

# Simple Adaptive Synergetic Control Scheme Based on The MIT Rule of the DC Motor

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## ABSTRACT

An adaptive synergetic control scheme of a DC motor via a DC-DC converter is presented in this article. The difficulty in implementing a synergetic control lies in the optimal choice of the control parameters. This operation becomes tedious when the number of closed loops in the control system is large. Several adaptive parameter methods are exposed in the literature, some of which are complex and others simple. A synergetic control parameter adaptation law is almost unexplored in the scientific literature. The proposed solution is an adaptation mechanism of the synergetic control parameter using the MIT (Massachusetts Institute of Technology) rule. A theoretical study carried out made it possible to highlight a law of adjustment of the current and the speed, the variation of which verifies the negative direction of the gradient of the defined cost function. Computer simulations in Matlab/Simulink show good controller performance in improving transient stability and settling time. In addition, synergetic control is an interesting tool for speed and current control of DC motor.

**Keywords:** Adaptive law, DC motor, MIT rule, Synergetic control.

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## I. INTRODUCTION

The incessant evolution of technology in this century has thrown us into a world where performance is a primary objective. Generally, in industrial process control, it is still not a question of determining or adjusting adequate control strategies to maintain system inputs at desired setpoints, but rather of optimizing one or more performance criteria while respecting operating constraints. For example, the control of DC motor requires the optimisation of certain physical parameters such as speed, position, angle and current. The DC motor has several applications, namely the attraction of electric vehicles, robotic manipulators or machine tools in industry [1] and requires precision, robustness and fidelity of the control systems. In order to improve the performance of DC motors, several control schemes and methods are proposed in the literature: Proportional Integral Derivative (PID) controller is used to regulate the speed of DC motors via DC-DC converters [2]. It is the most widely used because it has a simple configuration and good performance under certain operating conditions. PID regulators can be divided into two categories [3]. PID controllers with fixed and adaptive parameters whose laws of adaptation are derived from fuzzy logic [4], neural networks, MIT rule [5], recursive least square methods [6] and other hybrid methods in the literature. However, other robust control methods such as

sliding mode [7], meta-heuristic algorithm [1], fuzzy logic, neural network and many other non-linear control techniques are some of the methods for regulating the parameters of the DC machine to improve its operating performance. Despite these various methods of regulation, human satisfaction is far from being achieved. In [8], the theory of synergetic control is exploited in regulation of permanent magnet synchronous motor parameters, [9] and [10] use the same theory to control a static compensator and [11] shows that synergetic control contributes to the reduction of harmonics current injected by grid-connected photovoltaic systems. The work of [12] presents synergistic control as a strong and robust tool in the automation of robotic manipulators. It brings with notable satisfaction high quality precision and fidelity. In [13] the synergetic theory is used for indirect field-oriented control to improve the performance of an induction machine. The results presented show that the proper choice of the control parameter reduces peaks and oscillations during the transient phase. The selection of the control parameter for the synergistic control is manual. This work presents synergetic control as a robust and efficient tool for controlling industrial processes. The problem posed by synergetic control is the fateful choice of control parameters. No method on the choice of this parameter is indicated in the literature. In this study we propose an adaptive synergetic control technique based on the MIT rule and it contributes to:

- Reduce the time needed to choose the control parameters;
- Optimize the control parameters by simple rule;
- Reduce oscillations in transient mode;
- Improve the convergence time.

This work is structured in sections as follows. Section 2 introduces the power system and its mathematical model, which takes into account the equations that describe the DC motor. In section 3 we exploit synergetic theory to derive a law for controlling the speed and current of the DC motor from the problem formulated in section 2. The innovative and central part of our study is in section 4. In this section we highlight the mechanism that allows the synergetic control parameters to be updated. Section 5 presents the numerical results in the Matlab/Simulink environment. Comparative analysis with the classical synergetic control is invested in order to show the contributions of the proposed control method. The last section which is section 6 is the conclusion.

## II. POWER SYSTEM MODELLING

Let us consider Fig which describes the DC machine connected to the buck converter. The average matrix based on the study of [14] is given by the equation (1).

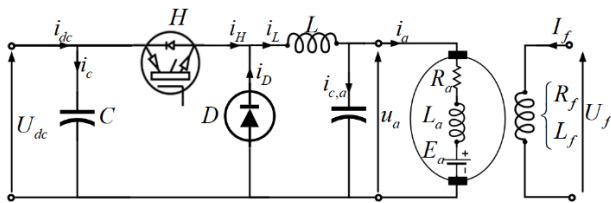


Fig.1. Power system connected DC machine.

$$\frac{d}{dt} \begin{bmatrix} i_L \\ i_a \\ u_a \\ \Omega \\ i_f \end{bmatrix} = \begin{bmatrix} 0 & 0 & -\frac{1}{L} & 0 & 0 \\ 0 & \frac{1}{L_a} & -\frac{R_a}{L_a} & 0 & 0 \\ \frac{1}{C_a} & -\frac{1}{C_a} & 0 & 0 & 0 \\ 0 & \frac{K}{J_t} & 0 & -\frac{f}{J_t} & 0 \\ 0 & 0 & 0 & 0 & -\frac{R_f}{L_f} \end{bmatrix} \begin{bmatrix} i_L \\ i_a \\ u_a \\ \Omega \\ i_f \end{bmatrix} + \begin{bmatrix} \frac{\alpha}{L} \\ -\frac{1}{L_a} \\ 0 \\ \frac{1}{J_t} \\ \frac{1}{L_f} \end{bmatrix} (U_{dc} \quad E_a \quad 1 \quad C_r \quad U_f) \quad (1)$$

where  $i_L$  is the current flowing through the inductance  $L$ ,  $i_a$ ,  $u_a$  are the armature current and voltage respectively,  $\Omega$  the speed,  $i_f$  and  $U_f$  are the field current and voltage,  $J_t$  the rotor moment of inertia,  $K$  is the torque constant,  $f$  is the viscous friction constant,  $C_r$  is the load torque and  $\alpha$  is the duty cycle.

Let us consider the reduced model extracted from (1) given as follow:

$$\begin{cases} \dot{x} = f(x,t) + g(x,t)u(x,t) \\ i_a \approx i_L \end{cases} \quad (2)$$

where  $x = [i_a \quad \Omega]^T$  are the state vector,

$$f(x,t) \triangleq \begin{bmatrix} -\frac{u_a}{L} \\ -\frac{f\Omega + C_r}{J_t} \end{bmatrix}, \quad g(x,t) \triangleq \begin{bmatrix} -\frac{U_{dc}}{L} \\ \frac{K}{J_t} \end{bmatrix} \quad \text{and} \quad u = [\alpha \quad i_a] \text{ is}$$

the control vector. Equation (2) is the formulation of the problem.

## III. SYNERGETIC CONTROL DESIGN

In order to achieve the objective of synergetic control, the macro-variable of the closed-loop system is defined as follows:

$$\Psi(x,t) = \phi(x,t) = x^* - x \quad (2)$$

$\Psi$  is the macro-variable,  $x^*$  is the reference vector and  $\Phi$  is the objective function that must satisfy the constraint defined by equation (4) [10], [15]

$$\phi(x,t) = 0 \quad (3)$$

In order to satisfy the requirement imposed by (4), the constraint on the evolution of macro-variable is defined as follows [9], [16]:

$$\lambda \dot{\Psi}(x,t) + \Psi(x,t) = 0 \quad (4)$$

where the control parameter  $\lambda$  indicates the speed of convergence of the closed loop system to the domain defined in (4). Substituting (2) with the time derivative of (3) gives equation (6).

$$\dot{\Psi}(x,t) = \dot{x}^* - f(x,t) - g(x,t)u(x,t) \quad (5)$$

By substituting (6) in (5), the following control vector is deduced:

$$u(x,t) = g^{-1}(x,t) \{ \dot{x}^* - f(x,t) + \lambda^{-1} \Psi(x,t) \} \quad (6)$$

The control law given in (7) is used to regulate the speed and current of the DC motor. However, the function  $\lambda(t)$  is often defined as constant and chosen manually. Therefore, an adaptive law of this parameter by the MIT rule will be proposed here.

## IV. ADAPTIVE LAW DESIGN

The adaption mechanism based on the MIT rule here is used to adjust the  $\lambda(t)$  parameter of the control law defined in (7). The cost function of this rule which minimises the micro-variable defined in (3) is:

$$j(\lambda(t)) = \frac{1}{2} \psi^2(x,t) \quad (7)$$

For this, it is preferable to adjust the parameter  $\lambda$  in the negative direction of the gradient of  $j$  as shown in equation (9).

$$\frac{\partial \lambda(t)}{\partial t} = -\gamma \frac{\partial j(x,t)}{\partial \lambda(t)} = -\gamma \psi(t) \frac{\partial \psi(x,t)}{\partial \lambda(t)} \quad (8)$$

where  $\lambda(t) = [\lambda_1(t) \ \lambda_2(t)]^T > 0$  and  $\gamma > 0$ . By transforming (9) into (10), we deduce the solutions given by (10).

$$\frac{\partial \lambda(x,t)}{\partial t} = -\gamma \psi(x,t) \frac{\partial \psi(x,t)}{\partial u(x,t)} \cdot \frac{\partial u(x,t)}{\partial \lambda(t)} \quad (9)$$

$$\begin{cases} \frac{\partial \psi(t)}{\partial u(x,t)} = g(x,t)\lambda(t) \\ \frac{\partial u(x,t)}{\partial \lambda(t)} = -\psi(x,t)g^{-1}(x,t)\lambda^{-2}(t) \end{cases} \quad (10)$$

For the convergence condition to be verified,  $\lambda$  must be chosen as indicated by (12).

$$\frac{\partial}{\partial t} (\lambda(t))^2 = 2\gamma (\psi(x,t))^2 \quad (11)$$

By substituting equation (12) in equation (9) we verify the direction of the negative gradient given as follows.

$$\begin{cases} \frac{\partial j(x,t)}{\partial \lambda(t)} = -\frac{\psi^2(x,t)}{\lambda(t)} \\ \frac{\partial \psi(x,t)}{\partial \lambda(t)} = -\frac{\psi(x,t)}{\lambda(t)} \end{cases} \quad (12)$$

### V. RESULTS AND DISCUSSIONS

In order to validate the adaptive synergetic control law, the numerical simulation results under the Matlab/Simulink environment are presented in Fig. 2 and 3. The performance of the system has been obtained under speed variation as described in fig. 3(a). The simulation parameters are given in Table 1 and Fig. 2 shows the parameters  $\tau_1$  and  $\tau_2$  adapted by the MIT rule in Fig. 2(a) and 2(b) respectively. Fig. 3 shows a detailed comparison between the two-control law. The variation and evolution of the DC motor speeds shown in Fig. 2(a) position the adaptive synergetic control as the best in convergence speed, accuracy and settling time. Zooms in Fig. 3(a) present an adaptive synergetic control as a tool for improving transient stability in DC motor speed control. The evolution of the torque presented in Fig. 3(c) is proportional to the current in Fig. 3(b). A considerable improvement in transitional regime trough of the proposed order is observed. It cancels the oscillations and improves the system response. Fig. 3(d) shows the armature voltage response of the motor so the benefits are identical to those shown in Fig. 3(b) and 3(c). The adaptive control proposed in this article provides a satisfactory reduction in the oscillations of the conventional control and contributes to improved system performance. Indeed, the adaptive method by the MIT rule of the  $\lambda$  parameter improves the performance of the synergetic controller while reducing oscillations, improves settling time, reduces noise, increases robustness, and makes the system more accurate and faithful. The particularity of the proposed control law lies in the search of the optimal values of  $\tau_1$  and  $\tau_2$  for the best system performance.

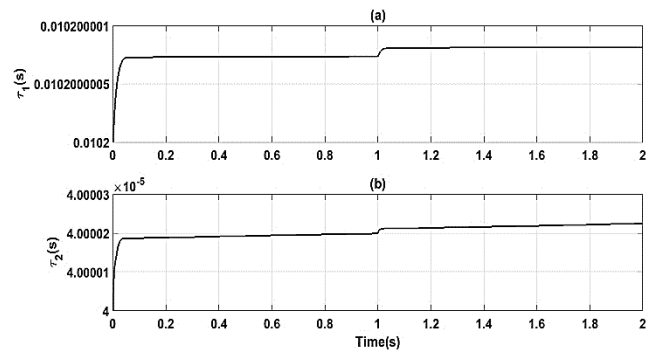


Fig. 2. Convergence rate adapted under variation speed.

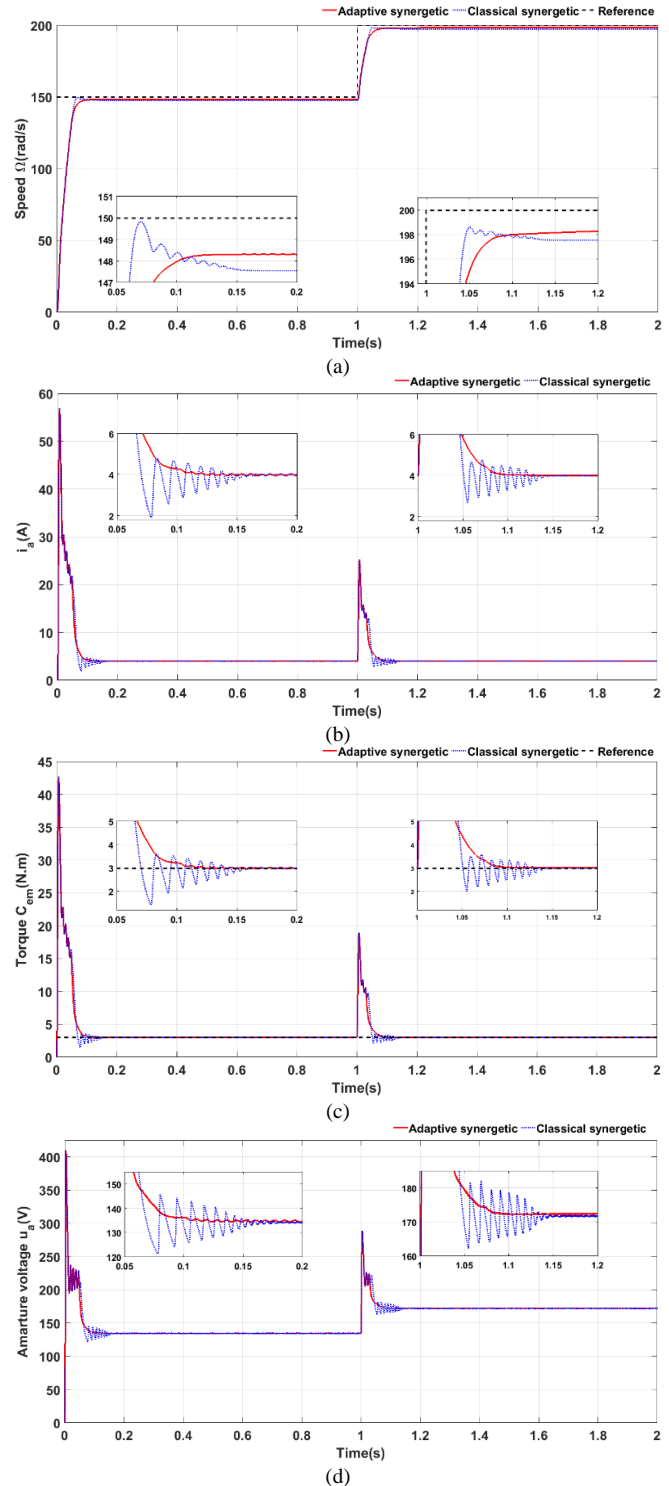


Fig. 1. System performances under varying speed: (a) Speed  $\Omega$ ; (b) Armature current  $i_a$ ; (c) Torque  $C_{em}$ ; (d) Armature voltage  $u_a$ .

TABLE 1: SIMULATION PARAMETERS

$R_a$	$L_a$	$f$	$K$	$I_{a,n}$	$J$
5.5Ω	0.0119H	$4.051 \times 10^{-4} Nms$	0.859	4.50	0.00705 kgm <sup>2</sup>
$\gamma$	$U_a$	$P$	$\tau_1$	$\tau_2$	
$10^{-8}$	220V	1kW	$5.38 \times 10^{-3}$	$27.8 \times 10^{-7}$	

## VI. CONCLUSION

In this paper, an adaptive synergetic control scheme of a DC motor via a DC-DC converter is presented. The implementation of an adaptation law using the MIT rule has made it possible to optimize the control parameters and remove the difficulty of choosing these parameters. The theoretical study carried out made it also possible to highlight a law of adjustment of the current and the speed, the variation of which verifies the negative direction of the gradient of the defined cost function. Computer simulations were made to verify the performance of the solution and shows how the system can be improved under the speed variation. Numerical simulations in Matlab/Simulink shows good controller performance in improving transient stability, settling time and reduce oscillation. In addition, synergetic control is an interesting tool for speed and current control of DC motor. The improvement of these performances allows to reduce losses, winding heating, acoustic noise and optimization of the motor efficiency. The proposed method can find application in the control of systems connected to the electrical network, in the control of asynchronous machines. Our future work focuses on the experimental implementation of synergetic control in order to verify this theory in DC motor control.

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