COST COMPARISON OF LARGE SCALE CRYSTALLINE AND THIN-FILM PV SYSTEMS

M. Bächler and C. Bindel
Phönix SonnenStrom AG, Hirschbergstr. 8, D – 85254 Sulzemoos, Germany,
email: Ulm@SonnenStromAG.de, Tel: +49-8135-938 010, Fax: +49-8135-938-099

ABSTRACT: More and more thin-film modules are entering the market of grid-connected systems, especially in the sector of (large scale) ground based systems. The properties of thin-film modules show some significant differences to “conventional” crystalline modules resulting in different balance-of-system design and different costs of BOS components. From a point of view of an investor thin-film modules cause increased BOS costs of 600-900€/kWp and higher O&M costs which are about another 100€/kWp for a 1MWp ground based system. However, there is a very high cost saving potential for PV systems with thin-film modules if some of the module parameters are modified, if the BOS components are adopted to the properties of thin-film modules and if the system integrators and/or installers optimize their installation technique too. Overall costs savings anticipated may be up to 300-400€/kWp with modest efforts from all parties. On the mid-term prospective a trend towards a differentiation between modules for small scale plants and large scale systems can be anticipated for both – thin film modules as well as crystalline modules.

Keywords: Cost Reduction, Large Scale Grid Connected PV systems, Thin Film

1 INTRODUCTION

The purpose of this paper is to identify and discuss the differences in balance-of-system (BOS) costs between “state of the art” crystalline modules and 2 different thin-film (TF) modules. As a basis for the comparison large scale ground based systems have been taken since the authors believe that due to silicon shortages, TF-modules will have an unique window of opportunity to enter the PV market of grid-connected system in the sector of large scale PV systems, especially as ground based systems. Therefore as a reference for comparison therefore a 1MWp ground based system has been used.

The figures presented are based on verified numbers since Phönix SonnenStrom AG realized this type of installations in the past already utilizing both module types: TF modules as well as crystalline (c-Si) modules.

Figure 1: PV Plant “Waltenhofen” with a 400kWp PV subfield with MHI modules (TF; upper half) realized by Phönix and a 720kWp PV subfield with BP modules (c-Si) realized by BP Solar in 2003/2004.

All the figures presented are based on end-user price level excluding VAT.

Since for an investor not only the investment costs but also operation and maintenance (O&M) costs are important any differences in these costs will be considered and discussed.

Please note that the figures presented are only valid for large scale ground based systems since costs for module supporting structures and partially DC-cabling as well as installation costs will differ for roof-top applications as well as for smaller system sizes.

2 DESCRIPTION OF PV MODULE PARAMETERS, BOS COMPONENTS AND KEY SYSTEM PARAMETERS

2.1 PV Module Parameters

Beside the module power, there are some parameters of PV modules which have some impact on BOS costs. Some of these parameters are well known whereas the effects of other parameters presented here are not discussed in detail yet.

1) Module efficiency

It is obvious that the higher the efficiency of the module (or power density P/m²), the lower the specific costs in terms of €/kWp for mounting structures, labor for installation and cabling will become since either less mounting material per kWp is needed and less modules are to be installed

2) Module power

The higher the power per single module, the lower the specific installation costs since less modules need to be handled.

3) “Power per m” P/m

The power density or module efficiency and the shape of the module, i.e. the ratio of module length to module width determines the amount of installation material needed. A module with 100Wp with a size of 1m x 1m (i.e. full square) needs double the supporting struts than a module with the same power with a size of 2m x 0.5m – provided the module is installed in portrait format. If the module would be installed in landscape format then this module would need four times the supporting struts compared to an installation in portrait format.

4) "Watts per Volt" P/U

This parameter describes the ratio between the MPP power and the MPP voltage. The higher the ratio the more modules and therefore power can be installed in series in a single PV string. Thus affecting the DC cabling costs, which are correlated to the number of strings. Especially if string monitoring is required, the DC cabling costs of individual strings are not negligible anymore.

5) Maximum system voltage Usys

This parameter, defined by the module manufacturer, define the maximum number of modules which can be installed in series per string. This value in combination with the ratio "Watts per Volt" determines the power per string and therefore also affects the DC cabling costs.

6) Module framed vs. unframed

In general the use of unframed modules, which are available at lower costs (€/kWp) require more sophisticated mounting systems and more careful handling. This results in higher BOS costs which counterbalance the advantage of the module costs in many cases.

In Table 1 and 2 some of these parameters are summarized for typical c-Si and TF modules.

	Power (Wp)	P/m² (W/m²)	P/m (W/m)	Frame
c-Si	160	122	161	Framed
TF 1	100	84	90	Framed
TF 2	60	85	100	Unframed

Table 1: Key Parameters for typical c-Si and two different TF modules (TF1, TF2)

	P/U (W/V)	Usys (V)	Modules per string (pcs)	Power per string (Wp)
c-Si	7.00	1000	27	4,320
TF 1	0.93	600	4	400
TF 2	0.84	700	7	420

Table 2: Key Parameters for typical c-Si and two different TF modules (TF1, TF2)

It is apparent, that TF modules have some handicaps in most of the above described parameters resulting in higher BOS costs.

2.2 Phönix Mounting System for Ground Based PV Plants

As a basis for the cost calculations, a mounting system for ground based systems was used (see Fig. 2). The system shows significant advantages in material costs, ease of installation and installation cost. Moreover, due to its limited maximum height (top of the modules is just 1.6m above ground) it is widely accepted even among environmental protection organizations.

The system mainly consists of posts, which are simply driven into the ground without any need for concrete or ballast foundations, horizontal struts mounted in an east-west direction and module rails which are mounted onto the struts and where the modules will be hooked on.

Figure 2: Mounting system for ground based systems

2.3 Power Conditioning Unit (PCU)

According to our philosophy large scale PV systems ought to be designed with a minimum number of (large) central inverters rather than hundreds of small string inverters.

However in this case the maximum system operation voltage of the PV modules has a significant impact on the inverter design and therefore also on inverter costs: All of the standard large scale inverters operate at voltage levels which are above the maximum system voltage of TF modules, since they are designed to operate with crystalline modules which allow for system voltages up to 1,000Vdc.

Out of this reason there are so called "low voltage" central inverter designs available from some manufacturers. Compared to "standard" inverters they have the following disadvantages:

- They are only available in power ranges up to 150kW per unit whereas single standard inverters are available up to 500kW per unit. This results in higher specific costs in terms of €/kW and increased space demand.
- A 150kWp inverter operating at 300Vdc (TF modules) has an nominal input current of 500Adc whereas the same inverter only has 250Adc at 600Vdc operating voltage (c-Si modules). Since the current determines significantly the costs of switch devices and power electronics, whereas there is almost no cost effect from the voltage, thus "low voltage" inverters show higher specific costs in terms of €/kW.
- The efficiency increases with higher operating voltages because switching losses are reduced. Here the "low voltage" inverters achieve average efficiencies of 93,5% compared to at least 95% with standard large scale inverters.

2.4 Summary of key system parameters

Based on above explanations the basic design of the 1 MWp for the 3 modules is given in Table 3:

	No. of modules	Modules per string	No. of strings	Inverters
c-Si	6156	27 seriell	229	Standard, 2x500kW units
TF 1	9999	4 seriell, 11 parallel	223	Low voltage 8x125kW units
TF 2	16667	7 seriell	2381	Low voltage 8x125kW units

Table 3: Key system parameters of 1 MWp system

Remarkable in this context is TF1 with a highly innovative wiring concept: The modules are connected in parallel by appropriate cables (max. 12 modules in parallel) and then these "substrings" are connected in series to other substrings (with identical number of modules connected in parallel). With this approach the number of strings in the field can be reduced to a similar number as for the conventional c-Si technology, whereas the design with TF2 requires 10 times more strings.

3 COST COMPARISON

3.1 Mounting Structure

The number of key components of the mounting structure as well as the resulting costs (incl. labor costs for installation of the mounting structure and the modules) are given Table 4:

	TF1	TF2	c-Si
No. of posts (pcs)	5,670	5,217	3,420
Struts (m)	11,340	10,434	6,840
Module rails (pcs)	10,099	16,766	6,206
Add. Clips for frameless modules	0	16,766	0
Costs in €/kWp	700	950	420

Table 4 Material and costs for mounting structure

One can clearly see the effects of the lower power density (or efficiency) and the module power on the amount of material needed. The frameless module TF2 requires additional mounting clips (for proper fastening of the module). These (additional) costs will counterbalance the costs savings generated by the lower amount of posts and struts compared to TF1 as one can see in Table 6.

In total the TF modules generate- roughly double the costs for a mounting system than c-Si modules. The advantage of 280€/kWp for c-Si compared to TF1 is equal to 28€-Cent/Wp (a unit which is more common for module pricing), whereas is it more than 500€/kWp or more than 50€-Cent/Wp for TF2 (mainly due to the smaller module size and the frameless design).

3.2 DC Cabling, PCU and other costs

The costs for DC cabling, power conditioning and some other costs such as required cable trenches and fences where significant differences between c-Si and TF exist are given below:

	TF1	TF2	c-Si
Solar cable (m)	35,680	47,620	22,900
Field boxes (pcs)	28	50	29
Inverters	8	8	2
Cable trenches (m)	800	800	500
Fences (m)	1,000	1,000	700

Tab. 5: Some selected components for DC cabling, PCUs, etc…

	TF1	TF2	c-Si
DC costs	83	150	85
PCU costs	487	487	300
Other costs (fences, trenches, etc…)	43	43	32
Total	**613**	**680**	**417**

Table 6: Cost figures in €/kWp for DC cabling, PCUs, etc…

It should be noted that the DC costs include the labor for wiring as well as additional installation material such as DC cables, cable connectors, etc… with are not given in detail in Table 5. Due to the advanced DC wiring approach of TF1 we can see similar DC costs to c-Si. The PCU costs also include, if needed LV/MV transformers plus the required switching cabinets and housings in case for TF1 and TF2 (these costs can be avoided for c-Si in this system design).

Because of the low maximum system voltage of the TF modules the inverter costs are significantly higher compared to c-Si systems. Cost effects of cable trenches and fences are almost negligible in the total costs.

The total costs are again higher (about 200 – 250€/kWp or 20-25€-Cent/Wp) for both of the TF modules compared to c-Si modules. The difference i5 mainly due to the inverter costs.

3.3 O&M costs

Besides the pure investment costs the operation and maintenance costs will influence the life time costs and are, from an investors point of view an important issue. Significant differences in O&M costs for TF- and c-Si systems are found in:

1) Site rental

With TF modules approx. 200kWp can be installed per hectar (10,000m²), whereas 400kWp can be installed with c-Si due to the higher efficiency of c-Si. Assuming an annual rent of 1,200€/hectar this is 6€/kWp for TF and only 3€/kWp for c-Si.

2) Inverter service

The cost for inverter services are determined by the initial investment costs. Therefore the specific costs for the design with c-Si modules are lower than the costs for the design using TF modules (see 3.2).

3) Overall plant O&M

The costs for overall plant operation, monitoring and maintenance including grass mowing, etc… also show some differences between TF and c-Si with slightly higher costs for TF systems.

In order to identify these effects we calculated the total costs for an operating period of 20 years and then determined the discounted cash value for the TF and c-Si systems which is given in Table 7.

	TF1	TF2	c-Si
Site rental	60	60	30
Inverter service	140	140	90
Plant O&M	140	140	120
Total	**340**	**340**	**240**

Table 7: Cost figures in €/kWp for O&M costs

In total the higher costs for the TF systems over 20 years is equivalent to 100€/kWp higher investment costs, i.e. it generates a cost advantage of 10-Cent/Wp for the c-Si module.

3.4 Summary

The total costs including BOS costs as well as the O&M costs for both TF and the c-Si systems are given in Table 8:

	TF1	TF2	c-Si
Mounting structure	700	950	420
DC, PCU, etc.	613	680	417
O&M	340	340	240
Total	**1,653**	**1,970**	**1,077**

Table 8: Total differences in BOS and O&M costs

There is a significant cost advantage for the c-Si in a range of 600 – 900€/kWp (or 60-90€-Cent/Wp), i.e. to achieve the same total system costs for the investor the costs for the TF modules must be this amount lower to compensate the higher BOS and O&M costs for the TF systems.

4 SCENARIOS FOR BOS COST REDUCTIONS

4.1 Introduction

The existing BOS technology is, mainly because of historical reasons, optimized for c-Si module technology. On the other side TF manufacturers are, since this technology is just entering the market of large scale systems, in many cases not very familiar with the needs and requirements of BOS components and system installers yet. Due to this “mismatch” some of the results above are not really a surprise. However one can anticipate significant effects and cost savings in the near future if either the BOS technology and/or the module design are optimized with regard to the overall system.

To identify the cost potential we compared some scenarios anticipating some module design modifications focusing on TF modules.

4.2 Scenario 1: Efficiency Increase c-Si and TF

For both, the c-Si and TF modules the effects of a 10% increase in module efficiency are summarized in Table 9 and Table 10. Table 10 in addition identifies the effect of a 50% increase in efficiency for TF modules (which can be seen on the horizon for some technologies).

	160Wp	176Wp
Mounting structure	420	384
DC, others, etc.	117	108
O&M	240	230
Total	**777**	**722**

Table 9: c-Si Scenario 10% efficiency increase

The main effects occur with the mounting structures – here the effect is almost linear. Only minor savings exist with DC-cabling, none with the PCU units and also only minor savings in site rental and plant O&M. In total the costs are reduced about 60€/kWp or 6€-Cent/Wp if the module efficiency can be increased by 10%.

	100Wp	110Wp	150Wp
Mounting structure	700	640	470
DC, others, etc.	126	116	89
O&M	340	330	305
Total	**1,166**	**1,086**	**864**

Table 10: TF Scenario 10% and 50% efficiency increase

As Table 10 indicates a 10% efficiency increase with TF will result in total savings of about 80€/kWp (8€-Cent/Wp), whereas an increase of 50% will save almost 400€/kWp. Main savings are due to, similar to the c-Si system, reduced mounting structure costs.

Regarding these effects it should be noted that an efficiency increase shows higher cost savings for ground based systems compared to roof-top systems since the costs of mounting structures are significantly higher for ground based systems.

4.3 Scenario 2: P/U ratio increase

By increasing the P/U ratio on the module level the DC cabling costs can be reduced since the number of strings will be reduced. Therefore less DC wiring on the module level, less field box and less DC wiring between field boxes and inverters is needed. Other BOS components are not affected by a change of this parameter.

A P/U ratio increase for the c-Si modules may come along with the change from 5” cells to 6”cells (about 44% increase) or - in future – from 6” to 8” (77% increase). For the TF modules a P/U increase means to reduce the number of cells per modules or to broaden the cells dimensions respectively. However there will be limitations when the current increases above certain levels.

Costs savings for an increase of P/U of 50% are expected to be 40€/kWp for TF modules and about 30€/kWp for c-Si modules.

4.4 Scenario 3: System Voltage Increase

Since we have seen that the low system voltage of TF modules leads to increased cost for DC-cabling as well as PCU we calculated the expected costs for a scenario with TF modules with 1,000Vdc system voltage in Table 11.

	60W	60W HV
Mounting structure	950	950
DC, others, etc.	193	132
PCU	487	300
O&M	340	290
Total	**1,970**	**1,672**

Table 11: TF Scenario for "High Voltage" Module (HV)

In above comparison the inverters for PCU where assumed to be standard 250kVA units – i.e. the 1MWp plant comprises a total of 4 units. There would additional cost saving potential if the same 500kVA units would be applied as they were used for the c-Si plant design (approx. 50€/kWp).

However, there is a significant potential for cost saving in the area of DC cabling (30% less strings) and the inverters (since standard inverters can now be used). But even the O&M costs decrease since the costs for the inverter services are correlated to the investment costs.

In total the increase of the system voltage can lead to cost savings of approximately 300€/kWp or 30€-Cent/Wp. Combined with a 10% increase in efficiency the total savings approach 350€/kWp.

5 CONCLUSIONS

5.1 Present Situation

Currently large scale ground based systems with TF modules result in higher BOS Costs and O&M costs compared to "standard" c-Si modules. Beside the lower efficiency and the module size this is mainly due to the higher DC cabling costs and inverter costs. In total (combination of BOS costs and O&M costs) the difference can range from 600-900€/kWp – depending on the type of TF module.

This difference must be compensated by lower module costs in order to achieve at least the same total system costs from investors point of view.

For different plant designs and applications (e.g. roof-top) the difference in BOS costs will be smaller than for the ground based system used here. O&M costs are expected to be similar for other applications.

It should be noted that more and more large scale ground based systems are being realized – this indicates that the TF module manufactures successfully cut down the module costs to allow total system costs to be at least comparable to the total system costs for ground based systems using c-Si modules.

5.2 Future Trends and Cost Saving Potential

There are significant cost saving potentials on the BOS and O&M costs for TF technology. Surprisingly the cost savings are much higher (almost by a factor of 4) if the operating system voltage of the modules increases from the current 600-700Vdc range up to 1,000Vdc compared to an increase in efficiency by 10%.

The combination of high operating voltage together with a moderate increase in module efficiency of 15% will cut down BOS and O&M costs by almost 350€/kWp. With this approach the cost disadvantages of the TF modules can be reduced by almost 50% and will allow TF technology an advanced market penetration.

If these measures are supported with other improvements such as increase of module size or increase of P/U-ratio then additional cost up to 100€/kWp or 10€-Cent/Wp can be anticipated.

In order to identify and achieve these cost saving potentials a closer collaboration among the manufacturers of modules and BOS components on one side and the installers on the other side is required.

It may be anticipated that in the mid-term a differentiation between module designs may be made which are designed either for the use in smaller systems (residential roof top, etc…) or large scale PV systems. These module designs than may be optimized towards minimum overall system costs reflecting the specific requirements discussed here such as efficiency, modules size, operating voltage, etc… But even other aspects such as module matching, module packaging, etc… may be improved on the module site. On the BOS side costs savings may result from optimization of mounting structures, improved installation approaches, usage of prefabricated DC-cabling, etc…