STM JOURNALS

International Journal of
Electrical Power and Machine Systems

Volume 2, Issue 1, 2024
January—June
DOI (Journal): 10.37591/IJEPMS

https://journals.stmjournals.com/ijepms

Review IJEPMS

Beyond Binary: A Holistic Exploration of Fuzzy Logic Systems in Control Theory–An Extensive Review and Future Directions

Ancy A.S.[1], Farsana Muhammed[2,*]

Abstract

Nowadays, nonrenewable energy or conventional energy sources are reduced due to the increased usage of energy for several purposes. Renewable energy sources are introduced for replacing these. Several methods are used for the storage and distribution of energy. One of the techniques is fuzzy logic control. In this paper we discuss the usage of energy and fuzzy logic system usage and its applications. This paper also discusses the reviews of these methods and their limitations. With the use of integrated renewable energy, the fuzzy logic control for battery storage and distribution generation also focuses on microgrid management. In this article, a microgrid with dispatchable distributed generation units is modeled. This study tests a fuzzy logic control method using DIgSILENT/PowerFactory simulations. Fuzzy logic is used in a number of controllers because it does not require an accurate model of the system to be controlled. Fuzzy logic works by executing rules that correlate the controller inputs with the desired outputs. This paper's focus is on the controller application in photovoltaics and renewable sources.

Keywords: Distributed generation (DG) units, battery storage, fuzzy logic, multi-agent, disturbance observer (DOB)

INTRODUCTION

Need of energy is increasing day by day so that the usable sources are also limited. For managing this problem, renewable energy sources like wind, solar, etc. are to be relied upon. For controlling this energy and minimizing the usage, we need a controller and for that a fuzzy logic system and control is introduced. Other than this there are several methods such as multi-agent system, teaching learning based optimization (TLBO) algorithm, etc. Fuzzy logic controller showed faster response and better performance. Self-adaptive virtual inertia control using fuzzy logic for microgrid stability has been proposed to enhance the frequency stability under high renewable energy penetration and disturbances. The fuzzy logic control for battery storage and about distribution generation (DG) also focus on microgrid management system with the help of renewable energy integration. This describes the modeling of a microgrid with dispatchable DG units. Fuzzy logic control strategy is tested with DIgSILENT/PowerFactory simulations in this paper. Detailed modeling of DG unit is explained. Battery energy storage system (BESS) and dispatchable DGs are tested. The BESS control system is shown in Figure 1 [1–4].

As a result, it enhances the microgrid management with efficient control strategies. The

***Author for Correspondence**
Farsana Muhammed
E-mail: farsanamuhammed217@gmail.com

[1]MTech Scholar, Department of Electrical and Electronics Engineering, Thangal Kunju Musaliar College of Engineering, Kerala, India
[2]Assistant Professor, Department of Electrical and Electronics Engineering, Thangal Kunju Musaliar College of Engineering (TKMCE), Kerala, India

Received Date: May 02, 2024
Accepted Date: June 04, 2024
Published Date: June 20, 2024

Citation: Ancy A.S., Farsana Muhammed. Beyond Binary: A Holistic Exploration of Fuzzy Logic Systems in Control Theory–An Extensive Review and Future Directions. International Journal of Electrical Power and Machine Systems. 2024; 2(1): 8–13p.

© STM Journals 2024. All Rights Reserved

adaptive fuzzy dynamic control for multi-machine power systems is discussed. Different types of learning methods are used. Literature focuses on the adaptive fuzzy dynamic surface control and the use of composite learning and disturbance observer. The previous design only focuses on the system tracking performance and the proposed strategy enhances fuzzy logic systems' (FLSs) approximation ability for power systems. These strategies very effectively suppress disturbances and enhance robustness and the experimental results validate the effectiveness of the proposed control algorithm [5].

A scheme for voltage control in power systems utilizes decentralized control, partitioning, multi-agent systems, and fuzzy logic. Several methods are used, for example, decentralization control, multi-agent system, fuzzy logic, and TLBO algorithm. These systems enhance the system performance, reliability and stabilize power system and fuzzy control methods have operational speed limitations. Load shedding is the last resort to stabilize power systems and multi-agent systems enhance system performance and reliability. Proposed algorithm for voltage control is shown in Figure 2.

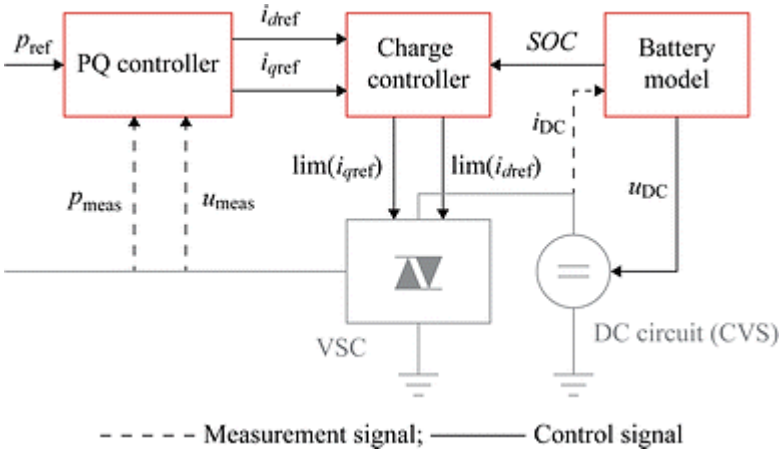

Figure 1. Battery energy storage system (BESS) control system.

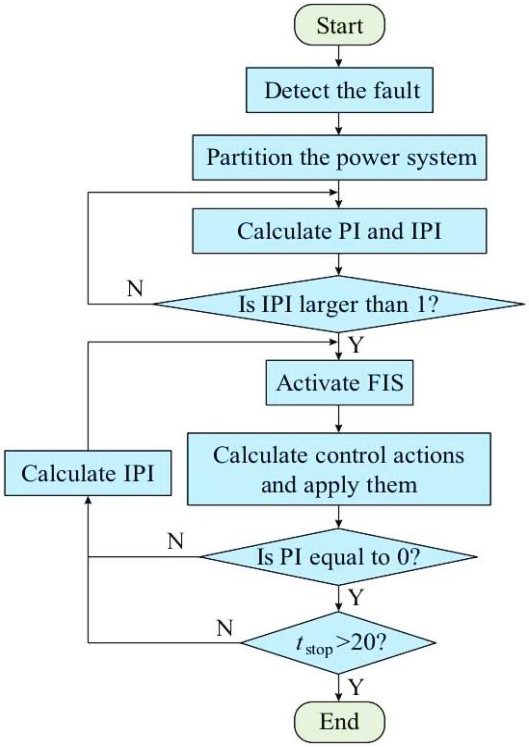

Figure 2. Proposed algorithm for voltage control.

© STM Journals 2024. All Rights Reserved

One degree-of-freedom (1 DOF) power assist device with fuzzy PID (proportional integral derivative) speed regulator. When it comes to control approaches and human-robot cooperation intuitiveness. Adaptive strategy in the control system design is used for handling object efficiency. A power assist device with fuzzy PID speed regulator for lifting was developed and the fuzzy logic controller showed faster response and better performance. Methods used are conventional PID controller, fuzzy logic control for velocity control, and admittance control loop with PD controller. Limitations faced are the nonlinear system challenges and that the fuzzy logic controller has bigger ripples in current output. Results are as follows: Fuzzy logic controller showed similar performance to the Maxon controller and fuzzy logic controller yielded faster velocity rise and reduced settling time implications control strategy for flame retardant (FR) of BESSs which utilizes fuzzy logic and hierarchical controllers to optimize FR and lifespan and battery energy storage system, these controllers are used for FR effectiveness. Methods used are fuzzy logic controller and hierarchical controllers for BESS management and ACE signal state, Strategy balances frequency regulation effect and operational economy of BESS. Rapid cycle of BESS that shortens lifetime is the main limitation in this system. Results suggest avoidance of repeated charging/discharging of BESS through hierarchical control. Reduction in ACE deviation ranges by at least 39 and 34.7 and optimal depth of discharge (DOD) of BESS is 0.39, with a throughput threshold range [6–8].

ADVANCED FUZZY LOGIC CONTROL

Advanced fuzzy-logic-based control for HVAC (heating, ventilation, air conditioning) management systems have been reported. Mathematical model is not needed to control Lambda method and Lambda controller outperforms other approaches in HVAC system regulation. Block diagram of HVAC system is shown in Figure 3.

Several methods are used, for example, LAMDA, PID controller, gain scheduling, LQ, linear quadratic gaussian (LQG), model predictive control (MPC), fuzzy logic and the results from this is LAMDA-PI controller yielded lowest integral of absolute value of error (IAE) values in HVAC system tests and LAMDA control outperformed PI and conventional fuzzy-PI controllers in regulation tasks but from the literature static model and hybrid model are used for the optimization. Frequency stability in microgrids is done with high renewable penetration, elf-adaptive virtual inertia control system using fuzzy logic. It addresses challenges in maintaining frequency stability with high renewable energy resource (RES) penetration and emphasizes the importance of dynamic stability and control strategies. For enhanced frequency stability under high renewable energy penetration and disturbances, the methods used are three main control processes: primary, secondary, and inertia control. Self-adaptive virtual inertia control-based fuzzy logic is proposed for frequency stability. Literature states that existing virtual inertia control methods have fixed virtual inertia constant values. Self-adaptive virtual inertia control techniques are proposed to address stability problems, proposed fuzzy logic-based virtual inertia control enhances frequency stability under disturbances. Results implies that proposed method shows remarkable performance in transient response improvement. Fast damping of oscillations and preservation of robust operation is demonstrated [9, 10].

This study focuses on detecting false data injection attacks in power systems. Method combines fuzzy logic and neural networks for efficient attack detection, Simulation scenarios with or without renewable energy generation are presented. A comparison of accuracy of three methods for detecting various False Data Injection Attacks (FDIAs) is given. Literature survey focuses on detecting false data injection attacks in power systems, utilizes fuzzy logic and neural networks for efficient attack detection and analyzes the impact of various FDIAs on multi-area LFC systems. Simulation scenarios show detection performance with renewable energy generation, and frequency deviations are analyzed under different attacks on the LFC system.

This paper discusses challenges in designing photovoltaics (PV)-based inverters and fuzzy logic controllers. It reviews fuzzy logic inverter controller system for PV applications and highlights the importance of alternative energy sources like solar PVs.

© STM Journals 2024. All Rights Reserved

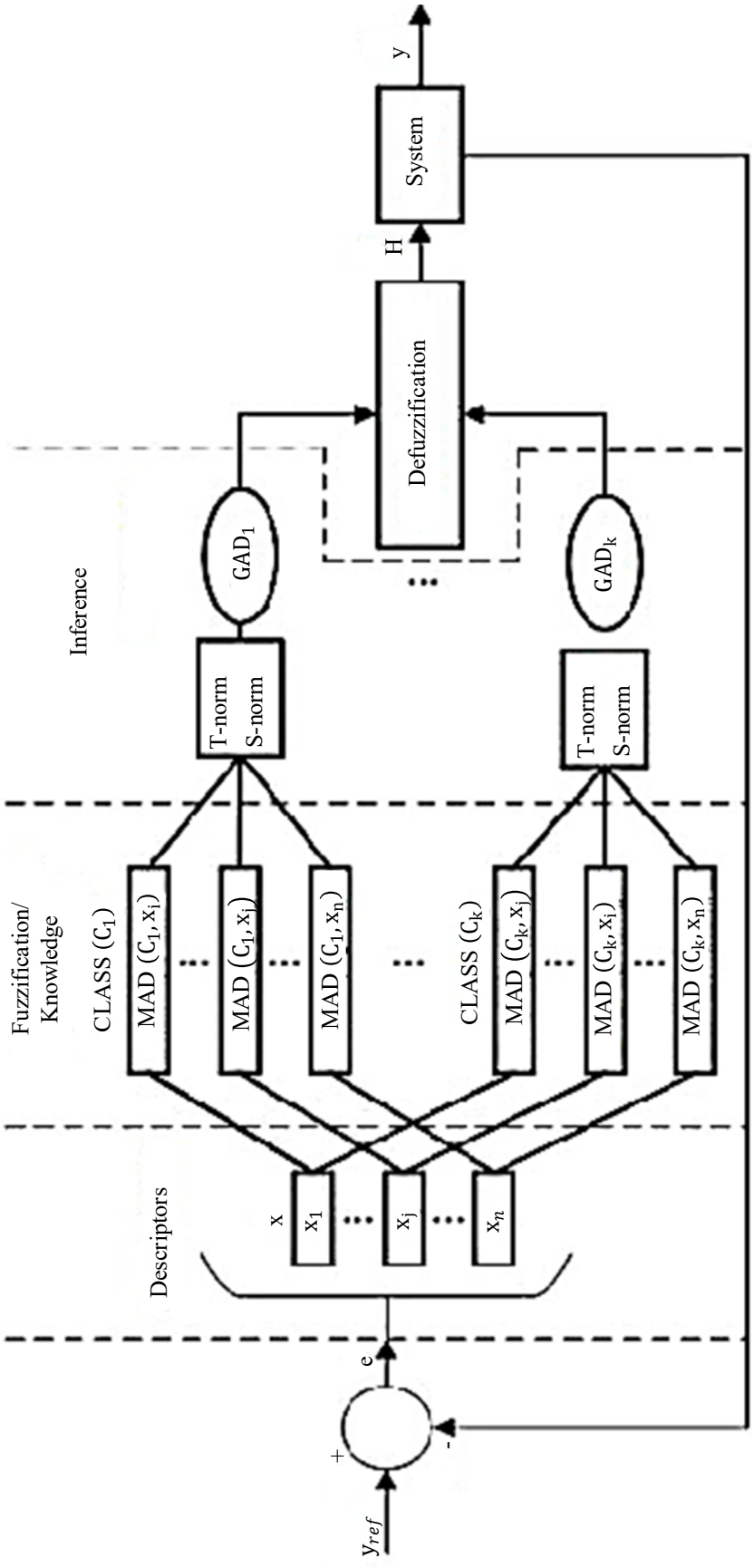

Figure 3. Block diagram of HVAC (heating, ventilation, air conditioning) system.

Different methods are used: first is fuzzy logic controller (FLC) with different control algorithms and the second is artificial intelligence (AI) control methods like artificial neural network (ANN), space vector pulse width modulation (SVPWM), and Direct Torque Control (DTC). Literature of this paper reviews fuzzy logic inverter controller system for PV applications, and it discusses FLC, inverter control algorithms, switching techniques, and challenges. It highlights FLC's design, computation, learning system, and control algorithm combinations. The study emphasizes the need for further research on inverter control systems. Fuzzy logic controllers are effective for PV inverter control systems and recommendations for designing efficient inverter control systems for PV applications are the results in this paper. It addresses issues like output harmonics, power factor, and switching schemes, which are practical implications. A novel method using interval type-3 fuzzy logic for solar energy management is presented. Robust methods for power control in PV/battery hybrid systems methods used are interval type-3 fuzzy logic systems with online learning approach and boost converters for switching between energy storage systems and PV panels. Literature survey compares proposed method with existing techniques under challenging conditions, discusses control methods for managing power extraction and load regulation. Results indicate that proposed method shows high performance under varying conditions and superior regulation performance compared to other controllers [4].

PRACTICAL IMPLEMENTATIONS

Decentralized voltage control method enhances power system performance, reduces number of control actions which is economically significant one, faster than centralized methods, decentralized control approach etc. Fuzzy PID speed regulator shows improved response time and enhanced control system performance for lifting object, along with faster velocity rise and reduced settling time. Implication proposes LAMDA for HVAC control in buildings, outperforming conventional controllers. LAMDA supports knowledge extraction and control decision-making in HVAC systems. LAMDA controller identifies system states and drives them to target states. The proposed fuzzy logic-based control adjusts virtual inertia for system stability, reduces frequency oscillations and improves system robustness. It enhances security of power systems by reducing damage and power loss and combines fuzzy logic and neural networks for robust detection. It enhances power control and battery charge planning for PV systems. Furthermore, the control shows high performance under challenging conditions like temperature variations and provides stability analysis using Lyapunov/LaSalle's theorems.

ADVANTAGES AND DISADVANTAGES

Comparison of Advantages and disadvantages with respect to methods used is shown in Table 1.

Table 1. Methods used and their advantages and disadvantages.

Method used	Advantage	Disadvantage
Fuzzy logic system, hierarchical controller	● Battery storage and generation ● Enhance performance, security, frequency	● Sensitive ● Short life time ● Less efficiency
Disturbance observer (DOB), artificial intelligence	● Efficient ● Effective	● Does not explicity ● Time consuming
Multi-agent system, TLBO algorithm	● Enhanced performance ● Stability	● Complex methods
Conventional PID controller, PD controller, self-adaptive	● Lightweight ● Human robotic cooperation	● May have ripples in output
Boost converter	● Manage power extraction and load regulation	● No specific limitations

CONCLUSIONS

There are several methods used in this paper, some of which are fuzzy logic controller, PID, PD, boost converter, and AI etc. From this paper some of these techniques are efficient and some technique need more efficiency. Light weight and cost-effective techniques are more reliable and some of the systems provide security to the system also. Fuzzy logic system and its controllers are more precise and

© STM Journals 2024. All Rights Reserved

some of the applications do not need any mathematical model. Power and load regulation can be included in this system. Application areas are fuel efficiency, environmental impact, robotics, and fuel efficiency in engine, etc.

Acknowledgments

I would like to express our sincere gratitude to all those who contributed to the completion of this review paper. Firstly, I extend our heartfelt appreciation to the authors of the primary studies we analyzed, whose research laid the foundation for our work. I am also grateful to the reviewers and editors whose insightful comments and suggestions significantly improved the quality and clarity of this manuscript. Additionally, I acknowledge the support and guidance provided by friends and mentors throughout the writing process. Special thanks to Farsana Muhammed, Assistant Professor, Department of Electrical and Electronics Engineering, for his invaluable assistance in data analysis and interpretation. I am indebted to TKM College of Engineering, Kollam, which made this research possible. Lastly, I would like to thank our families for their unwavering encouragement and understanding during this endeavor. Their love and support have been instrumental in our success. Thank you all for your contributions, without this, the publication would not have been possible

REFERENCES

1. Zhao H, Wu Q, Wang C, Cheng L, Rasmussen CN. Fuzzy logic based coordinated control of battery energy storage system and dispatchable distributed generation for microgrid. J Modern Power Syst Clean Energy. 2015; 3 (3): 422–428.
2. Zhu G, Nie L, Zhou M, Zhang X, Sun L, Zhong C. Adaptive fuzzy dynamic surface control for multi-machine power system based on composite learning method and disturbance observer. IEEE Access. 2020; 8: 163163–163175.
3. Shahbazi H, Karbalaei F. Decentralized voltage control of power systems using multi-agent systems. J Modern Power Syst Clean Energy. 2020; 8 (2): 249–259.
4. Raziyev Y, Garifulin R, Shintemirov A, Do TD. Development of a power assist lifting device with a fuzzy PID speed regulator. IEEE Access. 2019; 7: 30724–30731.
5. Wang K, Qiao Y, Xie L, Li J, Lu Z, Yang H. A fuzzy hierarchical strategy for improving frequency regulation of battery energy storage system. J Modern Power Syst Clean Energy. 2021; 9 (4): 689–698.
6. Escobar LM, Aguilar J, Garcés-Jiménez A, De Mesa JAG, Gomez-Pulido JM. Advanced fuzzy-logic-based context-driven control for HVAC management systems in buildings. IEEE Access. 2020; 8: 16111–16126.
7. Kerdphol T, Watanabe M, Hongesombut K, Mitani Y. Self-adaptive virtual inertia control-based fuzzy logic to improve frequency stability of microgrid with high renewable penetration. IEEE Access. 2019; 7: 76071–76083.
8. Chen Z, Zhu J, Li S, Liu Y, Luo T. Detection of false data injection attacks on load frequency control system with renewable energy based on fuzzy logic and neural networks. J Modern Power Syst Clean Energy. 2022; 10 (6): 1576–1587.
9. Hannan MA, Ghani ZA, Hoque MM, Ker PJ, Hussain A, Mohamed A. Fuzzy logic inverter controller in photovoltaic applications: issues and recommendations. IEEE Access. 2019; 7: 24934–24955.
10. Liu Z, Mohammadzadeh A, Turabieh H, Mafarja M, Band SS, Mosavi A. A new online learned interval type-3 fuzzy control system for solar energy management systems. IEEE Access. 2021; 9: 10498–10508.

© STM Journals 2024. All Rights Reserved