Applying the Paraconsistent Annotated Evidential Logic Eτ in a Solar Tracker for Photovoltaic Panels: An Analytical Approach

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Abstract. There is an increasing contrast between large urban centers and rural areas, even nowadays, where the most basic resources can be scarce, leading an increasing development of technologies based upon self-sustainable solutions, where the electrical power is an important demand to be supplied. Through Bibliographic and Experimental research, plus a prototype using embedded and real-time software, and its testing, it was possible to develop a workable solution. This paper presents a self-oriented solar panel based on Paraconsistent Annotated Evidential Logic Eτ, its construction and practical tests, where total power of 3.19375 W was obtained against 2.427556 W from a fixed panel of same type, representing an increase of 31.56239% in the overall power.

Keywords: Solar energy · Photovoltaic · Power optimization · Energetic sustainability · Paraconsistent Annotated Evidential Logic Eτ

1 Introduction

Nowadays, despite development of new technologies being a constant activity, many cases of very scarce resources are not rare, particularly in locations far from urban centers [13].

One of the most important of these resources is the electricity, often unavailable because of large distances between distribution networks and the locations itself, or even because the great importance of local ecosystems [1].

The difficulties in bringing rural electrification to these places, and the need to limit the use of fossil fuels, replacing them with non-polluting and renewable energy alternatives, make urgent investments in research and development of improved alternative energy sources [2].

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Fossil fuels are the main source of energy in the world and are at the center of the world's energy demands. However, its availability is limited, and its large-scale use is associated with environmental degradation. The negative effects known from use of these fuels include acid rain, depletion of the ozone layer and global climate changes [3].

Following this panorama, an important method for obtaining electricity without burning fossil fuels is through a photovoltaic solar panel. Supply only implies in the cost of equipment itself, with no carbon liberated during operation [4, 13].

However, an important problem is related to the positioning of the solar panel, which is often fixed and does not have the ability to follow the natural movement of the sun throughout the day, which is related to the question of Maximum Power Point (MPP) of the panel [5], as seen on Fig. 1.

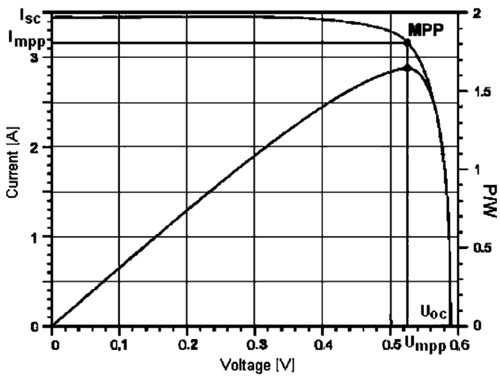

Fig. 1. Typical curve of a solar cell [5, 13].

Many systems are proposed to circumvent this problem, but without the ability to handle situations of inconsistency or contradiction in the collected data [6, 7].

By using embedded and real-time software, a controller board and a sample from the voltage provided by the photovoltaic panel, it is possible to obtain a correct positioning with a stepper motor mechanically attached to it [14].

Through Paraconsistent Annotated Evidential Logic Eτ, it is intended to reach an optimal performance by the decision-making process, being able to handle situations where the signals from the panel are not conclusive or contradictory [13].

2 Paraconsistent Logic

2.1 Historical Background

The Genesis of Paraconsistent Logic originated in 1910, by the work of logicians N.A. Vasil'év and J. Łukasiewicz. In 1948, Jaskowski, encouraged by his professor Łukasiewicz, discovered Discursive Logic. [8, 14]. Going beyond the work of Jaskowski, the Brazilian logician Newton C.A. Da Costa extended its systems for the treatment of inconsistencies, having been recognized for it as the introducer of

Paraconsistent Logic. Abe [8, 14], also a Brazilian logician, set several other applications of Annotated Systems, specially Logic Eτ, establishing the basic study of Model Theory and the Theory of Annotated Sets. Many previous publications have heterogeneous nomenclatures. This paper presents a new convention.

2.2 Certainty and Uncertainty Degrees

By using the properties of real numbers, it is possible to build a mathematical structure with the aim of materializing how to manipulate the mechanical concept of certainty, uncertainty, inconsistent and indeterminate, among others (Fig. 2) [18]. Such mechanism will embark the true and false states treated on classical logic, with all its consequences [14, 18]. Therefore, several concepts are introduced which are considered "intuitive" for the purpose above:

Perfectly defined segment AB: $(\mu - \lambda) = 0;\ 0 \leq \mu,\ \lambda \leq 1;$

Perfectly undefined segment CD: $[(\mu + \lambda) - 1] = 0;\ 0 \leq \mu,\ \lambda \leq 1;$

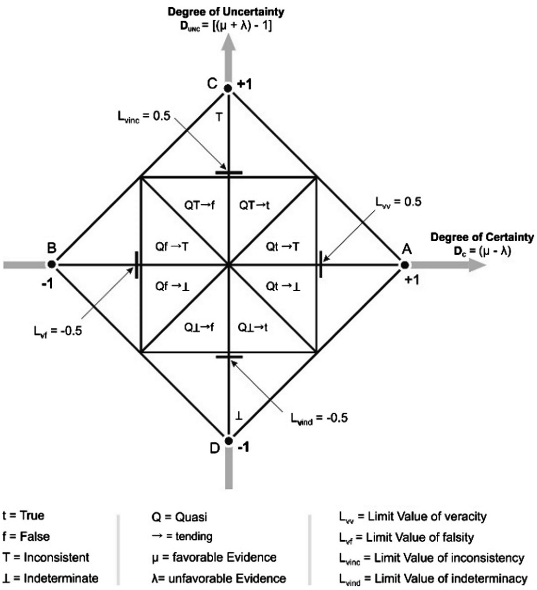

Fig. 2. τ reticulate [18].

Therefore, in the first case, the favorable evidence is the Boolean complement of unfavorable evidence and, second, the unfavorable evidence is the Boolean complement of favorable evidence, which shows that the evidence, both favorable and unfavorable 'behave' as if classic. It varies continuously from the false (0, 1) to the truth (1, 0) [14, 18].

The logical states can be defined by:

Inconsistency Degree:	$G_{inc}(\mu, \lambda) = \mu + \lambda - 1, \text{ since } \mu + \lambda - 1 \geq 0$
Indeterminacy Degree:	$G_{ind}(\mu, \lambda) = \mu + \lambda - 1, \text{ since } \mu + \lambda - 1 \leq 0$
Truth Degree:	$G_{tru}(\mu, \lambda) = \mu - \lambda, \text{ since } \mu - \lambda \geq 0$
Falsehood Degree:	$G_{fal}(\mu, \lambda) = \mu - \lambda, \text{ since } \mu - \lambda \leq 0$

It is seen that the Truth Degree "measures" how an annotation (μ, λ) "distances" from the perfectly defined segment and how it "approaches" of the state, and the degree of Falsehood "measures" how an annotation (μ, λ) "distances" from the segment perfectly defined, and how it "approaches" the false state [14, 18].

Similarly, the inconsistency degree "measures" how an annotation (μ, λ) "distances" from the undefined segment and how "close" it is from the inconsistent state, and the Indeterminacy degree "measures" how an annotation (μ, λ) "distances" of the undefined segment, and how "close" it is from the indeterminate state [14, 18].

Is called G_{unc} uncertainty degree (μ, λ) from an entry (μ, λ) to any of the degree of inconsistency or indeterminacy. For example, the maximum degree of uncertainty is in an inconsistent state, i.e. G_{inc} (1, 1) = 1. It is called the Certainty Degree G_{cer} (μ, λ) of an annotation (μ, λ) to any of the degrees of truth or falsity [14, 18].

2.3 Embedded and Real-Time Software

Embedded software can be defined as a combination of computer hardware and software, and perhaps additional mechanical or other parts, designed to perform a dedicated function. In some cases, embedded systems are part of a larger system or product [16].

Real-time systems can be any computer system, embedded or otherwise, that has timeliness requirements. The following question can be used to distinguish real-time systems from the rest: "Is a late answer as bad, or even worse, than a wrong answer?" In other words, what happens if the computation doesn't finish in time? If nothing bad happens, it's not a real-time system. If someone dies or the mission fails, it's generally considered "hard" real-time, which is meant to imply that the system has hard deadlines. Everything in between is "soft" real-time [17].

The principal role embedded software is not the transformation of data, but rather the interaction with the physical world. It executes on machines that are not, first and foremost, computers. There are cars, airplanes, competition cars, audio equipment, autonomous robots, toys, security systems, cell phones, heart monitors, weapons, Smart televisions, Laser printers, scanners, microwaves devices, traffic system, climate control systems, manufacturing systems, and so on. Software with a principal role of interacting with the physical world must, of necessity, acquire some properties of the physical world. It takes time. It consumes power. It does not terminate, unless it fails [17].

2.4 Paraconsistent Controller

The Para-analyzer controller was built in order to embark the paraconsistent logic by treating the values of favorable and unfavorable evidence, resulting in certainty and uncertainty degrees, plus a logical state [8, 13].

Both evidence values are obtained with an interval of 500 ms between them, which allows a proper distinction and the capture of the logic states Indeterminate (⊥) – with low intensity and uniform λ and μ, representing a dimly lit room – and Inconsistent (T), with high-intensity and uniform μ and λ, representing an external environment with nuisances like shadows of trees, birds or other moving obstacles [14, 18].

3 Practical Implementation and Results

The prototype was built upon a wooden base support and a mobile holder for the photovoltaic panel, tractioned by a stepper motor and a belt system.

For sensing purposes, the voltage supplied by the panel itself was sampled, applied to the input of the controller board and subjected to an inverter, as part of the embedded software, to obtain the favorable (μ) and unfavorable evidence degrees (λ).

Tests were run under normal sunlight conditions during three days, being the prototype subject of any weather variations except rain. An increase of 34.84213% in average power could be achieved in the end of the first day, 38.62905% on the second and 22.51104% on third day, as seen on graphics of Figs. 3, 4 and 5, respectively.

Day 1					
Fixed - Panel			LPAEτ - Panel		
V	A	W	V	A	W
11,3	0,1	1,13	13,9	0,19	2,641
12,1	0,12	1,452	14,3	0,2	2,86
12,8	0,12	1,536	14,4	0,21	3,024
13,6	0,18	2,448	14,7	0,22	3,234
14	0,2	2,8	14,6	0,2	2,92
15,2	0,22	3,344	14,5	0,2	2,9
15	0,22	3,3	15,3	0,23	3,519
14,7	0,21	3,087	15,2	0,23	3,496
14	0,2	2,8	15,4	0,22	3,388
13,7	0,16	2,192	15	0,2	3
13	0,14	1,82	15	0,2	3
11,5	0,11	1,265	14	0,19	2,66
	P(AVG)	2,2645		P(AVG)	3,0535
		Result %	34,84213		

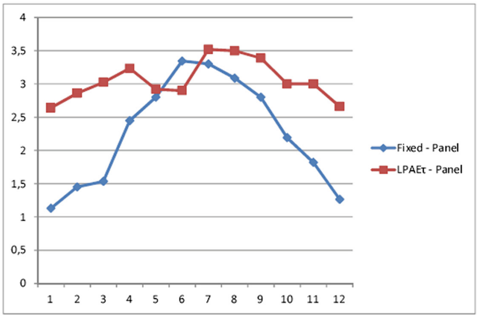

Fig. 3. Power output of Paraconsistent × Fixed panels – Day 1.

Day 2					
Fixed - Panel			LPAEτ - Panel		
V	A	W	V	A	W
10,7	0,14	1,498	13,4	0,19	2,546
12,7	0,15	1,905	14	0,2	2,8
12	0,15	1,8	13,9	0,19	2,641
12,3	0,17	2,091	15	0,23	3,45
14,4	0,17	2,448	15,7	0,24	3,768
15,6	0,24	3,744	16	0,27	4,32
15,4	0,23	3,542	15,8	0,24	3,792
15	0,21	3,15	15,7	0,24	3,768
14,3	0,2	2,86	15,2	0,22	3,344
13,7	0,16	2,192	14,8	0,22	3,256
12,8	0,14	1,792	14,5	0,21	3,045
11,5	0,11	1,265	13,8	0,18	2,484
	P(AVG)	2,35725		P(AVG)	3,267833
		Result %	38,62905		

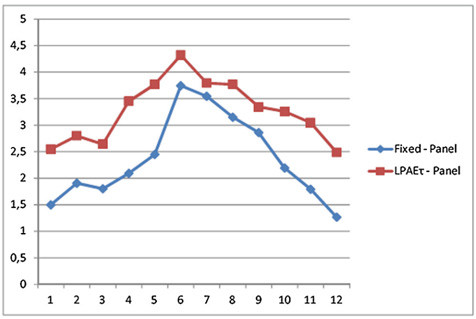

Fig. 4. Power output of Paraconsistent × Fixed panels – Day 2.

Day 3					
Fixed - Panel			LPAEτ - Panel		
V	A	W	V	A	W
13	0,18	2,34	13,8	0,2	2,76
14,2	0,2	2,84	14,6	0,22	3,212
14,3	0,19	2,717	14,8	0,22	3,256
14,3	0,18	2,574	14,8	0,22	3,256
14,4	0,18	2,592	15,3	0,24	3,672
15,5	0,24	3,72	15,5	0,25	3,875
15,5	0,23	3,565	16	0,26	4,16
14,7	0,21	3,087	15,1	0,22	3,322
14,4	0,2	2,88	15	0,22	3,3
13,8	0,18	2,484	14,2	0,2	2,84
12	0,15	1,8	14,2	0,21	2,982
11,1	0,12	1,332	13,8	0,18	2,484
	P(AVG)	2,660917		P(AVG)	3,259917
		Result %	22,51104		

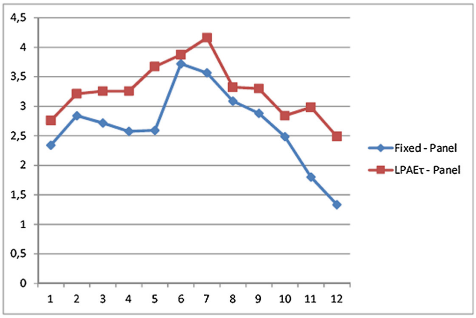

Fig. 5. Power output of Paraconsistent × Fixed panels – Day 3.

4 Final Results and Conclusions

This paper proposes a low-environmental impact alternative for places where electricity is not available, by using a self-oriented solar photovoltaic panel and Real-time embedded software.

The Paraconsistent Annotated Evidential Logic Eτ was used in order to make the decision process by the embedded software, allowing the panel to be more accurately positioned in situations of inconsistency or indeterminacy in the data collected. For each case, a reticulate chart can be created. In this work a general graph was presented, which may be the source for other studies.

By using the voltage supplied by the panel itself sampled and applied to the controller board it was possible to obtain favorable (μ) and unfavorable evidence degrees (λ) directly from the same source as the generated electricity, allowing a better tracking than using a separate sensor, as done in early projects.

After practical tests, the power generation of the prototype was enhanced by 31.56239% in an average value for the three days, as seen on graphic of Fig. 6.

Final Results			
Fixed - Panel		LPAEτ - Panel	
id	W	id	W
1	1,656	1	2,649
2	2,065667	2	2,957333
3	2,017667	3	2,973667
4	2,371	4	3,313333
5	2,613333	5	3,453333
6	3,602667	6	3,698333
7	3,469	7	3,823667
8	3,108	8	3,528667
9	2,846667	9	3,344
10	2,289333	10	3,032
11	1,804	11	3,009
12	1,287333	12	2,542667
P(AVG)	2,427556	P(AVG)	3,19375
	Result %	31,56239	

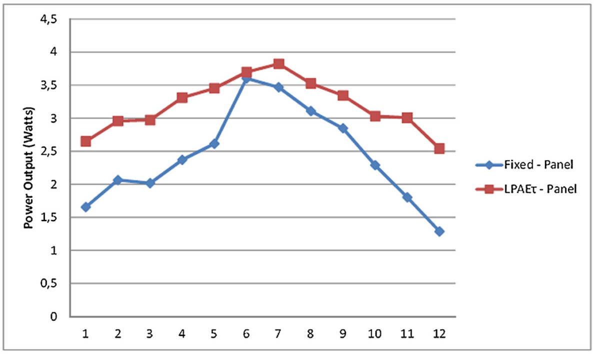

Fig. 6. Power output of Paraconsistent × Fixed panels – final results.

With this new analytical approach, the data collected were presented with a greater number of decimal places, decimals floating point (DFP), besides being recalculated, providing greater accuracy and confiability in the final results.

This shows that the results are compatible with other similar systems [9, 10] and demonstrates that the actual implementation is capable of being implemented as a solution for manufactures of any type.

This result is similar to others found in the literature, as found in Huang et al. [11] (35.8%) and Salas et al. [12] (2.8%–18.5%), specially when compared with fixed panel systems.

5 Future Works

Both the embedded software and the experimental arrangement presented here allow deployments in larger systems with more solar panels, combining greater sophistication and power generation capacity.

With the revisiting of this study, it reinforces the importance of the topic addressed in this research observing that it is an area in truly expansion and frequent evolution. New technologies such as mobile applications and the Internet of Things (IoT) can be integrated.

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