

# Modeling and Control of Induction Motor using Causal Informational Graph

S. Hassainia

Department of Electrical Engineering, SoukAhras, University, Algeria

R.Toufouti

Department of Electrical Engineering, Souk Ahras University, Algeria

S.Meziane

Department of Electrical Engineering, Souk Ahras University, Algeria

S.Kechida

Department of Electrical Engineering, Guelma University, Algeria

## ABSTRACT

In this paper, we'd like to present a tool for modeling and representing systems that allows a subsequent structuring of their control. This tool, which is the causal informational graph (CIG), allows to highlight the different relationships between energy variables in a system; supplemented by another tool that is the macroscopic energy representation (MER), which insists on the principle of action and reaction between the different elements of the system. These tools enable a dual interest, first developing the model for the system structure and its control. In this article we consider the application as electromechanical conversion chain with actuator as an induction machine.

## Keywords

Causal Informational Graph (CIG), Inverse model of control, Induction machine, Field oriented control

## 1. INTRODUCTION

Growing economic challenges require more effective and efficient systems. The electro-mechanical conversion is thus ensured by electrical systems increasingly complex: Heavy chain drive kinematics, multi-computer systems, multi-converters systems .. Control of such systems is a challenging task because it must respond to the management of energy transformation that occurs through several interacting elements.

Various tools have been developed to have a representation of ordered action of energetic variables in a system; they aim at supporting the implementation of system control under study. Amongst these tools, the causal informational graph (CIG) [1] as graphical representation allows a synthetic description of the relationships between the variables of a process according to the notion of cause and effect, then the structure of control can be deduced by reversing the graph.

In this paper the principles of CIG will be subsequently applied to determine a control algorithm for induction machine. The control is addressed in a modular approach.

## 2. CIG PROCESSORS

Processors are separate elements attached to an object or a set of localized objects within the studied process, they underpins a transformation relationship between one or more influencing magnitudes and an influenced magnitude; this relationship is induced by the principle of natural causality governing the energy operation of any object or group of objects [2] [8]. These transformational relations are of two types:

### 2.1. A Rigid Relationship

Bijective, reversible and independent of time, the input affects directly the output. The causality is external.

### 2.2. A Causal Relationship

Is characterized by a well-defined input and output, the cause and effect are interchangeable, and the relationship depends on time (a variation of the input implies an evolution of the output with a transient and steady state). The Causality is internal. Fig.1 gives symbolism to differentiate the two types of processors.

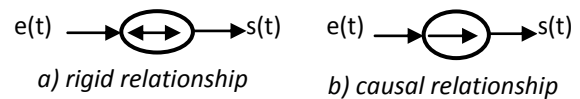


Fig.1: CIG representation of a processor

Natural causality for physical systems is integral causality: energy is a continuous function of time. Every physical entity may be represented by one or more connected processors.

## 3. MODEL CONTROL

The ideal process control consists in the inversion of its main causality chain in order to define the control input depending on the desired output. Two types of inversion are defined: rigid relationships are directly inverted show Fig.2.a; and the causal relationships which are reversed through an enslavement Fig.2.b as their inputs and outputs are not interchangeable [3].

An enslavement relationship allows an indirect reversing of the non reversible relationship, but requires an additional input, ( the present output) in order to minimize the gap and ensure the further reference [10].

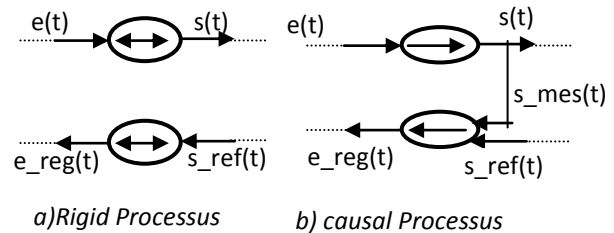


Fig.2: Relations inversion of CIG

## 4. ENERGETIC MACROSCOPIC REPRESENTATION

The energetic macroscopic representation is a condensed CIG whose graph is organized and simplified to make proof of the exchange variables of elements of an energetic conversion. A conversion of an electromagnetic chain relates an electric source ES to a mechanic source MC with:

- An electrical converter EC which adapts electrical power between the source and the machine;
- An electrical machine EM which secures an electromagnetic conversion;
- And a mechanic converter MC which adapts the mechanic energy between the machine and the mechanic source.

Each of the conversion elements can dispose of a regulating vector . This representation proves the relationship of action and reaction between the different elements of the conversion chain, fig.3

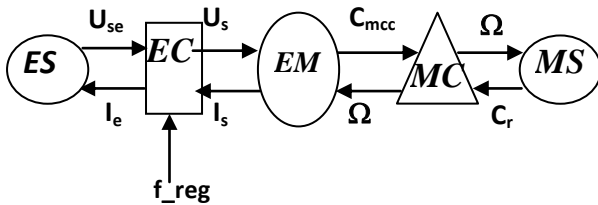


Fig.3: The chain of electromagnetic conversion

In such chain, we can find that the accumulation elements are the elements that provide connection, the sources and the elements of conversion, the case of the windings of an electrical machine.

### 4.1 Control Structure Deduced From a EMR

The CIG shows that the control of a process consists in the inversion of its model : find the right cause to generate the right effect [9] [11] ; this principle is applied to the EMR in order to deduce the control structure of an electromagnetic conversion chain.

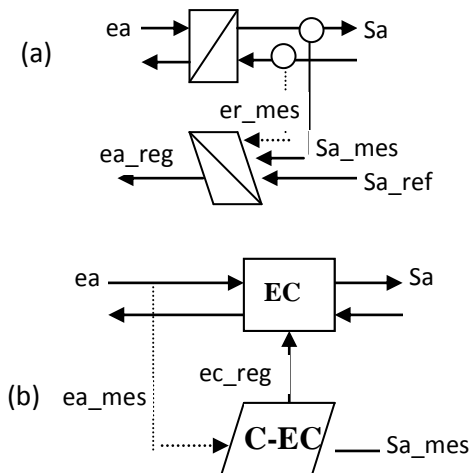


Fig.4: control structure

### 4.2. Application

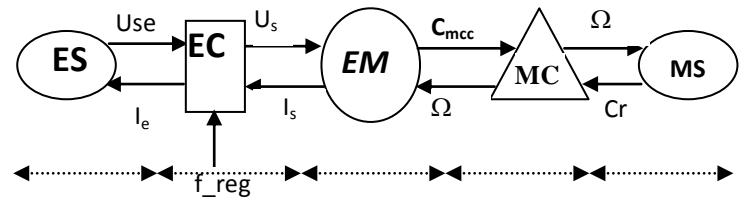


Fig.5: EMR of a conversion chain

#### 4.2.1. Sources definition

The electrical source imposes a continuous voltage  $U_{se}$ , the mechanic source is assimilated to the load that the machine tows which imposes a resistant torque; we just need a constant resisting torque.

#### 4.2.2. Representation of a static converter

The static converter is a three phase inverter characterized by its modulation function  $mce$  with

$$U_{ce} = \begin{vmatrix} Va \\ Vb \\ Vc \end{vmatrix} = mce \cdot U_{se}$$

Where

$$mce = 1/3 \begin{vmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{vmatrix} \begin{vmatrix} f_{11} \\ f_{21} \\ f_{31} \end{vmatrix}$$

$f_{11}, f_{21}, f_{31}$ , constitutes the connection functions of the static switchers of the inverter

#### 4.2.3. Representation of induction machine:

The induction machine considered is classical, it is constituted of a stator, and rotor cage; the air gap is constant; the modeling is based on classical assumptions: unsaturated magnetic circuit, constant permeance and the notch effects are neglected [9], [11].

The equations of the induction machine are defined in the arbitrary Park referential. The voltage equations are:

$$\begin{cases} V_{ds} = R_s \cdot i_{ds} + \frac{d\Phi_{ds}}{dt} - \omega_s \cdot \Phi_{qs} \\ V_{qs} = R_s \cdot i_{qs} + \frac{d\Phi_{qs}}{dt} + \omega_s \cdot \Phi_{ds} \\ V_{dr} = 0 = R_r \cdot i_{dr} + \frac{d\Phi_{dr}}{dt} - \omega_{rs} \cdot \Phi_{qr} \\ V_{qr} = 0 = R_r \cdot i_{qr} + \frac{d\Phi_{qr}}{dt} - \omega_{rs} \cdot \Phi_{ds} \end{cases} \quad (1)$$

Mechanical equations

$$J \frac{d\Omega}{dt} + f \cdot \Omega = C_{mcc} - Cr \quad (2)$$

$$C_{em} = \frac{M}{Lr} \cdot (\Phi_{dr} \cdot i_{qs} - \Phi_{qr} \cdot i_{ds}) \quad (3)$$

Flux equations

$$\begin{cases} \Phi_{ds} = Ls \cdot i_{ds} + M \cdot i_{dr} \\ \Phi_{dr} = Lr \cdot i_{dr} + M \cdot i_{ds} \\ \Phi_{qs} = Ls \cdot i_{qs} + M \cdot i_{qr} \\ \Phi_{qr} = Lr \cdot i_{qr} + M \cdot i_{qs} \end{cases} \quad (4)$$

Autopilot equations

$$\omega_s = \omega_r + p\Omega \quad (5)$$

Considering state variables statoric current and the rotoric flux, the calculations related to the modeling of induction machine in the Park referential linked to the turning field lead to the following expressions:

$$\begin{cases} V_{ds} = Rs \cdot i_{ds} + \sigma Ls \frac{di_{ds}}{dt} + e_{ds} \\ V_{qs} = Rs \cdot i_{qs} + \sigma Ls \frac{di_{qs}}{dt} + e_{qs} \\ V_{dr} = 0 = Rr \cdot i_{dr} + \frac{d\Phi_{dr}}{dt} + e_{dr} \\ V_{qr} = 0 = Rr \cdot i_{qr} + \frac{d\Phi_{qr}}{dt} + e_{qr} \end{cases} \quad (6)$$

The  $e_d$  and  $e_q$  terms resulting from electromechanical and electromagnetic coupling between the windings similar to electromotive forces developed by a DC machine are defined as follows:

$$\begin{cases} e_{ds} = -\frac{M \cdot Rr}{Lr} \Phi_{dr} - \sigma Ls \omega_s \cdot i_{qs} - \frac{M \cdot p}{Lr} \Omega \Phi_{qr} \\ e_{qs} = p \cdot \Omega \cdot \frac{M}{Lr} \Phi_{dr} + \sigma Ls \omega_s \cdot i_{ds} - \frac{MR_r^2}{L_r^2} \Phi_{qr} \\ e_{dr} = -(\omega_s - p \cdot \Omega) \Phi_{qr} + \frac{M}{Lr} Rr \cdot i_{ds} \\ e_{qr} = (\omega_s - p \cdot \Omega) \Phi_{dr} - \frac{M}{Lr} Rr \cdot i_{qs} \end{cases} \quad (7)$$

Thus the induction machine model is illustrated by the CIG of figure .6.

### 4.3 Strategy of Control

To control the induction machine, it is necessary to decouple the flux control and the current generating the torque. To this end, we call on a control called vector control which directs the flux on the axis of the Park referential by:  $\Phi_{dr} = \Phi_r$  et  $\Phi_{qr} = 0$ .

By using the voltage equations of the rotor, we will come to:

$$\begin{cases} M \cdot i_{ds} = \Phi_{dr} + \frac{Lr}{Rr} \frac{d\Phi_{dr}}{dt} \\ \omega_r \cdot \Phi_{dr} = \frac{MRr}{Lr} \cdot i_{qs} \end{cases} \quad (8)$$

And the torque is

$$C_{em} = p \cdot \frac{M}{Lr} \cdot \Phi_{dr} \cdot i_{qs} \quad (9)$$

From these equations, two magnitudes are to be controlled the flux and its position.

The flux is controlled by the current  $i_{ds}$  hence  $V_{ds}$ , the torque is controlled by the current  $i_{qs}$  hence  $V_{qs}$

For an indirect control, we impose:  $\Phi_{dr} = \Phi_{ref} = cste$

In respect to the rules of inversion of the CIG, we get to the control of the CIG fig.7 with speed correctors and current correctors. To choose the correctors, we can introduce the conventional corrector PI or IP or smart correctors.

Figure .8 illustrates the EMR of the conversion chain with the control axis brought out through Matlab Simulink.

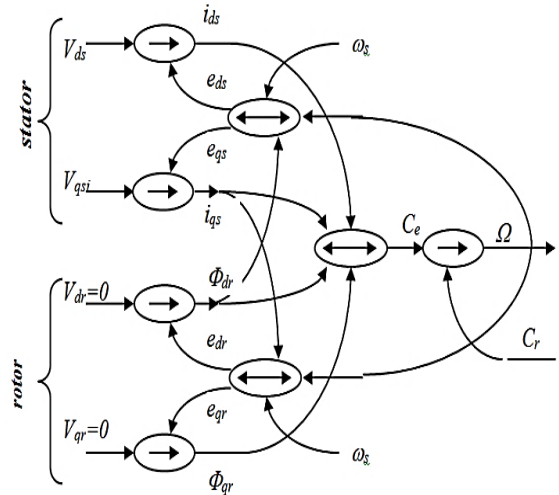


Fig.6: CIG Representation of the induction motor

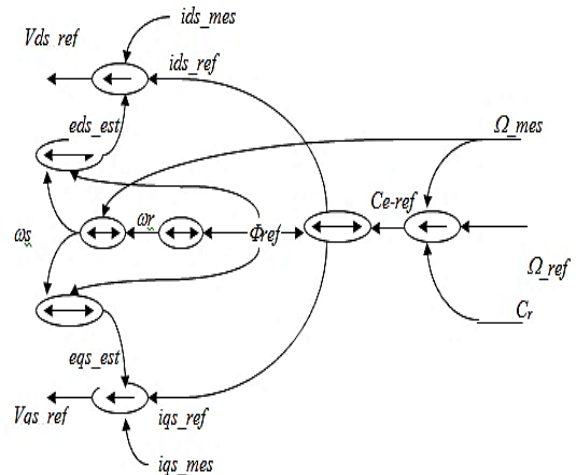


Fig.7: Control scheme of the induction motor



As the figure shows, the response of the flux is very good because the real and estimated rotor flux tracks the reference values adequately (figures 7a and 7b). That figure shows the satisfying induction motor functioning; the rotor flux is maintained independently of the electromagnetic torque.

## 5. CONCLUSION

In this paper, we have presented a control structuring method of an electromagnetic conversion chain. The choice of the electromagnetic conversion chain concerning a chain with an induction machine is to make proof of the usefulness of formalism CIG and its importance for structuring of electrical machine control laws and complex systems.

This formalism (CIG) helps functional comprehension and description of the induction machine and allows the formulation of the machine control strategy by use of a simple logical reasoning that dwells in the step by step inversion of causalities.

Such a tool turns to be of great usefulness in the complex systems: the complex inversion chains (multi-machines, multi-convertors).

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