Improvement Performance of Step-Down Converter through Intelligent Controllers

M.R. Yousefi , M.Bayati Poudeh , S.Eshtehardiha

Abstract— **In this paper, several different control methods based on intelligent system on DC-DC converter are compared with together. These DC-DC converters are used for the stabilization or the control of DC voltage of a battery. Lately, improvement the performance of the step-down converter is one of the goals of the engineers in the industries. In this paper controlled step-down converter using new several fuzzy logic controls law algorithms and PID controllers based on Genetic Algorithm (GA) and Particle Swarm Optimization (PSO) are studied. These controllers are designed to eliminate the overshoot and reduce the settling time response. All the analysis and simulations to duplicate on the above converter by MATLAB software were performed and confirm the capability of the control methods in the improvement of the above-mentioned converter functioning.**

Index Terms— **Fuzzy Logic Control, Genetic Algorithm, Step-Down Converter, Particle Swarm Optimization, PID Control**

I. Introduction

The DC-DC converters are widely used in regulated switch-mode DC power supplies and in DC motor drive applications. Often the input to these converters is an unregulated DC voltage, which is obtained by rectifying the line-voltage magnitude. Switch-mode DC to DC converters are used to convert the unregulated DC input into a controlled DC output at a desired voltage level. In DC-DC converter, the average dc output voltage must be controlled to equal a desired level, though the input voltage and the output load may fluctuate. Switch-mode DC-DC converters utilize one or more switches to transform dc form one level to another [1]. Buck converter is a one-input multiple-output system with a non-linear property due to its switching behavior, but at the same time when the switch is on and off its behavior is linear. Therefore, by employing the averaging method, it is possible to exchange a non-linear system with a linear one. Many of the methods used PI controller design independent of converter parameters [2].

Some control methods have defined the subject of control based on pole placement [6, 7]. Fuzzy PID and fuzzy state space control approach for buck converter is proposed in [5]. Also state space controller design of buck converter is used in [3, 4] and [7]. In [7], LQR and pole placement controllers are proposed to buck converter output voltage control, in which the two designing methods are based on trial and error.

The remainder of the paper is organized as follows. Describes modeling of Step-Down converter detailed in Section Π and the design of the proposed controller algorithm is detailed in Section Ш. Intelligent controller is shown in Section IV. The computer simulation results are presented and discussed in Section V. Finally Section concludes this paper.

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II. Step-Down Converter Circuit Model

The Step-Down converter circuit model is depicted in Fig. 1.

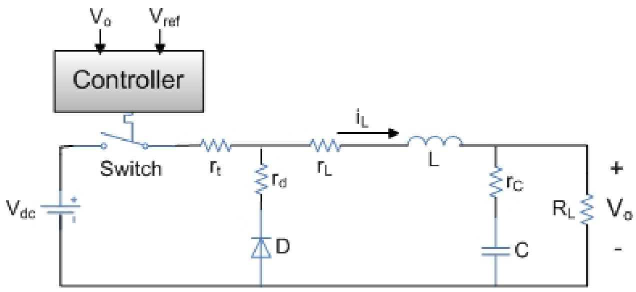

Fig. 1. Step-Down converter circuit

In this model, *Vo* is the system output voltage and V_{ref} is the converter voltage. To obtain the converter state equations in low-frequency state, it is required that the system state be studied in two states of switch on and off, that it is shown the mean values of state equations (1) [8].

$$\dot{X} = A*X + B*V_{dc}$$

$$A = d*A_1 + (1-d)*A_2 \quad (1)$$

$$B = d*B_1 + (1-d)*B_2$$

$$d = \frac{t_{on}}{T}$$

III. Introduction to PID Controller

A basic feedback system is given in Fig. 2. The variable e represents the tracking error, the difference between the desired input value V_{ref} and the actual output V_o. This error signal is fed to controller, and the output of the controller is given as

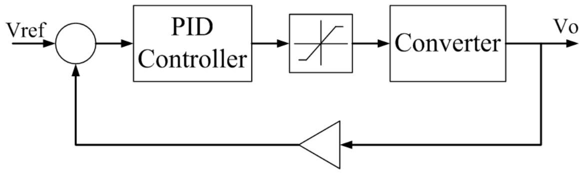

Fig. 2. PID controls and two degrees of freedom control system

Where,
K_p = Proportional gain
K_I = Integral gain
K_d = Derivative gain

$$G_{PID}(s) = K_P + \frac{K_I}{s} + K_D s = \frac{K_D s^2 + K_P s + K_I}{s} \qquad (2)$$

The proportional controller (K_p), will effect the steady state error and rise time. An integral control (K_I), controls the transient response and the steady state error. Inclusion of (K_d), has the effect of including anticipation in the system and making it faster [9].

There is a degree of dependence of these factors on each other. In fact, changing one of these variables K_p, K_d and K_I can change the effect of the other two.

IV. Intelligent Controllers

A. Genetic Algorithm

GA as a powerful and broadly applicable stochastic search and optimization techniques is perhaps the most widely known types of evolutionary computation method today. The GA has been used in various optimization problems including optimal control problems.

The genetic algorithm is an algorithm which is based on natural evolution and the survival of the best chromosome. There are three basic differences between genetic algorithm and optimization classical methods. Firstly, the genetic algorithm works on the encoded strings of the problem parameters. Each string is the representative of one answer to the problem, and the real quantities of the parameters are obtained from the decoding of these strings. Secondly, the genetic algorithm is a search algorithm which works on a population of search spaces. This quality causes the genetic algorithm to search different response spaces simultaneously reducing the possibility of being entrapped at local optimized points. Thirdly, the genetic algorithm does not need previous data from the problem response space such as convexity and derivable.

It is only necessary to calculate a response function named fitness function. This function expresses the rate of response proximity to the goal function of the intended algorithm. Different methods are used for encoding the parameters in genetic algorithm.

One of the common methods is the binary encoding in which for each parameter depending on the precision required, a few bits are allocated. The problem with this method of encoding is the encoding of the continuous parameters. In order to provide the required precision for the continuous parameters in this method of encoding we have to increase the number of the allocated bits for each parameter which results in longer strings and an increase in the volume of calculations resulting in longer algorithm time [10].

Another method used in genetic algorithm for the encoding of data is the real encoding. For every parameter in this method one real number is taken into consideration and in addition to the above methods, one can use encoding methods of the genetic functioning defined for these algorithms for real numbers (conversion, value, and tree).

B. Particle swarm optimization (PSO)

Particle swarm optimization (PSO) is a novel optimization method. The PSO is a population-based optimization tool first proposed by Kennedy and Eberhart. In PSOs, that are inspired by flocks of birds and shoals of fish, a number of simple entities (particles) are placed in the parameter space of some problem or function, and each evaluates the fitness at its current location. The advantages of PSO compared to other evolutionary computational techniques are [11]:

1. PSO is easy to implement.
2. There are few parameters to be adjusted in PSO.
3. All the particles tend to converge to the best solution quickly.

Each particle keeps track of its co-ordinates in the solution Space which are associated with the best solution (fitness) that has achieved for by that particle. This value is called personal best, ‘pbest’. Another best value obtained so far by any particle in the neighborhood of that particle. This value is called global best, ‘gbest’. The basic concept of PSO lies in accelerating each particle towards its ‘pbest’ and the ‘gbest’ locations, with a random weighted acceleration at each time step. Each particle tries to modify its position using the information such as the current positions, the current velocities, the distance between the current position and ‘pbest’, the distance between the current position and the ‘gbest’. The mathematical equations for the searching process are [12]:

$$v_i^{k+1} = w v_i^1 + c_1 rand_1(...)(pbest_i - s_i^k) + c_2 rand_2(....)(gbest - s_i^k) \qquad (3)$$

$$x_I^{K+1} = X_I^K + v_i^{k+1} \qquad (4)$$

Where

v_i^k Velocity of particle i at iteration k

W weighting function

c_1 and c_2 weighting factor rand uniformly distributed random number between 0 and 1.

s_i^k Current position of the particle i at iteration k

pbest $_i$ pbest of particle i, gbest best value obtained by any particle so far.

In the above procedure, the maximum velocity Vmax determines the resolution of fitness regions are searched between the present position and target position. If Vmax too high, particle might fly past good solution. If Vmax is too small, the convergence could be slower. According to experience of PSO, Vmax takes often 10% to 25% of the dynamic range of the velocity.

1) Weighting function

The following weighting function is usually utilized in velocity update function [11].

$$w = w_{max} - \frac{(w_{max} - w_{min}) * iter}{\max iter} \quad (5)$$

Where

W_{max} initial weight

W_{min} final weight

Maxiter maximum iteration number

Iiter current iteration number

2) Parameter of PSO

In this work, following parameters are chosen.

No of particles = 100 c1 and c2 =0.9

W_{max} =0.8 &

W_{min} =0.15

V_{max} =15% of range of parameter

Max. No of functional evaluation=700

C. Fuzzy Logic

In 1965, Zadeh proposed Fuzzy logic; it has been effectively utilized in many field of knowledge to solve such control and optimization problems [13]. Fuzzy logic has been available as a control methodology for over three decades and its application to engineering control systems is well proven. In a sense fuzzy logic is a logical system that is an extension of multi-valued logic although in character it is quite different. It has become popular due to the fact that human reasoning and thought formation is linked very strongly with the ways fuzzy logic is implemented. In power system area, it has been used to stability studies, load frequency control, unit commitment, and to reactive compensation in distribution network and other areas.

The most important specifications of fuzzy control method are their fuzzy logical ability in the quality perception of system dynamics and the application of these quality ideas simultaneously for power systems [14]. A simple block diagram of a fuzzy system is shown in Fig. 3.

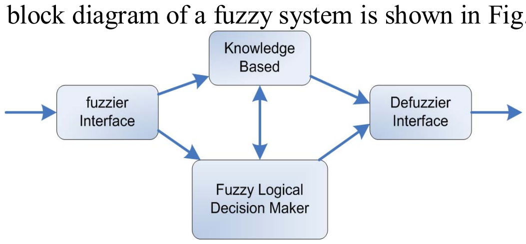

Fig. 3. Details of a fuzzy controller.

Four major units are fuzzification block, a fuzzy knowledge-base block, a fuzzy inference engine and a defuzzification block. The functions of the blocks and working principles of the fuzzy system are briefly summarized [15].

The fuzzification block measures the value of input variables, and performs a scale mapping that transfers the range of values of input variables into the corresponding universes of discourse, then performs the function of fuzzification, which converts input data into suitable linguistic values that may be viewed as labels of fuzzy sets.

The knowledge base is comprised of two components namely called fuzzy sets (data base) and fuzzy control rule base. The concepts associated with fuzzy sets are used to characterize fuzzy control rules and fuzzy data manipulation in an FLC [15]. The fuzzy rule base consists of a set of linguistic control rules written in the form:

IF a set of conditions are satisfied (premise), THEN a set of consequences are inferred The collection of fuzzy control rules that are expressed as fuzzy conditional statements forms the rule base or the rule set of an FLC. In particular, the choice of linguistic variables and their membership function have a strong influence on the linguistic structure of an FLC. Typically, the linguistic variables in an FLC are the state, state error, state error derivative, state error integral, etc.

One of the key problems is to find the appropriate fuzzy control rules. In general, there are four models of derivation of fuzzy control rules [15]:

Using the experience and knowledge of an expert.

Modeling the control actions of the operator.

Using a fuzzy model of a process.

Using self-organized fuzzy controllers.

The defuzzification block transforms the fuzzy control actions to continuous (crisp) signals, which can be applied to the physical plant.

V. THE STEP-DOWN CONVERTER SYSTEM SIMULATION

With regard to the state equations for the converter and taking into consideration Table 1, the step-down converter open loop response will be in the form of Fig. 4. To optimize the V_o several fuzzy control methods and PID controllers are used. The overshoot of the output voltage in open loop response was 23% peak-to-peak (Vpp) and the settling time of the step response was 3.6 ms.

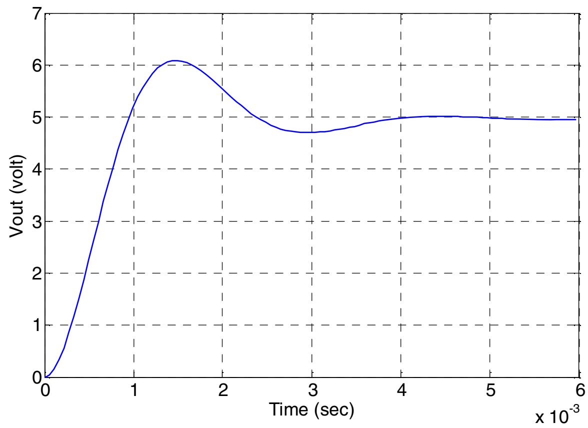

Fig. 4. Open Loop response of Step-Down converter

Table 2.Buck converter parameters

Symbol	Value	Symbol	Value
r_L	0.7 Ω	C	1450 μF
r_d	0.7 Ω	L	0.42 mH
r_c	1.18 Ω	R_L	118 Ω
r_t	0.2 Ω	V_{dc}	12 V
d	0.41		

As it is evident from the study of outputs, the open loop system cannot hold the output in constant and ideal conditions. Of course, the outputs will eventually approximate the ideal rate with regard to the stability of the system.

A. PID Controller

By applying PID controlling on the system and with regard to Table 2, the results of Fig. 5, are obtained.

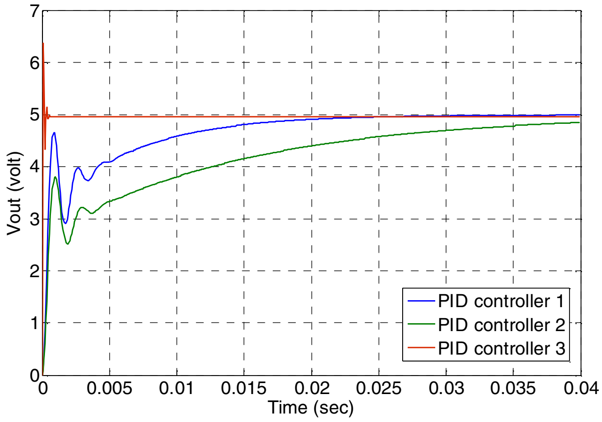

Fig. 5. Step-Down converter response with PID controller

TABLE 2. PID PARAMETERS

PID1	K_P=1.54, K_I=385.65, K_D=0
PID2	K_P=1.11, K_I=143.88, K_D=0
PID3	K_P=134.93, K_I=2.67, K_D=0.003

B. The Application of Genetic Algorithm for Adjusting PID Controlling Coefficients

By applying genetic algorithm for the optimization of PID controller response on K_P, K_I and K_D parameters the results in Fig. 6, are obtained in which $K_P=353.86$ and $K_I=10.62$ and $K_D=0.25$ [16] .

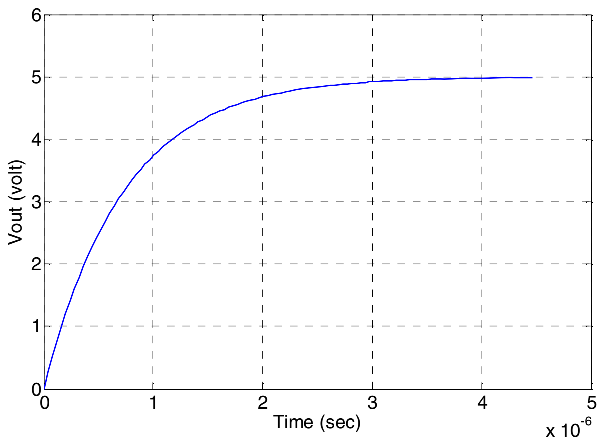

Fig. 6. Step-Down converter response with PID-GA controller

C. The Application of Particle Swarm Optimization for Adjusting PID Controlling Coefficients

Particle swarm optimization is used for the optimization of PID controller response. The results in Fig. 7 are obtained with K_P =223.86, K_I =8.23, K_D =0.5.

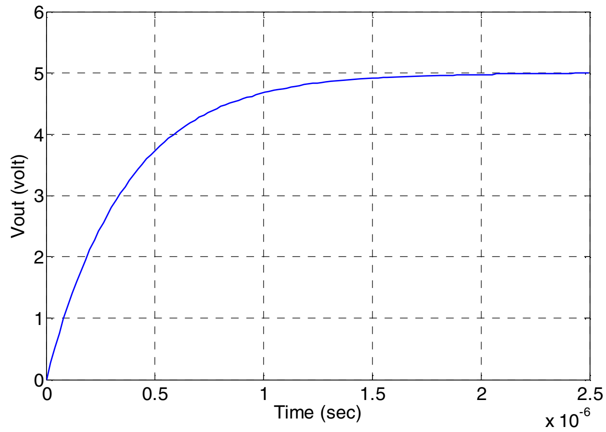

Fig. 7. Step-Down converter response with PID-PSO controller

D. The Application Fuzzy Logic

Better dynamic response and lower steady state error of the converter can be reached by introducing the fuzzy PID controller that is shown in Fig. 8. Due to this, the decomposed fuzzy PID controller can be used.

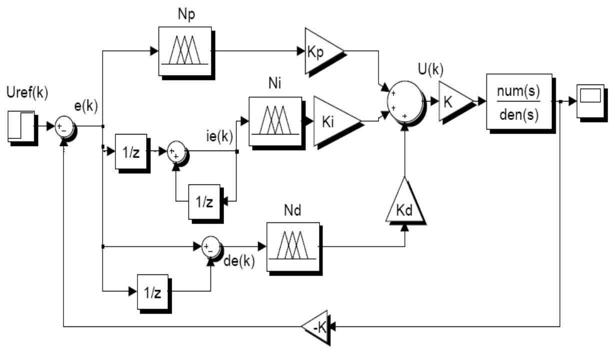

Fig. 8. Structure of fuzzy controller in exciter system

The linguistic description of the knowledge base is given by three RB's. The output signal is the sum of the defuzzified outputs of proportional FIS, differential FIS and integral FIS. The membership functions are shown in Fig. 9.

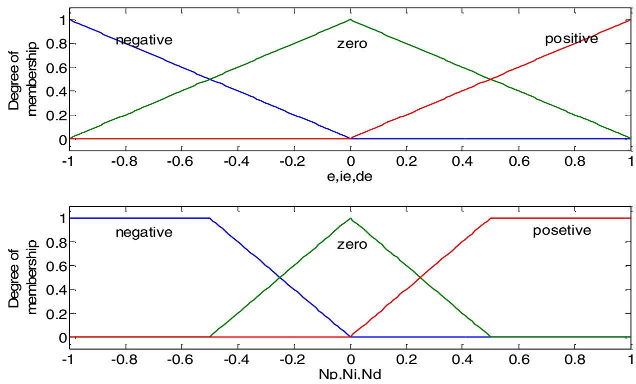

Fig. 9. Membership functions of a fuzzy PID controller (Input membership function: e, ie, de) and (Output membership function: Np, Ni, Nd)

The fuzzy rules were designed that for each input membership function the output membership function was assigned. In Table 3, 3 fuzzy rules for linguistic variable Np are shown. Similar fuzzy rules were assigned to the integral and differential part, which are shown in Table 4, and Table 5.

Table 3. Np fuzzy rules

Kp (Np)		
if e(k)=negative	then	y=negative
if e(k)=zero	then	y=zero
if e(k)=positive	then	y=positive

Table 4. Ni fuzzy rules

Ki (Ni)		
if ie(k)=negative	then	y=negative
if ie(k)=zero	then	y=zero
if ie(k)=positive	then	y=positive

Table 5. Nd fuzzy rules

Kd (Nd)		
if de(k)=negative	then	y=negative
if de(k)=zero	then	y=zero
if de(k)=positive	then	y=positive

In the simulation by using the gain parameters, the effect of the fuzzy controllers is defined.The output of the fuzzy PID controller is denoted by (6), and the gains are Kp=1.5, Kd=0.1, and Ki=1.2. The response of DC-DC converter with PID fuzzy controller is shown in Fig. 10 [8].

$$u(k) = Np(e(k)) + Nd(de(k)) + Ni(ie(k)) \qquad (6)$$

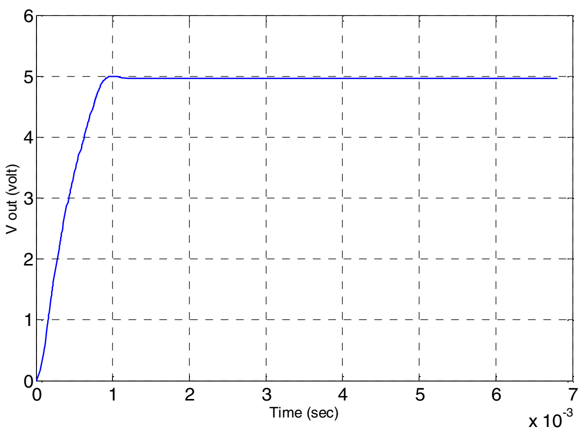

Fig. 10. Step response of a decomposed fuzzy PID controller

VI. CONCLUSION

The DC-DC conversion principle is a part of many electronics devices and is a subject of many research projects which are looking for the best control. In this paper, several different control methods are explained and used to improve the step-down converter performance. PID control method is useful in control the output voltage in step-down converter, and to optimizing the PID parameters two optimizing method (GA and PSO) are used. Fuzzy controller is another controller in this paper to control the voltage of the converter. These controllers are designed to eliminate the overshoot and reduce the settling time response. This paper demonstrated the effectiveness of the PID controller with PSO applied to the state space averaging DC-DC converter using MATLAB.

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