MBNA Publishing House Constanta 2021

Proceedings of the International Scientific Conference SEA-CONF

SEA-CONF PAPER • OPEN ACCESS

Design of an optimized Type-2 Fuzzy Logic PID Controller for Boost DC-DC Converters

To cite this article: Ahmed BENNAOUI, Slami SAADI, Aissa AMEUR, Ameur BENNAOUI and Zian SALAH, Proceedings of the International Scientific Conference SEA-CONF 2021, pg.61-70.

ISSN: 2457-144X; ISSN-L: 2457-144X

doi: 10.21279/2457-144X-21-008

Design of an optimized Type-2 Fuzzy Logic PID Controller for Boost DC-DC Converters

Ahmed BENNAOUI [1] , Slami SAADI [2] , Aissa AMEUR[1], Ameur BENNAOUI [3] , Zian Salah [1]

[1]Laboratoire des semi-coducteurs et des matériaux fonctionnels , University of Amar Telidji, Laghouat, Algeria.
[2]University of Djelfa, Algeria
[3]University of Science and Technology (USTO).Oran, Algeria

Corresponding author name and e-mail address : a.bennaoui@lagh-univ.dz, ;

Abstract. In this paper, The Particle Swarm Optimization algo-rithm used for tuning the size of the uncertainty in interval type-2 membership functions and choose the PID values for Type-2 Fuzzy Logic PID controller for Boost DC-DC converters. Simulation results show the type-2 fuzzy logic PID controller with PSO have better performances than the other used control-lers. To sum up; PSO optimization methods are helpful for choose the best size of the uncertainty in interval type-2 mem-bership functions and choose the PID gains for Type-2 Fuzzy Logic PID Controller.

1. Introduction

Type I fuzzy sets can model the uncertainty in the semantic concept of a single user, that is, the uncertainty within the individual. Type I fuzzy systems have been successfully applied in control and machine learning. Interval type II fuzzy sets can simultaneously model multiple In vivo uncertainty and inter-individual uncertainty, which have shown better performance than a type 1 fuzzy system in many applications, have become a research hotspot in recent years.

Why the performance of the interval type-2 fuzzy system may be better than that of the type-1 fuzzy system? [1][2] [3][4]:

- Interval type 2 fuzzy sets can simultaneously model intra-individual uncertainty and inter-individual uncertainty, while type 1 fuzzy sets can only model intra-individual uncertainty. For example, for the concept of "high temperature", everyone can have a type one fuzzy set (individual uncertainty), and different people's type one fuzzy sets are often different. The interval type-2 fuzzy sets can be used to fuse these different type-1 fuzzy sets, so as to consider the uncertainty between individuals.
- 2. To achieve the same function, the number of rules required by the interval type 2 fuzzy system is less than that of the type 1 fuzzy system. This makes it easier to model fuzzy systems based on expert experience. Even if the fuzzy system is obtained by data-driven, fewer rules also contribute to the interpretability of the model.

- The control surface of the interval type 2 fuzzy controller is smoother near the steady state, which helps to improve its robustness.
- Given the same number of rules, the interval-type two fuzzy system can realize the input and output mapping that the first-type fuzzy system cannot. One of our findings is that if a type 1 fuzzy system is used to replicate the input and output mappings of an interval type 2 fuzzy system, then the value of some membership functions of the type 1 fuzzy system must be negative or greater than 1. Fuzzy concentration is not allowed.
- The interval type 2 fuzzy system has new characteristics that the type 1 fuzzy system does not: the membership function of the same fuzzy set can have different values in different rules, while the membership function of the same fuzzy set in the type 1 fuzzy system The values in different rules must be the same.

The Interval type-2 fuzzy membership functions are easy to implement and they used in most of works related type-2 fuzzy logic. The more important concepts in interval-type 2 fuzzy sets are [4]

Upper membership function (UMF): A one-type fuzzy set formed by any point on the universe and the upper bound of the corresponding membership interval.

Lower membership function (LMF): A one-type fuzzy set formed by any point on the universe and the lower bound of the corresponding membership interval. The lower membership function can be non-normal, that is, its The maximum degree of membership is not 1.

Uncertainty coverage area (footprint of uncertainty, FOU): All areas between the upper and lower membership functions constitute the uncertainty coverage area. [4] and is illustrated in Figure 1

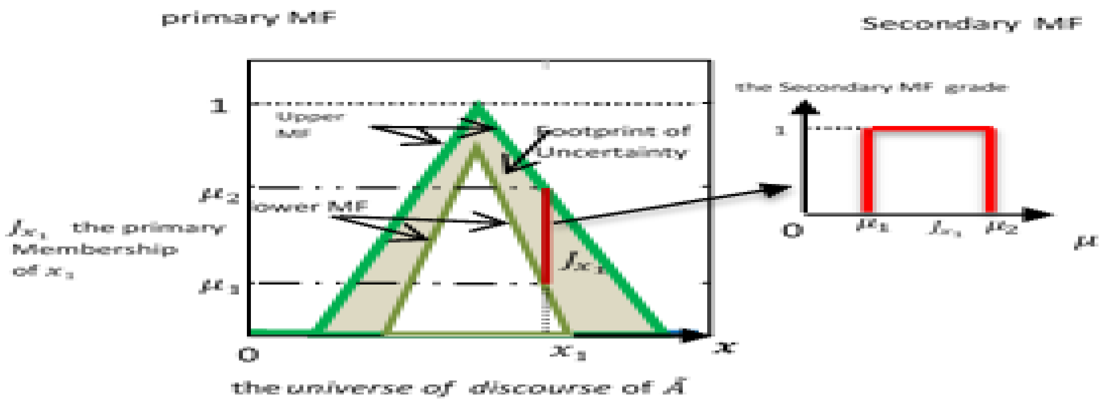


Fig 1 Interval type-2 fuzzy logic primary and secondary MFs

To construct the interval type-2 MFs, the type-1 membership functions are modified as illustrated in (Figure 2). [5][6] [7]

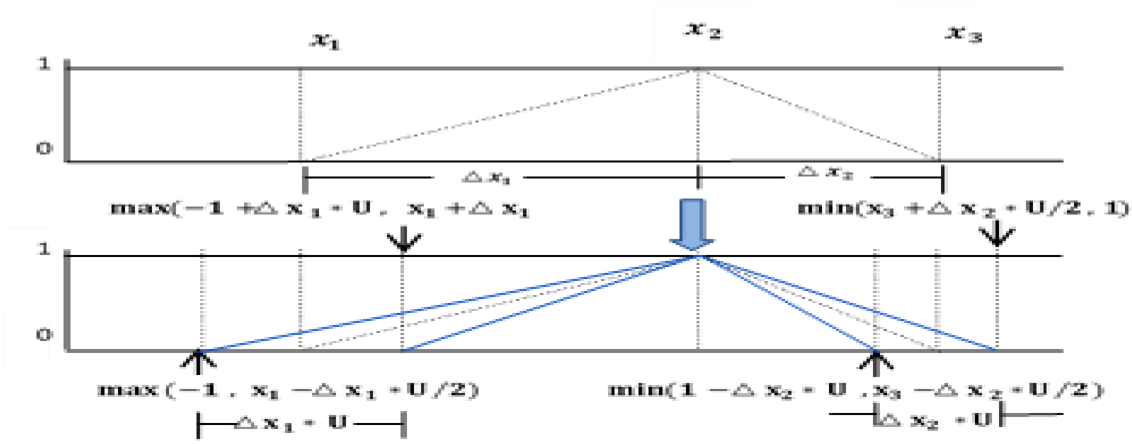


Fig 2 From type-1 to interval type-2 membership functions[5][6] [7]

The uncertainty (U) in the membership functions is the third considered parameter[5][6] [7], Some researchers studies investigate the optimization of self tuning the parameters of fuzzy PID controller [8] [9] [10] [11][112]. .

In most modern engineering actions, DC-DC converters have big significance since they have superior performance, less cost; they occupied a significant position in the power sources of laptops, mobile phones, home appliances [13] [14][15] . DC-DC converters are used in most industrial environment. The most common DC-DC converters types are: the Buck, Boost and Buck-Boost [13] [14][15]

In this papier ,we utilized the Particle Swarm Optimization (PSO) Algorithm for tuning the size of the uncertainty interval type-2 member-ship functions and choose the PID values of Type-2 Fuzzy Logic PID controller for Boost DC-DC converters.

inThis paper will be organized as following : section 2: Particle Swarm Optimization (Pso). section 3: Fuzzy PID Controller for a DC-DC Boost converter , section 4: Simulation and Re-sults,section .5:Conclusion

2. Particle Swarm Optimization (Pso)

Particle Swarm Optimization (pso),, is an algorithm registered in the family of evolutionary algorithms. It was proposed by Russel Eberhart (engineer in electricity) and James Kennedy (socio psychologist) in 1995 [17][18] .This method finds its source in the observations made during the simulations computerized flights of birds and schools of Reynold fish Heppner & Grenander.In other words, it draws heavily on the observation of gregarious relationships of migratory birds, which to travel "long distances" (migration, foraging, aerial displays,.), must optimize their trips in terms of energy expended, time,.),

The movement of its animals in swarms is complex, its dynamics obey rules and very specific factors to identify:

- Each individual has a certain "limited" intelligence (which allows you to make a decision).
- Each individual must know their local position and have information locality of each individual in his vicinity.
- Obey these three simple rules, “stay close to other people”, “go in the same direction ”or“ fly at the same speed ”.

All its factors and rules are essential for maintaining cohesion in` the swarm, this by adopting a complex and adaptive collective behavior. The PSO method [17][18] benefits in comparison with the other optimizations methods .
PSO includes two terms P_{best} and G_{best}. Position and velocity are updated over the course of iteration from these mathematical equations [16][17][18][19]:

$$V_i^{k+1} = wV_i^k + c_1.rand_1(..)(pbest_i - S_i^k) + c_2.rand_2(..)(pbest_i - S_i^k)$$
$$s_i^{k+1} = s_i^k + V_i^{k+1} \qquad (6)$$

Where
V_i^k Velocity ofparticle 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.

3. Fuzzy PID Controller for a DC-DC Boost converter

Fuzzy PID Controller systems have double inputs and single output..

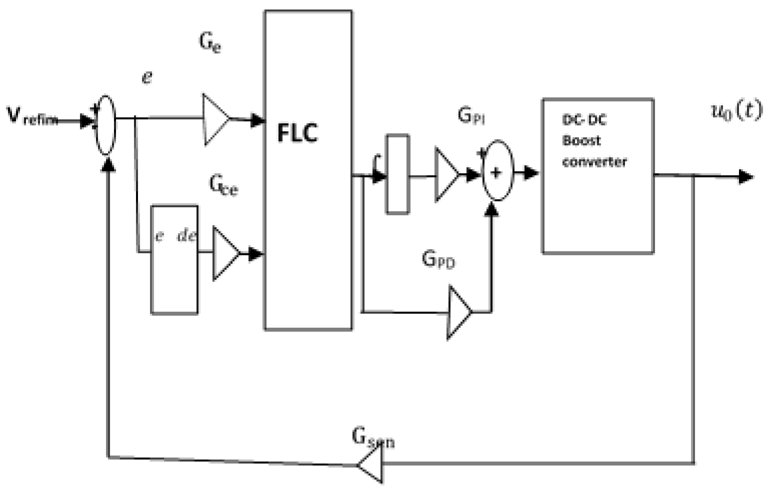


Fig 3 Structure of a fuzzy PID controller

Where: sensor of gain G_{sen} and the reference voltage V_{ref}
And $V_{refim} = G_{sen} * V_{ref}$, $e = V_{refim} - G_{sen} * u_0$ (7)

The final control action $\hat{d}$ applied to the converter is given by:

$$\hat{d} = G_{pd}\hat{d}_1 + G_{pi}\int \hat{d}_1\, d\tau$$

We use the two input fuzzy sets (for e and de) are composed of five membership functions[7] in (Figure. 4).and The rules and output membership functions are illustrated in [7].

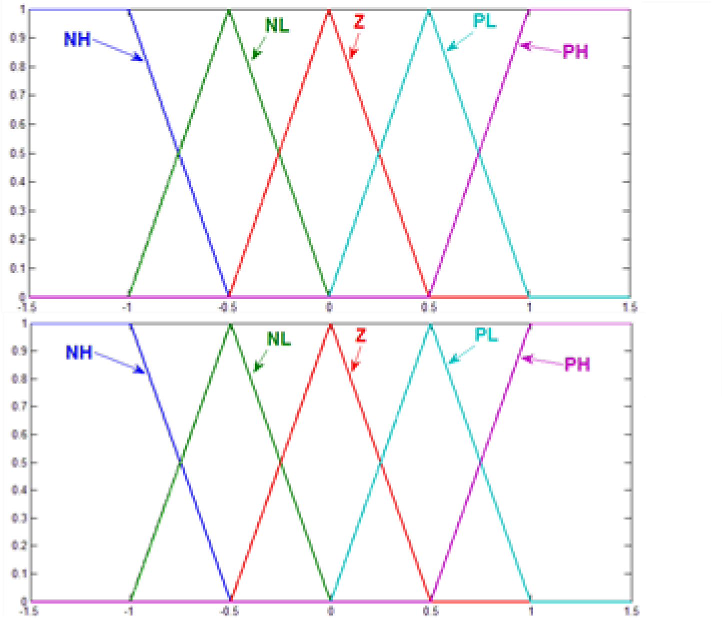


Fig 4 type-1 fuzzy membership functions (The error e and the change of error de) of Fuzzy Logic Controller

4. . Simulation Phases and Results

We proposed the PSO for tuning the parameters of fuzzy PID controllers .

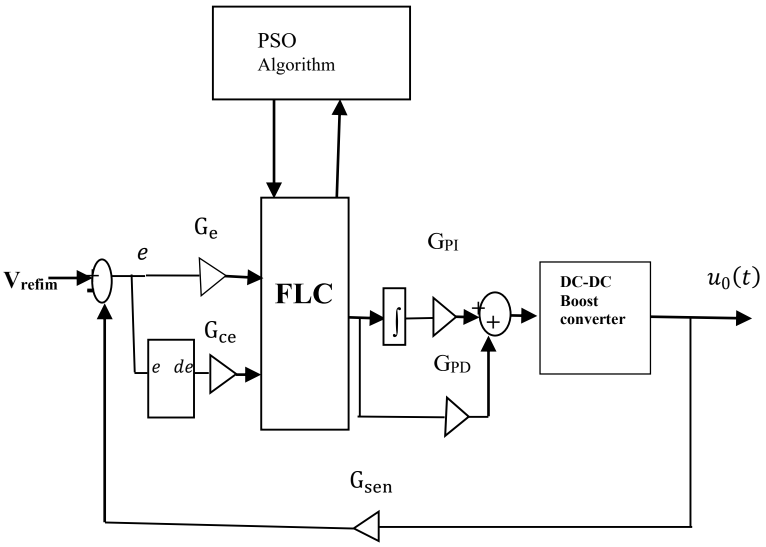


Fig 5 Tuning process of Fuzzy PID Controller parameters with PSO

- In our simulation, we use the following parameters of the DC–DC Boost converter: Series Inductance:L = 20[mH]. Parallel Capacitance:C = 20[μf] . Load resistance:R = 30[Ω] . Input Voltage:Vg = 15[V] . Switching frequency:f_{SW} = 5[kHz].

- The values of the fuzzy system input gains are Ge = 0.5; Gce = 9; sensor of gain Gsen = 0.04. The reference voltage: Vref = 37.5 V .

In this study ,we are taken as objective function following**:**

Fitness Function = $(10^3)*ISE+(10^4)*T_r$

Where Tr : rise time

ISE (IntegralSquare Error)= $\int_0^{+\infty}[e(t)]^2\,dt$

A. *The cases of simulation:*

1) *Type-1 Fuzzy Logic PID Controller with PSO*

We noted in the previous work [19] that the problem is how to choose the suitable PID value($G_{pd}\in[0\ \ 0.59]$, $G_{pi}\in[0\ \ 450]$) for Type-1 Fuzzy Logic PID Controller for Boost DC-DC Converters. So, we used PSO algorithm to choose the PID values of *Type-1 Fuzzy Logic PID Controller*

.

after simulation (Figure 9) of Type-1 Fuzzy Logic PID Controller with PSO for Boost DC-DC Converters,

- ✓ We obtained the PID values : G_{pd}=0.583; G_{pi}=432.2212 ;

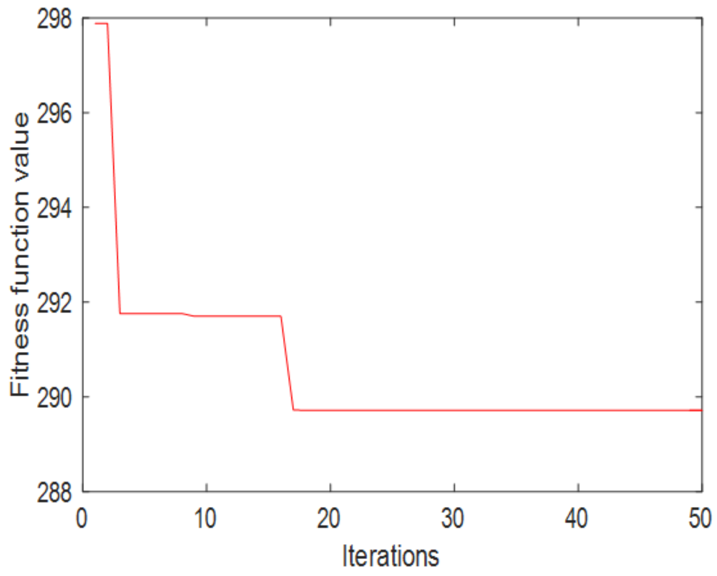


Fig 6 PSO convergence characteristic

2) *Type-2 Fuzzy Logic PID Controller with PSO*

We used the PSO algorithm to design the interval type-2 membership functions(Figure 11) of Type-2 Fuzzy Logic PID controller for Boost DC-DC Converters.

Where:

we proposed using PSO for tuning the size of the uncertainty (U∈ [0 , 1]) in interval type-2 membership functions and choosing the PID values (G_{pd}∈[0 , 0.59] , G_{pi}∈[0 , 450]) of Type-2 Fuzzy Logic PID controller .

After simulation (Figure 10) of Type-2 Fuzzy Logic PID Controller with PSO for Boost DC-DC Converters, We obtained:

- The PID values: : G_{pd}=0.3694; G_{pi}=347.6265;
- The size of the uncertainty (U) in interval type-2 membership functions : U= 0.8388;

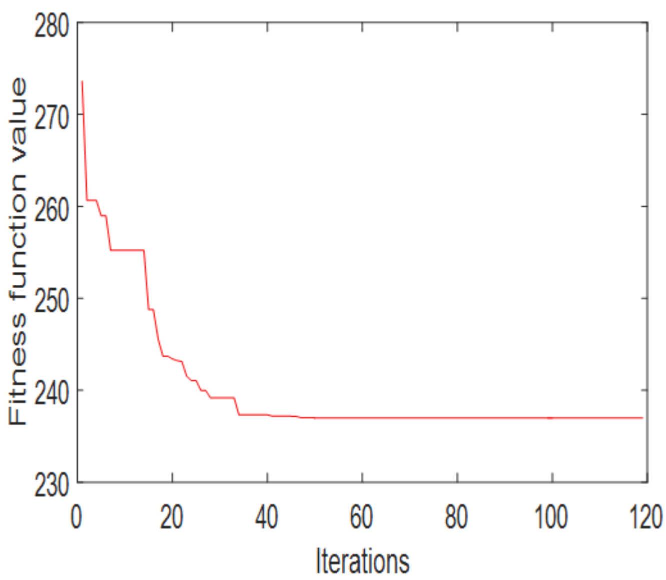


Fig 7 PSO convergence characteristic

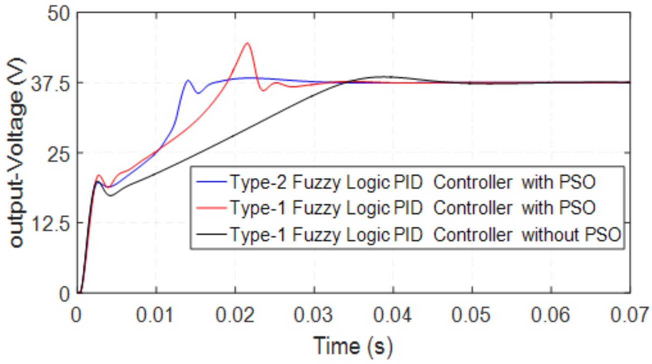


Fig 8 The Output Voltage of different Simulation Cases

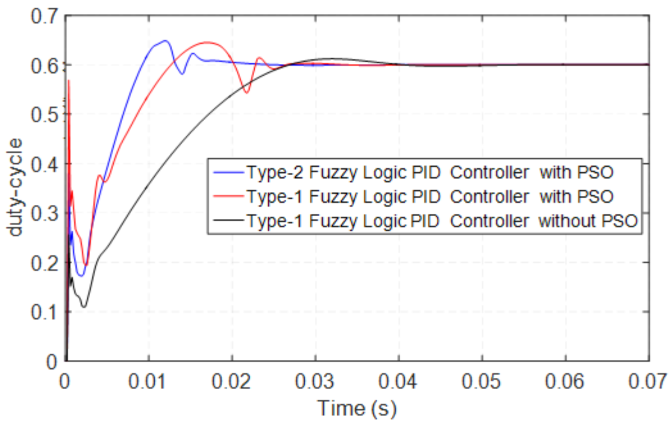
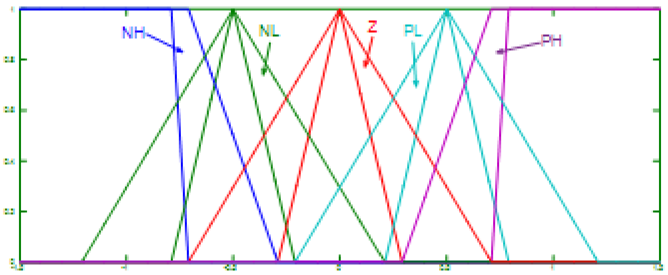
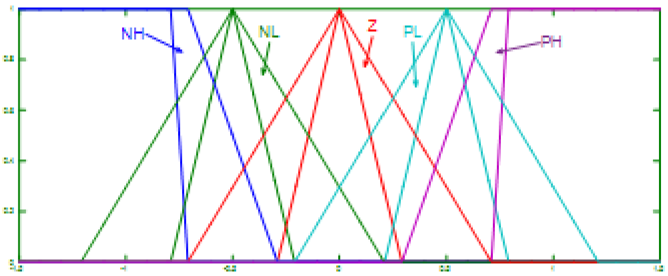


Fig 9 The Dut-Cycle of different Simulation Cases



e



de

Fig 10 Type-2 fuzzy membership functions (U= 83.88%) of *Type-2 Fuzzy Logic Controller*

Table 1. PERFORMANCE ANALYSIS OF BOOST DC-DC CONVERTER

	ISE	IAE	Tr	Overshoot%
Type-2 Fuzzy Logic PID Controller with PSO	0.1050	0.1270	0.0132	2.136%
Type-1 Fuzzy Logic PID Controller with PSO	0.1097	0.1392	0.0180	18.7266%
Type-1 Fuzzy Logic PID Controller without PSO[19]	0.1559	0.2250	0.0306	2.6904%

5. CONCLUSION

In this work, we proposed using algorithm PSO for tuning the size of the uncertainty (U) in interval type-2 membership functions and choose the PID values of Type-2 Fuzzy Logic PID controller for a DC-DC Boost converter.

Our analyses based on four performance indices: Integral square error (ISE), the integral of the absolute errors (IAE), Rise time (Tr) and Overshoot (%). Simulation results demonstrated the type-2 fuzzy logic PID controller with PSO for Boost DC-DC converter have better performances (minimum Overshoot% ,minimum rise time (Tr) ,and achieve lower the integral of the absolute errors (IAE) and the integral of square of errors (ISE)) than the other controllers (Figure 7 , Figure 8 ,Figure 9 and Table 1). In conclusion, The PSO algorithm is very practical in optimal design of interval type-2 membership functions and choosing PID values of Type-2 Fuzzy Logic PID controller for Boost DC-DC converters.

References

[1] Bernal, E., Lagunes, M.L., Castillo, O. et al. Optimization of Type-2 Fuzzy Logic Controller Design Using the GSO and FA Algorithms. Int. J. Fuzzy Syst. 23, 42–57 (2021). https://doi.org/10.1007/s40815-020-00976-w

[2] Liu, J., Zhao, T. & Dian, S. General type-2 fuzzy sliding mode control for motion balance adjusting of power-line inspection robot. Soft Comput 25, 1033–1047 (2021). https://doi.org/10.1007/s00500-020-05202-1

[3] Kaya, İ., Turgut, A. Design of variable control charts based on type-2 fuzzy sets with a real case study. Soft Comput 25, 613–633 (2021). https://doi.org/10.1007/s00500-020-05172-4

[4] Bennaoui, A., Saadi, S., Ameur, A. (2020). Invasive weed optimization algorithm for tuning transitioning from Type-1 to interval Type-2 fuzzy logic controller for boost DC-DC converters. Journal Européen des Systèmes Automatisés, Vol. 53, No. 2, pp. 195-202.

[5] Solano Martinez J (2012) Energy management of a hybrid electric vehicle: an approach based on type-2 fuzzy logic. Doctoral Thesis, Université de Franche-Comté Belfort

[6] Hissel D (1998) Contribution à la commande de dispositifs électrotechniques par logique floue Procédures de réglage sur site parplans d'expériences et méthodologie Taguchi. Doctoral Thesis,
Institut National Polytechnique de Toulouse

[7] Bennaoui A, Saadi S (2017) Type-2 fuzzy logic PID controller and different uncertainties design for boost DC-DC converters. Springer,Electrical Engineering Volume 99, Issue 1, pp 203–211

[8] Ming Yang and Xingcheng Wang , "Fuzzy PID Controller Using Adaptive weighted PSO for Permanent Magnet Synchronous Motor Drive", Second International Conference on Intelligent Computation Technology and Automation. IEEE 2009, pp.736-739.

[9] M. Sridhar, K.Vaisakh and K.S.Linga Murthy, "Adaptive PSO Based Tuning of PID- Fuzzy and SVCPI Controllers for Dynamic Stability Enhancement: A Comparative Analysis" Second International Conference on Emerging Trends in Engineering and Technology, ICETET-09. IEEE 2009, pp. 985-990.

[10] Ning Sheng ; Xiangjian Chen ; Huilin Ge ; Di Li. (12 March 2020). Optimal Interval Type 2 Fuzzy PID Controller and its Application in Inverted Pendulum System; 12 March 2020, IEEE 2nd International Conference on Automation, Electronics and Electrical Engineering (AUTEEE)

[11] Jyoti Ranjan Nayak , Binod Shaw,Binod Kumar Sahu, Application of adaptive-SOS (ASOS) algorithm based interval type-2 fuzzy-PID controller with derivative filter for automatic generation control of an interconnected power system, Engineering Science and Technology, an International Journal Volume 21, Issue 3, June 2018, Pages 465-485

[12] Bennaoui, A., Saadi, S., Ameur, A. (2020). Invasive weed optimization algorithm for tuning transitioning from Type-1 to interval Type-2 fuzzy logic controller for boost DC-DC converters. Journal Européen des Systèmes Automatisés, Vol. 53, No. 2, pp. 195-202. https://doi.org/10.18280/jesa.530205

[13] Vidal-Ldiarte. E, Martine. S. L, Guinjoan. F, Calvente. J, Gomariz. S (2008). Sliding and fuzzy control of a boot converter using an 8-bit microcontroller. *IEE Proc., Electron. Power Appl.*, Vol. 151, pp. 5-11,

[14] Gupta. R, Boudreaux. R, Nelms. R.M (1997). Implementation of a fuzzy controller for dc-dc converters using an inexpensive 8-b microcontroller. *IEEE Trans. Ind. Electron.* Vol. 44, pp.661-669.

[15] A. Bennaoui, S. Saadi and A. Ameur, "Performance Comparison of MFO and PSO for Optimal Tuning the fractional order fuzzy PID Controller for A DC-DC Boost Converter," 2020 International Conference on Electrical Engineering (ICEE), Istanbul, Turkey, 2020, pp. 1-5, doi: 10.1109/ICEE49691.2020.9249778.

[16] A. Bennaoui, S. Saadi and A. Ameur, "Performance Comparison of MFO and PSO for Optimal Tuning the fractional order fuzzy PID Controller for A DC-DC Boost Converter," *2020 International Conference on Electrical Engineering (ICEE)*, 2020, pp. 1-5, doi: 10.1109/ICEE49691.2020.9249778.

[17] R. S. Kumar and J. Suganthi, "Improving the boost converter PID controller performance using particle swarm optimization," European Journal of Scientific Research, ISSN 1450-216X, vol. 85, no. 3, pp. 327 – 335, September 2012.

[18] Jahandideh-Tehrani, M., Jenkins, G. & Helfer, F. A comparison of particle swarm optimization and genetic algorithm for daily rainfall-runoff modelling: a case study for Southeast Queensland, Australia. Optim Eng 22, 29–50 (2021). https://doi.org/10.1007/s11081-020-09538-3