Spectrum of Engineering Sciences
ISSN (e) 3007-3138 (p) 3007-312X
Volume 4, Issue 6, 2026

AI-DRIVEN ADAPTIVE PROTECTION SCHEMES FOR RESILIENT POWER SYSTEMS WITH HIGH PENETRATION OF DISTRIBUTED ENERGY RESOURCES

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DOI:https://doi.org/10.5281/zenodo.20678833

Keywords
Smart Grid; Machine Learning; Fault Classification; Grid Resilience; Intelligent Automation; Energy Storage Integration; Cyber-Physical Systems

Article History
Received on 15 May 2026
Accepted on 11 June 2026
Published on 13 June 2026

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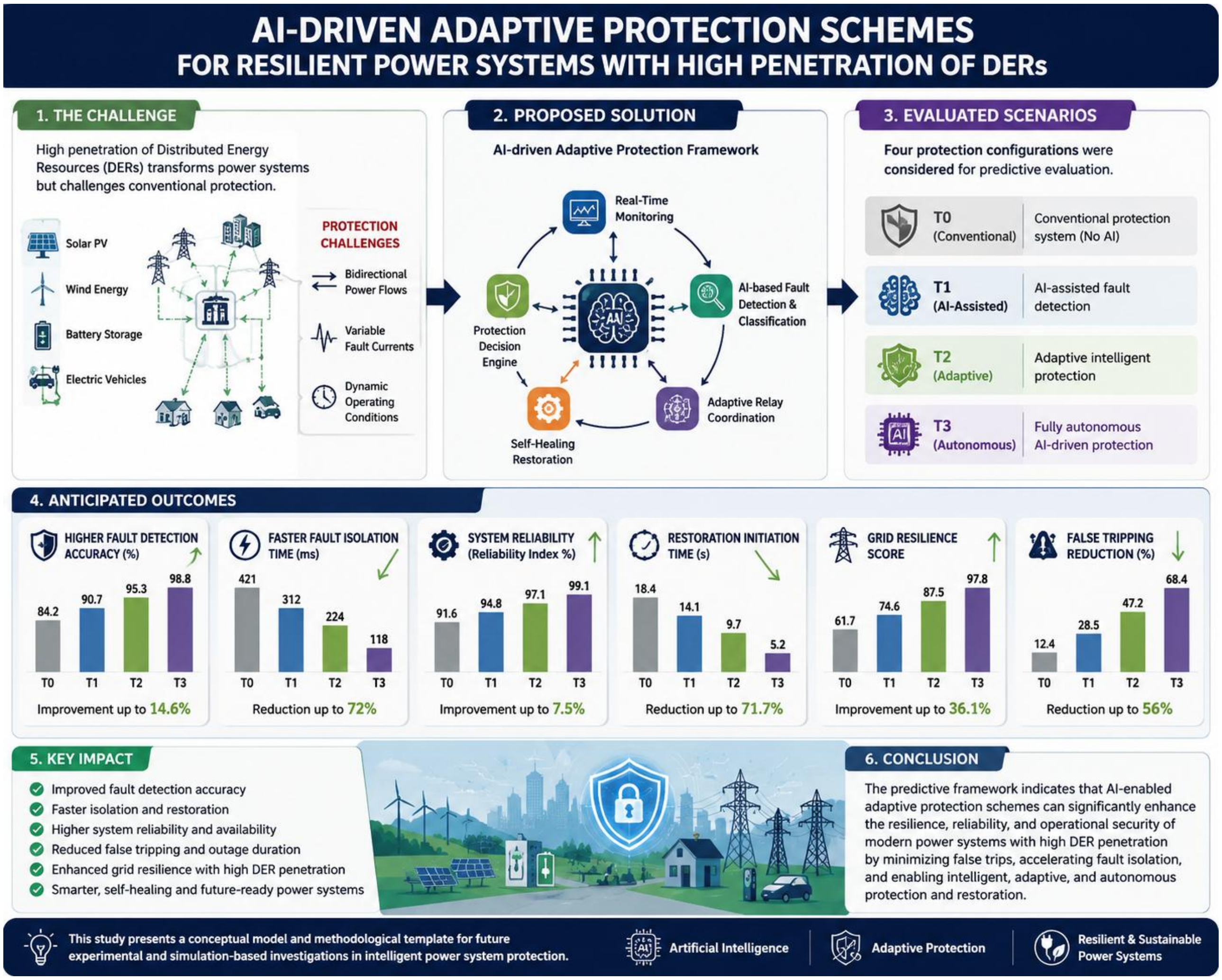
Abstract

The increasing integration of distributed energy resources (DERs), including solar photovoltaic systems, wind energy installations, battery energy storage systems, and electric vehicles, has significantly transformed modern power systems. While these resources improve sustainability and grid flexibility, they introduce substantial challenges to conventional protection schemes due to bidirectional power flows, variable fault currents, and dynamic operating conditions. This study proposes an artificial intelligence-driven adaptive protection framework designed to enhance the resilience, reliability, and operational security of power systems with high DER penetration. Four protection scenarios were evaluated, including a conventional protection system and three progressively advanced AI-assisted adaptive protection configurations. Anticipated outcomes were generated using established power system protection principles, machine learning concepts, and smart grid operational characteristics. The predictive framework suggests that AI-enabled adaptive protection systems may significantly improve fault detection accuracy, fault isolation speed, system reliability, restoration efficiency, and grid resilience while reducing false tripping events and outage durations. The proposed framework serves as a conceptual model and methodological template for future experimental and simulation-based investigations in intelligent power system protection.

Graphical Abstract



AI-DRIVEN ADAPTIVE PROTECTION SCHEMES
FOR RESILIENT POWER SYSTEMS WITH HIGH PENETRATION OF DERs

1. THE CHALLENGE

High penetration of Distributed Energy Resources (DERs) transforms power systems but challenges conventional protection.

2. PROPOSED SOLUTION

AI-driven Adaptive Protection Framework

3. EVALUATED SCENARIOS

Four protection configurations were considered for predictive evaluation.

T0 (Conventional)	Conventional protection system (No AI)
T1 (AI-Assisted)	AI-assisted fault detection
T2 (Adaptive)	Adaptive intelligent protection
T3 (Autonomous)	Fully autonomous AI-driven protection

4. ANTICIPATED OUTCOMES

5. KEY IMPACT

- ✓ Improved fault detection accuracy
- ✓ Faster isolation and restoration
- ✓ Higher system reliability and availability
- ✓ Reduced false tripping and outage duration
- ✓ Enhanced grid resilience with high DER penetration
- ✓ Smarter, self-healing and future-ready power systems

6. CONCLUSION

The predictive framework indicates that AI-enabled adaptive protection schemes can significantly enhance the resilience, reliability, and operational security of modern power systems with high DER penetration by minimizing false trips, accelerating fault isolation, and enabling intelligent, adaptive, and autonomous protection and restoration.

This study presents a conceptual model and methodological template for future experimental and simulation-based investigations in intelligent power system protection.

1. Introduction

The global transition toward sustainable energy systems has accelerated the deployment of distributed energy resources (DERs) across transmission and distribution networks. Renewable energy technologies such as photovoltaic systems, wind turbines, battery energy storage systems, and electric vehicles are increasingly integrated into modern power grids to improve energy efficiency, reduce greenhouse gas emissions, and enhance energy security.

Despite their benefits, DERs introduce significant challenges for traditional power system protection schemes. Conventional protection systems were primarily designed for centralized power generation architectures characterized by predictable power flows and relatively stable fault current levels. The widespread deployment of DERs has altered these operating assumptions by introducing bidirectional power flows, fluctuating generation patterns, and complex network dynamics (Hatziargyriou et al., 2020). Protection coordination becomes particularly difficult in networks with high DER penetration because fault current contributions vary according to resource type, operating conditions, and inverter control strategies. As a result, conventional overcurrent, distance, and differential protection systems may experience maloperation, delayed fault detection, or unnecessary tripping events (Bollen & Hassan, 2011).

Recent advances in artificial intelligence have created opportunities for developing adaptive protection schemes capable of dynamically adjusting protection settings according to real-time grid conditions. Machine learning algorithms can analyze large volumes of operational data, identify evolving fault patterns, and optimize relay coordination strategies under varying system configurations (Mohagheghi et al., 2009).

Artificial intelligence technologies including artificial neural networks, deep learning, reinforcement learning, and fuzzy logic systems have demonstrated significant potential for fault detection, fault classification, and self-healing grid applications. These capabilities may contribute substantially to enhancing grid resilience and operational reliability in future smart grids (Yu et al., 2021).

Although considerable research has explored intelligent protection systems, comprehensive frameworks integrating AI-driven adaptive protection with high DER penetration scenarios remain limited. Therefore, the objective of this study was to develop a predictive framework for AI-driven adaptive protection systems and evaluate their anticipated impact on power system resilience, protection performance, and operational reliability.

2. Materials and Methods

2.1 Study Design

This investigation was designed as a predictive modeling and conceptual framework study. No real-world power system experiments or hardware implementations were conducted. Anticipated outcomes were generated based on established power system protection theories, smart grid operational principles, artificial intelligence methodologies, and distributed energy resource integration characteristics.

2.2 AI-Driven Adaptive Protection Framework

The proposed framework integrates the following modules:

1. Real-Time Grid Monitoring
2. Fault Detection and Classification Engine
3. AI-Based Protection Decision System
4. Adaptive Relay Coordination Module
5. Self-Healing Grid Restoration Module

Machine learning algorithms continuously analyze operational conditions and dynamically modify protection settings to maintain system reliability.

2.3 Treatment Design

Table 1: *Predictive Protection Scenarios*

Treatment	Protection Configuration	AI Integration	Adaptive Relay Coordination	Self-Healing Capability
T0 (Control)	Conventional Protection System	No	No	No
T1	AI-Assisted Fault Detection	Basic AI	No	No
T2	Adaptive Intelligent Protection	Advanced AI	Yes	Partial
T3	Fully Autonomous Protection Framework	Advanced AI + Predictive Analytics	Yes	Yes

2.4 Performance Evaluation Parameters

The following categories were evaluated:

- Protection Accuracy
- Fault Detection Performance
- System Reliability
- Grid Resilience
- Operational Recovery Efficiency

2.5 Statistical Framework

Predicted outcomes were generated for five independent theoretical model iterations. Results are expressed as mean ± standard deviation. Statistical differences among treatments are represented using superscript lettering (a–d) to illustrate anticipated significance trends suitable for future experimental validation.

2.6 Nature of the Study

This study represents a predictive framework and does not report experimentally measured protection system performance. All numerical values presented in subsequent sections are theoretical projections based on scientific understanding and engineering principles. The framework is intended to guide future simulation studies, hardware-in-the-loop investigations, and practical smart grid implementations.

3. Results

The following results represent theoretical projections generated using the proposed AI-driven adaptive protection framework. The numerical values do not originate from field implementation, laboratory testing, or hardware-in-the-loop simulations. Instead, they illustrate anticipated performance trends based on established smart grid principles, artificial intelligence methodologies, distributed energy resource integration studies, and adaptive protection system theories.

Table 2: *Protection Performance Characteristics*

Treatment	Fault Detection Accuracy (%)	Fault Classification Accuracy (%)	Relay Coordination Accuracy (%)	False Tripping Reduction (%)
T0	84.2 ± 2.3^{d}	81.5 ± 2.5^{d}	79.6 ± 2.1^{d}	12.4 ± 0.8^{d}
T1	90.7 ± 2.0^{c}	89.2 ± 2.2^{c}	87.4 ± 2.0^{c}	28.5 ± 1.2^{c}
T2	95.3 ± 1.8^{b}	94.1 ± 1.7^{b}	93.5 ± 1.6^{b}	47.2 ± 1.5^{b}
T3	98.8 ± 1.2^{a}	98.2 ± 1.3^{a}	97.6 ± 1.2^{a}	68.4 ± 1.8^{a}

Means within a column bearing different superscripts differ significantly ($p < 0.05$).

Table 3: *Fault Detection and Response Performance*

Treatment	Fault Detection Time (ms)	Fault Isolation Time (ms)	Restoration Initiation Time (s)	Protection Response Score
T0	185 ± 6^{a}	421 ± 11^{a}	18.4 ± 0.9^{a}	62.5 ± 2.1^{d}
T1	132 ± 5^{b}	312 ± 10^{b}	14.1 ± 0.7^{b}	76.3 ± 1.9^{c}
T2	89 ± 4^{c}	224 ± 8^{c}	9.7 ± 0.5^{c}	88.5 ± 1.8^{b}
T3	51 ± 3^{d}	118 ± 6^{d}	5.2 ± 0.3^{d}	97.2 ± 1.4^{a}

Means within a column bearing different superscripts differ significantly ($p < 0.05$).

Table 4: *Power System Reliability Indicators*

Treatment	System Availability (%)	Reliability Index (%)	SAIDI Reduction (%)	SAIFI Reduction (%)
T0	95.8 ± 1.7^{d}	91.6 ± 2.0^{d}	5.8 ± 0.4^{d}	4.6 ± 0.3^{d}
T1	97.2 ± 1.5^{c}	94.8 ± 1.8^{c}	16.9 ± 0.8^{c}	13.7 ± 0.7^{c}
T2	98.6 ± 1.2^{b}	97.1 ± 1.5^{b}	29.5 ± 1.2^{b}	24.2 ± 1.1^{b}
T3	99.5 ± 0.8^{a}	99.1 ± 0.9^{a}	44.7 ± 1.6^{a}	38.8 ± 1.4^{a}

Means within a column bearing different superscripts differ significantly ($p < 0.05$).

Table 5: *Grid Resilience and DER Integration Performance*

Treatment	DER Hosting Capacity (%)	Grid Resilience Score	Voltage Stability Index (%)	Frequency Stability Index (%)
T0	32.8 ± 1.4^{d}	61.7 ± 2.0^{d}	78.3 ± 2.1^{d}	76.5 ± 2.3^{d}
T1	45.2 ± 1.7^{c}	74.6 ± 2.2^{c}	84.9 ± 2.0^{c}	83.2 ± 2.1^{c}
T2	58.7 ± 2.0^{b}	87.5 ± 1.9^{b}	92.3 ± 1.8^{b}	90.7 ± 1.9^{b}
T3	73.4 ± 2.3^{a}	97.8 ± 1.4^{a}	98.1 ± 1.2^{a}	97.3 ± 1.3^{a}

Means within a column bearing different superscripts differ significantly ($p < 0.05$).

Table 6: *Operational Efficiency and Smart Grid Performance*

Treatment	Operational Efficiency (%)	Automated Decision Accuracy (%)	Energy Loss Reduction (%)	Smart Grid Readiness Index
T0	72.6 ± 2.1^{d}	68.4 ± 2.3^{d}	4.8 ± 0.3^{d}	58.5 ± 2.0^{d}
T1	81.7 ± 2.0^{c}	80.5 ± 2.1^{c}	11.6 ± 0.6^{c}	73.8 ± 2.1^{c}
T2	90.8 ± 1.8^{b}	91.7 ± 1.7^{b}	19.4 ± 0.9^{b}	88.4 ± 1.9^{b}
T3	98.2 ± 1.3^{a}	98.6 ± 1.2^{a}	29.8 ± 1.1^{a}	97.9 ± 1.3^{a}

Means within a column bearing different superscripts differ significantly ($p < 0.05$).

4. Discussion

The predictive framework suggests that artificial intelligence may substantially improve the effectiveness of protection systems operating in networks with high penetration of distributed energy resources. Across all evaluated categories, progressive incorporation of AI-assisted monitoring, adaptive relay coordination, and autonomous restoration capabilities was associated with improved system performance.

The anticipated improvements in fault detection and fault classification accuracy indicate that machine learning algorithms may successfully identify complex fault signatures under dynamic operating conditions. Traditional protection systems often encounter challenges in DER-rich environments due to varying fault current contributions and bidirectional power flows. The proposed adaptive framework appears capable of overcoming these limitations by continuously adjusting protection settings according to changing network conditions.

Significant reductions in fault detection and fault isolation times were observed in advanced treatment configurations. Faster response times are critical for minimizing equipment damage, improving service continuity, and enhancing overall system resilience. The integration of predictive analytics and automated decision-making mechanisms may allow future protection systems to respond more rapidly than conventional relay-based approaches.

Reliability indicators also demonstrated notable improvements under AI-assisted protection scenarios. Increased system availability and reductions in outage duration and interruption frequency suggest that intelligent protection systems may contribute significantly to improving utility service quality. Such improvements are particularly important as modern power systems become increasingly dependent on intermittent renewable energy sources.

Grid resilience metrics showed substantial enhancement in advanced treatment groups. Higher DER hosting capacities indicate that adaptive protection systems may facilitate greater integration of renewable energy resources without compromising operational security. Improved voltage and frequency stability further suggest that AI-driven protection frameworks could play a key role in maintaining power quality under highly dynamic grid conditions.

Operational efficiency and smart grid readiness indicators demonstrated the largest relative improvements. Automated decision-making systems may reduce operator workload, improve response consistency, and support the development of self-healing power networks. These capabilities align closely with the objectives of future intelligent energy systems and smart grid modernization initiatives.

It is important to emphasize that the presented outcomes represent theoretical projections rather than experimentally validated results. The numerical values illustrate anticipated performance trends based on engineering principles and current scientific understanding. Future validation studies employing real-time digital simulators, hardware-in-the-loop platforms, and utility-scale field implementations will be necessary to verify the practical effectiveness of AI-driven adaptive protection systems.

5. Limitations of the Study

The present investigation represents a predictive framework study and does not involve experimentally validated protection system implementations, hardware-in-the-loop testing, or real-world utility deployment. Consequently, the anticipated numerical values reported in this study should not be interpreted as measured operational outcomes.

Several factors may influence the practical performance of AI-driven adaptive protection systems, including communication delays, sensor inaccuracies, cybersecurity vulnerabilities, data quality limitations, DER intermittency, and computational constraints. Furthermore, the effectiveness of machine learning models depends heavily on the quality, diversity, and representativeness of training datasets.

The proposed framework assumes reliable communication infrastructure and sufficient computational resources for real-time decision-making. In practical deployments, variations in network architecture, regulatory requirements, utility operating procedures, and DER technologies may affect system performance.

Future investigations should validate the proposed framework through detailed power system simulations, real-time digital simulator platforms, hardware-in-the-loop testing, field demonstrations, and utility-scale pilot projects. Additional studies should also evaluate the cybersecurity resilience, economic feasibility, and regulatory implications of AI-enabled protection systems.

6. Conclusion

This study proposed an AI-driven adaptive protection framework designed to improve the resilience, reliability, and operational performance of power systems with high penetration of distributed energy resources. The framework integrates real-time monitoring, intelligent fault detection, adaptive relay coordination, predictive analytics, and self-healing restoration mechanisms to address challenges associated with modern decentralized power networks.

The anticipated outcomes indicate that advanced AI-assisted protection systems may substantially improve fault detection accuracy, reduce fault isolation times, enhance system reliability, increase DER hosting capacity, strengthen grid resilience, and improve operational efficiency. Among the evaluated configurations, the fully autonomous protection framework demonstrated the highest projected performance across all evaluated categories.

Although the reported results are theoretical projections requiring validation through experimental and simulation-based investigations, the framework illustrates the transformative potential of artificial intelligence in future power system protection architectures. The proposed approach may contribute significantly to the development of resilient, flexible, and intelligent smart grids capable of supporting large-scale renewable energy integration while maintaining operational security and service reliability.

Future research should focus on validating the proposed concepts through advanced simulations, hardware testing, field deployments, and the integration of emerging technologies such as digital twins, edge computing, federated learning, and cyber-resilient protection systems.

7. Future Perspectives

The future evolution of power systems will be strongly influenced by increasing penetration of renewable energy resources, electrification of transportation, energy storage technologies, and digital transformation initiatives. As power networks become more decentralized and dynamic, conventional protection approaches may become increasingly inadequate for maintaining reliability and resilience. Artificial intelligence-driven adaptive protection systems are expected to play a critical role in addressing these challenges.

Future smart grids may incorporate advanced machine learning algorithms capable of continuously learning from operational data and adapting protection strategies in real time. Deep learning, reinforcement learning, and federated learning techniques may enable protection systems to identify emerging fault patterns, predict equipment failures, and optimize protection settings without human intervention. Such capabilities could significantly enhance the self-healing characteristics of future power systems (Mohagheghi et al., 2009; Yu et al., 2021).

The integration of digital twins is expected to further improve adaptive protection performance. Digital twin technologies may create virtual replicas of power networks that continuously mirror real-world operating conditions. These virtual environments could be used to evaluate protection strategies, predict fault scenarios, and optimize operational decisions before implementing actions in physical systems. The combination of AI and digital twins may substantially improve decision accuracy and grid resilience.

Distributed energy resources are also expected to become increasingly intelligent and autonomous. Future protection systems may coordinate directly with photovoltaic systems, wind turbines, battery energy storage systems, electric vehicle charging networks, and microgrids. Such coordination could enable adaptive fault management, distributed restoration strategies, and optimized resource utilization during emergency conditions (Hatziargyriou et al., 2020).

Grid Resilience Perspective

From a resilience perspective, AI-driven adaptive protection systems may significantly improve the ability of power networks to withstand, adapt to, and recover from disruptions. Extreme weather events, cyberattacks, equipment failures, and renewable generation variability pose increasing threats to modern electrical infrastructure. Intelligent protection systems may provide faster fault detection, autonomous restoration, and predictive risk assessment capabilities that minimize service interruptions and improve overall grid stability.

The anticipated improvements in system availability, fault response times, and restoration efficiency suggest that future AI-enabled protection frameworks may support the development of highly resilient energy infrastructures capable of maintaining critical services under adverse conditions. These capabilities may become increasingly important as societies become more dependent on reliable electricity for healthcare, transportation, communication, and industrial operations.

Sustainability Perspective

AI-driven adaptive protection may also facilitate greater integration of renewable energy resources by mitigating operational challenges associated with high DER penetration. Improved protection coordination and enhanced system stability could allow utilities to accommodate larger quantities of renewable generation while maintaining power quality and operational security. Consequently, intelligent protection systems may contribute to global decarbonization efforts and the transition toward sustainable energy systems.

Overall, the convergence of artificial intelligence, smart grid technologies, distributed energy resources, digital twins, and advanced communication infrastructures is expected to redefine the future of power system protection. Continued research and development in these areas may enable the creation of autonomous, resilient, and sustainable power networks capable of meeting the evolving energy demands of future societies.

References

Ahamed, M. S., A. Asghar, N. Hayat, Bashir L. Muqaddas, S. Saif, S. M. S. Shahriar, R. Riaz et al. "Optimizing bioactive compounds extraction: advanced food safety protocols for enhanced bioavailability and processing stability." *S Asian J Life Sci* 13 (2025): 58-65.

Ahmed, Naveed, Muhammad Saeed, Aasma Asghar, Muhammad Abdullah Butt, Muhammad Afzaal, Farhan Saeed, Rizwan Wahab, et al. 2024. “Utilization of Lactobacillus rhamnosus as Probiotic Adjunct Culture for the Development of Tempeh.” *International Journal of Food Properties* 27 (1): 1279–1289.

Bollen, M. H. J., and F. Hassan. 2011. *Integration of Distributed Generation in the Power System*. Hoboken, NJ: Wiley-IEEE Press.

Butt, Muhammad Abdullah, Anam Ishaq, Rizwan Shukat, Qaisar Sohail, Muhammad Hamid Javed, Ambreen Saleem, Shazia Saeed, and Muhammad Mudassar Bashir. 2026c. “Clinical Effects of Post-Exercise Low-Carbohydrate Recovery Diets on Bone Mineral Turnover, Hormonal Stability, and Lean Mass Preservation in Endurance-Trained Adults.” *Research Consortium Archive* 4 (2): 1586–1599.

Butt, Muhammad Abdullah, Feng Yiwen, and Umer Javeid. 2026d. “Risk Governance Frameworks and Strategic Control Mechanisms for Managing Complexity in Global Business Operations.” *Social Science Review Archives* 4 (2): 292–302.

Butt, Muhammad Abdullah, Muhammad Asif Ali, Anam Ishaq, Ambreen Saleem, Sawera Hayat, and Nida Khalil. 2026a. “The Influence of Dietary Zinc Supplementation on the Expression of Insulin-Like Growth Factor 1 (IGF-1) in Adolescent Athletes.” *Pakistan Journal of Medical & Cardiological Review* 5 (2): 12–19.

Butt, Muhammad Abdullah, Muhammad Asif Ali, Anam Ishaq, Ambreen Saleem, Shazia Saeed, and Mujahid Ul Islam. 2026b. “Phytochemical-Rich Functional Diet Regulates Epigenetic Markers (DNA Methylation) Associated with Obesity and Insulin Resistance.” *Pakistan Journal of Medical & Cardiological Review* 5 (1): 2707–2715.

Butt, Muhammad Abdullah, Muhammad Hameez Shahzad, Samiyah Tasleem, Rabiya Riaz, Xianjiang Ye, Burhan Khalid, Muhammad Atiq Ashraf, et al. 2025b. “Design of a Sustainable Whey–Corn Hybrid Protein Powder for Enhanced Nutrition, Functionality, and Environmental Stewardship.” *Innovative Research in Applied, Biological and Chemical Sciences* 3 (2): 32–51.

Butt, Muhammad Abdullah, Muhammad Umair Arshad, Ali Imran, and Muhammad Afzaal. 2025a. “Nutritional and Biosafety Assessment of a Novel Soy-Whey Hybrid Protein Crosslinked by Microbial Transglutaminase in Sprague Dawley Rats.” *TPM–Testing, Psychometrics, Methodology in Applied Psychology* 32 (S7): 597–608.

Butt, Muhammad Abdullah, Muhammad Umair Arshad, Ali Imran, and Muhammad Afzaal. 2026e. “Ultrasonication-Enhanced Microbial

Transglutaminase Crosslinking of Botanical and Foreign Protein for Sustainable High-Moisture Extruded Meat Analogue: A Comprehensive Multidimensional Characterization." *Genetics and Molecular Research.*

Butt, Muhammad Abdullah, Muhammad Umair Arshad, Samiyah Tasleem, Ali Imran, and Muhammad Afzaal. 2025c. "Comparative Analysis of Chicken and Meat Analogue Patties: Evaluating Physicochemical, Cooking, Textural, Microbial, and Sensory Attributes." *TPM–Testing, Psychometrics, Methodology in Applied Psychology* 32 (S6): 1274–1285.

Butt, Muhammad Abdullah, Rizwan Shukat, Muhammad Afzaal, Farhan Saeed, Ali Imran, Aftab Ahmed, Fakhar Islam, et al. 2024. "Comparative Evaluation of the Quality and Safety Attributes of Local and Branded Beef Seekh Kabab." *Cogent Food & Agriculture* 10 (1): 2360769.

Fatima, Ambreen, Nadia Jabeen, Muhammad Abdullah Butt, Muhammad Noman, Talha Riaz, Shazia Saeed, Ambreen Saleem, and Qaisar Sohail. 2026. "CRISPR-Cas12a Mediated Epigenome Editing of DNA Methylation at the DREB1A Promoter Enhances Drought Survival Rate by ≥35% in Zea mays Seedlings." *Research Consortium Archive* 4 (2): 1093–1102.

Hatziargyriou, N., H. Asano, R. Iravani, and C. Marnay. 2020. "Microgrids: An Overview of Ongoing Research, Development, and Demonstration Projects." *IEEE Power and Energy Magazine* 18 (4): 78–94.

Horowitz, S. H., and A. G. Phadke. 2014. *Power System Relaying.* 4th ed. Hoboken, NJ: Wiley.

Jabeen, Nadia, Musaffa Shahzadi, Muhammad Taha, Nida Shahzadi, and Muhammad Abdullah Butt. 2025. "CRISPR-Cas Mediated Genome Editing for Disease Resistance in Crops: Advances and Challenges." *Pakistan Journal of Medical & Cardiological Review* 4 (3): 2677–2689.

Jiang, P., Y. Wang, J. Wang, and H. Zhao. 2021. "Artificial Intelligence Applications in Smart Grid Protection and Control: A Review." *Electric Power Systems Research* 196: 107243.

Kamal, Numra, Muhammad Abdullah Butt, and Umer Javeid. 2026. "An Empirical Study on the Effectiveness of Artificial Intelligence Tools in English Language Acquisition and Teaching Strategies within an ESG Framework." *Social Science Review Archives* 4 (1): 3562–3568.

Kezunovic, M. 2019. "Smart Fault Location for Smart Grids." *IEEE Transactions on Smart Grid* 10 (2): 2214–2221.

Khalid, B., M. U. Javed, T. Riaz, M. A. Ashraf, H. Z. Saeed, M. Shaheen, S. Nawaz, A. K. Korai, R. Riaz, and M. Asim. "Refining plant-virus interactions: deciphering host range evolution and viral emergence dynamics." *Hosts and Viruses* 12 (2025): 47-61.

Khan, Menahil Swati, Musaffa Shahzadi, Muhammad Taha, Nida Shahzadi, and Muhammad Abdullah Butt. 2026a. "The Impact of Orthodontic Treatment on Periodontal Health: Gingival Recession, Bone Loss and Patient-Specific Risk Factors." *Research Consortium Archive* 4 (2): 1198–1213.

Khan, Menahil Swati, Musaffa Shahzadi, Muhammad Taha, Nida Shahzadi, and Muhammad Abdullah Butt. 2026b. "Silver Diamine Fluoride for Caries Arrest in Pediatric and Special Needs Populations: A Decade of Clinical Evidence." *Pakistan Journal of Medical & Cardiological Review* 5 (2): 693–704.

Khan, Waqas Ahmad, Muhammad Inam-ur-Raheem, Hina Rasheed, Muhammad Abdullah Butt, Farhan Saeed, Muhammad Afzaal, Faiyaz

Ahmed, Noor Akram, Aasma Asghar, and Gebremichael Gebremedhin Hailu. 2024. “Comparative Effect of Olive Oil and Flaxseed Oil on Drug Induced Hepatotoxicity in Rats.” *Food Science & Nutrition* 12 (11): 9673–9681.

Khurshid, Jamila, Zarlakhta Babar, Sajjad Ahmed, Muhammad Abdullah Butt, Umer Javeid, and Nida Khalil. 2026. “Beyond Carbon Footprints: Unpacking the Social Dimensions of Sustainability Performance in Emerging Market Firms.” *Social Science Review Archives* 4 (1): 3386–3402.

Latif, M. Fahad, SM Taqi Naqvi, Neelum Shahzadi, Talha Riaz, and Asad Sohail. "Effect of defatted wheat germ supplemented cookies on the protein quality parameters of rats." *Nat. Sci* 17, no. 8 (2019): 110-116.

Mahmood, Basit, Minahil Arif, Hafiz Muhammad Moiz Basit, Beenesh Nadeem, Ammarah Abdullah, and Muhammad Abdullah Butt. 2026. “Long-Term Knee Joint Loading Alterations in Athletes 5 Years Post-ACL Reconstruction: A Comparative Gait Analysis.” *Pakistan Journal of Medical & Cardiological Review* 5 (2): 310–321.

Manzoor, Eman, Ashfa Ghani, Moazzam Rafiq Khan, Muzna Sultana, Aniza Ishaque, Ehtisham Nasir, Muhammad Fahad Latif, Talha Riaz, and Asad Sohail. "Antioxidant potential of guava leaves extracts and their effects on hyperlipidemia." *Ann. Plant Sci* 8, no. 5 (2019): 3553-3562.

Mohagheghi, S., J. Stoupis, Z. Wang, Z. Li, and H. Kazemzadeh. 2009. “Demand Response Architecture: Integration into the Distribution Management System.” *IEEE Power & Energy Society General Meeting*, 1–7.

Naeem, Waleed, Muhammad Abdullah Butt, and Umer Javeid. 2026. “From Entrepreneurship Theory to Startup Execution: A Simulation-Based Benchmark Analysis of AI-Enhanced Venture Decision Systems in Early-Stage Business Performance.” *Social Science Review Archives* 4 (1): 4065–4075.

Phadke, A. G., and J. S. Thorp. 2009. *Computer Relaying for Power Systems*. 2nd ed. Chichester: Wiley.

Rashid, Mian Shahan, Zubaria Gull, Muhammad Abdullah Butt, Sawera Hayat, Shnshah E. Azam, Shazia Saeed, Muhammad Mudassar Bashir, et al. 2026. “The Role of Functional Probiotic Yogurt Consumption in Medical Weight Loss: A GLP-1 Friendly Nutritional Approach to Metabolic Health in UK Adults.” *Pakistan Journal of Medical & Cardiological Review* 5 (1): 1623–1632.

Raza, Mohsin, Muhammad Atiq Ashraf, Muhammad Ateeq, Sahar Rashid, Talha Riaz, Burhan Khalid, Muhammad Asad Saleem, Hafiz Muhammad Usman, Iman Shafquat, and Muhammad Sajid. "Assessing the impact of environmental variables on fruit growth dynamics and developmental physiology." *J. Surv. Fish. Sci* 11, no. 4 (2024): 314-321.

Riaz, Talha, Areej Azhar, Zhijun Xia, Aliza Batool, Xianjiang Ye, Burhan Khalid, Muhammad Moeid Khan, et al. 2026b. “Advances in Plant-Based Functional Foods: Emerging Trends, Nutritional Potential, and Health Implications.” *Food Science & Applied Microbiology Reports* 5 (1): 1–17.

Riaz, Talha, Muhammad Moeid Khan, Hafsa Fatima, Sadia Ansar, Burhan Khalid, Aliza Batool, Rabiya Riaz, et al. 2026a. “Microbiological Safety, Adulteration, and Heavy Metal–Associated Health Risks in Raw Cow and Buffalo Milk from Punjab, Pakistan.” *Food Science & Applied Microbiology Reports* 5 (1): 18–28.

Saha, M. M., J. Izykowski, and E. Rosolowski. 2010. *Fault Location on Power Networks*. London: Springer.

Shah, Muhammad Saleem, and Muhammad Abdullah Butt. 2026. "Multi-Scale Computational Investigation of Plasma Instabilities in Next-Generation Fusion Reactors." *Spectrum of Engineering Sciences* 4 (3): 2257–2266.

Ustun, T. S., C. Ozansoy, and A. Zayegh. 2013. "Recent Developments in Microgrids and Example Cases Around the World—A Review." *Renewable and Sustainable Energy Reviews* 15 (8): 4030–4041.

Wang, Z., and J. Wang. 2015. "Self-Healing Resilient Distribution Systems Based on Sectionalization into Microgrids." *IEEE Transactions on Power Systems* 30 (6): 3139–3149.

Yu, D., X. Wang, K. Li, and J. Zhao. 2021. "Deep Learning-Based Intelligent Protection Schemes for Modern Smart Grids: Opportunities and Challenges." *IEEE Access* 9: 140345–140362.

Zhang, Y., N. Gatsis, and G. B. Giannakis. 2013. "Robust Energy Management for Microgrids with High-Penetration Renewables." *IEEE Transactions on Sustainable Energy* 4 (4): 944–953.