SIMULATION-BASED ANALYSIS OF OPTIMAL PV MODULE SELECTION DURING PV SYSTEM DESIGN

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Abstract

Having in mind that among renewable energy resources we know today, solar energy is the most beneficial, relatively limitless, effective, and dependable, the aim of this paper is to analyse relevant technical characteristics of different PV modules in the same output power range, and their influences on overall system electricity generation. The PV power plant capacity is designed not to exceed 12 kW, in the weather conditions typical for the Novi Sad city region (Republic of Serbia). Simulation is based on NREL (National Renewable Energy Laboratory) photovoltaic performance model which combines module and inverter sub models with supplementary code to calculate a photovoltaic power system's hourly AC output given a weather file and data describing the physical characteristics of the module, inverter, and array. Furthermore, the characteristic losses are calculated and presented for fixed array PV system. Lastly, a selection of best-fitting variant was carried out through PROMETHEE Gaia multi-criteria decision making (MCDM) method.

Keywords: Solar Photovoltaic (PV); System Advisor Model (SAM); PROMETHEE Gaia; MCDM; Simulation; system design.

1. Introduction

Photovoltaic (PV) systems, among other renewable energy systems, strive to be both energy efficient and cost competitive in order to emerge as a prominent mode of electricity production for exponentially growing needs in modern manufacturing. However, conversion efficiency, defined as the percentage of solar insolation converted to electricity, has been one of the primary performance metrics for evaluating alternative PV technologies [1]. Unfortunately, conversion efficiency only addresses the operational energy efficiency of a PV module. Having this in mind, a more comprehensive analysis, which includes variety of parameters is necessary in order to ensure best performance system operation and functioning.

Determent of the energy amount generated by a PV system is a widely discussed topic [2]–[4], whether using detailed simulation models of its elements and subsystems [5]–[13] or more simplified methods [14], [15]. Subsequently, there are a variety of meteorological databases suitable for simulation purposes such as AEMET, European Solar Radiation

Atlas, NASA, METEONORM, ISPRA-GIS, HELIOS, Solar GIS, PV-Design Pro [4], etc., providing a solid foundation for photovoltaic energy ratings in a wide range of climatological conditions.

On the other hand, commercially available PV sizing software such as PVSYST, PVSOL, SAM, SOLARPRO, etc., apply unique algorithms to evaluate energy generated by the system as well as to minimize energy losses caused by various factors during generation.

Furthermore, in order to deal with the environmental concerns which make the path to sustainability goals difficult, the integration of appropriate renewable energy alternatives for electricity generation is of crucial importance. Since 2014, the use of minimum levels of energy from renewable sources in new and existing buildings is required by the building regulations of EU member states. Numerous studies, concerning the selection of the best renewable energy alternative, are available for Romania, Malaysia, Turkey, Lithuania, Saudi Arabia, Greece, and Ecuador [16]. These studies highlighted the fact that the selection of the best solutions among a vast diversity of alternatives (wind generators, biomass, solar energy, geothermal, hydro generators) taking into consideration different criteria (economic, environmental, social, etc.) is a complex problem when it comes to decision making process.

Additional studies, conducted in Finland, United Kingdom, Lithuania, and Greece [16] emphasized the necessity to take into account the renewable energy alternatives preferences of the building occupants, while another stream of research was focused on different uncertainties that can affect the evaluation of renewable energy alternatives.

Given the aforementioned and taking into account uncertainty of subjective opinions, the aim of this paper is to provide simulation-based exact data-supported parameters for 10-variant (10 different PV modules were considered) PV system which all elements remain the same except PV modules. The analysis is carried out for micro location (Novi Sad city region) in order to determine which of the observed PV modules ensures best system performance in terms of electricity generation with minimal losses and other drawbacks. The data generation is ensured through simulation which was carried out according to System Advisor Model (SAM) methodology. Moreover, generated data were subjected to Multi-criteria decision making (MCDM) analysis according to PROMETHEE Gaia methodology in order to segregate optimal variant for most efficient PV system setup. The main aim of this paper was to generate a hybrid methodology for PV systems design analysis and multi-criteria decision making process in order to ease integration of renewable (solar) energy into modern manufacturing practice.

2. Research Methodology

This section consists of two equally relevant topics. First one focuses on SAM simulation methodology for data-supported system parameters generation, while the second one discusses PROMETHEE Gaia MCDM methodology based on previously mentioned parameters.

2.1. SAM simulation methodology

SAM simulation methodology is based on photovoltaic performance model which combines specified modules and inverters with supplementary code to calculate a PV system's hourly AC output for a given weather file and data, describing the physical characteristics of the module, inverter, and array [17]. The model calculates the system's AC electrical output over one year as an array of 8760 hourly AC power values. It reads hourly solar resource and temperature data from a weather file, describing the resource at the system's location for the year, and uses them with inputs describing the system's design in equations to calculate module and inverter conversion efficiencies as well as related energy losses. The module and inverter model calculate solar energy to DC electricity and DC to AC electricity conversion efficiencies, respectively, and account for losses associated with each component. In the Fig. 1 a basic block diagram of the simulation model is given. For the sake of simplicity, simulation procedure is described through 8 main steps (S1-S8), while associated sub steps related to S1 and S6 are indicated with letters (A-E).

Fig. 1. Basic block diagram of the SAM simulation model

The given model performs the following calculations for each time step in one year as follows:

(S1) For each array (or up to four sub arrays):

(A) Calculate sun angles from date, time, and geographic position data from the weather file.

- (B) Calculate the nominal beam and diffuse irradiance incident on the plane of array (POA) irradiance. This depends on the solar irradiance data in the weather file, sun angle calculations, user-specified sub array parameters such as tracking and orientation parameters, as well as backtracking option for one-axis trackers.
- (C) Apply the user-specified beam and diffuse nearby-object shading losses to the nominal beam and diffuse POA irradiance.
- (D) For fixed sub arrays and sub arrays with one-axis tracking and self-shading enabled, calculate and apply the self-shading loss factors to the nominal beam and diffuse POA irradiance.
- (E) Apply user-specified monthly soiling factors to calculate the effective POA irradiance on the sub array.
- (S2) For sub arrays with no tracking (fixed) and self-shading enabled, calculate the reduced diffuse POA irradiance and self-shading DC loss.
- (S3) Determine sub array string voltage calculation method.
- (S4) For each of up to four sub arrays, run the module model with the effective beam and diffuse POA irradiance and module parameters as input to calculate the DC output power, module efficiency, DC voltage, and cell temperature of a single module in the sub array.
- (S5) Calculate the sub array string voltage using the method determined in S3.
- (S6) For each sub array, calculate the array DC power:
 - (A) Apply the fixed self-shading DC loss to the module DC power if it applies.
 - (B) Calculate the sub array gross DC power by multiplying the module DC power by the number of modules in the sub array.
 - (C) Calculate sub array DC power by multiplying the gross sub array power by the DC loss.
 - (D) Calculate the sub array string voltage by multiplying the module voltage by the number of modules per string.
 - (E) Calculate the array DC power by adding up the sub array values.
- (S7) Run the inverter model to calculate the gross AC power and inverter conversion efficiency.
- (S8) Calculate the AC power by applying the AC loss to the gross AC power.

2.2. PROMETHEE Gaia MCDM methodology

PROMETHEE (*Preference Ranking Organization METHod of Enrichment Evaluation*) method belongs to the class of methods for multiple ranging alternatives. It has iterative character and consists of a certain number of steps. The base class of problems that could be solved by this method is in the domain of MCDM [18]. More precisely, the problems in which in the finite set of alternatives A from which is necessary to choose the most acceptable one, linked to a number of criteria, could be considered for solving. Mathematical formulation of the problem is presented as follows:

$$\max[k_1(a), k_2(a), \dots, k_n(a)], n \geq 2, a \in A \quad (1)$$

Where:

A - The final set of available alternatives;
 $k_1 - k_n$ - n criteria, defined by decision maker.

Also, it should be noted that for the analysis purpose for the observed problem, method PROMETHEE II was used because it allows the complete ranking of alternatives. The specificity of this method is a function of preference. It serves to reduce the difference values for each pair of alternatives to a range of 0 to 1, by any criteria. Therefore, the normalization of the values in the matrix and obtaining information about preference (dominance, prosperity) of each alternative in relation to any among all the criteria could be achieved. The method of solving multi-criteria task by applying PROMETHEE II method, is given through 4 main steps:

- (S1) Determination of mutual preference of alternatives, $P(A_1, A_2)$, for each pair of alternatives from a set of alternatives A , in accordance with the selected type of preference functions and parameters of these functions.
- (S2) Formation of indexes of preference for each pair of alternatives. This characteristic is about the preference of alternative A_1 in relation to the alternative A_2 , but taking into account all criteria at the same time, in contrast to $P_j(A_1, A_2)$, which is also about the preference of alternative A_1 in relation to the alternative A_2 , but only by the j^{th} criterion.
- (S3) The formation of Index Preference Matrix
- (S4) Calculation of the positive $\Phi^+(A_1)$ and negative $\Phi^-(A_1)$ characteristic for each alternative from set A . $\Phi^+(A_1)$ shows how much the alternative A_1 is better than all the other alternatives from the A alternative set, by all criteria from a set of criteria K . Logically, $\Phi^-(A_1)$, gives the opposite information, more precisely, how much all of the other alternatives are better than the alternative A_1 .

Possibility of the non-comparability existence is excluded by introduction of characteristic $\Phi(A_1)$, which represents an overall preference of alternative A_1 , which could be calculated as follows:

$$\Phi(A_1) = \Phi^+(A_1) - \Phi^-(A_1) \quad (2)$$

According to the PROMETHEE II method, the alternative A_1 is preferred in relation to the alternative A_2 , if it is as follows:

$$A_1 P^{II} A_2 \text{ "iff" } \Phi(A_1) > \Phi(A_2) \quad (3)$$

Likewise, an alternative A_1 is indifferent in relation to the alternative A_2 if:

$$A_1 I^{II} A_2 \text{ "iff" } \Phi(A_1) = \Phi(A_2) \quad (4)$$

Based on these characteristics it is possible to make a final ranking of alternatives, which is discussed hereafter.

3. System sizing and SAM simulation results

The capacity of desired array size is designed not to exceed 12 kW, while system sizing consists from several steps starting from defining weather conditions at observed location which are briefly summarized in Table 1.

Station ID	131681	Global Horizontal	3.96 [kWh/m ² /day]
Data Source	ISD-TMYx	Direct Normal (Beam)	3.31 [kWh/m ² /day]
Elevation	87 [m]	Diffuse Horizontal	1.91 [kWh/m ² /day]
Latitude	45.25 °N	Average Temperature	10.5 [°C]
Longitude	19.883 °E	Average Wind Speed	3.0 [m/s]
Time Zone	GMT +1	Maximum Snow Depth	28 [cm]
		Annual Albedo	-999

Table 1. Weather conditions at observed location

Subsequently, the relevant characteristics of considered PV modules at referent conditions and associated temperature coefficients up to 10 alternatives are given in Table 2 (due to its large volume, it is shown on the next page). Furthermore, relevant characteristics of selected inverter are listed in the table 3.

Inverter characteristics		Sandia Coefficients	
Number of MPPT inputs	1	C₀	-2.0351e ⁻⁰⁶ [1/Wac]
CEC weighted efficiency	98.305 [%]	C₁	5.27102e ⁻⁰⁶ [1/Vdc]
European weighted efficiency	98.122 [%]	C₂	0.001088 [1/Vdc]
Max AC power	6000 [Wac]	C₃	0.000228 [1/Vdc]
Max DC power	6113.36 [Wdc]		
Power consumption during operation	16.7773 [Wdc]		
Power consumption at night	1.8 [Wac]		
Nominal AC voltage	240 [Vac]		
Max DC voltage	480 [Vdc]		
Max DC current	16.1303 [Adc]		
Min MPPT DC voltage	100 [Vdc]		
Nominam DC voltage	379 [Vdc]		
Max MPPT DC voltage	480 [Vdc]		

Table 3. Relevant characteristics of selected inverter

After the consideration of described weather file, PV module alternatives and inverter type it is possible to proceed with system design. It is important to mention that there are no limitations in terms of mounting area, which often represents the limiting factor for PV array setup. Also, no self-shading or external object shading was foreseen during system design. Lastly, table 4 provide relevant information regarding PV system tracking and orientation, as well as subsequently determined system losses. All of the above represent the necessary input for simulation of PV energy generation in order to ensure sustainable energy supply to defined energy demand load.

Finally, table 5 provides overview regarding SAM simulation results which are used as input parameters in following PROMETHEE Gaia analysis in order to determine optimal selection among 10 PV module alternatives by taking into account overall PV system performance and efficiency.

Parameter	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇	V ₈	V ₉	V ₁₀
Nominal efficiency [%]	15.5389	15.5119	15.3361	18.0089	15.4742	15.4661	18.3161	15.6884	18.4122	18.2941
Maximum power [W _{DC}]	303.163	300	299.975	300.029	300.2	300.042	300.384	300.12	300.303	300.024
Max power voltage [V _{DC}]	37.7	37.5	35.5	32.8	38	36.7	33.6	36.6	54.7	32.4
Max power current [A _{DC}]	8.1	8	8.4	9.1	7.9	8.2	8.9	8.2	5.5	9.3
Open circuit voltage [V _{DC}]	44.9	46.1	44.8	39.4	46.4	44.9	41.4	45.1	64	40.5
Short circuit current [A _{DC}]	8.5	8.6	8.8	9.7	8.7	8.7	9.4	8.7	5.9	9.5
Temperature coefficient C1 [%/°C]	-0.44	-0.431	-0.461	-0.472	-0.439	-0.446	-0.35	-0.45	-0.386	-0.38
Temperature coefficient C1 [W/°C]	-1.335	-1.293	-1.382	-1.415	-1.319	-1.338	-1.051	-1.351	-1.159	-1.14
Temperature coefficient C2 [%/°C]	-0.328	-0.319	-0.343	-0.345	-0.434	-0.346	-0.26	-0.33	-0.273	-0.287
Temperature coefficient C2 [V/°C]	-0.147	-0.147	-0.153	-0.136	-0.202	-0.155	-0.108	-0.149	-0.175	-0.116
Temperature coefficient C3 [%/°C]	0.06	0.047	0.066	0.032	0.076	0.041	0.04	0.05	0.062	0.031
Temperature coefficient C3 [A/°C]	0.005	0.004	0.006	0.003	0.007	0.004	0.004	0.004	0.004	0.003
Module area [m ²]	1.951	1.934	1.956	1.666	1.94	1.94	1.64	1.913	1.631	1.64
Number of cells [pcs]	72	72	72	60	72	72	60	72	96	60
Module NOCT temperature rating (T _{NOCT}) [°C]	46.2	46	50	47.5	47.3	47.7	44.7	46.7	46	44.2
Reference ideality factor (A _{ref}) [V]	1.90068	1.88418	1.88954	1.67538	2.05054	1.86021	1.51191	1.87819	2.57301	1.51162
Reference light current (I _{L,ref}) [A]	8.54297	8.57116	9.01401	9.72433	8.69292	8.72764	9.4348	8.72567	5.87316	9.81622
Reference diode saturation current (I _{0,ref}) [A]	4.75e-10	1.99e-10	4.56e-10	5.89e-10	1.23e-09	2.85e-10	1.20e-11	3.22e-10	9.03e-11	2.25e-11
Series resistance (R _s) [Ω]	0.185136	0.374864	0.453876	0.176232	0.299336	0.328824	0.355983	0.361955	0.242538	0.384206
Reference shunt resistance (R _{sh,ref}) [Ω]	532.524	287.614	626.5	396.054	113.245	375.218	699.297	556.389	451.241	485.778

Table 2. Relevant PV module characteristics at referent conditions and associated temperature coefficients for each up to 10 alternatives (V₁ – V₁₀).

Tracking and orientation		System losses		
Tracking	No (fixed)	Average Annual Soiling		
Tilt	20 [°]	Diodes and connections		
Azimuth	180 [°]	DC wiring		
Ground coverage ratio	0.3	Ac wiring		
Shading	No			

Table 4. PV System tracking, orientation and system losses

Photovoltaic System - Performance Model (12 DC kW Nameplate, Novi Sad, Serbia, Coordinates: 45.25 °N, 19.88 °E GMT +1)										
	V ₁	V ₂	V ₃	V ₄	V ₅	V ₆	V ₇	V ₈	V ₉	V ₁₀
Module level										
Cell material	Multi-c-Si	Multi-c-Si	Multi-c-Si	Mono-c-Si	Mono-c-Si	Multi-c-Si	Mono-c-Si	Multi-c-Si	Mono-c-Si	Mono-c-Si
Module area [m ²]	1.95	1.93	1.96	1.67	1.94	1.94	1.64	1.91	1.63	1.64
Module capacity [W _{DC}]	303.16	300	299.97	300.03	300.2	300.04	300.38	300.12	300.3	300.02
Quantity [pcs]	40	40	40	36	40	40	36	40	40	36
Total capacity [kW _{DC}]	12.13	12	12	10.8	12.01	12	10.81	12	12.01	10.8
Total area [m ²]	78	77	78	59	77	77	59	76	65	59
Inverter level										
Unit capacity [kW _{AC}]	6	6	6	6	6	6	6	6	6	6
Input voltage [V _{DC}]	100 - 480	100 - 480	100 - 480	100 - 480	100 - 480	100 - 480	100 - 480	100 - 480	100 - 480	100 - 480
Quantity [pcs]	2	2	2	2	2	2	2	2	2	2
Total capacity [kW _{AC}]	12	12	12	12	12	12	12	12	12	12
DC to AC Capacity Ratio	1.01	1	1	0.9	1	1	0.9	1	1	0.9
AC losses [%]	2	2	2	2	2	2	2	2	2	2
Array level										
Strings	5	5	5	4	5	5	4	5	8	4
Modules per string	8	8	8	9	8	8	9	8	5	9
System overall										
GHI [kWh/m ² /day]	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96	3.96
POA [kWh/m ² /day]	4	4	4	4	4	4	4	4	4	4
Net to inverter [kWh _{DC}]	16,610	16,770	16,730	14,820	16,540	16,630	15,400	16,720	16,480	15,460
Net to grid [kWh _{AC}]	16,140	16,290	16,260	14,390	16,070	16,160	14,960	16,250	16,020	15,020
Capacity factor	15.2	15.5	15.5	15.2	15.3	15.4	15.8	15.5	15.2	15.9
Performance ratio	0.82	0.84	0.83	0.82	0.82	0.83	0.85	0.83	0.82	0.86
AC wiring loss [kWh]	163.112	165.444	164.332	145.448	162.426	163.285	151.154	164.199	161.906	151.791
DC diode & connections loss [kWh]	86.9365	88.1786	87.5701	77.5456	86.5726	87.0218	80.5899	87.5084	86.2779	80.9197
DC mismatch loss [kWh]	347.746	352.714	350.28	310.182	346.29	348.087	322.36	350.033	345.112	323.679
Inverter night time loss [kWh _{yr}]	16.4628	16.4556	16.4556	16.4736	16.4628	16.4556	16.4736	16.4556	16.4664	16.4736
Inverter consumption loss [kWh _{yr}]	85.425	85.6605	84.535	89.2851	86.1836	85.2607	89.831	85.1394	82.7743	88.7825
First year kWh(AC)/kW(DC) [kWh/Kw]	1331.61	1364.89	1355.83	1333.11	1339.09	1346.88	1383.78	1354.07	1334.35	1391.27
Temperature coefficient C1 [W/°C]	-1.335	-1.293	-1.382	-1.415	-1.319	-1.338	-1.051	-1.351	-1.159	-1.14
Temperature coefficient C2 [%/°C]	-0.147	-0.147	-0.153	-0.136	-0.202	-0.155	-0.108	-0.149	-0.175	-0.116
Temperature coefficient C2 [V/°C]	0.005	0.004	0.006	0.003	0.007	0.004	0.004	0.004	0.004	0.003

Table 5. SAM simulation results

4. PROMETHEE Gaia simulation results

In this research, 10 PV modules types (alternatives) were evaluated upon 19 relevant criteria starting from module and ending at system level. Relevant criteria values were generated through SAM simulation procedure, while PROMETHEE II method was used to rank all observed alternatives and provide best-fitting one for the described PV system functionality and performance. Adequate data regarding alternatives, criteria, calculation functions, preferences, statistics and finally evaluations are summarized in tables 6 and 7, which are provided hereinafter.

Additionally, PROMETHEE analysis results are briefly summarized in the form of flow table with associated performance aggregated score (Table 8). Also, PROMETHEE partial and complete rankings are given in the figure 2.

Fig. 2. PROMETHEE partial (left) and complete (right) rankings

Sensitivity analysis of criteria weights is performed to determine stability intervals for each weight, in which final ranking of alternatives remains unchanged. The stability interval values for the proposed problem are presented in Table 9. From these results, it can be concluded that criteria weights can vary to certain extent without changing the order of alternatives. Also, another conclusion could be made regarding that all criteria have influence on final ranking of alternatives since none of the stability intervals belong to the range from 0 to 1.

Subsequently, sensitivity analysis was performed to further confirm the quality of criteria weights. Stability intervals show that the order of alternatives will remain the same for certain range of weight changes for any of the criteria. Also, there are no criteria that are not affecting the final order of alternatives. These facts provide fundamental confidence that criteria weights used in the ranking part of the proposed method are valid, while simultaneously justifies the model in terms of robustness.

Criteria (C ₁ – C ₁₉)	Unit	Preferences					Statistics					
		Min/Max	Scaled Weight	Preference function	Thresholds	Q: Indifference	P: Preference	S: Gaussian	Min	Max	Average	Std. Dev.
Module area	[m ²]	min	0.02	Gaussian	absolute	n/a	n/a	0.15	1.63	1.96	1.82	0.14
Module capacity	[W _{DC}]	max	0.08	Gaussian	absolute	n/a	n/a	0.95	299.97	303.16	300.4	0.93
Quantity	[pcs]	min	0.02	Gaussian	absolute	n/a	n/a	1.93	36	40	38.8	1.83
Total capacity	[kW _{DC}]	max	0.08	Gaussian	absolute	n/a	n/a	0.59	10.8	12.13	11.66	0.56
Total area	[m ²]	min	0.05	V-shape	absolute	n/a	17.52	n/a	59	78	70.5	8.35
DC to AC Capacity Ratio		max	0.08	Gaussian	absolute	n/a	n/a	0.05	0.9	1.01	0.97	0.05
First year kWh _{AC} /kW _{DC}	[kWh/kW]	max	0.08	V-shape	absolute	n/a	41.44	n/a	1331.61	1391.27	1353.49	19.98
Net to inverter	[kWh _{DC}]	max	0.08	Gaussian	absolute	n/a	n/a	706.88	14820	16770	16216	671.76
Net to grid	[kWh _{AC}]	max	0.08	Gaussian	absolute	n/a	n/a	690.37	14390	16290	15756	656.01
Capacity factor		max	0.08	Gaussian	absolute	n/a	n/a	0.24	15.2	15.9	15.45	0.23
Performance ratio		max	0.08	Gaussian	absolute	n/a	n/a	0.01	0.82	0.86	0.83	0.01
AC wiring loss	[kWh]	min	0.02	Gaussian	absolute	n/a	n/a	7.04	145.45	165.44	159.31	6.7
DC diode & connections loss	[kWh]	min	0.02	Gaussian	absolute	n/a	n/a	3.74	77.55	88.18	84.91	3.56
DC mismatch loss	[kWh]	min	0.02	Gaussian	absolute	n/a	n/a	14.96	310.18	352.71	339.65	14.23
Inverter night time loss	[kWh]	min	0.02	Gaussian	absolute	n/a	n/a	0.008	16.456	16.474	16.464	0.008
Inverter consumption loss	[kWh]	min	0.02	Gaussian	absolute	n/a	n/a	2.25	82.77	89.83	86.29	2.16
Temperature coefficient C ₁	[W/°C]	min	0.08	Gaussian	absolute	n/a	n/a	0.118	-1.415	-1.051	-1.278	0.113
Temperature coefficient C ₂	[V/°C]	min	0.08	Gaussian	absolute	n/a	n/a	0.027	-0.202	-0.108	-0.149	0.025
Temperature coefficient C ₃	[A/°C]	max	0.08	Gaussian	absolute	n/a	n/a	0.001	0.003	0.007	0.004	0.001

Table 6. PROMETHEE criteria preferences and statistics overview

Rank	Alternative	Φ	Φ^+	Φ^-	PA Score
1	V3	0.1382	0.2525	0.1143	100.00
2	V5	0.1012	0.2523	0.1511	92.77
3	V2	0.1009	0.2270	0.1262	92.70
4	V8	0.0636	0.1936	0.1300	86.00
5	V1	0.0582	0.2384	0.1802	85.07
6	V6	0.0321	0.1744	0.1423	80.74
7	V9	-0.0305	0.1762	0.2067	71.23
8	V10	-0.0689	0.2830	0.3519	65.95
9	V7	-0.0999	0.2648	0.3647	61.96
10	V4	-0.2948	0.1297	0.4245	41.24

Table 8. PROMETHEE Flow Table with Performance Aggregated Score

Criteria ($C_1 - C_{19}$)	Unit	Evaluations																
		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}							
Module area	[m ²]	1.95	1.93	1.96	1.67	1.94	1.94	1.64	1.91	1.63	1.64							
Module capacity	[W _{DC}]	303.16	300	299.97	300.03	300.02	300.04	300.38	300.12	300.3	300.02							
Quantity	[pcs]	40	40	40	36	40	40	36	40	40	36							
Total capacity	[kW _{DC}]	12.13	12	12	10.8	12.01	12	10.81	12	12.01	10.8							
Total area	[m ²]	78	77	78	59	77	77	59	76	65	59							
DC to AC Capacity Ratio		1.01	1	1	0.9	1	1	0.9	1	1	0.9							
First year kWh _{AC} /kW _{DC}	[kWh/kW]	1331.61	1364.89	1355.83	1333.11	1339.09	1346.88	1383.87	1354.07	1334.35	1391.27							
Net to inverter	[kWh _{DC}]	16610	16770	16730	14820	16540	16630	15400	16720	16480	15460							
Net to grid	[kWh _{AC}]	16140	16290	16260	14390	16070	16160	14960	16250	16020	15020							
Capacity factor		15.2	15.5	15.5	15.2	15.3	15.4	15.8	15.5	15.2	15.9							
Performance ratio		0.82	0.84	0.83	0.82	0.82	0.83	0.85	0.83	0.82	0.86							
AC wiring loss	[kWh]	163.11	165.44	164.33	145.45	162.43	163.28	151.15	164.2	161.91	151.79							
DC diode & connections loss	[kWh]	86.94	88.18	87.57	77.5	86.57	87.02	80.59	87.51	86.28	80.92							
DC mismatch loss	[kWh]	347.75	352.71	350.28	310.18	346.29	348.09	322.36	350.03	345.11	323.68							
Inverter night time loss	[kWh]	16.463	16.456	16.456	16.474	16.463	16.456	16.474	16.45	16.466	16.474							
Inverter consumption loss	[kWh]	85.42	85.66	84.53	89.29	86.18	85.26	89.83	85.14	82.77	88.78							
Temperature coefficient C_1	[W/°C]	-1.335	-1.293	-1.382	-1.415	-1.319	-1.338	-1.051	-1.351	-1.159	-1.14							
Temperature coefficient C_2	[V/°C]	-0.147	-0.147	-0.153	-0.136	-0.202	-0.155	-0.108	-0.149	-0.17	-0.116							
Temperature coefficient C_3	[A/°C]	0.005	0.004	0.006	0.003	0.007	0.004	0.004	0.004	0.004	0.003							

Table 7. PROMETHEE criteria evaluations overview

Criteria	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{16}	C_{17}	C_{18}	C_{19}
Scaled Weight	0.02	0.08	0.02	0.08	0.05	0.08	0.08	0.08	0.08	0.08	0.08	0.02	0.02	0.02	0.02	0.02	0.08	0.08	0.08
Stab. Int. [%]	Min	0.00	5.48	0.00	3.91	0.00	3.86	6.73	2.84	2.85	6.72	6.33	1.17	1.17	0.13	0.00	7.31	7.65	7.66
	Max	4.16	8.14	5.25	20.40	11.95	21.47	7.74	8.18	8.20	7.78	7.73	6.25	6.26	1.63	1.92	20.08	11.87	8.83

Table 9. Stability interval values for the proposed problem per criterion ($C_1 - C_{19}$)

5. Conclusion

In this paper key parameters for determining the energy performance of a conceptual, 12 kW nominal output power, PV power plant with 10 possible alternatives in terms of PV modules system integration were observed. The aim of this paper was to provide scientific and technical approach in order to define optimal functionality and performance of overall PV-based energy generation system. In the first iteration, SAM simulation model was used to generate PV system performance parameters for aforementioned alternatives, while second iteration considers these parameters as inputs for following PROMETHEE Gaia analysis in order to determine optimal PV modules selection among these alternatives by taking into account overall PV system performance and efficiency. Finally, it was determined that the best system performance could be achieved with alternative V₃. Within this system setup, total PV system capacity of 12 kW is ensured, energy yield amounts 1364.89 kWh/kW, annual net amount of energy fed into grid is 16,290 kWh with capacity factor value of 15.5 and performance ratio 0.84. Also, it was confirmed that the proposed method is convenient for this type of problems, in which there is a vagueness and uncertainty related to determination of criteria weights but precise information about the attributes that are describing criteria. Moreover criteria suitability was validated through stability interval analysis, also provided in this manuscript. Lastly, this research contributes to the existing literature by widening the area in which PROMETHEE method can be used, while future plans consider the application of this approach in the concrete case for metal forming manufacturing system. The observed system is custom-based machining facility specialized in the field of automotive and aviation industry with focus on machine-made parts, details, components, assemblies and fixtures in quantities of single-piece prototypes to large volume production machining.

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7. References

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