

[<Back>](#)

---

## How should one design a low inrush current three phase universal autotransformer for 10kVA continuous output power as per IEC 61558 ?

### *Technical specification relevant only to design*

#### Electrical data and diagram

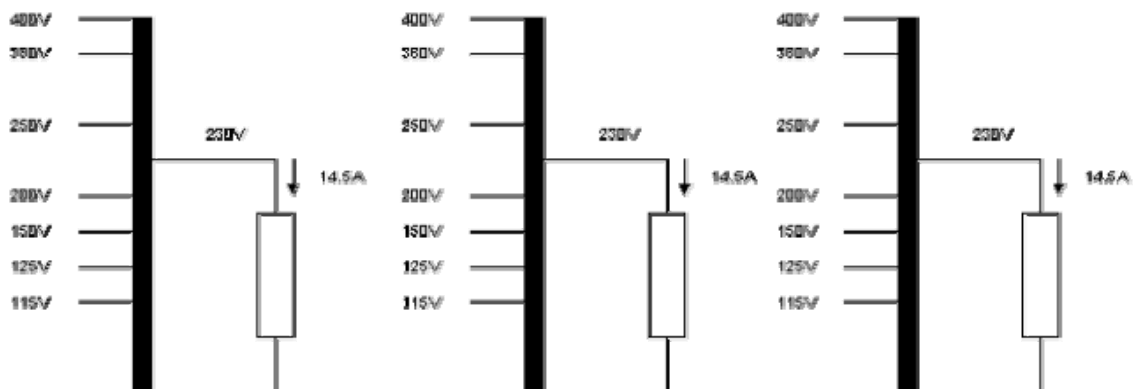
Input voltages sinusoidal	115V, 125V, 150V, 200V, 250V, 380V,400V
Frequency	50/60Hz
Nominal output voltage	230V
Nominal output current	14.5A (10kVA)

#### Ambient and operating conditions:

Ambient temperature	40°C
Mode of operation	Continuous operation
Test conditions	Non-inherently short-circuit proof

#### Specification

- Autotransformer as per IEC 61558
- Insulation class E



## ***Design criteria***

### **IEC 61558**

An autotransformer with non-inherently short-circuit protection as per IEC 61558 is equipped with a internal protection. Very often, we arrive at a combined protection solution consisting of a primary-side fuse (short circuit protection) and a thermal cut-out (overload protection). For this reason, short-circuit and overload is not design criteria. The criterion for design for purposes of IEC 61558 is only temperature  $\theta$  **nominal** at the overvoltage of 6%.

Insulation class	A	E	B	F	H
Max. winding temperature in nominal operating mode $\theta$ <b>nominal</b> (°C)	100	115	120	140	165

### **Insulation class**

Max winding temperature in nominal operating mode =115°C  
*Insulation class E is prescribed.*

### **The criterion for design**

The autotransformer has to be designed for the temperature rise <75°K at 40°C ambient temperature and insulation class E.

*The criteria of design is the temperature rise: **Criterion=2***

### **Bobbin unit**

An autotransformer is constructed exclusively with single-chamber bobbin units.

### **Induction and Fe-quality**

Low Inrush-current transformers are operated at a low induction (1.2T-1.5T). In the output range up to approx. 200VA, cold-rolled Fe quality 5.3W/kg is used at 1.5T, 50Hz. Over and above that, we find cold-rolled Fe-quality 4.00W/kg at 1.5T, 50Hz and grain-oriented Fe-quality 1.11W/kg at 1.5T, 50Hz.

### **Inrush current**

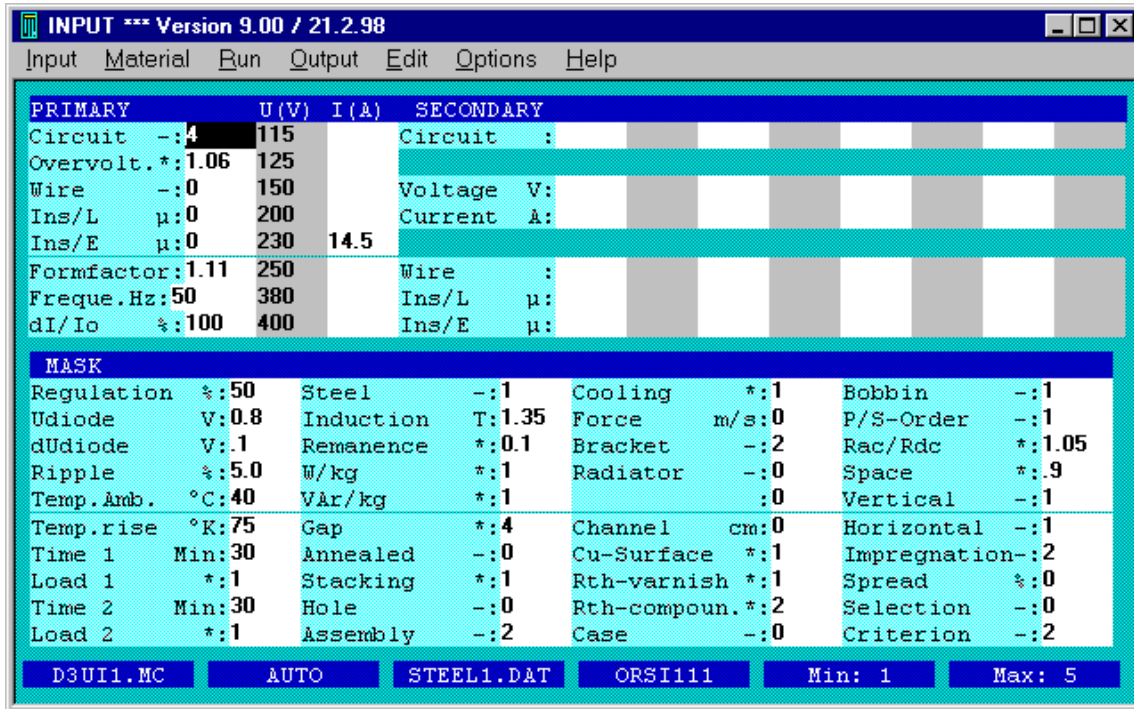
The peak value of the inrush current in the first period after switch-on at the zero-axis crossing point should not exceed a factor of 15 x the peak value for nominal input current. This can best be achieved if:

- The nominal induction is 1.2T-1.5T.
- The core is constructed with a defined gap of approx. 0.05-0.10 mm, so as to reduce residual magnetism (remanence).

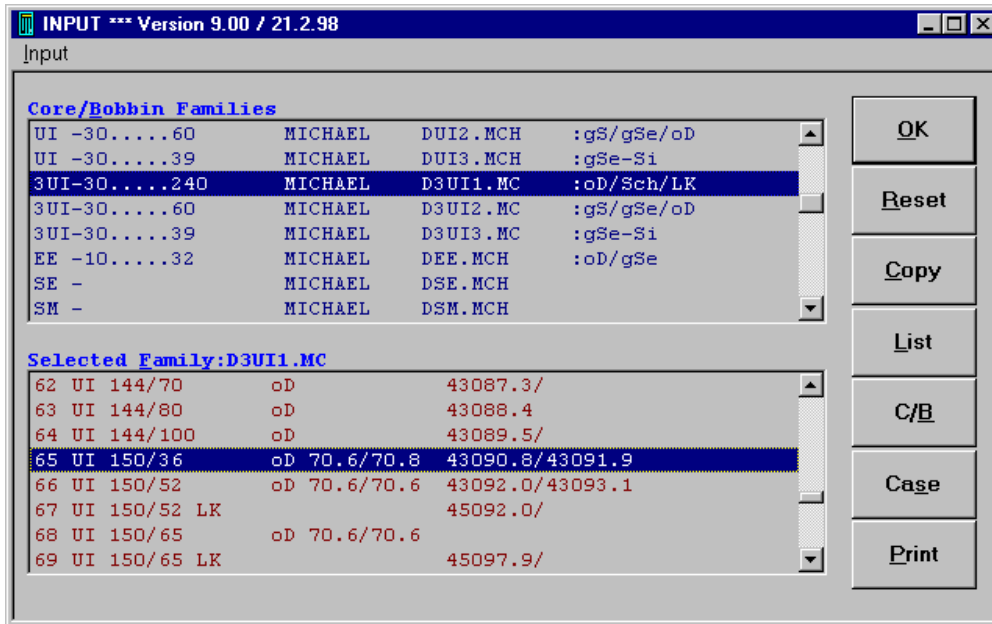
## ***Design procedure***

1. If you are not yet acquainted with Rale design software please read the text "**How should I design a small transformer?**" Keep a copy of this text within convenient reach whenever performing design work.
2. Fill in the design input mask as follows. If you need any help, press functions key F1. There is extensive description for each input field.

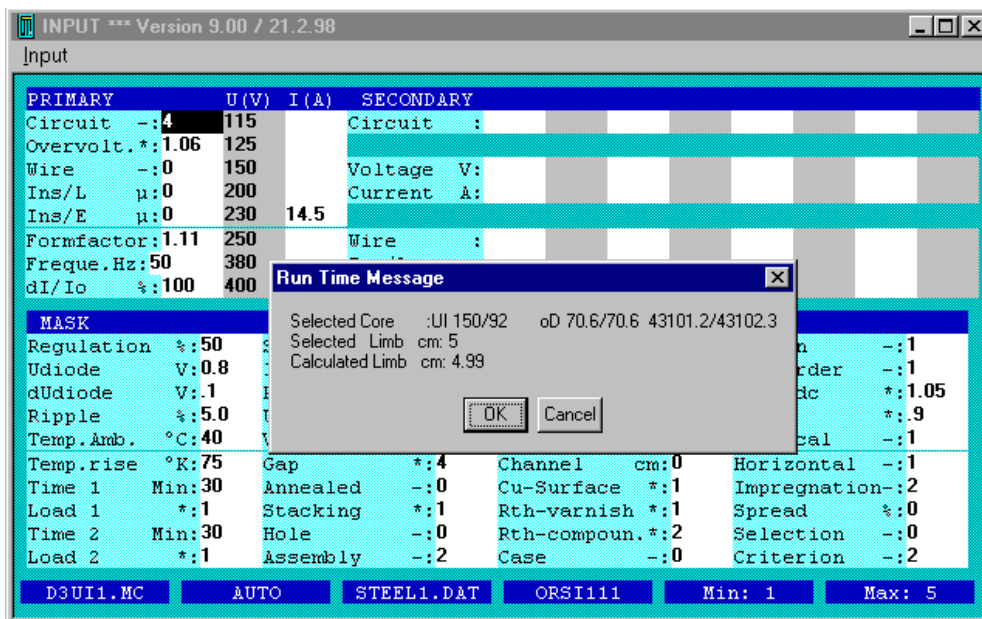
**IF YOU WANT TO CREATE OFF-LINE AN INPUT FILE FOR DESIGN OF AN AUTOTRANSFORMER YOU CAN'T DELETE THE FIRST SECONDARY WITH YOUR OLD DEMO PROGRAM. YOU HAVE TO DO IT ON-LINE! IN ORDER TO DO IT, PLACE THE CURSOR ON ANY POSITION OF THE FIRST SECONDARY WINDING AND PRESS Ctrl+D .**



- The **Selection** input field is set at **0**. This means that the program should search on-line for a suitable core for this application, from your selected core family. The primary **Circuit** is set to **4** for the star connection of the windings. The **Overvoltage = 1.06** means that the prescribed temperature rise of **75°K** must not be exceeded at the **6%** overvoltage of the primary voltage. Note that the induction is set lower in order to limit the inrush current. For this reason the core is constructed with a defined gap of 0.10 mm (**Gap = 4 x 0.025mm= 0.1mm** with **Assembly = 2**), so as to reduce residual magnetism (**Remanence= 0.1 x 1.35T = .135T**).
- Save your input data file. In this specimen design calculation, we saved the input data in input data file **CAL0012E.TK1**. This input data file was supplied together with this document. Copy it into the directory in which your Rale demo program is installed.
- Connect up to the Rale design server.
- Load up your input data file.
- Now select the three-phase core family and (optional) the core from which a suitable core is to be searched by the computer program.

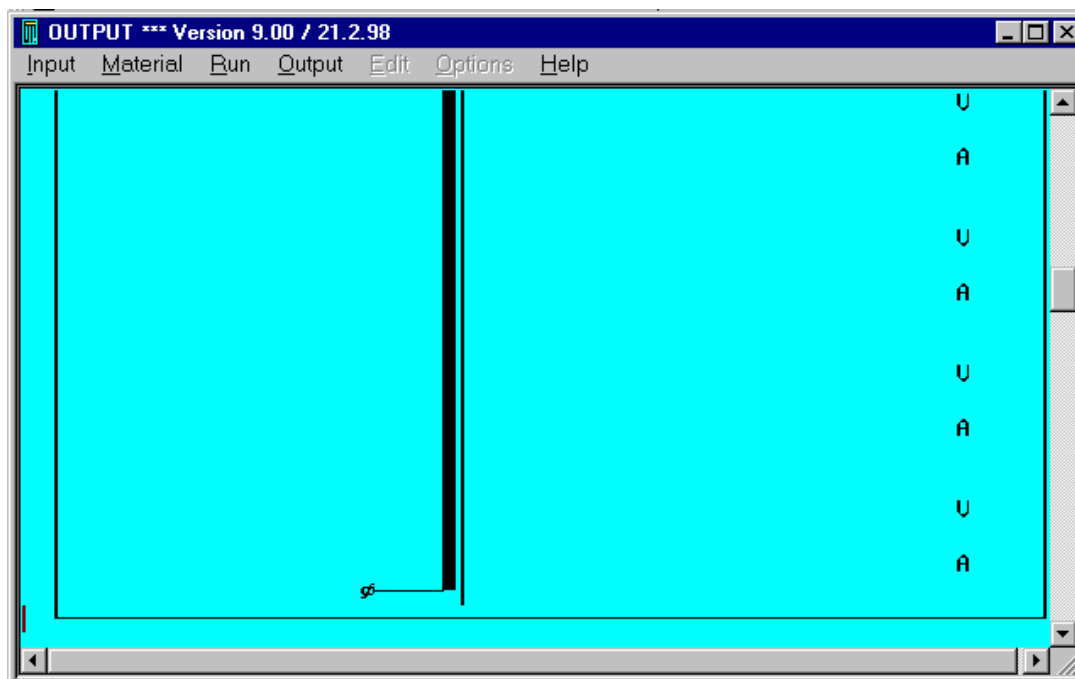
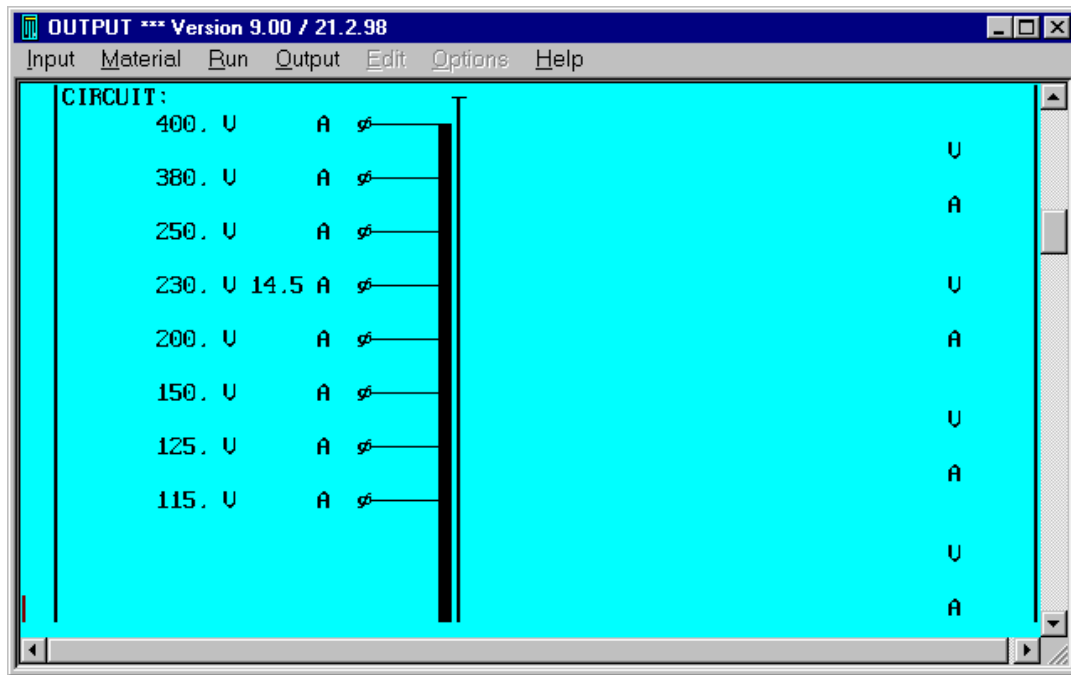


- Click on **OK**.
- Start your design work. In the system for automatic selection of the core from your prescribed core family, the program will offer you an adequately sized core for your application. Click on OK in order to accept the core.

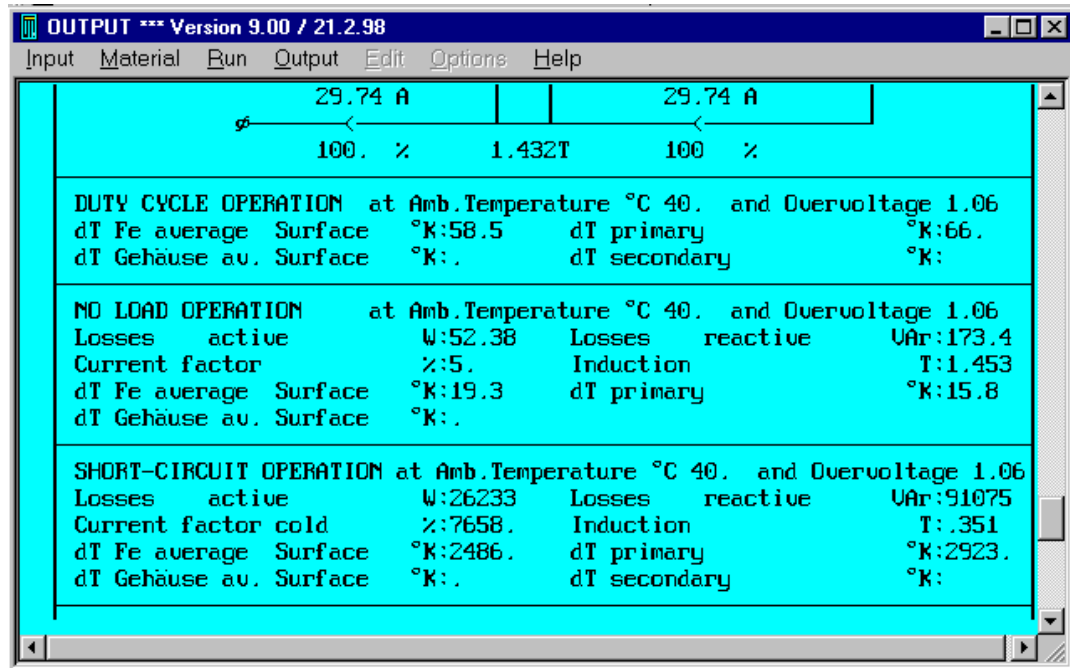
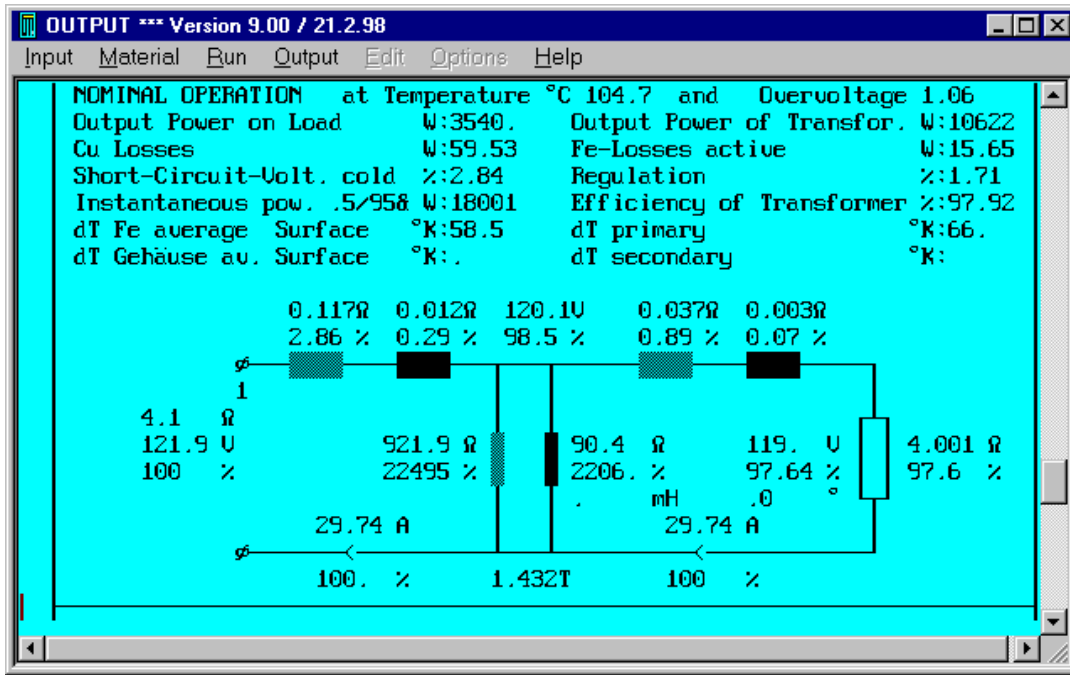


On completion of the design work, the following design data will be available and can be printed on the three pages:









```

OUTPUT *** Version 9.00 / 21.2.98
Input Material Run Output Edit Options Help

dT Gehäuse av. Surface °K:
SHORT-CIRCUIT OPERATION at Amb.Temperature °C 40. and Overvoltage 1.06
Losses active W:26233 Losses reactive VAR:91075
Current factor cold Z:7658. Induction T:351
dT Fe average Surface °K:2486. dT primary °K:2923.
dT Gehäuse av. Surface °K: dT secondary °K:

PRIMARY (Tap:1 ) 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8----
Voltage Input/Output U:121.9 132.5 159. 212. 244. 265. 402.8 424.
Out. Voltage no load U: 248.
Current Input/Output A:29.74 14.51
Current in segment A:15.22 14.54 14.53 14.52 14.51 0. 0. 0.
Icc-Current cold A:2278. 1119.
Io -Current A:1.486
Inrush Current peak ^A:602.2
Inrush Current rms A:257.5
Cu-Losses W:59.5
Resistance cold R:.0879 .0975 .1215 .1721 .2031 .2718 .5079 .5912
Reactance R:.0119 .0129 .0154 .0205 .0236 .0236 .0236 .0236

```

```

OUTPUT *** Version 9.00 / 21.2.98
Input Material Run Output Edit Options Help

Resistance cold R:.0879 .0975 .1215 .1721 .2031 .2718 .5079 .5912
Reactance R:.0119 .0129 .0154 .0205 .0236 .0236 .0236 .0236
Eddy-Current Factor :1. 1. 1. 1. 1. 1. 1. 1.

SECONDARY 1---- 2---- 3---- 4---- 5---- 6---- 7---- 8----
Output Voltage U:
Output Current A:
Out. Voltage no load U:
Sec. Voltage U:
Sec. Current A:
Sec. Voltage cold U:
Sec. Load R:
Icc cold A:
Cu-Losses warm W:
Resistance cold R:
Reactance R:
Eddy-Current Factor :
Capacitor mF:

```

10. Checking of the design data follows this.

- We now check the winding data and the filling factor (76<100%).
- The maximum temperature of the windings is 40°C+66°K = 106°C < 115°C.
- The inrush current factor is slightly less than 15 x: 14.4<15.
- The primary windings' wire size calculated by the program is not optimized for production. In the test program, only three-wire thickness should be employed: 2.65mm to 115V, 2.50mm between 115V and 230V and 1.90mm between 230 and 400V.

This is followed by checking of the output voltage at the nominal input voltage of 230V:  $U_{in} = 1$ .

TEST *** Version 9.00 / 21.2.98								
Input Material Run Output Edit Options Help								
PRIMARY	1	2	3	4	5	6	7	8
Turns	85.1	92.7	111.7	149.8	173.2	187.5	284.2	299.1
Family	0							
Number	99	98	98	98	98	93	93	93
Parallel	1	1	1	1	1	1	1	1
Ins/L $\mu$	0.0							
Load					15.86			
f-thic mm	2.65	2.5	2.5	2.5	2.5	1.9	1.9	1.9
f-wide mm	2.65	2.5	2.5	2.5	2.5	1.9	1.9	1.9
Layers	1.71	0.14	0.36	0.72	0.44	0.21	1.40	0.22
SECONDARY	1	2	3	4	5	6	7	8
Turns								
Family								
Number								
Parallel								
Ins/L $\mu$								
Load s. O:								
f-thic mm								
f-wide mm								
Layers								
U sec V:								
U0 sec V:								

FormFact.:	1.11
U input *:	1.06
FREQ. Hz:	50
T amb. °C:	40.0
t1 on Min:	30.0
Load 1 *:	1.00
t2 on Min:	30.0
Load 2 *:	1.00
STEEL -:	1
Margin cm:	0.35
Case -:	0
Tap -:	1
RWH %:	80.1
dT-rise°K:	66.1
dU %:	1.7
IO %:	5.
Ii <sup>^</sup> /In <sup>^</sup> :	14.4
P Fe W:	15.65
P Cu W:	59.52
Bn T:	1.432
B0 T:	1.453
Br T:	.143

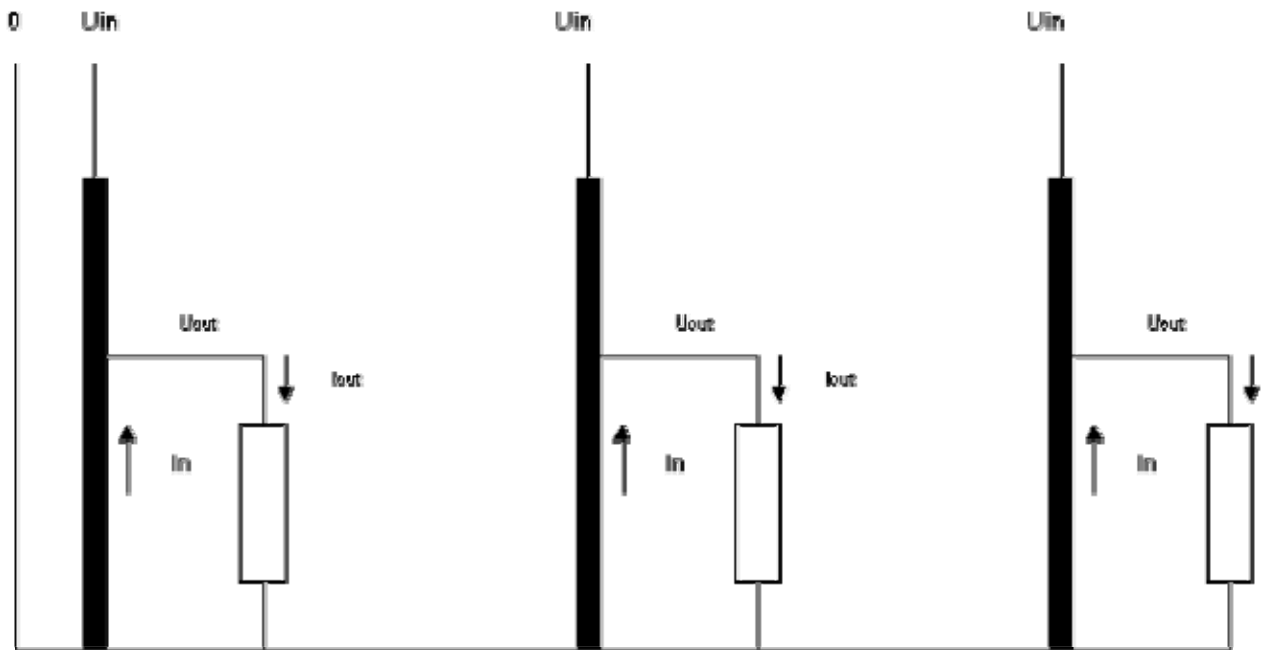
11. It is recommended at this position that you change the input voltage tap (Tap = 1...8) and test temperature rise and the output voltage. Note that the program starts designing by the tap with max. core power and selects the wires for the max. power losses in order to control prescribed temperature rise. The value of the output voltage can be designed as prescribed only for ONE input voltage.
12. If the design data is not satisfactory, then there are two ways by which we can implement the desired correction:
  - You can return to the input mask (function key F2) correct the input data and redesign the transformer.
  - Or you can access the test program (function key F5), modify the designed transformer manually and redesign the transformer by that means.
13. On completion of the design work, you can print out the design data on-line, or save it on your local PC and print it out off-line. The output data file from this design example, **CAL0012E.TK2** is supplied together with this document. Copy it into the directory in which your Rale demo program is installed.

### Tips&Tricks

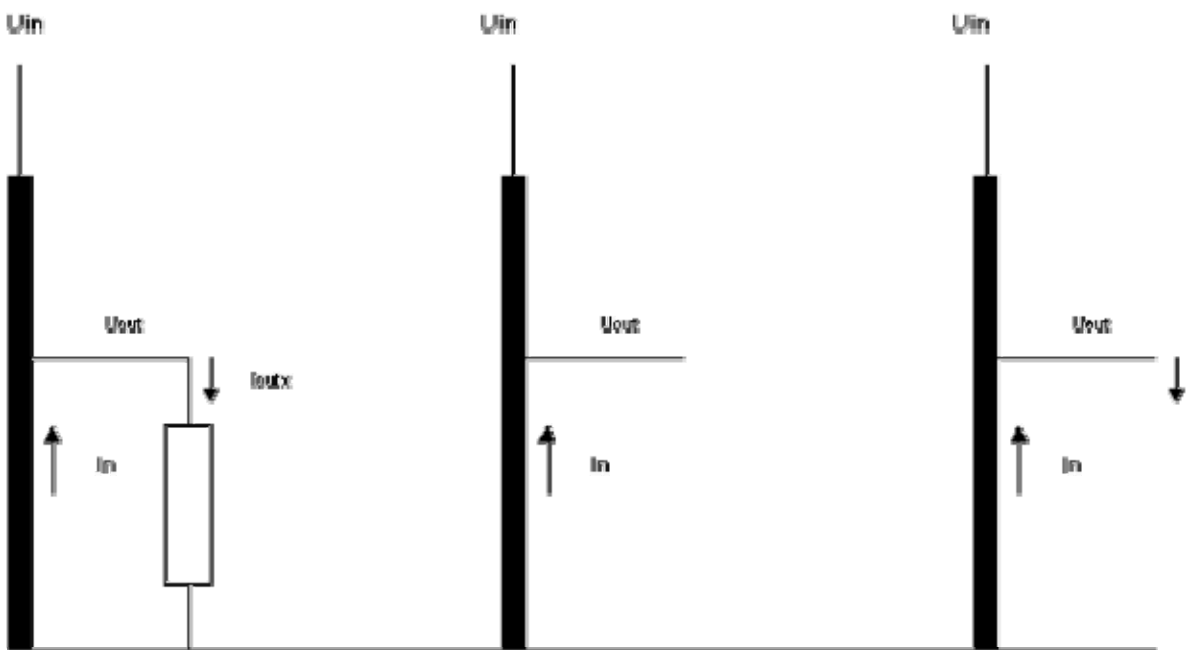
#### Three phase Autotransformer and non-symmetrical load

If have designed an autotransformer for the operation in accordance with the following figure **A** and your autotransformer works under the operation described in the figure **B** the use inherently a thermal protection. But if you don't like to use a thermal protection, then the following table for the declaration of the allowed non-symmetrical load of your autotransformer.

$U_{in}/U_{out}$	$I_{out}/I_{in}$
0.95	0.15
0.90	0.25
0.85	0.30
0.80	0.42
0.75	0.50



B



## Supply Voltages Worldwide

100V 60Hz	Japan, Korea, Okinawa
100V 50Hz	Japan
105V 60Hz	Korea
110V 60Hz	Belize, Brazil, Colombia, Dominican Republic, Ecuador, Guam, Guyana, Haiti, Honduras, Panama, Peru, Philippines, Taiwan
110V 50Hz	Azores, Belgium, Bolivia, France, Guyana, Haiti, Jamaica, Lebanon, Somalia, Turkey
115V 60Hz	Brazil, El Salvador, Netherlands Antilles, Panama, Philippines, Surinam, Trinidad and Tobago, Barbados, Bolivia, France
115V 50Hz	Barbados, Bolivia, France
120V 60Hz	American Samoa, Bahamas, Bermuda, Brazil, Canada, Cayman Islands, Colombia, Costa Rica, Ecuador, Guam, Guatemala, Haiti, Liberia, Netherlands Antilles, Nicaragua, Okinawa, Puerto Rico, Venezuela, Virgin Islands (American)
120V 50Hz	Cambodia, France, Luxembourg, Venezuela, Vietnam
125V 60Hz	Brazil
125V 50Hz	France, Indonesia
126V 60Hz	Panama
127V 60Hz	Brazil, Ecuador, Mexico, Netherlands Antilles, Saudi Arabia, Tahiti
127V 50Hz	Algeria, Belgium, Brazil, Cameroon, Canary Islands, France, Italy, Libya, Madagascar, Mallorca Island, Monaco, Morocco, Netherlands Antilles, Senegal, Spain, Surinam, Togo, Tunisia, Vietnam
130V 50Hz	Belgium

150V 60Hz	Colombia
200V 50Hz	Hong Kong
220V 60Hz	Afghanistan, Belize, Brazil, Korea, Peru
220V 50Hz	Afghanistan, Algeria, Angola, Argentina, Austria, Azores, Bangladesh, Belgium, Benin, Bolivia, Botswana, Bulgaria, Burundi, Cambodia, Cameroon, Canary Islands, Cape Verde, Central African Republic, Chad, Chile, China (P.R.), Congo, Czech Republic, Denmark, Djibouti, Egypt, Equatorial Guinea, Ethiopia, Faeroe Islands, Finland, France, French Guiana, Gabon, Gambia, German D.R., Fed. Rep of Germany, Ghana, Greece, Greenland, Guadeloupe, Guinea, Guinea-Bissau, Hungary, Iceland, India, Indonesia, Iran, Iraq, Ireland,, Italy, Ivory Coast, Jerusalem, Jordan, Laos, Lebanon, Lesotho, Luxembourg, Macau, Madagascar, Madeira, Mallorca Island, Mali, Martinique, Monaco, Morocco, Mozambique, Nepal, Netherlands, Netherlands Antilles, New Caledonia, Niger, Paraguay, Peru, Poland, Portugal, Romania, Rwanda, Saudi Arabia, Somalia, South Africa, Spain, Sweden, Switzerland, Syria, Thailand, Togo, Tunisia, Turkey, the former USSR, United Arab Emirates, United Kingdom (Northern Ireland), Upper Volta, Uruguay, Vietnam, Yemen (Arab Rep.), Yugoslavia, Croatia, Slovenia, Macedonian, Bosnia-Herzegovina, Zaire, Zambia, Zimbabwe
230V 60Hz	Antigua, Bahrain, Brazil, St. Kitts and Nevis, Trinidad and Tobago
230V 50Hz	Bahrain, Bolivia, Belgium, Burma, Cameroon, Channel Islands, Dominica, France, Grenada, India, Israel, Libya, Malawi,

	Malaysia, Maldives, Mauritius, Montserrat, New Zealand, Nigeria, Norway, Pakistan, St. Vincent, Saudi Arabia, Sierra Leone, Singapore, Somalia, South Africa, Sri Lanka, Swaziland, Tanzania, United Arab Emirates, United Kingdom (Northern Ireland), Western Samoa, Yemen (Aden), Zimbabwe
240V 60Hz	American Samoa
240V 50Hz	Australia, Channel Islands, Cyprus, Fiji, Gibraltar, Isle of Man, Kenya, Kuwait, Malaysia,, Malta, Oman, Papua, Qatar, St. Lucia, Seychelles, South Africa, Sudan, Tonga, Uganda, United Arab Emirates, United Kingdom (England, Scotland, Wales)
250V 50Hz	Australia, South Africa
380V 50Hz	France

---



---

[<Back>](#)