Choosing the optimal multi-junctions photovoltaic cells for application in the field of concentrated photovoltaic

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Abstract: - In this study, the technical criteria for choosing the optimal multi-junctions photovoltaic cell for application in concentrated photovoltaic field is presented. In this matter, the initial context has been set, respectively the technical characteristics of object to which implementation of a system based upon the multi-junction photovoltaic cell is wanted. The specific characteristics of cells and the decision criteria of the technical solution have been set. In order to choose the right version, two multicriteria methods to rationalize the decision have been applied, after analyzing the existent typologies and establishing the compatible versions with the demands from high concentrated system. In the end of this study, the obtained results have been compared.

Key-Words: - multi-junctions photovoltaic cell (MJ Cell), concentrated photovoltaic, choosing the optimal technology, Onicescu Method, global evaluation of performance technology.

1 Introduction

The photovoltaic cells have known a considerable diversification in the last decade, from both technological and performance point of view.

The leading edge technologies in this field succeed to obtain a bigger conversion of the sun radiation in electricity by using materials with different photonic properties for each radiation spectrum. This aspect is also observed from the analysis of the graphic presented by the National Renewable Energy Laboratory (NREL, 04-2013). Regarding to this, the firs twenty positions of the performance tests are occupied by multi-junction cells used in concentrated photovoltaic systems.

The concentration of the sun radiation to convert it into electricity, leads to considerable reduction of the photovoltaic cells surface, directly proportional with the concentration report. Taking into account this aspect, we can observe the strategic tendency to increase the concentration report to the maximum limits where the specific photovoltaic cells can optimally function.

The diversity of the types of multi-junction photovoltaic cells, comes out from the numbers of junctions used, type of materials used for each junction and the technology used. The integration of these cells in high performance concentrated photovoltaic systems, needs a complex process of research and innovation that is driven by the analysis of the main characteristics of cells, such as efficiency, optimum concentration ratio, cell size, price, optimal operating temperature and so on.

In this direction, this study aims to identify a method which shall be used in research and innovations process of the concentrated photovoltaic systems for choosing the multi-junction cell type with according to several decisional criteria and to their level of importance.

Taking into account the relevance and the impact of the decisional criteria in choosing the cell, related to the concentrated photovoltaic system, the goal regarding the method used in this study is to find a way of classifying the multi-junction cells types in order of the optimal results achieved. This study aims not to classify the actual existent multi-junction cells, but to be a useful tool in the direction of research and innovation, that shall analytically support the optimal decision to be taken.

The dynamism of the technological developments in the photovoltaic field is much emphasized on the basis of the new findings in the field. Moreover, together with the development of the new materials with special photonic properties, like Graphene or Carbyne, the types of photovoltaic cells shall know an accelerated diversification. This tendency shall be felt in particular at the cells used

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in the concentrated systems, because of the high cost of the special materials, but also of their net-superior performance in the sun radiation with high concentrations. In this context, it can be highlighted the importance of this thesis for identifying an optimal choosing method of the multi-juction photovoltaic cell, at any time, based on decisional criteria well proved and evaluated.

2. Problem Formulation

In elaboration and foundation of ranking the typologies of multi-junctions (MJ) photovoltaic cell technology the following stages are necessary: identification and definition of decision process elements, setting the alternatives, setting the evaluation criteria, setting the important coefficient for the evaluation criteria, definition of evaluation tables, establishing the matrix of decision consequences, calculation of aggregation functions, calculation of global indexes and ranking the versions [1, 2, 3].

2.1 Identification and definition of elements

Concentrated photovoltaic systems currently hold the record for efficiency in photovoltaic field with 34% efficiency tested system. These systems concentrate solar radiation on the surface of multi-junction solar cells through optical systems.

Multi-junction photovoltaic cells succeed to obtain a bigger conversion of the sun radiation into electricity (44.7%) by using materials with different photonic properties (III-V group) for each solar radiation spectrum.

The integration of optimal multi-junction cells in concentrated photovoltaic systems has a very big impact on the results and must be driven by the analysis of the main characteristics of cells, such as efficiency, optimum concentration ratio, cell size, price, optimal operating temperature and so on.

In order to set the type of multi-junctions photovoltaic cell to be used in the domain of concentrated photovoltaic systems, initially the existent typologies must be analyzed and it is imposed to be set the typologies that are optimal with the objective's requests where a system like this, based upon MJ cell, will be implemented.

In the present study, after analysis of actual stage of knowledge, detailed information have been obtained upon five types of multi-junction photovoltaic cell technology. Those types being stated below in table 1.

Table 1 Multi-junctions cell

T_i	Multi-junctions cell types	Abbrev.
T1	Triple Junction Solar Cell with eff. 38%	3JC_38%
T2	Triple Junction Solar Cell with eff. 40%	3JC_40%
T3	Triple Junction Solar Cell with eff. 42%	3JC_42%
T4	Triple Junction Solar Cell with eff. 44%	3JC_44%
T5	Four Junction Solar Cell with eff. 45%	4JC_45%

In order to evaluate these five types of MJ cells it is necessary to identify the criteria based upon which the decision is taken. In this matter, it is recommended that these criteria should be coherent and exhaustive, and their number below ten [1]. Given the nature of these criteria, they must be maximized or minimized depending on the desired results. In the first case, the bigger value of criteria is important, and in the second case, the lowest values of criteria are important [2, 3, 6].

In the present case, the following criteria of choosing the MJ cell are presented in table 2.

Table 2 Technology assessment criteria

C_j	Name of criteria	U.M.	Scale
C1	Efficiency	%	maximized
C2	Cell dimensions	mm^2	minimized
C3	Costs of Production	€/W	minimized
C4	Optimal concentrations	x (suns)	maximized
C5	Efficient operation capability at concentrations above 1000 x		maximized

These evaluation criteria have been set based upon the technical characteristics given by the MJ cell technology, in accordance to the particularities of the case [4,5,7,8] as presented in table 3.

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Table 3 Specific characteristics of MJ Cell

Name of criteria	3JC_38%	3JC_40%	3JC_42%	3JC_44%	4JC_45%
Efficiency	38%	40%	42%	44%	45%
Cell dimensions (mm^2)	100	100	100	30,25	6,25
Costs of Production (€/Wh)	1,6	1,76	1,92	2,08	2,16
Optimal concentrations	500	500	1000	1000	350
Efficient operation capability at concentrations above 1000 x	no	no	yes	yes	no

2.2 Multicriteria methods of decision foundation

2.2.1 Application of Onicescu Method

The calculation has been performed in two versions: in the first version the choosing criteria has the same importance, and then the calculation has been performed in the version in which different coefficients as importance are used.

2.2.1.1 Version 1 - choosing criteria equal as importance:

a) Setting the matrix of decision version consequences according to table 4.

Table 4 Matrix of decision versions consequences

T_i	MJ Cell Types	Name of criteria - Cj				
		C1	C2	C3	C4	C5
T1	3JC_38%	38%	100	1,6	500	no
T2	3JC_40%	40%	100	1,76	500	no
T3	3JC_42%	42%	100	1,92	1000	yes
T4	3JC_44%	44%	30,25	2,08	1000	yes
T5	4JC_45%	45%	6,25	2,16	350	no

b) Setting the matrix of ordered versions

The versions are ordered depending on each criteria in descending order of consequences [2, 3], obtaining a new matrix according to table 5.

Table 5 Matrix of ordered versions

Place	Criteria - C_j				
	C_1	C_2	C_3	C_4	C_5
1	T5	T5	T1	T4	T4
2	T4	T4	T2	T3	T3
3	T3	T3	T3	T2	T5
4	T2	T2	T4	T1	T2
5	T1	T1	T5	T5	T1

c) Setting the positions matrix

The new matrix shows how many times a version „i” occupies place „j” [2], in which „i” represents the constructive type of fuel (T1,T2,T3,T4,T5), and „j” takes values according to table 6.

Table 6 Matrix of positions

MJ Cell Types	Position				
	1	2	3	4	5
T_1	1	0	0	1	3
T_2	0	1	1	3	0
T_3	0	2	3	0	0
T_4	2	2	0	1	0
T_5	2	0	1	0	2

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d) Ranking the versions.

The optimal version is set by calculation of aggregation functions after formula (1) [2]:

$$f: T \rightarrow R, defined\ by:$$

$$f(Ti) = ai1\frac{1}{2} + ai2\frac{1}{2^2} + \ldots + aim\frac{1}{2^m} \qquad (1)$$

Where: aim represents how many times version „i" occupies place „j".

After performing the calculation, the version with the highest value is considered the optimal solution [2].

2.2.1.2 Version 2 - choosing criteria of different level of importance

a) Setting the matrix of decision versions consequences and the versions matrix ordered as in the first version;

b) Setting the important coefficients afferent to the evaluation criteria:

In order to set the importance coefficients a scale is used from 1 to 3, one being maximum importance and 3 being low importance [2]. Coefficients of importance are presented synthetic in table 7.

Table 7 Coefficients of importance used for selection

C_j	Name of criteria	k_j
C1	Efficiency	1
C2	Cell dimensions	3
C3	Costs of Production	2
C4	Optimal concentrations	2
C5	Efficient operation capability at concentrations above 1000 x	2

c) Setting the share matrix.

Attribution of importance coefficients, differentiated by relation (2) [2]:

$$P = \frac{1}{2^k} = \left(\frac{1}{2^1}; \frac{1}{2^2}; \frac{1}{2^2}; \frac{1}{2^1}; \frac{1}{2^3}; \frac{1}{2^2}; \frac{1}{2^1}; \frac{1}{2^1}\right) \qquad (2)$$

where: P represents criteria share

k – coefficient of importance [2].

d) Ranking versions after relation (3) [2]:

$$f: V \rightarrow R, defined\ by:$$

$$f(Vi) = \sum_{j=1}^{m} Pj \times 2^{-loc(Vi,Cj)} \qquad (3)$$

where: Pj represents criteria share;

loc (vj,Cj) – place of version „i" after criteria „j".

After performing the calculation, the version with the highest value is considered to be the optimal one [2].

2.2.2 Method of global evaluation of performances

a) Setting the importance coefficients afferent to the evaluation criteria.

Table 8 Coefficients of importance used for selection

C_j	Name of criteria	k_j
C1	Efficiency	3
C2	Cell dimensions	1
C3	Costs of Production	2
C4	Optimal concentrations	2
C5	Efficient operation capability at concentrations above 1000 x	2

For setting the importance coefficients a scale of ranking from 1 to 3 is used, where 1 is low importance and 3 is maximum importance. The chosen importance coefficients are synthetic presented in table 8 [1, 3, 6].

b) Choosing the evaluation scales.

In order to express the evaluation of versions through each criteria, a scale of qualifiers is used initially, instead of a number one, as follows: very good (VG), good (G), medium (M), satisfactory (S), unsatisfying (US). Because the calculation needs figures, a conversion must be made of qualifiers in numbers, as it is presented below. The conversion of qualifiers in numbers is made after the specialty literature, according to the table 9 [1, 3].

Table 9 Transformation of qualifiers in numbers, depending on the importance qualifiers

	Very well	Well	Mediocre	Satisfactory	Unsatisfactory
Criteria weight 3	10	7,5	5	2,5	0
Criteria weight 2	8	6,5	5	3,5	2
Criteria weight 1	7	6	5	4	3

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c) Setting the matrix with the qualifiers and the matrix with the numbers

Based upon the technical data of the multi-junctions photovoltaic cells typology, a qualifiers matrix is established, being presented synthetic in table 10.

Table 10 Qualifiers matrix

MJ Cell Types	C_j				
	C1	C2	C3	C4	C5
3JC_38%	US	M	VG	M	S
3JC_40%	M	M	VG	M	S
3JC_42%	G	M	G	VG	G
3JC_44%	VG	G	M	VG	G
4JC_45%	VG	VG	S	S	US

The obtained qualifiers will be transformed into numbers, and the data is written in the matrix according to table 11. For transforming the qualifiers in numbers, the transformation relations will be used (tab. 9).

Table 11 Numbers matrix

MJ Cell Types	Cj				
	C1	C2	C3	C4	C5
3JC_38%	0	5	8	5	3,5
3JC_40%	5	5	8	5	3,5
3JC_42%	7,5	5	6,5	8	6,5
3JC_44%	10	6	5	8	6,5
4JC_45%	10	7	3,5	3,5	2

d) The calculation of global index and ranking the results.

Evaluation of MJ cells typology will be made with the help of the global index, calculated after the relation (4), which evaluates the quality of each MJ cell, and has the expression [2, 3, 6]:

$$Ig = \max \sum_{j=1}^{n} \mathrm{Ni} \times \mathrm{kj} \qquad (4)$$

where: Ig is the global index of evaluation of performances;

Ni – given number;

kj - coefficient of importance afferent to the criteria.

After performing the calculation, the version with the highest value of global index is considered to be the optimal solution [2].

3 Problem Solution

Using the above formula, calculation has been made for each case, as it follows:

3.1 Onicescu Method

The optimal version is set by calculation of aggregation functions according to formula (1) and (3).

3.1.1 Version 1 - choosing criteria equal as importance:

In case of version where the choosing criteria are equal as importance, the results are put in table 12.

Table 12 The values calculated for criteria equal as importance

T_i	Types	Calculated Value	Position
T_1	3JC_38%	0,66	4
T_2	3JC_40%	0,56	5
T_3	3JC_42%	0,88	3
T_4	3JC_44%	1,56	1
T_5	4JC_45%	1,19	2

Analyzing the data, it can be observed a difference of versions, the calculated version being 0,56 to 1,56.

3.1.2 Version 2 - Choosing criteria with different importance criteria

In case of version where the choosing criteria have different coefficients, the results are put in table 13.

Table 13 Values calculated for criteria with different importance criteria

T_i	Types	Calculated Value	Position
T1	3JC_38%	0,17	4
T2	3JC_40%	0,15	5
T3	3JC_42%	0,23	3
T4	3JC_44%	0,42	1
T5	4JC_45%	0,36	2

Analyzing this data, it can be observed a difference of versions, the calculated version being from 0,15 to 0,42.

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3.2 Method of global evaluation of performances

In case of global evaluation of performances method, the calculation was performed after formula (4), and the results are put in table 14.

Table 14 Values of global index

MJ cell types	C_j: C1	C2	C3	C4	C5	Global indicator	Position
k_j	3	2	2	3	1		
3JC_38%	0	5	8	5	3,5	38	5
3JC_40%	5	5	8	5	3,5	53	4
3JC_42%	7,5	5	6,5	8	6,5	69,5	2
3JC_44%	10	6	5	8	6,5	75	1
4JC_45%	10	7	3,5	3,5	2	55	3

Analyzing this data, it can be observed a difference of versions, the global index having values from 38 to 75.

3.3 Data summary – comparison of results

For solving this problem, the calculation have been finalized and the final results were synthetic submitted in table 15.

After analyzing the data presented in table 15, one can conclude that optimal multi-junctions cell typology to be used in the field of concentrated photovoltaic system is not necessarily the cell with the highest efficiency or the lowest cost, as might interpret in the absence of multi-criteria analysis methods.

In this case the Triple Junction Solar Cell with efficiency 44% outperforms other cells due to achieving higher levels of satisfaction of key decision criteria.

Table 15 Final data regarding choosing the type of MJ cell

Fuel Cells Types	Method: Onicescu 1	Onicescu 2	Global Evaluation of Performances
3JC_38%	4	4	5
3JC_40%	5	5	4
3JC_42%	3	3	2
3JC_44%	1	1	1
4JC_45%	2	2	3

4 Conclusion

The multicriteria analysis describes the structured approach that was used to determine the general preferences among many alternatives, options which lead to fulfilling a number of objectives. The purpose of these methods is to perform a comparative evaluation of alternative versions.

From the study that was performed, results the fact that choosing the technical solution can be influenced by the chosen mathematic pattern.

The method of global evaluation of performances facilitates choosing the optimal version, it is a logical support to found the decision, but it anticipates the advantages of different criteria taken into account, still it exists a certain degree of subjectivity in establishing the importance coefficients given to the decision criteria.

The Onicescu Method presents the advantage of elimination subjectivity in appreciation of versions, but it maintains the degree of subjectivity in establishing the importance coefficients given to the decision criteria.

After this study of case, analyzing by comparison the results, it can be said that in the case where the Onicescu Method is used to rank the typologies taken into consideration, the optimal technology of multi-junctions photovoltaic cell to be used in the domain of concentrated photovoltaic system is the same, both in the version where the choosing criteria were equal as importance and in the version where the choosing criteria have different importance coefficients. Using the method of global evaluation of performances, it can be seen that the results for optimal technology to be used in the domain of concentrated photovoltaic, is the same as the method Onicescu.

This thing cannot be generalized because it is possible that in case of usage of different scales of classification one obtains different final results, but the final top is always very close

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