Chaotic Ant Swarm Optimized Fractional Order $PI^{\lambda}D^{\mu}$ Controller for DC-DC Boost Converter

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Abstract:

The Fractional order PID (FOPID) controller is a generalized standard PID controller using fractional calculus.Aim of this paper is to design the FOPID controller using Chaotic Ant Swarm (CAS) optimization algorithm. The objective function contains overshoot, steady state error , rise time and settling time. The tuning of FOPID controller is put forward as nonlinear optimization problem. CAS algorithm, a population based search algorithm based on the chaotic behavior of the individual ant and self-organization behavior of ant colonies is used to obtain the optimum values of parameters of the FOPID controller. The designed CAS-FOPID controller is used to control DC-DC Boost Converter. From the Comparison of the controller with other FOPID and PID controllers it is understood that the CAS-FOPID controller can ensure good control performance with respect to different reference voltages and gives a constant output voltage despite of any load variations.

Keywords:*Fractional calculus,Fractional order PID controller ,CAS algorithm, optimal control, DC-DC Boost Converter*

1. Introduction:

DC-DC Boost converters have found significant attention in recent decades. Output voltage must track the reference command with appropriate transient and steady state error in order to control these converters. These converters are inherently time varying and nonlinear systems with complex behavior and hence the design of controller for them have gained high attention[5]. Design of controllers for converters is done based on approximate dynamic model of the system.Here we use state space averaging method for linearizing the system. Controller design task is based on the converter small signal model and it cannot provide response having low steady state error and oscillations. Also variation in duty cycle effects the output of the converter. Several nonlinear controller techniques such as fuzzy control, H_{∞} control, μ analysis and synthesis control can be implemented.

The PID controllers belongs to the dominating industrial controllers due to the simplicity in design and good performance and hence there has been a continuous attempt to improve their quality and robustness and one of the method is to use fractional order PID controllers with fractional derivation and integration parts.

Design of FOPID controller can be considered as a real parameter optimization problem in a five dimensional hyper space. The tuning of the FOPID controller is put forward as a nonlinear optimization problem. CAS algorithm which is a newly developed algorithm inspired by chaotic behavior of individual ant and self-organization behavior of ant colonies, is used to search the optimal parameters of FOPID controller [2].

2. Fractional systems:

Fractional order dynamic systems are described by fractional order differential equations. We can adjust the control systems frequency response directly and continuously by expanding the derivatives and integrals to fractional orders.

2.1 Fractional order calculus (FOC):

Even though the non-integer order calculus is as old as integer order calculus , it remained unexplored in engineering.The reason is mainly the inherent complexity and the apparent self-sufficiency of the fractional order calculus. But recently its application was exclusively in mathematics.In FOC the integration and differentiation is generalized to a fractional order fundamental operator ${}_aD_t^{\alpha}$ where a and t are limits and α is the order which can be of any real number. Among the several definitions most commonly used definition for FOC is Grunwald-Letnikor(GL) and the Riemann-Lioville (RL) definitions.The GL definition is as follows:

$$ {}_aD_t^{\alpha} f(\mathrm{t}) = \lim_{h\to 0} h^{-\alpha} \sum_{j=0}^{[(t-a)/\mathrm{h})]} -1^{j} \binom{\alpha}{j} f(\mathrm{t-jh}) .....(1) $$

Where the [.] means the integer part and the RL definition is as follows:

$$ {}_aD_t^{\alpha} f(\mathrm{t}) = \frac{1}{\Gamma(\mathrm{n}-\alpha)} \frac{d^n}{dt^n} \int_a^t \frac{f(\tau)}{(t-\tau)^{\alpha-n+1}} d\tau ....(2) $$

for $(n\text{-}1<\alpha<n)$ and Γ[.] is Euler's Gamma function.

2.2 Fractional order PID (FOPID) controller

The ordinary PID controller alone does not guarantee the optimal control of the system.By introducing more general control actions of form s_n,$1/s_n$,here *n* can be any natural real number, we could develop more powerful and flexible design method to satisfy the controlled system requirements. The FOPID controller denoted by $PI^{\lambda}D^{\mu}$ controller general equation is given in the equation 3. Here the integral order λ and derivative order μ are fractional.

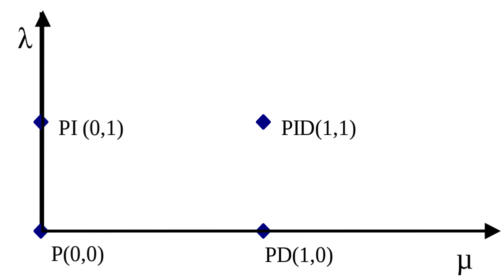

Fig 1. Plane of FOPID controller

$$ C_F(\mathrm{s}) = k_p + {k_i}/{s^{\lambda}} + k_d s^{\mu} ....(3) $$

If $\lambda=1$ and $\mu=1$, standard PID controller is obtained and If $\lambda=0$ and $\mu=1$ we get a normal PD controller and if $\lambda=1$ and $\mu=0$ a PI controller and If $\lambda=0$ and $\mu=0$, a simple proportional controller . Fig 1 shows the plane of $PI^{\lambda}D^{\mu}$ controller. From this we can understand that all classical type of PID controllers are special cases of FOPID controllers.

3.Chaotic Ant Swarm(CAS)Optimization:

CAS is a population based search algorithm which can combine the chaotic behavior of individual ant and intelligent organization of ant colonies. In CAS each ant can find food source decide which one of the food source is better and memorize the information of the best food source[1].

Consider the optimization problem in l-dimensional search space S, K ants locate in the space S and try to minimize function f: S to R. The position of the i^{th} ant in the colony is assigned a symbol $z_i=(z_{i1},z_{i2},\ldots\ldots,z_{il})$, and i=1,2…..K. When the ant is moving the position of the single ant is influenced by three factors first one is the current position then the best position found by itself and also any member of its neighbors and finally the organization variable.

Mathematically the equation for this can be written as given below:

$$y_i(n) = y_i(n-1)^{(1+r_i)}$$

$$z_{id}(n) = z_{id}(n-1)\, e^{(1-e^{(-ay_i(n))})(3-\psi_d z_{id}(n-1))} + (p_{id}(n-1) - (z_{id}(n-1))\, e^{(-2ay_i(n)+b)})....(4)$$

Where n indicates the current time step , (n-1) the previous step, $z_{id}(n)$ is the current state of d^{th} dimension of i^{the} ant and $p_{id}(n)$ is the best position found by i^{th} ant and its neighbours within (n-1)steps .$y_i(n)$ is the current state of organization variable and its initial value usually selected as $y_i(0)=0.999$. *a* is sufficient large positive constant and can be selected as a=200 0r 300. *b* is a constant and r_i is the organization factor of i^{th} ant. Ψ_d gives the search ranges of d^{th} element of variable in the search space.

4. Optimization of FOPID Controller For Boost converter using CAS Algorithm:

In this subsection , a brief description of Boost converter under study and the design procedure for CAS-FOPID controller which is used to control the output of the boost converter is explained.

4.1 Boost Converter:

A boost converter is a DC-DC converter with an output voltage greater than the source voltage. They are essentially known as step-up power converters. It has at least two semiconductor switches and one energy storage element. The input and output voltage relationship is controlled by switch duty cycle[5]. By controlling the input to the PWM circuit we can control the duty cycle and in turn switching frequency and hence output voltage which is explained in the block diagram given in Fig.2.

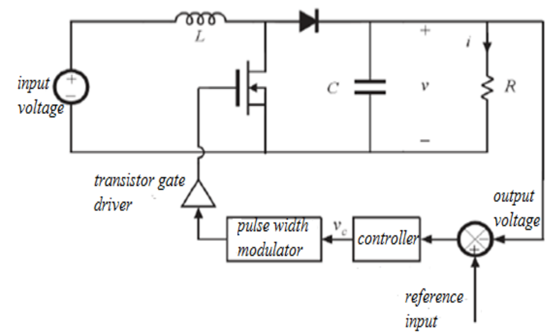

Fig 2. Block Diagram of Boost Converter control

The understudy Boost Converter as shown in figure converts 5V input to 10V output. Output load current is 500mA. The switching frequency is 5MHz. The circuit parameters of the converter are listed in Table I.

TABLE I
CIRCUIT PARAMETERS OF BOOST CONVERTER

Parameters	Value	Unit
Load Resistance, R	20	Ω
Inductance , L	162	µH
Capacitance , C	220	µF

4.2 Fitness function definition:

A fitness function should be defined to evaluate the fitness of each ant . There are several criterions for design of controllers that includes integral absolute error (IAE), integral of squared error (ISE)and integral of time weighted squared error are often used in literatures. Here a performance criterion j(z) in time domain is defined and is expressed as:

$$j(z) = (1-e^{\beta}).(m_p + E_{ss}) + e^{-\beta}.(t_s - t_r).....(5)$$

ß is the weighting factor ,M_p ,E_{ss} ,t_r ,t_s are respectively the overshoot , steady state error, rise time and settling time.

4.3 The design process of CAS-FOPID controller:

The design process of CAS-FOPID controller for dc-dc boost converter is summarized as follows :

Step1:Determine the parameters of boost converter

Step2:Set the parameters of CAS algorithm

Step3: Specify the lower and upper bounds of the controller parameters.

Step4:Set t=0 and randomly initialize the position of K ants within the range of each controller.

Step5:Calculate the integer order approximate transfer function of FOPID controller.

Step6:Apply the integer order approximate transfer function of FOPID controller to the system and find the closed loop transfer function.

Step7:Calculate overshoot M_p ,Steady-state error E_{ss} ,rise time t_r and settling time t_s from the step response of the closed loop system.

Step 8:Evaluate the fitness of each ant using equation 5.

Step 9:Determine the neighbors of each ant update the best position P_i found by i^{th} ant and its neighbors.

Step 10: Move the ant to a new position according to the equation 4.

Step 11:Let t=t+1 and go to step 5 until the maximum number of iterations is reached.

Step 12:Output the best position found by the whole ant swarm.

The values of the parameters obtained is listed in Table II. And the response for CAS-FOPID controlled boost converter is shown in Fig 6.

5. Results and Discussions:

This section presents the results and discussion of CAS-FOPID controller for boost converter and its comparison with other conventional tuned FOPID controllers and integer order PID controllers. Conventional tuning of FOPID controller is done using Stability Boundary Locus Plot(SBL) method. Variation of output for different reference voltage and the response for load disturbance is also discussed here.Openloop response for boost converter Shows that response is oscillatory also has an offset and is shown in fig 3.

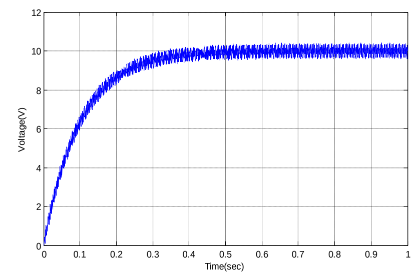

Fig 3.Open loop response of Boost Converter

TABLE II
CONTROLLER PARAMETERS

controllers	K_P	K_I	K_D	**λ**	**μ**
CAS-FOPID	4	20	2	0.5	0.5
SBL-FOPID	2	16	1	0.5	0.5
PID	0.16	1.4	0.004	1	1

5.1 comparison of CAS-FOPID controller with other controllers:

Closed loop control for boost converter is done using PID controller. The parameters are listed in Table III. The response of the controller is shown in Fig.4 and from figure it is seen that output is less oscillatory and settling faster. In order to improve the response and to eliminate oscillation a more generalized controller known as FOPID controller is used which is tuned using SBL method and response is shown in Fig.5. here the oscillation is reduced as well as response settling time and steady state error is reduced.

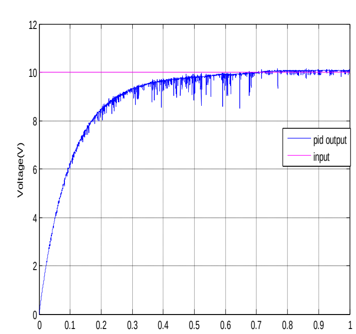

Fig.4 Response for boost converter control using PID controller

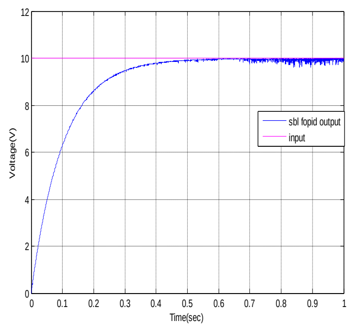

Fig.5 Response for boost converter control using SBL-FOPID controller

In order to eliminate the oscillations completely and to further reduce settling time and steady state error we go for optimized FOPID Controller. Here CAS algorithm is used for optimizing parameters of controller and the response is as shown in Fig.6.

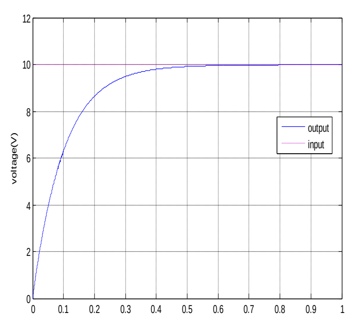

Fig 6. Response for boost converter control using CAS-FOPID controller

The oscillation is completely eliminated as well as the response settling time and steady state error is significantly reduced.

TABLE III
COMPARISON OF RESPONSES

parameters	**PID controller**	**SBL-FOPID controller**	**CAS-FOPID controller**
Settling time	0.65 s	0.6 s	0.5 s
Rise time	0.3 s	0.21 s	0.23s
IAE	42.71	12.16	4.747
ISE	0.2046	0.003187	0.0003304
ITAE	0.3421	0.04188	0.01967

The response for different controllers are compared and listed in Table III. The results shows that CAS-FOPID controller offers a better controlling option than ordinary integer order PID controller.

6. Conclusion and Future Work:

Here the parameters of FOPID controller is designed using Chaotic Ant Swarm optimization (CAS) through minimizing the non linear objective function consisting of overshoot, steady state error, rise time and settling time. The designed CAS-FOPID controller has been successfully applied to the boost converter. Conventional tuning is done based by a method called Stability Boundary Locus Plot. Number of comparisons show that CAS-FOPID controller has superior performance than other FOPID/PID controllers. Future work includes the online optimization to find the proper values of controller parameters.

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