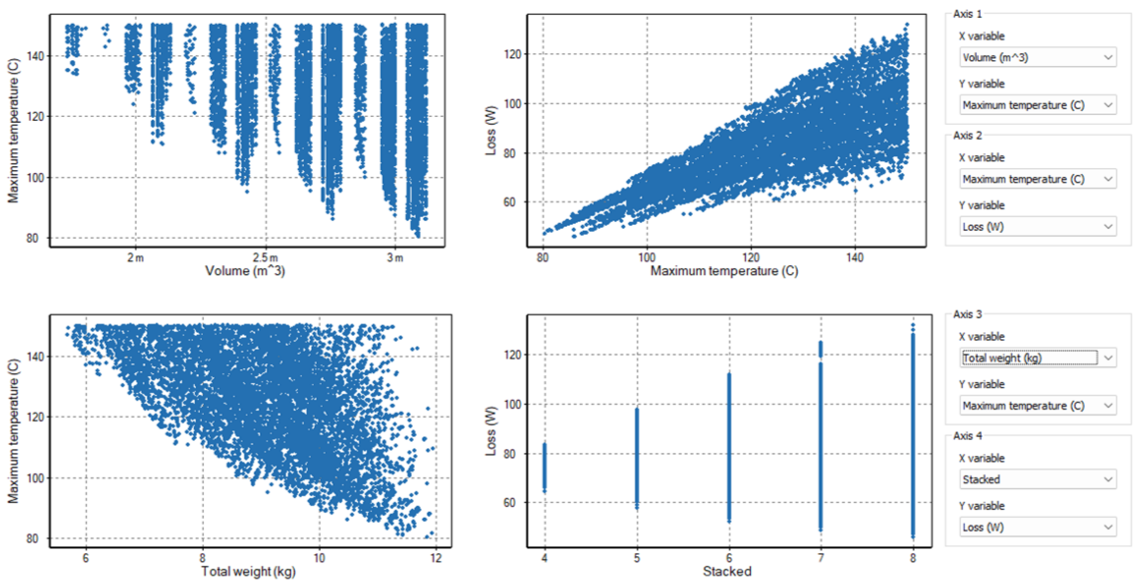


Figure 13: Design results

Once every valid solution is known, we can start filtering out the ones that are considered most convenient for this particular project. To do so, click and drag the cursor to select the desired devices in any graph; those designs will be highlighted in every other graph, enabling an easy comparison of up to 8 variables at the same time.

In the first place, since it is one of the requisites for the project, let's keep only the designs that reach a temperature lower than 90 °C using natural convection, as shown in Figure 14:

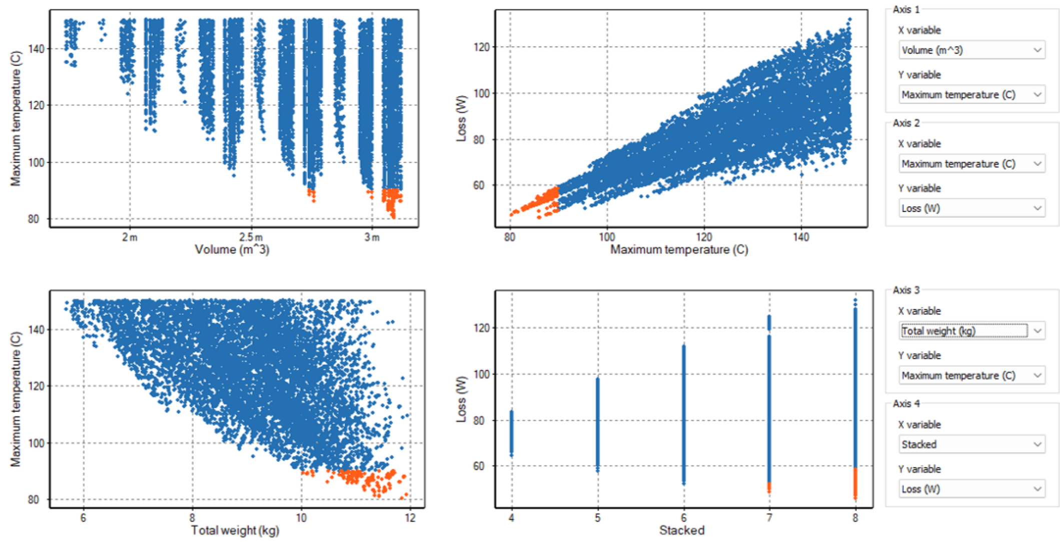


Figure 14: Design results after filtering by Temperature

At the bottom-right graph, we can see that the device can be constructed by using seven or eight stacked cores. The transformer is already going to be very big and expensive, so to alleviate that as much as possible, let's reduce the design space even more, to only the devices that need 7 stacked cores. The remaining results are shown in orange in Figure 15.

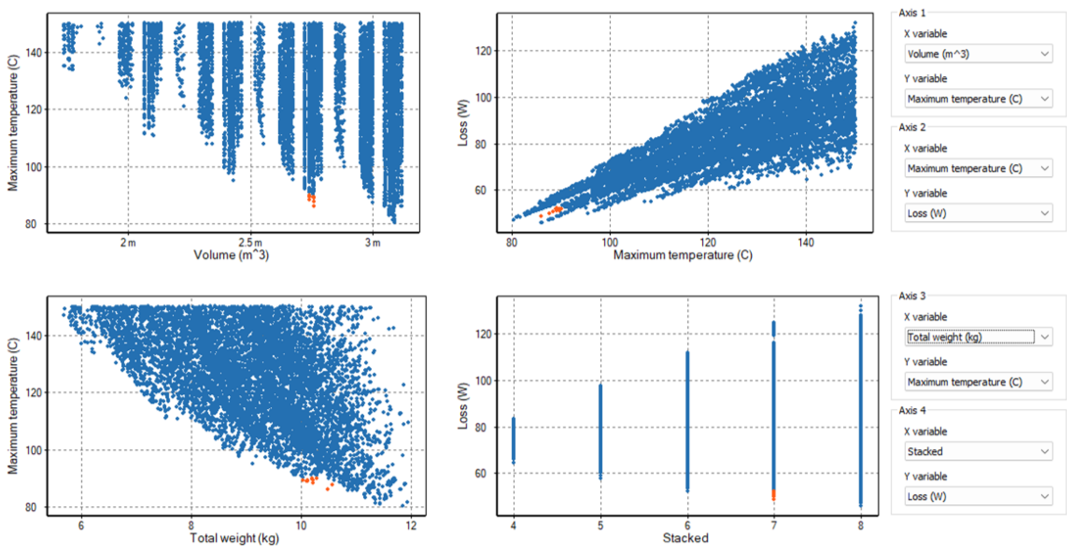
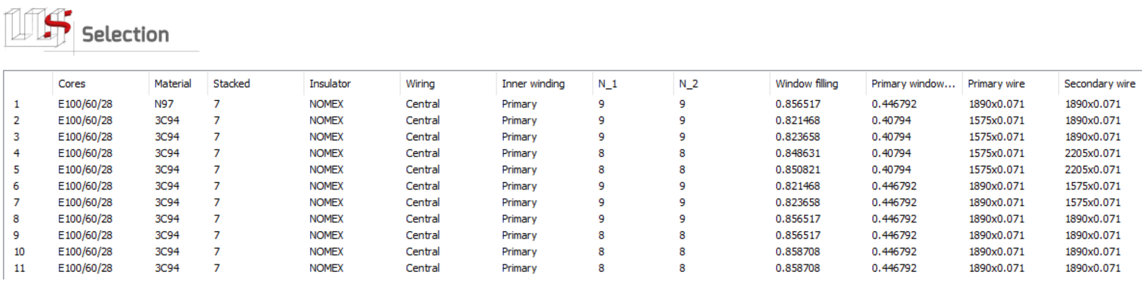


Figure 15: Design results after filtering by Stack

Once a subset of all the possible combinations has been selected, a detailed description of the remaining designs can be used for a fine selection of the design to build. That can be done in the next dialog: "Selection", which is now available in the lateral menu.

4 Selection

In this dialog, the selected devices can be inspected in detail to choose the one that best fits the needs of the current project. The definition of every parameter can be consulted in the provided help (accessed by pressing '*f1*' or clicking in the corresponding button, always available at the bottom-left corner). The user can change the width of every field or even hide the ones not considered important, as shown in Figure 16.


Selection

	Cores	Material	Stacked	Insulator	Wiring	Inner winding	N_1	N_2	Window filling	Primary window...	Primary wire	Secondary wire
1	E100/60/28	N97	7	NOMEX	Central	Primary	9	9	0.856517	0.446792	1890x0.071	1890x0.071
2	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.821468	0.40794	1575x0.071	1890x0.071
3	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.823658	0.40794	1575x0.071	1890x0.071
4	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.848631	0.40794	1575x0.071	2205x0.071
5	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.850821	0.40794	1575x0.071	2205x0.071
6	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.821468	0.446792	1890x0.071	1575x0.071
7	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.823658	0.446792	1890x0.071	1575x0.071
8	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.856517	0.446792	1890x0.071	1890x0.071
9	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.856517	0.446792	1890x0.071	1890x0.071
10	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.858708	0.446792	1890x0.071	1890x0.071
11	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.858708	0.446792	1890x0.071	1890x0.071

Figure 16: Selection. Available devices

The devices shown in the figure are the ones selected in the previous step, so all of them comply with the imposed restrictions.

Since all of them were selected from a lump of designs that were very close to each other in the graphs, they are all very similar. Every design selected uses the same core geometry (7 stacked E100/60/28), two core materials (N97 or 3C94), and different wires. They even have very similar losses (around 50 W), similar maximum temperatures (around 90º), similar weights (around 10 kg), etc.

These similarities highlight the advantages of the SmartNetics approach. As can be seen, a device with approximately the same value in a given parameter can be built in many different ways, and sometimes allowing a slight increase in a parameter can allow for a much better design in every other aspect. In a different approach, only one of these devices would be available, for example the one with the lowest losses. This illustrates the disadvantages of that approach, where designs that are very similar in a given parameter could be discarded by a small difference that wouldn't even have any impact on the converter, without considering the big improvement they could provide in other metrics.

In this case, since all of them are more or less the same in terms of cost, efficiency, volume, etc., we will select the ones that are easier to manufacture. This metric is hard to describe with a single number, but the first thing we will do is use the ones with a lower number of turns. From Figure 16 we can see that the device can be manufactured either using 8 or 9 turns, so let's select only the ones with eight in columns "N_1" and "N_2":

Selection

	Cores	Material	Stacked	Insulator	Wiring	Inner winding	N_1	N_2	Window filling	Primary window...	Primary wire	Secondary wire
1	E100/60/28	N97	7	NOMEX	Central	Primary	9	9	0.856517	0.446792	1890x0.071	1890x0.071
2	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.821468	0.40794	1575x0.071	1890x0.071
3	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.823658	0.40794	1575x0.071	1890x0.071
4	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.848631	0.40794	1575x0.071	2205x0.071
5	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.850821	0.40794	1575x0.071	2205x0.071
6	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.821468	0.446792	1890x0.071	1575x0.071
7	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.823658	0.446792	1890x0.071	1575x0.071
8	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.856517	0.446792	1890x0.071	1890x0.071
9	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.856517	0.446792	1890x0.071	1890x0.071
10	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.858708	0.446792	1890x0.071	1890x0.071
11	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.858708	0.446792	1890x0.071	1890x0.071

Figure 17: Selection. Devices with 8 turns

Some of those designs use a different wire for primary and secondary, which would increase the cost and make the required materials harder to buy and store, so we will select only the devices that use the same wire for primary and secondary in columns "Primary wire" and "Secondary wire":

Selection

	Cores	Material	Stacked	Insulator	Wiring	Inner winding	N_1	N_2	Window filling	Primary window...	Primary wire	Secondary wire
1	E100/60/28	N97	7	NOMEX	Central	Primary	9	9	0.856517	0.446792	1890x0.071	1890x0.071
2	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.821468	0.40794	1575x0.071	1890x0.071
3	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.823658	0.40794	1575x0.071	1890x0.071
4	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.848631	0.40794	1575x0.071	2205x0.071
5	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.850821	0.40794	1575x0.071	2205x0.071
6	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.821468	0.446792	1890x0.071	1575x0.071
7	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.823658	0.446792	1890x0.071	1575x0.071
8	E100/60/28	3C94	7	NOMEX	Central	Primary	9	9	0.856517	0.446792	1890x0.071	1890x0.071
9	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.856517	0.446792	1890x0.071	1890x0.071
10	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.858708	0.446792	1890x0.071	1890x0.071
11	E100/60/28	3C94	7	NOMEX	Central	Primary	8	8	0.858708	0.446792	1890x0.071	1890x0.071

Figure 18: Selection. Devices with the same wire

All these three designs are very similar to each other, so let's move the bar at the bottom a little bit to see more details, as shown in Figure 19.

Selection

Primary vertical wires	Primary horizontal wires	Secondary vertical wires	Secondary horizontal wi...	Primary layers	Secondary layers	BpL_1	BpL_2	R_{DC;1}	R_{DC;2}	P_{w
2	2	2	2	1	1	9	9	0.00317946	0.00366438	13.8
2	2	2	2	1	1	9	9	0.00379751	0.00362943	15.8
4	1	2	2	2	1	5	9	0.00379275	0.00364026	16.4
2	2	2	2	1	1	8	8	0.00338596	0.00278624	13.6
2	2	4	1	1	2	8	4	0.00338607	0.00278733	13.6
2	2	2	2	1	1	9	9	0.00319675	0.00439586	13.8
2	2	4	1	1	2	9	5	0.00319868	0.00438516	13.8
2	2	2	2	1	1	9	9	0.00316357	0.00364606	13.7
2	2	2	2	1	1	8	8	0.00283835	0.00327124	11.7
2	2	4	1	1	2	8	4	0.00283844	0.00327252	11.7
4	1	2	2	2	1	4	8	0.00283946	0.00327351	11.7

Figure 19: Selection. Additional details

All of them use 4 wires in parallel for both primary and secondary. Checking how the wires in parallel are stacked, we can see that there is one that uses the same stacking for primary and secondary (2 wires in vertical and 2 in horizontal). Selecting one that uses the same stack eases winding placement and manufacturability, so that is going to be the selected one.

Once the desired design is found, it can be selected by clicking on the "Select design" button below. Once done, the data of the device is replicated at the bottom, as shown in the next figure:

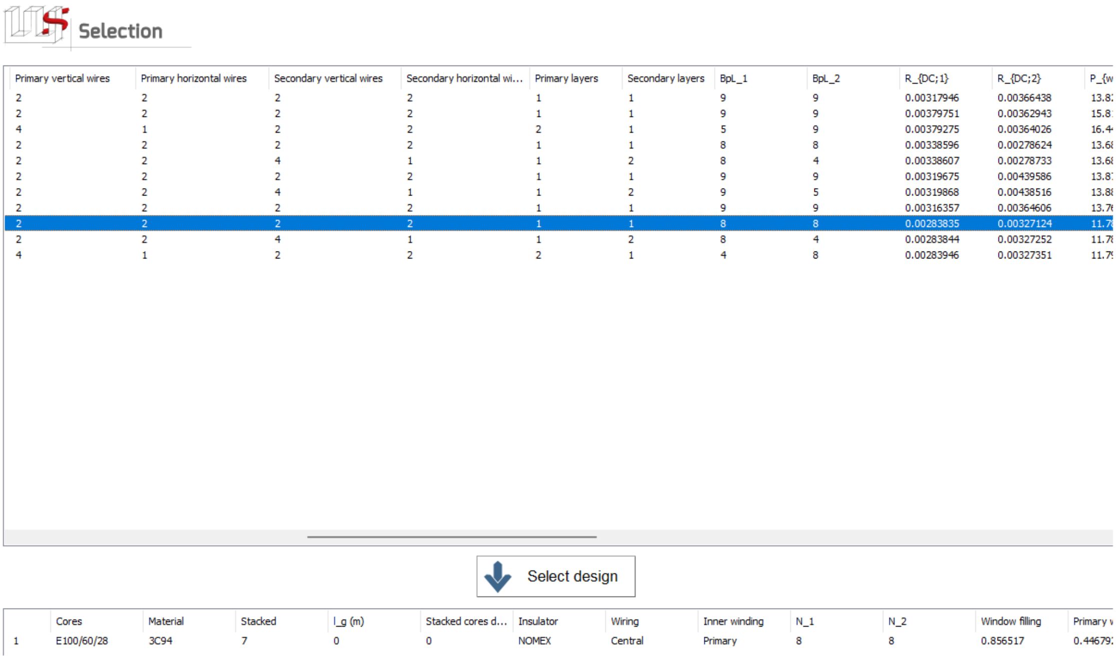


Figure 20: Selection. Single device

Once a design is selected, the last button on the lateral menu, "Device", is enabled, and the user can proceed with the last step of the process.

5 Device

In this last dialog, the user can see the details of the selected device and export it to third-party tools for validation.

The user can navigate through the 5 available tabs:

- Geometry
- Performance
- Report
- Ansys
- Altair

5.1 Geometry

In this first tab, a graphical representation of the device is shown, along with a drawing of a single core and wire with their main dimensions, as shown in Figure 21.

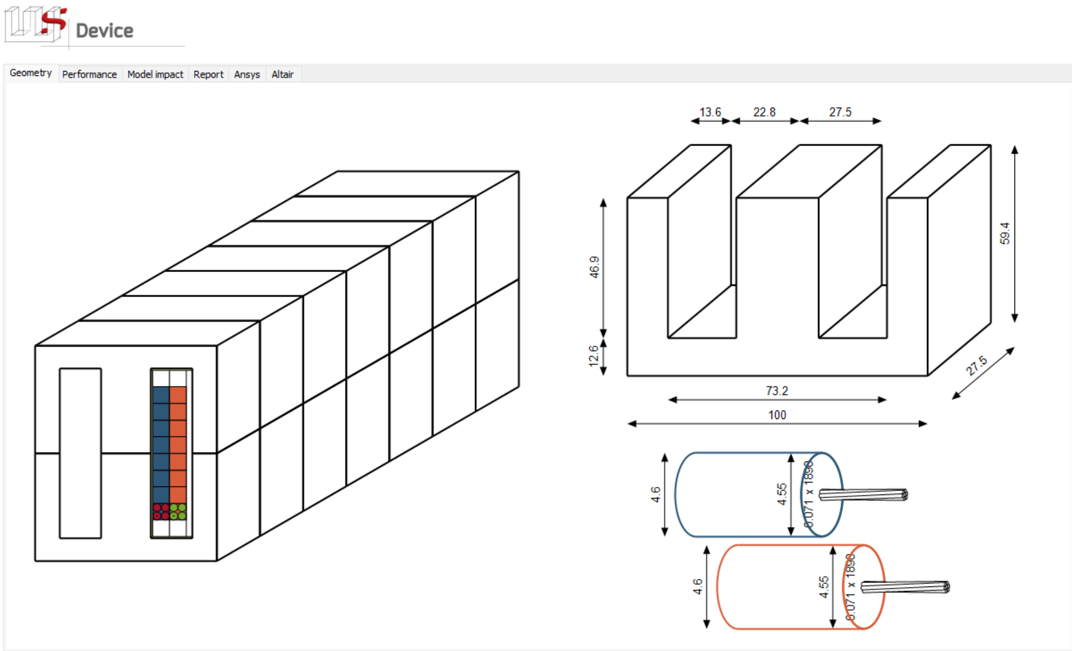


Figure 21: Geometry visualization

5.2 Performance

In the second tab, the user can see the distribution of temperatures in the different parts of the device, depicted in Figure 22. The temperatures shown are calculated for the center of the device and divided into: center of the central column “TnC”, center of the lateral columns “TnL”, center of the top and bottom yokes “TnI”, and center of the windings “Tw1” and “Tw2” (a single winding for inductors).

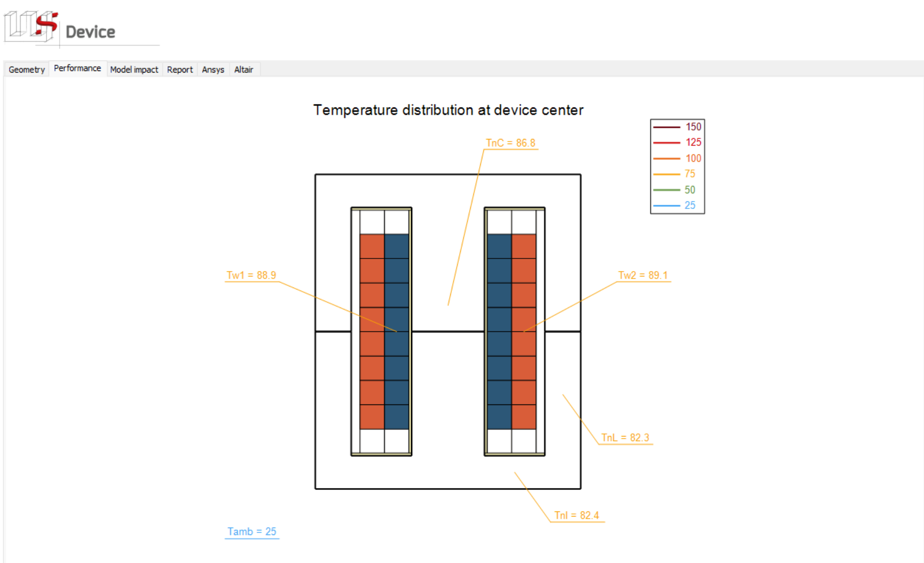


Figure 22: Temperature distribution

5.3 Model impact

Although the model to be used for every calculation was selected in the second step ("Configuration"), the user can see in this tab the results that would have been provided by the other available models. This way, the user can get important information that can help them in the current design and in future ones. The impact of the models selected for the calculation of core loss, conductor loss, and inductance is shown in Figure 23.

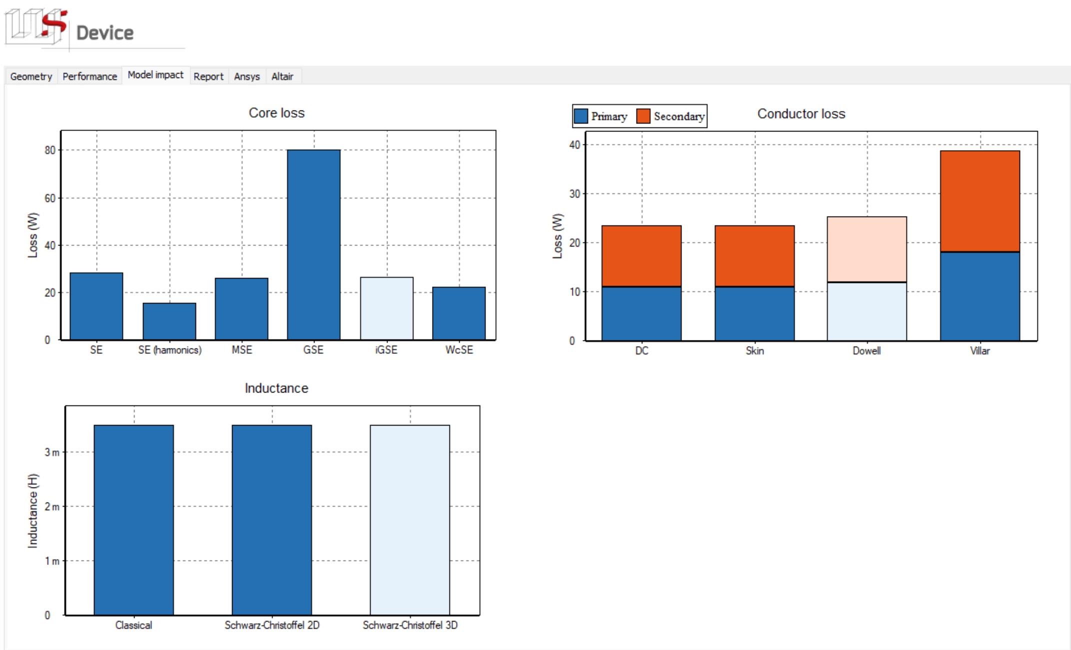


Figure 23: Model impact

In the case of core loss (displayed at the top left corner), by selecting the most precise model ("iGSE"), the underestimation given by the use of the regular Steinmetz model ("SE") or the overestimation provided for this particular waveform by its generalization ("GSE") can be avoided.

5.4 Report

In the fourth tab, the user can generate a high-resolution report that includes the desired information. The user can select what fields to include in the said report:

- Include geometry: includes the graphs displayed in the "Geometry" tab.
- Include performance: includes the graph displayed in the "Performance" tab.
- Include model impact: includes the graphs displayed in the "Model impact" tab.
- Include component list: generates a list of the components needed to build the device.

- Include input signals: replicates the signals (current for inductors; current and voltage for transformers) used as input for the design in the first dialog.
- Include design configuration: generates a list of every configuration option used for the design.

Once the desired options are selected, the user can click on "Generate report" to generate the PDF file in the path selected below.

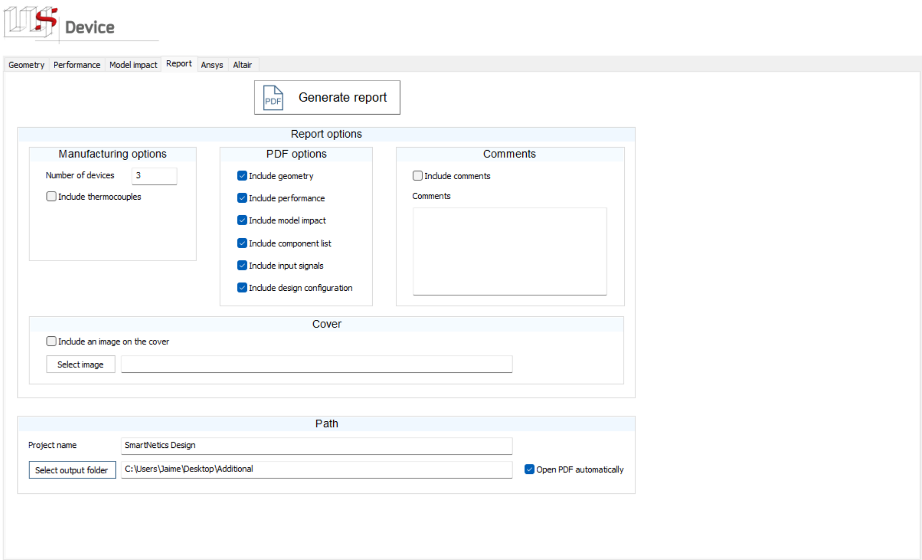


Figure 24: Report configuration

Please keep in mind that the PDF is generated by a LaTeX file that needs MikTex to compile. If it is not installed, the user will be asked to do so (and guided through its corresponding Help section).

5.5 Ansys

Every design in SmartNetics is based on analytical models. This way, thousands of possible combinations can be tried in a short time. Once a particular design is selected, a deeper analysis can be carried out by means of Finite Element tools.

In this regard, SmartNetics allows direct export to Ansys-Maxwell and Ansys-Icepak, where the device can be simulated. To do so, the first step is to generate the model, which is defined in a Python script. This is done when clicking on "Generate Ansys model" and no Ansys installation is required.

Once the model is created, the user can launch Ansys themselves and run it, in the same computer SmartNetics is installed or any other with a valid Ansys license. Ansys can also be launched directly from this screen, by clicking on "Launch Ansys" (Ansys is a third-party software and has to be installed beforehand).

In the case of Ansys, the user can carry out electromagnetic simulations by means of Ansys-Maxwell or Temperature simulations by means of Ansys-Icepak. For this example we will run a temperature simulation, taking into account insulators, wire sleeves, and bobbin for increased precision. To reduce simulation time, the X and Y region percentages have been reduced to 25% and, taking advantage of its symmetry, only one quarter of the device is going to be simulated (2.25D under "Generate symmetry simplifications"). The full simulation configuration is shown in Figure 25.

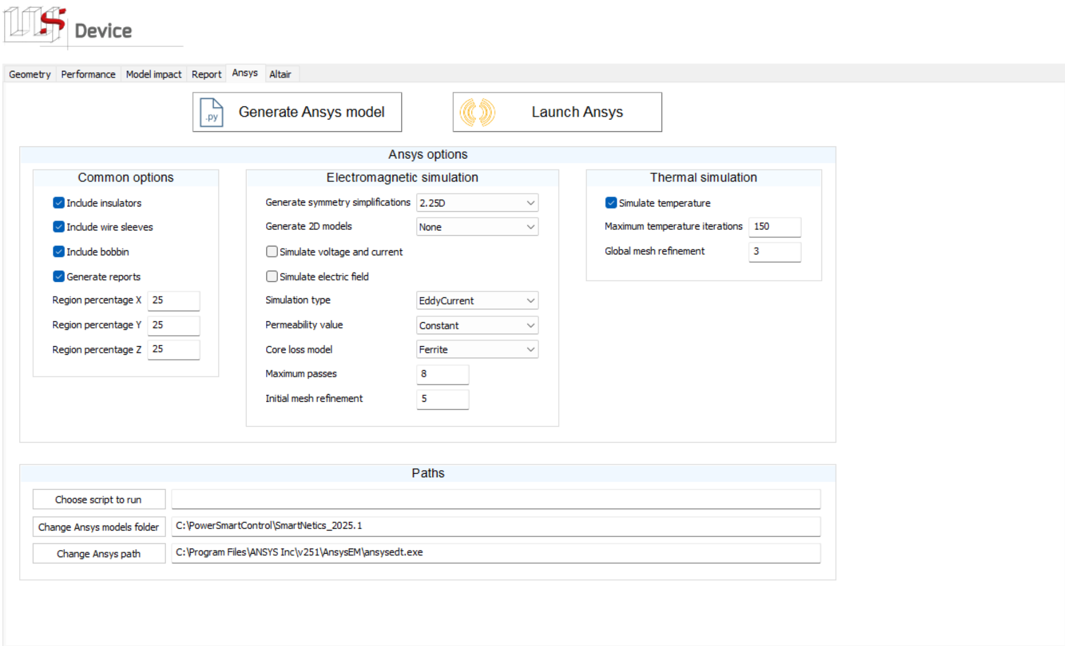


Figure 25: Ansys simulation configuration

Once the user clicks on "Generate Ansys model" and then on "Launch Ansys", the simulator automatically opens and builds the geometry, assigning the required materials, boundaries, and perturbations, as shown in the next figure.

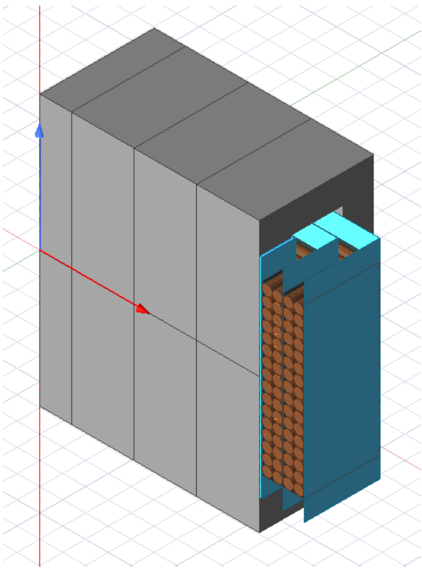


Figure 26: Ansys 3D geometry with 1/4 symmetry

Once the model is generated, the user can click on "Analyze all" to start the simulation, as shown in Figure 27.

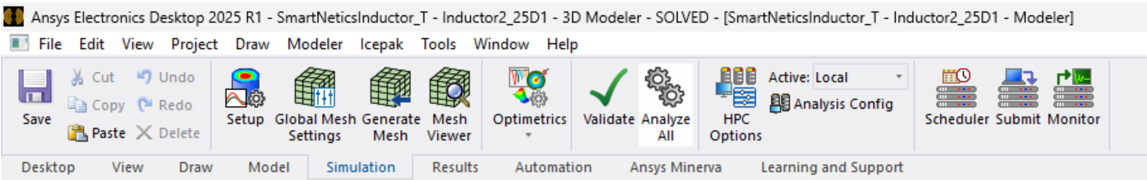


Figure 27: Ansys "Analyze all" button

The temperature simulation results from Ansys, along with the temperature estimation previously obtained in SmartNetics, are shown in the next figure for the *YZ* plane.

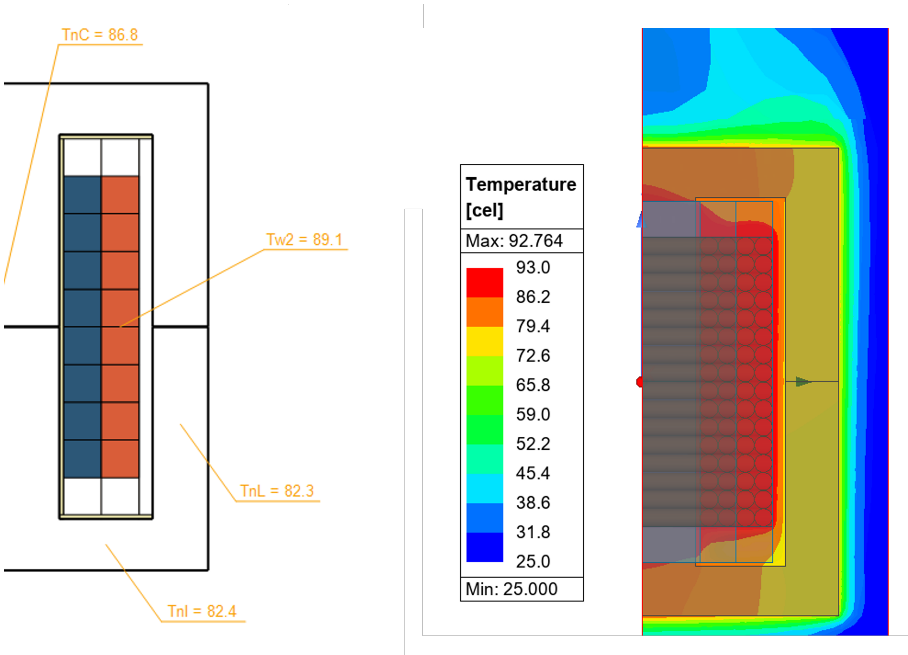


Figure 28: Ansys-Icepak temperature results

As can be seen, there is a very good match between the simulation and the estimation shown in Figure 22, with a predicted maximum temperature of 89.1 °C versus the 92.76 °C given by Ansys.

This highlights one of the advantages of the proposed approach: first use analytical equations, which allow the design of thousands of magnetics in a very short amount of time; and then validate the decision with a Finite Element software, which can achieve a very high precision but at the cost of an increase in time and resources.

5.6 Altair

The remaining option for the validation of the design in a third-party software is the simulation in another Finite Element tool: Altair-Flux. The configuration options are shown in Figure 29 and are similar to the ones in Ansys, with slight changes due to the differences in both programs.

As in the previous step, the user can click on “Generate Flux model” (no Flux installation is required) to generate a Python file with the full description of the model, including geometry, materials, main waveform values, etc. Once generated, the user can run the simulation on a different machine or on the one SmartNetics is installed, by clicking on “Launch Flux” (for this step, Flux must be previously installed in the path selected below).

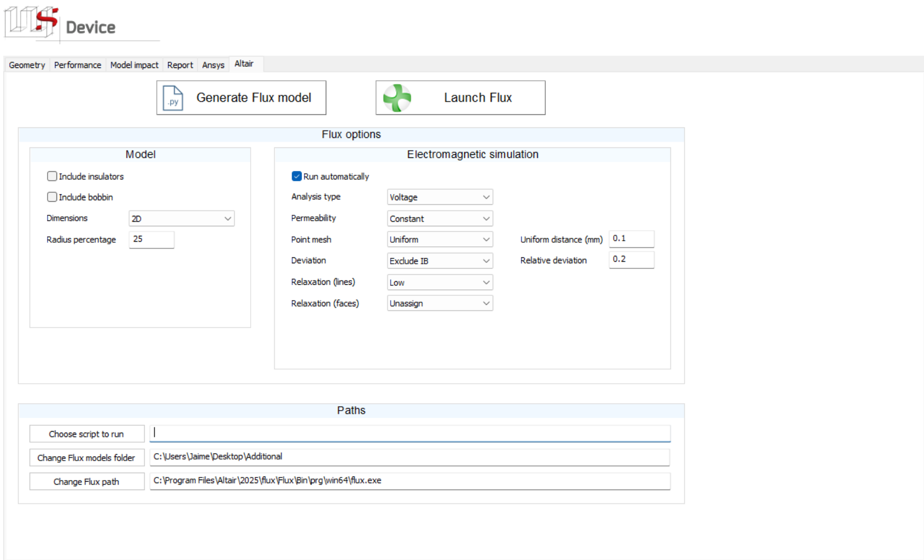


Figure 29: Flux simulation configuration

Since “Run automatically” is checked, once the model is built inside Flux, the simulation starts automatically. The results of the simulation are displayed at the output section of the Flux window, as shown in the next figure.

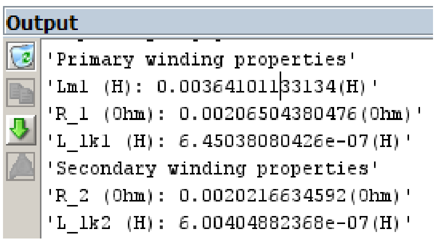


Figure 30: Flux simulation results

The inductance and resistance calculated values are shown in the “Output” box inside Flux. As can be seen, the inductance value is a bit higher than expected (3.64 mH versus the expected 3.49 mH), which can be explained by the many effects taken into account in a Finite Element tool and not in the analytical expressions. This detailed analysis is once again one of the benefits of the exportation to third-party tools provided by SmartNetics.

Conclusion

In this tutorial, an example of how to fully design, export, and simulate a transformer using SmartNetics has been carried out. Starting from current, voltage, and turns ratio definitions, the user can control any aspect of the design process. Once every possible device is designed, the user can easily select the one that best suits their needs, and for the selected design, they can generate a report or export it for simulation in third-party Finite Element Analysis software.

As has been shown, the advantage of the proposed approach over the classical one (where only the device that is the best in one or two properties is provided) is clear. Thanks to this strategy, a device that has only a slightly lower performance in one aspect (and so would be discarded in the classical approach) but much better in every other, can be identified, allowing the selection of the device that best suits the current project.

Once the device that is considered best for the project (regardless of the definition of "best") is selected, the user can export it to third-party software for its validation. In this tutorial, we have validated the result against two Finite Element Analysis tools: Ansys-Icepak and Altair-Flux, with very good results in both of them, assessing the validity of the proposed approach.

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 slight changes.