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Long-term Behaviour of Grid-Connected PV Systems over more than 15 Years

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1. Introduction

- **Besides tests of PV inverters started in 1989, since 1992 the PV laboratory of BFH-TI in Burgdorf has also carried out several analytical monitoring projects without any interruptions.**
- **At present 43 grid-connected PV plants with 72 inverters are monitored.**
- **Most of the plants are in the town of Burgdorf, but several external plants are also included in the project (e.g. since 1993 two high alpine plants at 3454m and 2670m).**
- **In this paper, the main results of this long-term monitoring are presented.**

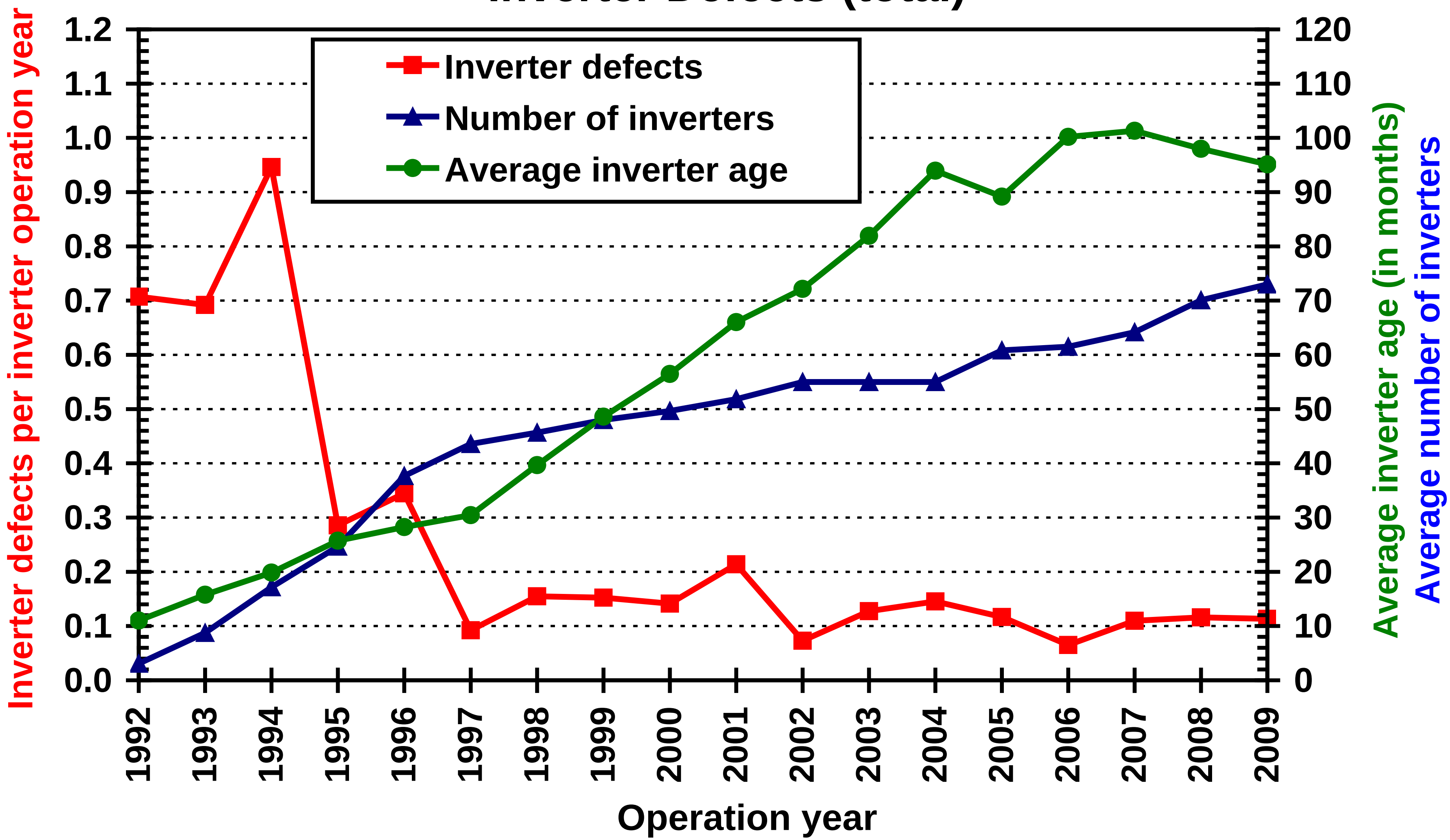
2. Inverter reliability and energy lost due to inverter defects

- As for reliability, inverters are usually the most critical part of a grid-connected PV plant.

- During the monitoring projects mentioned above, valuable statistical data about inverter defects and reliability could be obtained.

- On the next two slides, the number of inverter defects per inverter operation year and average number of inverters monitored by the PV laboratory of BFH-TI between 1992 and 2009 is shown.

Inverter Defects (total)



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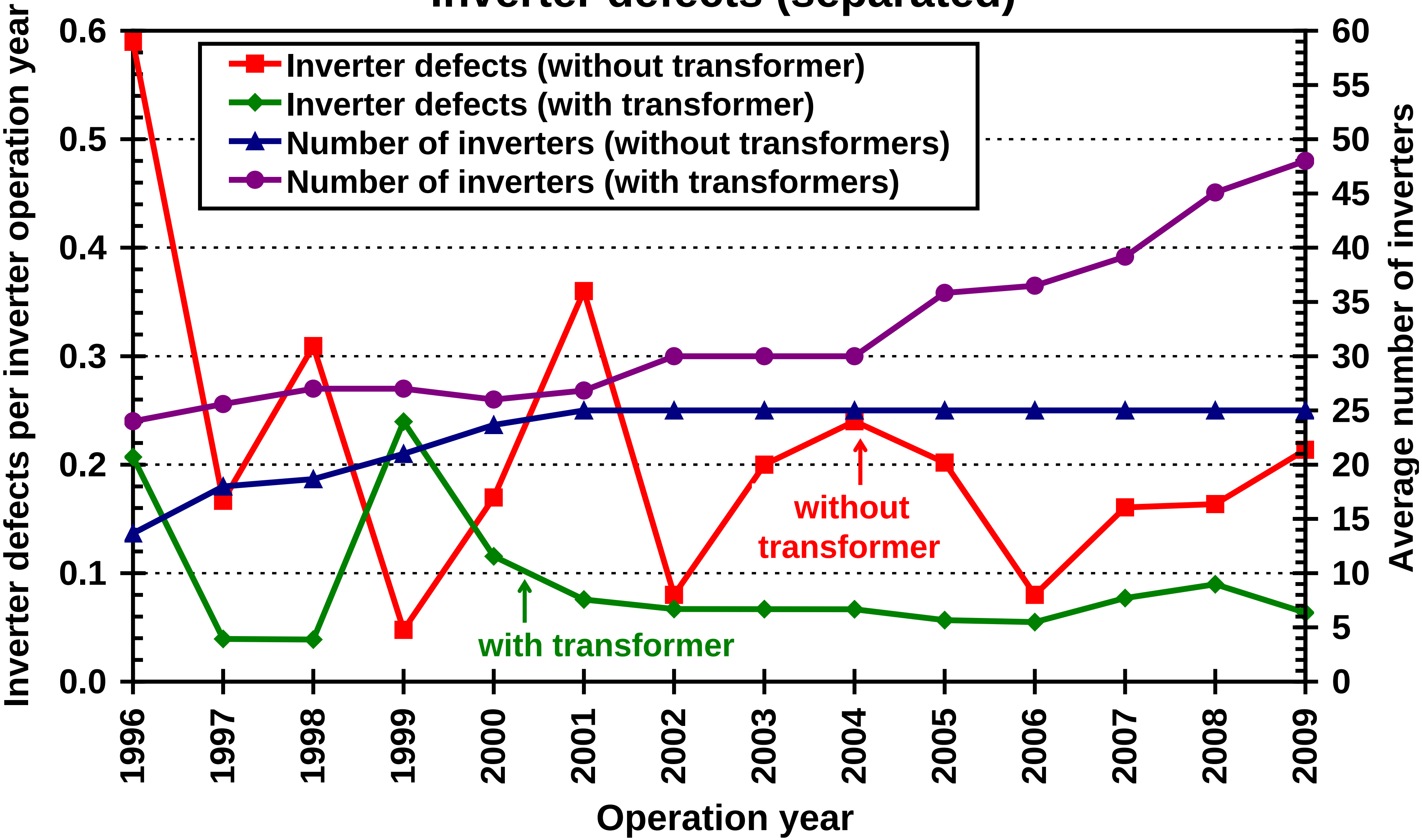
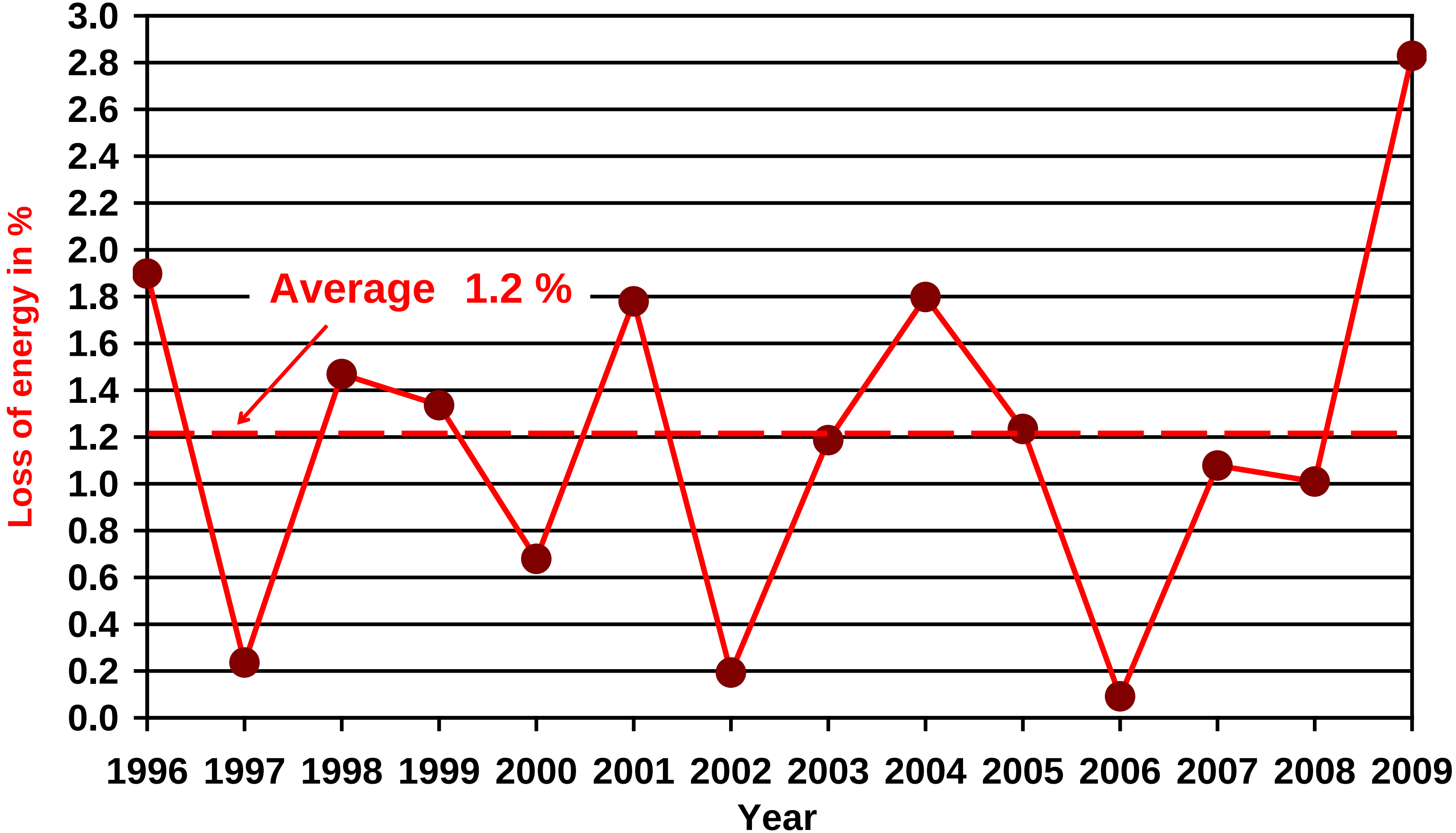
Inverter defects (separated)



Inverters with transformer seem to be more reliable!

Energy Losses due to Inverter Defects



Lost energy due to inverter defects at the plants in Burgdorf: Average 1.2 % of total energy production.

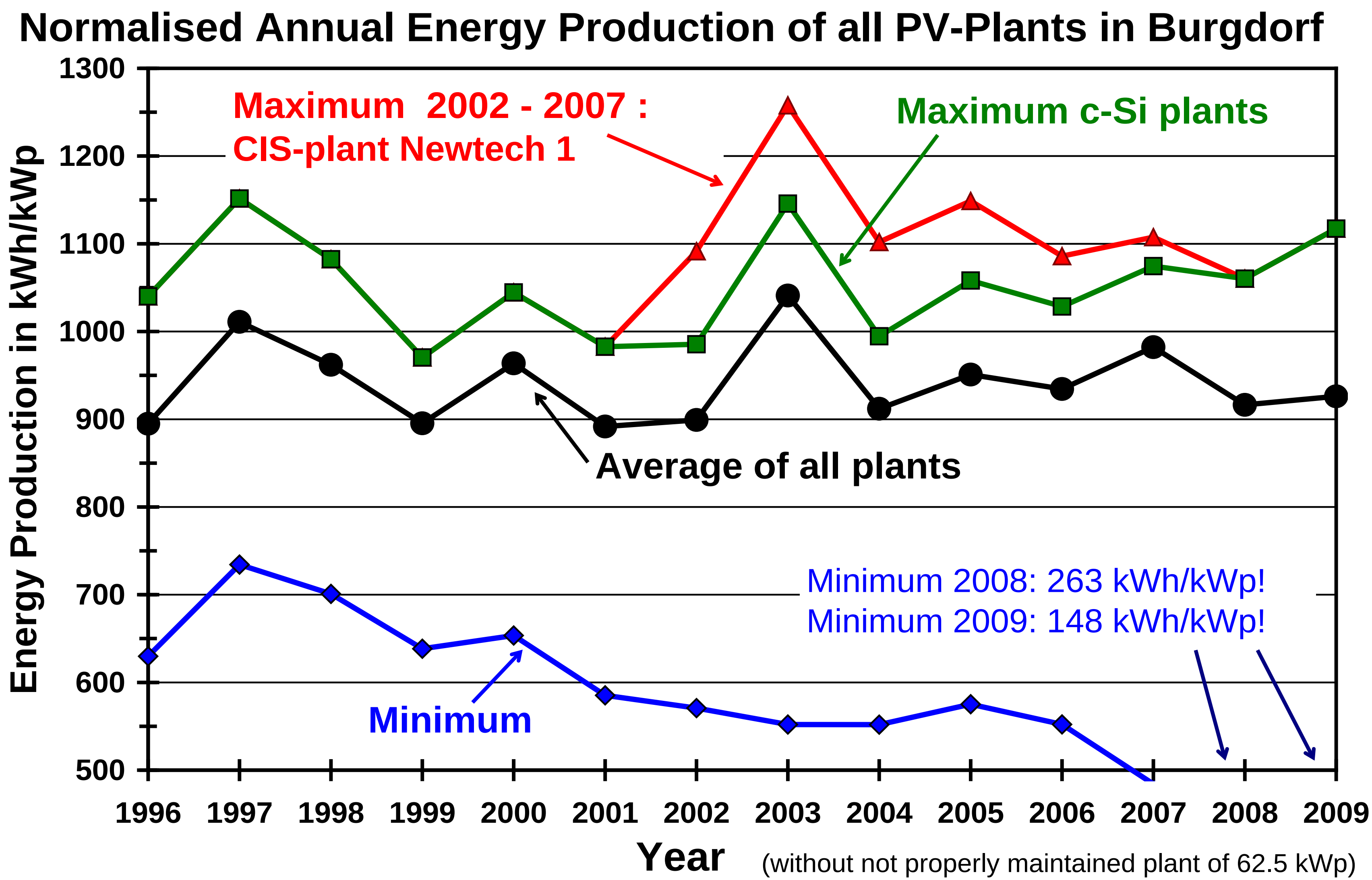
3. Evolution of Energy Yield vs. Time in Burgdorf

- **In order to compare PV plants of different size, it is best to compare normalised energy yields (energy divided by installed PV peak power in kW_p).**

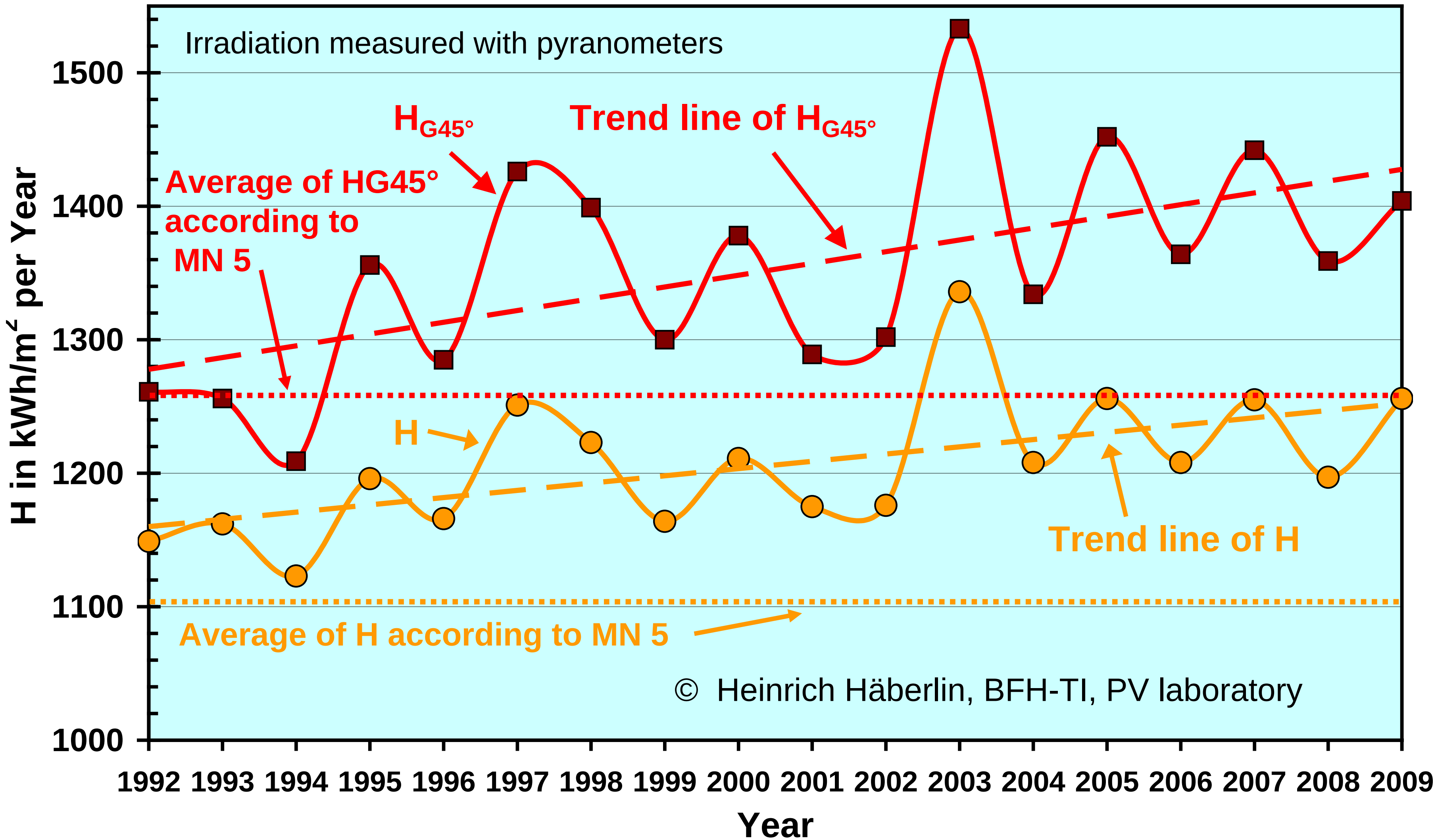
- **In order to eliminate the influence of irradiation changes between different years, data have to be converted to a standard year with average irradiance conditions.**

- **By elimination of the energy losses due to inverter defects and snow coverage, it is possible to reveal other influences (mainly array problems) on the energy yield.**

3.1 Normalised energy yields of PV plants in Burgdorf



Annual Irradiation H and HG45° in Burgdorf 1992 - 2009



Considerable variation of irradiation, increasing tendency!

3.2 Normalised energy yields of older PV plants in Burgdorf referred to standard year

- **In order to eliminate the influence of irradiation changes between different years, measured data were converted to a standard year with average irradiance conditions (H = 1163 kWh/m²).**
- **To analyse the long-term behaviour and possible degradations of PV arrays, PV plants have to be monitored continuously over a sufficient period of time.**
- ***Therefore for a further analysis, only plants were considered which have been in operation for more than 12 years*** (32 plants with a total power of 171 kWp).

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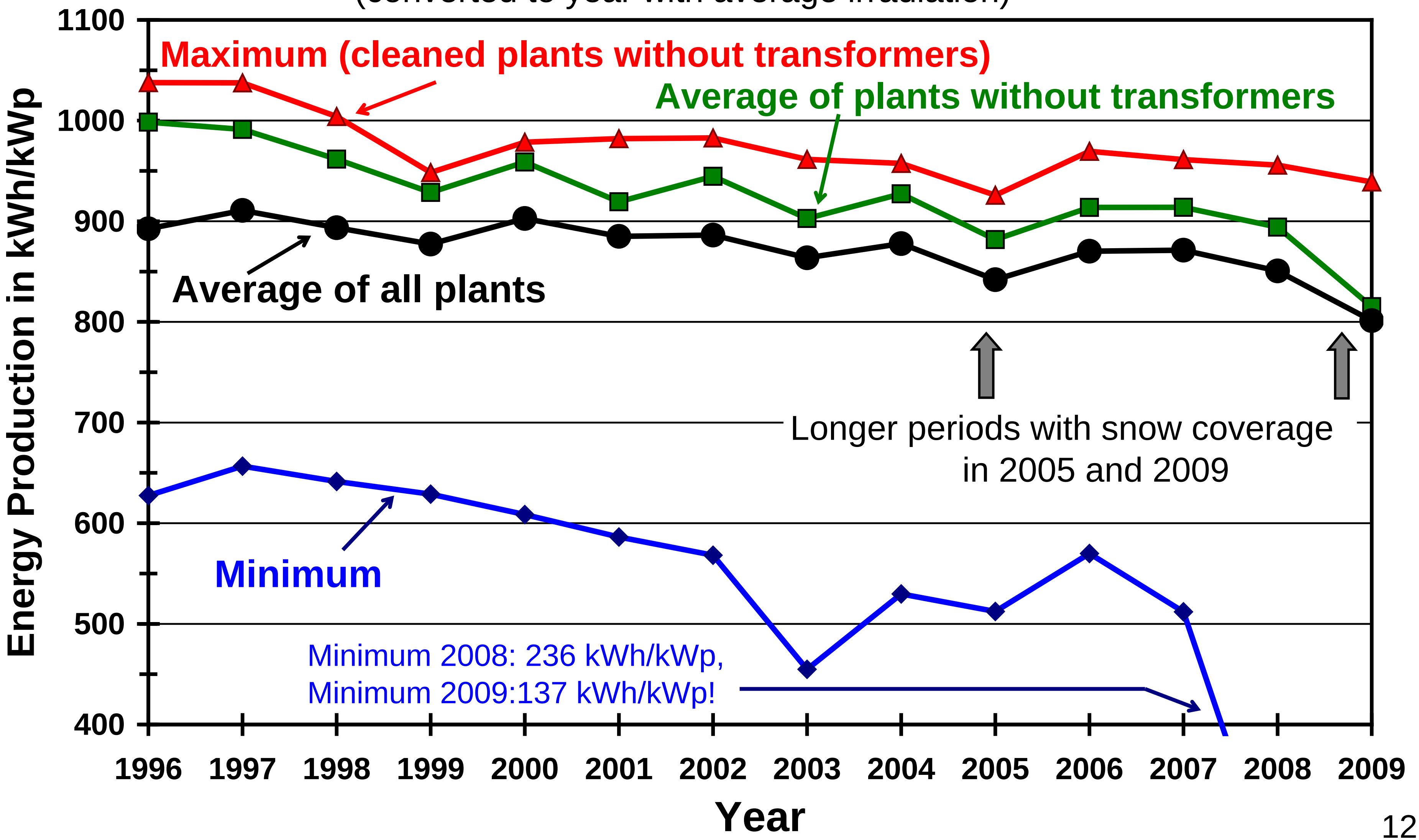
Normalised Annual Energy Production of older PV Plants in Burgdorf

(converted to year with average irradiation)

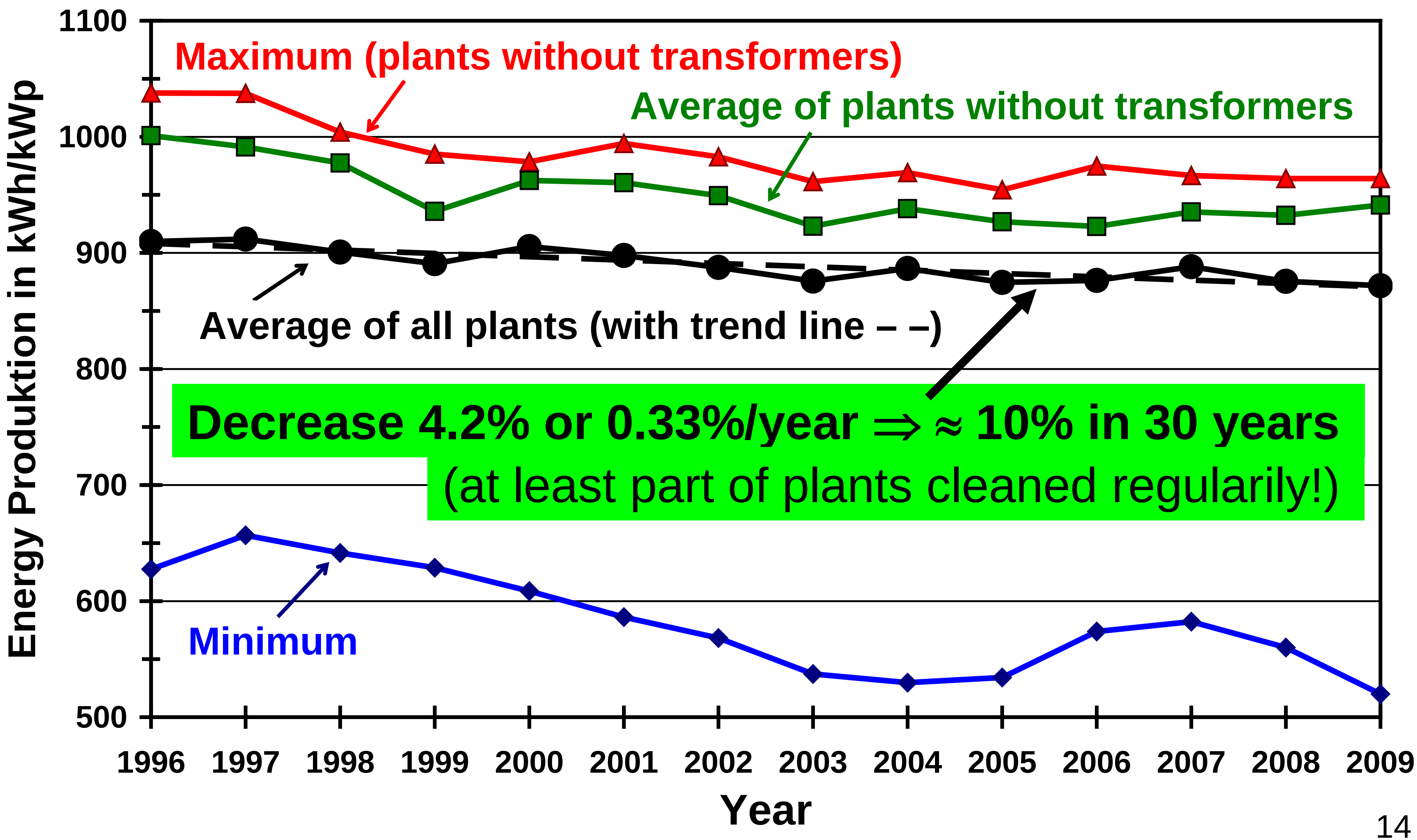


3.3 Normalised energy yields of older PV plants in Burgdorf referred to standard year (without energy losses due to inverter defects and snow)

- **In order to examine the long-term behaviour of the PV generator alone, besides the conversion to a standard year also the influence of inverter defects and snow coverage in winter must be eliminated (see next slide).**

Normalised Annual Energy Production of older PV Plants in Burgdorf

(converted to year with average irradiation, without losses due to inverter defects + snow)



3.4 Reduction of energy yield and STC-power of the PV plant of BFH-TI's PV laboratory

Since spring 1994, the PV laboratory has operated a PV test plant of 60 kWp on the roof of its building. Gradually a permanent pollution has developed at the lower edge of the (framed) PV modules with a tilt angle β = 30° [2], [7]).

For an assessment of the energy yield of an array with a relatively low tilt angle it makes sense to examine the generator correction factor $k_G = Y_a / Y_T$ in the months April to September (not affected by snow covering) [1], [7].
k_G should be close to 1 in an ideal case.

The next slide shows k_G from 1994 to 2009 for sub-plant West (20 kWp) of BFH-TI's PV plant.

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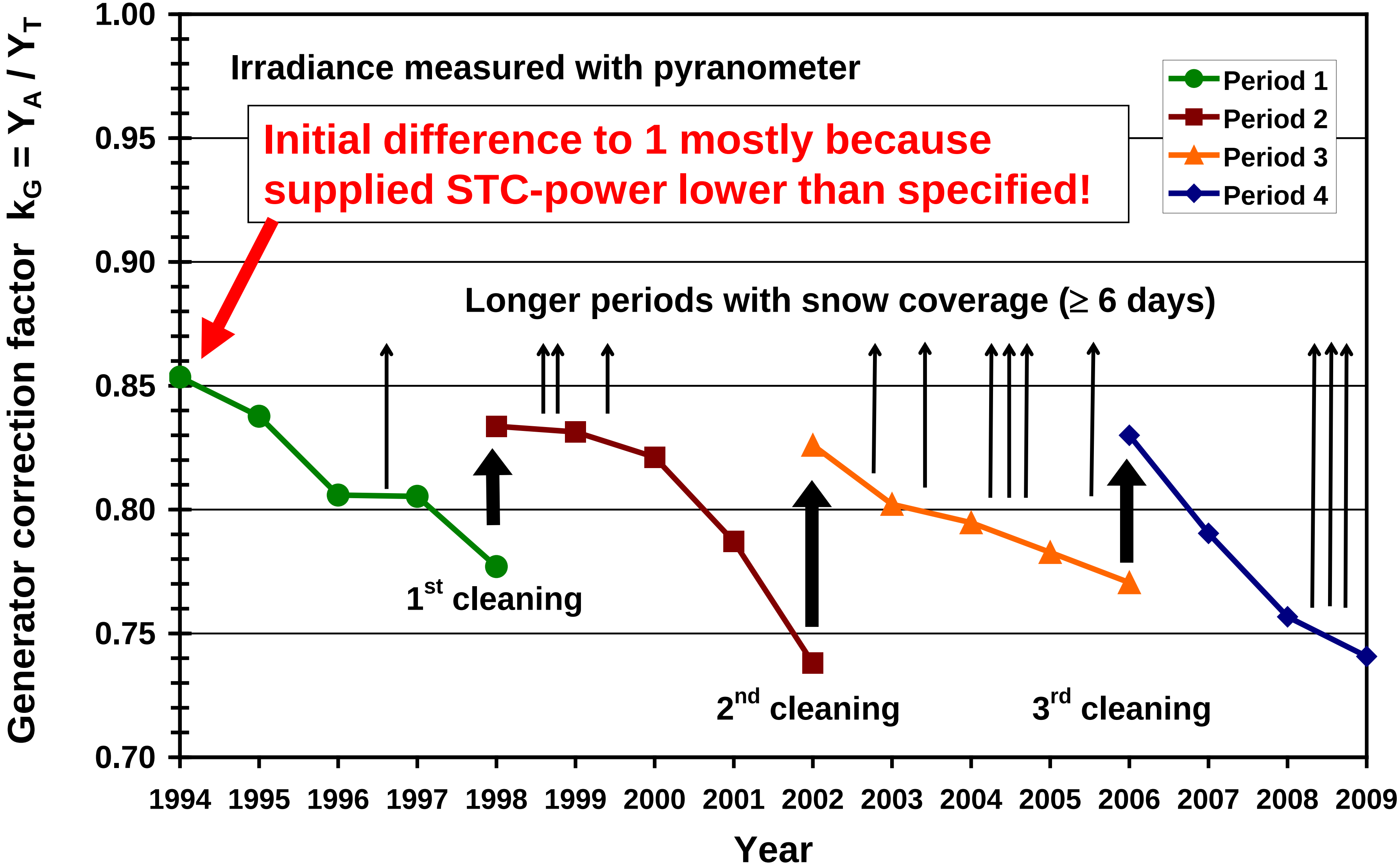
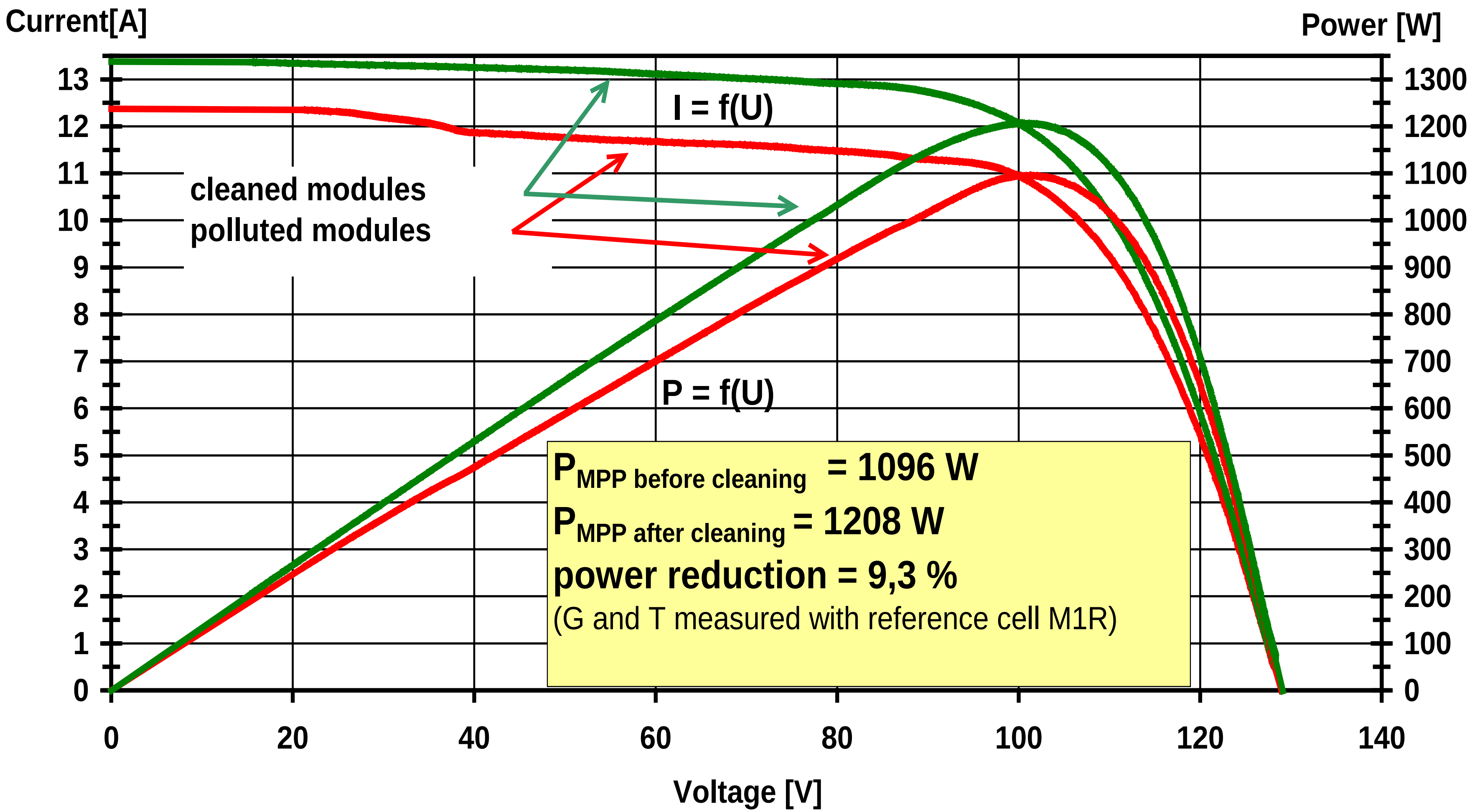
PV Plant West of PV Laboratory of BFH-TI Burgdorf:

PV generator correction factor in summer (April - October)



Measurement of an I-V-Curve of PV Plant HTI Burgdorf

Array 6W2B converted to STC, measured 30.7.02 and 22.08.02



By cleaning most of the power loss can be recovered!

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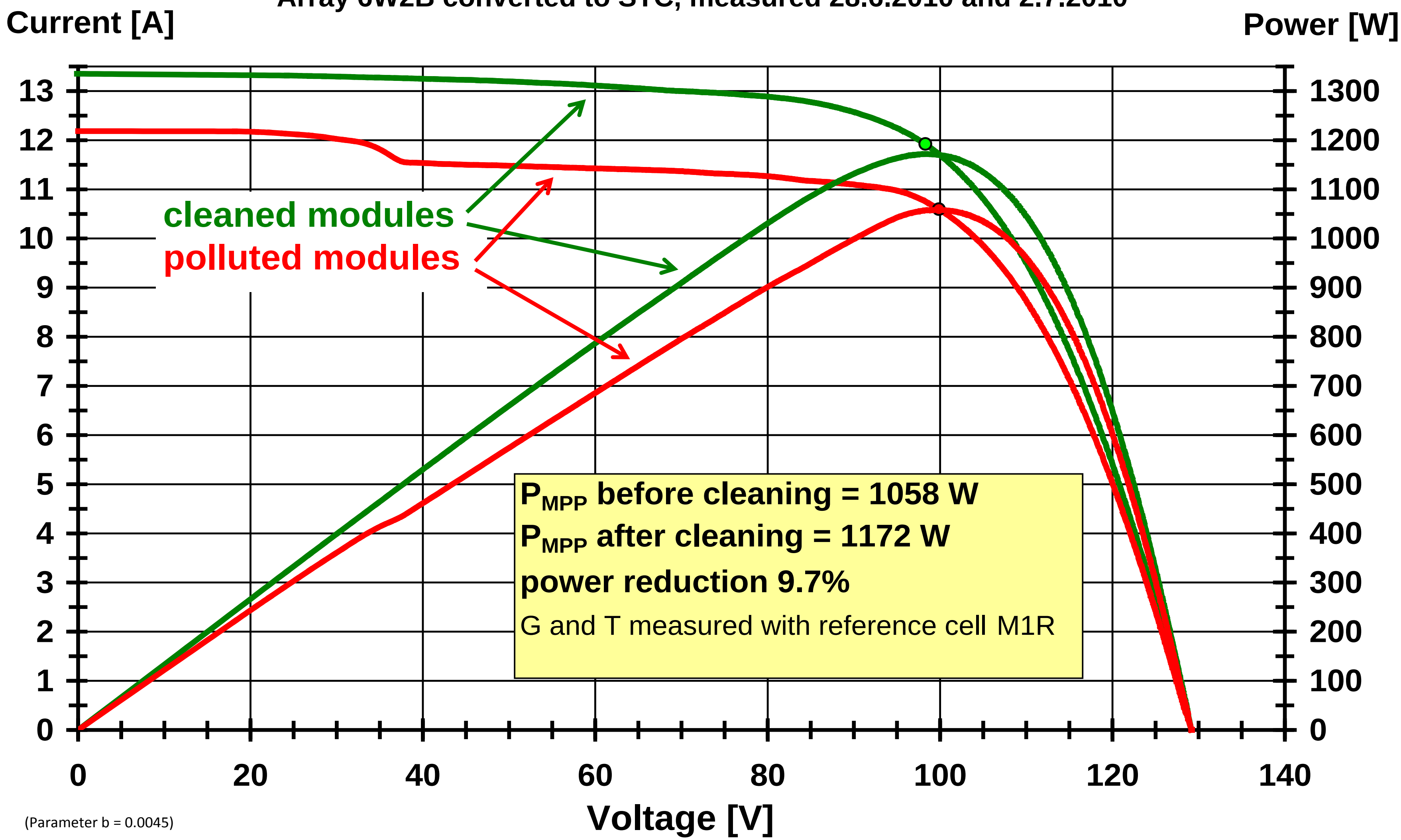
Measurement of an I-V Curve of PV Plant BFH-TI Burgdorf

Array 6W2B converted to STC, measured 28.6.2010 and 2.7.2010



By cleaning most of the power loss can be recovered!

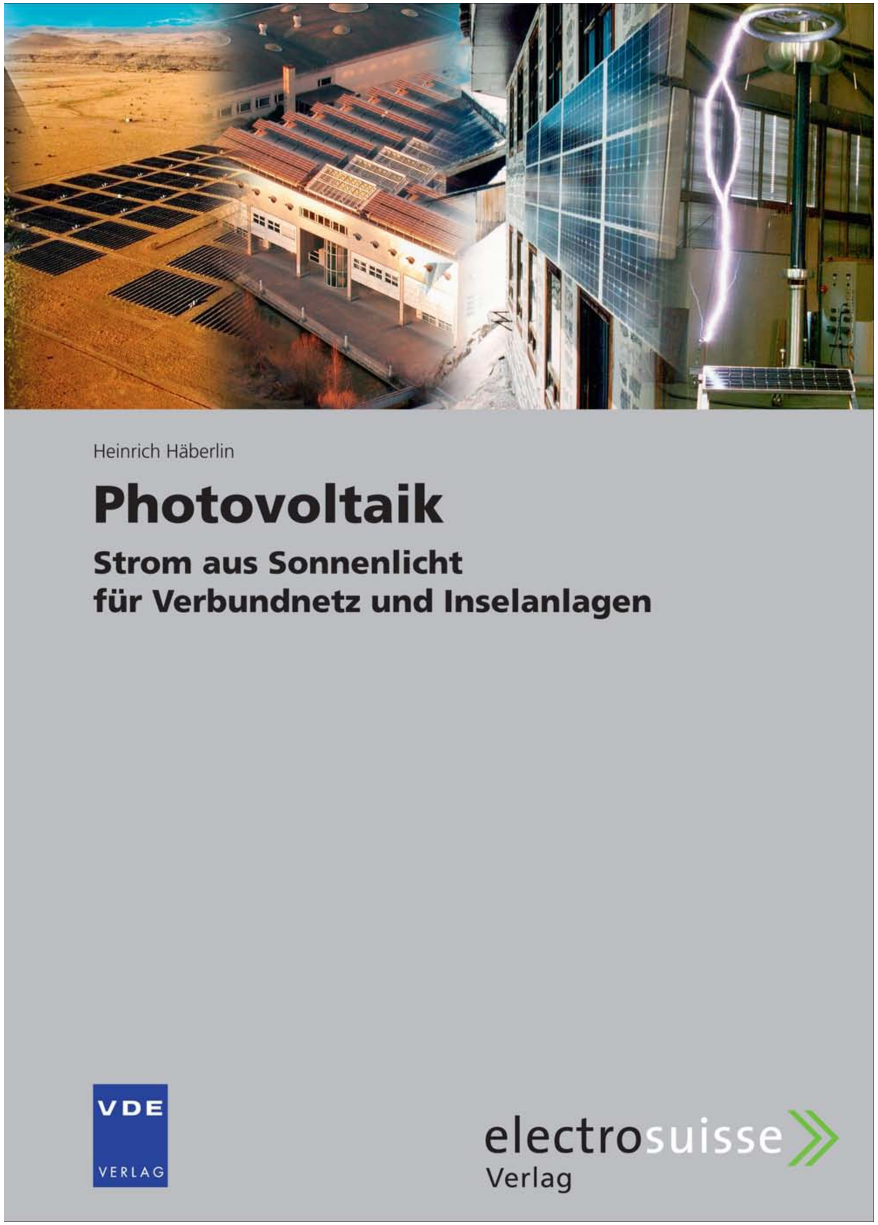
4. Conclusions

- **At the plants monitored in Burgdorf, between 1996 and 2009 about 1.2% of energy was lost due to inverter defects (minimum 0.1%, maximum 2.8% per year).**

- **Referred to a standard year with average irradiation, the loss of normalised energy production from 1996 to 2009 was about 4.2% or about 0.33% per year.**

- **Depending on plant location, tilt angle and module type, a periodical cleaning of the modules may make sense to prevent a decrease in energy yield.**

- **A life expectancy of PV plants of 20 to 30 years seems to be reasonable. Especially for small plants a replacement of the inverter every 8 – 15 years may be necessary.**



Additional information about pollution, ageing and degradation of PV plants and about PV systems technology in general can be found in my extended book "Photovoltaik", (in German, edition 2010, full in color, 760 p., published by Electrosuisse- and VDE-Verlag).

An English translation will be published in autumn 2011 by Wiley science publishers.

END

Many thanks for your attention.

Pre-prints of the *complete paper* are available on the internet (address below) under > publications [144].

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