International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802362

AI-Driven Adaptive Power Management for Hybrid Power Plants with Battery Energy Storage System

M Vasanthakumar M.E., Mba, (Ph.D.,), S. Idhayadharshini M.E, (Ph.D.,), Rohini M, Vaishnavi K, Srinathi R, Nandhini S

Associate Professor, Department of Electronics and Communication Engineering, AVS Engineering College, Salem, Tamil Nadu, India

Assistant Professor, Department of Electronics and Communication Engineering, Vivekananda College of Engineering for women, Namakkal, Tamil Nadu, India

UG Scholar, Department of Electronics and Communication Engineering, AVS Engineering College, Salem, Tamil Nadu, India

Publication History: Received: 25.02.2026; Revised: 20.03.2026; Accepted: 25.03. 2026; Published: 28.03.2026.

ABSTRACT: The usage of the renewable energy such as solar and wind has increased drastically in the recent years. Integrating this energy into modern power system create problem like unstable power, insufficient usage and power wastage. This work proposes an AI-driven adaptive power management for hybrid renewable energy systems integrated with a Battery Energy Storage System (BESS).

It uses an AI to control and manage the power to make the system efficient. An intelligent control approach, referred to as HybridVolt AI, is employed to dynamically manage power flow by selecting the most appropriate energy source based on real-time generation conditions and system requirements. A Battery management system is used to continuously monitor the voltage and the current level to prevent the battery from overcharging and to ensure safe operation of the system.

The system further enhances reliability through automatic protection mechanisms that isolate the load under abnormal conditions. In addition to that it also had IoT-enabled monitoring facilities for remote access to operational data. The proposed framework demonstrates improved energy efficiency, enhanced system reliability, and effective utilization of renewable resources. By integrating intelligent decision-making with hybrid energy systems, the approach provides a scalable and practical solution for advanced power management in modern energy infrastructures.

KEYWORDS: Artificial Intelligence, Hybrid Renewable Energy System, Battery Energy Storage System (BESS), Power Management, Solar Energy, Wind Energy, Internet of Things (IoT), Embedded Systems, Smart Grid.

I. INTRODUCTION

The demand for electricity is increasing day by day, and at the same time, there is a strong push towards using cleaner energy sources. Solar and wind energy are good alternatives, but they are not always available due to changing weather conditions. Because of this, maintaining a steady power supply becomes difficult.

To handle this problem, hybrid systems are used where more than one energy source is combined. While this improves reliability to some extent, managing these sources properly is not easy. Many existing systems still follow fixed control methods, which do not adapt well to changing conditions. This often leads to energy loss or inefficient usage.

Battery Energy Storage Systems (BESS) are commonly used to store extra energy and supply it when needed. However, if the battery is not monitored correctly, it can get damaged or lose efficiency over time.

In this work, an AI-based approach is used to make the system more flexible and responsive. The proposed system can monitor conditions in real time and choose the best available energy source. It also includes battery protection and IoT monitoring, making the system more practical for real-world use.

International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802362

II. LITERATURE REVIEW

The use of renewable energy sources along with intelligent control systems has increased in recent years due to the need for efficient and reliable power management. Since sources like solar and wind are not always consistent, many approaches have been developed to improve the performance of hybrid energy systems.

Artificial Intelligence-based methods are commonly used to manage power flow between different energy sources and storage systems. These approaches help in improving efficiency by adjusting power usage based on real-time conditions. However, many of these systems mainly focus on optimization and do not fully address safety or protection issues.

Battery Energy Storage Systems are also widely used to balance energy supply and demand. They help in storing excess energy and supplying it when needed, which improves system stability. Still, in many cases, there is no proper mechanism to intelligently select the best available energy source.

Fuzzy logic-based techniques have been applied to handle variations in renewable energy generation. While they improve system stability, they depend on fixed rules and cannot adapt to changing conditions.

Recent developments combine AI with IoT technologies to enable real-time monitoring and control. Even though these systems provide better visibility and control, many of them do not offer a complete solution that integrates control, protection, and monitoring together.

Overall, there is a need for a more integrated approach that can handle all these aspects in a single system, which is the focus of this work.

III. RESEARCH METHODOLOGY

The proposed system is designed by combining solar and wind energy sources along with a Battery Energy Storage System to ensure a continuous and efficient power supply. The main objective is to use an AI-based control strategy to manage power flow intelligently based on real-time conditions.

An Arduino-based controller is used as the core of the system, where the AI-based decision logic (HybridVolt AI) is implemented. The system continuously collects data such as voltage and current from solar panels, wind turbines, and the battery using sensors. This real-time data is used as input for decision-making.

The AI logic works by comparing the availability and efficiency of each energy source. Based on this analysis, the system automatically selects the most suitable source. For example, if solar energy is strong, it is given priority. If solar power is low, the system switches to wind energy, and when both are insufficient, the battery is used as a backup. This adaptive decision-making helps in improving overall efficiency.

A Battery Management System is integrated to monitor battery conditions and ensure safe charging and discharging. The system also includes a relay-based protection mechanism that disconnects the load during abnormal conditions such as overload or voltage fluctuations. In addition, an IoT-based monitoring system is used to display real-time data and allow remote access. This helps users to track system performance and ensures better control.

Overall, the methodology combines real-time data sensing, AI-based decision-making, and protection mechanisms to create a reliable and efficient hybrid power management system.

IV. RESULTS AND DISCUSSION

The proposed system was tested under different operating conditions to evaluate its performance and reliability. It was observed that the system is capable of switching smoothly between solar, wind, and battery sources based on availability without causing interruption to the load.

During normal daytime conditions, solar energy was mainly used as the primary source since it was readily available. When solar power decreased due to weather changes, the system automatically switched to wind energy. In situations where both solar and wind energy were insufficient, the battery provided backup power, ensuring a continuous supply.

International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802362

The AI-based control logic helped in making quick and effective decisions by analyzing real-time data from sensors. This improved the overall efficiency of the system and reduced unnecessary energy loss. The system was able to utilize available resources effectively without manual intervention.

The Battery Management System played an important role in maintaining safe battery operation. It prevented overcharging and deep discharge, which helps in extending battery life. The relay-based protection mechanism also worked efficiently by disconnecting the load during abnormal conditions such as voltage fluctuations or overload, thereby protecting the system components.

The IoT-based monitoring system provided real-time updates of voltage, current, and power status. This made it easier to observe system performance and ensured better control. Overall, the system showed stable operation, improved energy utilization, and reliable performance under different conditions.

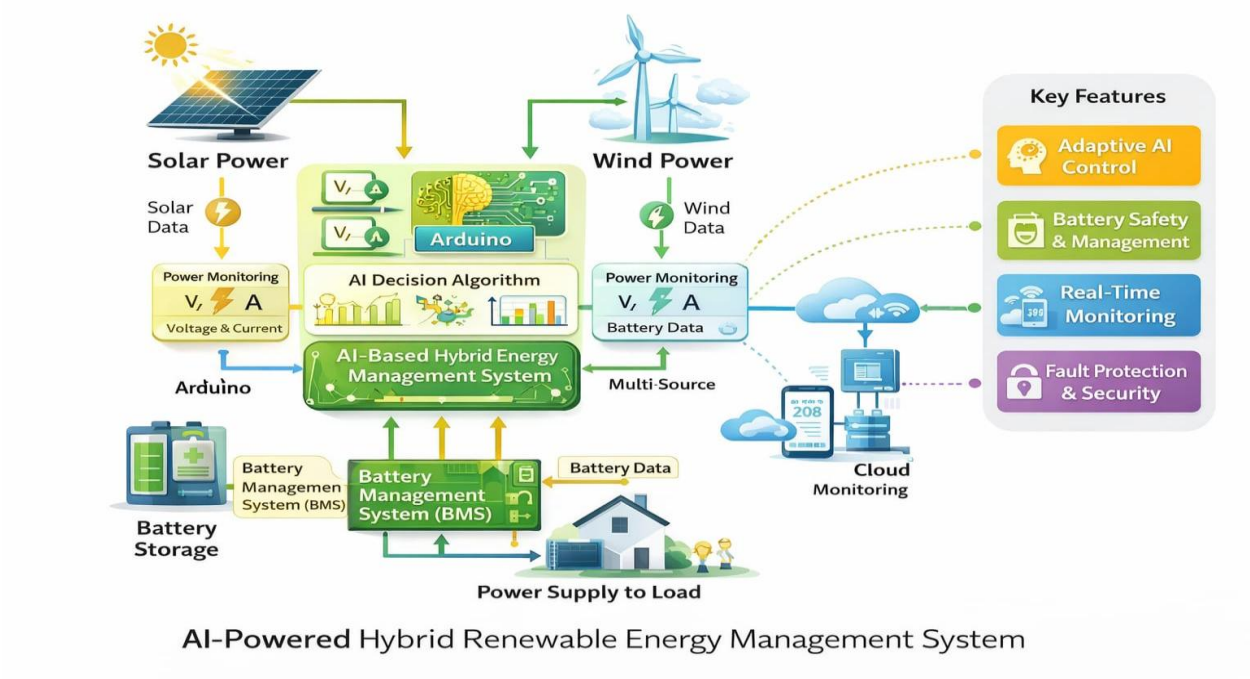

FIG: 1

V. CONCLUSION

In this work, a simple and practical hybrid power management system has been developed using an AI-based approach. The system combines solar, wind, and battery storage to provide a continuous and stable power supply under different conditions.

The AI-based control helps the system decide which energy source to use at the right time without manual effort. This makes the overall system more efficient and reduces energy wastage. The Battery Management System also plays an important role by keeping the battery safe and improving its lifespan.

The addition of IoT monitoring makes it easier to observe system performance in real time, which can be useful for users in understanding how the system is working. The protection features further ensure that the system operates safely even during abnormal situations.

Overall, the system works reliably and shows that combining AI with renewable energy can improve performance in a practical way. This approach can be useful for small-scale applications now and can also be extended for larger systems in the future.

International Journal of Engineering & Extended Technologies Research (IJEETR)

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802362

VI. FUTURE WORK

Future improvements in the proposed hybrid power management system can focus on enhancing its intelligence and adaptability under different operating conditions.

1. **Advanced AI Techniques:** More advanced AI or machine learning algorithms can be implemented to improve decision-making based on historical and real-time data.
2. **Real-Time Learning Capability:** The system can be designed to continuously learn from changing environmental conditions and adjust its operation automatically.
3. **Improved Battery Management:** Further enhancement of the Battery Management System can help in better prediction of battery health and increase overall lifespan.
4. **Cloud Integration:** Integrating cloud-based platforms can allow long-term data storage, analysis, and remote monitoring from anywhere.
5. **Scalability:** The system can be expanded for larger applications such as smart grids, residential complexes, or industrial power systems.
6. **Fault Detection and Protection:** Advanced fault detection mechanisms can be added to identify issues early and prevent system failure.
7. **Enhanced IoT Security:** Improving the security of the IoT system is important to protect data and ensure safe communication between devices.

By implementing these improvements, the system can become more efficient, reliable, and suitable for real-world large-scale applications.

REFERENCES

1. H. Zhang, X. Li, and Y. Wang, “AI-Based Energy Management for Hybrid Renewable Systems,” IEEE Access, vol. 9, pp. 112–124, 2021.
2. A. Kumar and P. Singh, “Intelligent Power Management Using Battery Energy Storage Systems,” International Journal of Energy Research, vol. 44, no. 5, pp. 3567–3578, 2020.
3. M. Ali, R. Khan, and S. Ahmed, “Fuzzy Logic Control for Hybrid Renewable Energy Systems,” Renewable Energy, vol. 145, pp. 123–132, 2019.
4. C.Nagarajan and M.Madheswaran - ‘Stability Analysis of Series Parallel Resonant Converter with Fuzzy Logic Controller Using State Space Techniques’- Taylor &Francis, Electric Power Components and Systems, Vol.39 (8), pp.780-793, May 2011. DOI: 10.1080/15325008.2010.541746
5. C.Nagarajan and M.Madheswaran - ‘Experimental verification and stability state space analysis of CLL-T Series Parallel Resonant Converter’ - Journal of Electrical Engineering, Vol.63 (6), pp.365-372, Dec.2012. DOI: 10.2478/v10187-012-0054-2
6. C.Nagarajan and M.Madheswaran - ‘Performance Analysis of LCL-T Resonant Converter with Fuzzy/PID Using State Space Analysis’- Springer, Electrical Engineering, Vol.93 (3), pp.167-178, September 2011. DOI 10.1007/s00202-011-0203-9
7. S.Tamilselvi, R.Prakash, C.Nagarajan,“Solar System Integrated Smart Grid Utilizing Hybrid Coot-Genetic Algorithm Optimized ANN Controller” Iranian Journal Of Science And Technology-Transactions Of Electrical Engineering, DOI10.1007/s40998-025-00917-z,2025
8. S.Tamilselvi, R.Prakash, C.Nagarajan,“ Adaptive sliding mode control of multilevel grid-connected inverters using reinforcement learning for enhanced LVRT performance” Electric Power Systems Research 253 (2026) 112428, doi.org/10.1016/j.epsr.2025.112428
9. S.Thirunavukkarasu, C. Nagarajan, 2024, “Performance Investigation on OCF and SCF study in BLDC machine using FTANN Controller," Journal of Electrical Engineering And Technology, Volume 20, pages 2675–2688, (2025), doi.org/10.1007/s42835-024-02126-w
10. C. Nagarajan, M.Madheswaran and D.Ramasubramanian- ‘Development of DSP based Robust Control Method for General Resonant Converter Topologies using Transfer Function Model’- *Acta Electrotechnica et Informatica Journal* , Vol.13 (2), pp.18-31,April-June.2013, DOI: 10.2478/aeei-2013-0025.
11. C.Nagarajan and M.Madheswaran - ‘DSP Based Fuzzy Controller for Series Parallel Resonant converter’- *Springer, Frontiers of Electrical and Electronic Engineering*, Vol. 7(4), pp. 438-446, Dec.12. DOI 10.1007/s11460-012-0212-0.
12. C.Nagarajan and M.Madheswaran - ‘Experimental Study and steady state stability analysis of CLL-T Series Parallel Resonant Converter with Fuzzy controller using State Space Analysis’- *Iranian Journal of Electrical & Electronic Engineering*, Vol.8 (3), pp.259-267, September 2012.

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802362

13. C.Nagarajan and M.Madheswaran, "Analysis and Simulation of LCL Series Resonant Full Bridge Converter Using PWM Technique with Load Independent Operation" has been presented in ICTES'08, a IEEE / IET International Conference organized by M.G.R.University, Chennai.Vol.no.1, pp.190-195, Dec.2007Suganthi Mullainathan, Ramesh Natarajan, "An SPSS and CNN modelling based quality assessment using ceramic materials and membrane filtration techniques", Revista Materia (Rio J.) Vol. 30, 2025, DOI: https://doi.org/10.1590/1517-7076-RMAT-2024-0721
14. M Suganthi, N Ramesh, "Treatment of water using natural zeolite as membrane filter", Journal of Environmental Protection and Ecology, Volume 23, Issue 2, pp: 520-530,2022
15. A. Singh, V. Gupta, and R. Sharma, "AI-Driven Smart Grid Energy Storage Management with IoT Integration," IEEE Transactions on Smart Grid, vol. 15, no. 2, pp. 678–689, 2024.
16. S. Patel and N. Verma, "IoT-Based Monitoring and Control of Renewable Energy Systems," Journal of Cleaner Production, vol. 280, pp. 124–135, 2021.
17. K. Ramesh and D. Prakash, "Hybrid Renewable Energy Systems: Design and Control Strategies," Energy Reports, vol. 7, pp. 456–468, 2022.
18. Gopinathan, V. R. (2024). Real-Time Fault-Tolerant Multi-Cloud Database Architectures for High Availability Applications. International Journal of Future Innovative Science and Technology (IJFIST), 7(4), 13148.
19. Chandra, S., Rengarajan, A., Sahoo, G. S., & Sharma, S. (2023, December). Identifying Neuronal Damage and Plasticity by Analyzing Changes in Diffusion Tensor Imaging. In International Conference on Data Science, Machine Learning and Applications (pp. 433-438). Singapore: Springer Nature Singapore.
20. Sugumar, R. (2025). Federated AI in Offline-First Mobile Health Architectures for Privacy-Preserving Clinical Intelligence. International Journal of Science, Research and Technology, 8(4), 14589-14600.
21. Murugeshwari, B., Rajalakshmi, S., & Sudharson, K. (2023). Hybrid Approach for Privacy Enhancement in Data Mining Using Arbitrariness and Perturbation. Computer Systems Science & Engineering, 44(3).
22. Pandey, V. K., Mishra, S., Rengarajan, A., Savita, & Roomi, M. M. (2024, March). Enhancing Weather Forecasting with Machine Learning Techniques. In International Conference on Renewable Power (pp. 147-156). Singapore: Springer Nature Singapore.
23. Soundappan, S. J. (2025). Next Generation AI Enabled Holistic Cognitive Platform for Secure Cloud Network Intelligence Enterprise Systems and Digital Trust Optimization. International Journal of Computer Technology and Electronics Communication, 8(5), 11534-11542.
24. Mathew, A. (2022). Leveraging Big Data Analytics to Power AI and ML (Machine Learning) Automation. Educational Research (IJMCER), 4(5), 131-134.
25. Sugumar, R. (2024). AI-Augmented Quality Engineering for Performance Optimization and Test Orchestration in Distributed Systems. International Journal of Science, Research and Technology, 7(5), 12835-12846.
26. Akila, R. (2024). A deep reinforcement learning approach for optimizing inventory management in the agri-food supply chain. J. Electrical Systems, 20(4s), 2238-2247.
27. Mahendran, M., Anbazhagan, K., Pavithran, G., Nivas, A., & Pandey, S. D. (2022). Earthquake Damage Prediction using Machine Learning. Grenze International Journal of Engineering & Technology (GIJET), 8(1).
28. Gopinathan, V. R. (2025). Enterprise AI Frameworks for Financial Data Engineering Behavioural Analytics and Intelligent Cloud Solutions. International Journal of Research Publications in Engineering, Technology and Management (IJRPETM), 8(4), 12499-12506.
29. Kondalsamy, P., & Kaliappan, K. (2025). An Optimal Prediction of Leaf Disease Based on Hybrid Deep Learnings and Metaheuristic Technique. Traitement du Signal, 42(1), 363.
30. Deivendran, P., Babu, P. S., Malathi, G., Anbazhagan, K., & Kumar, R. S. (2023). Emotion Recognition for Challenged People Facial Appearance in Social using Neural Network. arXiv preprint arXiv:2305.06842.
31. Sugumar, R. (2025). Unified AI Framework for Predictive Data Engineering and Real Time Prescription and Billing Systems. International Journal of Advanced Engineering Science and Information Technology (IJAESIT), 8(5), 17261.
32. Vekariya, V., Kumar, S., & Rengarajan, A. (2024). A distinctive and smart agricultural knowledge-based framework using ontology. In Sustainability in Digital Transformation Era: Driving Innovative & Growth (pp. 207-213). CRC Press.
33. Gopinathan, V. R. (2025). Software engineering practices for AI-driven systems: From development to deployment (MLOps perspective). International Journal of Science, Research and Technology, 8(1), 13493-13500.
34. Mathew, A. R. (2022). Threats and protection on E-sim: a prospective study. Novel Perspectives of Engineering Research, 8, 76-81.
35. Naveena, S., & Kavitha, K. (2025). Gossypium herbaceum: Folium disease identification and classification using Efficient Net-Coordinate Convolutional Neural Network (EcoNet). Engineering Applications of Artificial Intelligence, 152, 110701.

|ISSN: 2322-0163| www.ijeetr.com | A Bimonthly, Peer Reviewed, Scholarly Indexed Journal |

| Volume 8, Issue 2, March - April 2026 |

DOI:10.15662/IJEETR.2026.0802362

36. Rengarajan, A., Mishra, A., Kulhar, K. S., Shrivastava, V. P., & Alawneh, Y. J. J. (2024, March). Role of Deep Reinforcement Learning in Mitigating Cyber Security Issues: A Review. In International Conference on Renewable Power (pp. 37-48). Singapore: Springer Nature Singapore.
37. Achari, A. P. S. K., & Sugumar, R. (2024, November). Performance analysis and determination of accuracy using machine learning techniques for naive bayes and random forest. In AIP Conference Proceedings (Vol. 3193, No. 1, p. 020199). AIP Publishing LLC.
38. Mathew, A., & Alex, H. (2022). Detect & protect-medical device cybersecurity. Curr. Overview Sci. Technol. Res, 1, 60-68.
39. Sammy, F., Chettier, T., Boyina, V., Shingne, H., Saluja, K., Mali, M., ... & Shobana, A. (2025). Deep Learning-Driven Visual Analytics Framework for Next-Generation Environmental Monitoring. Journal of Applied Science and Technology Trends, 114-122.
40. Anbazhagan, K. (2024). Trustworthy and Adaptive AI Systems for Enterprise Analytics Cybersecurity and Decision Optimization Using API-First and Cloud-Native Architectures. International Journal of Technology, Management and Humanities, 10(03), 65-74.
41. Mathew, A. (2021). Deep reinforcement learning for cybersecurity applications. Int J Comput Sci Mob Compu, 10(12), 32-38.
42. Dhinakaran, D. (2022). Joe Prathap P. M, Selvaraj D, Arul Kumar D and Murugeshwari B," Mining Privacy-Preserving Association Rules based on Parallel Processing in Cloud Computing,". International Journal of Engineering Trends and Technology, 70(3), 284-294.
43. Karthika, K., Anusha, K., Kavitha, K., Harshadha, R., Dharshini, D. S., & Sundhar, N. A. (2025, April). Frequency Reconfigurable Antenna using Advanced Materials: A Study. In 2025 3rd International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA) (pp. 1-6). IEEE.
44. Thavamani, C., & Rengarajan, A. (2024). Clustering related behaviour of users by the use of partitioning and parallel transaction reduction algorithm. International Journal of Advanced Intelligence Paradigms, 29(2-3), 122-132.
45. Sugumar, R. (2025). Unified AI Framework for Predictive Data Engineering and Real Time Prescription and Billing Systems. International Journal of Advanced Engineering Science and Information Technology (IJAESIT), 8(5), 17261.
46. Soundappan, S. J., & Sugumar, R. (2016). Optimal knowledge extraction technique based on hybridisation of improved artificial bee colony algorithm and cuckoo search algorithm. International Journal of Business Intelligence and Data Mining, 11(4), 338-356.
47. SakthiPreetha, A., Kavitha, K., Karthika, K., & Manohari, R. G. (2025, April). A Novel Metasurface-Embedded Antenna for WBAN Communications. In 2025 3rd International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA) (pp. 1-4). IEEE.
48. Murugeshwari, B., Selvaraj, D., Sudharson, K., & Radhika, S. (2023). Data Mining with Privacy Protection Using Precise Elliptical Curve Cryptography. Intelligent Automation & Soft Computing, 35(1).
49. Gopinathan, V. R. (2025). Software engineering practices for AI-driven systems: From development to deployment (MLOps perspective). International Journal of Science, Research and Technology, 8(1), 13493-13500.
50. Anbazhagan, K., Kumar, R., Thilagavathy, R., & Anuradha, D. (2024, March). Shortest Job First with Gateway-based Resource Management Strategy for Fog Enabled Cloud Computing. In 2024 4th International Conference on Data Engineering and Communication Systems (ICDECS) (pp. 1-6). IEEE.
51. Kannadhasan, S., Vasuki, S., Kavitha, K., Karthikeyan, P., & Usha, S. G. A. (Eds.). (2025, April). Preface: Role of Artificial Intelligence and IoT in Engineering, Technology & Science [ICRAETS 2024]. In AIP Conference Proceedings (Vol. 3258, No. 1, p. 010001). AIP Publishing LLC.
52. Dhinakaran, D., Prathap, P. J., Selvaraj, D., Kumar, D. A., & Murugeshwari, B. (2022). Mining privacy-preserving association rules based on parallel processing in cloud computing. International Journal of Engineering Trends and Technology, 70(3), 284-294.