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Design and Diagnosis of current faults in electrical power systems of permanant magnet synchrones machine

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***Abstract*—This paper focuses on the diagnosis of electrical faults in electrical drives based on the permanent magnet synchronous machine (PMSM) which is supplied by a system of voltages delivered by a voltage inverter, this is controlled by the hysteresis strategy with three reference currents. High current or cut-off can cause problems for three-phase equipment and the most common impact of these faults is overheating of the equipment and consequently degradation of electrical insulation and reduction of service life. A modeling of the system performance in the healthy and faulty machine cases has been simulated. In this paper, firstly, the system is analyzed for the different supply current faults of types: unbalance and current break. Then, the fault detection of the permanent magnet synchronous machine can be illustrated by the evolution of the parameters that describe the electrical and mechanical characteristics of the machine. The results of the simulation are realized by Simulink MATLAB.**

***Index Terms*—Permanent magnet synchronous machine,Stator faults, Converter, Hysteresis control, Diagnosis fault.**

I. INTRODUCTION

In industrial systems, the purposes on machine health monitoring and diagnosing faults has attracted a lot of interest in the context of maintenance systems, because the potential benefits to be gained from the reduction of maintenance costs, improvement of productivity and availability of machines.In effect, the detection of industrial equipment failures, when done effectively, is a means of effectively: firstly to ensure that the equipment does not deteriorate and secondly, to avoid having to disconnect power to healthy machines. Fault diagnosis in permanent magnet synchronous machines (PMSM) has acquired an extremely important role in recent years as the requirements for safety, availability and reliability of industrial processes have been becoming more stringent in industrial systems [10], [2].Problems relating to ageing and failure of this type of system have a greater impact on the operating constraints, [11], [17].The purpose of diagnosis in industrial systems is to detect and locate failures that have occurred in the system and to identify the causes of these failures control.In electrical machines The term ”failure” means any problem that causes the machine to perform abnormally and that can cause it to overheat in the short or long term ,witch their causes are multiple.The proportion are as indicated in the literature can be classified in [13], [5], [3]:

- 50% for Faults in the stator .
- 20% for Rotor faults .
- 20% for mechanical faults .
- 10% for other factors.

The problems of the power supply phases, introduces a faulty operation of the system. Therefore, the diagnosis part of monitoring, which aims to detect and isolate faults in induction machines at an advanced state.Many studies have investigated the detection and diagnosis of modulations in steady state or transient [15], [1].The industrial diagnosis is based on between the behavior of the faulty process and the knowledge of the healthy process behavior or its model, in this context this work, will focus specifically on the electrical faults that can occur in the stator of permanent magnet machines. Winding faults are among the most common. The magnet machine has a characteristic of permanent fluxing due to the presence of the magnets at the rotor. As a result, certain categories of failure, such as inter-turn short circuits are particularly critical because even disconnecting the machine from its power supply device does not allow the fault to be ”extinguished”. The presence of a variable flux in the short-circuited coil maintains the presence of an electromotive force and therefore a current that can prove to be destructive.

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To address these faults which we cited, we designed a study with supply current faults created to assess the impacts on system performance. The article is structured as follows: we have designed a study with created supply current faults to evaluate the impacts on the system performance. We propose first,a model of the permanent magnet synchronous machine, with the use of the Park transformation to simplify the model. Furthermore, the study of the association PMSM and inverter of voltage controlled by hysteresis to simulate the system in the healthy state. Secondly, we have investigated the electrical and mechanical behavior of the machine when it is submitted to disequilibrium and failures of statoric interruptions,this is carried out in the case of defaults of current supply during a period of operation of the synchronous motor with permanent magnet, this one being initially supposed in stationary operation, finally, the numerical simulation of the various regimes of operation of the synchronous machine with permanent magnets was carried out by MATLAB simulink.

II. PERMANENT MAGNET SYNCHRONOUS MACHINE DESIGN.

The performance of the machine is determined by three different types of equations, namely:

- Electrical equations
- Magnetic equations
- Mechanical equations

The electrical and dynamic behaviours of a system can only be studied if it can be determined by a mathematical model using the Park transformation ,witch the latter applies a change in variables to the currents, voltages, and fluxes that consists of transforming the three phase-related windings to (d, q) orthogonal ones, rotating at a speed ω_r.

The transformation matrix is given by:

$$[P(\theta)] = \frac{2}{3}\begin{pmatrix} \cos\theta & \cos(\theta - 2\pi/3) & \cos(\theta + 2\pi/3) \\ -\sin\theta & -\sin(\theta - 2\pi/3) & -\sin(\theta + 2\pi \\ /3\ \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \end{pmatrix}$$

The transformation inverse matrix is as follows :

$$[P(\theta)]^{-1} = \begin{pmatrix} \cos\theta & -\sin\theta & \frac{1}{\sqrt{2}} \\ \cos(\theta - 2\pi/3) & -\sin(\theta - 2\pi/3) & \frac{1}{\sqrt{2}} \\ \cos(\theta + 2\pi/3) & -\sin(\theta + 2\pi/3) & \frac{1}{\sqrt{2}} \end{pmatrix}$$

Using the Park transformation to the system of equations, we express all the variables in a reference system related to the rotor. [14], [12], [6], [9] : The equations that result of the permanent magnet synchronous machine are the following :

$$V_d = R_s i_d + \frac{d}{dt}\ \varphi_d - \omega_r\ \varphi_q \tag{1}$$

$$V_q = R_s i_q + \frac{d}{dt}\ \varphi_q + \omega_r\ \varphi_d \tag{2}$$

The flows can be formulated on the d and q axis by the following equations:

$$\varphi_d = L_d\ i_d\ + \varphi_f \tag{3}$$

$$\varphi_q = L_q\ i_q \tag{4}$$

A. Mechanical equations

The dynamics of the machine is given by the following mechanical equation:

$$J\frac{d}{dt}\mathit{\Omega}_r = \ C_e - C_r - \ \ f_c\ \ \mathit{\Omega}_r \tag{5}$$

The expression of the electromagnetic torque as a function of the currents is as below:

$$C_e = \frac{3}{2}p\left[(L_d - L_q)\, i_d i_q + \ \ i_q\varphi_f\right] \tag{6}$$

Such as:

$$\Omega_{\mathrm{r}} = \frac{d}{dt}\ \theta \tag{7}$$

$$\theta = \int\ \theta.dt \tag{8}$$

$$w_r = p.\ \mathit{\Omega}_r \tag{9}$$

$$\theta_r = p.\theta \tag{10}$$

with :

$\mathrm{V_a}, \mathrm{V_b}, \mathrm{V_c}$ Voltage of the stator phases; $\mathrm{i_a}, \mathrm{i_b}, \mathrm{i_c}$;The currents of the stator phases; $\varphi_a,\ \varphi_b,\ \varphi_c$ The total fluxes through the statoric coils; $\mathrm{i_f}$The rotor current ; $L_{f,}L_s$Cyclic stator and rotor inductances per phase; M_{sf}Rotor inductance mutual $\mathrm{R_f}$The rotor resistance, $\mathrm{R_s}$ the stator resistance ,V_fThe rotor voltage;$\mathrm{C_e}$The electromagnetic couple;C_r resistant couple , J The moment of inertia of the rotating machine; f_cCoefficient of friction ;p number of pairs of poles; Ω_{r} The speed of rotation of the machine;ω_r The electrical speed of the rotor $\mathit{\Omega}$ speed mechanical angle; θ angular velocity.

III. POWER SUPPLY BY VOLTAGE INVERTER CONTROLLED IN CURRENT

A. Voltage inverter modeling

Figure **??** represents the schematic diagram of a voltage inverter composed of six transistors, shunted in antiparallel by recovery diodes. The semiconductors of the inverter are considered as idealized elements [8], [7].

To simplify the design, we associate to each inverter arm a logical connection function F_j (j=1,2,3).

The definition of the logic functions is as given below:

- K_j= = 1 if K_i is close and K'_i open
- K_j= 0 if K'_i is close and K_i open

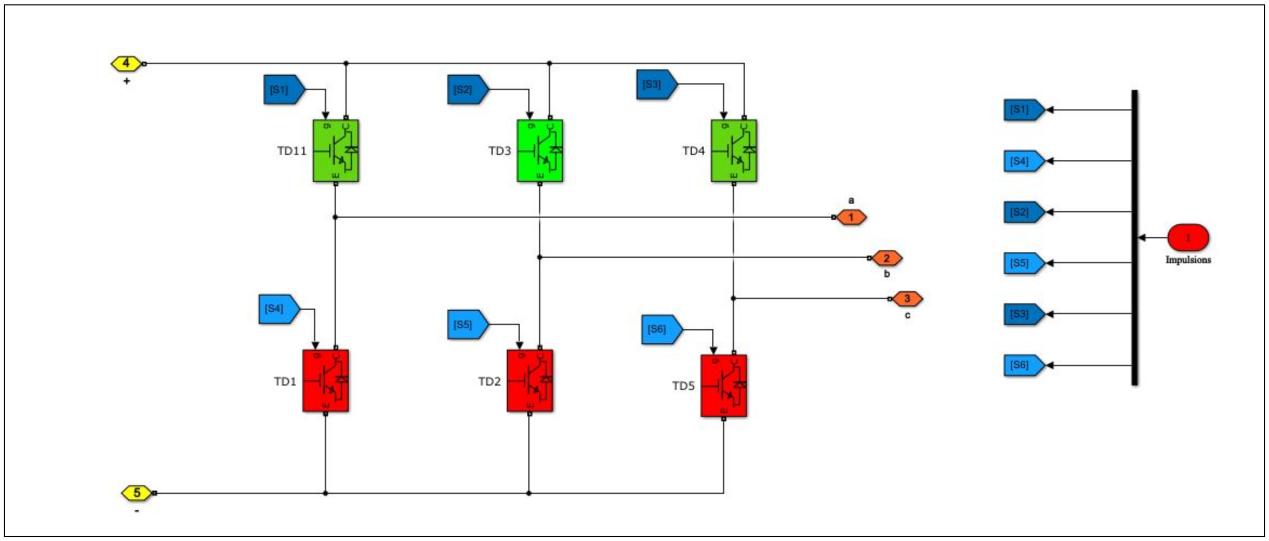

Fig. 1. Schematic of a voltage inverte

The simple voltages are as follows:

$$\begin{bmatrix} \mathrm{V_a} \\ \mathrm{V_b} \\ \mathrm{V_c} \end{bmatrix} = \frac{E}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} K_1 \\ K_2 \\ K_3 \end{bmatrix} \tag{11}$$

It remains to determine the logic functions K_i ,these depend on the control strategy of the inverter.

B. *Hysteresis current control algorithm principle*

The concept of this monitoring consists in keeping the real currents within a band, of given width, centered around the reference currents. A comparison is made between real currents and reference currents [4], [16].The outputs of the comparators represent the control logic of the switches in figure 2.

The results obtained with Mathlab simulink are shown in figure 3.

IV. SYSTEM MODELING IN THE PRESENCE OF A FAILURE

A. *Different types of faults*

In a three-phase power system, the voltages and currents on each of the three phases are generally identical and the phase angle is 120 degrees. When the voltages or currents have a difference in signal amplitude, an imbalance occurs on the supply phases and can cause problems in the performance witch is resulting in the degradation of electrical machine and a reduction in equipment life. We propose to investigate the electrical and mechanical performance of the machine in the presence of stator failures,this last is affected by stator imbalances when the supply current is faulty, then we suggests a fault of power supply break of the type monophase biphase and triphase during the operating time of the permanent magnet synchronous machine. The simulation model which is proposed to study the power supply failure is shown in figure 4.

For the purpose of determining the different types of unbalanced and power supply phase break, the following expressions are given:

- $\mathrm{I_a}=\mathrm{a}_1*\mathrm{I_a}$.
- $\mathrm{I_b}=\mathrm{b}_1*\mathrm{I_b}$.
- $\mathrm{I_c}=\mathrm{c}_1*\mathrm{I_c}$.

The numerical simulation of the healthy and faulty performance in different regimes of the permanent magnet synchronous machine has been achieved by Simulink MATLAB.

TABLE I
THE PARAMETERS OF THE MACHINE (PMSM)

Parameters	***Value***	***Parameters***	***Value***
P_n (w)	1500	$\varphi_f(Wb)$	0.1546
R_s (Ω)	1.4	J (N.ms/rad)	1.76e-3
L_d (H)	0.0066	C_r (N.m)	5
L_q (H)	0.0058	f_c (Ns/rad)	38.818e-5

V. SIMULATION RESULTS IN NORMAL AND FAULTY STATE

A. *Current inequality of the power supply phases*

The simulation of the differents functioning regimes of the permanent magnet synchronous machine has been realized by Mathlab simulink. Figures 5,6 and 7, illustrates the results obtained from the evolution of the fundamental variables, which are the supply phase currents, the speed and the torque, in the PMSM supplied by a voltage inverter controlled by hysteresis during a start-up with a resistive torque Cr=12N.m.In the presence of an unbalanced supply current of the single-phase, two-phase and three-phase design , at instant t=1s.

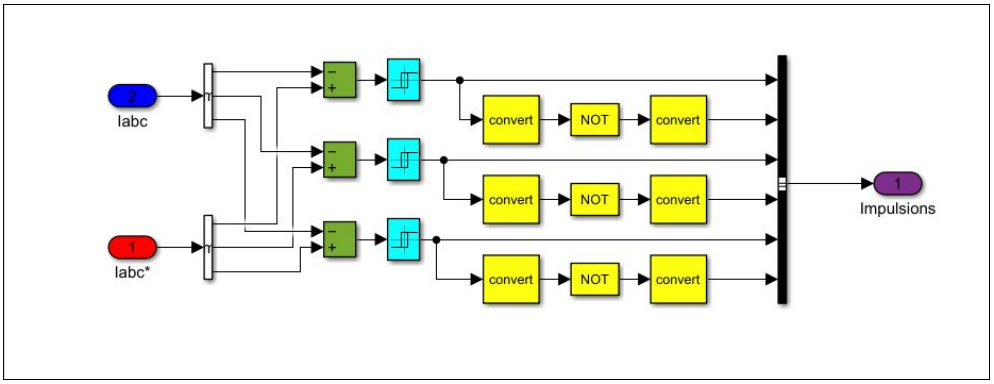

Fig. 2. Synoptic diagram of the first arm control of the inverter

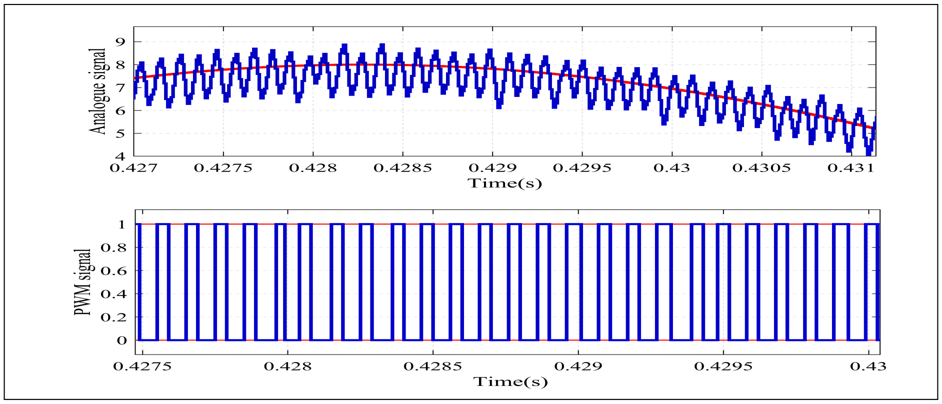

Fig. 3. Response of the phase current ia with hysteresis control

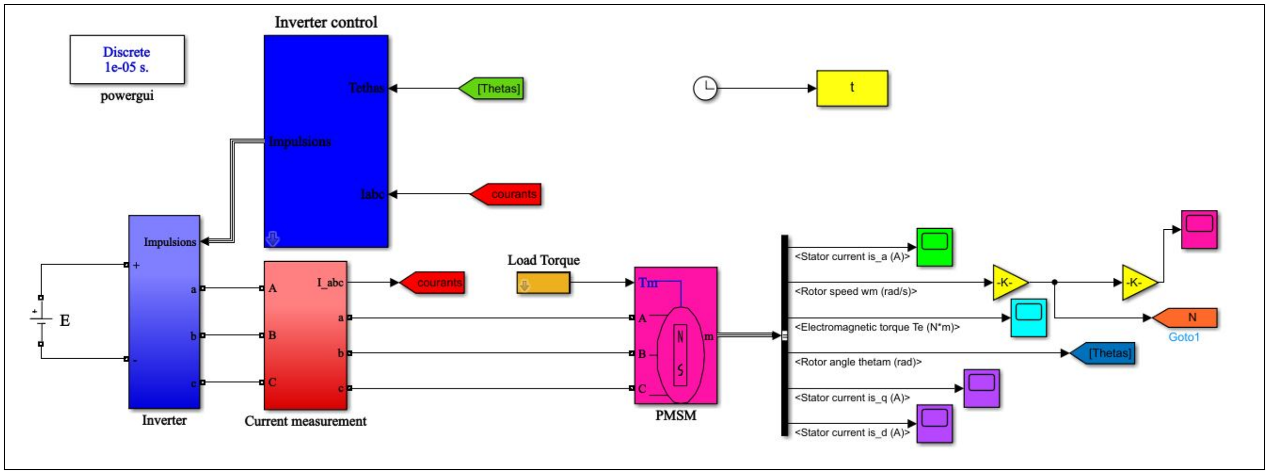

Fig. 4. The PMSM simulation model associated with a current-controlled voltage inverter

B. Current breaking of the supply phases

Figures 8,9 and 10, shows the results with the same machine operating conditions but in the presence of a current break in the mono phase, bi phase and tri phase supply. The obtained forms curves of fault are presented on figures 5,6, 7, and 8,9,10. For the three phases (Ia,Ib,Ic) and the currents of the fault at the time t=1s. It is clear that a decrease of amplitude of the phase current equilibrium, and the increase in the current of the other phases in breaking of phase of current supply.For speed it is noticed that undulations and a considerable dimuniation undergo has are turn of the presence of defect. To the curves of couple it is noticed ripples and variation of amplitude due to the occurrence from the default.

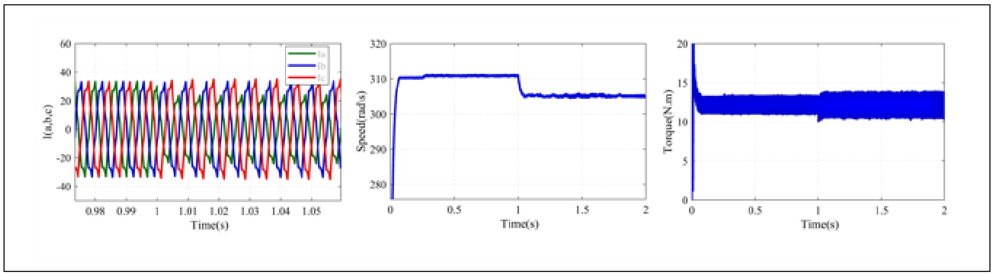

Fig. 5. Simulation results of a mono phase unbalance current supply.

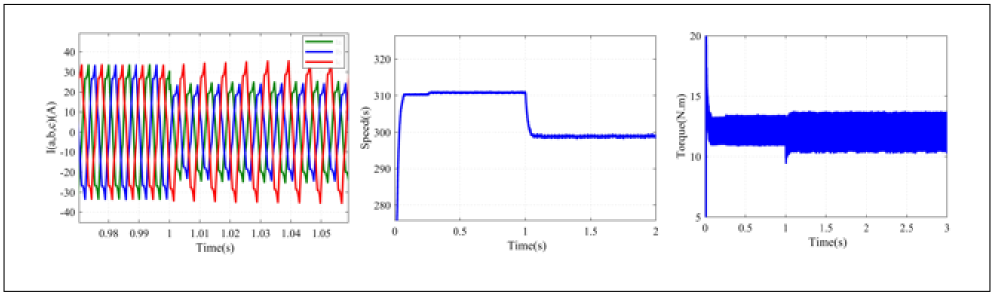

Fig. 6. Simulation results of a biphase unbalance current supply.

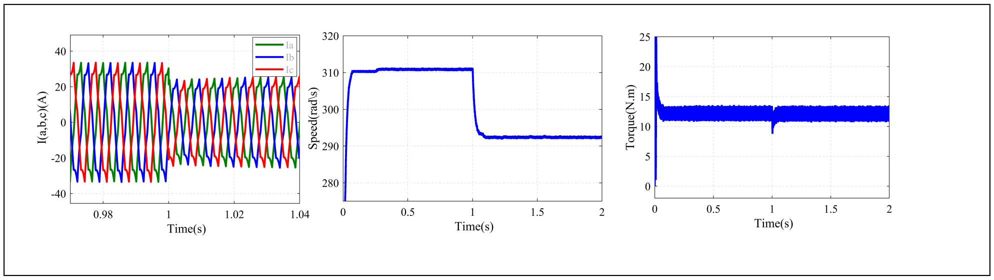

Fig. 7. Simulation results of a triphase unbalance current supply.

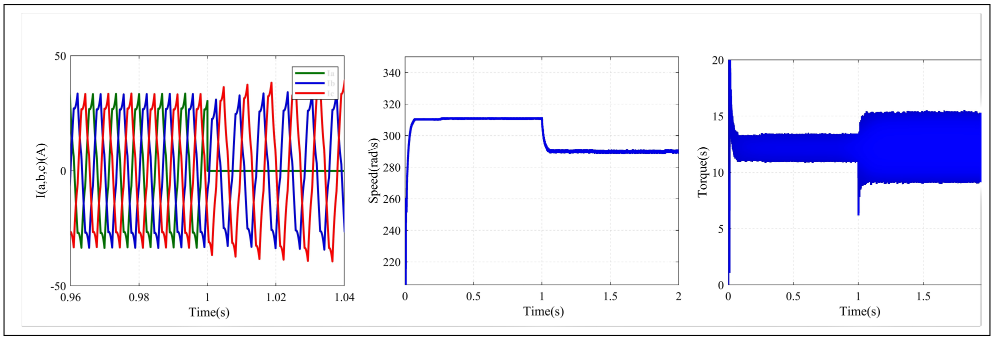

Fig. 8. Simulation results of a monophase supply current break.

C. Conclusion

This paper investigated the electrical and mechanical behavior in normal and faulty functioning of a permanent magnet synchronous machine fed by a hysteresis current controlled voltage inverter. Numerical simulation of the various operating modes of the permanent magnet synchronous machine has been realized by Simulink MATLAB. The electrical factors are distinguished in comparison with the average regime by an abnormal variation at the time of fault occurrence. For the mechanical performance of the machine, the impact is a shunt of the speed value depending on the type of default, and the variation of the electro-mechanical torque is also considered.

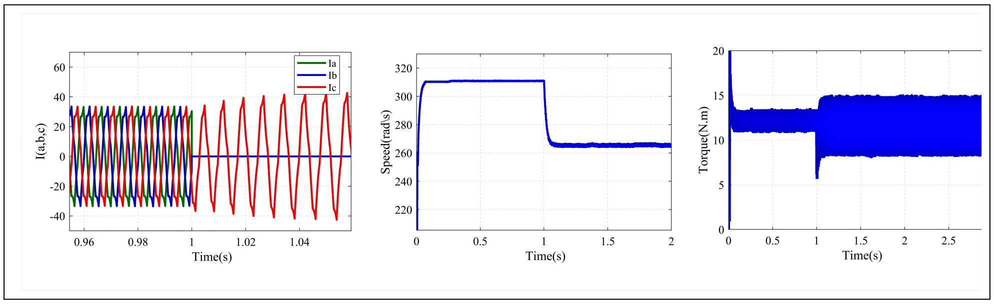

Fig. 9. Simulation results of a biphase supply current break.

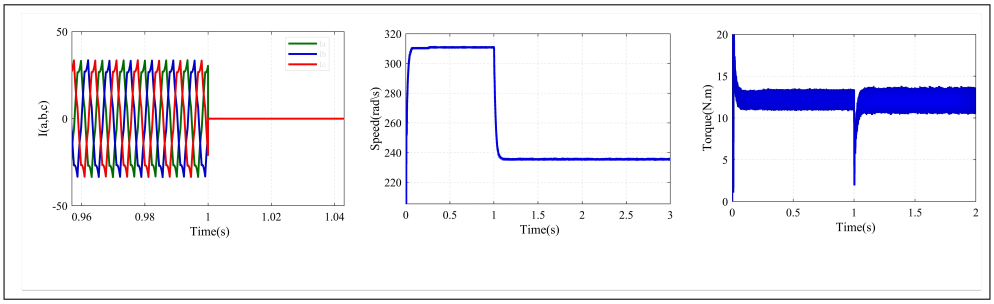

Fig. 10. Simulation results of a triphase supply current break.

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