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A Comprehensive Simulation and Comparative Analysis of PI and Fuzzy Logic Controllers for Buck Converter-Driven PMDC Motors

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Abstract—Permanent Magnet Direct Current (PMDC) machines are heavily utilized across the modern industrial landscape, largely favoured for their exceptional torque linearity and mechanical dependability in automation and robotic assemblies. However, ensuring stable velocity regulation when exposed to sudden dynamic load shifts remains a critical engineering challenge. This manuscript delivers an extensive comparative assessment of a PMDC motor driven by a DC-DC buck chopper, evaluating two distinctly divergent regulatory paradigms: a traditional Proportional-Integral (PI) feedback loop and an intelligent Fuzzy Logic Controller (FLC). Utilizing the MATLAB/Simulink environment for rigorous parametrization and waveform analysis, the empirical evidence demonstrates that linguistic rule-based control successfully neutralizes the severe transient oscillations and current surges inherent to rigid PI algorithms. Ultimately, the FLC provides a critically damped, accelerated, and structurally secure response, proving vastly superior for non-linear electromechanical drives.

Index Terms—PMDC Motors, DC-DC Buck Converter, Proportional Integral (PI) Control, Fuzzy Logic Controller (FLC), MATLAB/Simulink, Electromechanical Transients.

I. INTRODUCTION AND THEORETICAL BACKGROUND

The historical transition within industrial electromechanical systems has been fundamentally driven by the need to eradicate the immense thermal dissipation associated with primitive rheostats and linear voltage regulators [5], [7]. Contemporary industrial frameworks demand maximized electrical efficiency, instantaneous dynamic correction, and formidable starting torque [9].

To overcome legacy hardware constraints, semiconductorbased solid-state switching—primarily utilizing Pulse Width Modulation (PWM) topologies—was adopted, completely replacing resistance-based regulation [1]. When integrated with modern solid-state conversion units, PMDC configurations offer unmatched operational advantages, ensuring strict torqueto-speed linearity, rapid mechanical acceleration, and highly predictable steady-state functionality [10].

Despite these mechanical advantages, conventional PI controllers—which govern the vast majority of industrial drives—are mathematically rigid. They depend entirely on linear transfer functions, causing them to falter and produce dangerous transients when exposed to unpredictable load variations or parametric uncertainties [3]. This research presents a comprehensive evaluation of startup stabilization times, armature current inrush, and torque surges, explicitly contrasting traditional PI tracking against an advanced linguistic Fuzzy Logic Controller (FLC).

II. SYSTEM ARCHITECTURE AND PARAMETRIZATION

A highly resilient PMDC setup requires the precise modulation of continuous armature voltage via high-frequency PWM switching [8]. The proposed topology harnesses a primary DC source to energize a step-down buck converter, which passes the filtered energy to an H-Bridge chopper array to dictate motor operation.

A. PMDC Motor Mathematical Dynamics

The dynamic voltage balance and mechanical rotational physics are mathematically expressed by the following differential equations:

(1)
$$V_a = E_b + I_a R_a + L_a \frac{dI_a}{dt}$$

(2)
$$T_e = J\frac{d\omega}{dt} + B\omega + T_L$$

Here, the generated electromagnetic torque is $T_e = K_t I_a$ and the opposing back-electromotive force is $E_b = K_e \omega$.

The PMDC machine utilized in this simulation operates at a rated voltage of 24 V, a mechanical speed of 3000 RPM, a rated load torque of 1 Nm, and a nominal armature current of 4 A. The angular velocity (ω) translates to 314.16 rad/s, establishing a Back EMF constant (K_e) of 0.076 V/rad/s.

To guarantee that the motor generates the required 1 Nm torque at 4 A, the Torque Constant (K_t) is empirically tuned to 0.25 Nm/A. Further electrical parameters designed to maintain simulation fidelity include an armature resistance (R_a) of 0.05 Ω. Additional mechanical and inductive constants include an inductance of $L_a = 2$ mH, a rotor inertia of $J = 0.002$ kg · m^2, and a viscous friction coefficient of $B = 0.0002$.

TABLE I
FINAL PMDC MOTOR PARAMETERS FOR SIMULINK

Parameter	Value
Armature resistance (R_a)	0.05Ω
Armature inductance (L_a)	2 mH
Torque constant (K_t)	0.25 Nm/A
Back EMF constant (K_e)	0.076 V/(rad/s)

Rotor inertia (J)	0.002 kg · m^2
Friction coefficient (B)	0.0002

TABLE II
SIMULATED LOAD CONDITIONS (T_L)

Load Torque (T_L)	Condition Meaning
0 Nm	No load condition
0.5 Nm	Half load
1 Nm	Rated load
1.5 Nm	Overload

B. DC-DC Buck Converter Specifications

The selected DC-DC conversion unit operates as a stepdown Buck chopper in Continuous Conduction Mode (CCM) [1]. Converting an input of 36 V (V_{in}) down to the necessary 24 V (V_{out}) requires an operational duty cycle (D) computed via:

$$D = \frac{V_{out}}{V_{in}} = \frac{24}{36} \approx 0.67 \text{ (or 67\%)} \quad (3)$$

Assuming a high-frequency switching parameter of $f_s = 20$ kHz and a permitted inductor ripple current (ΔI_L) representing 30% of the 4 A load (1.2 A), the essential critical inductance (L) is calculated:

$$L = \frac{(V_{in} - V_{out}) \cdot D}{\Delta I_L \cdot f_s} = \frac{(36 - 24) \times 0.67}{1.2 \times 20000} \approx 335 \ \mu H \quad (4)$$

A standard commercial inductor rated at 330 μH is integrated into the model.

To strictly maintain a 1% peak-to-peak output voltage ripple ($\Delta V_c = 0.01 \times 24 = 0.24$ V), the smoothing capacitor (C) is calculated:

$$C = \frac{\Delta I_L}{8 \cdot f_s \cdot \Delta V_c} = \frac{1.2}{8 \times 20000 \times 0.24} \approx 31.25 \ \mu F \quad (5)$$

To ensure robust filtering capabilities, a highly practical 68 μF capacitor (falling within the typical 47–100 μF range) is utilized for the physical simulation.

TABLE III
FINAL BUCK CONVERTER DESIGN FOR SIMULATION

Parameter	Value
Input voltage (V_{in})	36 V
Output voltage (V_{out})	24 V
Duty cycle (D)	0.67
Switching frequency (f_s)	20 kHz
Inductor (L)	330 μH
Capacitor (C)	68 μF
Motor rated current	4 A

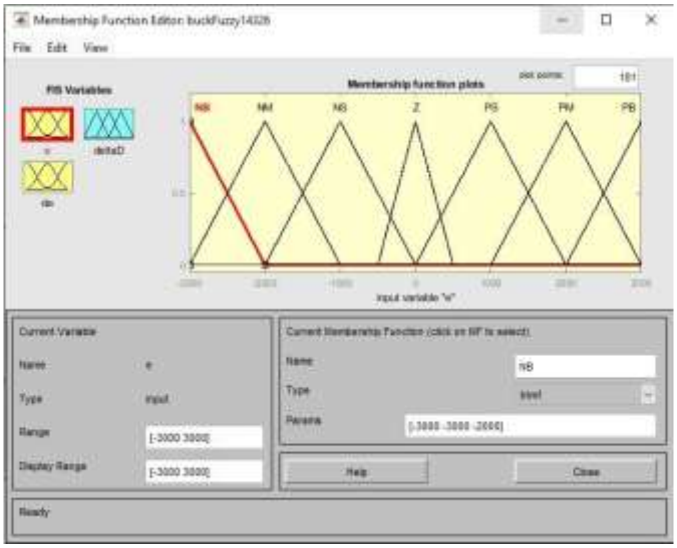
III. REGULATORY METHODOLOGIES

A. Proportional-Integral (PI) Feedback Loop

The functional premise of the standard PI mechanism revolves around isolating velocity discrepancies by contrasting a predefined setpoint against the real-time angular velocity. The resulting error dictates the corrective action based on linear gains. For this framework, exhaustive manual tuning isolated an optimal proportional gain (K_p) of 0.9 and an integral gain (K_i) of 0.001. Unfortunately, the linear mathematical constraints of PI frameworks inherently limit their ability to suppress non-linear dynamic spikes [3].

B. Intelligent Fuzzy Logic Control (FLC) Paradigm

Representing a significant evolutionary leap beyond rigid Boolean tracking, the FLC paradigm processes dynamic data through fluid, condition-based linguistic rules, successfully mimicking human cognitive adaptability [6]. The system processes two fundamental variables: Speed Error (E) and Change in Error (ΔE). As illustrated in Fig. 2, these numerical inputs undergo a fuzzification process where they are mapped onto overlapping triangular membership functions, categorizing them into distinct linguistic descriptors (such as Negative Big, Zero, Positive Small, etc.).



Current Variable
Name e
Type input
Range [-3000 3000]
Display Range [-3000 3000]

Current Membership Function (click on MF to select)
Name NB
Type trimf
Params [-3000 -3000 -2000]

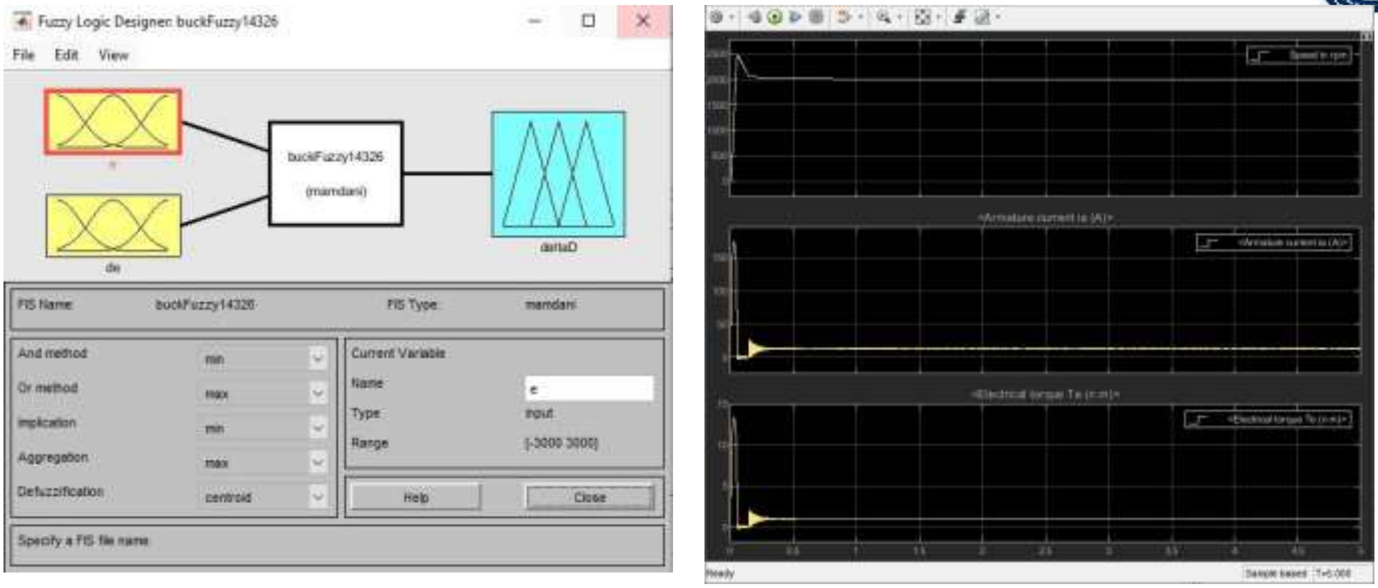
Ready

Fig. 1. Mamdani inference surface and rule viewer demonstrating the nonlinear operational mapping of the FLC.

Once fuzzified, the inference engine subjects these linguistic states to a meticulously formulated 49-rule base. This multidimensional rule mapping, visualized in the surface logic ensures that any combination of error vectors generates a highly optimized, non-linear corrective response. Finally, the centroid defuzzification method translates these conclusions back into precise PWM duty cycles [12].

IV. SIMULINK IMPLEMENTATION AND COMPARATIVE ANALYSIS

To empirically validate the theoretical discrepancies between the two control architectures, complete closed-loop sys-



FIS Name: buckFuzzy14326
FIS Type: mamdani
And method: min
Or method: max
Implication: min
Aggregation: max
Defuzzification: centroid
Current Variable
Name: e
Type: input
Range: [-3000 3000]
Specify a FIS file name

Fig. 2. Fuzzification phase: Triangular membership functions configured for the FLC inputs (Error and Change in Error)

tems were constructed within the MATLAB/Simulink ecosystem.

A. Baseline Evaluation: PI Controller Dynamics

The primary power stage incorporates the 36 V DC source, the 330 µH inductor, and the 68 µF smoothing capacitor. Fig. 3 delineates the complete internal architecture of the PI-regulated drive, highlighting the interconnected LC filter and the error-driven feedback loop governing the PWM pulse generator.

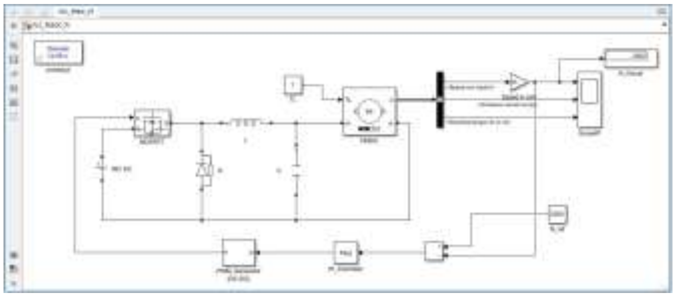
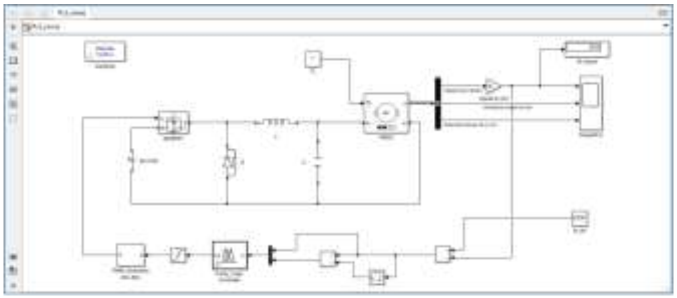


Fig. 3. Complete Simulink architecture of the Buck Converter-fed PMDC motor utilizing a Proportional-Integral (PI) control loop.

To execute the comparative trial, the traditional mathematical PI block was entirely removed and substituted with the Mamdani FLC module. As depicted in Fig. 5, all physical power stage parameters were kept strictly identical to guarantee absolute testing integrity.



The resulting oscilloscope outputs, captured in Fig. 4, lay bare the extreme transient vulnerabilities of traditional linear regulation. The uppermost waveform illustrates a drastically underdamped velocity profile. The motor violently accelerates past the target reference to a peak overshoot, requiring approximately 0.35 to 0.40 seconds to fully decay into a stable steady state.

Furthermore, the unoptimized linear response triggers massive, instantaneous current demands. The armature experiences a catastrophic inrush current peaking at ∼ 170 A. Consequently, this extreme current surge propagates directly into

Fig. 4. Dynamic waveform outputs under standard PI regulation, detailing speed, armature current, and electrical torque transients.

the mechanical domain, subjecting the rotor shaft to violent electromagnetic torque spikes peaking at ~ 13 Nm. Notably, visible chattering and ripple persist in both the current and torque signals until the controller finally smooths out near the 0.40-second mark, which drastically degrades the operational lifespan of motor linkages.

B. Optimization via Fuzzy Logic Controller (FLC)

Fig. 5. Modified Simulink architecture featuring the integrated Fuzzy Logic Controller (FLC) replacing the conventional PI block

The empirical results generated by the linguistic controller are profoundly superior. As shown in the waveforms in Fig. 6, while the speed initially hits a similar peak overshoot of around 2400 rpm, the curve then decisively and smoothly drops down to the steady-state target of 2000 rpm, completely flattening out between 0.20 and 0.25 seconds.

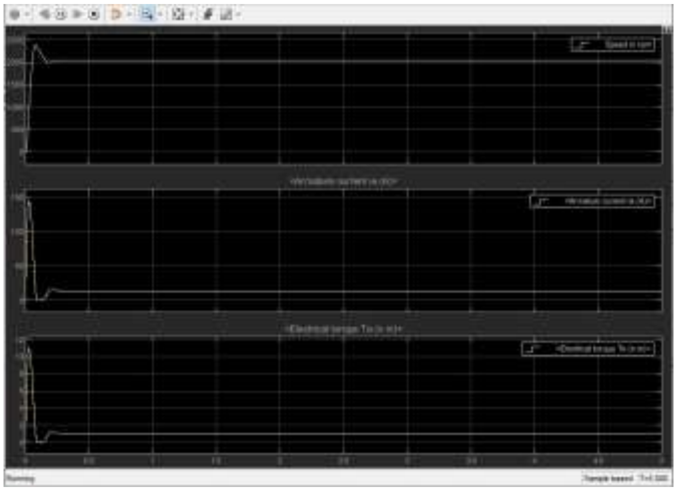


Fig. 6. Dynamic waveform outputs under FLC regulation, demonstrating critically damped speed response and suppressed current/torque transients.

Crucially, the FLC’s conditional logic anticipates the reference target and throttles the voltage appropriately, heavily restricting the peak armature current surge to approximately 145 A. As a direct result, the maximum electrical torque stress is safely mitigated to approximately 11 Nm. The FLC provides a highly damped, smooth transient response with virtually no persistent ripple.

C. Performance Data Synthesis

Table IV provides a synthesized numerical comparison of both methodologies based on the generated outputs. The FLC methodology definitively outperforms the linear PI feedback approach across all measurable transient dimensions.

TABLE IV
SYNTHESIZED EMPIRICAL DATA COMPARISON

Parameter	FLC (Fuzzy Logic)	PI (Proportional-Integral)
Settling Time	~ 0.25 seconds	~ 0.40 seconds
Peak Current (i_a)	~ 145 A	~ 170 A
Peak Torque (T_e)	~ 11 Nm	~ 13 Nm
Transient Behavior	Smooth, rapid settling	Noticeable ripple/chattering

V. CONCLUSION

This extensive simulation of a chopper-fed PMDC drive definitively exposes the severe operational deficiencies inherent to traditional PI control logic. Constrained by rigid mathematical linearity, the manually tuned PI controller ($K_p = 0.9$, $K_i = 0.001$) consistently struggles to manage startup electromechanical transients, yielding an underdamped velocity profile burdened by a sluggish ~ 0.40s stabilization period. The resulting ~ 170 A inrush currents induce extreme mechanical stress, exposing the physical system to ~ 13 Nm torque spikes accompanied by noticeable chattering.

Conversely, the deployment of a 49-rule Mamdani Fuzzy
Logic Controller safely accelerated the stabilization sequence to an impressive ~ 0.20 to 0.25 seconds. By actively throttling the initial current surge to a manageable ~ 145 A and capping the torque spikes at ~ 11 Nm, the FLC guarantees a highly resilient, critically damped, and structurally secure mechanical response that exhibits virtually no ripple—unequivocally cementing its superiority over conventional industrial control mechanisms.

REFERENCES

[1] K. Yao, Y. Qui, M. Xu, and F. C. Lee, "A novel winding-coupled Buck Converter for high frequency, High-step-down DC-DC conversion," IEEE Transactions on Power Electronics, Vol. 2, 2005.

[2] V. Sudha and M. Nandhini Gayathri, "Simulation of Buck Converter fed PMDC drive using PI and Fuzzy Logic Controllers," International Journal of Applied Engineering Research, vol. 10, no. 17, pp. 37566– 37570, 2015.

[3] S. Assly Steffy, B. Mangaiyarkarasi, S. Sherin Jasper, K. Priyanka, and K. Soorya, "Analysis and Simulation of speed control of PMDC motor by PI controller," International Journal of Advanced Research in Computer and Communication Engineering, Vol. 3, Issue 2, 2014.

[4] B. Mahesh kumar, G. Ravi, and R. Chakrabarti, "Sensorless speed control of Permanent Magnet Direct Current motor with Fuzzy based Estimation," Iranian Journal of Electrical & Computer Engg., vol. 8 No.2, 2009.

[5] M. H. Rashid, Power Electronics Handbook, 2nd ed. Burlington, MA, USA: Elsevier, 2007.

[6] T. J. Ross, Fuzzy Logic with Engineering Applications, 3rd ed. West Sussex, U.K.: John Wiley & Sons, 2010.

[7] P. C. Sen, Principles of Electric Machines and Power Electronics, 3rd ed. Hoboken, NJ, USA: John Wiley & Sons, 2013.

[8] S. Prakash and R. Dhanasekaran, "Interleaved buck converter fed PMDC drive system," International Journal of Technology and Engineering Science, Vol. 1(6), 2013.

[9] C. L. Xia, Permanent Magnet Direct Current Motor Drives and Controls, 1st ed. Beijing, China: Wiley Press, 2012.

[10] C. L. Xia, "Mathematical Model and Characteristics Analysis of the PMDC Motor," in Permanent Magnet Direct Current Motor Drives and Controls, 1st ed. Hoboken, NJ, USA: Wiley, 2012, ch. 2, pp. 25–62.

[11] A. K. Dewangan, S. Shukla, and V. Yadu, "Speed Control of a Separately Excited DC Motor Using Fuzzy Logic Control Based on Matlab Simulation Program," International Journal of Scientific & Technology Research, Vol. 1, Issue 2, 2012.

[12] J. Chakravorty and R. Sharma, "Fuzzy Logic Based Method of Speed Control of DC Motor," International Journal of Emerging Technology and Advanced Engineering, Vol. 3, Issue 4, 2013.

[13] L. Janpana, R. Chaisricharoenb, and P. Boonyananta, "Control of the PMDC Motor in Combine Mode," ELSEVIER, 2012.