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PSO BASED FUZZY LOGIC CONTROL DESIGN FOR A DC/DC BOOST CONVERTER

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Abstract

In this study, a DC / DC boost converter was designed for wind energy systems in Matlab / Simulink and output voltage control was examined under variable load conditions. The designed converter was controlled to obtain desired constant output voltage when the input voltage was variable or to obtain desired variable output voltage when the input voltage was constant. The system performance is compared using classical PI controller and Fuzzy Logic Control (FLC). Also, some system parameters are optimized with PSO to improve system performance using the weighted absolute error (ITAE) criteria as a fitness function. Thus smarter and more efficient control is provided for the proposed system. The simulation study is realized via Matlab/Simulink and the results are evaluated.
Keywords: DC/DC Boost Converter, Fuzzy Logic Control, Particle Swarm Optimization

DA/DA YÜKSELTEN ÇEVİRİCİ KONTROLÜ İÇİN PSO TABANLI OPTİMUM BULANIK MANTIK DENETLEYİCİ TASARIMI

Öz

Bu çalışmada, rüzgâr enerji sistemleri için Matlab/Simulink'de bir DA/DA yükselten çevirici tasarlanmış ve çıkış gerilimi kontrolü farklı yük durumları için incelenmiştir. Tasarlanan DA/DA yükselten çevirici, girişine uygulanan değişken gerilimini, çıkışında istenilen sabit gerilime dönüştürmek veya sistem girişine sabit gerilim uygulayıp çıkışından istenilen değişken gerilim elde etmek için kontrol edilmiştir. Sistemde kontrolör olarak geleneksel denetleyicilerden oransal-integral (PI) ve bulanık mantık denetleyici (BMD) kullanılarak denetleyici performansları karşılaştırılmıştır. Ayrıca denetleyicilerin performansını iyileştirmek için denetleyicilere ait bazı parametreler, zaman ağırlıklı mutlak hatanın integrali (ITAE) performans kriterlerine göre parçacık sürü optimizasyonu (PSO) yöntemi yardımıyla optimize edilmiştir. Böylece sistem için daha akıllı ve verimli bir kontrol sağlanmıştır. Sistem benzetimi Matlab/Simulink'de gerçekleştirilmiş ve elde edilen sonuçlar değerlendirilmiştir.
Anahtar Kelimeler: DA/DA Yükselten Çevirici, Bulanık Mantık Denetleyici, Parçacık Sürü Optimizasyonu

1 Introduction

DC/DC converters can adjust output voltage to desired value using PWM method [1]. Nowadays, DC-DC converters circuits are the mostly used circuits in power electronics applications, since all semiconductor components are powered by DC sources [2, 3]. DC-DC converters are controlled in order to obtain a stabilized output voltage from a given input DC Voltage [3-5]. DC/DC converters are used in many fields such as electrical vehicle technology, switching mode power supplies, energy production, control and communication devices and robotic apps [5-9].

Popular types of DC/DC converters as buck, boost, buck-boost, cuk are widely used in applications. Buck and Boost converters are the basic types of DC/DC converters. Other types are derived from them [9-12]. An ideal type of boost converter is shown in Figure 1. As can be seen, a boost converter consists of a semi-conductor switch, a diode, an inductor, a capacitor and the load. Output voltage of the boost converter is always bigger then the input voltage [6-12].

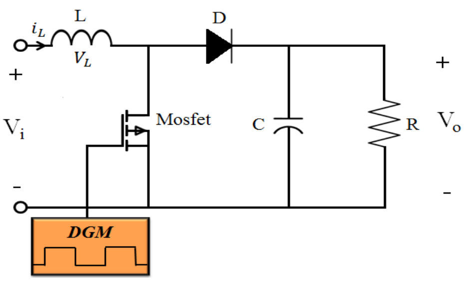

Figure 1. General structure of the Boost converter.

Control of the boost converter which is shown in Figure 1. is carried out via the ON-OFF situation of semi-conductor power mosfet. In Continuous Conduction Mode (CCM), when mosfet is ON, diode is reverse polarized then input circuit is disconnected from the output circuit. During this time, inductor is charged by the power supply and inductor current flows continuously. While input DC Power supplies the inductor, capacitor supplies the load as well [5-9]. Changes of V_{GS} and I_L in interval of $0<t\leq T_d$ is shown in Figure 2.

When MOSFET is OFF, the load is supplied from both inductor and DC power supply. Thus boosted output voltage is obtained from lower input voltage. Because of power components are exposed to output voltage, circuit is never run idled. Otherwise, output voltage excessive rises and that may cause damages. Changes of V_{GS} and I_L in interval of $T_d<t\leq T$ is shown in Figure 2.

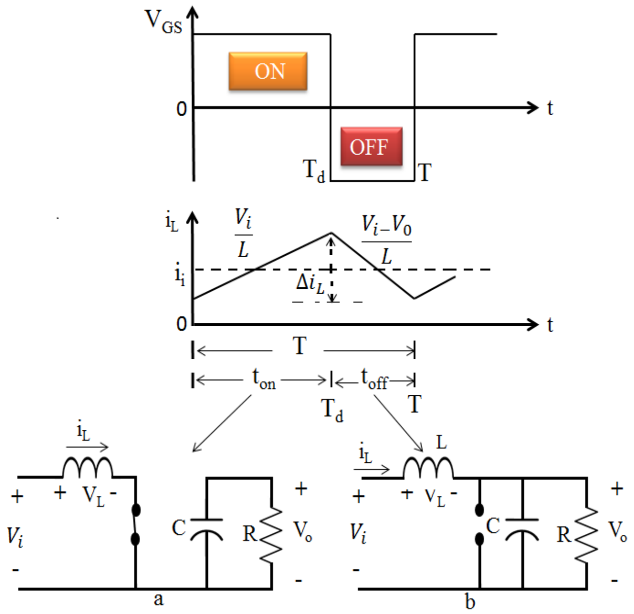

Figure2. Continuous current conduction state a) Switch in "ON" situation b) Switch in "OFF" situation

As can be seen in Figure 2. in interval of $0<t\leq T_d$, in other words when MOSFET is ON, voltage of the diode is VD = -Vo. So diode is reverse polarized. Consequently, that causes input and output sides of circuit is separated. Thus inductor voltage V_L is equal to the Vi. Inductor voltage and current are given respectively in equations (1) and (2).

$$V_L = V_i = L\frac{di_L}{dt} \tag{1}$$

$$i_L = \frac{1}{L}\int_0^t V_i\, d_t + i_{L0} \tag{2}$$

i_{L0} is initial value of the inductor current in t=0. Maximum value of the inductor current i_L occurs when $t=T_d$. This situation is expressed in equation (3).

$$i_{LTd} = \frac{V_i d_t}{L} + i_{L0} \tag{3}$$

In interval of $0<t\leq T_d$, inductor current rises linearly with the slope of Vi/L. In interval of $T_d<t\leq T$, inductor current falls with the slope of $(V_L - V_0)/L$. This is shown in Figure 2. Δi_L refers to unit change of the inductor current and it is expressed mathematically as in equation (4).

$$\Delta i_L = \frac{V_0 D(1-D)}{f_s L} \tag{4}$$

Where fs is the switching frequency and D is the duty cycle. Δi_L reaches the maximum value when D is 0,5. As can be seen in equation (5) switching current is equal to sum of input current and the average inductor current.

$$i_{ant} = i_g + \frac{\Delta i_L}{2} \tag{5}$$

When $t = T_d$, MOSFET changes mode OFF during the toff time. When MOSFET is OFF, inductor behaves as current source and makes diode is ON as shown in Figure 2(b). During this time inductor voltage is expressed in equation (6).

$$V_L = V_i - V_0 = L\frac{di_L}{dt} < 0 \tag{6}$$

When MOSFET is OFF, current that flows through the circuit in other words current that flows through inductor and diode is expressed mathematically in equation (7) and (8).

$$i_D = i_L = \frac{1}{L}\int_{Td}^t V_L dt + i_{LTd} = \frac{1}{L}\int_{Td}^t (V_i\text{-}V_o)dt + i_{LTd} \tag{7}$$

$$i_D = i_L = \left(\frac{V_i - V_o}{L}\right)(t\text{-}Td) + i_{LTd} \tag{8}$$

i_{LTd} current is value of the i_L current at t=Td. So peak to peak inductor current can be expressed as equation (9).

$$\Delta i_L = i_{LTd} - i_{LT} = \frac{(V_o - V_i) - (1\text{-}D)T}{L} = \frac{V_o D(1-D)}{f_s L} \tag{9}$$

In boost converters, relationship of the input voltage and output voltage is obtained when the average inductor voltage or net current changes in a period is considered as zero. This relation is given in equation (10) [6]-[9].

$$\frac{V_o}{V_i} = \frac{1}{(1\text{-}D)} \tag{10}$$

D value changes in interval of $0 < D < 1$. When equation (10) is examined, output voltage gets the lowest value when D=0 and it is equal to the input voltage. When duty cycle D is equal to 1, output voltage is infinite and it means an undesired event. For this reason in applications, D is selected the interval of $0.1 < D < 0.9$.

The inductance and capacitance values of the DC/DC converter which is given in figure 1 should be determined. Thus the average value of inductance current and output current at limit region are given in equation (11) and equation (12) respectively.

$$i_{is} = \frac{\Delta i_L}{2} = \frac{V_i DT}{2L} = \frac{V_0 D(1-D)}{2f_s L} \tag{11}$$

$$i_{os} = i_{is}(1-D) = \frac{V_0 D(1-D)^2}{2f_s L} \tag{12}$$

When $D = 0.5$, i_{is} reaches its maximum value and when $D = 1/3$, i_{os} reaches its maximum value, with these given information, the load resistant at limit region (R_{LSmin}) is given in equation (13).

$$R_{LSmin} = \frac{V_0}{i_{os-mak}} = 13{,}5 f_s L_{min} \tag{13}$$

The minimum value of L in continuous conduction mode is given in (14) and values of L for D is given in (15). The equation for the minimum value of C is given in (16) [6]-[11].

$$L_{min} = \frac{2}{27}\frac{V_0}{f_s i_{os-mak}} = \frac{2}{27}\frac{R_{Lmak}}{f_s} \tag{14}$$

$$L_{min}\begin{cases}\dfrac{R_{Lmak}D_{mak}(1-D_{mak})^2}{2f_s}, D < \dfrac{1}{3}\\[2ex] \dfrac{R_{Lmak}D_{min}(1-D_{min})^2}{2f_s}, D \geq 1/3\end{cases} \tag{15}$$

$$C_{min} = \frac{V_0 D_{mak}}{f_s R_{Lmin} V_{ctt}} \tag{16}$$

Where V_{ctt} is ripple voltage on the capacitance. The DC/DC converter is designed using given equations above.

2 Fuzzy Logic Controller

Fuzzy logic technology developed by Zadeh in 1965 is based on [8] defined fuzzy rules and it is used to examine the systems including unknown parameters [13-14].

Unlike the classical control methods, FLC applies input signal to the system in order to obtain the desired output signal without requiring the knowledge of the system. FLC emulates a human expert. In this case, the knowledge of the human operator would be put in the form of a set of fuzzy linguistic rules [15]. These rules provide to generate multi-level control signal values between from zero to one which increases the controller performance and efficiency [16-18].

The fuzzy controller is composed of three main sections. These are fuzzification, rule base and inference mechanism, and defuzzification. A block diagram of a fuzzy control system is shown in Fig. 3.

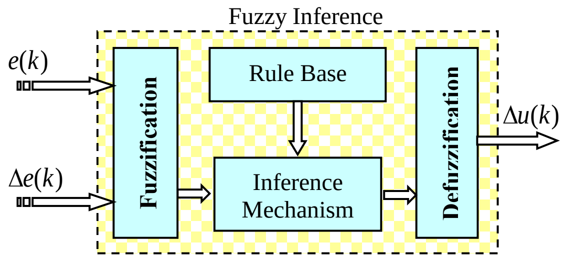

Figure 3. The block diagram of fuzzy logic based controller

As seen from Fig. 3, e(k) and Δe(k) are the crisp inputs of the FLC. e(k) is the error which is the difference between the referance signal output signal. Δe(k) is symbolized to change of error. The mathematical equations of these inputs are given below.

$$e(k) = r(k) - y(k)$$
$$\Delta e(k) = e(k) - e(k-1) \tag{11}$$

The first section of the FLC is the fuzzification which is used to convert input crisp values to fuzzified numbers. After fuzzification section, the fuzzified values are used in rule base section. In this section, linguistic control rules and inference mechanism are used to generate fuzzfied results. These results are defuzzified in the defuzzification section and crisp control signal is applied to the system to be controlled [18-20]. Fuzzification and defuzzification operations are given in Figure 4 and 5, respectively.

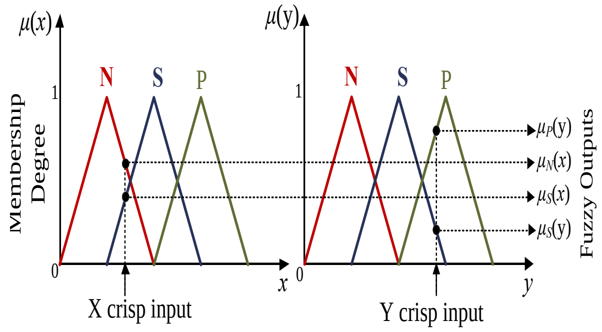

Figure 4. Schematic of the fuzzification.

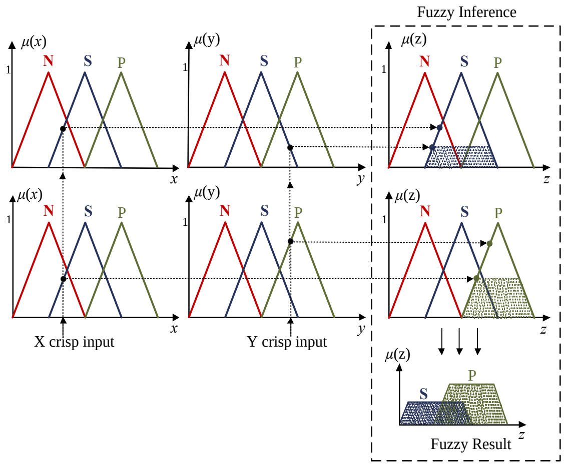

Figure 5. Mamdani's defuzzication method.

Membership functions (MF) are one of the main block of a FLC. MFs are used to convert crisp inputs to fuzzified ones. Variable types of MFs can be found in literature. Some of these functions are triangular, trapezoidal, Gaussian, Sigmoidal and Bell curves, etc. Triangular MFs of which mathematical description given in (12) are implemented in this study [15-20].

$$\mu(x) = \max\left[\min\left(\frac{x - x_1}{x_2 - x_1}, \frac{x_3 - x}{x_3 - x_2}\right), 0\right] \tag{12}$$

Where x1, x2 and x3 are the lower limit value, maximum point of the triangle and upper limit value, respectively. Triangular MF graphic presentation is shown in Fig. 6.

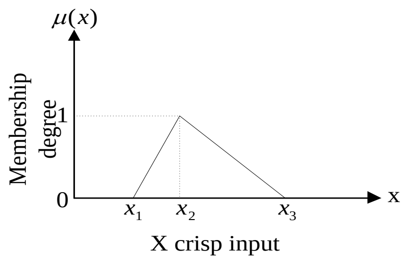

Figure 6. Triangular MF

The rule table including 25 rules for designed FLC is given in Table 1. Variable inputs are repsresented as error (e) and change in error (de). The linguistic expressions are named as negative big (NB), negative small (NS), zero (Z), positive big (PB) and positive small (PS), respectively.

Table 1. FLC rule table

Δu		e				
		NB	NS	Z	PS	PB
de	NB	NB	NB	NS	NS	Z
	NS	NB	NS	NS	Z	PS
	Z	NS	NS	Z	PS	PS
	PS	NS	Z	PS	PS	PB
	PB	Z	PS	PS	PB	PB

2.1 Optimization of the Controllers

In this study, FLC and classical PI controller are used. The proposed controller structures are given in Fig. 7 and Fig. 8.

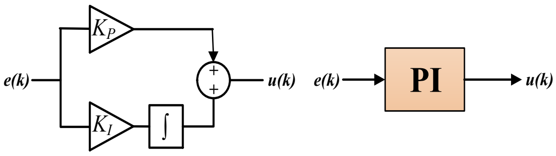

Figure 7. PI controller

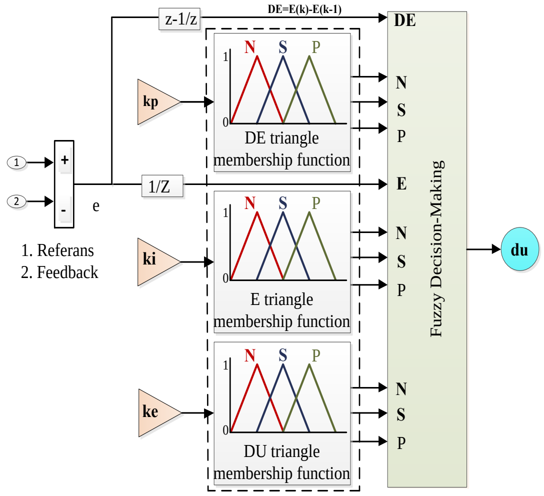

Figure 8. Matlab/Simulink block diagram representation of the designed FLC

In order to obtain the best controller performances, the parameters of the FLC (kp, ki, ke) and PI (KP, KI) controller are tuned by particle swarm optimization (PSO) method. Integral of time weighted absolute error (ITAE) is used as an objective function. The mathematical eguation of the ITAE is given in (13).

$$\mathrm{ITAE} = \int_0^T t|r(t) - y(t)|dt = \int_0^T t|e(t)|\, dt \qquad (13)$$

Where r, y and e are the reference signal, output signal and error signal, respectively. PSO algorithm is performed 10 times and the optimized controller parameters are given in Table 2.

Table 2. Optimized controller parameters

PSO	PI		BMD		
	KP	KI	kp	ki	ke
	1.19	0.69	3.09	1.01	7.99

2.2 Particle swarm optimization (PSO)

Most of the optimization algorithm used to solve engineering problems. These mimics the behavior of the creatures and systems in nature. One of these algorithms is the PSO developed by Dr. Eberhart ve Dr. Kennedy in 1995 [21]. PSO algorithm is commonly used for nonlinear and multivariable problems [22]. Compared to other optimization algorithms, PSO provides simplicity and higher implementation [23].

PSO is a population based algorithm which simulates the movements of the bird flocking and fish schooling by using the velocity (V) and position (X) equations given below [21-25].

$$V_i^{k+1} = wV_i^k + c_1 r_1 (pbest_i - x_i^k) + c_2 r_2 (gbest - x_i^k) \qquad (14)$$

$$x_i^{k+1} = x_i^k + V_i^{k+1} \qquad (15)$$

In the above equations, k is the iteration number, pbesti is the individual best value of the particle, gbest is the best value of the swarm, c1 and c2 are the acceleration constants, r1 and r2 are randomly selected numbers varying from 0 to 1, w is defined as the weighting factor.

3 System Matlab/Simulink Model and Simulation Results

The simulation block diagram designed in Matlab/Simulink for a DC-DC boost converter is shown in Figure 9.

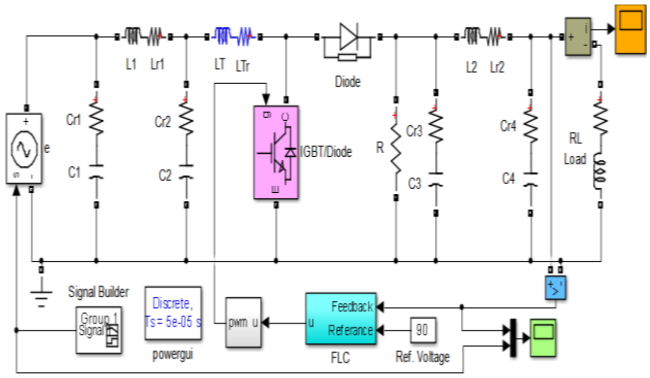

Figure 9. Matlab/Simulink block diagram for DC-DC converter controlled by fuzzy logic controller.

Simulation studies are realized with controllers, where the controller parameters are determined by PSO, for different operation conditions in Matlab/Simulink program.

DC-DC converter output voltage is shown in Figures 10-11 for RL load during variable input and constant output voltage state.

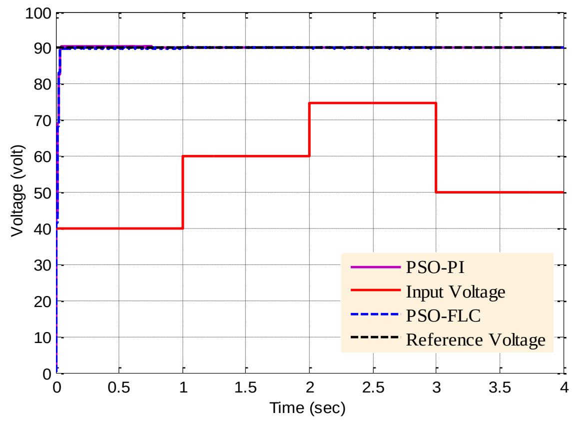

Figure 10. DC-DC converter output voltage (RL load)

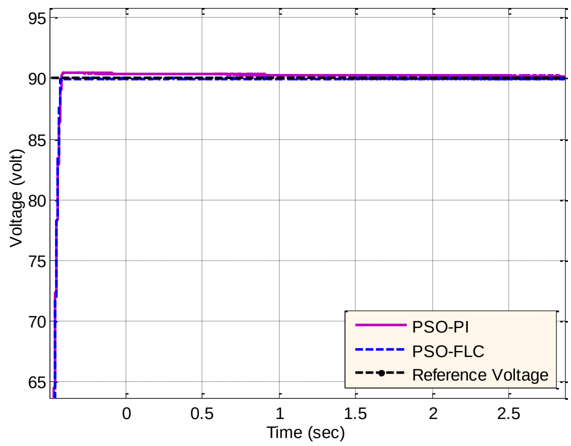

Figure 11. DC-DC converter output voltage (RL load)

DC-DC converter output voltage is shown in Figures 12-13 for R load during variable input and constant output voltage state.

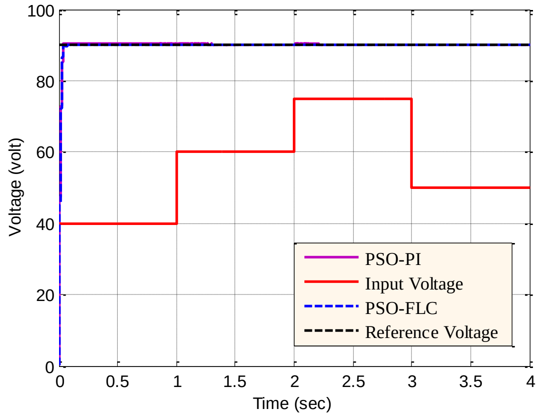

Figure 12. DC-DC converter output voltage (R load)

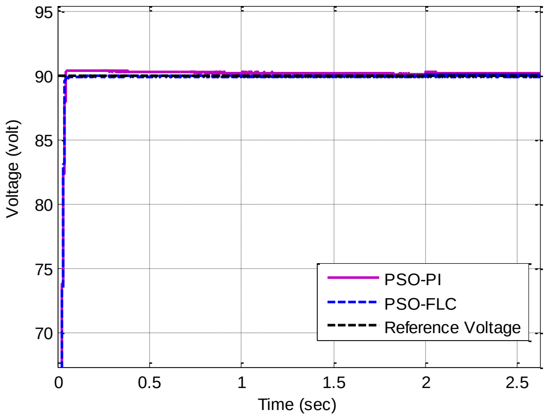

Figure 13. DC-DC converter output voltage (R load)

As shown in figures, the PI controller performed poorly according to the FLC in terms of overshoot and time of settlement for variable input DC-DC converter and constant output voltage with different load states.

DC-DC converter output voltage is shown in Figures 14-15 for RL load during constant input and variable output voltage state.

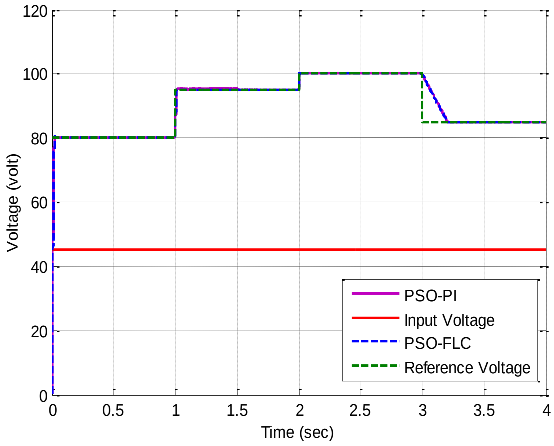

Figure 14. DC-DC converter output voltage (RL load)

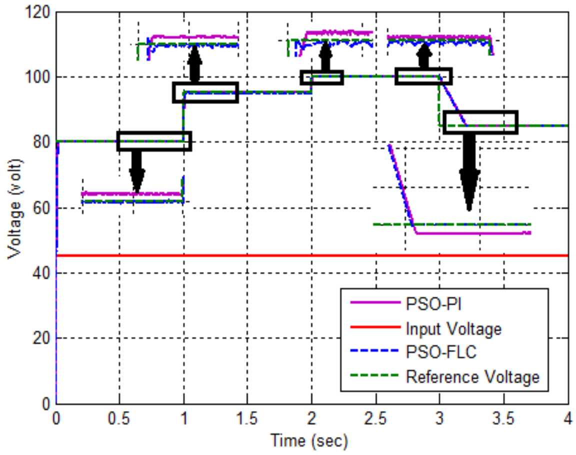

Figure 15. DC-DC converter output voltage (RL load)

As shown in Figures 14-15, the FLC has a better performance than the PI controller as regards overshoot and time of settlement.

4 Conclusion

In this study, the output voltage control of a DC/DC boost converter designed for wind energy systems, were examined for different loads and operating conditions. Also, control of DC-DC converter is carried out by the PI and FLC and performances of controllers are compared. The FL controller shows better performances than the PI controller for different loads and operation conditions. Also, optimization of the system controller parameters with PSO provides more intelligent and efficient control.

As a result, both controllers control the system stably, but the PI controller represents worse performance than the FLC according to overshoot and time of settlement.

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