28 years of operational data for a utility scale 103 kW_p PV plant (1989-2017)

Analysis of degradation of PV modules, inverters and system performance with technical and economical comparison to the repowered 260 kWp plant (2017-2019)

TNC Consulting AG
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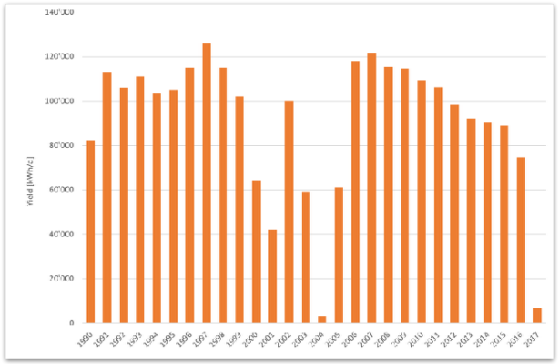
Agenda

- Overview of PV plant analysed. Where do we come from?
- Economical and technical development. What have we achieved so far?
- Degradation of key components (PV modules, inverters). How bad is it?
- System performance. Why it is essential to keep the system in focus for successful PV applications?
- Findings and conclusions

Overview of the PV plant analysed

- First PV noise barrier plant 1989 Mark I
- 103 kW_p PV plant
- 2'208 Kyocera 48 W_p polycristalline LA361J48 PV modules
- Siemens Simatic 100 kW inverter prototype
- Average annual PR 0.78
- Specific annual yield 1'085 kWh/kW_p

Overview of the PV plant analysed



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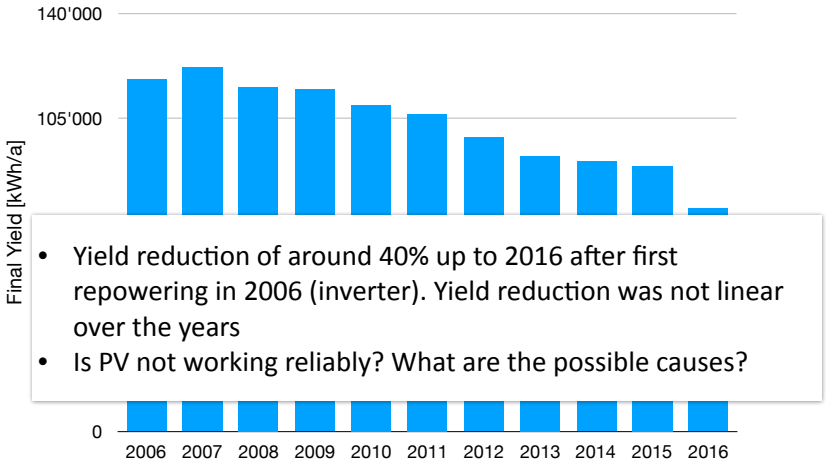
Overview of the PV plant analysed

„The plant performed well according to its design specifications. It reached the highest performance ratio, mean final yield and plant efficiency that we have found up to now (in 10 years of PV plant monitoring). Thus it becomes a reference target for future PV installations."

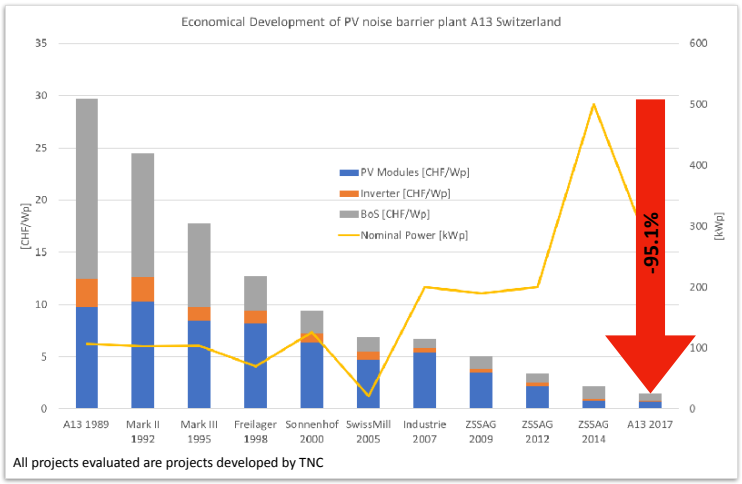
Final Report On System Monitoring, September 1992
Joint Research Centre, European Solar Test Installation
by G. Blaesser & A. Tournier

Why repowering this plant?



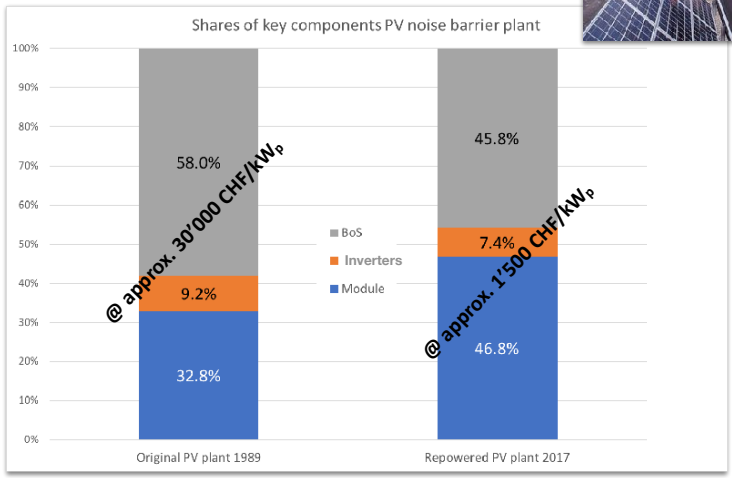
- Yield reduction of around 40% up to 2016 after first repowering in 2006 (inverter). Yield reduction was not linear over the years
- Is PV not working reliably? What are the possible causes?

Economical learning curve

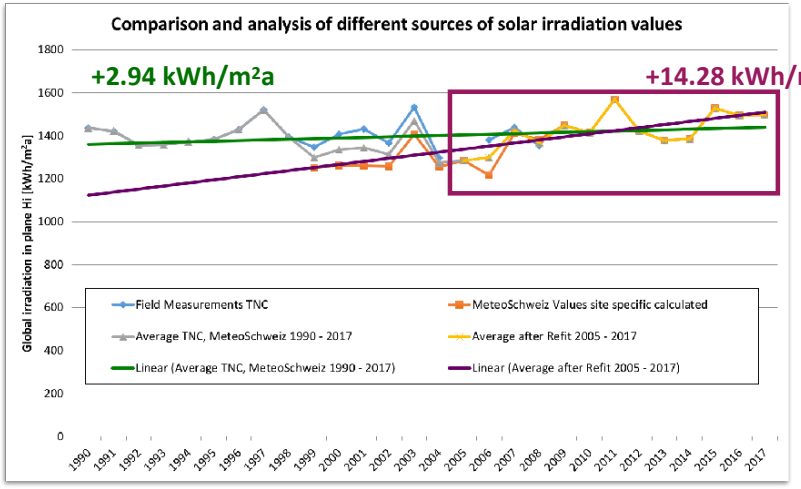


All projects evaluated are projects developed by TNC

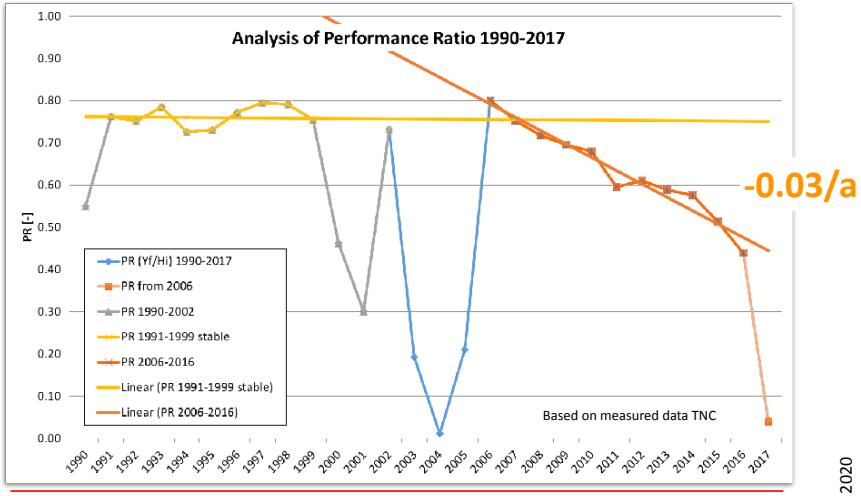
Economical achievements



Why is final yield not sufficient?



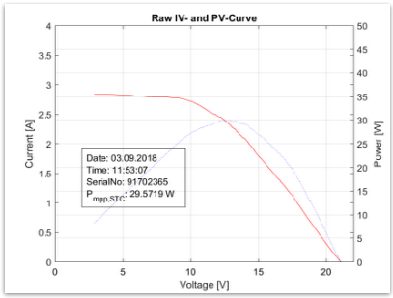
System performance, PR

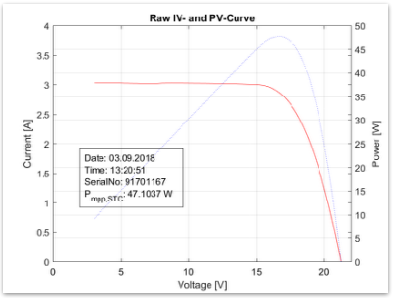


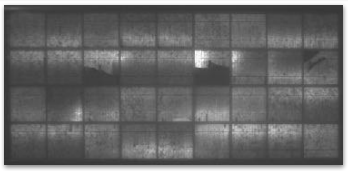
Were the PV modules failing?

- Kyocera LA361J48 PV modules
- State of the art 1989
- Nominal power 48 W_p
- Module efficiency 11%
- 36 polycristalline solar cells
- connection box with screwed enclosure
- diode within connection box
- 23 PV modules available directly from the plant
- 8 modules non light-exposed

Were the PV modules failing?

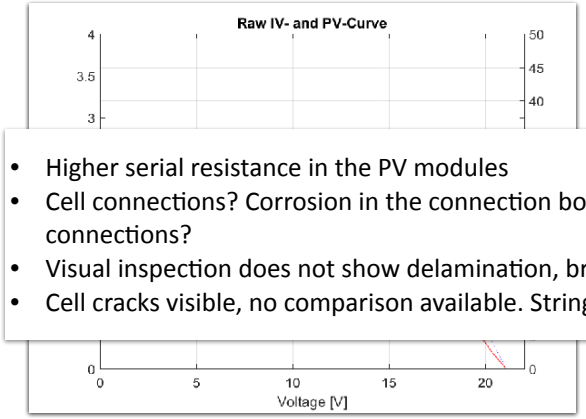


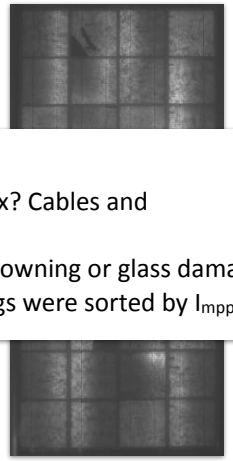




Based on Lab measurements ZHAW

Were the PV modules failing?

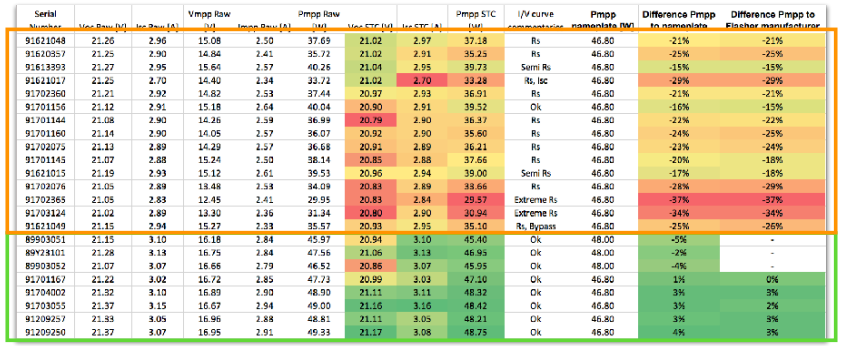




- Higher serial resistance in the PV modules
- Cell connections? Corrosion in the connection box? Cables and connections?
- Visual inspection does not show delamination, browning or glass damage
- Cell cracks visible, no comparison available. Strings were sorted by I_{mpp}

Based on Lab measurements ZHAW

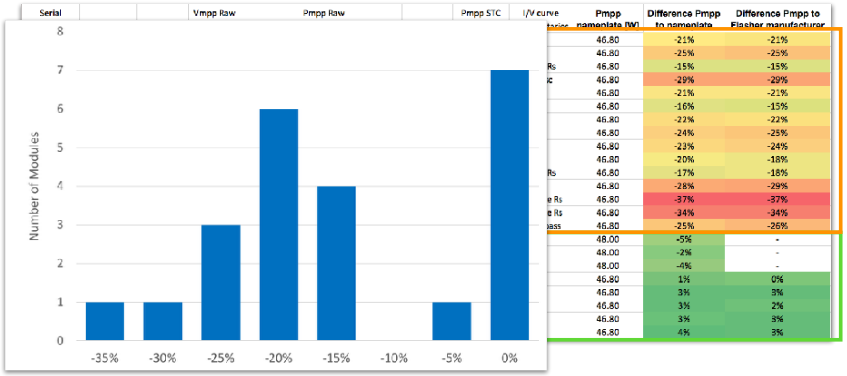
Were the PV modules failing?



Serial Number	Voc Raw [V]	Isc Raw [A]	Vmpp Raw [V]	Impp Raw [A]	Pmpp Raw [W]	Voc STC [V]	Isc STC [A]	Pmpp STC [W]	I/V curve comments/ics	Pmpp nameplate [W]	Difference Pmpp to nameplate	Difference Pmpp to Fischer manufacturer
91611048	21.26	2.96	15.08	2.50	37.69	21.02	2.97	37.18	Rs	46.80	-21%	-21%
91610857	21.25	2.90	14.84	2.41	35.72	21.02	2.91	35.25	Rs	46.80	-25%	-25%
91613393	21.27	2.95	15.64	2.57	40.26	21.04	2.95	39.73	Semi Rs	46.80	-15%	-15%
91611017	21.25	2.70	14.40	2.34	33.72	21.02	2.70	33.28	Rs, Isc	46.80	-29%	-29%
91702360	21.21	2.92	14.82	2.53	37.44	20.97	2.93	36.91	Rs	46.80	-21%	-21%
91701156	21.12	2.91	15.18	2.64	40.04	20.90	2.91	39.52	Ok	46.80	-16%	-15%
91701144	21.08	2.90	14.26	2.59	36.99	20.79	2.90	36.37	Rs	46.80	-22%	-22%
91701160	21.14	2.90	14.05	2.57	36.07	20.92	2.90	35.60	Rs	46.80	-24%	-25%
91702075	21.13	2.89	14.29	2.57	36.68	20.91	2.89	36.21	Rs	46.80	-23%	-24%
91701145	21.07	2.88	15.24	2.50	38.14	20.85	2.88	37.66	Rs	46.80	-20%	-18%
91611015	21.19	2.93	15.12	2.61	39.53	20.96	2.94	39.00	Semi Rs	46.80	-17%	-18%
91702076	21.05	2.89	13.48	2.53	34.09	20.83	2.89	33.66	Rs	46.80	-28%	-29%
91702365	21.05	2.83	12.45	2.41	29.95	20.83	2.84	29.57	Extreme Rs	46.80	-37%	-37%
91703124	21.02	2.89	13.30	2.36	31.34	20.80	2.90	30.94	Extreme Rs	46.80	-34%	-34%
91611049	21.15	2.94	15.27	2.33	35.57	20.93	2.95	35.10	Rs, Bypass	46.80	-25%	-26%
89903051	21.15	3.10	16.18	2.84	45.97	20.94	3.10	45.40	Ok	48.00	-5%	-
89928101	21.28	3.13	16.75	2.84	47.56	21.06	3.13	46.95	Ok	48.00	-2%	-
89903052	21.07	3.07	16.66	2.79	46.52	20.86	3.07	45.95	Ok	48.00	-4%	-
91701167	21.22	3.02	16.72	2.85	47.73	20.99	3.03	47.10	Ok	46.80	1%	0%
91704002	21.32	3.10	16.89	2.90	48.90	21.11	3.11	48.32	Ok	46.80	3%	3%
91703055	21.37	3.15	16.67	2.94	49.00	21.16	3.16	48.42	Ok	46.80	3%	2%
91209257	21.33	3.05	16.96	2.88	48.81	21.11	3.05	48.21	Ok	46.80	3%	3%
91209250	21.37	3.07	16.95	2.91	49.33	21.17	3.08	48.75	Ok	46.80	4%	3%

- Non light-exposed modules show no power degradation
- PV modules from the plant show power degradation of 15…37%, ø 20%
- Average annual reduction of 0.55…1.32% in nominal power

Were the PV modules failing?



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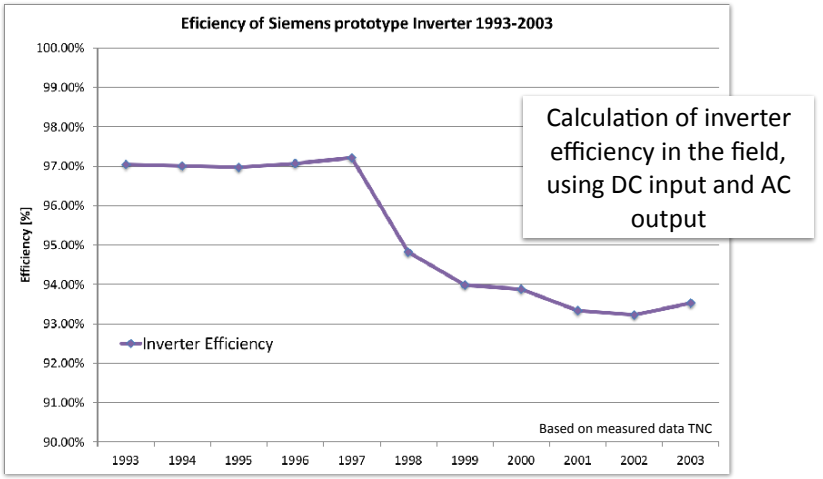
Maybe it was the inverters?



Calculation of inverter efficiency in the field, using DC input and AC output

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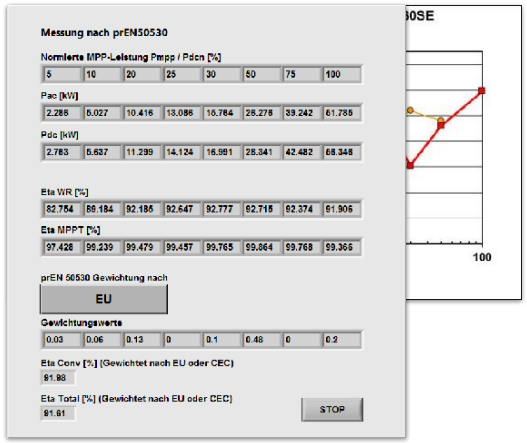
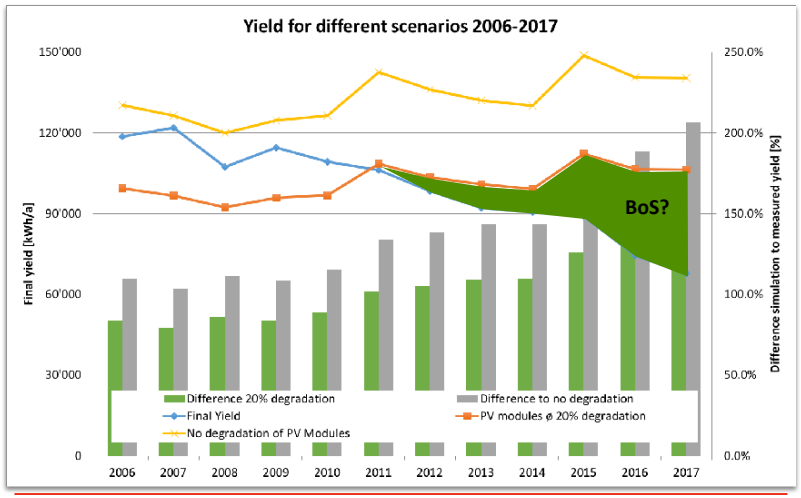


Based on Lab measurements BFH

- SolarMax 60SE
- Retrofit 2005
- Measurements done at operational voltage (405 V DC)
- No comparison to original state of inverter available
- Calculated inverter efficiency first year of operation: 92.64%
- Efficiency measured at Burgdorf: 91.61%
- Reduction is only -1.12%

Balance of System BoS



Balance of System BoS

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- BoS accounts for around 50% of yield reduction
- BoS influence on yield can be as high as inverter and modules
- Detailed analysis of components is not possible because of disposed components during repowering 2017
- Measured field experience is crucial for understanding degradation and critical paths in degradation of system performance
- Connection boxes, connectors and cables need monitoring and maintenance

Findings and conclusions

- Economical learning curve: System cost reduction of >95% is astonishing
- Technological achievements: module efficiency of commercially available PV modules doubled from 1989 to 2017
- Yield is not sufficient for monitoring, application of solar irradiation and Performance Ratio are essential
- PV modules and Inverters (2 Gen.) seem to show degradation as expected or less after 28 years of field exposure
- Detailed analysis of yield reduction shows BoS share of yield reduction is up to 50%. There needs to be a discussion about BoS components and their performance.
- Longterm field experience and measured data is essential

Questions?