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Implementation of Particle Swarm Optimization in Fuzzy Logic Controller for an Improved Transient Response of a DC/DC Buck-boost Converter

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Abstract. The computational efficiency of the PSO inspired us to optimize an FLC controller used in a dc/dc buck-boost converter for an improved transient response. The main objective of the study is to implement PSO as the tuning algorithm for the Fuzzy Logic Controlled buck-boost converter. A simulation setup was developed through MATLAB/Simulink to simulate a PSO tuned FLC controlled buck-boost converter. The PSO algorithm was coded in MATLAB and was able to tune the FLC. Results showed that the input MF of the FLC was successfully tuned by PSO and was able to give a mean difference of 1.0065 in peak overshoot ratio, 1.0841 voltage deviation ratio, 0.3861s in peak time, 0.3538s in rise time, and 1.0968s in settling time. Overall, the PSO tuned FLC controlled buck-boost converter gave a significantly better performance than that of the untuned FLC controlled buck-boost converter.

Keywords: fuzzy logic controller; particle swarm optimization; buck-boost converter; matlab/simulink

1. Introduction

This research focused on the implementation of PSO to tune the fuzzy logic-controlled buck-boost converter, factors to be assessed in this study are seeking the desired output voltage and the voltage regulation. The advantages of the buck-boost converter and FLC inspired us to work on this study and utilized its usage to develop a simulation setup. Researchers tried to further improve the performance of the buck-boost converter and FLC so we could use its max potential when tuned with PSO.

Different conventional control algorithms have been presented in PV applications to assess the computational performance of the converter. Fuzzy logic controllers are the most suitable control technology for PV systems. As Wahab [1] points out, the intensity of sunlight varies with the weather, resulting in large variations in the voltage provided by solar panels. The buck-boost converter is used to identify whether to buck or boost based on the intensity of sunlight, according to the study. As a result, a fuzzy logic controller is used in the buck-boost converter to accumulate the system's output voltage. Fuzzification, fuzzy inference, knowledge base, and defuzzification are all components of fuzzy logic, according to Ang et al. [2]. The crisp values are fuzzified into linguistic variables or membership functions. The knowledge base, on the other hand, is made up of if-then control rules that are based on the input parameters. Finally, defuzzification is the process of transforming linguistic variables back into crisp values. The research of Sundareswaran et al. [3] shows that FLC combined with particle swarm optimization increases the total output voltage in terms of the buck-boost converter's transient and dynamic response.

Abdillah et al [4] used the application of FLC on a buck-boost converter for a wind power plant system but no optimization for the FLC was included. Sundareswaran et al. [3] used a buck-boost controller to regulate the voltage output and used PSO in the feedback controller but did not employ FLC as the control paradigm. While looking at the work of Ömür Akyazı [5], he showed how he used PSO as a tuning parameter in a fuzzy logic control scheme for a dc/dc boost converter, but not a buck converter. FLC was employed on several types of converters in the work of S.Maity et al. [6], but no optimization of FLC was done. PSO was employed to tune an FLC in one study, however, in the work of N. Sa-ngawong. Sugeno-Type FLC Ngamroo [7] was tuned for a PV generator. In the study of Sharma et al. [8], when applying five

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global optimization test functions such as Beale, booth, Matyas, levy, and Schaffer, show that particle swarm optimization outperforms genetic algorithms. It would also be best to ascertain the accuracy of the buck-boost converter when controlled with FLC tuned with particle swarm optimization algorithm.

The main objective of the study is to implement particle swarm optimization as the tuning algorithm for the Fuzzy Logic Controlled buck-boost converter. Specifically, the researchers aim to develop a MATLAB/Simulink model of the dc-dc buck-boost converter integrated with the fuzzy controller, code PSO in MATLAB, tune the FLC in regulating dc/dc converter voltage output with particle swarm optimization, and evaluate the performance in terms of peak overshoot ratio, voltage deviation ratio, peak time, rise time, and settling time of the dc-dc buck-boost converter.

The testing of the simulation setup was conducted in Simulink with a variable DC voltage source. Also, PSO was not compared to another optimization algorithm in terms of tuning FLC. Tuning was done via MATLAB/SIMULINK, not any other programming environment. This study focused on the DC-DC Buck-Boost converter only.

2. Methodology

2.1. Process Flow of the Study

Figure 1 below shows the process flow of the study.

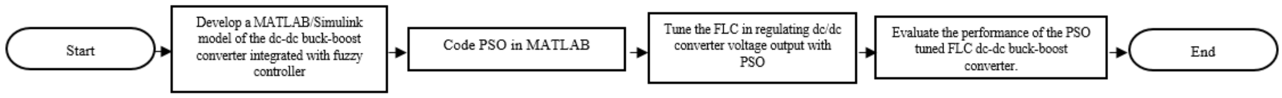

Fig. 1: Process flow of the study

The researchers developed a MATLAB/Simulink model of a fuzzy logic-controlled dc/dc buck-boost converter. The developed PSO algorithm was used to tune the FLC to improve performance in regulating the charging voltage of a lead-acid battery. Evaluation of the performance of the system was based on its transient response.

2.2. MATLAB/Simulink model of DC/DC Buck-Boost

The MATLAB/Simulink model of DC/DC Buck-Boost is shown below in Figure 2.

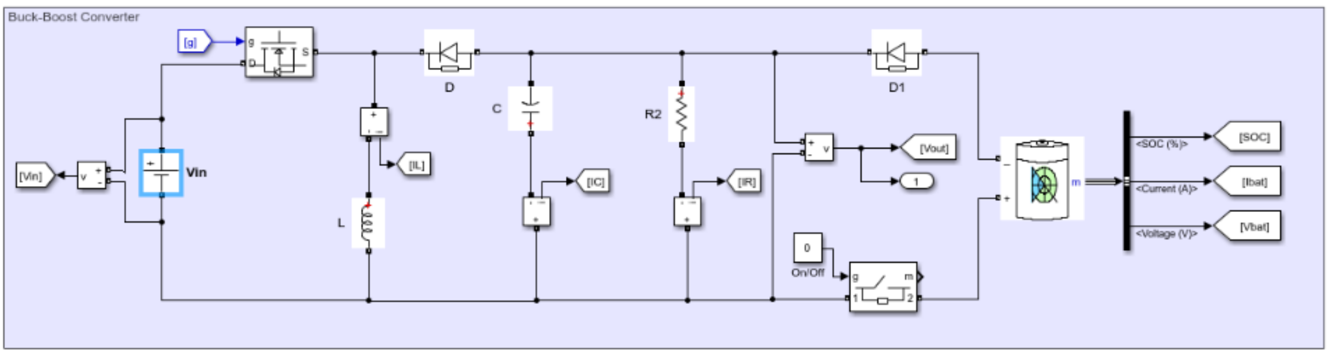

Fig. 2: MATLAB/Simulink model of DC/DC Buck-Boost

This model of DC/DC Buck-Boost converter is based on the inverting topology. It consisted of basic components such as a capacitor, inductor, resistor, and switch. In this study, we used the FLC as our switch to control the duty cycle.

2.3. Optimization Process

The researchers tuned the FLC with Particle Swarm Optimization to improve the accuracy of the duty cycle. PSO is an optimization technique that was inspired by the swarming nature of a flock of birds. It solves a problem by having a population of candidate solutions called particles. These particles move toward the best position particles every iteration. It is guided by the best-known position in the search space.

2.4. Fuzzy Logic Controller

In the FLC, we used 2 inputs and 1 output. Each input/output has 5 triangular membership functions. The optimization was directed at the error input which had the most effect on the output of the system. The membership function and fuzzy rules are shown below in Figure 3 and Table 1 respectively.

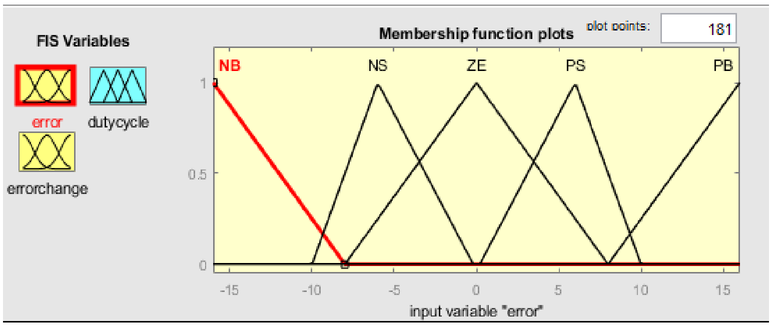

Fig. 3: Membership function

Table 1: Fuzzy rules

E \ ΔE	NB	NS	ZE	PS	PB
NB	NB	NB	NB	NB	NB
NS	NS	NS	NS	NS	NS
ZE	ZE	ZE	ZE	ZE	ZE
PS	PS	PS	PS	PS	PS
PB	PB	PB	PB	PB	PB

3. Results and Discussion

The simulation gave emphasis on the transient response of the system such as peak overshoot ratio, voltage peak deviation, rise time, settling time, and peak time.

3.1. Peak Overshoot Ratio

Table 2 and Figure 4 show stable results for PSO tuned FLC and FLC. Using T-test: Paired Two Sample for Means, the peak overshoot ratio of PSO Tuned FLC is 1.006s while that of untuned FLC is 1.004s which means they both achieve good results for this criterion.

Table 2: Peak overshoot ratio

TRIAL	Vin(V)	Vout		Peak Overshoot Ratio	
		(PSO)	(FLC)	PSO Tuned FLC (sec)	FLC (sec)
1	5.00	14.7324	14.4531	1	1
2	7.00	14.7244	14.4372	1.0009	1.001
3	9.00	14.7167	14.4174	1.0003	1.0005
4	11.00	14.6872	14.4073	1.0082	1.0032
5	13.00	14.6612	14.3221	1.0043	1.0047
6	15.00	14.6353	14.3069	1.0095	1.0054
7	17.00	14.6226	14.3463	1.0157	1.0071
8	19.00	14.6189	14.2502	1.008	1.008
9	21.00	14.6041	14.3838	1.0086	1.0023
10	23.00	14.5961	14.2356	1.009	1.0089

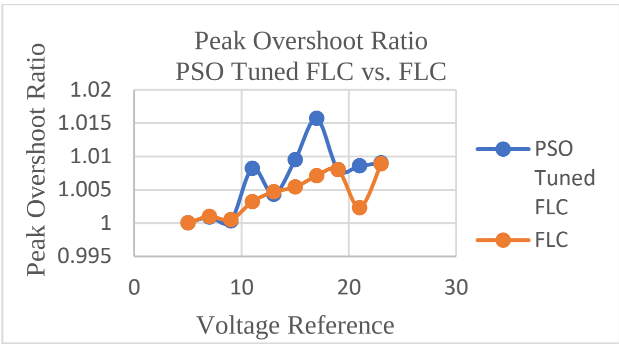

Fig 4: Peak overshoot ratio

3.2. Voltage Deviation Ratio

Table 3 and Figure 5 show that in boost mode at a reference voltage of 14.4V, tuned FLC is much more stable rather than FLC. By doing a T-test analysis, the voltage deviation of the tuned FLC which is 1.08s proves better than that of the untuned FLC which is 1.28s.

Table 3: Voltage deviation ratio

TRIAL	Vin(V)	Vout		Voltage Deviation Ratio	
		(PSO)	(FLC)	PSO Tuned FLC (sec)	FLC (sec)
1	5.00	14.7324	14.421	1.1721	1.3997
2	7.00	14.7244	14.3767	1.14	1.2126
3	9.00	14.7167	14.37	1.1076	1.1651
4	11.00	14.6872	14.4044	1.0741	1.1063
5	13.00	14.6612	14.3624	1.0643	1.1141
6	15.00	14.6353	14.3069	1.0735	1.3347
7	17.00	14.6226	14.3463	1.0636	1.2293
8	19.00	14.6189	14.2502	1.0533	1.2438
9	21.00	14.6041	14.3838	1.0485	1.8433
10	23.00	14.5961	14.2356	1.0445	1.1922

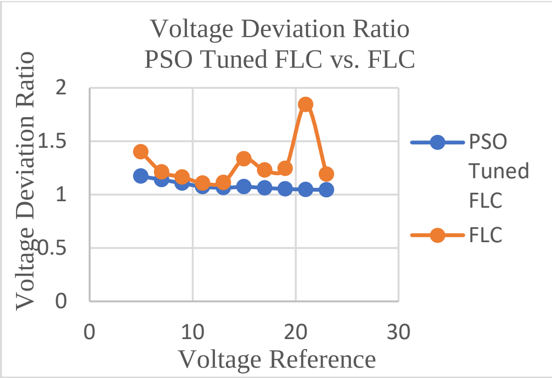

Fig 5: Voltage deviation ratio

3.3. Peak Time

Table 4 and Figure 6 show a reference voltage of 14.4V. Furthermore, they show that the untuned FLC has a peak time between 0.2046s and 1.5073s while the tuned FLC is only between 0.2071s and 0.6227s. By doing T-test analysis, tuned FLC has a mean of 0.386s while FLC has 1.005s. This proved that the tuned FLC has a much better performance in peak time than the untuned FLC.

Table 4: Peak time

TRIAL	Vin(V)	Vout		Peak Time	
		(PSO)	(FLC)	PSO Tuned FLC (sec)	FLC (sec)
1	5.00	14.7324	14.421	0.6227	1.5073
2	7.00	14.7244	14.3767	0.5968	1.0429
3	9.00	14.7167	14.37	0.5439	1.0219
4	11.00	14.6872	14.4044	0.4376	0.7959
5	13.00	14.6612	14.3624	0.3694	0.6658
6	15.00	14.6353	14.3069	0.3237	1.4698
7	17.00	14.6226	14.3463	0.2814	1.2781
8	19.00	14.6189	14.2502	0.2515	1.1325
9	21.00	14.6041	14.3838	0.2271	0.2046
10	23.00	14.5961	14.2356	0.2071	0.933

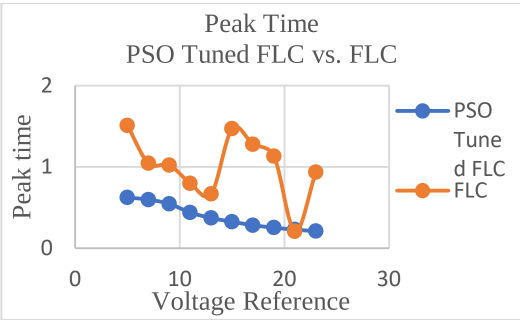

Fig 6: Peak time

3.4. Rise Time

Table 5 and Figure 7 show most values of the untuned FLC are greater than 1 second while the PSO tuned FLC has values much lesser than 1 second. The untuned FLC gave rise time between 0.4814s and 1.3563s while the PSO tuned FLC was between 0.1907s and 0.5515s.

Table 5: Rise time

TRIAL	Vin(V)	Vout		Rise Time	
		(PSO)	(FLC)	PSO Tuned FLC (sec)	FLC (sec)
1	5.00	14.7324	14.421	0.5515	1.3363
2	7.00	14.7244	14.3767	0.5456	0.9608
3	9.00	14.7167	14.37	0.5038	0.9579
4	11.00	14.6872	14.4044	0.4047	0.7433
5	13.00	14.6612	14.3624	0.3414	0.6231
6	15.00	14.6353	14.3069	0.2993	1.3563
7	17.00	14.6226	14.3463	0.2597	1.1776
8	19.00	14.6189	14.2502	0.232	1.0429
9	21.00	14.6041	14.3838	0.2093	0.4814
10	23.00	14.5961	14.2356	0.1907	0.8589

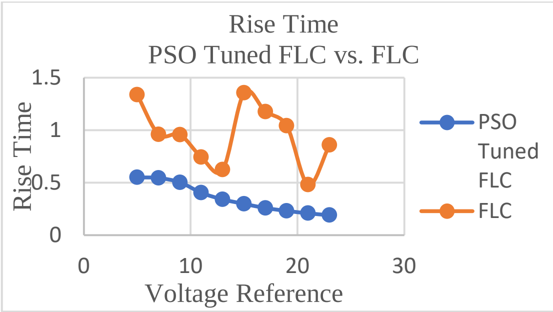

Fig 7: Rise time

3.5. Settling Time

Table 6 and Figure 8 show that almost all the settling time values of the untuned FLC were more than 1.7s while the PSO tuned FLC did not go up more than 1.4s. This shows that the PSO tuned FLC has a significantly better settling time rather than that of the untuned FLC.

Table 6: Settling time

TRIAL	Vin(V)	Vout		Settling Time	
		(PSO)	(FLC)	PSO Tuned FLC (sec)	FLC (sec)
1	5.00	14.7324	14.421	1.3098	2.271
2	7.00	14.7244	14.3767	1.2548	1.9748
3	9.00	14.7167	14.37	1.2378	2.2877
4	11.00	14.6872	14.4044	1.1326	1.7477
5	13.00	14.6612	14.3624	1.1261	2.5048
6	15.00	14.6353	14.3069	1.0456	2.3946
7	17.00	14.6226	14.3463	1.0018	2.0567
8	19.00	14.6189	14.2502	0.9771	2.6176
9	21.00	14.6041	14.3838	0.9472	0.6327
10	23.00	14.5961	14.2356	0.935	1.9005

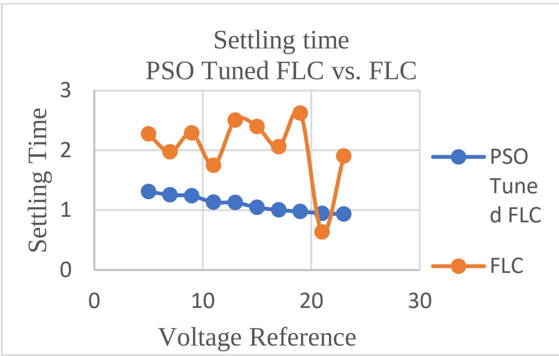

Fig 8: Settling time

3.6. T-Test

To determine any significant difference between Tuned FLC and without tuning, a T-test was performed. The null hypothesis will be rejected, and the alternative hypothesis will be accepted if the $P \leq 0.05$. The rejected null hypothesis in this study denotes a significant difference between the PSO tuned FLC and the FLC without PSO tuning. The results of the statistical analysis are summarized in Table 7 below.

Table 7: T-test result for comparison between the peak overshoot ratio, voltage deviation ratio, peak time, rise time, and settling time.

Test	Null Hypothesis	Target p-value	Resulting p-value	Remarks
1	There is no significant difference between the Peak overshoot ratio of the PSO tuned and FLC only.	0.05	0.054468924	There is no significant difference between the peak overshoot ratio of PSO tuned and untuned FLC.
2	There is no significant difference between the voltage deviation ratio of the PSO tuned and FLC only.	0.05	0.019745728	There is a significant difference between the voltage deviation ratio of PSO tuned and untuned FLC.
3	There is no significant difference between the peak time of the PSO tuned and FLC only.	0.05	0.000461545	There is a significant difference between the peak time of PSO tuned and untuned FLC.
4	There is no significant difference between the rise time of the PSO tuned and FLC only.	0.05	9.03782E-05	There is a significant difference between the rise time of PSO tuned and untuned FLC.
5	There is no significant difference between the settling time of the PSO tuned and FLC only.	0.05	0.000362158	There is a significant difference between the settling time of PSO tuned and untuned FLC.

4. Conclusion

This study successfully developed a PSO-tuned FLC-controlled buck-boost converter. The fuzzy controller has been successfully integrated into the buck-boost converter using MATLAB/Simulink. PSO algorithm was successfully encoded in MATLAB to tune the FLC. The input MF of the FLC was successfully tuned by PSO and was able to give a mean difference of 1.0065 in peak overshoot ratio, 1.0841 voltage deviation ratio, 0.3861s in peak time, 0.3538s in rise time, and 1.0968s in settling time. Statistically, it was proven that the PSO tuned FLC gave a significantly lower value than that of the untuned FLC in terms of voltage deviation ratio, peak time, rise time, and settling time but no significant difference in terms of peak overshoot ratio.

5. Recommendation

Implementation of the PSO tuned FLC controlled buck-boost system in real-time could be considered in a future study. The optimization of the fuzzy rules, additional membership function, and use of different defuzzification techniques to further improve the performance of an FLC-controlled buck-boost converter could also be studied.

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7. References

[1] Wahab, W. (2017) Design and Simulation of an Output Voltage Controller for Solar Power (PV) Application Using Fuzzy Logic Controller. 2017 15th International Conference on Quality in Research: International Symposium on Electrical and Computer Engineering

[2] Ang, G., Arcibal P. J., Crisostomo L. M., et al. (2017). Implementation of a fuzzy controlled buck-boost converter for photovoltaic systems.

[3] Sundareswaran, K., K. Kuruvinashetti and P.S. Nayak (2014). Application of Particle Swarm Optimization for output voltage regulation of dual input buck-boost converter. 2014 ICGCCEE.

[4] [Abdillah M., Asy'ari M. K., Musfaya A., et al. (2020). Design and Implemented Buck-Boost Converter Based Fuzzy Logic Control on Wind Power Plant

[5] Akyazı O. (2017). PSO Based Fuzzy Logic Control Design for a DC/DC Boost Converter.

doi:10.22531/muglajsci.272730

[6] S. Maity et al., "Performance Analysis of Fuzzy Logic Controlled DC-DC Converters," 2019 International Conference on Communication and Signal Processing (ICCSP), 2019, pp. 0165-0171, doi: 10.1109/ICCSP.2019.8698113.

[7] N. Sa-ngawong and I. Ngamroo, "PSO-based Sugeno fuzzy logic controller of photovoltaic generator for frequency stabilization in stand-alone power system," 2013 IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2013, pp. 1-6, doi: 10.1109/APPEEC.2013.6837242.

[8] Sharma J. and Singhal R. S. (2015). Comparative Research on Genetic Algorithm, Particle Swarm Optimization and Hybrid GA-PSO. 2015 2nd International Conference on Computing for Sustainable Global Development (INDIACom), 2015, pp. 110-114.

[9] Harikrishna Y., Lecture Notes on Control System. 2021 https://www.scribd.com/document/421939281/CS

[10] Yudong Zhang, Shuihua Wang, Genlin Ji, "A Comprehensive Survey on Particle Swarm Optimization Algorithm and Its Applications", Mathematical Problems in Engineering, vol. 2015, Article ID 931256, 38 pages, 2015. https://doi.org/10.1155/2015/931256

[11] G. Zhang, K. Yang, P. Liu, E. Ding, and Y. Zhong, "Joint Channel Bandwidth and Power Allocation Game for Selfish Cooperative Relaying Networks," in IEEE Transactions on Vehicular Technology, vol. 61, no. 9, pp. 4142-4156, Nov. 2012, doi: 10.1109/TVT.2012.2211389.