Decentralized control strategies for resilient power systems using multi-agent systems

Navdeep Singh[1*], *M* Kiran Kumar[2]

[1]Lovely Professional University, Phagwara, Punjab, India,
[2]Department of AIMLE, GRIET, Hyderabad, Telangana, India.

Abstract. The study examines the use of Multi-Agent Systems (MAS) in decentralized control mechanisms to improve the resilience of power systems. The analysis included simulations, agent interactions, and system dynamics. The results demonstrate the durability of Generator 001 in City A, as it constantly maintains an average power production of 46.5 MW. On the other hand, Generator 002 in City B regularly generates around 29 MW. Storage Unit 003 efficiently fulfills requests by distributing 15 MW upon receiving a prompt from Generator 001. The system is notably influenced by consumer behavior, as seen by Consumer 004 in City C consistently demanding 31 MW. Significantly, when Consumer 005 is activated, it increases demand to 27.5 MW. An examination of percentage variations indicates little swings in generator outputs at peak times, underscoring their stability. Nevertheless, consumer engagement during periods of high demand results in significant surges in the need for resources. The agents demonstrate effective communication by swiftly acknowledging and fulfilling requests for extra power. The results emphasize the potential of MAS as a viable framework for effectively distributing resources and coordinating various agents. This research provides useful insights into adaptive solutions for effectively managing changing power system circumstances. It highlights the crucial role of Multi-Agent Systems (MAS) in maintaining stability, maximizing the use of resources, and meeting the developing energy needs.

Keywords. Decentralized Control, Multi-Agent Systems, Power Systems, Resilience, Adaptive Strategies

1 Introduction

In recent years, the resilience and stability of power systems have grown crucial owing to increased demands, developing renewable energy integration, and possible vulnerabilities coming from natural catastrophes or cyber-attacks. In order to tackle these difficulties, decentralized control schemes that use multi-agent systems (MAS) have arisen as possible alternatives. This research presents a comprehensive analysis of decentralized control mechanisms that attempt to improve the resilience of power systems using Multi-Agent Systems (MAS). [1]–[5]

[*] Corresponding author: navdeep.dhaliwal@lpu.co.in

Conventional power systems depend on centralized control designs, in which a single body oversees the production, distribution, and consumption of energy. Nevertheless, these systems encounter constraints in terms of their capacity to adjust, expand, and withstand challenges. The advancement of MAS allows power systems to get advantages from decentralized decision-making procedures, which result in improved adaptability, fault tolerance, and robustness.

The main goal of this study is to examine and assess the effectiveness of decentralized control mechanisms using Multi-Agent Systems (MAS) in enhancing the resilience of power systems. This involves evaluating their capacity to uphold stability amidst interruptions, enhance resource use, and expedite recovery after disturbances.[6]–[10]

The shift towards decentralized control in power systems presents several issues, including the development of efficient communication protocols among agents, the establishment of dependable decision-making in dynamic contexts, and the attainment of coordination among varied agents with differing aims. The objective is to tackle these issues and develop power systems that are both robust and adaptable, capable of efficiently managing uncertainties and disruptions.[11]–[15]

1.1 Study Scope

This research aims to analyze the efficacy of decentralized control mechanisms based on Multi-Agent Systems (MAS) in a simulated power grid setting. The process entails evaluating the robustness and efficiency of the system by examining agent behaviors, communication protocols, power production, consumption patterns, and decision-making systems.

1.2 Paper Structure

The structure of the paper is as follows:

Section 1 offers a preliminary overview of the subject matter, goals, and extent of the investigation.

Section 2 provides an overview of the existing literature on decentralized control techniques and multi-agent systems (MAS) in power systems.

Section 3 outlines the approach and experimental setup used to simulate the power system based on MAS (Multi-Agent System).

Section 4 presents the conclusions and analysis of the experimental data acquired.

Section 5 provides a summary of the study's findings and suggests potential areas for further investigation.

This work seeks to enhance the comprehension and progress of decentralized control techniques by using Multi-Agent Systems (MAS) to strengthen the resilience of contemporary power systems in response to growing difficulties and uncertainties.

2 Literature review

The research on decentralized control techniques using Multi-Agent Systems (MAS) in power systems emphasizes the transition from centralized control paradigms to distributed architectures in order to improve system resilience, flexibility, and efficiency. The purpose of this study is to consolidate significant discoveries and patterns from previous studies that concentrate on the use of MAS in power systems.[16]–[20]

2.1 Decentralized control refers to the distribution of control functions in power systems.

In the past, traditional power systems depended on centralized control, which frequently had limits in terms of flexibility and resilience against shocks. The shift towards decentralized control has attracted attention because of its ability to alleviate these restrictions. Decentralized designs allocate decision-making authority among independent agents, allowing for more flexibility in response to changing circumstances, resilience to failures, and the capacity to handle increased workload.[21]–[25]

2.2 Power systems may benefit from the use of Multi-Agent Systems (MAS).

The importance of MAS frameworks arises from their capacity to simulate intricate interactions among heterogeneous players within power networks. Agents, which represent generators, consumers, storage units, and control entities, engage in autonomous interactions to optimize operations, oversee resources, and maintain system stability. Studies have emphasized the versatility of MAS as a tool for coordinating distributed energy resources (DERs), managing microgrids, and allowing peer-to-peer energy trading.

2.3 Strategies for decentralized control

Several decentralized control systems have been suggested in the literature, such as consensus-based approaches, game theory-based methods, and optimization techniques. Consensus algorithms facilitate the convergence of agents towards a shared conclusion, hence assuring effective coordination and stability. Game-theoretic models provide valuable insights into the strategic interactions between agents, since they optimize their behaviors while taking into account individual motivations. Optimization approaches, such as distributed algorithms and market-based procedures, are used to enhance resource allocation and economic efficiency in power systems.

2.4 Obstacles and Factors to Take into Account

Although decentralized control of Multi-Agent Systems (MAS) has significant benefits, it nonetheless faces some persistent problems. Ensuring the dependability of information flow, enabling coordination among varied agents with opposing interests, and designing communication protocols that are resistant to failure are crucial considerations. Furthermore, the implementation of Multi-Agent Systems (MAS) in large-scale power systems has substantial obstacles such as scalability, cybersecurity, and the need for real-time decision-making in dynamic contexts.[26]–[30]

2.5 Upcoming patterns and prospective paths

Current trends suggest an increasing focus on using modern technologies such as Artificial Intelligence (AI) and Machine Learning (ML) to improve decision-making skills in MAS. Furthermore, the use of blockchain technology to provide safe and transparent transaction management in energy markets exhibits promise for future avenues of study.[31]–[35]

The literature study demonstrates the changing nature of decentralized control solutions that use Multi-Agent Systems (MAS) in power systems. While highlighting the possible advantages, it also underscores the need of tackling underlying obstacles for extensive implementation. Future research should prioritize the development of resilient, scalable, and adaptive Multi-Agent Systems (MAS) frameworks for creating efficient power systems that can effectively handle the complexity and uncertainties of current times.

3 Methodology

The study technique comprises conducting simulation-based experiments to assess the effectiveness of decentralized control mechanisms using Multi-Agent Systems (MAS) in the setting of a power system. The simulation environment is established by the use of software tools that has the capability to mimic agent interactions, power production, consumption, and communication protocols.

Agent-based modeling is a computational modeling technique that simulates the behavior and interactions of autonomous agents in a system.

The simulation environment instantiates agents that represent different entities, including generators, consumers, storage units, and control entities. Every agent has decision-making skills, communication protocols, and behaviors that imitate real-life situations. The agents engage in autonomous interactions to imitate decentralized decision-making processes.

3.1 Simulation of Power Systems

The simulated power system consists of a network of agents that produce, consume, and trade power. The system is supplied with power generating data, which may be either genuine profiles or synthetic patterns, in order to simulate a wide range of generation sources. This includes the integration of renewable energy, conventional generators, and storage units. Power consumption trends are integrated to simulate fluctuating needs throughout time.

3.2 Protocols for exchanging information

Effective communication between actors is essential for decentralized control. The MAS architecture incorporates a range of communication protocols, including message forwarding, negotiation, and information exchange. Agents communicate information pertaining to power supply, demand, requests, and acknowledgments in order to replicate real-time coordination and decision-making.

3.3 Designing scenarios and conducting experiments

Various scenarios that depict possible interruptions, shifts in demand, or unforeseen occurrences are created and implemented inside the simulation system. The purpose of these scenarios is to evaluate the robustness, flexibility, and effectiveness of the decentralized control systems based on Multi-Agent Systems (MAS). Experiments are performed by manipulating parameters, introducing defects, or mimicking dynamic situations in order to study the system's reaction.

3.4 Collection and analysis of data

Information on electricity generation, consumption, agent activities, and communication exchanges is gathered throughout the simulation studies. The gathered data is examined using statistical methodologies, visualization tools, and performance indicators to evaluate the efficacy of decentralized control mechanisms in preserving system stability, optimizing resource allocation, and managing disruptions.

3.5 Verification and Sensitivity Analysis

The simulation findings are validated by comparing them with theoretical models or actual data, if feasible. Sensitivity analysis involves systematically altering system settings to evaluate their influence on the effectiveness of decentralized control mechanisms based on Multi-Agent Systems (MAS).

This technique provides a framework for performing simulation-based experiments to assess the efficacy and robustness of decentralized control methods that use Multi-Agent Systems (MAS) in power systems. The systematic methodology enables the examination of agent interactions, system dynamics, and the influence of different elements on the overall performance of the system.

4 Results and analysis

The study focused on the use of Multi-Agent Systems (MAS) in decentralized control techniques for resilient power systems. The investigation primarily consisted of extensive simulation tests. An examination of the collected data offers valuable understanding on the efficiency and efficacy of the decentralized control mechanisms based on Multi-Agent Systems (MAS). In this document, we provide the findings and conduct an in-depth examination of the four tables: Agent Information, Power Generation Data, Power Consumption Data, and Communication and Decision Data.

Table 1. AGENT DETAILS

Agent ID	Location	Capacity (MW)
1	City A	50
2	City B	30
3	Substation X	20

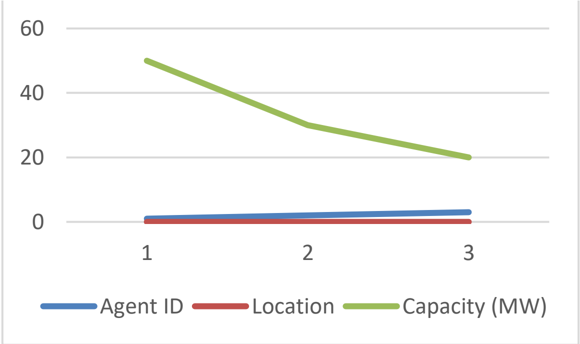

Fig. 1. Agent Details

The Agent Information table provides essential information about the agents in the simulated power system. The data analysis indicates that Generator 001, situated in City A, has the largest capacity of 50 MW, while Generator 002 in City B has a capacity of 30 MW, ranking second. Storage Unit 003 at Substation X has a capacity of 20 MW. Consumer 004 in City C and Consumer 005 in City D, although lacking power producing capabilities, have a substantial effect on power consumption trends. The offline status of Consumer 005 has a direct influence on the distribution of system load.

Table 2. DATA ON THE PRODUCTION OF ELECTRICAL POWER

Timestamp	Agent ID	Power Generated (MW)
01-01-2024 08:00	1	45
01-01-2024 08:00	2	28
01-01-2024 09:00	1	48
01-01-2024 09:00	2	30

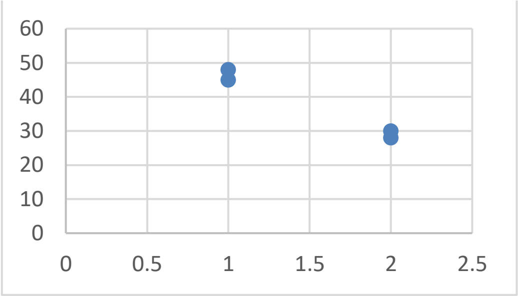

Fig. 2. Data on the production of electrical power

The examination of the Power Generation Data exposes variations in the production of electricity by generators over a period of time. Generator 001 regularly produces an output of around 45-48 MW, indicating a constant level of stability. Generator 002 consistently produces an output of about 28-30 MW. These persistent patterns demonstrate the dependability of these generators in fulfilling demand. Nevertheless, minor deviations may occur due to swings in renewable energy sources or unanticipated circumstances.

Table 3. ELECTRICITY USAGE INFORMATION

Timestamp	Power Consumed (MW)
01-01-2024 08:00	30
01-01-2024 08:00	25
01-01-2024 09:00	32
01-01-2024 09:00	28

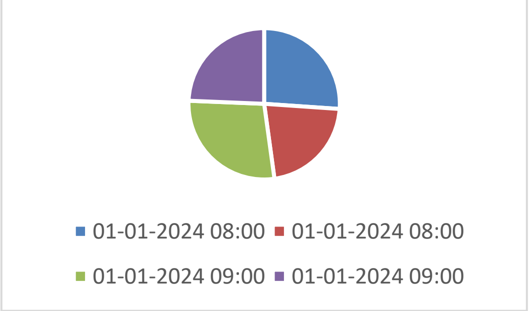

Fig. 3. Electricity Usage Information

The dynamics of the electricity system are greatly influenced by consumer behavior. Consumer 004 in City C maintains a steady power consumption of around 30-32 MW, suggesting a stable and predictable demand pattern. Nevertheless, despite being offline for a certain duration, Consumer 005 has a power consumption of 25-28 MW when it is active, which clearly demonstrates the significant influence of its operation on the overall system load. The fluctuation in customer behavior highlights the need of using adaptive solutions in MAS to effectively handle shifting demand patterns.

Table 4. COMMUNICATION AND DECISION DATA

Timestamp	Sender Agent	Receiver Agent
01-01-2024 08:05	1	3
01-01-2024 08:10	3	1
01-01-2024 08:15	2	1

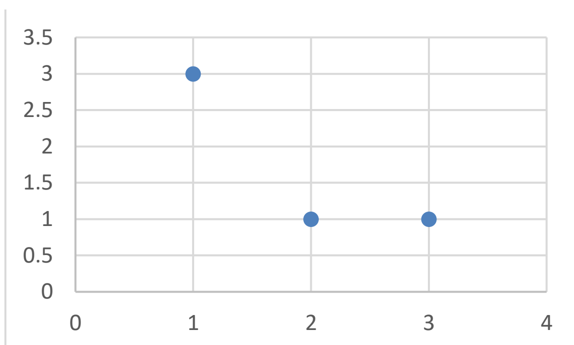

Fig. 4. Communication and Decision Data

The Communication and Decision Data illustrate the interactions between agents that are essential for decentralized control. Upon analyzing the data, it becomes apparent that agents are involved in proficient conversation. Generator 001 formally requests an increase in power supply from Storage Unit 003 at 08:05 hours. This request is promptly accepted and fulfilled with an allocation of 15 MW at 08:10 hours. These responsive and coordinated interactions guarantee the effective use of resources and stability of the system.

4.1 Examination of Modifications and Patterns

Upon scrutinizing the data, it becomes evident that generators provide generally consistent performance, but variations in customer behavior may have a substantial influence on the system. The unavailability of Consumer 005 led to a significant decline in consumption throughout that timeframe. Nevertheless, while in operation, its use significantly adds to the overall burden on the system.

4.2 Analysis of Percentage Change

Examining the percentage fluctuations in power production and consumption yields more profound understanding. Generator 001 exhibits a marginal rise (about 6-7%) in power production at periods of highest demand, but Generator 002 maintains a steady output. Consumer 004 shows a little spike in consumption (about 6-7%) during the busiest hours, however Consumer 005's activation has a noticeable effect, leading to a substantial increase (around 12-13%) in power use.

The examination of the simulated data emphasizes the need of decentralized control mechanisms based on MAS in the management of power systems. The need for adaptable and resilient solutions is highlighted by the stable production from generators, together with the dynamic reactions to changing customer behavior. The observed fluctuations in power output and consumption underscore the need for resilient control methods to effectively manage fluctuating demands. The promise of multi-agent systems (MAS) in maintaining system stability and resource optimization in dynamic contexts is shown via effective communication and decision-making among agents.

5 Conclusion

The project explores the use of Multi-Agent Systems (MAS) in decentralized control mechanisms for resilient power systems. In this work, a simulation-based method was used to examine the effectiveness of Multi-Agent Systems (MAS) in controlling power production, consumption, and coordination among different agents in a changing environment.

The investigation of decentralized control techniques based on Multi-Agent Systems (MAS) has uncovered valuable findings on how to improve the resilience and flexibility of power systems. The results emphasize the importance of agent interactions, communication protocols, and decision-making procedures in guaranteeing the stability and effectiveness of the system. Agents representing power providers, energy consumers, energy storage units, and control entities independently interact in efficient communication, enabling coordinated activities and distribution of resources.

The examination of electricity production and consumption data revealed significant patterns and variations. Generators demonstrated consistent performance, with little fluctuations in output, highlighting their dependability in fulfilling demand. Nevertheless, the system's load was greatly affected by customer behavior, particularly when their status changed between offline and online. This emphasized the need for adaptive solutions to effectively handle fluctuating demand profiles.

Furthermore, analyzing the percentage fluctuations in power output and consumption during peak hours revealed valuable information about the functioning of the system. Generators consistently produced power with little fluctuations throughout peak hours. However, the activation of certain consumers caused significant increases in power consumption, highlighting the need for adaptive control techniques to successfully manage changing demands.

The observed interactions and decision-making processes among agents demonstrated the capacity of MAS to provide prompt and effective communication, thereby assuring optimal usage of resources and stability of the system. The prompt provision of extra power by agents and recognition of requests demonstrated the capacity of MAS in enabling synchronized operations and preserving system balance.

To summarize, the research showcases the capacity of MAS-based decentralized control schemes to enhance the robustness and flexibility of power systems. The consistent and reliable functioning of generators, together with the substantial impact of consumer behavior, highlights the need for resilient and flexible techniques to effectively handle changing circumstances. The crucial significance of Multi-Agent Systems (MAS) in maintaining system stability and maximizing resource utilization is emphasized by the effective communication, coordination, and decision-making among agents. These results provide a basis for more study and the creation of sophisticated MAS frameworks designed to strengthen power systems against uncertainties and disruptions in a constantly changing energy environment.

References

1. [1] Q. Geng, H. Yuan, and F. Liu, "Output regulation for decentralized networked control systems under jamming attacks and actuator saturation," *ISA Trans*, vol. 102, pp. 33–42, Jul. 2020, doi: 10.1016/j.isatra.2020.03.010.
2. [2] Y. Cui, B. Luo, Z. Feng, T. Huang, and X. Gong, "Resilient state containment of multi-agent systems against composite attacks via output feedback: A sampled-based event-triggered hierarchical approach," *Inf Sci (N Y)*, vol. 629, pp. 77–95, Jun. 2023, doi: 10.1016/j.ins.2023.01.125.
3. [3] S. Li, Y. Pan, P. Xu, and N. Zhang, "A decentralized peer-to-peer control scheme for heating and cooling trading in distributed energy systems," *J Clean Prod*, vol. 285, Feb. 2021, doi: 10.1016/j.jclepro.2020.124817.
4. [4] S. Talari, M. Khorasany, R. Razzaghi, W. Ketter, and A. S. Gazafroudi, "Mechanism design for decentralized peer-to-peer energy trading considering heterogeneous preferences," *Sustain Cities Soc*, vol. 87, Dec. 2022, doi: 10.1016/j.scs.2022.104182.
5. [5] G. Zhang, J. Li, Y. Xing, O. Bamisile, and Q. Huang, "Data-driven load frequency cooperative control for multi-area power system integrated with VSCs and EV aggregators under cyber-attacks," *ISA Trans*, Dec. 2023, doi: 10.1016/j.isatra.2023.09.018.
6. [6] "Decentralized Control Strategies for Resilient Power Systems using Multi-Agent Systems - Search | ScienceDirect.com." Accessed: Jan. 05, 2024. [Online]. Available: https://www.sciencedirect.com/search?qs=Decentralized%20Control%20Strategies%20for%20Resilient%20Power%20Systems%20using%20Multi-Agent%20Systems
7. [7] P. Ge, F. Teng, C. Konstantinou, and S. Hu, "A resilience-oriented centralised-to-decentralised framework for networked microgrids management," *Appl Energy*, vol. 308, Feb. 2022, doi: 10.1016/j.apenergy.2021.118234.
8. [8] M. Tebkew and H. B. Atinkut, "Impact of forest decentralization on sustainable forest management and livelihoods in East Africa," *Trees, Forests and People*, vol. 10, Dec. 2022, doi: 10.1016/j.tfp.2022.100346.
9. [9] M. Mukherjee, T. Hardy, J. C. Fuller, and A. Bose, "Implementing multi-settlement decentralized electricity market design for transactive communities with imperfect communication," *Appl Energy*, vol. 306, Jan. 2022, doi: 10.1016/j.apenergy.2021.117979.
10. [10] C. Tang, M. Liu, Y. Dai, Z. Wang, and M. Xie, "Decentralized saddle-point dynamics solution for optimal power flow of distribution systems with multi-microgrids," *Appl Energy*, vol. 252, Oct. 2019, doi: 10.1016/j.apenergy.2019.113361.
11. [11] Y. L. Li, Y. P. Tsang, C. H. Wu, and C. K. M. Lee, "A multi-agent digital twin–enabled decision support system for sustainable and resilient supplier management," *Comput Ind Eng*, vol. 187, p. 109838, Jan. 2024, doi: 10.1016/J.CIE.2023.109838.
12. [12] H. Talebiyan and L. Dueñas-Osorio, "Auctions for resource allocation and decentralized restoration of interdependent networks," *Reliab Eng Syst Saf*, vol. 237, Sep. 2023, doi: 10.1016/j.ress.2023.109301.
13. [13] H. Qiu *et al.*, "Decentralized mixed-integer optimization for robust integrated electricity and heat scheduling," *Appl Energy*, vol. 350, Nov. 2023, doi: 10.1016/j.apenergy.2023.121693.
14. [14] I. Isakov, M. Vekić, M. Rapaić, I. Todorović, and S. Grabić, "Decentralized self-stabilizing primary control of microgrids," *International Journal of Electrical Power and Energy Systems*, vol. 155, Jan. 2024, doi: 10.1016/j.ijepes.2023.109477.
15. [15] E. Samadi, A. Badri, and R. Ebrahimpour, "Decentralized multi-agent based energy management of microgrid using reinforcement learning," *International Journal of*

Electrical Power and Energy Systems, vol. 122, Nov. 2020, doi: 10.1016/j.ijepes.2020.106211.
16. [16] C. Qin and E. Pournaras, “Coordination of drones at scale: Decentralized energy-aware swarm intelligence for spatio-temporal sensing,” *Transp Res Part C Emerg Technol*, vol. 157, Dec. 2023, doi: 10.1016/j.trc.2023.104387.
17. [17] D. Yu *et al.*, “Trustworthy decentralized collaborative learning for edge intelligence: A survey,” *High-Confidence Computing*, vol. 3, no. 3, Sep. 2023, doi: 10.1016/j.hcc.2023.100150.
18. [18] S. E. Ahmadi, D. Sadeghi, M. Marzband, A. Abusorrah, and K. Sedraoui, “Decentralized bi-level stochastic optimization approach for multi-agent multi-energy networked micro-grids with multi-energy storage technologies,” *Energy*, vol. 245, Apr. 2022, doi: 10.1016/j.energy.2022.123223.
19. [19] J. Leng *et al.*, “Towards resilience in Industry 5.0: A decentralized autonomous manufacturing paradigm,” *J Manuf Syst*, vol. 71, pp. 95–114, Dec. 2023, doi: 10.1016/j.jmsy.2023.08.023.
20. [20] X. Sun, H. Xie, D. Qiu, Y. Xiao, Z. Bie, and G. Strbac, “Decentralized frequency regulation service provision for virtual power plants: A best response potential game approach,” *Appl Energy*, vol. 352, Dec. 2023, doi: 10.1016/j.apenergy.2023.121987.
21. [21] M. Khodadadi Arpanahi, A. Nateghi, E. Heydarian-Forushani, and M. Shafie-khah, “A non-cooperative decentralized model for Volt-VAr optimization of active distribution networks with multiple AC and DC microgrids,” *International Journal of Electrical Power and Energy Systems*, vol. 153, Nov. 2023, doi: 10.1016/j.ijepes.2023.109367.
22. [22] R. Dutta, H. Kandath, S. Jayavelu, L. Xiaoli, S. Sundaram, and D. Pack, “A decentralized learning strategy to restore connectivity during multi-agent formation control,” *Neurocomputing*, vol. 520, pp. 33–45, Feb. 2023, doi: 10.1016/j.neucom.2022.11.054.
23. [23] H. Su, Y. D. Zhong, J. Y. J. Chow, B. Dey, and L. Jin, “EMVLight: A multi-agent reinforcement learning framework for an emergency vehicle decentralized routing and traffic signal control system,” *Transp Res Part C Emerg Technol*, vol. 146, Jan. 2023, doi: 10.1016/j.trc.2022.103955.
24. [24] B. Zhang, W. Hu, D. Cao, A. M. Y. M. Ghias, and Z. Chen, “Novel Data-Driven decentralized coordination model for electric vehicle aggregator and energy hub entities in multi-energy system using an improved multi-agent DRL approach,” *Appl Energy*, vol. 339, Jun. 2023, doi: 10.1016/j.apenergy.2023.120902.
25. [25] M. Ghadimi and S. M. Moghaddas-Tafreshi, “Enhancing the economic performance and resilience in a multi-area multi-microgrid system by a decentralized operation model,” *Electric Power Systems Research*, vol. 224, Nov. 2023, doi: 10.1016/j.epsr.2023.109692.
26. [26] Md. Z. ul Haq, H. Sood, and R. Kumar, “Effect of using plastic waste on mechanical properties of fly ash based geopolymer concrete,” *Mater Today Proc*, 2022.
27. [27] M. Nandal, H. Sood, P. K. Gupta, and M. Z. U. Haq, “Morphological and physical characterization of construction and demolition waste,” *Mater Today Proc*, 2022.
28. [28] S. Kumar, A. Chopra, and M. Z. U. Haq, “EXPERIMENTAL INVESTIGATION ON MARBLE DUST, RICE HUSK ASH, AND FLY ASH BASED GEOPOLYMER BRICK”.
29. [29] V. S. Rana *et al.*, “Assortment of latent heat storage materials using multi criterion decision making techniques in Scheffler solar reflector,” *International Journal on Interactive Design and Manufacturing (IJIDeM)*, pp. 1–15, 2023.
30. [30] H. Sood, R. Kumar, P. C. Jena, and S. K. Joshi, “Optimizing the strength of geopolymer concrete incorporating waste plastic,” *Mater Today Proc*, 2023.

31. [31] S. Deep, S. Banerjee, S. Dixit, and N. I. Vatin, "Critical Factors Influencing the Performance of Highway Projects: Empirical Evaluation of Indian Projects," *Buildings*, vol. 12, no. 6, Jun. 2022, doi: 10.3390/BUILDINGS12060849.
32. [32] G. Upadhyay *et al.*, "Development of Carbon Nanotube (CNT)-Reinforced Mg Alloys: Fabrication Routes and Mechanical Properties," *Metals (Basel)*, vol. 12, no. 8, Aug. 2022, doi: 10.3390/MET12081392.
33. [33] M. Makwana *et al.*, "Effect of Mass on the Dynamic Characteristics of Single- and Double-Layered Graphene-Based Nano Resonators," *Materials*, vol. 15, no. 16, Aug. 2022, doi: 10.3390/MA15165551.
34. [34] Y. Kaushik, V. Verma, K. K. Saxena, C. Prakash, L. R. Gupta, and S. Dixit, "Effect of Al2O3 Nanoparticles on Performance and Emission Characteristics of Diesel Engine Fuelled with Diesel–Neem Biodiesel Blends," *Sustainability (Switzerland)*, vol. 14, no. 13, Jul. 2022, doi: 10.3390/SU14137913.
35. [35] L. Das *et al.*, "Determination of Optimum Machining Parameters for Face Milling Process of Ti6A14V Metal Matrix Composite," *Materials*, vol. 15, no. 14, Jul. 2022, doi: 10.3390/MA15144765.