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PARTICLE SWARM OPTIMIZATION OF A FINITE CONVERGENCE CONTROL FOR DC-DC CONVERTERS

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ABSTRACT

DC-DC converters are widely used as power electronics devices. Many control methods were developed for DC-DC converters control mostly with asymptotic convergence. Sliding mode control is a proven robust control approach and will be used to achieve finite time convergence. Furthermore a particle swarm optimization (PSO) algorithm will be used to optimize controller parameters which used an ITAE criterion. The simulation of terminal sliding mode control of a DC-DC converter is carried out for different operating conditions and its results will be compared to classic sliding mode control results, we will show the validity of terminal sliding mode control approach.

Keywords: *DC-DC converter, PSO, finite time convergence, terminal sliding mode (TSMC).*

1. 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) is one of the effective nonlinear robust control approaches since it provides system dynamics with an invariance property to uncertainties once the system dynamics are controlled in the sliding mode [12]. Its major advantages are the guaranteed stability and the robustness against parameter, line, and load uncertainties. Moreover, being a controller that has a high degree of flexibility in its design choices, the SMC is relatively easy to implement as compared with other types of nonlinear controllers (Fuzzy control, synergetic control …). Such properties make it highly suitable for control applications in nonlinear systems. The strong robustness of SMC plays a very important role in guaranteeing the normal operation of DC converter. SMC can make the DC-DC converter provide stable output even when load varying or the input voltage varies.

Terminal sliding mode control has the advantage of finite time convergence and tiny steady state error. But there exist singular points in conventional terminal sliding mode control [1]. Nonsingular terminal sliding mode control can avoid the singularity, but the upper bounds of the disturbances usually must be known for calculating the switching gain.

The mathematical model for a typical Buck DC-DC converter is described in section 2.

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Section 3 presents a brief description of sliding mode control design. Designing a terminal sliding mode controller is given in section 4. In Section 5, used PSO algorithm and simulation results are presented to confirm the effectiveness and the applicability of the proposed method in section 6.

2. MODEL OF DC-DC CONVERTER

A basic DC-DC converter circuit known as the buck converter is illustrated in fig.1, consisting of one switch, a fast diode and RLC components. The switching action can be implemented by one of three-terminal semiconductor switches, such as IGBT or MOSFET.

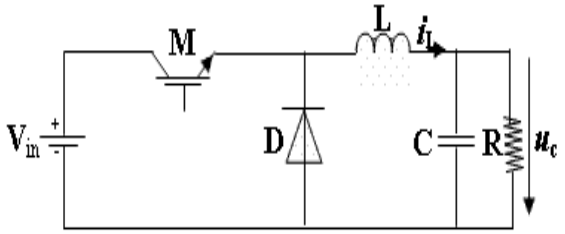


Figure.1 Buck DC-DC converter.

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

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

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

Select 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

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

3. SLIDING MODE CONTROL OF BUCK DC-DC CONVERTER

Sliding mode control is widely used [2, 3]. Its success is based on its simplicity of implementation and its robustness to parameter variations and external disturbances. The synthesis of the control law is done in two steps:

In the first step, the definition of a surface S of said slide having the desired dynamics which can be chosen as follows:

$$S = \dot{e} + \lambda e \tag{5}$$

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

$$e = x_1 - r \quad ; \quad \dot{e} = x_2 - \dot{r}$$

To guarantee the existence of sliding mode, the control must satisfy the condition

$$S\dot{S} < 0 \tag{6}$$

In the second step, preparing a control law so as to force the system to reach for the sliding surface and then to remain on the slide surface until it reaches the origin of the phase plane. This control law consists of two parts: The equivalent control term and discontinuous.

The equivalent control is obtained by the conditions of invariance of the surface given by:

$$S = 0 \quad ; \quad \dot{S} = 0$$

Therefore, the expression of the equivalent command is:

$$u_{eq} = \frac{LC}{V_{in}}\left[\frac{x_1}{LC} + \frac{x_2}{RC} + \lambda\dot{e} + \ddot{r}\right] \quad (7)$$

The term batch u_s command provides the slip speed and robustness face the external disturbances and parametric. The discontinuous portion of the command is given by:

$$u_s = -k.sign(S) \quad (8)$$

Where: $k > 0$.

Therefore, the total order can be defined by:

$$u = \frac{LC}{V_{in}}\left[\frac{x_1}{LC} + \frac{x_2}{RC} + \lambda\dot{e} + \ddot{r} + k.sign(S)\right] \quad (9)$$

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

4. TERMINAL SLIDING MODE CONTROL OF BUCK DC- DC CONVERTER.

The terminal sliding mode control design is based on a particular choice of the sliding surface and the determination of a control law permitting to drive the system movement slide on the surface, a terminal sliding mode is established and a fast finite convergence is granted.

Nonlinear sliding surface is defined as follows:

$$S = e + \frac{1}{\beta}\dot{e}^{\frac{p}{q}} = (x_1 - r) + \frac{1}{\beta}(x_2 - \dot{r})^{\frac{p}{q}} \quad (10)$$

Where $\beta > 0$, p and q are positive odd constants, and

$$1 < \frac{p}{q} < 2.$$

Suppose that t_r is the time from $S(0) \neq 0$ to $S = 0$, and t_s is the time when the tracking error is zero.

When the system reaches the sliding surface, there exists

$$S = e + \frac{1}{\beta}\dot{e}^{\frac{p}{q}} = 0 \quad (11)$$

By transforming, the following equation can be derived

$$\dot{e} = -\beta^{\frac{p}{q}} e^{\frac{p}{q}} \quad (12)$$

Then t_s can be obtained as follows

$$t_s = \frac{p}{\beta^{\frac{q}{p}}(p-q)}\left|e(t_r)\right|^{1-\frac{p}{q}} \quad (13)$$

By adjusting p , q and β , the system can reach steady state in a limited time of t_s .

Lyapounov function is defines as follows:

$$V = \frac{1}{2}S^2 \quad (14)$$

The sufficient condition for the existence of the terminal sliding mode is

$$\dot{V} = \frac{1}{2}\frac{dS^2}{dt} < -\eta|S| \quad (15)$$

Where $\eta > 0$.

The condition (15) leads to

$$S\dot{S} < -\eta|S| \quad (16)$$

Differentiating (10) with respect to time and using in (16), one obtain the following result

$$\dot{V} = S(x_2 - \dot{r} + \frac{1}{\beta}\frac{p}{q}(x_2 - \ddot{r})^{\frac{p}{q}-1}(\frac{-x_1}{LC} - \frac{x_2}{RC} + \frac{V_{in}}{LC}d - \ddot{r})) \quad (17)$$

The terminal sliding mode controller is designed as

$$d = -\frac{LC}{V_{in}}(-\frac{x_1}{LC} - \frac{x_2}{RC} - \ddot{r} + \beta\frac{p}{q}(x_2 - \dot{r})^{2-\frac{p}{q}} + (\eta + k)sign(S)) \quad (18)$$

Where $k > 0$.

Substituting (18) into (17) leads to:

$$\dot{V} = S\dot{S} = \frac{1}{\beta}\frac{p}{q}(x_2 - \dot{r})^{\frac{p}{q}-1}(-(\eta + k)|S|) \quad (19)$$

Because

$$1 < \frac{p}{q} < 2 \quad (20)$$

So

$$0 < \frac{p}{q} - 1 < 1 \quad (21)$$

Because p and q are positive odd constants, when $(x_2 - \dot{r}) \neq 0$, there exists

$$(x_2 - \dot{r})^{\frac{p}{q}-1} > 0 \quad (22)$$

So

$$\dot{V} \leq \frac{1}{\beta}\frac{p}{q}(x_2 - \dot{r})^{\frac{p}{q}-1}(-\eta|S|) = \frac{-1}{\beta}\frac{p}{q}(x_2 - \dot{r})^{\frac{p}{q}-1}\eta|S| = -\eta'|S| \quad (23)$$

Where

$$\eta' = \frac{1}{\beta}\frac{p}{q}(x_2 - \dot{r})^{\frac{p}{q}-1}\eta > 0 \quad (24)$$

Therefore the controller can meet Lyapunov stability.

5. V. PARTICLE SWARM OPTIMIZATION (PSO)

Particle swarm optimization (PSO) is a novel optimization method 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 shoals of fish (1995) [15], a number of simple entities (particles) is placed in the parameter space of problem or function, and each evaluates the fitness 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.

The mathematical equations for the searching process are:

$$V_i^{k+1} = wV_i^k + c_1.rand_1(..)(pbest_i - S_i^k) + c_2.rand_2(..)(pbest_i - S_i^k) \quad (25)$$

$$x_i^{k+1} = x_i^k + V_i^{k+1} \quad (26)$$

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.

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 Figure.2.

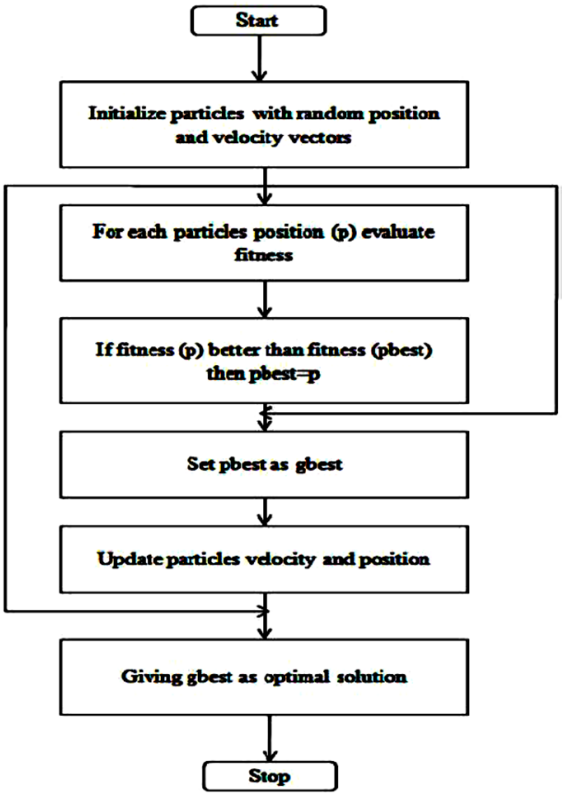


Figure.2. PSO algorithm.

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 the gbest.

The objective function considered is based on the error criterion. The performance of a controller is best evaluated in terms of error criterion. A number of such criteria are available and in the proposed work.

Controller's performance is evaluated in terms of Integral Time Absolute of Errors (ITAE).

$$J = \int_0^t t.|e(t)|dt \qquad (27)$$

ITAE weighs the error with time and hence emphasizes the error values over a range of 0 to t; the latter is the expected settling time.

The proposed approach employs a PSO search for the optimum parameter settings of the proposed DC-DC converter terminal sliding mode control. Control parameter to be tuned through the optimization algorithm is (***p/q***), with the aim to minimize the selected fitness objective function thus improving system response performance in terms of settling time and overshoot.

6. 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: $p = 5, q = 3$.

Figures.3 and 4 show the responding profiles of output voltage, sliding surface, control input and tracking error of the two controllers. The obtained results in regulation mode for the sliding mode control (SMC) and the terminal sliding mode control (TSMC) are shown in figures ((3.a), (4.a)). The results show that the TSMC presents a faster convergence to the desired state than SMC's. Indeed the position error reaches zero in a time nearly equal to 0.6s by SMC whereas by TSMC this error reaches zero in a time of the order of 0.4s.

In order to test the robustness of the two control laws, we add a perturbation at the instant 2s. The results shown in figures ((3.b), (4.b)) for the two controls SMC and TSMC are obtained. The obtained results show that the two controls laws verify the robustness property to disturbances for both approaches.

Figures (3.c) and (4.c) show the responding profiles corresponding to load fluctuation. The load resistance varies from 8Ω to 20Ω at the time of 1s and returns to 8Ω at the time of 1.5s.

From these results, one can see that tracking output voltage indicates a small rise time and nearly zero error which are desired performances.

Figure.5. Show the results of simulation using PSO.

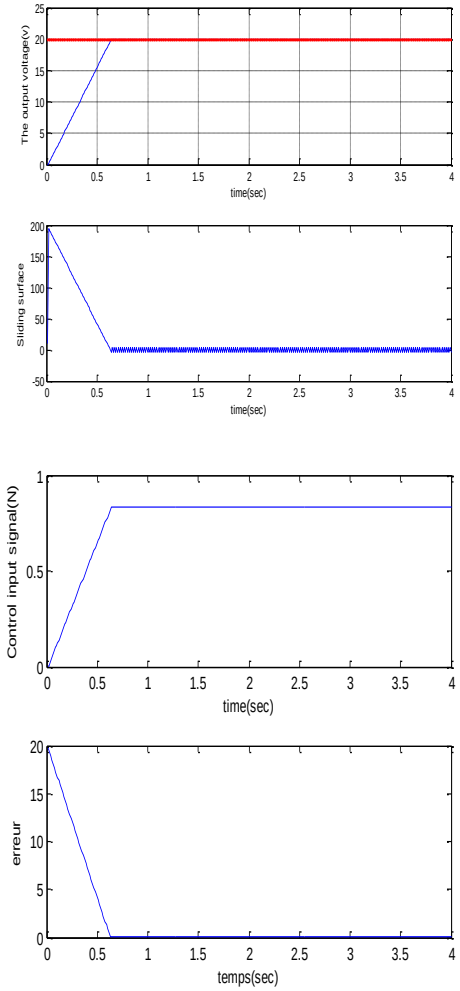
Optimized value for (p/q) is sought through PSO and optimal value was found to be equal to 1.5772. Simulation results show better chatter free performances.

7. CONCLUSION

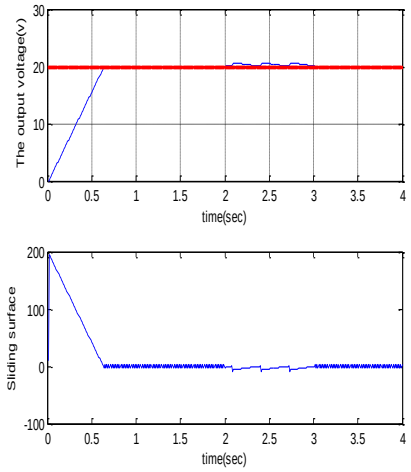
In this paper the development and simulation of terminal sliding mode control of a DC-DC converter using PSO to optimize control parameters are presented.

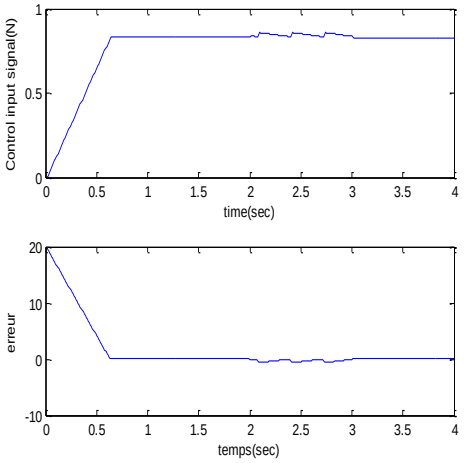
Terminal approach guarantees finite time convergence increasing therefore system robustness because it reduces reaching phase duration. Acceptable global performances are maintained despite load or line variation.

As an unexpected result, A chattering decrease using PSO is noticed while fast convergence is reached thus empowering much sought invariance after a shorter time than the one obtained with its classical counterpart.

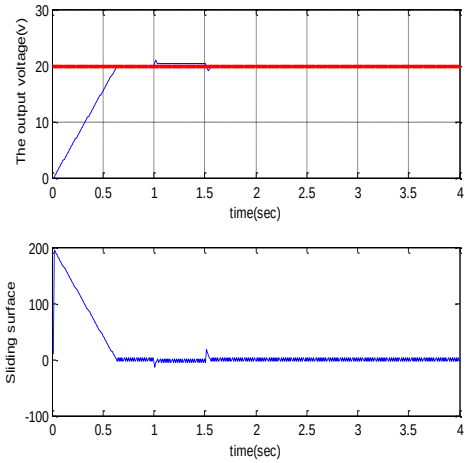


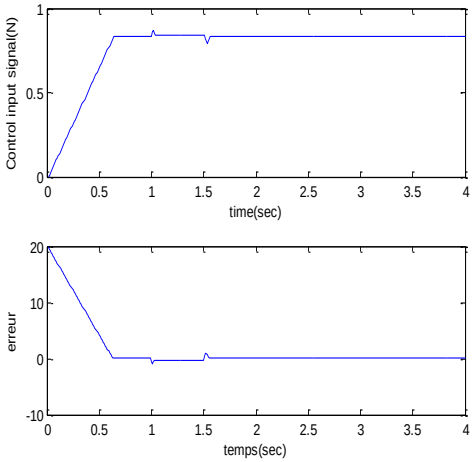
Normal operation for a reference voltage r=20v.





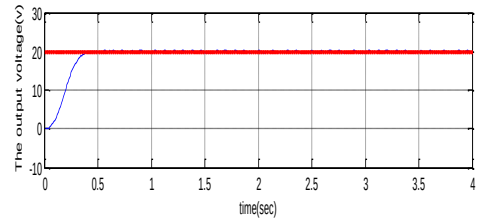
Application of the disturbance in the [2- 3] time range.

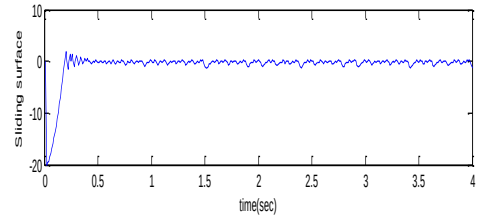


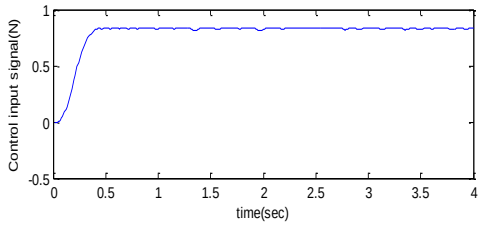


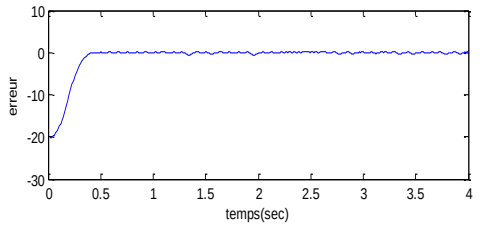
Periodic change of the resistor from R=8 to 20 ohms in the [1- 1.5s] time frame.

Figure.3 Simulation signals for SMC control.

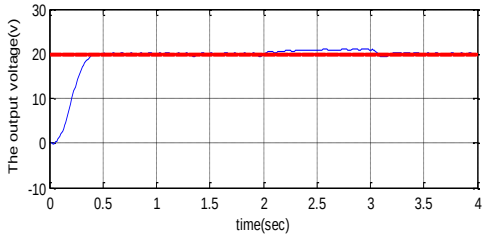


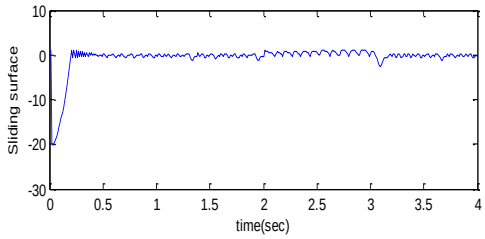


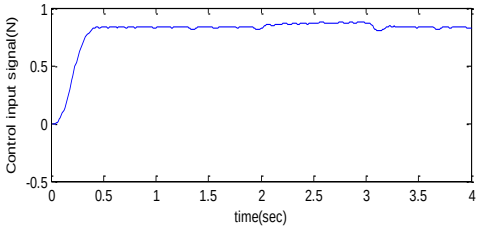


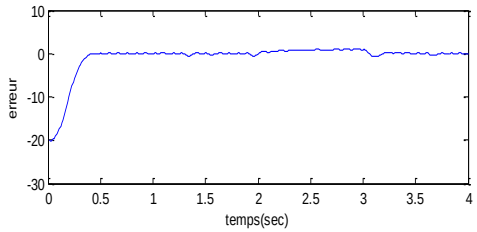


Normal operation for a reference voltage r=20V.

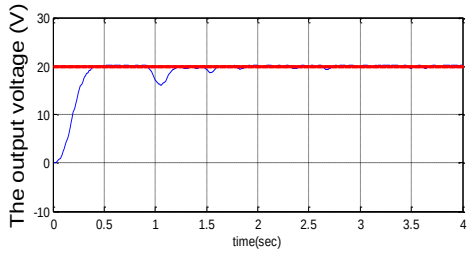


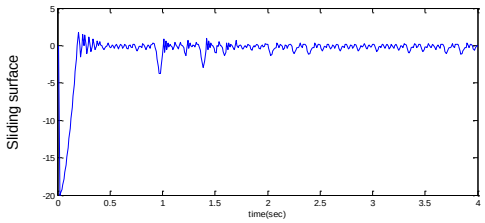


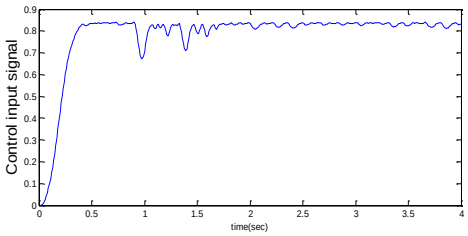


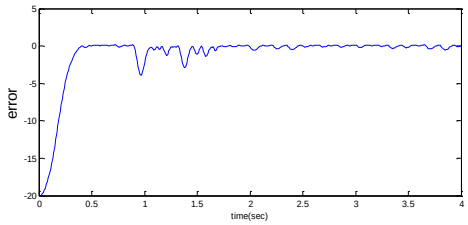


Application of the disturbance in the [2- 3s] time range.



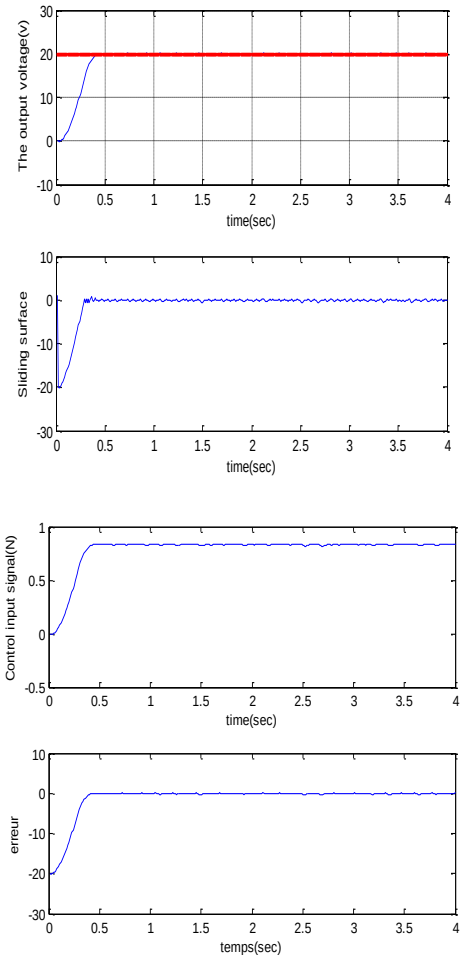




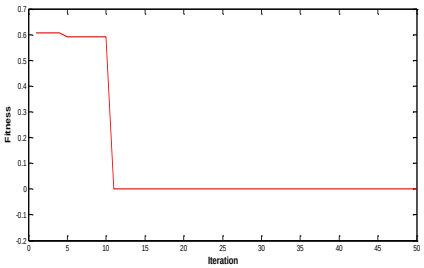


A periodic change of the resistor from 8 to 20 ohms in the [1-1.5] time frame.

Figure.4 TSMC Simulation results.



Results simulations with PSO.



Function objective evolution.

Figure.5 Results of PSO-TSMC approach.

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جامعة فرحات عباس ، سطيف

الملخص:

تستخدم المحولات مستمر- مستمر على نطاق واسع في الأجهزة الالكترونية وقد وضعت العديد من الطرق لتطوير التحكم في هاته المحولات للاستجابة في وقت محدد. تحكم انزلاق الوضع هو نهج ثبت قوة تحكمه و سيستخدم لتحقيق التقارب المحدود الوقت, وزيادة على ذلك سيتم استخدام سرب جسيمات التحسين (PSO) كخوارزمية لتحسين معايير الثوابت باستخدام المعادلة (ITAE). نتيجة تحكم نهائي انزلاق الوضع للمحول مستمر- مستمر قد أجريت تحت اختبارات مختلفة, و نتائجها سوف تقارن مع نتائج تحكم انزلاق الوضع الكلاسيكي, و سنعرض تفوق تحكم انزلاق الوضع النهائي.