DC-DC Converter

Efficiency Comparison

Simon DEGRES 16/09/2020

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1. Document history

Date	Version	Author	Change description
08/09/2020	1.0	Simon DEGRES	**Creation**
16/09/2020	1.1	Simon DEGRES	**Add information**
22/06/2021	1.2	Simon DEGRES	Remake Scenario for new version

2. Overview

2.1 Goal

The test bench is composed of a power supply, an ammeter, a DC-DC converter and a programmable load. It's possible to calculate the input and output power of the system in order to calculate the efficiency of the DC-DC converter.

Thanks to a four-terminal sensing available with the instruments, the dropout voltage in the cable is compensated.

The DC-DC Converter test bench allows to plot efficiency curves in order to compare different parameters that can influence power conversion. The goal is to measure and maximize the efficiency on a DC-DC Converter. We can also plot the losses and the dropout voltage of the converter.

2.2 Features:

- Editable parameters for measure
- Calibration possibility
- Efficiency and Losses Curves
- Dropout Voltage in the DC-DC

2.3 Instrument

2.3.1 Programmable Load: TENMA_7213210

FIGURE 1: TENMA_7213210

2.3.2 Power Supply: ITECH_IT6724C

FIGURE 2: ITECH_IT6724C

2.3.3 Ammeter: GWINSTEK_8341

FIGURE 3: GWINSTEK_8341

3. Setup

3.1 Electrical diagram DC-DC efficiency test bench

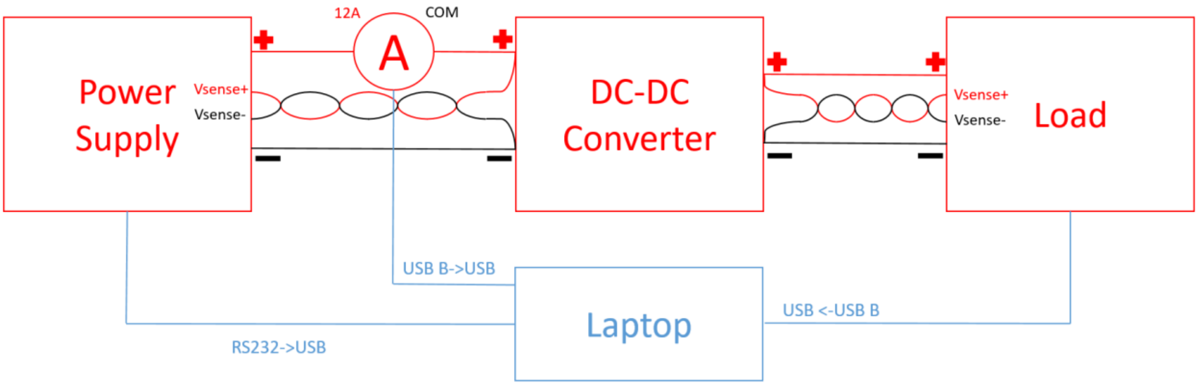


FIGURE 4: ELECTRICAL SCHEMATIC

3.2 Power Connections

Power connections are represented on the diagram with red and black cable with the positive and negative terminal.

3.3 Four-terminal sensing

We use four-terminal sensing to compensate the dropout voltage in the wire. By connecting Vsense directly on the DC-DC, the measurement is made at the input and the output of the converter. It's call remote sense.

Wires are also twisted in order to compensate the inductive disturbance. And they are represented with the twisted wires in red and black.

3.4 Connection to Laptop

The connection between the laptop and all the instruments is made using, depending on the case, standard USB cables or RS232 to USB converters. Thanks to a Powershell script, we can send commands to the instruments and get all the measure that we want.

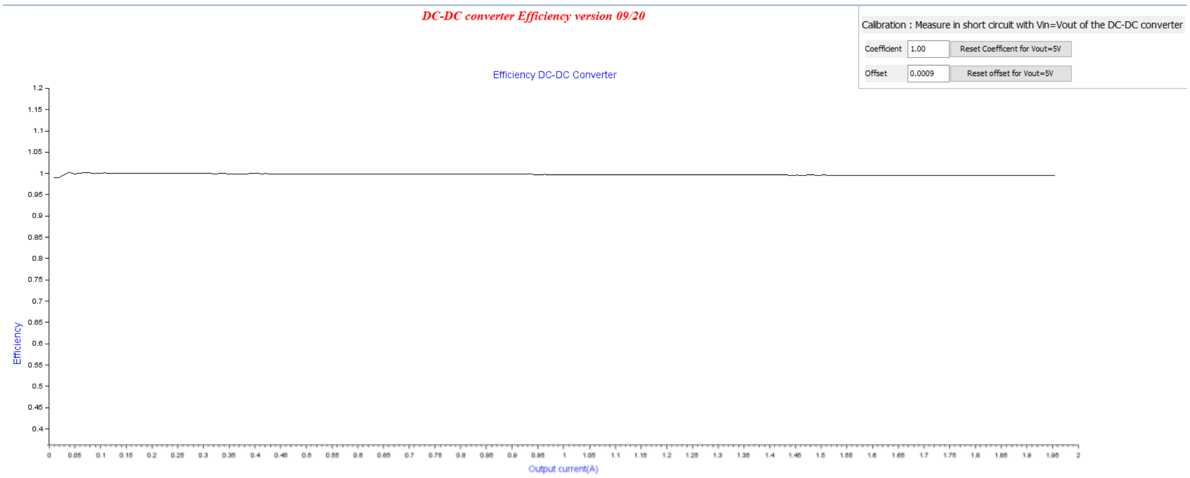
3.5 Short-circuit to calibrate

We connect directly the power supply to the load with a short circuit – that means, bypassing the DC-DC converter – and we make the calibration with a voltage equal to the output voltage of the converter that we want to observe. The calibration allows to limit the uncertainty of the measure of the output current. We obtain an efficiency curve equal to one.

4. Uncertainty

4.1 Calibration in short-circuit

We add an offset to Iout to calibrate the measure and we obtain this curve:



4.2 Calculation

4.2.1 Uncertainty type A

3 measures in the same condition allows us to determine the standard deviation.

$$U_A = \frac{\sigma}{\sqrt{3}}$$

For example, when Iout=299.2mA, Iin=137mA, Vout=4.967 et Vin =12V

We have $U_A(Pin) = \frac{\sigma}{\sqrt{3}} = \frac{0.32\times10^{-3}}{\sqrt{3}} = 0.18mW$ and $U_A(Pout) = \frac{\sigma}{\sqrt{3}} = \frac{0.86\times10^{-3}}{\sqrt{3}} = 0.50mW$

4.2.2 Uncertainty type B

$$y = f(x_1, x_2, \dots, x_k)$$

$$u^2(y) = \sum_{k=0}^{n} \left(\frac{\partial y}{\partial x_1}\right)^2 u^2(x_1) + \left(\frac{\partial y}{\partial x_2}\right)^2 u^2(x_2) + \cdots + \left(\frac{\partial y}{\partial x_k}\right)^2 u^2(x_k)$$

$$P = U \times I$$

$$u(P) = \sqrt{I^2 \times u^2(U) + U^2 \times u^2(I)}$$

We can found u(I) and u(U) in the manual of the instrument that measure the parameter.

Iin is measured by the ammeter with a Range of 500mA, so $\mathrm{U(Iin)} = \mathrm{Iin} \times 0.001 + 4 \times 10\mathrm{nA}$

Vin is measured by the supply, so $\mathrm{U(Vin)} = \mathrm{Vin} \times 0.0003 + 10\mathrm{mV}$

Iout is measured by the load but fixed by the ammeter when the calibration is done. With a Range of 500mA, so $\mathrm{U(Iout)} = \mathrm{Iout} \times 0.001 + 4 \times 10\mathrm{nA}$

Vout is measured by the load, with a Range of 18V, so $\mathrm{U(Vout)} = \mathrm{Vout} \times 0.0003 + 0.00025 * 18\mathrm{V}$

With our example, Iout=299.2mA, Iin=137mA, Vout=4.967 et Vin =12V

We calculate the power: $Pin = 12 \times 0.137 = 1.65W$ $Pout = 4.967 \times 0.2992 = 1.49W$

We calculate the uncertainty associated to power: $U_B(Pin) = 2.92mW$ $U_B(Pout) = 2.49mW$

4.2.1 Uncertainty type C

$$U_C = \sqrt{{U_A}^2 + {U_B}^2}$$

$$U_C(Pin) = 2.93mW$$

$$U_C(Pout) = 2.54mW$$

$$\eta = \frac{Pout}{Pin}$$

$$u(\eta) = \sqrt{\frac{1}{Pin^2} \times u^2(Pout) + \left(\frac{-Pout}{Pin^2}\right)^2 \times u^2(Pin)}$$

$$\eta = \frac{1.49}{1.65} = 89.99\% \quad U_C(\eta) = 0.22\%$$

Finally, we associate the uncertainty to the efficiency with 95% chance supposing a normal law by multiplying by 2 the uncertainty:

$$\eta = 89.99\% \pm 0.44\% \;\; => \;\; \eta \in [89.55\% - 90.43\%]$$

We can put this uncertainty on curves to see how it evolves in function of the current.

The curve below represent the efficiency of a DC-DC Converter associated with a MAPI and a switching frequency of 700 kHz.

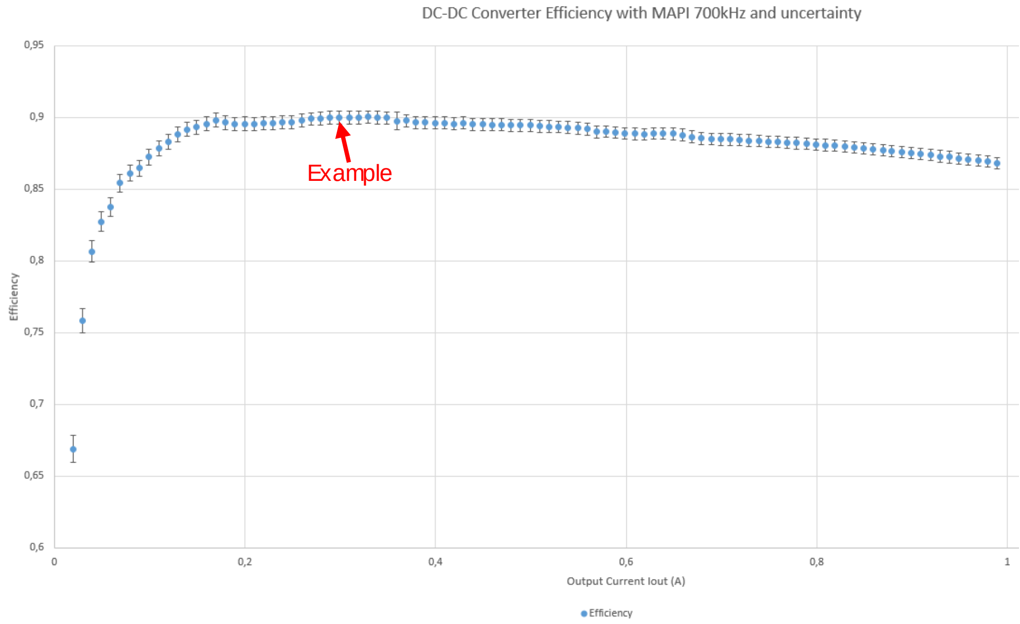


FIGURE 5: DC-DC WE-MAPI700KHZ WITH UNCERTAINTY AND CALIBER 0.5A

If we want to measure higher current which is not possible with our converter because it only provides 2A at the output. We can see on the curve below that there is less precision because of the calibre on little current but it improves when the current is rising.

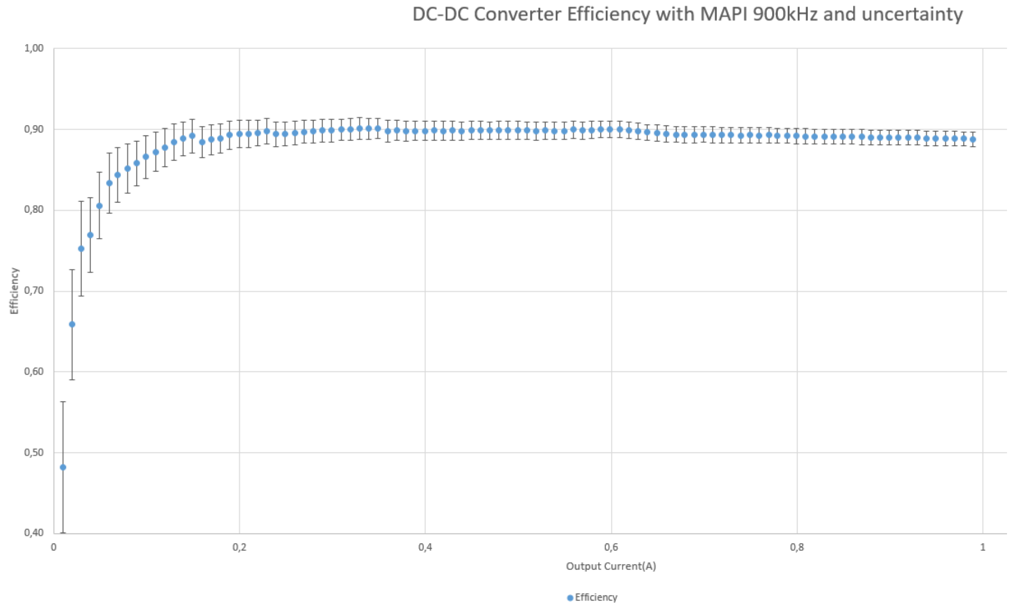


FIGURE 6: DC-DC WE-MAPI700KHZ WITH UNCERTAINTY AND CALIBER 5A

4.3 Specifications

SPECIFICATIONS

Models		72-13200	72-13210
Input rating	Power Voltage Current	150W 0-120V 0-30A	300W 0-120V 0-30A
CC mode	Range Resolution Accuracy	0-3A / 0-30A 0.1mA / 1mA ± (0.05% of set+0.045% off.s)	0-3A / 0-30A 0.1mA / 1mA ± (0.05% of set+0.045% off.s)
CV mode	Range Resolution Accuracy	0-18V / 0-120V 0.1mV / 10mV ± (0.05% of set+0.025% off.s)	0-18V / 0-120V 0.1mV / 10mV ± (0.05% of set+0.025% off.s)
CR mode	Range Resolution Accuracy	0.05Ω-10Ω / 10Ω-7.5kΩ 0.1Ω ± (0.05% of set+0.025% off.s)	0.05Ω-10Ω / 10Ω-7.5kΩ 0.1Ω ± (0.05% of set+0.025% off.s)
CW mode	Range Resolution Accuracy	150W 0.01W ± (0.1% of set+0.1% off.s)	300W 0.01W ± (0.1% of set+0.1% off.s)
STOP	Range Rising Falling	0-3A / 0-30A 0.0001-0.3A/us- 0.001-1.5A/us 0.0001-0.3A/us- 0.001-1.5A/us	0-3A / 0-30A 0.0001-0.3A/us- 0.001-1.5A/us 0.0001-0.3A/us- 0.001-1.5A/us
Voltage Measurement	Range Resolution Accuracy	0-18V / 0-120V 1mV / 10mV ± (0.03% of set+0.025% off.s)	0-18V / 0-120V 1mV / 10mV ± (0.03% of set+0.025% off.s)
Current Measurement	Range Resolution Accuracy	0-3A / 0-30A 0.1mA / 1mA ± (0.05% of set+0.045% off.s)	0-3A / 0-30A 0.1mA / 1mA ± (0.05% of set+0.045% off.s)
Power Measurement	Range Resolution Accuracy	150W 0.01W ± (0.1% of set+0.1% off.s)	150W 0.01W ± (0.1% of set+0.1% off.s)

FIGURE 7: TOLERANCE LOAD TENMA

ITECH — Technical Specification

Parameters		IT6723C	IT6724C
Rated values (0 °C-40 °C)	voltage	0~32V	
	current	0~110A	
	power	850W	1500W
Load regulation ±(%of Output+Offset)	voltage	≤0.03%+30mV	
	current	≤0.1%+10mA	
Line regulation ±(%of Output+Offset)	voltage	≤0.01%+5mV	
	current	≤0.1%+10mA	
Setup resolution	voltage	10mV	
	current	10mA	
Readback resolution	voltage	10mV	
	current	10mA	
Setup accuracy (one year 、 25°C±5°C) ±(%of Output+Offset)	voltage	≤0.03%+10mV	
	current	≤0.1%+60mA	

FIGURE 8: TOLERANCE SUPPLY ITECH

DC Current

Range	Resolution	Full Scale	Accuracy (1 year 23˚C ±5˚C)	Shunt Resistance	Burden Voltage
500µA	10nA	510.00	0.05%+5	100Ω	0.06V max
5mA	100nA	5.1000	0.05%+4	100Ω	0.6V max
50mA	1µA	51.000	0.05%+4	1Ω	0.14V max
500mA	10µA	510.00	0.10%+4	1Ω	1.4V max
5 A	100µA	5.1000	0.25%+5	10mΩ	0.5V max
10 A	1mA	12.000	0.25%+5	10mΩ	0.8V max

FIGURE 9: TOLERANCE AMMETER GWINSTEK

5. Example of use

5.1 Help

First of all, if you need some help, there are some advice that can help you to use this interface.

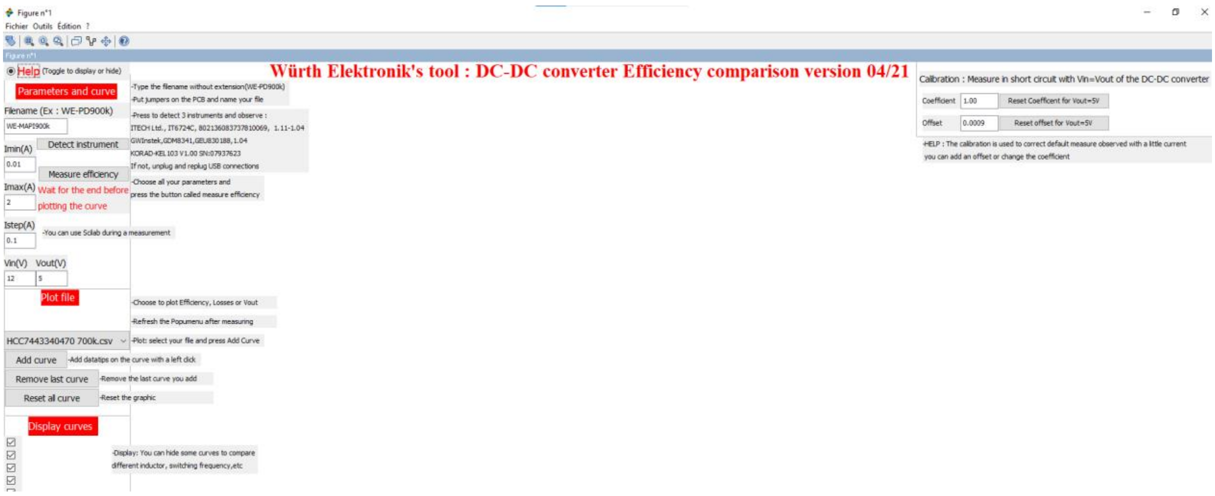


FIGURE 10: HELP

5.2 Instrument Detection

Then, you need to verify that you will be able to discuss with all the instruments. By clicking on "Instrument Detection", a popup with the name of your 3 instruments will appear. You can see how many instruments are connected.

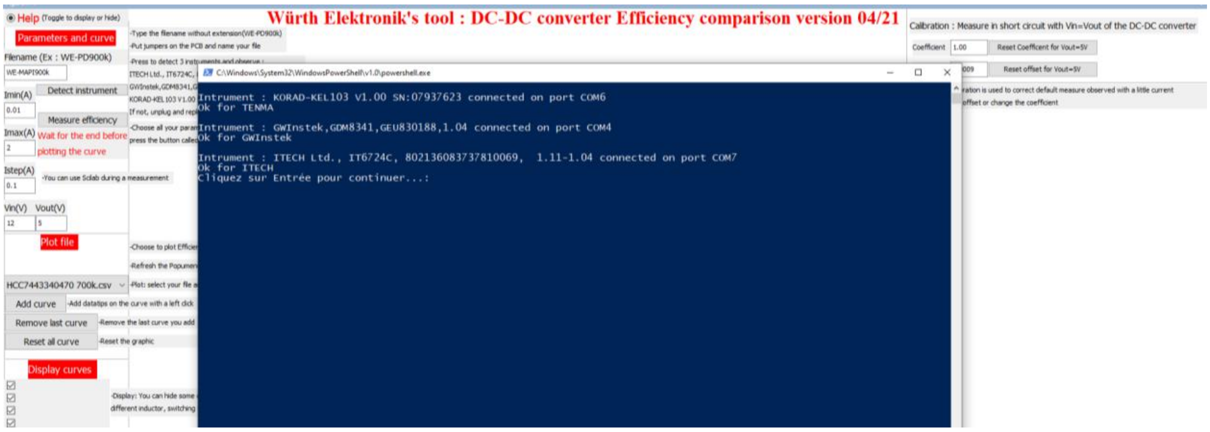


FIGURE 11: INSTRUMENT DETECTION

If not, unplug and plug all the USB connections. If it's still not working, verify that your instruments are powered.

5.3 Calibration

You will then make your calibration. Plug the input directly on the output to make a short circuit, choose your parameters (Choose Vin = Vout of your DC-DC converter), choose the name “zero.csv” and click on “Measure efficiency”.

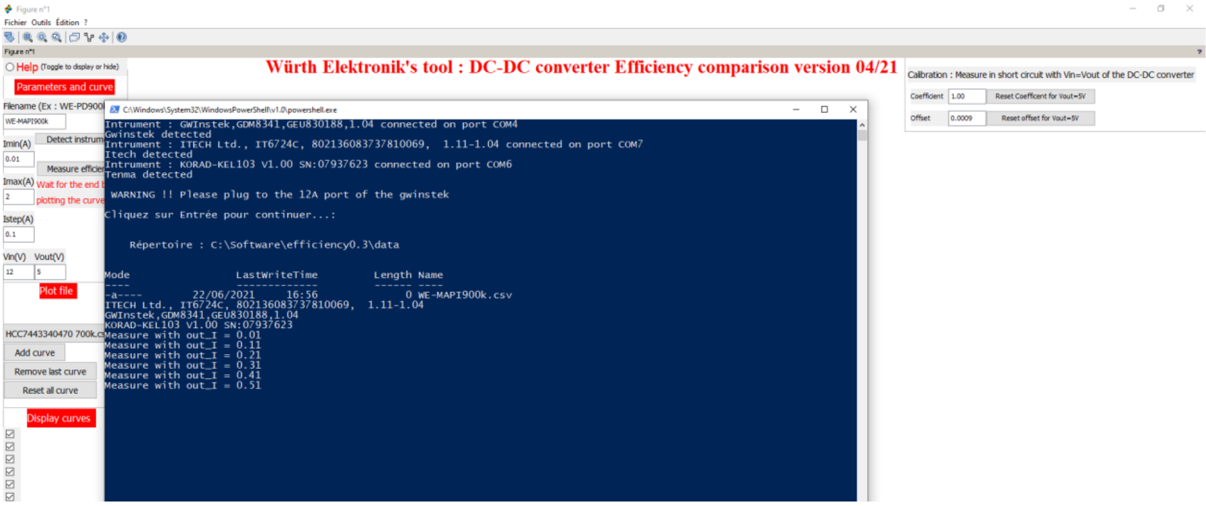


FIGURE 12: CALIBRATION MEASURE

A popup will appear and if everything is ok, you will observe “Measure with out_I = 0.01” From your Imin to your Imax.

Then, your will have to plot your data. Because you erase the file zero.csv every time you make a calibration, you can directly plot by choosing your calibration curve in the popupmenu on the left side of the interface.

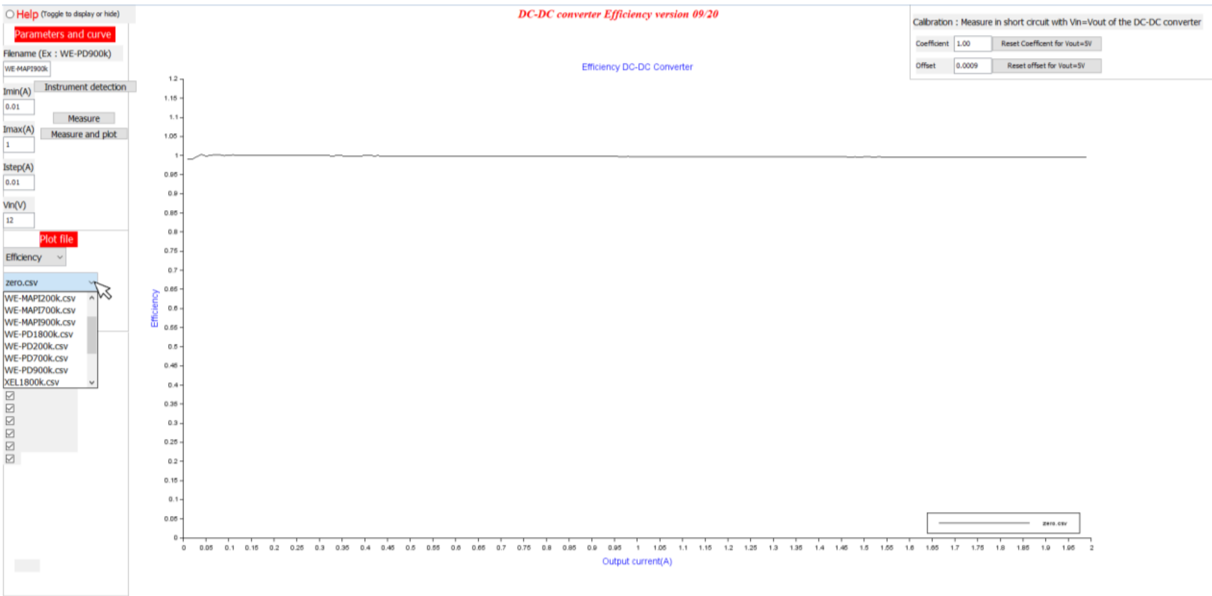


FIGURE 13: CALIBRATION PLOT

You have to see a horizontal curve equal to 1. You can modify the offset and the coefficient to calibrate. Every time you change the coefficient or the offset, you have to add the different curve by clicking on "Add Curve" to compare the new coefficient or offset. Be careful, you can't know which color correspond to which offset or coefficient you choose.

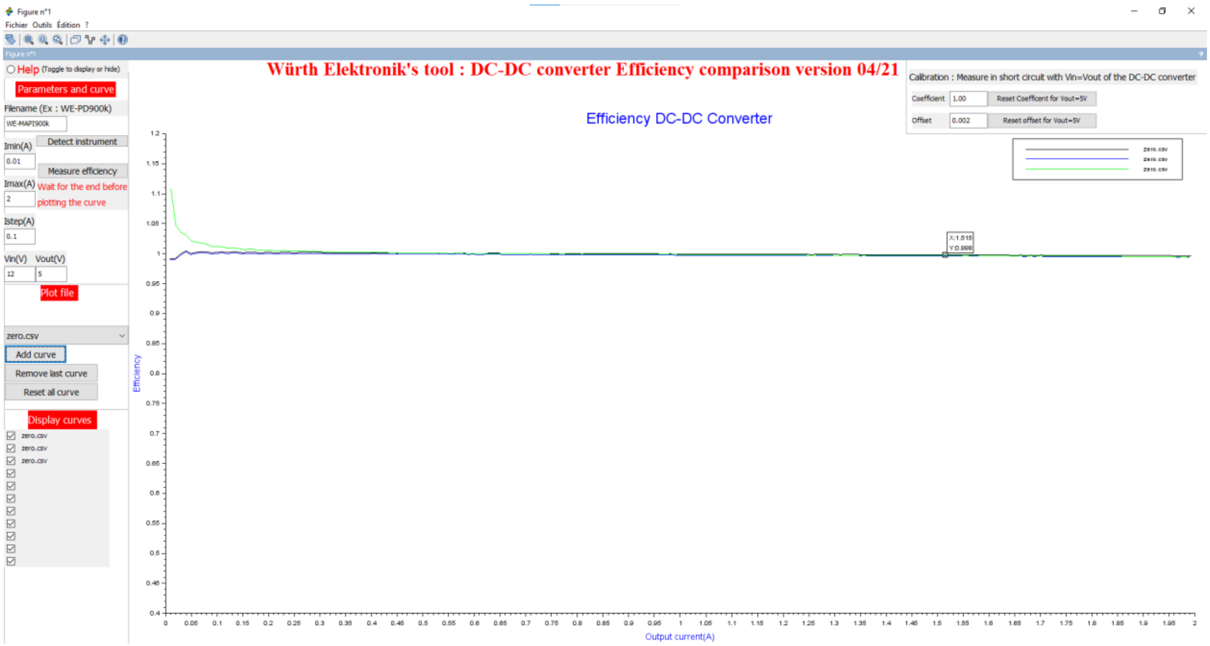


FIGURE 14: CHOOSING OFFSET

5.4 Plotting Data

After your calibration, you will be able to plot everything you have as data. You can plot the efficiency in function of the output current.

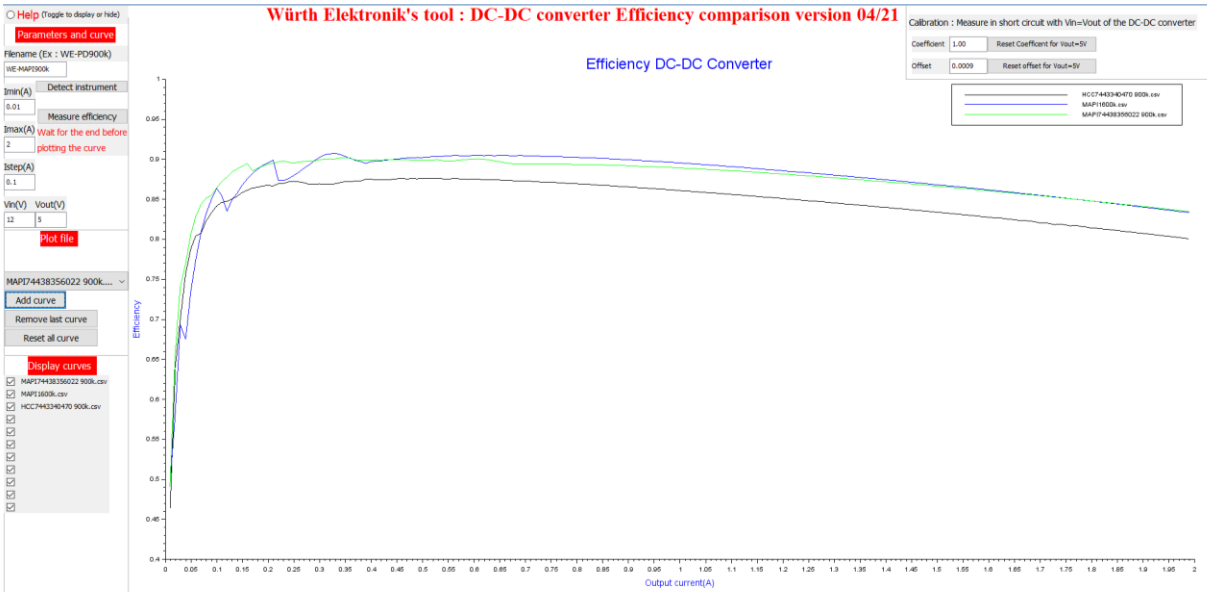


FIGURE 15: PLOT DATA

If you want to add some data and make a measurement. Just choose your DC-DC converter or your switching frequency and your inductor if you use the DC-DC redexpert. Then name your file without space and be careful if you use the name of a file which already exists because your old data will be crushed.

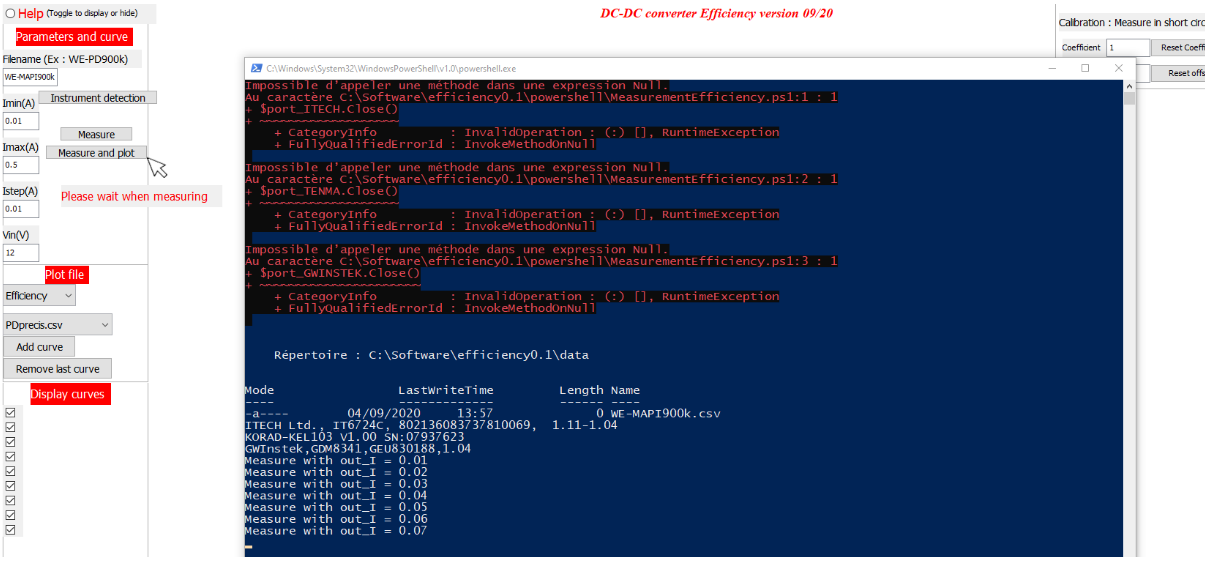


FIGURE 16 : MAKE A MEASUREMENT

After a measurement, just click on the refresh button to actualize the popupmenu in order to plot the new data.

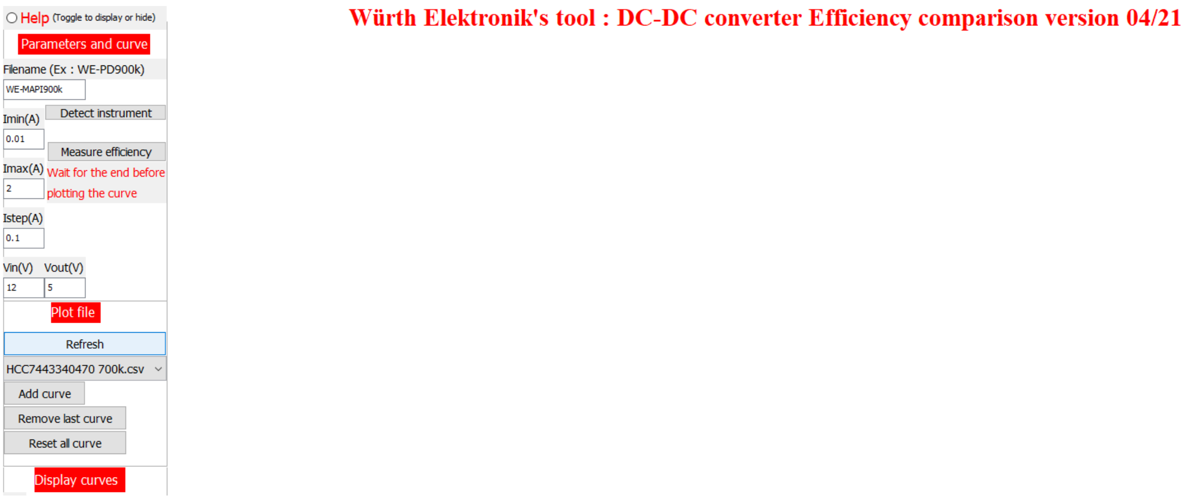


FIGURE 17: REFRESH THE POPUPMENU

Now that you have every data that you want. You can compare 2 or more different curves, for example 2 different switching frequency, you will be able to hide other curves by uncheck them at the bottom left.

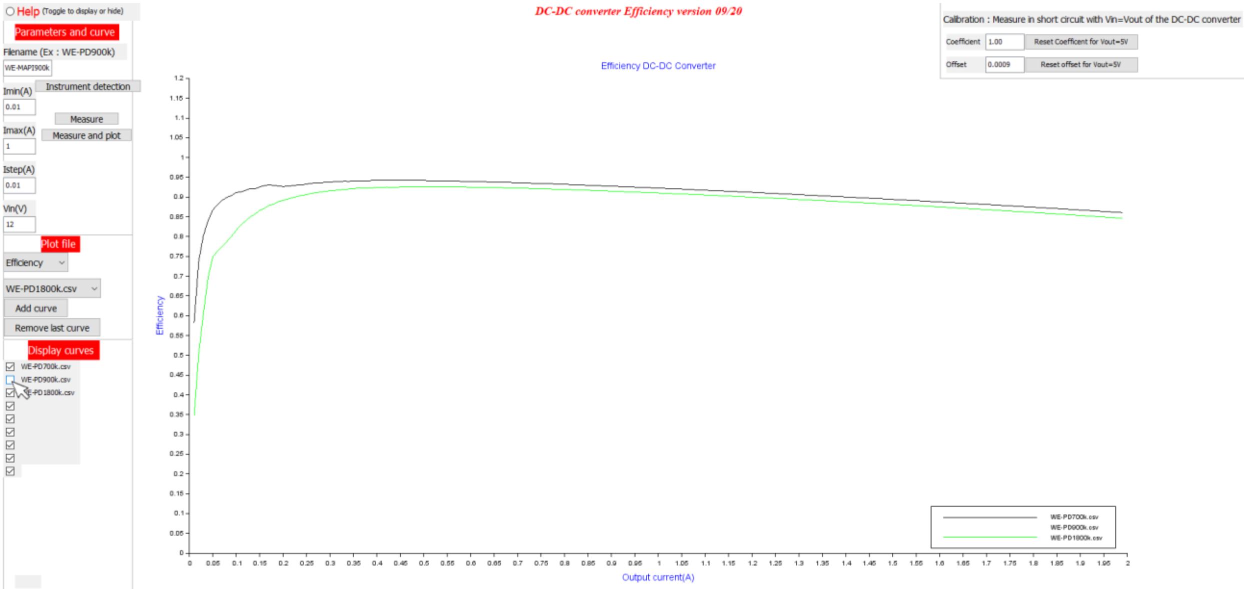


FIGURE 18: HIDE CURVES TO COMPARE PARAMETERS

5.5 Dropout Voltage and Losses

Finally, you can see on the two other graphic the losses and the dropout voltage if you want to check that you're output voltage has not fell too much.

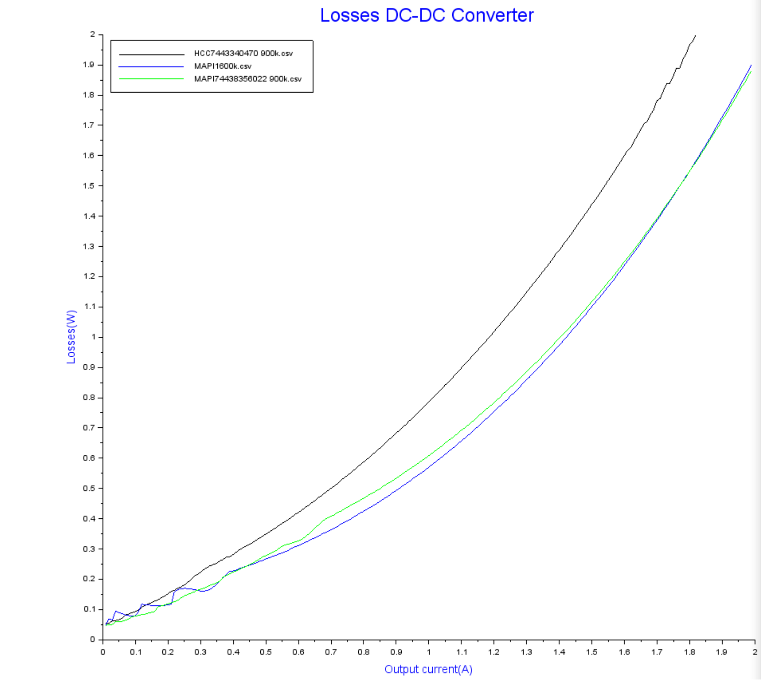


FIGURE 19: LOSSES VS OUTPUT CURRENT

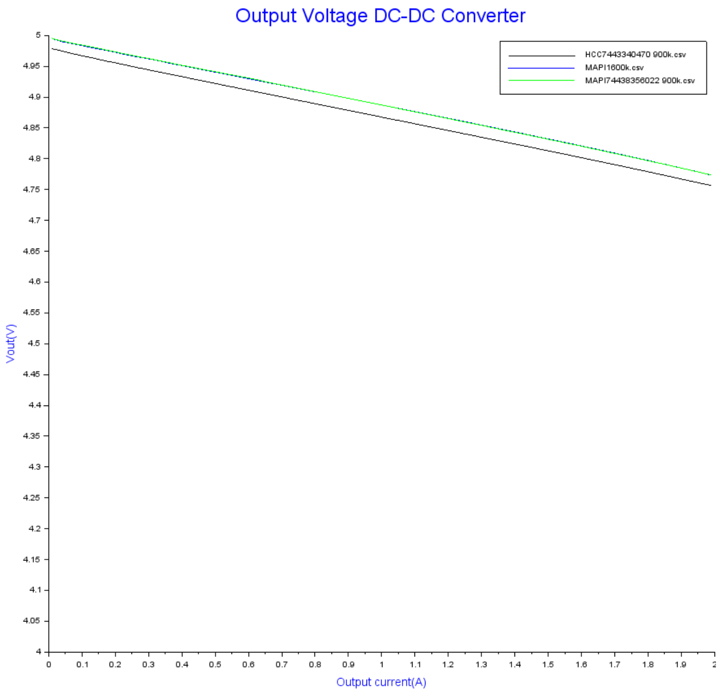


FIGURE 20 : OUTPUT VOLTAGE

6. Parameters Comparison

6.1 Switching Frequency with WE-MAPI 744 383 560 22

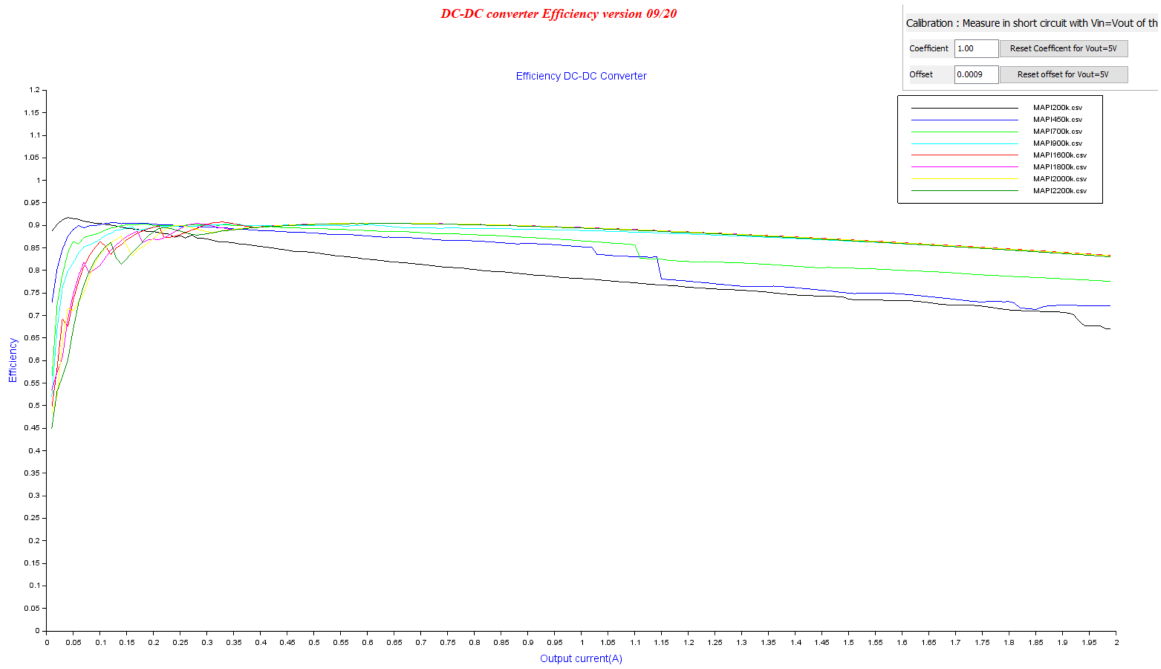


FIGURE 21: SWITCHING FREQUENCY COMPARISON

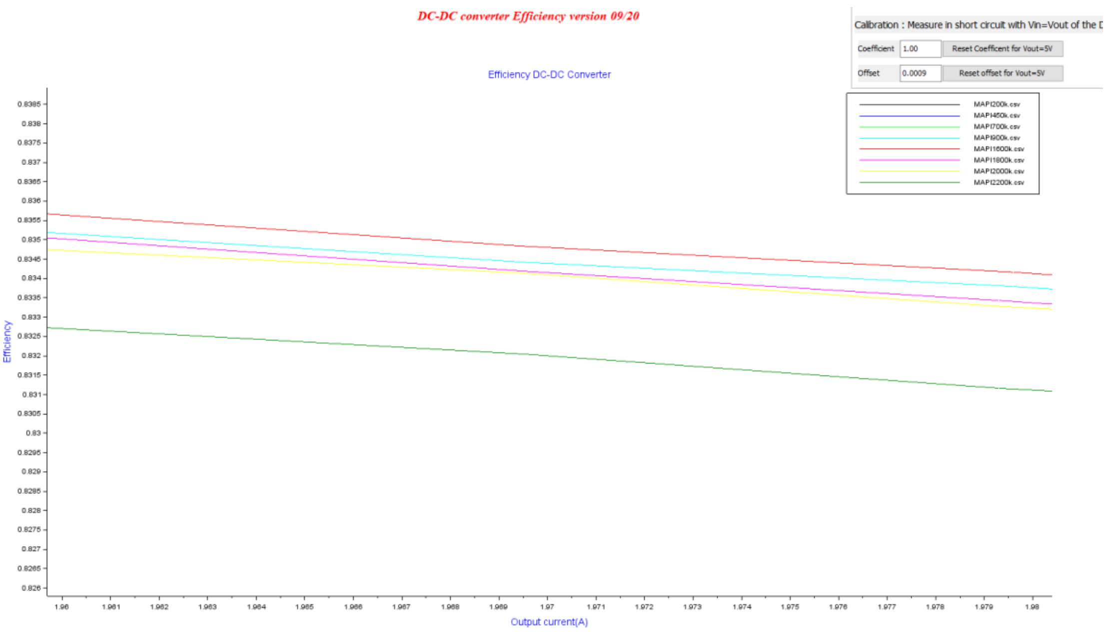


FIGURE 22: ZOOM SWITCHING FREQUENCY

We can observe that from 900 kHz to 1,6MHz, the efficiency is higher than with other switching frequency.

6.2 WE-MAPI 744 383 560 22 VS WE-MAPI 744 383 560 22 H T

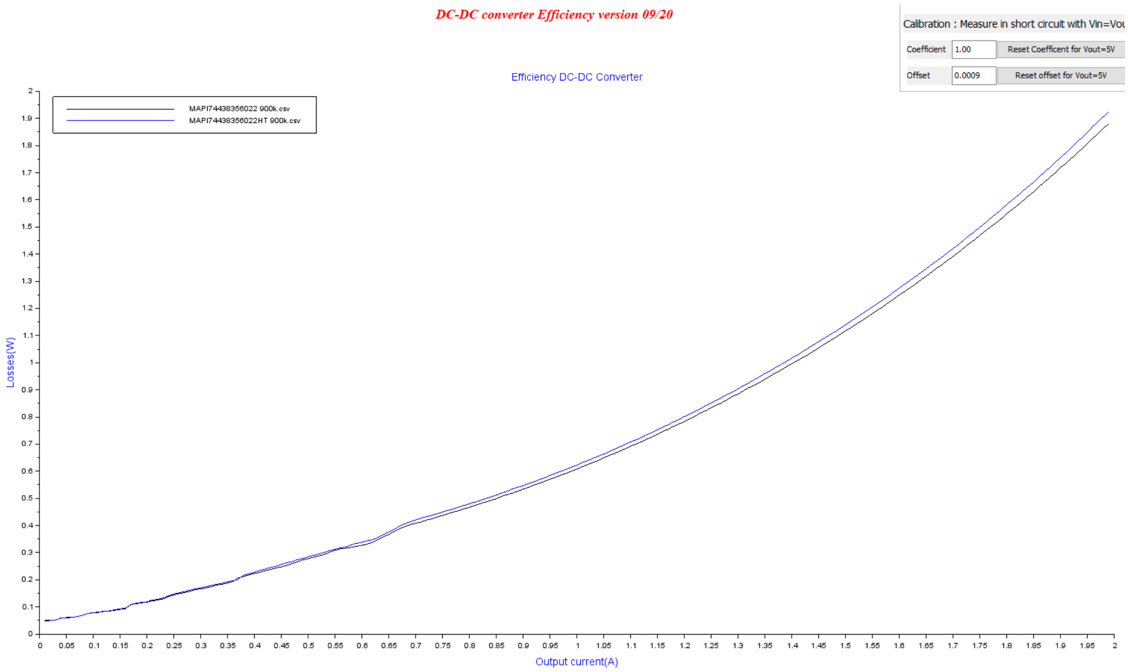


FIGURE 23: WE-MAPI VS WE-MAPI HT

We can observe a little difference, there is a little bit more losses with HT. It means that the efficiency will be lower.

7. Figures table

8. Bill of Materials

8.1 Programmable Load (120V/30A):

TENMA_7213210: 221.18 £= 240.06 €

https://uk.farnell.com/tenma/72-13210/dc-electronic-load-prog-30a-120v/dp/2848407

8.2 Power Supply (32V/110A):

ITECH_IT6724C: 1 380 €

https://www.mbelectronique.fr/it6724c--alimentation-de-laboratoire--mbe

8.3 Ammeter (1000V/10A):

GWINSTEK_8341: 328.00 €

https://www.tme.eu/fr/details/gdm-8341/multimetres-numeriques-stationnaires/gw-instek/

8.4 DC-DC converter (4.5V-40V ->5V/2A):

Buck Demonstration kit for REDEXPERT

Reference: 988 141

8.5 Terminal Block:

2 Plug: 691313410002

3 Receptacle: 691351400002

8.6 4 cable for sensing and 4 cable for power

- Power : 2x 4mm cable (6 AWG)
- Sensing : 2x 0.5mm (24 AWG)

8.7 3 Cables for connection between laptop and instruments:

2 “USB-B to USB-A”: 692903100000

1 “RS232 to USB converter”: More than 1 meter

https://www.mouser.fr/Wire-Cable/Cable-Assemblies/USB-Cables-IEEE-1394-Cables/_/N-bkrea?Keyword=rs232+cable&FS=True