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Packaging and installation of the organic photovoltaic cells

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Anotace:
Pro potlačení problému postupné degradace organických solárních článků při provozu solární elektrárny je navrhovaná koncepce výměny "opotřebovaných" organických solárních článků. S ohledem na současné náklady na instalaci a aktuální cenu elektřiny musí být účinnost původně instalovaných článků alespoň 10%, aby se zajistilo, že investice se vrátí za méně než 20 let. To znamená, že v případě organických fotovoltaických článků vyrobených tak, aby umožňovaly snadnou a levnou montáž a za podmínek vhodného nahrazení "opotřebených" článků je koncept elektrárny s organickými fotovoltaickými články ekonomicky obhajitelný.

Abstract: To overcome the problem with gradual degradation of organic solar cells the concept of replacement of "worn-out" organic solar cells is proposed. Considering the current costs of installation and current price of electricity the efficiency of initially installed cell must be at least 10% to ensure that these investments will return in less than 20 years. This means that in case of organic solar cells manufactured so as to provide an easy and inexpensive installation and under the conditions of appropriate replacement of "worn-out" cells the implementation of organic-solar power-plant is economically defensible.

1 INTRODUCTION

The plastic supports used in organic solar cells fabrications facilitate low production costs in high volumes. Combined with the flexibility of organic materials and different possibilities how to change its structure, organic solar cells are potentially cost-effective for photovoltaic applications. Due to its flexibility and low weight respective PV-modules could be much simpler which should also result in lower installation costs.

To time the efficiency of organic photovoltaic cell is high enough to be implemented in photovoltaic power plant. Usually, a minimum efficiency of 8% is considered as necessary to compete with 15% efficient PV modules.

However, while module costs are proportional to the installed power, the installation costs grow with the installed area. Consequently, PV modules with low efficiency will need large area with higher installation costs and will not be able to compete.

In an optimal case installation costs are about 30 - 40% of the overall costs but in case of low conversion efficiency they could be much higher.

On the other hand there are many other problems associated with organic photovoltaic cells, as low stability and gradual decrease of conversion efficiency [1]. The loss of efficiency is usually associated with degradation of the layers with a low work function, which are necessary for operation of the organic solar cells.

However, by introducing of inverted design technology this fast electrode degradation could be prevented. The low work function metals (originally used to form the cathode of the organic solar cell) have been replaced by transparent oxides like zinc oxide or titanium dioxide or the work function of stable electrode materials has been modified using a thin interfacial layer. To shape the anode the materials like silver, gold or standard hole-injection layers has been applied.

An additional advantage of the inverted device design is that all layers can be deposited from solution and no vacuum process is required [2, 3]. Similarly as in case of inorganic photovoltaic solar cells tandem cells as a direct way to higher efficiency are considered but to time this technology is not mature [4, 5].

Of course, in terms of reducing the cost of production of solar electricity there are few other types - between them most promising are considered CIGS cells. Interesting are also the photovoltaic cells based on perovskites.

Record CIGS cell efficiencies are to time more than 22 % and production-size modules reach efficiency higher than 16%. Further grow up to 25% for lab and 18% for production grade cells is expected before 2020. CIGS production cost reached to time the level of 10 CZK per Wp ($0.40 per Wp) and further drop is expected if production will be scaled up to few hundreds of MW power per year in one factory. However, extremely larger scale production of CIGS could be limited by finite global supply of indium.

Perovskite solar cells are potentially much cheaper than both silicon and CGIS cells and their reported efficiency is higher than 20 percent and is further improving. However, these results have been achieved only in lab and by very small area cells, typically less than a square centimeter. To scale up from lab size it is not trivial because the defect density grows here very rapidly with the area.

Conversion efficiency of both types, CGIS and perovskite does not decrease significantly even after prolonged exposure to sunlight. The model of gradual replacement of “worn out” cells suggested hereafter is, therefore, intended only for organic solar cells.

2 MODEL OF THE POWER PLANT

Considering the maintenance of organic power plant the problem turns to be more complex. Upon continued drop of the efficiency of installed organic PV cells there can happen that the funds received for produced electricity does not even cover maintenance costs. To avoid such a case it is advisable to replace original PV- cells at an appropriate time. Investment in this power plant which is largely shaped by the cost of installation would be such way preserved.

2.1 Basic considerations

Over several years the price of organic solar cells (OSC) undoubtedly falls, the conversion efficiency will be larger and degradation slower.
For basic assessment we consider the average price of organic solar cells (OSC), the average price of electricity for the end customer, the average increase of price of electricity per year and the average efficiency of OSC which is expressed in percentage use of impacting radiation power.
To model real situation we must also consider step by step decrease of the efficiency of original OSC and regular maintenance costs (per year in percentage of the total investment). We also need to reckon with the repair of serious failures which is here supposed to happen approximately in period of three years.
Replacing the old solar cells with new ones after few years we may profit from the probable increase in efficiency and the drop in purchase price.

2.2 Cost of organic solar cells versus price of electricity

The income that could be taken from the 1 m^2 is computed using the solar radiation per year per one m^2 (RAY = 1MWh / year.m^2). For example - when considering the efficiency of respective organic photovoltaic cells F = 8%, the energy which could be taken in period of one year for each squared meter of solar power plant is RE = 80KWh.
The annual income (AI) is consequently expressed using the price of electricity (E) as:
AI = RE . E = 80 KWh ⁄ year . m^2 . 4,75 CZK⁄KWh = 380,- CZK ⁄ year . m^2
Cost of the solar panels was estimated using the expected purchase price in CZK per Wp.
Example: Having the previous case with the efficiency F=8%, the power extracted from one m^2 is:
RE = 80KW. Considering the average purchase price per Wp is P = 11 CZK we obtain:
PE = RE×P = 80W/ m^2 . 11 CZK/Wp = 880 CZK/ m^2.

2.3 Cost of the equipment

For the low efficiency solar cells we must consider, that the price of whole equipment will be much higher than the price paid for solar cells. Using low efficiency cells we need much larger surface, much more space, more supports, more cables and connections and more time to make interconnections.
Based on common experience we therefore consider that for the low price low efficiency cells the price of solar panels would be about 20% of total costs. Than for the case of 8% efficiency solar cells we obtain for purchase price of the equipment:
PEQ = PE×4 = 3520 CZK - the money spent for the whole power station per m^2 of solar cells will be then
TI = PR+PEQ = 4400 CZK / m^2.

2.4 Cost of maintenance

a) Price of the maintenance per year (for parameters given previously):
MTN=TI ×2% =TI×2⁄100=4400×2⁄100= 88 CZK/m^2.
b) Price of the maintenance for serious failure each third year (for actual values):
FLR =TI ×2% =TI×2⁄100=4400×2⁄100= 88 CZK /m^2.

2.5 The annual income

The annual income is expressed by following equation:

$$y(n+1)=[y(n)+CM(n)] .(FD.EI) - CM(n+1) \quad (1)$$

Where:
FD is the coefficient related to the drop in efficiency D_f (for D_f = 5 % : FD = 0,95),
EI is the coefficient for the increase in price of electricity I_f (for I_f = 1 % : EI =1,01),
CM (n) are maintenance costs in an inflationary environment:
CM (n) = TI . MTN . $(1+I)^n$ +[n|3]. FLR. $(1+3I)^{[n|3]}$

Where:
TI is the total investment per m^2,
I is the coefficient expressing the rate of inflation, I_f (for I_f = 1 % : I =1,01).
Note:
Every year there is a need to pay for regular maintenance MTN (2% of TI).
Every third year there is a need to pay for repair of serious failure FRL (2% of TI)

Net annual income in the year n+1 is then

$$\mathbf{y(n) = a^n y(0) + \sum_{k=0}^{n-1} a^{n-k-1} g(k)} \quad (2)$$

Where:
y(0) is the income per one m^2 at the start of operation
a is the coefficient for annual change of income
n, k are indexes for respective year.

2.6 The total income

Total income is computed as a sum of individual incomes in each year of the solar power production. Note that the total income is influenced by gradual drop of the efficiency, by maintenance costs and by purchase of new solar cells after few years of production.

3 RESULTS

As a result of modeling there is possible to define two important limits:
1) If the efficiency of installed cells is less than 8% then by the annual drop in efficiency 5 % the investment will never pay back.
2) The efficiency of initially installed cells must be at least 10% and the annual drop in efficiency should not exceed 5 % to ensure that the investments will return in less than 20 years.
At cheaper way of installation than is supposed in this model case the input cost will fall rapidly and the time to return on investment will be reduced. As a result of simulations the reduction is more than one year for a decrease of installation cost by 10%.
Example of model assessment for this case is depicted in Fig.1 and in Fig.2.

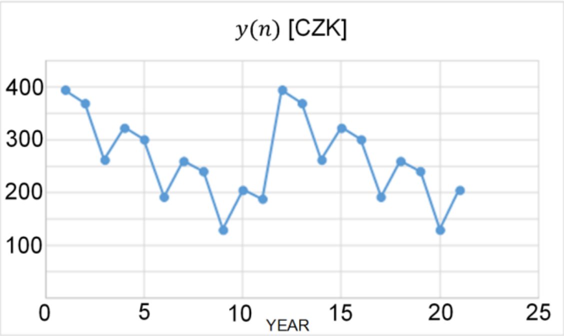

Fig. 1: Model solar-power-plant with organic cells.
Annual income from organic-solar-power-plant with consideration of maintenance costs and emergency repairs.
Note the increase after 11th year due to the purchase of new cells.

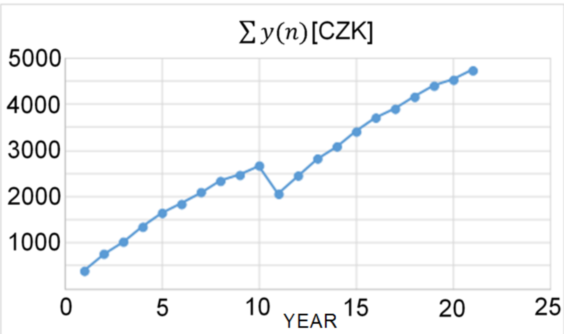

Fig. 2: Model solar-power-plant with organic cells
Total income. Note that return on investment is less than 18 years.
Note the decrease in11th year due to the purchase of new cells.

Here presumed cell efficiency is 10% and annual drop in efficiency is 5%. Cost of investment per 1 m^2 is 4000 CZK. After 11 years the original cells were replaced by cells with the same conversion efficiency and the same annual drop of efficiency.

4 CONCLUSION

The concept of replacement of "worn-out" organic solar cells seems to be very convenient. However the detailed analysis shows that considering the current costs of installation and current price of electricity the efficiency of initially installed cells must be at least 10% to ensure that these investments will return in less than 20 years.
These results shows that in case of organic solar cells manufactured to provide an easy and inexpensive installation and under the conditions of appropriate replacement of "worn-out" cells the implementation of organic-solar power-plant is economically defensible.

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