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# Particle Swarm Optimisation of a Terminal Synergetic Controllers for a DC-DC Converter

H. Abderrezek, M. N. Harmas

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***Abstract*—**DC-DC converters are widely used as reliable power source for many industrial and military applications, computers and electronic devices. Several control methods were developed for DC-DC converters control mostly with asymptotic convergence. Synergetic control (SC) is a proven robust control approach and will be used here in a so called terminal scheme to achieve finite time convergence. Lyapounov synthesis is adopted to assure controlled system stability. Furthermore particle swarm optimization (PSO) algorithm, based on an integral time absolute of error (ITAE) criterion will be used to optimize controller parameters. Simulation of terminal synergetic control of a DC-DC converter is carried out for different operating conditions and results are compared to classic synergetic control performance, that which demonstrate the effectiveness and feasibility of the proposed control method.

***Keywords*—**DC-DC converter, PSO, finite time, terminal, synergetic control.

## I. Introduction

DC-DC converters have been widely used in most of the industrial applications such as DC motor drives, computer systems and communication equipments. Design of high performance control is a challenge because of its nonlinear and time variant nature. Generally, linear conventional control fails to accomplish robustness under nonlinearity, parameter variation, load disturbance and input voltage variation.

Sliding mode control (SMC) has been extensively used in robust control approaches in many nonlinear applications like DC/DC converter to power system stabilizers and a large effort has been directed to address its main drawback: dangerous chattering ever present in SMC due to the discontinuous law component [1], [2]. Many approaches have been proposed to reduce the latter but mostly at the expense of robustness performance [3], [4]. Synergetic control like sliding mode control is based on the basic idea that if we could force a system to a desired manifold with designer chosen dynamics using continuous control law, we should achieve similar performance as SMC without its main inconvenient: chattering phenomenon.

Terminal synergetic control (TSC) has the advantage of finite time convergence and tiny steady state error. The strong robustness of this control plays a very important role in guaranteeing the normal operation of DC converter, and it can make the DC-DC converter provide stable output even for load varying or when the input voltage varies.

Abderrezek. Hadjer and Harmas Mohamed Nadjib are with the Electrical Engeniring Department, University of Ferhat Abbas Setif1, setif, Algeria (e-mail: hadjer_ji@ live.fr, mharmas@ univ_setif.dz).

Optimization techniques inspired by swarm intelligence have become increasingly popular over the last decade. They are characterized by a decentralized operation that mimics the behavior of swarms of social insects, flocks of birds, schools of fish. The advantage of these approaches over traditional techniques is their robustness and flexibility. These properties make the success of the swarm intelligence paradigm for the design of algorithms increasingly face complex problems. In this work, we focus on one the most successful optimization algorithm inspired by swarm intelligence techniques: particle swarm optimization (PSO). The latter shall be used to optimize synergetic controller parameters and applied to a DC-DC converter.

The mathematical model for a typical Buck DC-DC converter is described in Section II. Section III presents a brief description of synergetic control. Design of a terminal synergetic controller is given in Section IV. In the following section, PSO algorithm is introduced and simulation results confirming the effectiveness and the applicability of the proposed method are presented in Section VI.

## II. Model of Dc-Dc Converter

Basic DC-DC converter schematic circuit known as a buck converter is illustrated in Fig. 1, consisting of one switch, a fast free-wheeling diode and an R, L, and C components. The switching action can be implemented by one of three-terminal semiconductor switches, such as IGBT or MOSFET.

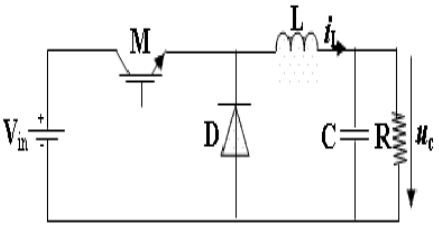



Fig. 1 DC-DC Buck converter

When the converter works in the continuous conduction mode, the system can be described as in [1].

$$\begin{bmatrix} \dot{i}_L \\ \dot{u}_C \end{bmatrix} = \begin{bmatrix} 0 & \frac{-1}{L} \\ \frac{1}{C} & \frac{-1}{RC} \end{bmatrix} \begin{bmatrix} i_L \\ u_C \end{bmatrix} + \begin{bmatrix} \frac{V_{in}}{L} \\ 0 \end{bmatrix} u \quad (1)$$

where u is the switching state, when u=1, the switch M is turned on, and when u=0, M is off.

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Selecting the output voltage and its derivative as system state variables, that is

$$\begin{cases} x_1 = u_C \\ x_2 = \dfrac{du_C}{dt} \end{cases} \tag{2}$$

Then the state space model describing the system is derived as

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -\dfrac{x_1}{LC} - \dfrac{x_2}{RC} + \dfrac{V_{in}}{LC}u \end{cases} \tag{3}$$

when the switching frequency is high enough and ripples are small, if we suppose the duty ratio of a switching period is *d* then the state space average model can be rewritten as

$$\begin{cases} \dot{x}_1 = x_2 \\ \dot{x}_2 = -\dfrac{x_1}{LC} - \dfrac{x_2}{RC} + \dfrac{V_{in}}{LC}d \end{cases} \tag{4}$$

## III. Synergetic Control of Buck Dc-Dc Converter

Introduced in the last decades, synergetic control is rapidly gaining acceptance not only by the robust control community but also by the industrial partners, as illustrated by its implementation in power electronics [5], [6]. We briefly introduce the basics of synergetic control.

The synergetic control synthesis of the system given in (4) begins by defining a designer chosen macro-variable given as in:

$$\psi = k.e + \dot{e} \tag{5}$$

where $k \succ 0$.

Suppose the expected tracking voltage is *r*, then the tracking error and its derivative are defined as:

$$e = r - x(1) \quad ; \quad \dot{e} = \dot{r} - x(2)$$

The control will force the system to operate on the manifold

$$\psi = 0 \ .$$

The designer can select the characteristics of this macro-variable according to the control specifications and as a trivial case a linear combination of variables of interest can be an appropriate choice. Control vector dimension is used to elaborate commensurate macro-variables.

Not unique, the desired dynamic evolution of the macro-variables can be simply chosen as:

$$T\dot{\psi} + \psi = 0 \tag{6}$$

where T is a design parameter specifying the convergence speed to the equilibrium manifold.

Directly substituting the governing (5) and (6) into (4) of the buck converter and rearranging, a control law is obtained, given by:

$$d = \frac{L.C}{V_{in}}\left[\ddot{r} + \frac{x(1)}{L.C} + \frac{x(2)}{R.C} + k.\dot{e} + (1/T).\psi\right] \tag{7}$$

The control elaborated guarantees only an asymptotic convergence to the final state, to have a faster convergence, it is necessary to modify the macro variable.

## IV. Converter Terminal Synergetic Control

The terminal synergetic control design is based on a particular choice of the macro variable which results in the determination of a control law to force the system to track a reference signal in a finite time. A terminal synergetic is established and a fast finite convergence is granted [7], [8].

Let a nonlinear macro-variable be defined as follows:

$$\psi(e) = \dot{e} + \alpha.e + \beta.e^{\frac{q}{p}} \tag{8}$$

where $\alpha > 0, \beta > 0$, $p$ and $q$ are positive constants, and $q > p$.

Using the same procedure as in the synergetic approach, (6) can be expressed as:

$$\ddot{e} + \alpha\dot{e} + \beta\frac{q}{p}\dot{e}e^{\frac{q}{p}-1} = -\frac{1}{T}\psi(e) \tag{9}$$

After a few simple steps, a terminal synergetic controller is obtained as:

$$d = \frac{C.L}{V_{in}}\left[\frac{x(1)}{L.C} + \frac{x(2)}{R.C} + \frac{\psi(e)}{T} + \alpha.\dot{e} + \beta.(\frac{q}{p}).\dot{e}.e^{\frac{q}{p}-1}\right] \tag{10}$$

Stability can be evaluated using the following Lyapounov function candidate:

$$V = \frac{1}{2}\psi(e)^2 \tag{11}$$

which leads, after differentiation then using (9), to:

$$\dot{V} = \psi(e)\dot{\psi}(e) \tag{12}$$

$$\dot{V} = \psi(e).(\ddot{e} + \alpha\dot{e} + \beta\frac{q}{p}\dot{e}e^{\frac{q}{p}-1}) = \psi(e).(-\frac{1}{T}\psi(e))$$

$$\dot{V} = -\frac{1}{T}\psi(e)^2 < 0 \tag{13}$$

Therefore the controller can meet Lyapunov stability.

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## V. Particle Swarm Optimisation (PSO)

Particle swarm optimization (PSO) is a fairly new optimization algorithm and is considered a population-based optimization tool first proposed by Kennedy and Eberhart. In PSO method which is inspired by flocks of birds and schools of fish (1995) [9], they are candidate solutions for the optimization problem here dubbed particles; these particles are moved around in the search-space according to a few simple formulae. A number of simple entities (particles) is placed in the parameter space of problem or function, and each evaluates the fitness (fitness is the name given to the objective function, it is the function that the optimization algorithm will have to optimize) at its current location. The advantages of PSO compared to other evolutionary computational techniques are:

- PSO is easy to implement.
- There are few parameters to be adjusted in PSO.
- All the particle tends to converge to the best solution rapidly.

PSO has been used in many engineering fields such a power systems stabilizers, converter control [10-12].

### *A.Basic PSO Algorithm*

In the PSO algorithm each individual is called a "particle", and is subject to a movement in a multidimensional space that represents the belief space. Particles have memory, thus retaining part of their previous state. There is no restriction for particles to share the same point in belief space, but in any case their individuality is preserved. Each particle's movement is the composition of an initial random velocity and two randomly weighted influences: individuality, the tendency to return to the particle's best previous position, and sociality, the tendency to move towards the neighborhood's best previous position.

Each particle tries to modify its position using the following information:

- the current positions,
- the current velocities,
- the distance between the current position and *pbest*,
- the distance between the current position and *gbes*t.

The mathematical equations for the searching process are [4]:

$$V_i^{k+1} = wV_i^k + c_1.rand_1(..)(pbest_i - S_i^k) + c_2.rand_2(..)(pbest_i - S_i^k) \quad (14)$$

$$s_i^{k+1} = s_i^k + V_i^{k+1} \quad (15)$$

where

$V_i^k$ Velocity of particle i at iteration k

$w$ Weighting function

$c_1, c_2$ weighting factor are uniformly distributed random numbers between 0 and 1.

Pbest: it's the best known position of particle.

gbest: it's the best known position of the entire Swarm.

$S_i^k$ Current position of the particle i at iteration k *pbest* of particle i 'gbest' value is obtained by any particle so far in the above procedure. The flow chart of PSO algorithm is shown in Fig. 2.

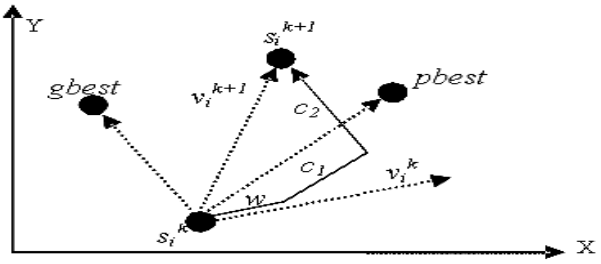



Fig. 2 The velocity and position updates in PSO

### *B.Algorithm Process*

The steps of standard PSO algorithm are as follows:

Step 1. Initialize a group of particles including the speed and random location;

Step 2. Evaluate the fitness of each particle;

Step 3. Compare their fitness with the best location of their experience for each particle, and then update the current location *pbest* if it is better.

Step 4. Compare its fitness with the best position *gbest* of their overall experience for each particle, and then set new *gbest* if it is better.

Step 5. Change the speed and location of particles according to equations (14) and (15);

Step 6. If no interruptive condition is satisfied (maximum value or number of iteration), then return to step2.

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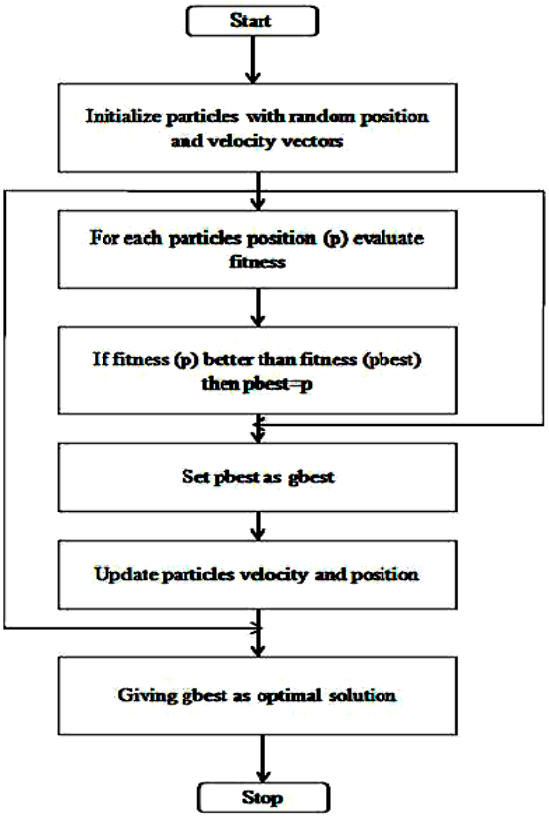



Fig. 3 PSO algorithm

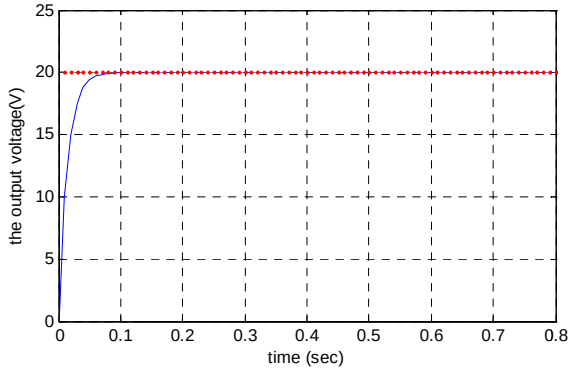
The objective function considered is based on an error criterion which is often the case when evaluating controller performances. A number of such criteria are available and in the proposed work controller's performance is evaluated in terms of Integral Time Absolute of Error (ITAE).

$$J = \int_0^t t.|e(t)|dt \tag{16}$$

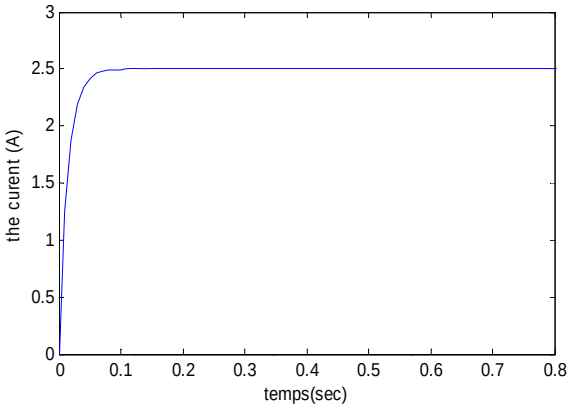
ITAE weighs the error with time and hence emphasizes the error values over a range of 0 to t. The proposed approach employs a PSO search for the optimum parameter settings of the proposed DC-DC converter terminal synergetic control. Control parameters to be tuned through the optimization algorithm are T and (*q/p*), with the aim to minimize the selected fitness objective function thus improving system response performance in terms of settling time and overshoot.

## VI. Simulation Results

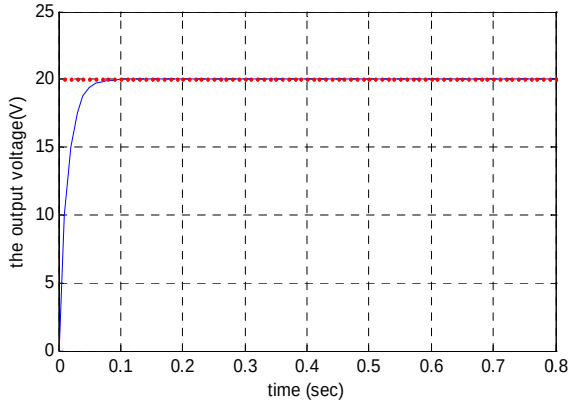
The proposed controllers were used to DC-DC converter and simulation operation was carried out. Parameters of DC-DC converter are chosen as: $L = 80\mu H; E = 24V; R = 8\Omega; C = 2000\mu F$. The expected tracking voltage is $r = 20v$. The initial state of this system is $x = [0, 0]^T$. The main parameters used in designing controller are: $q = 5, p = 2$. The simulation software used is MATLAB 7.11.0.




(a) Output voltage for a 20v reference

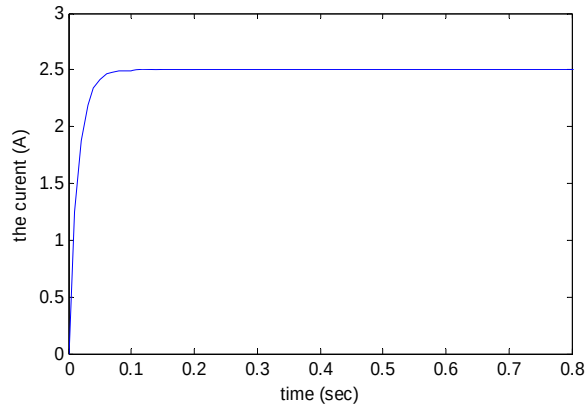



(b) Inductor current signal for a 20v reference voltage.

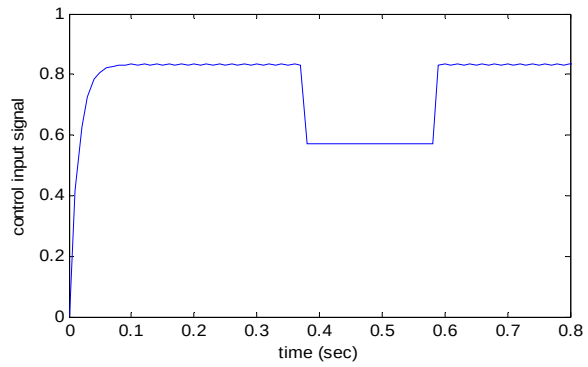



(c) Output voltage for line variation

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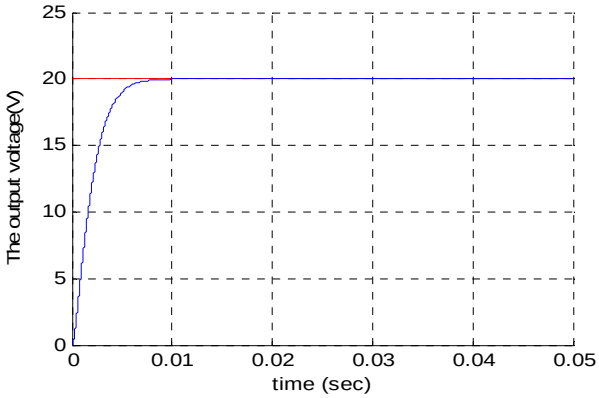



(d) Inductor current signal for line variation

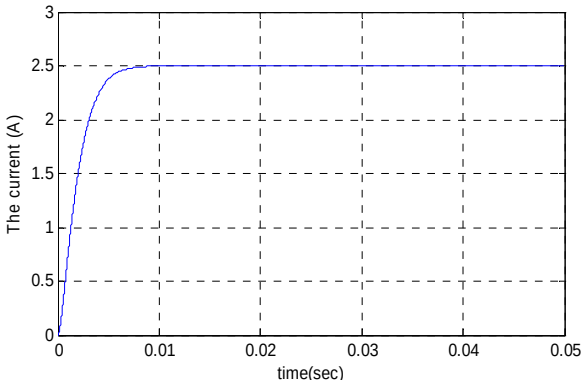



(e) Control input signalfor line variation

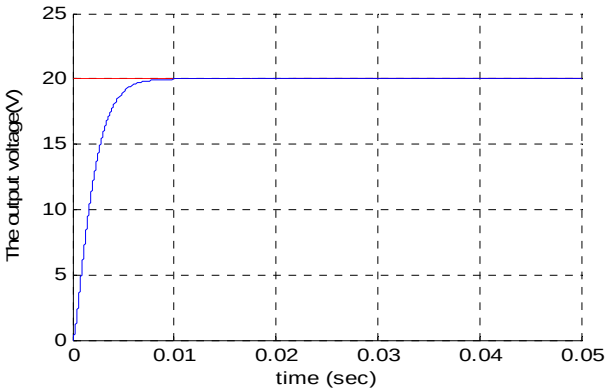
Fig. 4 Simulation signals for synergetic control



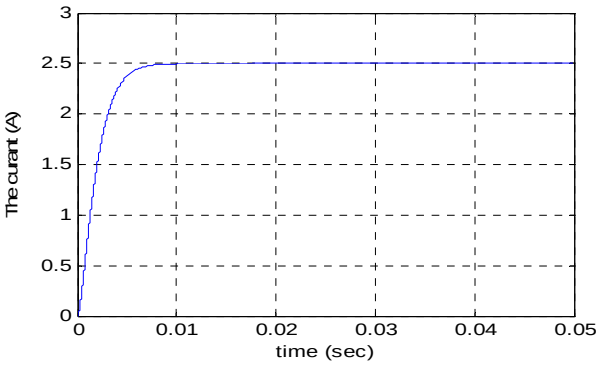

(a) Output voltage for a 20v reference



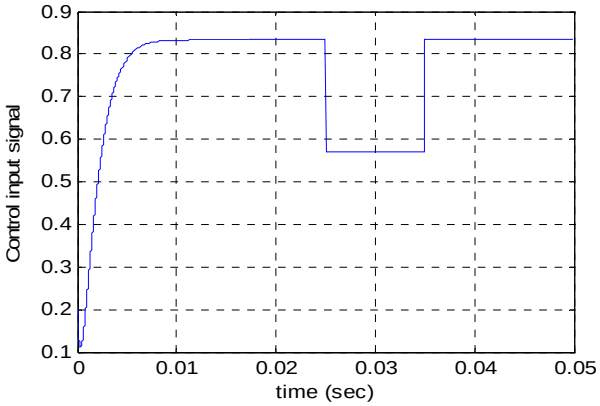

(b) Inductor current for a 20 v reference



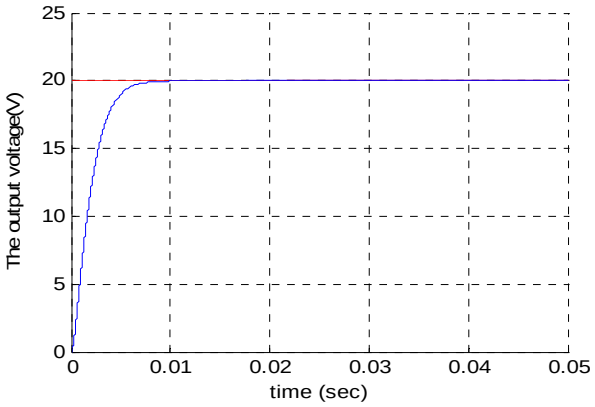

(c) Output voltage for line variation



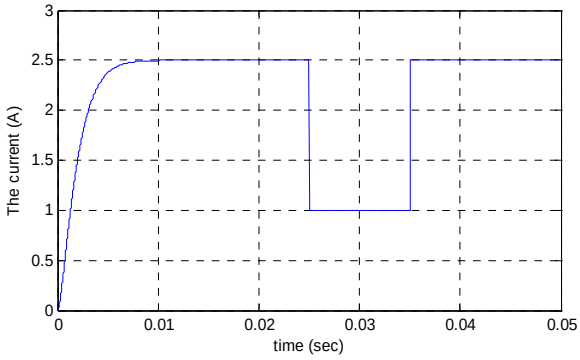

(d) Inductor current for line variation




(e) Control signal for line variation




(f) Output voltage for load variation




(g) Inductor current for load variation

Fig. 5 Simulation results for terminal synergetic control

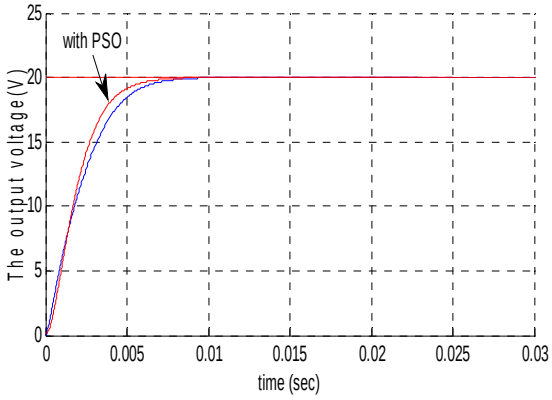



Fig. 6 Outpout voltage of TSC with and without PSO for a 20 v reference

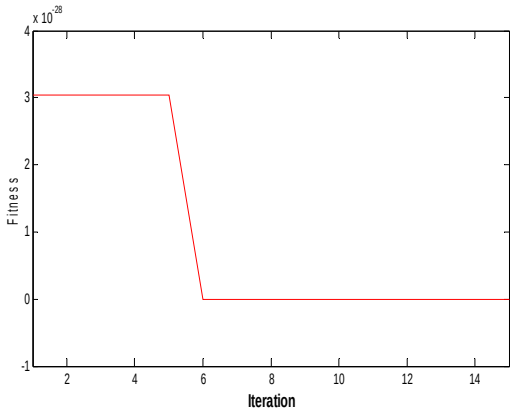



Fig. 7 The objective function (ITAE)

Figs. 4 and 5 show the responding profiles of output voltage, Inductor current, control input and tracking error of the two controllers. The obtained results in regulation mode for the synergetic control (SC) and the terminal synergetic control (TSC) are shown in Fig. 4 (a) and 5 (a). The results show that terminal synergetic control presents a faster convergence to the desired state than its classical counterpart. Indeed position error reaches zero in a time nearly equal to 0.1s using synergetic control whereas by terminal synergetic control this error reaches zero in a time of the order of 0.01s.

In order to test the robustness of the two control laws, we varied the source voltage from 24V to 35V at 0.25s time and back to 24V after 10 sec. It can be seen from these curves that the output voltage can track the reference with nearly zero error. Because the output voltage is proportional to the product of duty cycle and source voltage, when the source voltage changes, the tracking output voltage keep steady by adjusting duty cycle d. Simulation results are shown in Figs. 4 (b) and 5 (b) for the two approaches regular and terminal synergetic control.

Figs. 4 (c) and 5 (c) show the responding profiles corresponding to load fluctuation. The load resistance varies from 8Ω to 20Ω at the time of 0.25s and returns to 8Ω at the time of 0.35s.

From these results, one can see that tracking output voltage indicates a small rise time and nearly zero error which are desired performances. Fig. 6 shows the results of simulation using PSO. Optimal values found for T and (q/p) through PSO are respectively 1.0609 and T=0.0012. The objective function (ITAE) is depicted in Fig. 7.

## VII. Conclusion

In this paper the development and simulation of terminal synergetic control of a DC-DC converter using PSO to optimize control parameters are presented. Terminal Synergetic approach guarantees finite time convergence increasing therefore system robustness because it reduces reaching phase duration. Acceptable global performances are maintained despite load or line variation.

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Severe operating conditions have been used to assess the validity of the proposed approach showing remarkable performance with no chattering.

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**H. Abderrezek** was born in Algeria, 1988, She received the degree of engineering in automatic from Electrical Engineering Department University of Setif1 in 2011. She is currently an M.Sc. student in Electrical engineering department. She is interested in subjects of optimization techniques, control technique for power electronics.



**M. N Harmas** was born in Algeria, he received the degree of professor in ferhat abbas university of setif1, department of electronics, Algeria in 2013. He is currently a professor in Electrical engineering department. He interested field is control systems, power systems, power electronics

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