Newtech – 3 different Thin Film PV Plants of 1kWp under direct Comparison

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Abstract: Besides tests of PV inverters started in 1989, since 1992 the PV laboratory of HTI in Burgdorf has also carried out several analytical monitoring projects without any interruptions with a continuously increasing number of plants and inverters. At present 42 grid-connected PV-plants with up to 55 inverters are monitored. Most of the plants are in the town of Burgdorf, but since 1993 also two high alpine plants at 3454m and 2670m are included in the project. The purpose of these long-term monitoring projects is to register all relevant influences on energy yield, degradation mechanisms, reliability, and life expectancy of grid-connected PV plants which can not be detected during relatively short initial monitoring campaigns of 1- 2 years, that are often performed after the erection of new PV plants, but stopped later in order to save costs.

Since December 2001 also a **PV pilot plant with three different thin-film technologies ($CuInSe_2$/CIS, a-Si tandem cells, a-Si triple cells)** was included in the project. In this paper, the operating experience of the first 29 months since the very first day of operation is presented. Energy production of these three thin-film plants can be compared directly with that of many crystalline plants in Burgdorf and in other parts of Switzerland monitored in the same project. In October 2003, an attempt was made to alleviate the gradual degradation of the performance of sub-plant Newtech 3 with a-Si triple cells by a thermal insulation placed at the back of the modules. First results of this measure are encouraging.

KEYWORDS: Thin-Film - 1 : PV system - 2 : Performance - 3.

1. Overview over the whole plant

This pilot and demonstration plant was planned and realised in the framework of the monitoring project “Long-term behaviour of grid connected PV systems 2” in co-operation with ADEV Burgdorf. It is located on a flat roof of a building of the company Ypsomed in Burgdorf. The plant consists of three sub-plants of about 1 kWp each with different cell technologies, but identical grid-connected inverters (Top Class Spark from ASP, with transformer) to ensure a fair comparison of the technologies used. The modules are exactly facing south with a tilt angle of 30°, are not shaded all day long even in winter and have metal frames. The plant started operation on Dec. 17, 2001 and was analytically monitored from the very first day like other PV plants in the monitoring project mentioned above, in which many stations in Burgdorf and other parts of Switzerland (among others PV plant Jungfraujoch) have been analytically monitored for many years. Thus a exact comparison of energy yield and performance ratio between these thin-film technologies and mono- and poly-Si plants is possible.

1.1 Sub-plant Newtech 1 with $CuInSe_2$-(CIS-) cells (modules ST-40)

This sub-plant consists of 24 modules (with metal frames) Siemens (now Shell) ST 40 (40 Wp), 3 strings of 8 modules in series, nominal power at STC: $P_{STC\text{-}Nom}$ = 960 Wp, TK ≈ –0,33%/K.
Measured in March 02: P_{STC} ≈ 1010Wp.

1.2 Sub-plant Newtech 2 with tandem cells of amorphous Si

This sub-plant consists of 20 modules (with metal frames) Solarex MST 43-LV (43 Wp), 2 strings of 10 modules in series, nominal power at STC: $P_{STC\text{-}Nom}$ = 860 Wp, TK ≈ –0,22%/K.
Measured in March 02: P_{STC} ≈ 810Wp.

1.3 Sub-plant Newtech 3 with triple cells of amorphous Si

This sub-plant consists of 16 modules (with metal frames) Uni-Solar US-64 (64 Wp), 2 strings of 8 modules in series, nominal power at STC: $P_{STC\text{-}Nom}$ = 1024 Wp. TK ≈ –0,21%/K. Measured in March 02: P_{STC} ≈ 1000Wp.

Fig. 1: View of the three Sub-plants Newtech 1 – 3 (photographic layout in order to show all plants)
Sub-plant Newtech 1 consists of 24 CIS-modules Siemens (now Shell) ST-40 on one panel (in the middle)
Sub-plant Newtech 2 consists of 20 a-Si modules Solarex (now BP Solar) MST43 LV on two panels (at right)
Sub-plant Newtech 3 consists of 16 a-Si modules Uni-Solar US-64 on two panels (at left).

With the measuring system the following parameters are measured:

- Irradiance into array plane with a heated pyranometer
- Module temperature of each plant (Newtech 1, 2 and 3) with a sensor PT 100
- Ambient temperature with a sensor PT 100
- DC current produced by each plant
- DC voltage at inverter input of each plant
- AC power injected into utility grid for each plant
- AC voltage at inverter output for one phase

These values are sampled every two seconds. Data are stored temporarily in a data logger Campbell CR10. Under normal conditions, every 5 minutes average values are calculated and stored from these values. However, in case of an error, the original data are stored as an error file, allowing detailed analysis of such an error. Every day, data are transmitted to the PV laboratory of HTI in Burgdorf early in the morning by means of a modem and a GSM link for further analysis and storage.

2. Monthly and annual energy production

2.1 Normalised Energy Yields

In order to compare performance of PV plants of different size and at different locations, normalised quantities are very useful.

By dividing energy production in a given period (month, year) by rated PV generator power at STC (Newtech 1: 960 Wp, Newtech 2: 860 Wp, Newtech 3: 1024 Wp), array yield Y_a (DC) and final yield Y_f (AC) is obtained. Reference yield Y_r is calculated by dividing irradiation in the same period by $1kW/m^2$. If array temperature is measured, the temperature corrected reference yield Y_T can be calculated from Y_r taking into account the temperature dependent reduction of PV conversion efficiency (details see [1]). Using *average daily values* eliminates the influence of different lengths of months.

Fig. 2 to 7 show a normalised yearly analysis for 2002 and 2003 for the PV plants Newtech 1, 2 and 3 with monthly values of Y_f , Y_a , temperature corrected reference yield Y_T and reference yield Y_r . All values are referred to nominal PV generator power. Thermal capture losses $L_{CT} = Y_r - Y_T$, miscellaneous capture losses $L_{CM} = Y_T - Y_a$, system losses $L_S = Y_a - Y_f$ and performance ratio $PR = Y_f / Y_r$ (number on top of bar) are also indicated [1]. In fig. 2 to fig. 7 irradiance is measured with a heated pyranometer.

In the following figures, a normalised yearly analysis for 2002 and 2003 for each plant is given. As far as annual irradiation and energy yield is concerned, 2003 was by far the best year registered in Burgdorf since the beginning of the monitoring projects 1992. With all three sub-plants, every half year field measurements of the effective peak power at STC of the arrays were performed to get also an information about degradation that is independent of energy production.

2.2 Operating results in 2002 and 2003 of plant Newtech 1 with CIS-modules ST-40

In both years, this plant had by far the highest specific energy yield and performance ratio of all PV plants (including mono-c-Si and poly-c-Si) in Burgdorf [4]. Its PR is close to that of good mono-crystalline PV plants in the Swiss Alps (e.g. Jungfraujoch) [5]. The operating behaviour of this technology seems to be similar to that of crystalline Si-cells. Especially good is the fact that with these modules measured STC-power was considerably higher than the nominal power indicated by the manufacturer.

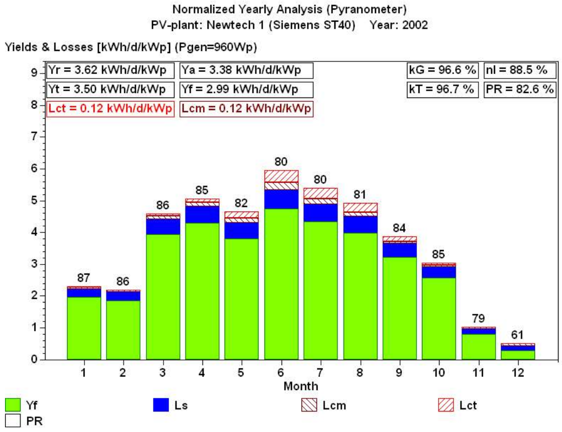

Fig. 2: Normalised yearly analysis for 2002 of PV plant Newtech 1 with CIS-modules Siemens ST40. Specific annual energy yield 2002: 1091 kWh/kWp, PR = 82.6%, winter energy fraction 31.8%.

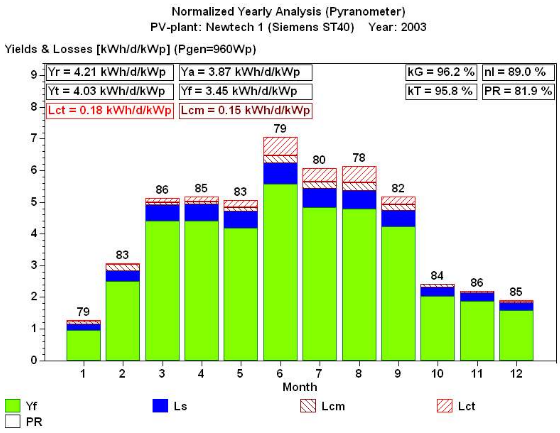

Fig. 3: Normalised yearly analysis for 2003 of PV plant Newtech 1 with CIS-modules Siemens ST40. Specific annual energy yield 2003: 1259 kWh/kWp, PR = 81.9%, winter energy fraction 32.0%. A minor production loss could be observed only during the hot an dry summer months.

2.3 Operating results in 2002 and 2003 of plant Newtech 2 (a-Si-tandem modules MST43)

In 2002 and 2003, the energy yield and performance ratio of this plant was the lowest of the three Newtech thin-film plants, but its performance ratio (PR) values were still comparable to those of a nearby good mono-Si plant with an inverter with transformer. Energy production at low irradiance levels is relatively low. Under such conditions, the output voltage drops considerably and then the inverter operates outside of the MPP despite the relatively wide input voltage window. Cell efficiency is relatively low, moreover during the winter months module power degrades considerably, but during the spring and summer months the module power recovers mostly, but not completely. A permanent degradation of about 3% seems to have occurred between summer 2002 and summer 2003 due to the Staebler-Wronski effect.

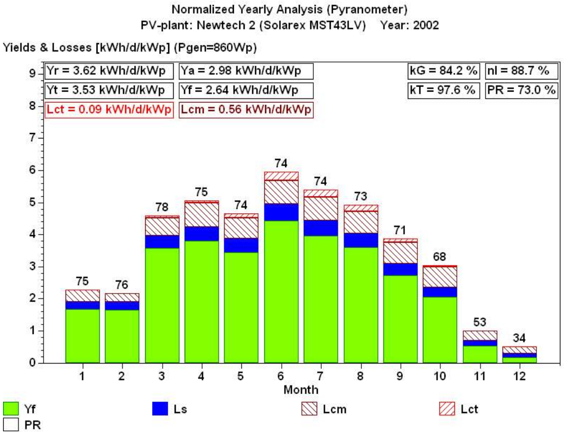

Fig. 4: Normalised yearly analysis for 2002 of PV plant Newtech 2 with a-Si modules BP Solarex MST43-LV. Specific annual Energy yield 2002: 964 kWh/kWp, PR = 73.0%, winter energy fraction 30.4%. Starting in October, PR decreases considerably due to module degradation.

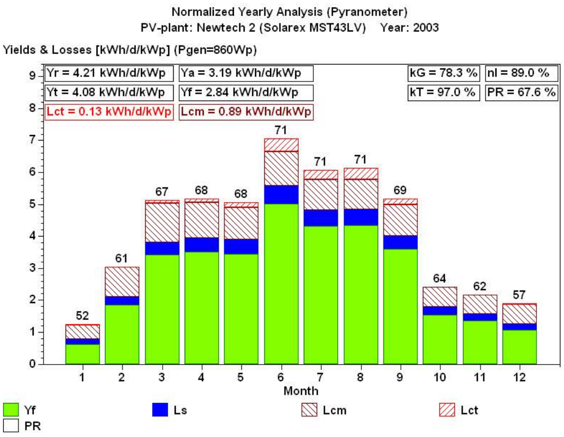

Fig. 5: Normalised yearly analysis for 2003 of PV plant Newtech 2 with a-Si modules MST43-LV. Specific annual Energy yield 2003: 1037 kWh/kWp, PR = 67.6%, winter energy fraction 28.6%. Due to degradation, PR is considerably lower than in 2002.

The degradation due to low temperatures in winter and the subsequent recovery in spring and summer 2003 could also be confirmed by power measurements of the array. On March 24, 2003, measured STC-power of Newtech 2 was 726 Wp, whereas on Sept 3, 2003, measured STC-power had increased to 758 Wp. In the normalised yearly analysis this gradual recovery can also be clearly seen by the gradual increase of PR during spring 2003.

2.4 Operating results in 2002 and 2003 of plant Newtech 3 with a-Si-triple modules US-64

The performance ratio of this plant was higher than that of all crystalline PV plants in Burgdorf. This plant has a relatively high performance ratio PR at low irradiance levels. Seasonal degradation and recovery behaviour was similar to that of plant Newtech 2. A permanent degradation of about 2% seems to have occurred between summer 2002 and summer 2003.

Despite the triple-cell technology used, Unisolar modules US-64 also show the typical seasonal variation and gradual degradation like other amorphous Si cells. However, the degradation observed seems to be a little lower than that of the tandem modules MST 43LV.

The degradation due to low temperatures in winter and the subsequent recovery in spring and summer 2003 could also be confirmed by power measurements of the array. On March 24, 2003, measured STC-power of Newtech 3 was 895 Wp, whereas on Sept 3, 2003, measured STC-power had increased to 951 Wp. In the normalised yearly analysis this gradual recovery can also be clearly seen by the gradual increase of PR during spring 2003.

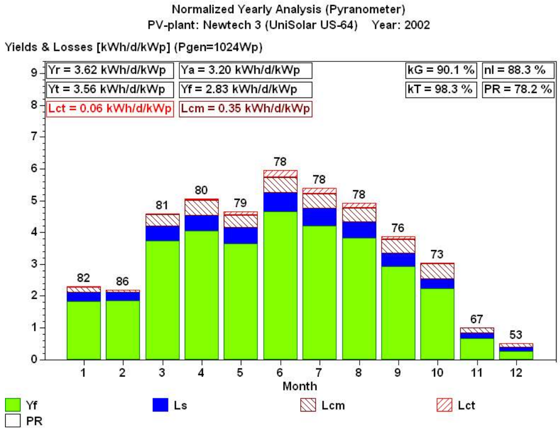

Fig. 6: Normalised yearly analysis for 2002 of PV plant Newtech 3 with a-Si modules Unisolar US-64. Specific annual Energy yield 2002: 1033 kWh/kWp, PR = 78.2%, winter energy fraction 31.1%. Starting in October, PR decreases considerably due to module degradation.

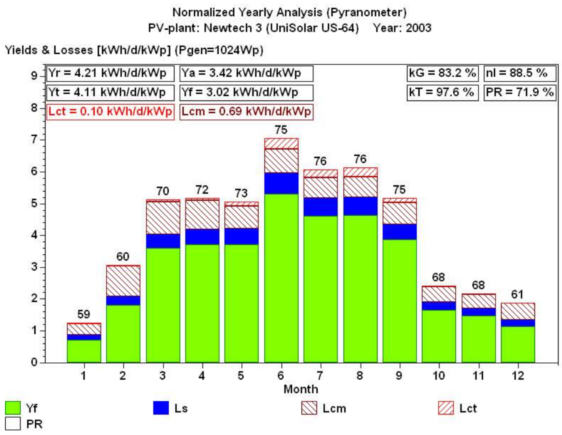

Fig. 7: Normalised yearly analysis for 2003 of PV plant Newtech 3 with a-Si modules Unisolar US-64. Specific annual Energy yield 2003: 1102 kWh/kWp, PR = 71.9%, winter energy fraction 28.6%. Due to degradation, PR is considerably lower than in 2002.

On October 2, 2003, ***a thermal insulation*** was mounted at the back of the modules of this plant in order to alleviate the seasonal degradation and the gradual loss of performance. First results are encouraging (see next page).

3. Comparison between the Newtech plants and with some other PV plants

In fig. 8 monthly DC energy conversion efficiencies, in fig. 9 the PV generator correction factor $k_G = Y_a/Y_T$ of the three Newtech plants and of two plant with mono-crystalline Si cells are compared. In the ideal case, k_G should be ≈ 1. Energy production of the plants Newtech 1 to 3 and Gfeller was affected by snow covering in Feb. 2003 and Jan. 2004.

Fig. 8 shows, that in summer 2002 energetic efficiency of the amorphous technologies is relatively constant, but it decreases considerably during autumn and the winter months. However, with some delay, most, but not all of the degradation encountered in autumn and winter is recovered in summer 2003. Energetic efficiency of the CIS plant behaves like that of crystalline plants. In fig. 9 it can be recognised, that the generator correction factor k_G of the CIS plant is considerably higher than the corresponding value of other plants, which is due mainly to the fact that effective STC power of the modules supplied is higher than the rated value. After 2.5 years a slight decrease of performance can also be noted at the CIS-plant Newtech 1. High specific energy yields of CIS- and a-Si-triple plants were reported also in other papers [2, 3].

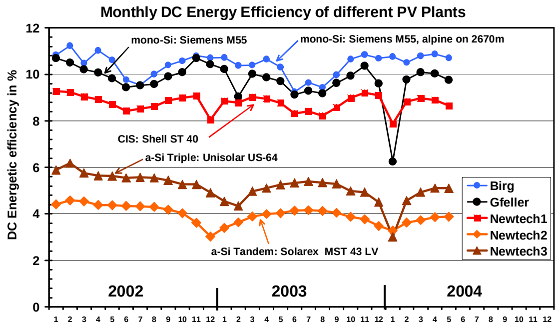

Fig. 8: Monthly DC energy conversion efficiency of the three PV plants Newtech 1 to 3 and of two PV plants with mono-c-Si (alpine plant on 2670m).

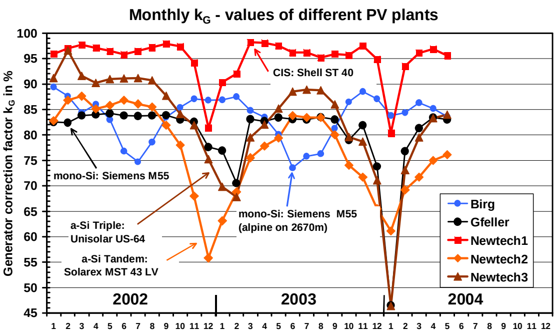

Fig. 9: Monthly values of the generator correction factor $k_G = Y_a/Y_T$ of the three Newtech plants and of 2 plants with mono-c-Si cells (alpine plant on 2670m).

If the short edges of the ST-40 modules are mounted horizontally like in PV plant Newtech 1, due to the long shape of the cells the sensitivity to snow covering and pollution is very low (see months with snow: Feb. 2003 and Jan. 2004). The behaviour of CIS cells is also quite good at low irradiance (see Nov. and Dec. 2002).

The unevenness of the plastic module surface of the modules US-64 used in plant Newtech 3 has a certain drawback on days with snow covering of the PV generator, as the snow does not slide down from the modules as fast as on other modules with glass surface. Therefore the snow remains longer on the modules, reducing energy production in winter months with extended snow periods. This can be clearly seen by comparing the values $k_G = Y_a / Y_T$ of Newtech 2 and Newtech 3 during the months with longer snow coverings (Feb. 2003 and Jan. 2004). Usually the k_G-values of Newtech 3 are considerably higher than that of Newtech 2, but in these months the k_G -values of Newtech 3 are lower.

3.1 Effect of thermal insulation of amorphous a-Si modules

If the influence of snow covering is eliminated (Feb. 2003 and Jan. 2004) , it can be clearly seen that due to the thermal insulation at the back, in winter 2003/2004 the further degradation of the modules of Newtech 3 could be alleviated and that the recovery in spring started earlier. Therefore the thermal insulation mounted in October 2003 seems to have a positive effect. It will be interesting to see if the values in summer 2004 will reach the same values like in summer 2003 and if the modules will not overheat. Because of the low temperature coefficient and the (desired) recovery of the degradation encountered during the winter months, PV plants with amorphous modules are probably very interesting in situations where cooling on the back is bad or not possible (e.g. direct mounting on thermally isolating material).

4. Conclusions

The long-term monitoring of the Newtech plants will be continued also during the next years. Therefore data about the further evolution of energy production and degradation of the technologies used will be available in the future. Monitoring data of all 3 Newtech plants and 7 others are available on-line at the link given below.

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Further information about the research activities of the PV laboratory of HTI (former name: ISB) on the internet: http://www.pvtest.ch.