Contribution of Combinational Logic to the Autonomous Behavior of DEVS Systems: Application to Photovoltaic Solar Panels

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Abstract

DEVS (Discrete Event System Specification) systems enable dynamic and event-driven modeling of complex systems. Combinational logic can contribute to the autonomous behavior of these systems by defining internal rules that link inputs (natural factors: sunlight, temperature, wind) to outputs (photovoltaic panel efficiency) without external intervention.

This paper illustrates how integrating combinational logic into a DEVS model, simulated on a Java-based platform developed during my PhD, improves the system's responsiveness and autonomy. Experimental field data are used as a basis to validate the models and demonstrate that DEVS alone is sufficient, but that combinational logic represents a valuable complement.

Keywords: DEVS, combinational logic, autonomous systems, simulation, solar panels, natural factors

1. Introduction

DEVS (Discrete Event System Specification) systems make it possible to dynamically and event-driven model complex systems such as photovoltaic installations. In this context, environmental factors—sunlight, temperature, and wind—constitute critical inputs whose variations directly impact solar panel performance.

During my doctoral research, we developed a Java-based simulation platform using DEVS to reproduce these variations and study the behavior of photovoltaic systems under real or simulated conditions. Field data collected on-site were used to feed and validate this platform.

The objective is to study how DEVS can model the autonomous behavior of solar panels and how combinational logic can improve these models.

2. Materials and Methods

2.1 Materials

The materials were used in the PhD project, whose solution constitutes one of the case studies of this article (Doumbia N. T. & Keita A. K., 2024).

2.2 Methods

2.2.1 Modeling

Modeling consists of organizing knowledge about a system in order to solve a specific problem (Bernard P. Zeigler, 2000).

2.2.1.1 Simulation

Simulation reproduces the dynamic behavior of a system from a model in order to draw conclusions applicable to the real world. Computer simulation aims to design, execute, and analyze a model using a computer.

2.2.1.2 Computer Simulation Approaches

- ✓ Cellular automata
- ✓ Multi-agent systems
- ✓ Discrete events (DEVS)

2.2.1.3 Logic and Boolean Algebra

- ✓ Logic studies the laws of reasoning.
- ✓ Boolean algebra deals with binary functions (0 and 1) and operators: NOT, AND, OR.

2.2.1.4 DEVS (Discrete Event System Specification)

In DEVS, the photovoltaic system can be represented by an atomic model where each internal transition (δ_int) corresponds to the autonomous evolution of the system's state according to changes in natural factors.

According to value ranges reported in scientific publications:

- Sunlight: the panel state changes from "low" to "optimal or favorable" when solar irradiation is between 400 W/m² and 800 W/m², and becomes less favorable between 800 and 1000 W/m². Any interval outside these ranges is considered unfavorable for energy production.

- Temperature: the thermal state of the panel adjusts performance according to a favorable range (20–30 °C), less favorable when above 30 °C and less than or equal to 45 °C. Outside these intervals, conditions are considered unfavorable.
- Wind: wind moderates temperature and slightly influences performance. It is favorable between 4 and 8 m/s and less favorable between 8 and 15 m/s.

The atomic model of each factor is represented by the following diagram:

Illustration 1: Atomic model

M = (X, Y, S, δ_ext, δ_int, λ, ta), where, **X** is the set of input ports and input values, **Y** is the set of output ports and output values, **S** = { (v, S_v) | v ∈ State } is the set of system states, **State** is the set of state variables, **S_v** is the set of possible values for the variable *v*. **δ_ext : Q × S → S** is the external transition function, where **Q** = { (e, s) | s ∈ S, 0 ≤ e ≤ ta(s) }, and **e** represents the elapsed time in state *s*. **δ_int : S → S** is the internal transition function defining state changes caused by internal events, **λ : S → Y** is the output function, and **ta : S → ℝ⁺** is the state lifetime function of the system (ta: time advance function).

Thus, each internal event in DEVS updates the state of the three factors, enabling simulation of the continuous evolution of performance under real conditions.

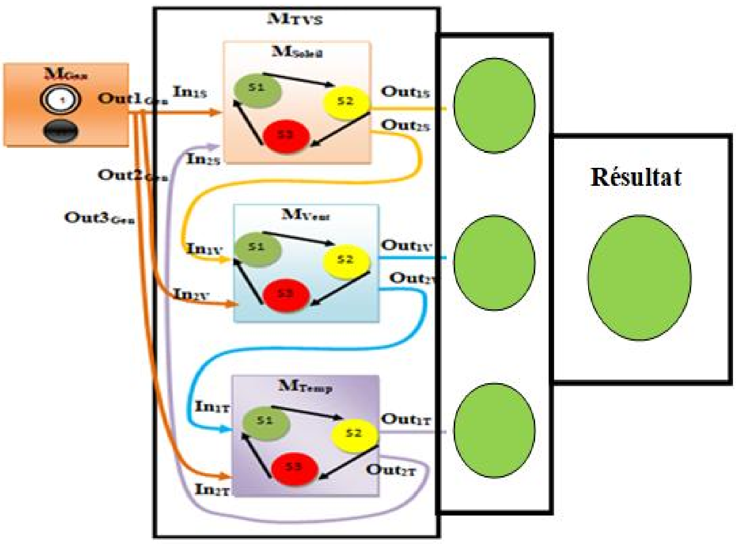

Illustration 2: coupled model

2.2.1.5 Analysis of the DEVS Atomic Model

The internal transition δ_int: S → S (or transition from one state to another) is only possible if the current state is different from the next state. In combinational logic terms, this can be interpreted as a current state different from its successor (S ≠ S').

This procedure must continue to guarantee the autonomous evolution of systems, hence the application of these management rules to operating systems. To preserve the context of the internal transition law in DEVS, the following must be excluded:

- All truth table rows where states are active simultaneously
- All truth table rows where states are inactive simultaneously

The following must be retained:

- All truth table rows with at most one active state, as previously demonstrated in the analysis of the internal transition law (for an internal transition between two states, at least one state must differ in its attributes).

Consequently, we obtain the truth tables, equations, and the atomic logical model presented below.

Table 1: Truth table

Modèle atomique à 3 états (s1, s2, s3)			Ou – exclusif	
S1	S2	S3	$M_{atomique}$ (Y)	
0	0	0	0	
0	0	1	1	A retenir
0	1	0	1	
0	1	1	0	
1	0	0	1	
1	0	1	0	
1	1	0	0	
1	1	1	1 // 0	

Table 2: Three-state atomic model

Modèle atomique à 3 états (s1, s2, s3)			Ou – exclusif	$M_{atomique}$ (Y)
S1	S2	S3	$M_{atomique}$	
0	0	1	1	$\overline{S1}.\overline{S2}.S3$
0	1	0	1	$\overline{S1}.S2.\overline{S3}$
1	0	0	1	$S1.\overline{S2}.\overline{S3}$

$M_{atomique} = \overline{S1}.\overline{S2}.S3 + \overline{S1}S2.\overline{S3} + S1.\overline{S2}.\overline{S3} = S1 \oplus S2 \oplus S3$

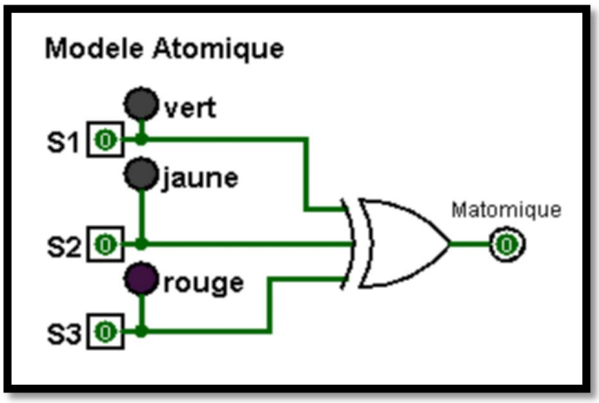

Illustration 3: Atomic model logic

2.2.1.6 Experimentation

Applied to the case study of natural systems influencing the performance of photovoltaic solar panels (Doumbia N. T. & Keita A. K., 2024), we obtain the truth table of the coupled model of the three factors, whose circuit is simulated using the hierarchical design concept in the Logisim simulation software.

Table 3: Truth table for the three factors

Modèles			M_{temp}	M_{vent}	M_{Soleil}	M_{TVS}
S1	S2	S3	$S1 \oplus S2 \oplus S3$	$S1 \oplus S2 \oplus S3$	$S1 \oplus S2 \oplus S3$	M_{temp} et M_{vent} et M_{Soleil}
0	0	1	1	1	1	$S1 \oplus S2 \oplus S3 . S1 \oplus S2 \oplus S3 . S1 \oplus S2 \oplus S3$
0	1	0	1	1	1	
1	0	0	1	1	1	

2.2.1.7 Simulation and Validation

The developed Java-based DEVS platform allows:

Loading experimental field data (irradiation, temperature, wind),

Automatically triggering internal transitions in the DEVS model,

Observing results in real time, comparable to measurements from the experimental field.

This approach demonstrates that DEVS alone is sufficient to model and simulate the system. Internal transitions provide complete autonomy to manage environmental variations.

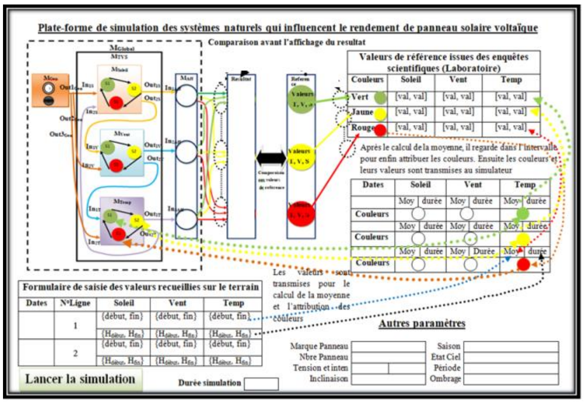

Illustration 4: DEVS-JAVA plaform

2.2.2 Contribution of Combinational Logic

Although DEVS already allows system modeling, integrating combinational logic rules within the internal transition function (δ_int) offers several advantages:

Defining more refined autonomous behavior by simultaneously combining the states of the three factors to determine performance,

Reducing the complexity of certain transitions when multiple events coexist,

Enabling local decision-making without external intervention, which is useful for large-scale or real-time simulations,

Enabling the design, simulation, and verification of logical circuits corresponding to DEVS models and integrating natural factor classification logic.

Thus, combinational logic does not replace DEVS but improves the model's responsiveness and autonomy.

Tableau 4: Classification of Natural Factors

Sun (W/m²)	Temperature (°C)	Wind (m/s)	Color	Status
≥400 and ≤800	≥10 and ≤30	≥3 and ≤8	Green	Favorable
>800 and ≤1000	>30 and ≤45	>8 and ≤15	Yellow	Less favorable
≠ green and yellow	≠ green and yellow	≠ green and yellow	Red	Unfavorable

2.2.2.1 Hierarchical Design of Combinational Logic

This approach makes it possible to manage complex systems by using atomic blocks to build hierarchical coupled models.

Rule for simulating the MTVS coupled model: as with the pure DEVS model, a row is considered only if the three values belong to the same category (green, yellow, or red). Mixed rows are ignored.

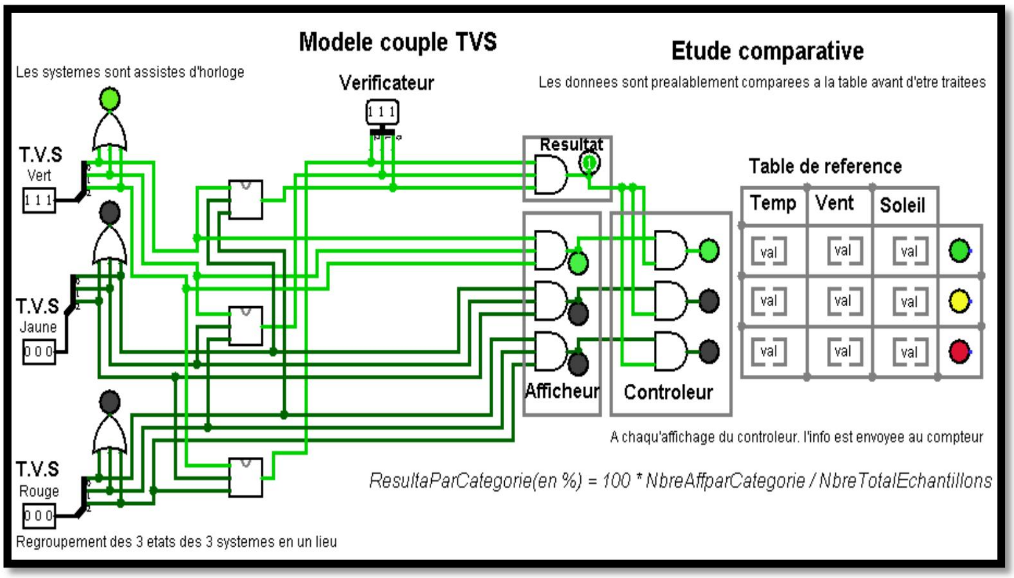

Illustration 5: coupled model logic

3. Results

Table 5: Comparison between Pure DEVS and DEVS + Combinational Logic

Comparison	Autonomy	Responsiveness	DEVS Complexity	Maximum Efficiency Method
Pure DEVS	High	Good	Good	94%
DEVS + combinational logic	Very high	Good	Very good	96%

Simulation based on real data confirms DEVS's ability to faithfully reproduce panel behavior, while combinational logic provides a significant improvement in autonomous management of multiple states.

4. Discussion

Combinational logic, when integrated into DEVS, enables the system to make internal decisions based on environmental conditions, thereby strengthening autonomy. This approach is particularly suited to distributed systems or real-time simulations where frequent human intervention is impossible or costly.

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5. Conclusion

Internal transitions in DEVS make it possible to effectively model variations in natural factors influencing photovoltaic panels.

The use of combinational logic constitutes a powerful complement, increasing the autonomy and responsiveness of simulated systems. This approach, validated by field data, shows that DEVS remains sufficient for simulation, but that combinational logic can optimize autonomous behavior in complex systems.

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