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Research Article

Fault Analysis and Diagnosis in a Three-Level NPC Voltage Inverter

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Abstract – This article discusses an external, qualitative method for diagnosing faults in static converters (DC/AC) based on the analysis of current vector trajectory signatures in the stationary reference frame.

Keywords- Three-Phase Inverter With NPC Structure, PWM, MAS, Diagnostics.

I. INTRODUCTION

Voltage inverters are a crucial component of power electronics and are used in various applications. One of the most well-known applications is variable speed AC machines. The development of fully controllable, powerful, robust, and fast semiconductor components, along with the almost universal use of pulse-width modulation techniques, has driven the rapid evolution of this function. [1-2].

II. THE STRUCTURE OF THE NPC THREE-PHASE THREE-LEVEL INVERTER.

Figure (1) shows the topological structure of a three-phase, three-level voltage inverter, which comprises three single-phase arms. Two secondary DC voltage sources are obtained from the main DC voltage source using a capacitive voltage divider formed by identical filter capacitors C1 and C2. Each secondary source delivers half of the voltage (E/2), and the structure creates a neutral point (M) between the two capacitors to avoid charge imbalance.

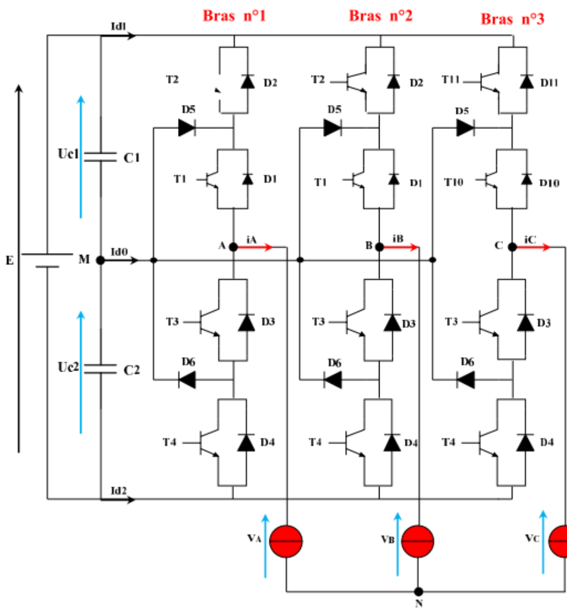

Figure 1. Shows the power structure of the NPC three-phase three-level inverter.

III. CONTROL TECHNOLOGY (PWM)

Pulse-width modulations are the most suitable methods for the inverter, as it can generate a set of constant levels. It is important to use clear and precise language when discussing technical topics [3-4].

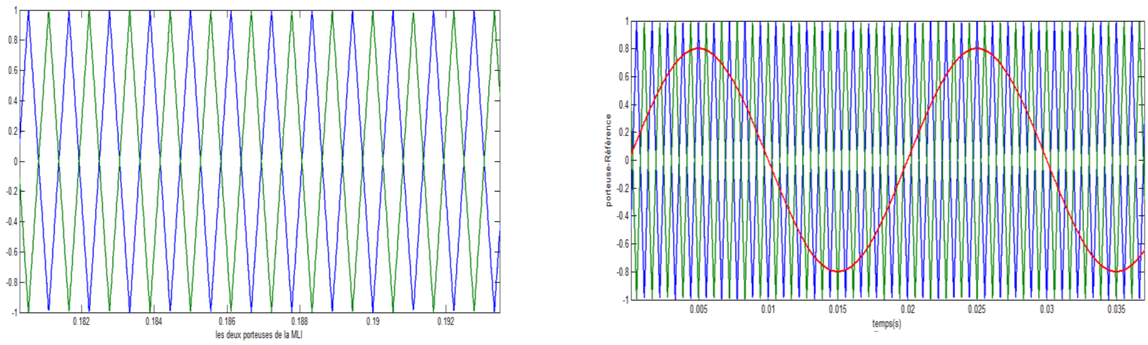

Figure 2. Technical PWM

IV. ASYNCHRONOUS MACHINE CONTROL

A global simulation of the drive of the asynchronous machine fed by the three-level inverter will be conducted. The results obtained and the influence of the PWM will be shown.

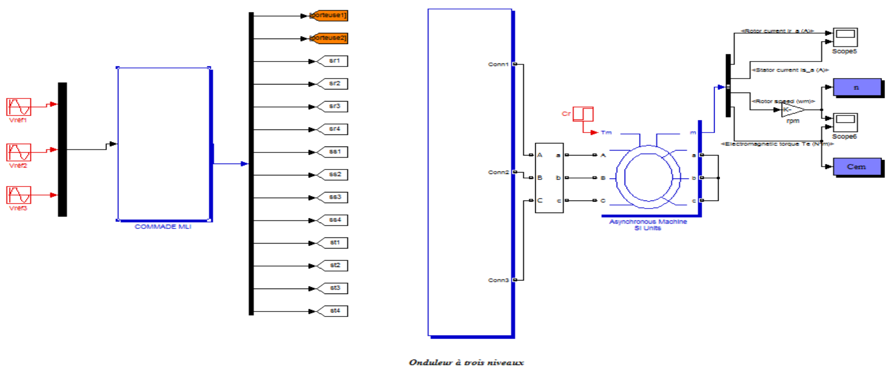

Figure 3. Simulation diagram of the three-level inverter-MAS combination.

V. RESULT OF SIMULATION: COMBINATION OF THREE-LEVEL INVERTER AND ASYNCHRONOUS MACHINE

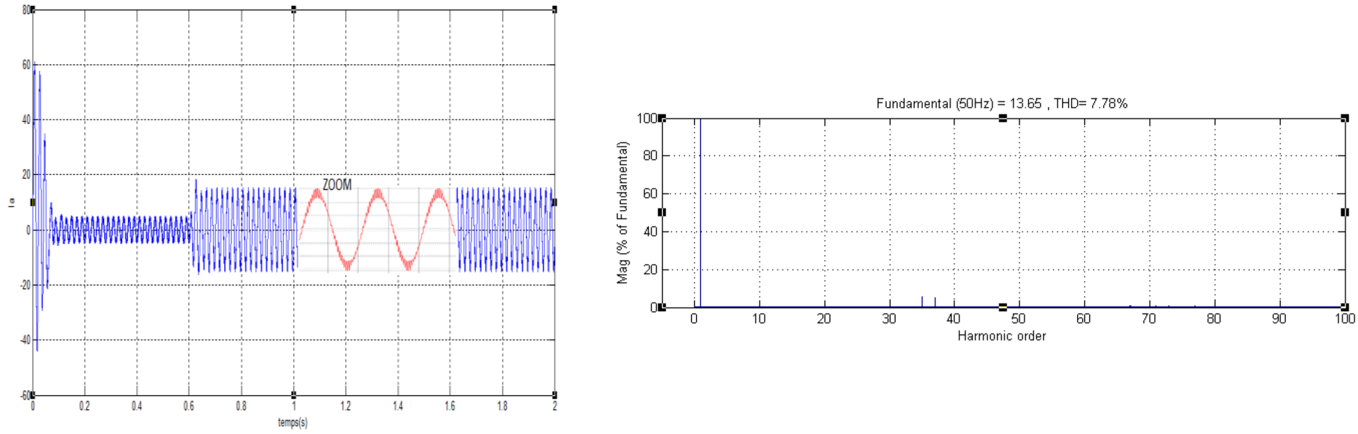

Figure 4. Current Ia and spectral analysis

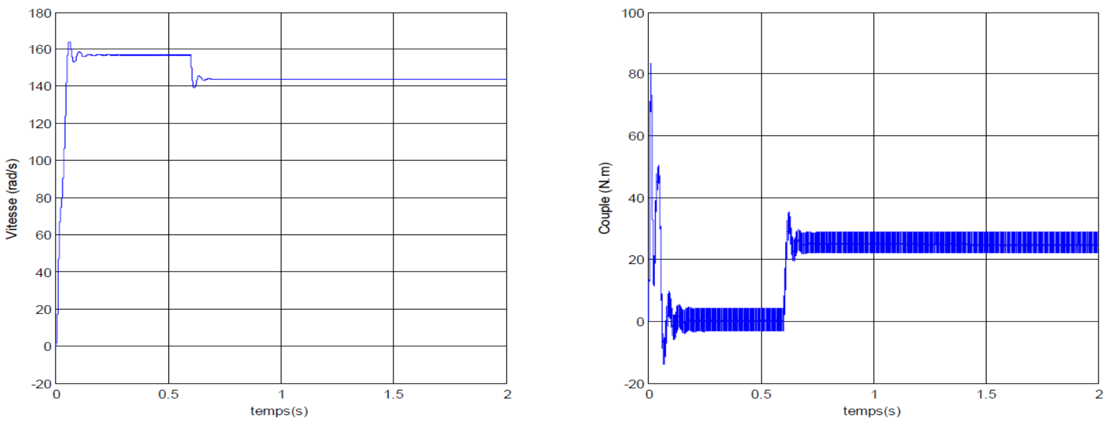

Figure 5. Motor speed and electromagnetic torque

Operating the machine with the PWM inverter introduces higher harmonics, which cause oscillations in the electromagnetic torque. The open-loop control of the model does not perform well because the excessive dynamics impose excessively high transient currents [5-6-7-8].

VI. APPLICATION TO FAULT DIAGNOSIS AND TRANSISTOR OPENING, IN A THREE-PHASE VOLTAGE INVERTER

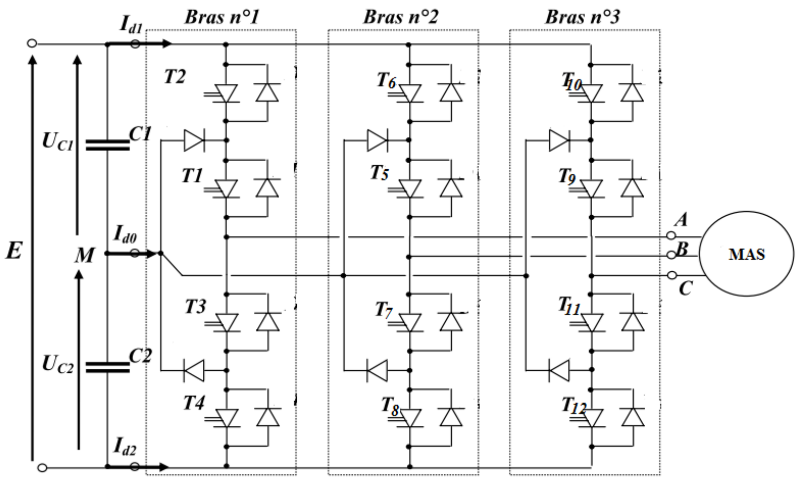

Figure 6. Topological structure of the voltage inverter.

Fault diagnosis in the phase (a)

- **Fault detection phase by slope calculation**

If one of the transistors (T1, T2) or (T3, T4) is open, the phase current (ia) will be zero for half of the current period [3].

If one of the transistors (T1, T2) or (T3, T4) is open, the phase current (ia) will be zero for half of the current period. This will result in the components of the current vector being expressed as:

$$i_\alpha = 0 \; and \; i_\beta = i_b\sqrt{2} \tag{1}$$

The slope is equal to:

$$A = \tan(\beta) = \frac{\Delta i_\alpha}{\Delta i_\beta} \tag{2}$$

So:

$$\beta = 0 \; or \; \beta = \pi \; and \; \theta = \frac{\pi}{2} \; or \; \theta = -\frac{\pi}{2} \tag{3}$$

- **The fault location phase is initiated by analyzing the sign of the phase current (ia).**

By utilizing a simple Schmitt trigger to monitor the sign of the phase current, it is possible to locate the faulty transistor.

Please refer to the figures below for illustration.

To generate the opening fault: on the circuit, an ideal switch is connected in series with the transistor and opened at time t = 0.3s.

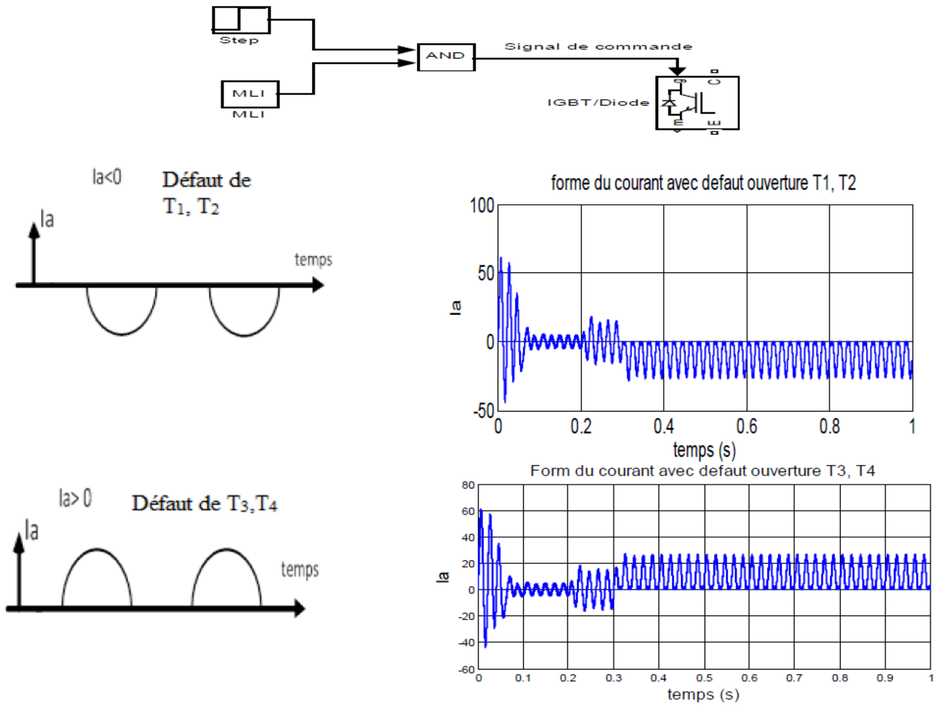

Figure 7. Location of transistor during phase fault (a)

Diagnosis of Fault in Phase Arm:

If either (T5, T6) or (T7, T8) is open, the phase current (ib) will be zero for half of the current, and the slope will have the value:

$$A = \sqrt{3} \quad and \quad i_a = \sqrt{3}\, i_\beta \tag{4}$$

The defective switch can be identified by analyzing the current's sign (ib).

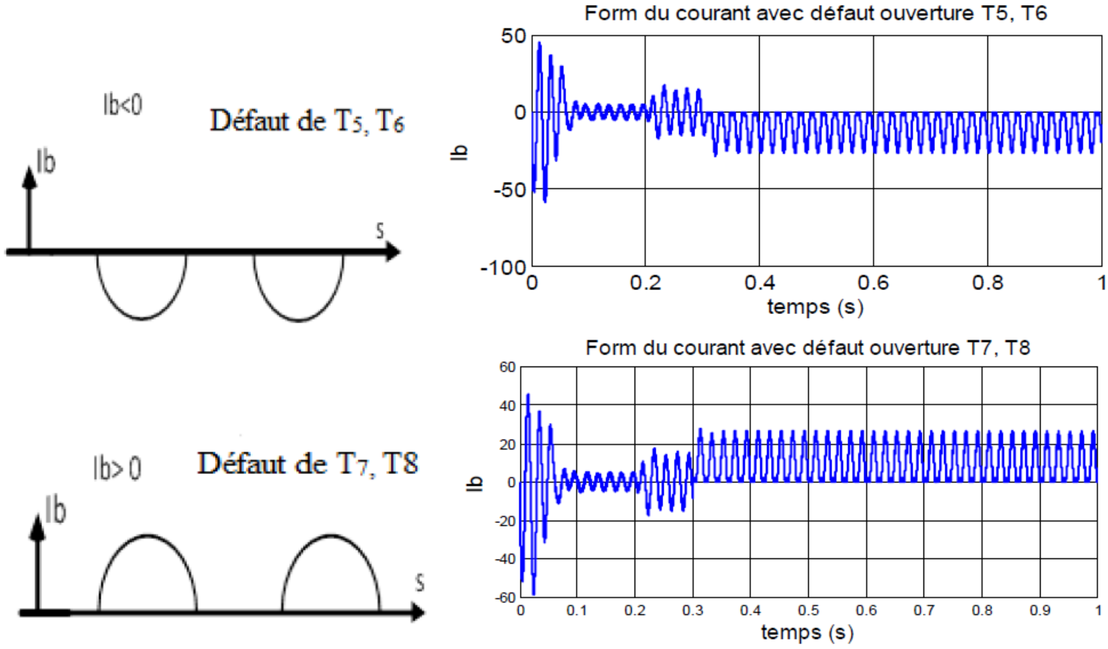

Figure 8. Location of transistor during phase fault (b)

Diagnosis of fault in phase arm (c)

If either (T9, T10) or (T11, T12) is open during the current period, the current (ic) will be zero for half of that period.

As a result, the slope will have the following value:

$$A = -\sqrt{3} \quad and \quad i_a = -\sqrt{3}\, i_\beta \tag{5}$$

The location of the faulty switch can be determined by analyzing the sign of the current (ic).

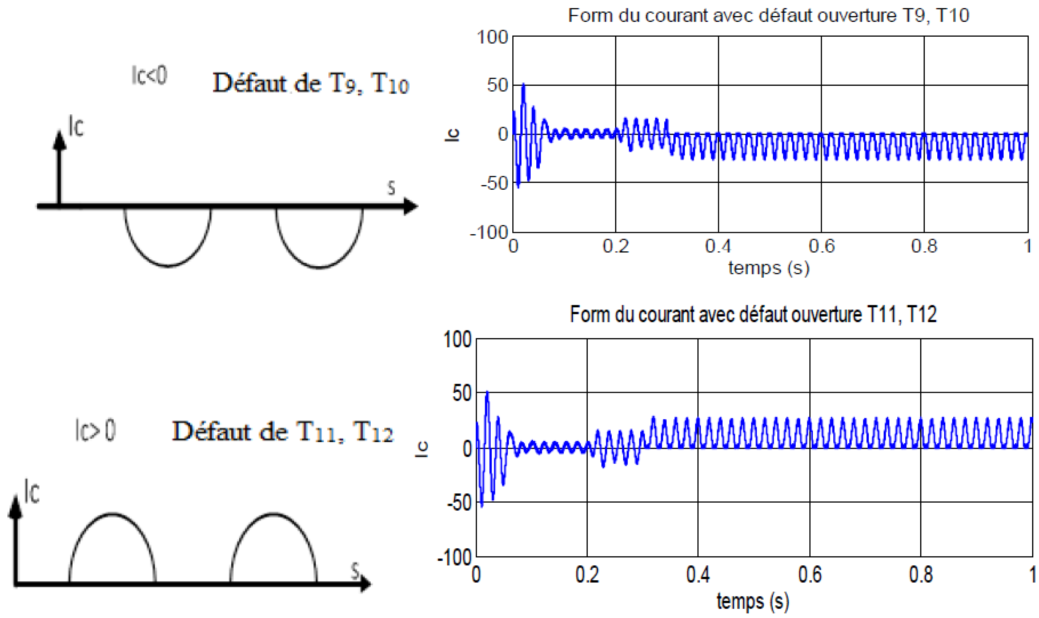

Figure 9. Location of transistor during phase fault (c)

The opening fault signatures of the twelve transistors of the inverter are typical.

Figure 10 shows that the trajectories of the current vector in the presence of defects consist of a non-linear part (semicircle) and a linear part (diameter of the semicircle).

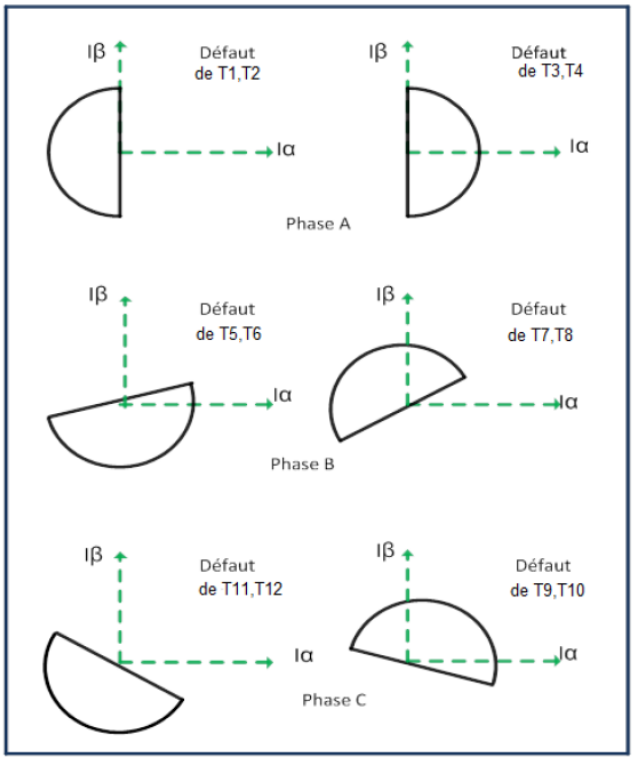

Figure 9. The opening fault mode trajectories of T1-T12 are as follows:

Diagnostic Summary for Inverter Opening Faults

- **Faulty half-arm detection phase:**

Detection of average current values using sign table:

Table1. Table for detecting faults

	I_{am}	I_{bm}	I_{cm}	$I_{\alpha m}$	$I_{\beta m}$
T1, T2	-	+	+	+	-
T3, T4	+	-	-	+	-
T5, T6	+	-	+	+	-
T7, T8	-	+	-	-	+
T9, T10	+		-	+	+
T11, T12	-	-	+	-	-

Table2.Summary Table

Malfunctioning switch	Trajectory space.	The "A" slope
T1, T2	90°< ϴ < 270°	0
T3, T4	210°< ϴ <30°	$\sqrt{3}$
T5, T6	330°< ϴ <150°	- $\sqrt{3}$
T7, T8	270°< ϴ <90°	0
T9, T10	150°< ϴ <330°	-$\sqrt{3}$
T11, T12	30°< ϴ <210°	$\sqrt{3}$

Transistor Fault Signature

In this section on simulation results, we focus on the trajectory of the current vector, also known as the park contour, which represents a typical fault signature.

- **Signature in the system correct**

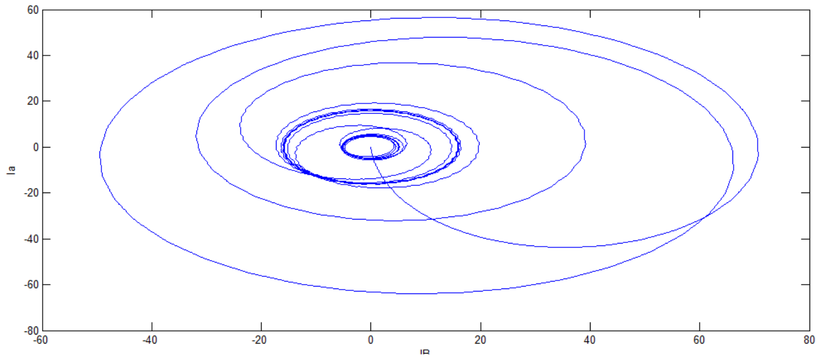

Figure 10. Park contour in the system correct

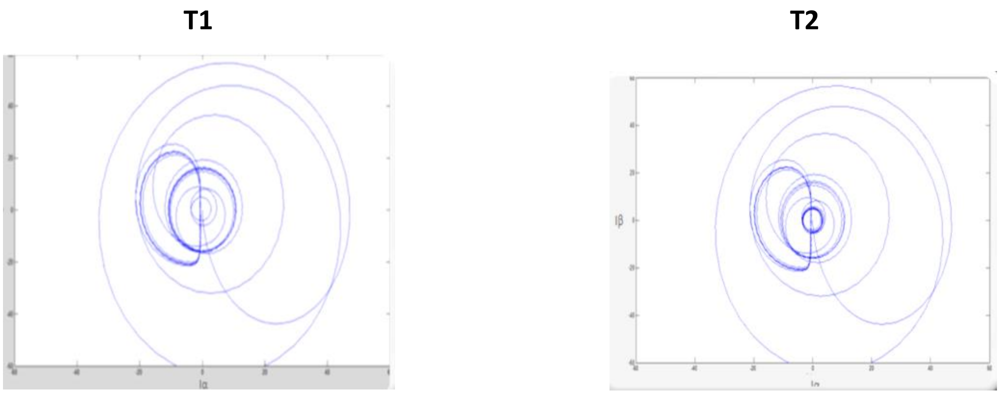

Figure 11. park contours for (T1 ,T2) opening faults

Locating Switch Opening Faults:

- Phase A has been selected.
- The average voltage across the switches in the half-arm localized by the Park contour is provided.

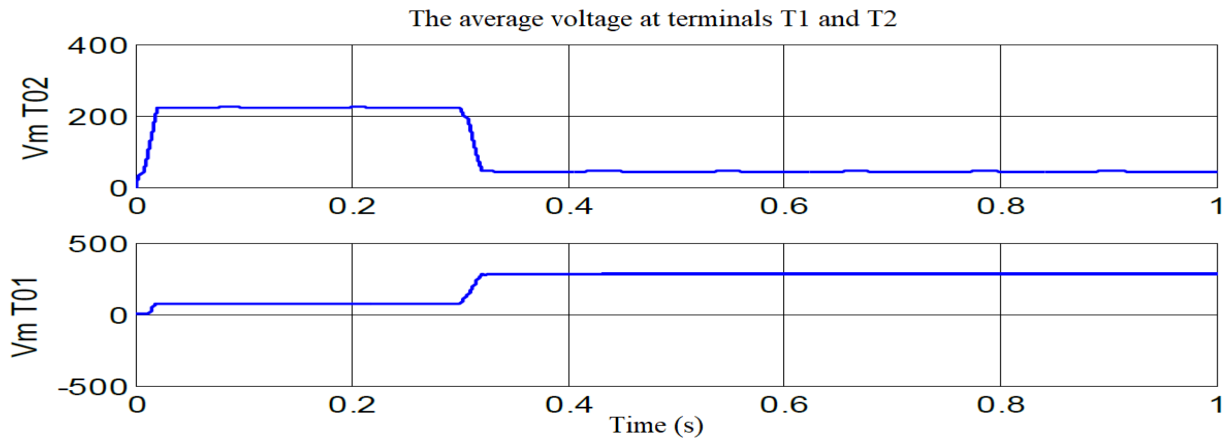

Figure 12. Average switch voltages when T1 is open.

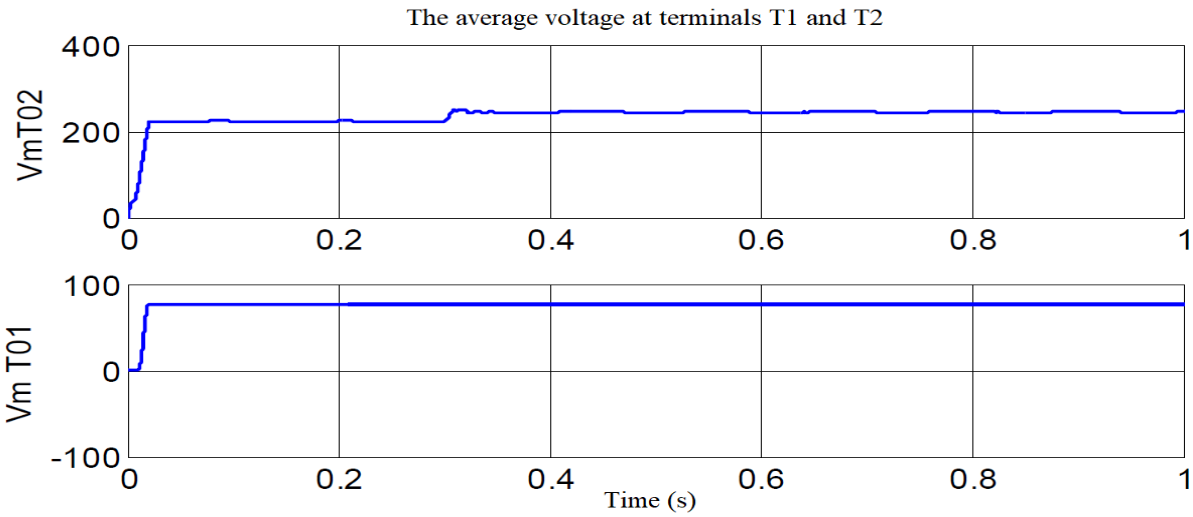

Figure 13. Average switch voltages when T2 is open.

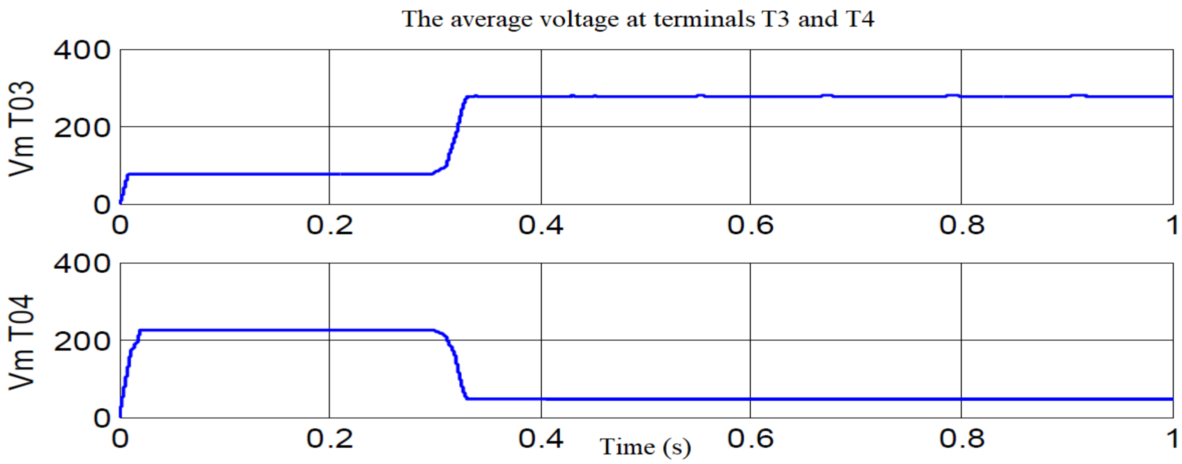

Figure 14. Average switch voltages when T3 is open.

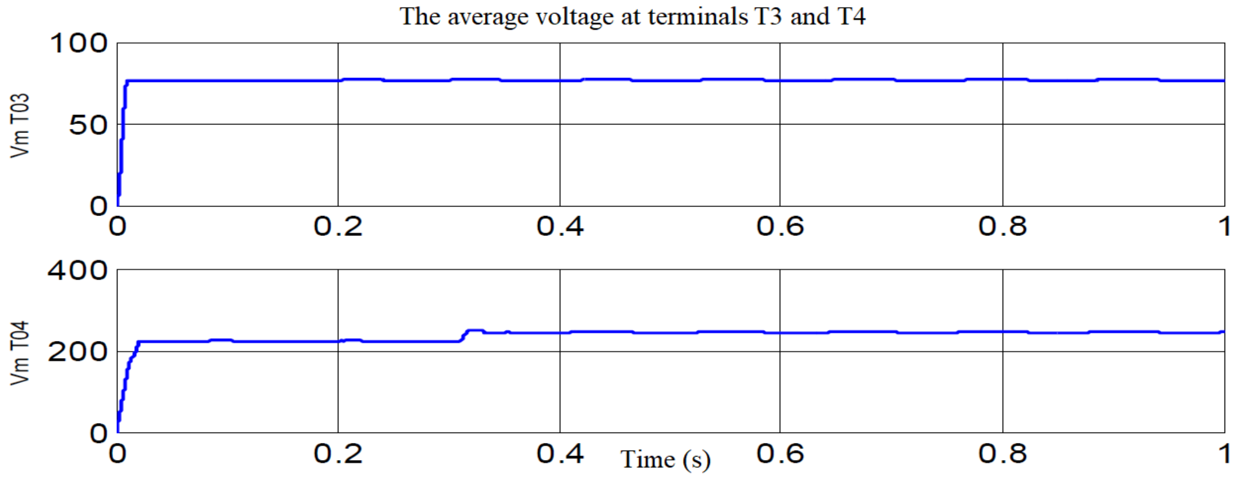

Figure 15. Average switch voltages when T3 is open.

Locating faults in the half-low of phase A.

- VmT01 > VmT02, the fault is in switch T01.
- VmT02> VmT01, the fault is in switch T02.

Fault indicator

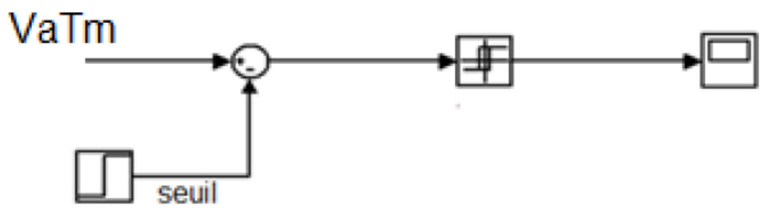

Figure 16. fault indicator diagram

- Opening fault indicator for T1

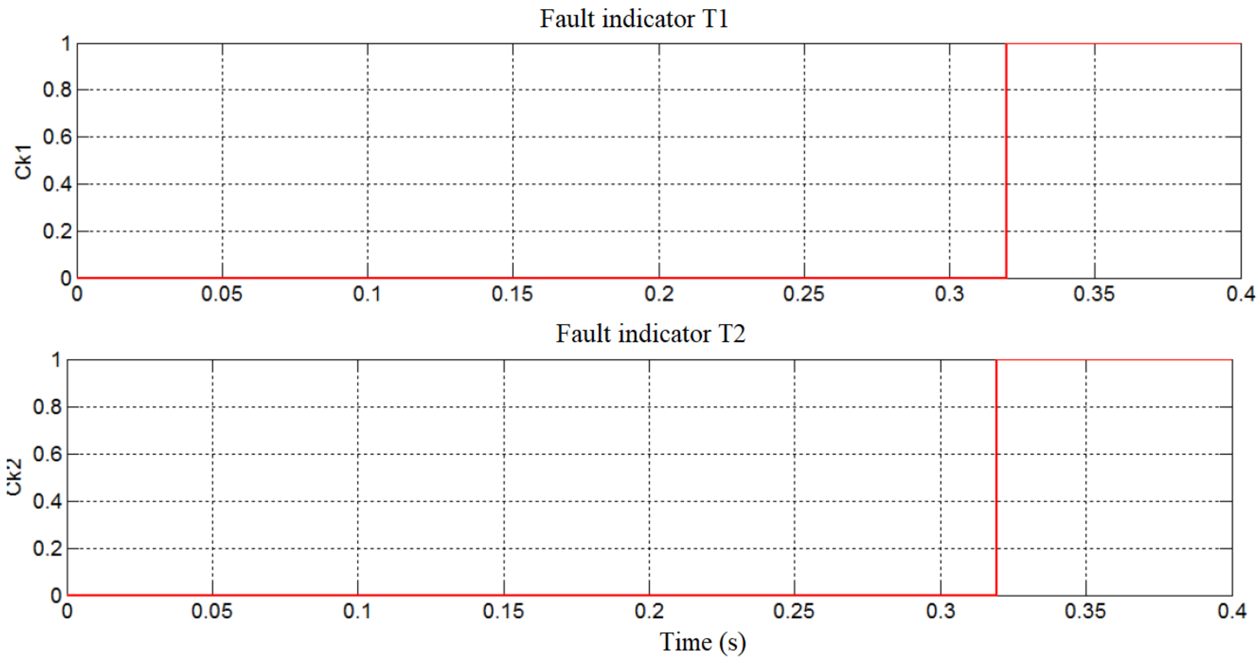

Figure 17. Fault indicator at opening

- Opening fault indicator for T2

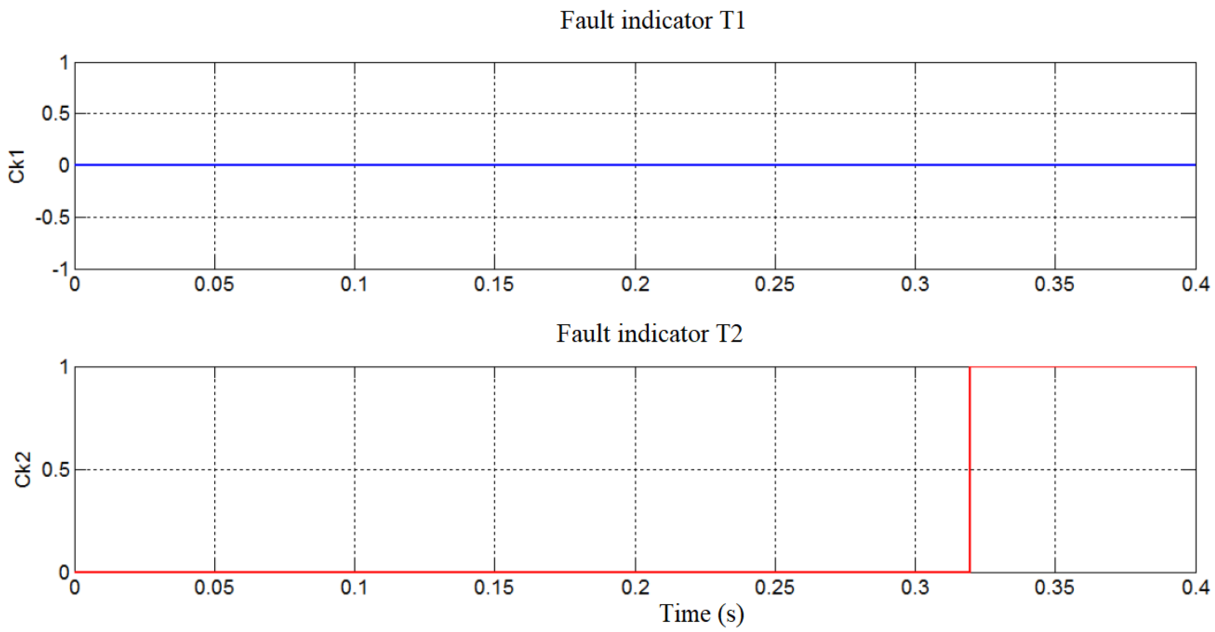

Figure 18. Fault indicator at opening

- If CK1=1 and CK2=1: T1 fault
- If CK1=0 and CK2 = 1 then: T2 fault

VII. CONCLUSION

This article describes a two-step process for diagnosing transistor opening defects.

- The first step involves using the Park contour to locate the deteriorated half-arm.

- The second step involves monitoring the evolution of the voltages across the switches.

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