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Research Article

Control to Three-phase Inverter by Sliding Mode

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Abstract: In this study, it is treated the modeling and the ordering of a three-phase inverter. The studied system is a load supplied with a three-phase inverter by means of a transformer. The ordering of the inverter is with PWM (pulse-width modulation/pulse-width Modulation) and its regulation is made by the sliding method. This method is presented in this document with its various laws. The simulation of the unit is made and the results presented.

Keywords: Control, disturbance, energy, inverter, PWM, sliding mode, three-phase

INTRODUCTION

The global energy crisis and environmental problems have led developed countries to invest in renewable energy research. Developing countries have to follow this process for exploitation of green energy, for having more potential for renewable energy. They need high energy growth including electrical to boost their economies.

Such electrical energy is a catalyst for the development of income-generating activities through the creation of micro-enterprises and micro-industries.

With respect to Senegal, two major electrification solutions have been adopted, facing dispersion of non-urban sites (remote from the national grid) to supply and their current levels of energy demands:

- For widely dispersed and/or low energy demand habitation sites, the low individual supply per concession ("SPD systems") is the best technical and economic solution.
- For denser habitation sites and/or a substantial energy demand, the solution of micro-network has been implemented.

In most cases, these "green" energy, once produced, need to be conditioned before use. Various electric power conditioning structures have been constructed and are being based on static converters. This document presents the DC-AC conversion with a three-phase voltage inverter.

This inverter is controlled by PWM/PWM (pulse-width modulation/pulse-width Modulation). The objective is to regenerate a 3-phase network. To ensure a good quality of energy, two control loops (voltage and current) have been implemented. The implemented control loop for the power will be of sliding mode control.

Several theses items and develop control sliding mode. Most of theses and articles focus on the association between a three-phase inverter debiting of an asynchronous machine. In Kazmierkowski and Luigi (1998) are published in the journal IEEE Transactions an article using a sliding control mode. Fernando and Silva (2000) in his publication in uses the same command for controlling a power converter at different levels. Charles (2011), the order by sliding mode control DC-AC converter.

In this study, the robustness of the controller is tested. Disturbances are load variations, as renewable energy is dependent on weather conditions and the three-phase inverter must be used this green energy.

This study presents the results of the performance of this type of control.

Keyhani *et al*. (2009) proposed in Fig. 1 the structure used.

The transformer ensures galvanic isolation and adaptation between the inverter and the load. Inductive and capacitive filters help reduce the total harmonic distortion.
Figure 2 shows the model of the transformer.

THE SYSTEM MODELING AND CONTROL PRESENTATION

System modeling: Based on Fig. 1 and 2, the system can be modeled by the following equations:

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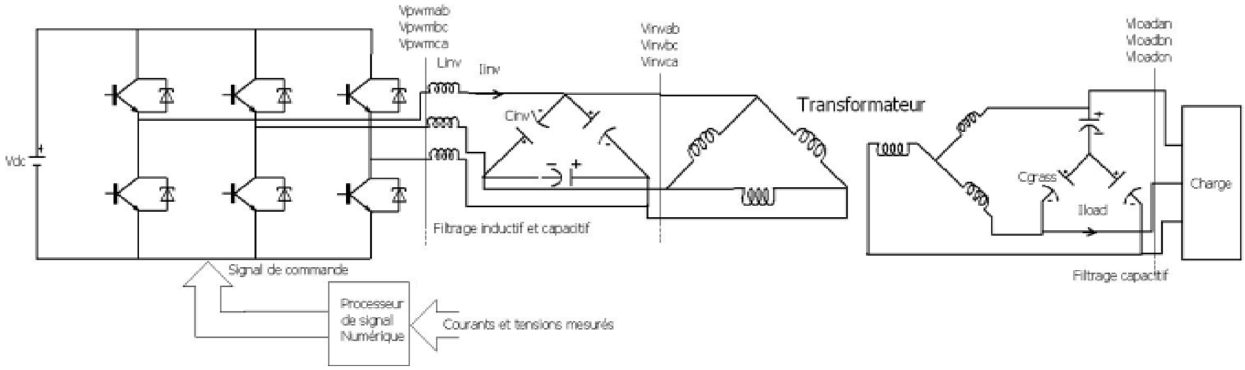


Fig. 1: Structure of the studied system

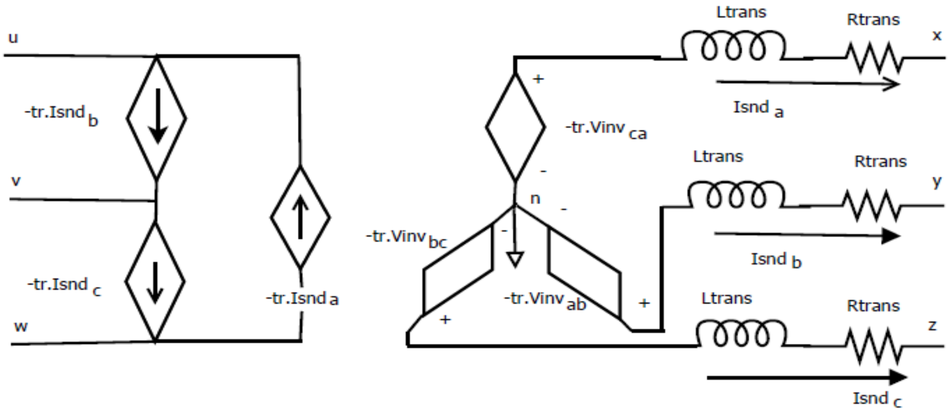


Fig. 2: Model of the transformer

Tr_i and Tr_v are matrices for Y-Δ transform. Ks is the PARK transformation to pass stationary DQ reference frame.

Sliding mode control: The sliding mode Variable Structure Control (VSC) is well known for its robustness to internal uncertainty (shift in network parameters) and external (disturbance due to load) uncertainty and omitted phenomena at modeling while having a superb dynamic response (Vadim, 1993).

Control principle: The sliding mode control is a class of variable structure control. It is effective and robust for linear and nonlinear systems. The main task of the sliding mode control is to provide a switching face, according to the existence, convergence and stability theorems. The switching face can be achieved by the state space through appropriate changes in the structure of the control system (Madani *et al.*, 1998).

The purpose of the sliding mode control is the steady state trajectory be driven to a sliding surface S and slides around. Once the sliding surface is reached, the system dynamics will remain insensitive to variations in the process parameters and external disturbances (Sivert *et al.*, 2004).

As a result, design of the sliding mode controller requires two crucial steps (Madani *et al.*, 1998; Perruquetti and Barbot, 2002):

- The type of surfaces and numbers of the same represented by vector $S(x) = 0$, to specify.
- The control law to determine using a new batch input $u(x)\ n$, in order to attract the state trajectory to the surface.

Theoretical basis for sliding mode control: Assuming a system of continuous control represented by the state system (Trzynadlowski, 2001):

$$\dot{x} = A(x,t) + B(x,t)u$$

where,

$x \in R^n$ = The state vector for the system
$u \in R^m$ m = The vector of control inputs

In the variable structure control, the response of such a system usually goes through three phases or modes known as Reaching Mode (RM), Sliding Mode (SM) and the Steady-State mode (SS) (Gao *et al.*, 1995). These are shown in the phase plane at Fig. 3:

Selection of the sliding surface: The primary objective for a sliding mode controller is to direct the states of controlled system to a defined S-surface and maintain the system on such a surface. This S-surface contributes

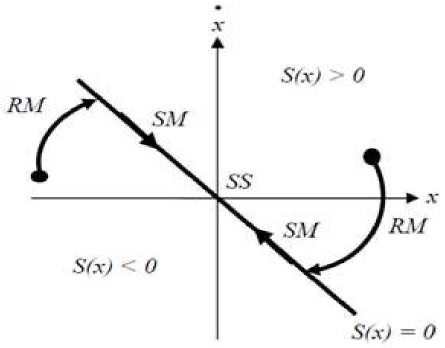


Fig. 3: Trajectory of a system of second order to VSC

to define linear function S(x) called switching function such as (Gao and Hung, 1993) (x) function:

$$S(x) = S.x$$

where: $S \in R^{m\times n}$ and $S = \{x \,\forall\, \}R^{n} : S.x = 0$

Usually the number of sliding surfaces is equal to dimension of command vector *u* (Slotine, 1991).

In the same publication, the author give a general form for the linear function *S*(*x*) must satisfy the conditions for system convergence and stability:

$$S(x) = \left(\frac{\partial}{\partial t} + \lambda\right)^{n-1} e(x)$$

where,

$e(x)$: Error between the variable to adjust and its reference: $e(x) = x^{*} - x$
λ : A positive constant
n : A relative degree

Sliding mode condition for existence: The criterion for existence of the sliding manifold ensures that the sliding surface is attained by the system. The sufficient condition for existence of the sliding mode S = 0 in a finite time is that the pair of inequalities in the following equation is true by (Vadim, 1977):

$$\begin{cases} \lim\limits_{s\to 0^{-}} \dot{S} > 0 \\ \lim\limits_{s\to 0^{+}} \dot{S} < 0 \end{cases}$$

The existence issue is like a widespread stability problem. Another very used way to study the existence of sliding mode is Lyapunov second method.

Lyapunov scalar function is defined positive (*V* (*x*) >*0*), the control law is to decrease this function, i.e., $(\dot{V}(x) < 0)$. Zhiwen *et al.* (2005) say one scalar function *V* (*x*) is selected as follows:

$$V(x) = \tfrac{1}{2} S^{t}(x) S(x)$$

where, S^{t} t is the transpose of S
The derivative of this function is:

$$\dot{V}(x) = S^{t}(x)\dot{S}(x)$$

For single-variable systems it is written as follows:

$$V(x) = \tfrac{1}{2} S^{2}(x)$$

In order to have *V* (*x*) decreased, its derivative must be negative: $\dot{V}(x) = S(x)\dot{S}(x) < 0$ as long as the inequality holds, the system dynamics on *S* (*x*) and its stability are independent from the system $\dot{x} = A(x,t) + B(x,t)u$; they only depend on parameters of the selected surface.

This is to explain invariance of these control laws with respect to disturbances on the control part.

When the phase trajectory remains on surface *S* (*x*), the system is said to be in sliding mode until it reaches a steady state.

This fundamental inequality help determine the control parameters.

TESTED MODEL

To explore the system, we propose the following overall pattern Fig. 4:

The “robust actuator control” helps regulate voltage by generating the preferred currents. The “switch-on current-limiter” helps maintain the power dynamics in a predefined range. Such reference currents

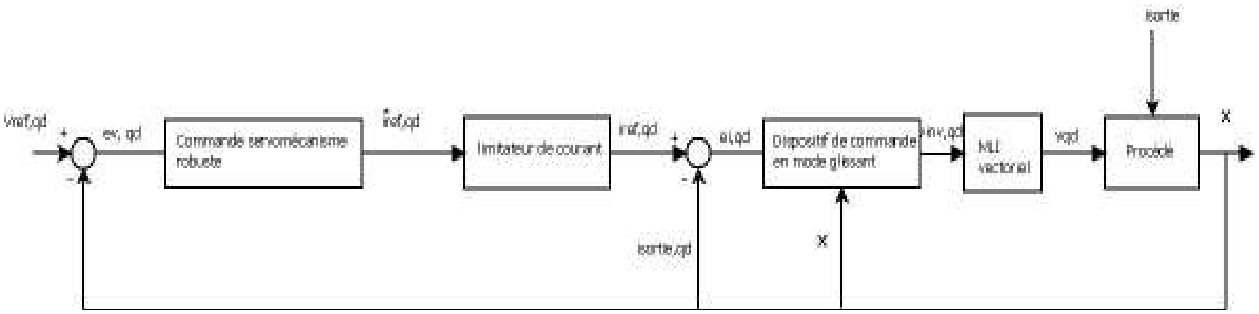
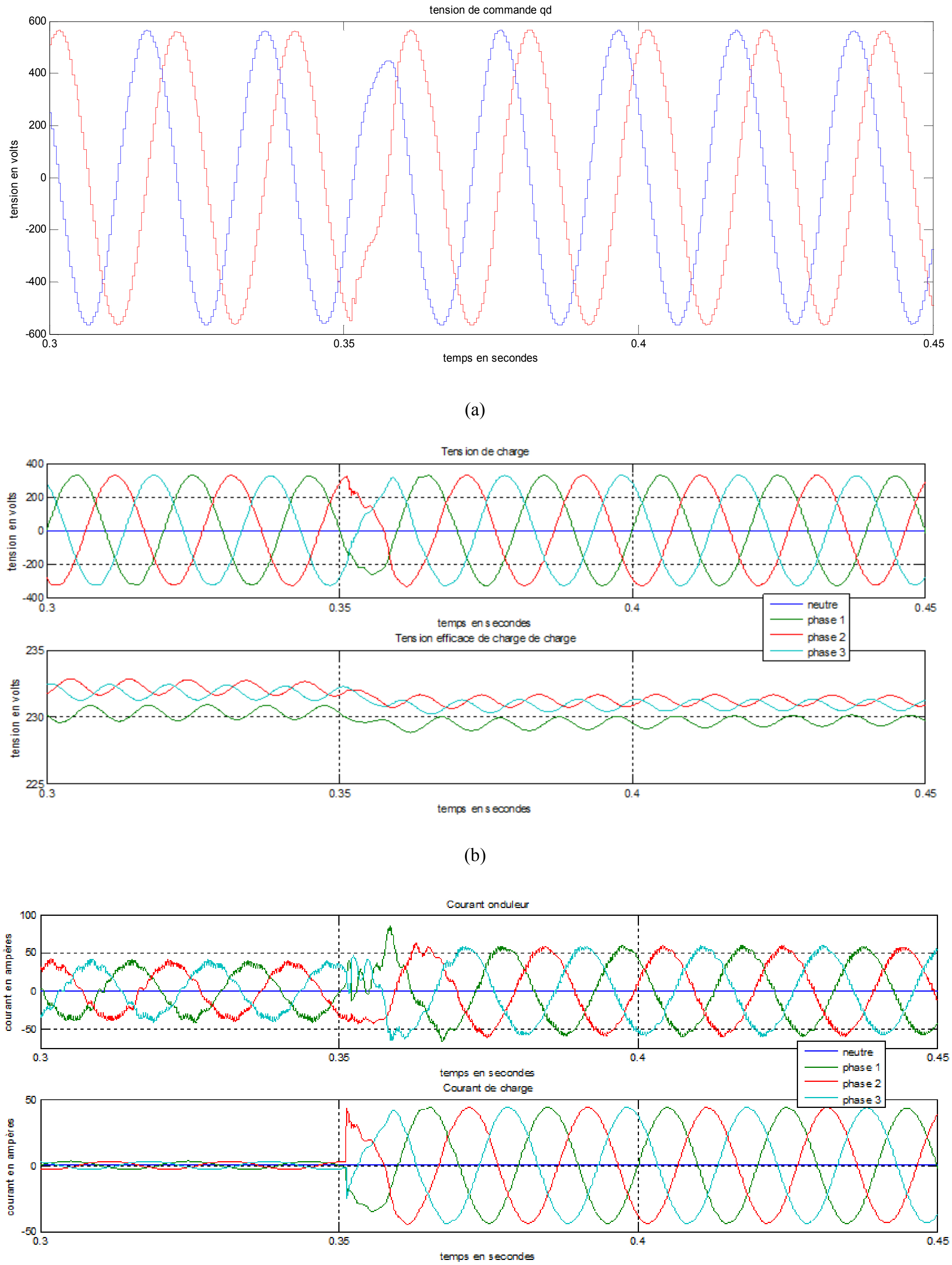


Fig. 4: Synoptic diagram of the model



(a)

(b)

(c)

Fig. 5: Slot load: from no load to full load

are used by an internal control loop built around a control device sliding mode. The device generates the PWM space vector modulating signal.

SIMULATION RESULTS

To test this control robustness, simulation results are presented in this section. Several scenarios are implemented.

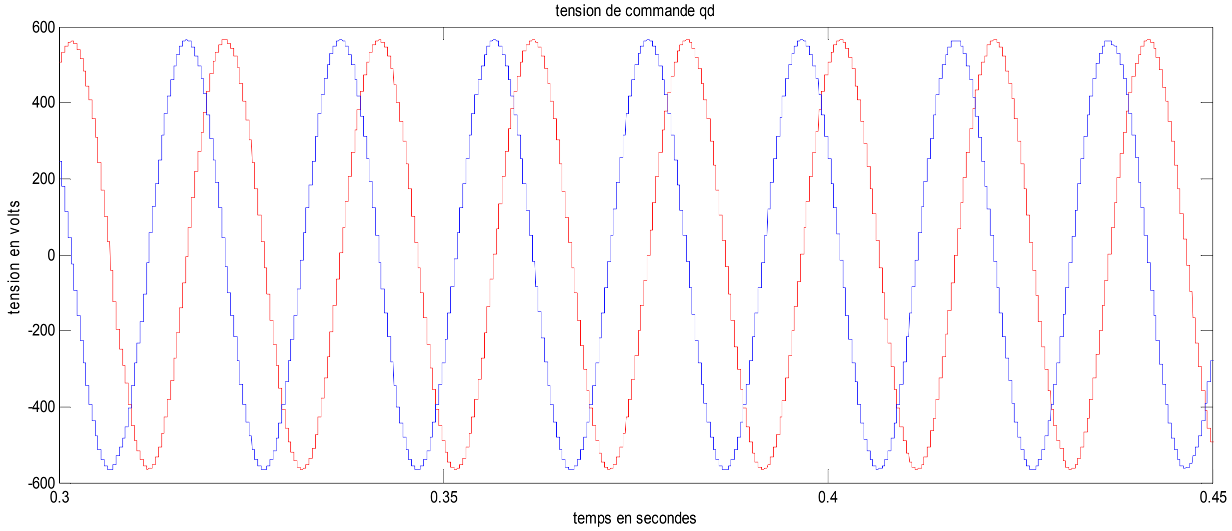
Slot load:

From no load to full load: The disturbance is the shift from vacuum to load in this Fig. 5. The system is stabilized in less than a half period (10 msec). The Fig. 5a presents the variation of the dq voltage command. The Fig. 5b presents the instantaneous voltage load and the RMS voltage. At last the Fig. 5c presents the inverter and load current.

Slot load:

From full load to no load: The transition from full load to empty in these Fig. 6 does not cause disruption of electrical quantities on the load. The Fig. 6a presents the variation of the dq voltage command. The Fig. 6b presents the instantaneous voltage load and the RMS voltage. At last the Fig. 6c presents the inverter and load current.

Transition from full operating balanced load to disconnection of the two phases load: When two phases of the load are disconnected in this



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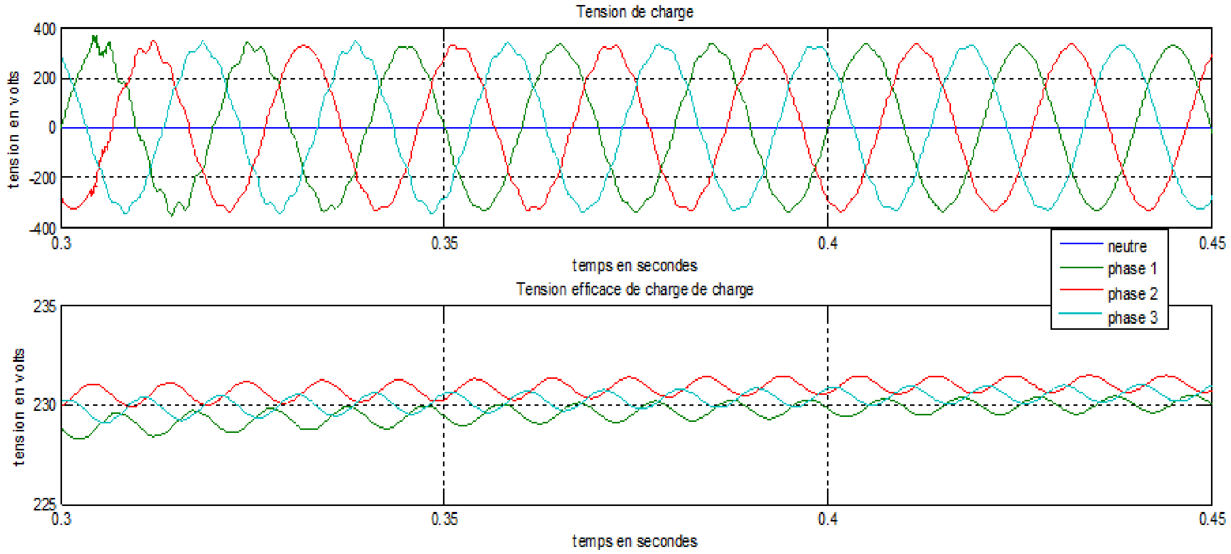

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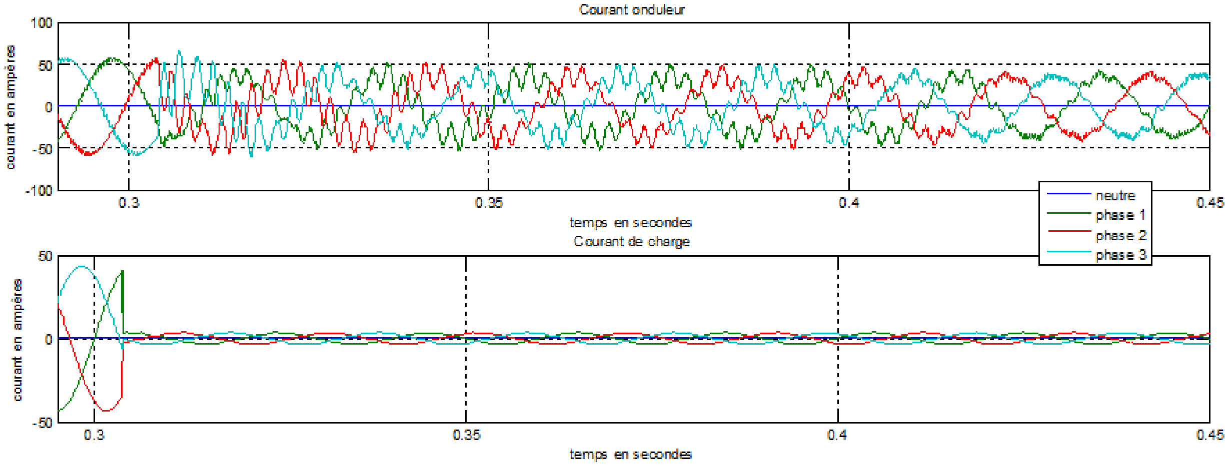

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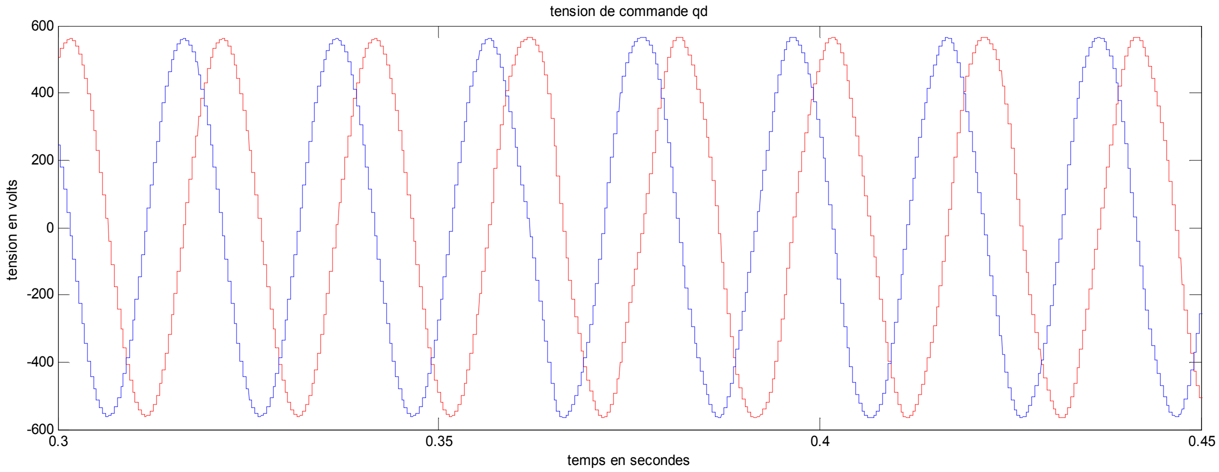
Fig. 6: Slot load: from full load to no load



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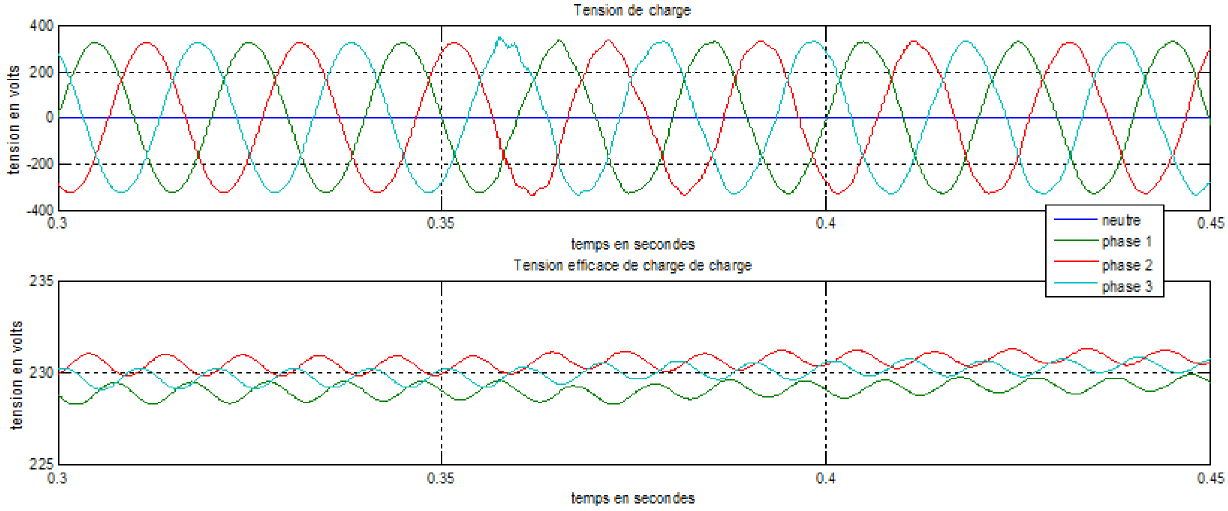

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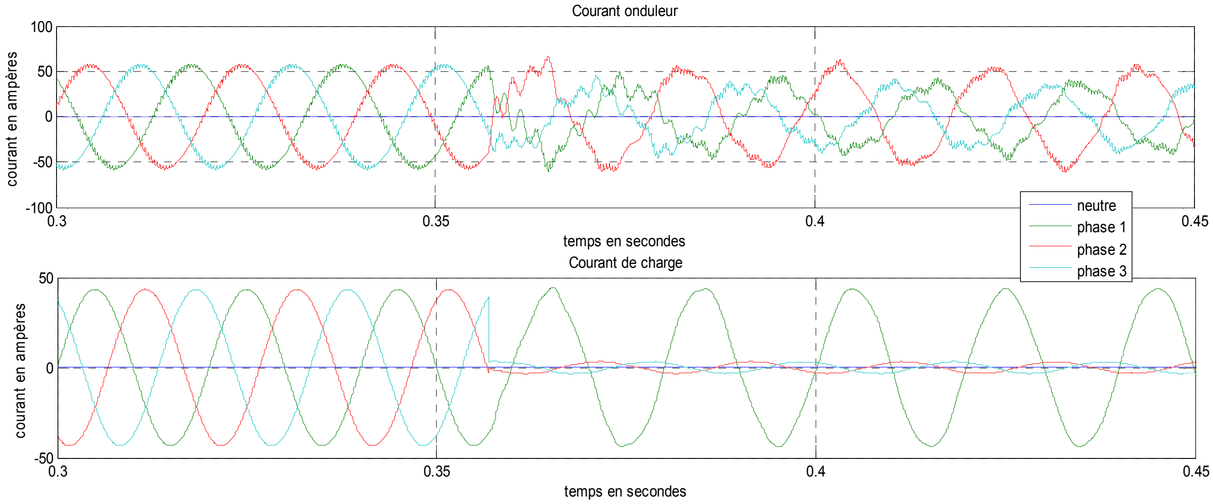

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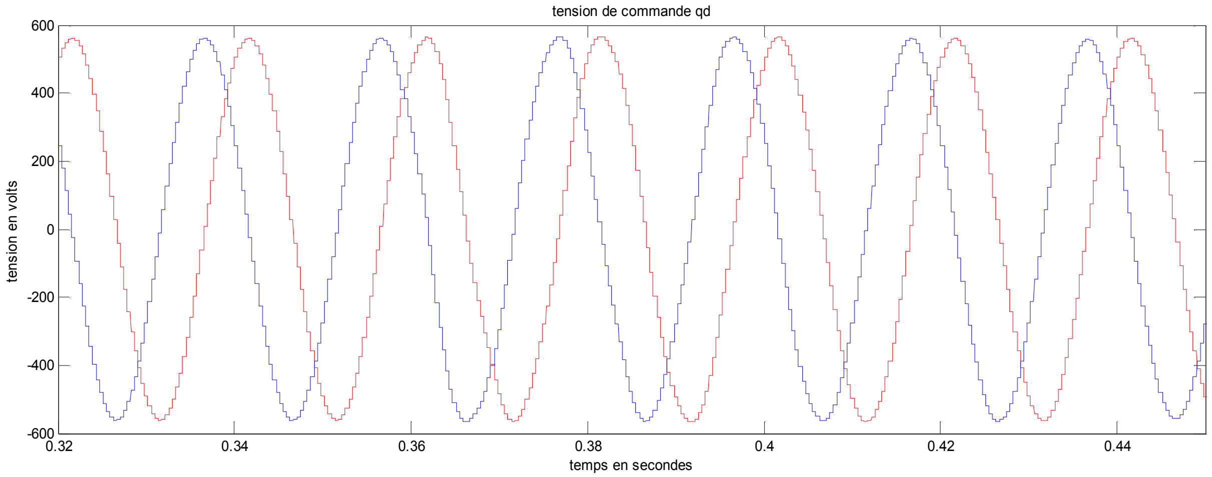
Fig. 7: Transition from full operating balanced load to disconnection of the two phases load



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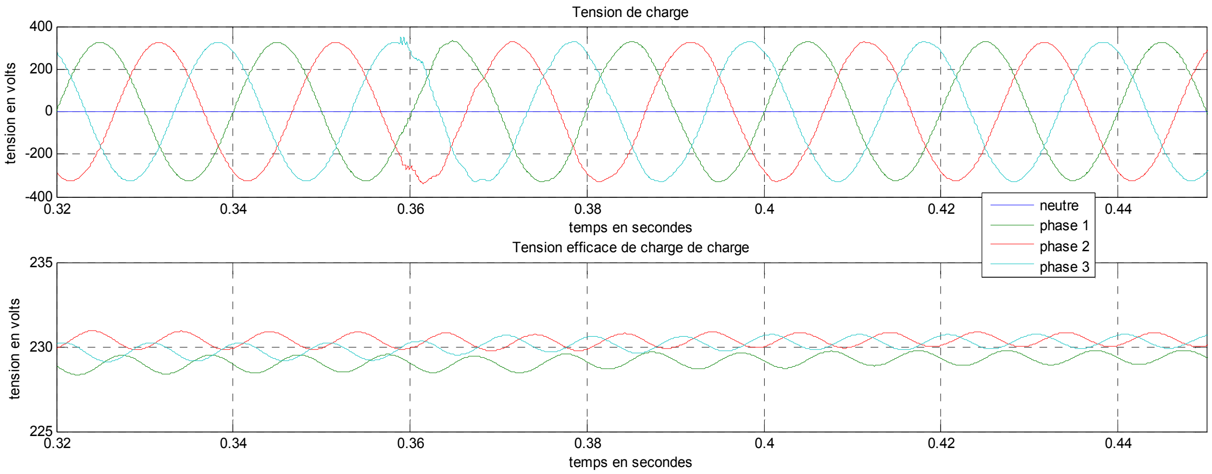

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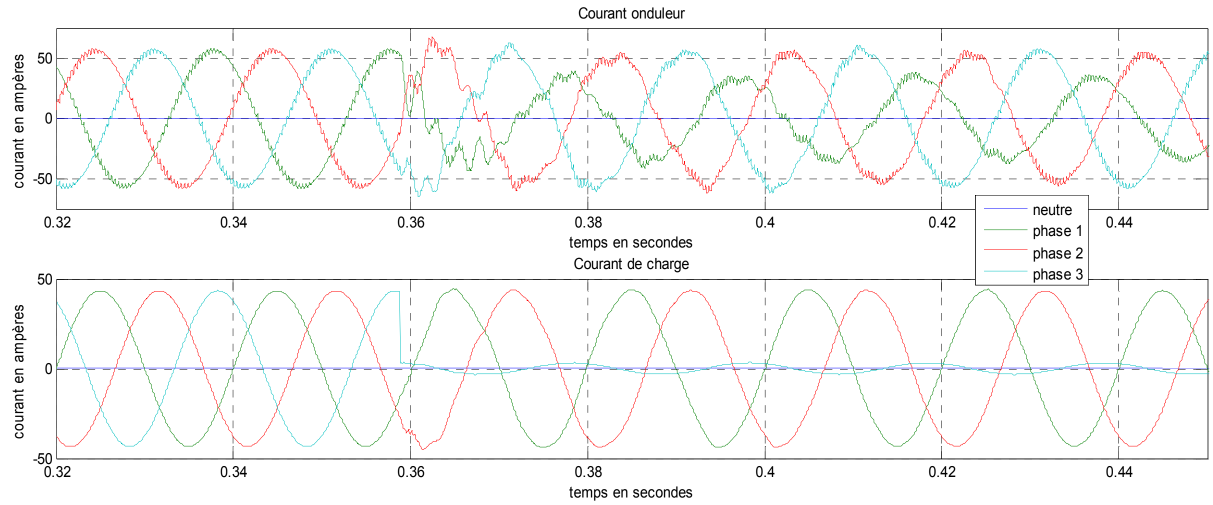

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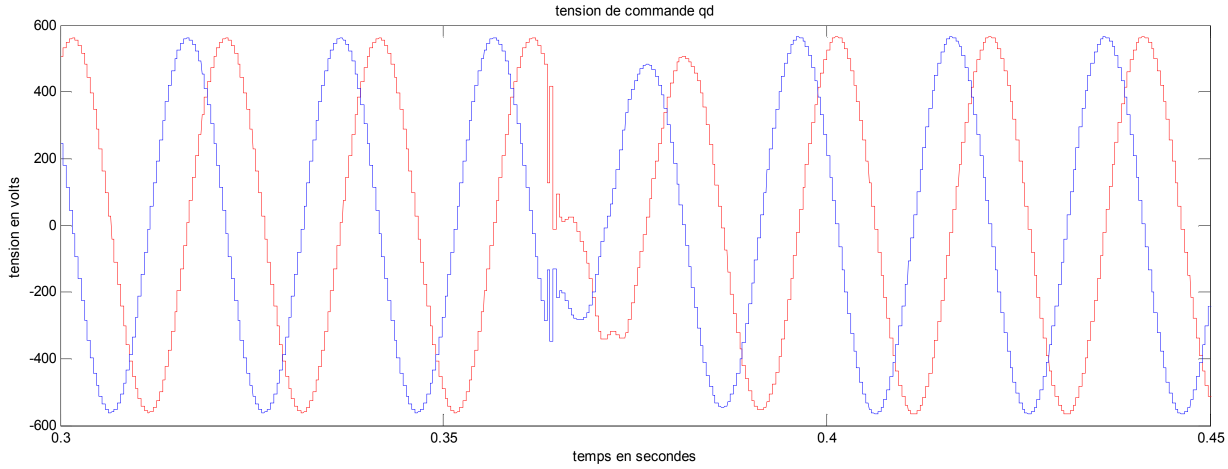
Fig. 8: Transition from full operating balanced load to disconnection of any of load phase



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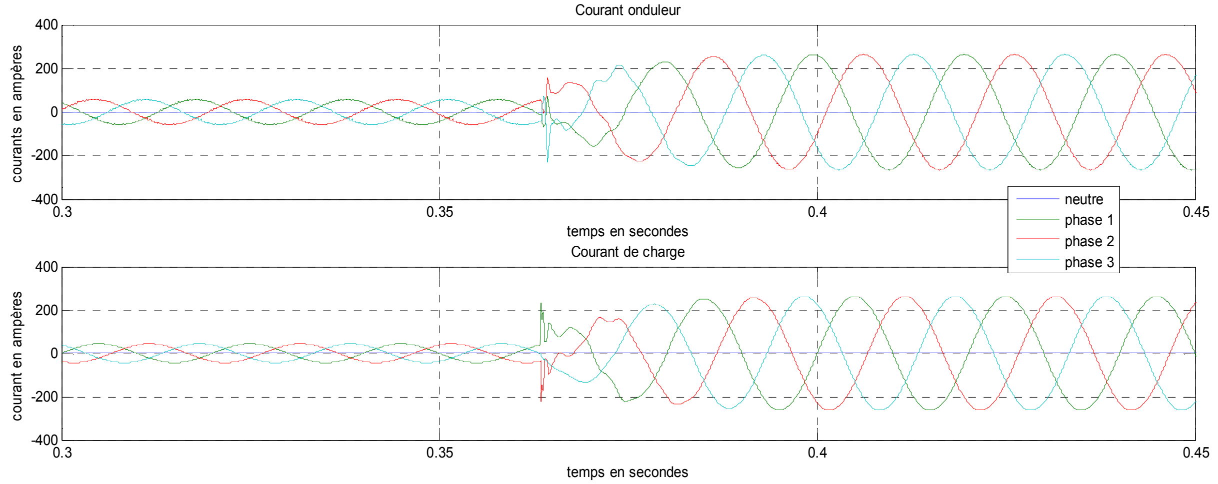

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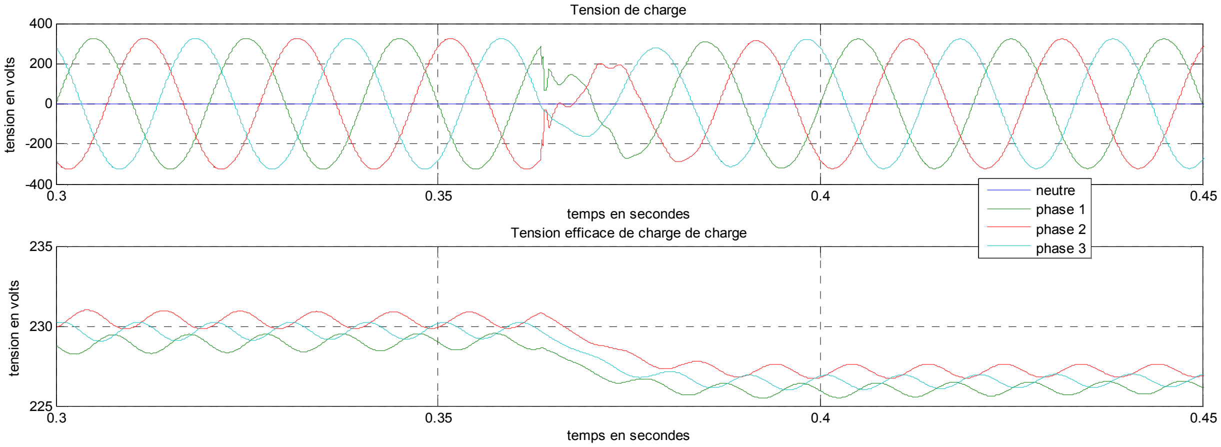

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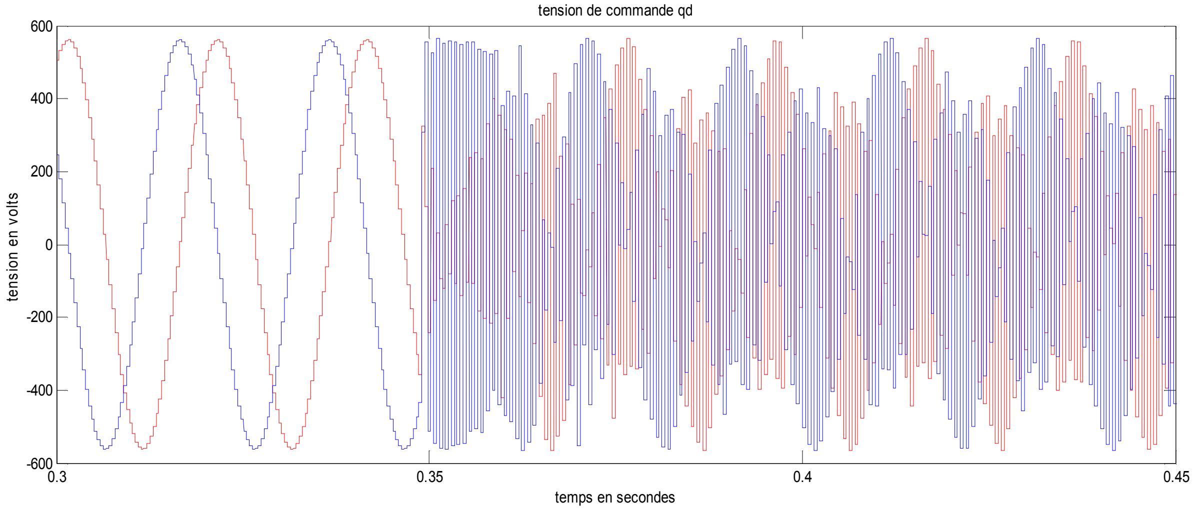
Fig. 9: Transition from full operating load to a 400% load



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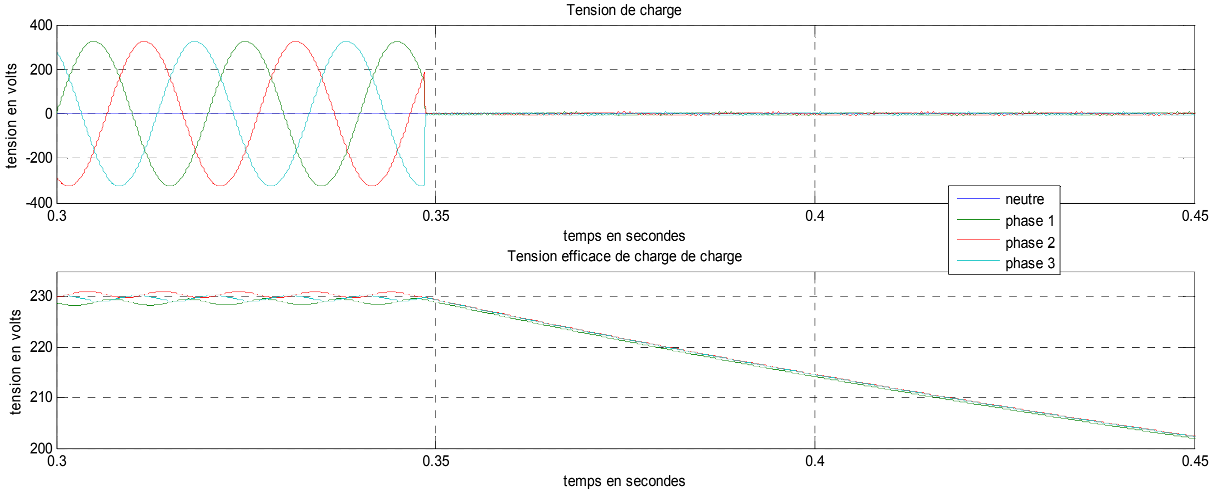

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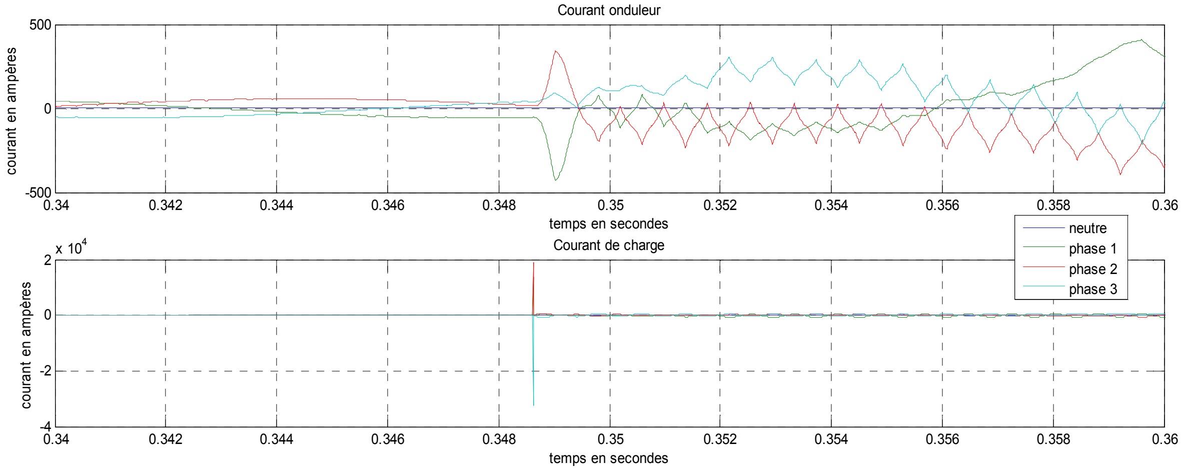

(c)

Fig. 10: From full load to short-circuit

Figure 7 the system reacts accordingly. The transformer secondary voltages remain unchanged.

The Fig. 7a presents the variation of the dq voltage command. The Fig. 7b presents the instantaneous voltage load and the RMS voltage. At last the Fig. 7c presents the inverter and load current.

Transition from full operating balanced load to disconnection of any of load phase: The system remains robust when the load is two phase. We see that in these Fig. 8.

The Fig. 8a presents the variation of the dq voltage command. The Fig. 8b presents the instantaneous voltage load and the RMS voltage. At last the Fig. 8c presents the inverter and load current.

Transition from full operating load to a 400% load: In case of overload in this Fig. 9, the voltage drops to stabilize at less than 10 msec.

The Fig. 9a presents the variation of the dq voltage command. The Fig. 9b presents the instantaneous voltage load and the RMS voltage. At last the Fig. 9c presents the inverter and load current.

From full load to short-circuit: Upon occurrence of a short circuit in these Fig. 10, the voltage is instantly canceled and the short-circuit current at the secondary transformer peaks at 20 kA.

The Fig. 10a presents the variation of the dq voltage command. The Fig. 10b presents the instantaneous voltage load and the RMS voltage. At last the Fig. 10c presents the inverter and load current.

CONCLUSION

Renewable energies are dependent on the climatic conditions. Its exploitation will be subjected to multiple disturbances (variations of the sunning, speed of the winds, loads). It is consequently essential to have robust static inverters. The order by sliding mode control makes it possible to have robustness abrupt variations of the conditions of operating.

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