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Adaptive and Secure Dynamic Voltage Restoration in Smart Power Networks: A Text-Based Integrative Research Study on PI-Controlled DVRs, Converter Coordination, Energy Management, and Cyber-Physical Resilience

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ABSTRACT

This article develops a publication-ready integrative research study on dynamic voltage restorers (DVRs) controlled through proportional-integral (PI) strategies in modern smart power environments. The study is grounded strictly in the provided references and addresses an increasingly important problem in electrical engineering: how to maintain voltage quality, mitigate sag events, strengthen distribution reliability, and position DVR-based architectures within broader smart-grid, renewable-energy, storage, and cyber-physical operating contexts. The reviewed literature consistently demonstrates that PI-controlled DVR systems remain central to practical voltage restoration because they balance implementation simplicity, interpretability, controllability, and acceptable dynamic response under industrial and distribution-level disturbances (Chen & Li, 2023; Singh & Sharma, 2022; Wang & Zhang, 2023). At the same time, recent studies point toward a more complex operating environment in which DVRs are no longer isolated compensating devices, but parts of multi-layered infrastructures that include grid-linked solar systems, battery charging subsystems, bidirectional converters, electric vehicle interfaces, cloud-assisted monitoring, and increasingly intelligent digital control ecosystems (Ganesh Kumari et al., 2022; Katyal et al., 2024; Ayyappa et al., 2025; Thangam et al., 2021).

Using a qualitative integrative methodology, this article synthesizes conceptual, control-oriented, and application-focused insights from the supplied sources. The results show four major findings. First, PI-controlled DVRs remain one of the most operationally viable approaches for sag mitigation and voltage regulation across industrial and smart-grid settings (Hussain & Qamar, 2023; Patel & Kumar, 2023; Rao & Kumar, 2024). Second, optimization of controller tuning materially improves compensation quality, response speed, and stability margins (Khan & Li, 2023; Kumar & Gupta, 2024; Sharma & Kumar, 2023). Third, converter topology and storage coordination strongly influence the practical success of DVR deployments in renewable and distributed energy contexts (Swetha et al., 2021; Katyal et al., 2024). Fourth, as power systems become digitized, cybersecurity, cloud resilience, and explainable intelligent supervision become essential complementary dimensions rather than external concerns (Haritha et al., 2024; Vellela & Balamanigandan, 2024; Mandava, Vellela, Gorintla, et al., 2025). The article concludes by proposing a comprehensive interpretive framework for next-generation DVR deployment and identifies research directions linking power quality engineering with trustworthy cyber-physical intelligence.

Keywords: Dynamic voltage restorer, PI controller, voltage sag mitigation, smart grid, power quality, converter coordination, cyber-physical security.

INTRODUCTION

Electrical power systems have undergone a profound transformation over the past two decades. Traditional centralized power architectures are being reshaped by renewable generation, electric mobility, distributed storage, bidirectional power flow, digital monitoring, cloud-based supervisory functions, and intelligent control. Within this changing environment, power quality has become a central issue rather than a secondary operational concern. Modern industrial users, digital infrastructures, automated production lines, data-sensitive facilities, and smart buildings all depend on stable voltage conditions for safe and reliable performance. Even short-duration voltage disturbances can damage equipment, interrupt production processes, corrupt computational tasks, shorten device lifespans, and produce substantial economic losses. Among these disturbances, voltage sag remains one of the most operationally disruptive phenomena in practical power systems, especially in industrial and distribution settings (Chen & Wang, 2023; Jiang & Wu, 2023; Xu & Liu, 2023).

The dynamic voltage restorer has emerged as one of the most significant compensating devices for this problem. A DVR is generally understood as a series-connected custom power device designed to inject a compensating voltage into the supply line whenever a sag or related disturbance occurs, thereby preserving the desired load-side voltage profile. The practical appeal of the DVR lies in its targeted function: rather than redesigning the entire power network or overbuilding source-side infrastructure, it addresses voltage quality at the point where sensitive loads actually require support. This application logic helps explain why DVR research has remained active across industrial electronics, power delivery, energy conversion, and smart-grid studies (Singh & Sharma, 2022; Patel & Kumar, 2023; Rao & Kumar, 2024). The supplied references consistently present the DVR not as an abstract device, but as an engineering solution whose performance depends on control architecture, optimization strategy, converter coordination, and context-specific deployment requirements.

Among control methods used for DVR operation, PI control remains especially prominent. The persistence of the PI controller in the literature is not accidental. Although advanced intelligent and nonlinear control methods are often proposed in the broader control systems literature, PI strategies continue to occupy a privileged position in applied power engineering because of their conceptual simplicity, implementation maturity, low computational burden, and relatively transparent tuning process. Several of the provided studies explicitly show that PI-based DVR control can support effective voltage restoration, sag compensation, and overall power quality improvement when appropriately designed and tuned (Chen & Li, 2023; Mishra & Gupta, 2022; Zhang & Li, 2023). Other studies go further, arguing that optimization of PI parameters materially strengthens dynamic response, steadiness, and mitigation performance under varying conditions (Khan & Li, 2023; Kumar & Gupta, 2024; Sharma & Kumar, 2023). Taken together, these sources show that the engineering question is not whether PI control is obsolete, but rather how it can be refined, contextualized, and integrated into increasingly complex smart power environments.

This issue becomes more important when the DVR is examined in relation to wider developments in energy systems. The references provided for this article do not only concern DVRs. They also include work on photovoltaic battery charging architectures, grid-linked solar power systems with storage, SEPIC converters, bidirectional DC/AC and DC/DC converters for plug-in hybrid vehicles, and battery balancing strategies for electric vehicles (Ganesh Kumari et al., 2022; Thangam et al., 2021; Katyal et al., 2024; Swetha et al., 2021; Ayyappa et al., 2025). At first glance, these topics might appear peripheral to DVR research. In reality, they are highly relevant. Modern voltage quality compensation is increasingly situated in systems where converter efficiency, storage management, bidirectional energy exchange, and distributed resource coordination affect not only energy flow but also compensating performance. A DVR deployed in a conventional radial feeder without renewable integration faces a different operational environment from one deployed in a digitally monitored smart grid that contains solar generation, battery storage, vehicle charging interfaces, and rapidly varying load patterns. Consequently, a contemporary study of PI-controlled DVR systems must go beyond controller behavior in isolation and consider the broader electro-energetic ecosystem in which compensation occurs.

Another important reason for expanding the analytical frame is the digitization of power infrastructures. Several provided references address topics such as intrusion detection, secure cloud environments, blockchain-SDN architectures, explainable artificial intelligence, and trustworthy decision support (Biyyapu et al., 2024; Haritha et al., 2024; Vellela & Balamanigandan, 2024; Mandava, Vellela, Malathi, et al., 2025; Mandava, Vellela, Gorintla, et al., 2025). These are not classical power quality papers, yet they are directly relevant to the future of smart grids. As electric power systems become more software-defined, data-intensive, and communication-dependent, cybersecurity and interpretability become part of functional reliability. A DVR that performs well in a laboratory environment may fail to deliver dependable value in the field if its supervisory signals, coordination layer, monitoring data, or adaptive logic are vulnerable to manipulation, opacity, or communication failure. The deeper implication is that voltage quality engineering is evolving from a hardware-control problem into a cyber-physical trust problem. This article therefore treats cyber resilience and explainability not as decorative additions, but as necessary dimensions of next-generation DVR deployment.

The literature supplied also reveals a conceptual gap. Most DVR studies focus on control effectiveness, sag mitigation capability, or voltage restoration outcomes in relatively bounded technical environments (Hussain & Qamar, 2023; Jiang & Wu, 2023; Zhao & Yang, 2023). Meanwhile, studies on converters, storage, distributed energy coordination, cloud security, and explainable intelligence often proceed in separate domains (Katyal et al., 2024; Haritha et al., 2024; Mandava, Vellela, Malathi, et al., 2025). What remains insufficiently articulated is an integrative perspective showing how PI-controlled DVRs can be understood as part of a larger smart-grid architecture that combines compensation performance, converter interoperability, storage-aware operation, communication resilience, and trustworthy digital oversight. This gap is significant because future distribution systems will not reward narrowly optimized subsystems that cannot coordinate with the broader operating environment.

Accordingly, the central problem addressed in this article is the following: how can PI-controlled dynamic voltage restorers be theoretically and operationally understood as core devices within secure, adaptive, and distributed smart power networks? The article does not attempt to invent unsupported numerical results. Instead, it offers a rigorous text-based integrative research study grounded strictly in the supplied references. Its objectives are fourfold. First, it synthesizes the literature on PI-controlled DVR performance in voltage regulation and sag mitigation. Second, it examines the significance of controller optimization and context-sensitive tuning for practical deployment. Third, it situates DVR systems within adjacent developments in converters, storage systems, photovoltaic integration, and smart-grid energy management. Fourth, it interprets cybersecurity, cloud resilience, and explainable intelligence as emerging requirements for future DVR ecosystems.

The originality of this article lies in the interpretive bridge it constructs across these literature streams. Rather than treating DVR control, converter design, storage coordination, and digital trust as unrelated topics, it argues that they are now mutually constitutive components of modern power quality engineering. In this sense, the article is both synthetic and constructive. It synthesizes the supplied evidence while constructing a broader research logic for how engineers and researchers might think about next-generation voltage restoration systems. Such a perspective is urgently needed because the success of future smart grids will depend not simply on whether individual components perform well in isolation, but on whether they remain stable, understandable, secure, and interoperable under real operating pressures.

The remainder of this article develops that argument in a continuous scholarly format. The methodology explains the qualitative integrative design used to derive findings from the supplied references. The results identify the dominant patterns emerging from the literature on PI-controlled DVRs and their wider system context. The discussion interprets the implications of these patterns for research and deployment, including limitations and future directions. The conclusion closes by articulating a coherent pathway for advancing DVR-centered voltage quality engineering in secure and intelligent smart power systems.

Methodology

This study adopts a qualitative integrative research methodology based strictly on the references supplied by the requester. The methodological objective is not to perform a statistical meta-analysis, a simulation study, or a laboratory validation, because such procedures would require primary datasets, experimental parameters, or replicated computational environments not contained within the source list. Instead, the present article uses an interpretive, text-based synthesis approach suited to producing an original, publication-ready research narrative from a bounded corpus of technical and conceptual literature. The chosen methodology is appropriate because the references represent multiple but interrelated research strands: dynamic voltage restorer performance, PI controller optimization, power quality management, converter architectures, energy storage coordination, smart-grid applications, cybersecurity mechanisms, and explainable digital intelligence.

The first methodological stage involved thematic delimitation. Although the supplied corpus spans power electronics, converter control, energy management, wireless and cloud security, intrusion detection, and explainable AI, the dominant technical core concerns voltage regulation and sag mitigation through DVR systems operated with PI-based control strategies. For that reason, DVR-centered power quality engineering was treated as the primary anchor theme. However, the methodology did not exclude references outside that immediate theme. Instead, those references were evaluated for system-level relevance. For example, studies on battery charging converters, solar PV energy management, and bidirectional converter design were interpreted as supporting literature for understanding the operational ecosystem in which future DVRs may function (Ganesh Kumari et al., 2022; Katyal et al., 2024; Ayyappa et al., 2025). Similarly, studies on cloud security, intrusion detection, and explainable AI were read as informing the digital trust and resilience requirements of intelligent grid infrastructures (Biyyapu et al., 2024; Haritha et al., 2024; Mandava, Vellela, Gorintla, et al., 2025).

The second methodological stage involved thematic coding. Each reference was read through the lens of one or more analytical categories. These categories were developed inductively from the titles and scope of the provided literature. The resulting interpretive categories were: voltage sag mitigation, voltage regulation quality, PI controller effectiveness, controller optimization, industrial deployment context, smart-grid applicability, converter topology relevance, energy storage and bidirectional flow coordination, digital supervisory resilience, cybersecurity, and explainability of intelligent support systems. References were then grouped according to their strongest thematic contribution, while also allowing certain sources to contribute to multiple categories. For example, a paper on optimized DVR control could inform both controller effectiveness and smart-grid applicability, while a study on cloud-integrated network security could inform both digital resilience and cyber-physical reliability.

The third stage involved comparative synthesis. Within the DVR-focused literature, the study compared how different authors framed the goals of PI-controlled compensation. Some sources emphasized voltage regulation under general distribution network conditions (Chen & Li, 2023; Li & Zhao, 2022). Others foregrounded voltage sag mitigation in industrial environments (Jiang & Wu, 2023; Hussain & Qamar, 2023; Xu & Liu, 2023). Still others placed DVRs in smart-grid settings where voltage quality improvement intersected with system adaptability and modernized infrastructure demands (Patel & Mehta, 2022; Sarkar & Sinha, 2024; Soni & Garg, 2024). These differences were not treated as contradictions. Instead, they were interpreted as reflecting the expanding application envelope of DVR technology. Comparative synthesis also focused on the distinction between baseline PI control and optimized PI control. Here, the methodological aim was to identify a recurring pattern: numerous studies did not merely affirm the usefulness of PI control, but specifically emphasized parameter optimization as a decisive factor in improving compensation quality (Patel & Kumar, 2023; Khan & Li, 2023; Kumar & Gupta, 2024; Sharma & Kumar, 2023).

The fourth stage involved contextual integration. This was an essential part of the study because a purely device-level reading of the corpus would have left significant references analytically isolated. Converter-focused studies were integrated into the narrative to clarify how future DVR deployments may interact with battery systems, solar PV resources, plug-in hybrid vehicles, and grid-tied storage arrangements (Swetha et al., 2021; Thangam et al., 2021; Katyal et al., 2024; Ayyappa et al., 2025). This contextualization rests on a theoretical premise strongly supported by contemporary smart-grid thinking: voltage quality compensation cannot be understood independently from the broader architecture of power flow control and distributed energy management. In practical terms, the converter characteristics that govern charging, inversion, balancing, and energy exchange also shape the environment in which voltage support resources must act.

The fifth stage involved cyber-physical extrapolation grounded in the supplied references. This stage required particular care because the cybersecurity and explainability papers are not direct studies of DVR hardware. To remain methodologically rigorous, the study did not claim that these sources empirically tested DVR systems. Instead, it interpreted them as adjacent evidence relevant to digitalized power infrastructures. For example, intrusion detection and secure cloud environment studies were used to argue that increasingly connected smart-grid compensation systems will require robust communication protection and anomaly awareness (Biyyapu et al., 2024; Vellela & Balamanigandan, 2024). Blockchain-SDN work was used to reflect on secure data coordination in cloud-integrated IoT contexts, which resembles the communication complexity emerging in smart power systems (Haritha et al., 2024). The explainable AI studies were not used to claim present AI control of DVRs, but rather to support a future-facing interpretive argument: when adaptive intelligence influences power quality decisions, transparency and trust will become essential operational values (Mandava, Vellela, Malathi, et al., 2025; Mandava, Vellela, Gorintla, et al., 2025).

The sixth methodological stage was conceptual framework development. After comparative synthesis and contextual integration, the literature was used to construct a multi-layer interpretive framework for next-generation DVR deployment. This framework is not presented as a mathematical model or proprietary architecture. It is an analytically reasoned structure built from the evidence patterns in the supplied corpus. The framework has four interdependent layers: compensating control, power electronic integration, energy management coordination, and cyber-physical trust. The compensating control layer concerns the DVR’s immediate function in voltage restoration and sag mitigation through PI-driven action. The power electronic integration layer concerns converter topology, storage interfaces, and bidirectional flow architectures. The energy management coordination layer concerns smart-grid and renewable-connected operating contexts. The cyber-physical trust layer concerns communication security, anomaly resilience, and interpretability of digital oversight. This framework serves as the conceptual backbone of the results and discussion sections.

To preserve scholarly integrity, the methodology also involved a disciplined evidentiary rule: every major technical interpretation in the article was grounded in one or more supplied references. Where broader inferences were made, they were explicitly developed from the intersections of those references rather than from external literature. This restriction is important because the task specifies that the article must be based strictly on the provided sources. Accordingly, the article does not introduce external studies, numerical claims, or theoretical authorities beyond the listed references. It also avoids presenting unverified experimental outcomes. The originality of the paper arises from synthesis, interpretation, and integrative conceptual development rather than from fabricated data.

The methodological approach has several strengths. It allows a coherent research article to emerge from a diverse but related corpus. It respects the technical specificity of the source literature while enabling broader scholarly interpretation. It also suits the absence of shared datasets, common metrics, and uniform experimental protocols across the provided references. At the same time, the approach has limitations. Because it is qualitative and text-based, it cannot quantify comparative effect sizes, rank controller variants by numerical superiority, or validate implementation under a single standardized testbed. Moreover, because the source list includes both tightly related and more indirectly related studies, interpretive discipline is needed to avoid overextending conclusions. This article addresses that limitation by distinguishing direct evidence from system-level inference throughout the narrative.

In sum, the methodology combines thematic coding, comparative synthesis, contextual integration, and conceptual framework development to produce a rigorous original article. Its aim is not to replace simulation or experimental work, but to create a theoretically rich and publication-ready scholarly contribution that organizes the supplied references into a meaningful research structure. Through this method, the study identifies the principal findings on PI-controlled DVR performance, clarifies the role of optimization, situates voltage restoration within evolving converter and storage ecosystems, and establishes the relevance of cybersecurity and explainability to future smart-grid compensation systems.

Results

The integrative analysis of the provided references reveals a coherent but multi-layered body of findings. At the most immediate level, the literature strongly supports the position that PI-controlled dynamic voltage restorers remain highly effective for voltage sag mitigation, voltage regulation, and broader power quality enhancement across distribution and industrial settings. At a second level, the literature indicates that simple deployment of PI control is not sufficient; controller tuning and optimization are decisive for achieving improved dynamic performance. At a third level, the research corpus shows that the future relevance of DVRs depends on how effectively they are embedded within converter-rich, storage-enabled, and renewable-integrated systems. At a fourth level, the nontraditional but relevant digital infrastructure references suggest that future power quality systems will increasingly depend on cyber-physical security, cloud robustness, and interpretable supervisory intelligence. These findings are described below in continuous analytical form.

The first major result is the strong convergence of the literature around the technical viability of the PI-controlled DVR as a practical solution for power quality management. Across the provided sources, the DVR appears not as a speculative technology but as a mature and adaptable compensator capable of maintaining voltage quality under disturbed conditions. Chen and Li (2023) present PI controller-based DVR operation as an effective strategy for voltage regulation in distribution networks, indicating that the device can preserve stable load-side voltage when line-side disturbances occur. Chen and Wang (2023) similarly associate DVR deployment with voltage sag compensation and broader enhancement of power quality. Jiang and Wu (2023) place emphasis on industrial power grids, reinforcing the point that the problem addressed by DVRs is not merely theoretical. Industrial users often operate highly sensitive loads whose tolerance for voltage deviation is limited, and the literature consistently positions the DVR as a critical protective device in such contexts.

This convergence becomes even clearer when examining the application range of the DVR studies. Some papers emphasize general distribution systems, while others specify industrial applications, smart grids, or broader power electronic environments (Li & Zhao, 2022; Xu & Liu, 2023; Sarkar & Sinha, 2024). Rather than indicating fragmentation, this range indicates adaptability. A central finding of the literature is that the same core technology can be tailored across multiple operational scales and environments. This adaptability strengthens the significance of the PI-controlled DVR because it suggests that the underlying control logic is robust enough to survive contextual variation. The practical implication is that engineers continue to rely on PI-based strategies precisely because they offer a transferable control framework across different implementations.

The second major result concerns the importance of optimization in PI-controlled DVR systems. Many of the supplied references move beyond generic support for PI control and focus specifically on optimization as a route to better performance. Patel and Kumar (2023) examine enhanced voltage regulation using an optimized DVR with PI control, while Wang and Zhang

(2023) address the mitigation of voltage sags through optimization strategies. Kumar and Gupta (2024) frame the issue in terms of design and optimization for voltage regulation, and Khan and Li (2023) explicitly link optimized PI control to both power quality improvement and sag mitigation. Sharma and Kumar (2023) similarly discuss optimization of the DVR for voltage sag mitigation through a PI control algorithm. This repeated emphasis across the literature reveals a clear pattern: the value of PI control lies not only in the controller structure itself, but in the quality of its parameterization.

This pattern is technically important because PI control is often criticized in advanced control discourse as being too simple for complex, nonlinear, or rapidly changing systems. The literature reviewed here complicates that critique. These studies do not deny complexity; instead, they demonstrate that careful tuning and optimization can substantially extend the performance envelope of PI-based systems. In this sense, the findings challenge a simplistic opposition between classical and advanced control paradigms. The research corpus suggests that engineering value depends less on novelty for its own sake and more on whether a controller can be tuned to deliver timely, stable, and predictable compensation under the actual conditions encountered in modern networks. The persistence of optimized PI control in recent studies indicates that it remains operationally competitive because it balances controllability, implementation familiarity, and performance.

The third major result is that voltage regulation and voltage sag mitigation are treated throughout the literature as closely linked but analytically distinct objectives. Some studies present voltage regulation as the primary goal, emphasizing the maintenance of desired voltage levels in distribution networks and smart-grid settings (Chen & Li, 2023; Kumar & Gupta, 2024; Zhao & Yang, 2023). Others focus more narrowly on sag events and compensation speed during disturbances (Zhang & Li, 2023; Hussain & Qamar, 2023; Wang & Zhang, 2023). The distinction matters because it implies different performance priorities. Voltage regulation emphasizes sustained stability and quality over operating periods, while sag mitigation emphasizes transient intervention and dynamic restoration during fault-related or disturbance-driven events. Yet the literature also shows that these objectives are deeply interconnected. A DVR that cannot respond quickly enough to a sag will fail to preserve regulation from the load perspective. Conversely, a DVR that compensates aggressively but destabilizes the load voltage over time may address the transient event while undermining broader quality goals. The result, therefore, is that effective DVR design must integrate transient responsiveness with steady-state quality preservation.

The fourth major result is that the literature increasingly situates DVR performance in smart-grid contexts rather than in isolated feeder models. Patel and Mehta (2022), Sarkar and Sinha (2024), and Soni and Garg (2024) all link optimized DVR operation and voltage quality improvement to smart-grid environments. This contextual movement is significant. In a conventional power system, compensation devices might be evaluated largely in terms of local effectiveness. In a smart grid, however, compensation becomes part of a larger responsive infrastructure characterized by distributed generation, variable load behavior, sensor-rich monitoring, and communication-enabled decision making. The literature therefore implies that DVR success in modern systems is not only a question of compensation amplitude or restoration speed, but also a question of system compatibility. Devices must be able to function under conditions where network states are more dynamic and operational dependencies are more interconnected than in earlier grid architectures.

The fifth major result concerns the relevance of converter and storage literature to the practical evolution of DVR systems. The provided references on battery charging converters, SEPIC systems, bidirectional vehicle-related converter design, and solar PV energy management collectively suggest that smart power networks are increasingly governed by complex power electronic interfaces (Ganesh Kumari et al., 2022; Thangam et al., 2021; Katyal et al., 2024; Ayyappa et al., 2025). This matters because a DVR is itself a power electronic compensation device. Its field performance cannot be fully understood apart from the converter-dense environments in which it will increasingly operate. For example, grid-linked solar PV systems with battery storage introduce variability in power availability and control coordination (Katyal et al., 2024). Battery charging and balancing architectures influence how stored energy may be managed and made available in support functions (Ganesh Kumari et al., 2022; Swetha et al., 2021). Bidirectional converter systems for hybrid vehicles indicate a future in which energy exchange across loads, storage devices, and the grid becomes increasingly fluid (Ayyappa et al., 2025). The combined result is that DVR research must now be interpreted in relation to broader converter interoperability and storage-aware operating logic.

The sixth major result is that energy management and voltage quality should not be treated as independent domains. Katyal et al. (2024) show that enhanced performance in grid-linked solar PV systems depends on coordinated energy management with battery storage. Although their study is not directly about DVRs, its inclusion in the supplied corpus becomes analytically meaningful when read alongside power quality studies. In a renewable-integrated grid, voltage disturbance compensation may depend on how power reserves, storage availability, and dispatch logic are organized. A compensation device does not operate in an energy vacuum. The availability of supportive energy resources, the responsiveness of conversion stages, and the intelligence of energy management approaches all affect how voltage support can be delivered in practice. This suggests a significant shift in research thinking: future DVR design may need to move from purely event-driven compensation logic toward deeper integration with distributed energy resource management.

The seventh major result concerns the implied transition from stand-alone control to digitally enhanced supervisory ecosystems. Several provided references are not classical power system control papers, yet they illuminate the direction of technologically advanced infrastructure. Vellela and Balamanigandan (2023) discuss intelligent energy management in wireless sensor network environments, and Vellela and Balamanigandan (2024) focus on efficient attack detection and prevention in secure mobile cloud environments. Haritha et al. (2024) address distributed blockchain-SDN models for robust data security in cloud-integrated IoT networks. These studies collectively point to a future in which critical infrastructures depend on layered sensing, communication, and digital decision systems. When read alongside DVR literature, the implication is clear: the modern compensating device will increasingly belong to a monitored, data-mediated, remotely visible, and potentially cloud-coordinated infrastructure. This is a profound change from earlier views of power compensators as essentially local devices. It creates new opportunities for adaptive control and coordinated monitoring, but it also introduces new vulnerabilities.

The eighth major result is therefore the emergence of cybersecurity and trust as power quality concerns. Biyyapu et al. (2024) develop a feature aggregation model with hybrid sampling for network intrusion detection, while Haritha et al. (2024) explore secure blockchain-SDN architectures in cloud-integrated IoT settings. These are not direct studies of grid compensation, but the result of reading them in context is unmistakable: as electrical infrastructures become intelligent and interconnected, secure operation depends on more than electrical stability. A DVR coordinated through digital systems could be undermined by malicious signaling, compromised data integrity, or communication-layer faults. From this standpoint, voltage quality is inseparable from information quality. A theoretically strong control scheme may become operationally weak if the informational context in which it acts is corrupted. The literature therefore supports an expanded interpretation of reliability in smart grids, one that includes cyber resilience as an enabling condition for dependable compensation.

The ninth major result concerns explainability. Mandava, Vellela, Malathi, et al. (2025) and Mandava, Vellela, Gorintla, et al. (2025) focus on explainable AI in healthcare risk assessment and user trust in financial decision-support systems. These fields differ from power engineering, yet the conceptual lesson is transferable. Systems that shape consequential operational decisions require interpretability to support trust, diagnosis, and responsible oversight. When applied to future smart-grid control, this insight becomes highly relevant. If adaptive or learning-based supervisory systems are used to tune or coordinate DVR behavior, engineers and operators will need to understand why certain actions are recommended or executed. Otherwise, technical performance may be accompanied by organizational distrust or unsafe opacity. The result emerging from the integrative reading is that future voltage quality systems may need not only better control, but more explainable control environments.

The tenth major result is that recent DVR literature implicitly supports a layered performance model rather than a single-metric evaluation logic. Some studies foreground voltage regulation quality (Patel & Kumar, 2023; Zhao & Yang, 2023). Others emphasize mitigation of sags and flicker (Mishra & Gupta, 2022). Others focus on industrial robustness, smart-grid adaptability, or energy conversion alignment (Jiang & Wu, 2023; Rao & Kumar, 2024; Soni & Garg, 2024). The integrated finding is that DVR performance is multi-dimensional. It should be judged not solely by whether the load voltage is restored, but also by how quickly restoration occurs, how stably the compensated voltage is maintained, how well the controller handles changing operating conditions, how efficiently the compensation function aligns with surrounding converter and energy systems, and how securely the device participates in a digital infrastructure. This broader performance model is one of the most important outcomes of the present study.

The eleventh major result concerns the continuing relevance of industrial deployment. Several references explicitly anchor the DVR problem in industrial applications, industrial electronics, or industrial power grids (Hussain & Qamar, 2023; Jiang & Wu, 2023; Singh & Sharma, 2022). This repeated orientation suggests that the most compelling practical case for DVR systems remains in contexts where process interruption has high economic or safety consequences. Industrial settings also tend to present challenging electrical environments because of motor loads, switching events, and highly sensitive automated systems. The literature therefore reinforces the argument that industrial deployment remains a key proving ground for DVR innovation. At the same time, the migration of similar ideas into smart-grid and renewable-connected contexts suggests that industrial lessons may now need to be generalized toward more distributed infrastructures.

The twelfth major result is that the provided corpus supports a conceptual transition from device optimization to system orchestration. Early or narrowly focused DVR thinking might ask how to design a better controller for a compensator. The broader literature represented here asks a more complex question: how should a compensating function be embedded in a network that includes renewables, storage, EV-related converters, cloud-based digital ecosystems, and secure data pathways? This transition is visible not because any one source answers the full question, but because the references collectively create the conditions under which the question becomes unavoidable. The synthesis thus suggests that the future of DVR research lies at the intersection of local control excellence and system-level orchestration.

Taken together, the results support a clear conclusion: PI-controlled DVRs remain central and viable technologies for voltage sag mitigation and voltage regulation, but their future value depends increasingly on optimized tuning, integration with advanced converter and storage infrastructures, coordination with energy management frameworks, and resilience within digitally connected and secure smart-grid ecosystems. These results form the basis for the deeper interpretation that follows.

Discussion

The findings of this study carry significant theoretical and practical implications for the evolution of power quality engineering. At the center of the discussion is a paradox that the literature helps clarify. On the one hand, the dynamic voltage restorer is a relatively established technology, and the PI controller is one of the most classical strategies in control engineering. On the other hand, the continued publication of recent studies on optimized PI-controlled DVR systems indicates that this domain remains technologically fertile rather than exhausted (Patel & Kumar, 2023; Kumar & Gupta, 2024; Rao & Kumar, 2024). The reason is that engineering maturity does not imply irrelevance. Instead, mature technologies often persist because they provide the most reliable bridge between theoretical controllability and operational deployability. The DVR, especially under PI-based control, exemplifies this pattern.

One important implication is that modern power engineering should resist the temptation to equate sophistication with superiority in a purely rhetorical sense. It is common in emerging technical discourse to assume that more complex intelligent methods necessarily supersede classical methods. The literature reviewed here suggests a more nuanced conclusion. PI-controlled DVR systems continue to attract research attention because they solve real problems in ways that are interpretable, tunable, and implementation-ready (Chen & Li, 2023; Singh & Sharma, 2022). Optimization enhances rather than replaces this classical foundation (Khan & Li, 2023; Sharma & Kumar, 2023). This observation matters not only for DVR design, but for control engineering more broadly. Practical infrastructure demands devices and algorithms that can be commissioned, maintained, audited, and trusted under real-world conditions. Simplicity, when paired with proper tuning and contextual integration, can be a strength rather than a deficiency.

At the same time, the literature does not support complacency. The repeated emphasis on optimization reveals that baseline PI control is rarely sufficient in demanding environments. Disturbance types vary, network conditions shift, load sensitivities differ, and smart-grid environments introduce greater dynamism than conventional systems. Thus, the real lesson is not that traditional control is enough as-is, but that traditional control remains powerful when refined through systematic optimization. In practical terms, this means the future of PI-controlled DVR research may lie in hybridization: maintaining the structural clarity of PI control while using advanced supervisory or optimization layers to adapt parameters to changing conditions. Such an approach would preserve interpretability while improving responsiveness. Although the provided references do not all explicitly articulate this hybrid model, their collective logic clearly points toward it.

A second major implication concerns the changing identity of the DVR itself. Historically, the DVR may be understood as a custom power device associated primarily with local voltage restoration. In the literature synthesized here, however, it appears increasingly as one component within a broader smart power architecture. This shift is conceptually important. Once a DVR is located in a converter-rich, storage-enabled, renewable-connected smart grid, its performance can no longer be evaluated only by local compensation behavior. It becomes part of a network of interdependencies involving converter efficiency, energy availability, storage management, grid coordination, and digital communication. The inclusion of solar PV energy management, battery charging, SEPIC conversion, EV battery balancing, and bidirectional converter studies in the source corpus makes this point especially visible (Ganesh Kumari et al., 2022; Swetha et al., 2021; Thangam et al., 2021; Katyal et al., 2024; Ayyappa et al., 2025).

This has consequences for research design. Many future studies may need to move beyond narrow test scenarios in which a DVR is evaluated against a standard disturbance in a relatively isolated distribution context. While such testing remains valuable, it may no longer be sufficient to capture real deployment complexity. Researchers may need to examine how DVR performance changes when compensation interacts with distributed storage response, renewable intermittency, vehicle charging activity, and converter coordination constraints. A DVR might perform well in one scenario yet behave differently when energy buffers are constrained, when inverter interactions create additional harmonics or delays, or when compensation priority must be coordinated with broader energy management goals. The literature synthesized in this article does not resolve these questions empirically, but it provides a strong conceptual basis for why they should become central to future inquiry.

A third major implication concerns the redefinition of power quality as a cyber-physical concept. Traditionally, power quality has been understood in electrical terms: voltage magnitude, waveform purity, sag duration, flicker, and related disturbance metrics. That understanding remains indispensable. Yet the integration of cloud systems, data networks, intelligent monitoring, and digital coordination means that power quality support devices now exist within informational infrastructures as well as electrical ones. The references on intrusion detection, secure cloud environments, and blockchain-SDN models reveal that future infrastructure reliability cannot be guaranteed solely by electrical correctness (Biyyapu et al., 2024; Haritha et al., 2024; Vellela & Balamanigandan, 2024). If the signals on which a supervisory system relies are corrupted, delayed, spoofed, or obscured, then even electrically sound control hardware may behave in unsafe or ineffective ways.

This insight has broad significance. It suggests that the engineering value of a DVR must increasingly be considered in relation to communication integrity and digital resilience. A series compensator that restores voltage effectively in a simulation environment might still fail as part of a fielded smart-grid ecosystem if the surrounding digital layer is insecure. The concept of compensation therefore expands. It no longer refers only to injected electrical voltage; it also refers to the infrastructure’s ability to maintain trustworthy state awareness and command integrity. This does not mean that every DVR must become a blockchain device or a cybersecurity platform. Rather, it means that researchers and system designers can no longer assume that compensation performance is independent from secure digital coordination.

The literature on explainable AI introduces another dimension to this argument. Although the explainability studies in the supplied references concern healthcare and financial decision support rather than power electronics, they highlight a principle of growing importance: high-stakes systems require not just accurate actions, but understandable actions (Mandava, Vellela, Malathi, et al., 2025; Mandava, Vellela, Gorintla, et al., 2025). In the context of future smart grids, this principle becomes highly relevant if machine intelligence is used to monitor power quality, prioritize restoration actions, or dynamically retune controller parameters. Operators responsible for critical infrastructure cannot rely indefinitely on opaque systems whose recommendations cannot be interpreted. Therefore, if AI-enhanced DVR supervision becomes more common, explainability will likely become a design requirement. The literature supports this inference indirectly but powerfully.

A fourth major implication concerns industrial relevance. The repeated focus on industrial applications across the DVR literature indicates that the most pressing practical motivation for voltage restoration remains the protection of sensitive industrial loads (Hussain & Qamar, 2023; Jiang & Wu, 2023). This should not be underestimated. Academic studies often broaden into generalized smart-grid discourse, but the industrial setting still offers one of the clearest and most consequential use cases for DVR technology. Voltage sags in industrial environments can cause abrupt shutdowns, process loss, data corruption, and equipment stress. From this perspective, the PI-controlled DVR continues to matter not because it is theoretically elegant, but because it addresses a class of disturbances with immediate operational consequences.

However, the industrial setting is also changing. Industrial facilities increasingly contain distributed energy resources, localized storage, digital twins, intelligent automation, cloud-connected monitoring systems, and cyber-physical interfaces. As a result, the industrial use case itself may be evolving into a microcosm of the broader smart grid. This means the future industrial DVR may need to be more communicative, more adaptable, and more secure than the devices implied in earlier custom power paradigms. The integrative literature suggests that the field is moving toward this reality, even if the shift is not yet uniformly articulated in the same vocabulary.

A fifth important implication concerns the relationship between local optimization and system-wide coordination. Many of the DVR studies emphasize improving controller response, sag compensation, and regulation quality through optimization (Wang & Zhang, 2023; Khan & Li, 2023; Kumar & Gupta, 2024). This is an essential engineering objective. Yet if the future power system is increasingly distributed and interactive, then a local optimum may not always produce a system optimum. For instance, a highly aggressive local compensation action might conflict with broader energy dispatch constraints, storage prioritization logic, or inverter coordination strategies. Conversely, a locally conservative strategy might protect overall network balance while slightly reducing immediate compensation strength. The literature reviewed here does not offer a definitive optimization hierarchy, but it strongly implies that next-generation design must think at both levels simultaneously. Controller excellence remains necessary, but orchestration across subsystems becomes equally important.

This observation leads to a sixth implication: the need for layered architecture thinking. The conceptual framework developed in this article includes four layers: compensating control, power electronic integration, energy management coordination, and cyber-physical trust. The supplied references support the importance of each layer. Compensating control is directly addressed by the DVR studies. Power electronic integration is supported by converter and charging research. Energy management coordination is illuminated by PV and storage work. Cyber-physical trust is informed by security and explainability studies. The strength of this layered perspective is that it offers a way to reconcile what might otherwise seem like a heterogeneous source list. More importantly, it offers a structured way to think about future research. Scholars can ask not only whether a controller works, but also how it integrates, coordinates, and remains trustworthy.

There are also counter-arguments and cautionary points worth addressing. One possible objection is that integrating cybersecurity, cloud resilience, and explainable AI into DVR discourse risks diluting the specificity of power electronics research. This is a valid concern. Not every voltage restoration problem requires a discussion of blockchain, cloud intrusion, or explainable decision systems. Overextension can turn a focused engineering problem into an overly diffuse systems narrative. Yet the integrative approach used here avoids that pitfall by grounding these dimensions in an emerging smart-grid context rather than claiming they are intrinsic to every DVR installation. The point is not that all present DVRs require all these features, but that the direction of digital infrastructure makes these issues increasingly relevant to future deployments.

Another possible objection is that the article synthesizes conceptually adjacent fields without presenting unified empirical validation. That objection is also valid and points directly to one of the study’s limitations. Because the article is based on a supplied reference list rather than shared datasets or standardized simulations, it cannot empirically test a fully integrated DVR-converter-security framework. Its contribution is interpretive and conceptual rather than experimental. However, this limitation should not be mistaken for weakness alone. Integrative research plays an important role in identifying emerging linkages before unified experimental paradigms become common. In this case, the literature already shows enough thematic convergence to justify a structured interpretive framework, even if future studies must still verify it under controlled conditions.

The study also has a source-bound limitation. The available references are rich but unevenly distributed across subtopics. The DVR and PI control literature is strongly represented, while adjacent fields such as AI explainability and network security are represented through a smaller number of studies and from other domains. This means the article’s arguments about explainability and cyber resilience are best understood as theoretically grounded extrapolations rather than direct empirical findings about DVR hardware. Future research could strengthen this dimension by examining power-quality-specific cybersecurity architectures, secure controller communication layers, and interpretable adaptive tuning schemes designed specifically for custom power devices.

Another limitation concerns the absence of quantified performance comparisons. The present article identifies repeated patterns such as the importance of optimized PI tuning and the effectiveness of DVRs in voltage sag mitigation, but it does not rank the referenced studies according to uniform metrics because such harmonization is not possible from the provided information alone. This means the conclusions should be read as pattern-based rather than metrically ranked. Nevertheless, pattern-based conclusions remain valuable when multiple independent sources repeatedly support similar interpretations.

Despite these limitations, the article points toward a promising future research agenda. One direction is the development of adaptive PI frameworks in which the core controller remains interpretable while supervisory optimization adjusts parameters according to real-time network conditions. Such research would build directly on the optimization emphasis in the supplied DVR literature while remaining aligned with the interpretability lesson derived from explainable AI studies. A second direction is integrated DVR-storage-renewable coordination, especially in systems where battery and converter architectures materially influence compensation resources. This line of inquiry would connect directly to the references on PV systems, battery charging, balancing, and bidirectional converters (Ganesh Kumari et al., 2022; Swetha et al., 2021; Katyal et al., 2024; Ayyappa et al., 2025). A third direction is secure digital orchestration, where anomaly detection and communication protection mechanisms are co-designed with power quality support logic. This direction would operationalize the implications of the intrusion detection and blockchain-SDN studies for power engineering contexts (Biyyapu et al., 2024; Haritha et al., 2024). A fourth direction is intelligent but explainable supervisory control, where adaptive decision support is used to enhance rather than obscure engineering accountability.

There is also a broader conceptual lesson for infrastructure research. Modern technical systems are increasingly judged not only by how well they perform a narrow function, but by how resiliently, intelligibly, and interoperably they perform it within a networked environment. The DVR is a good example of this evolution. Once treated primarily as a compensating device for voltage sag, it now stands at the crossroads of power quality engineering, power electronics integration, smart-grid coordination, and digital trust. The literature reviewed in this article does not announce that transformation in a single voice, but when read together, the signal is unmistakable.

Ultimately, the discussion supports a reframing of the field. The future question is not simply how to build a better DVR. It is how to build a voltage restoration capability that remains fast, stable, optimized, interoperable, energy-aware, secure, and understandable in increasingly distributed smart power environments. The provided references, taken as a whole, support precisely this broader vision. The enduring relevance of PI-controlled DVRs lies not in resisting technological change, but in serving as a robust and adaptable foundation on which that change can be responsibly organized.

Conclusion

This article set out to generate a complete, publication-ready original research study based strictly on the provided references, with the aim of explaining the contemporary and future significance of PI-controlled dynamic voltage restorers in smart power systems. The central conclusion is clear: the DVR remains one of the most practical and relevant devices for voltage sag mitigation and voltage regulation, and PI control continues to be a highly viable operational strategy because of its balance between simplicity, interpretability, and effectiveness (Chen & Li, 2023; Patel & Kumar, 2023; Rao & Kumar, 2024). However, the literature also shows that the future of DVR performance does not lie in static controller deployment. It lies in optimized tuning, adaptive coordination, and system-level integration.

A key finding of the study is that the recent literature consistently emphasizes optimized PI control rather than generic PI use. This indicates that controller structure and controller parameterization must be treated together if high-quality compensation is to be achieved under modern grid conditions (Khan & Li, 2023; Sharma & Kumar, 2023; Kumar & Gupta, 2024). Another major finding is that voltage quality support can no longer be understood in isolation from the broader converter and storage environment. Grid-linked solar systems, battery charging architectures, balancing systems, SEPIC converters, and bidirectional converter platforms all indicate that future power systems will be increasingly shaped by interdependent power electronic subsystems (Ganesh Kumari et al., 2022; Thangam et al., 2021; Katyal et al., 2024; Ayyappa et al., 2025). In this environment, DVR deployment must be interpreted as part of a coordinated energy ecosystem.

The article also concludes that digitalization changes the meaning of reliability in power quality engineering. As smart grids become more communication-rich and software-mediated, the dependability of compensation functions will increasingly depend on secure data pathways, anomaly resilience, and trustworthy supervisory logic (Biyyapu et al., 2024; Haritha et al., 2024; Vellela & Balamanigandan, 2024). The explainable AI studies included in the corpus further suggest that if intelligent supervisory systems influence compensation decisions in future infrastructures, interpretability will become essential for operator trust and responsible system governance (Mandava, Vellela, Malathi, et al., 2025; Mandava, Vellela, Gorintla, et al., 2025).

Taken together, the references support a broader conceptual model in which next-generation DVR systems should be understood through four interlocking dimensions: compensating control, power electronic integration, energy management coordination, and cyber-physical trust. This framework does not reject the classical engineering foundations of the DVR; rather, it extends them into the realities of distributed, renewable-rich, digitally connected smart power networks. The lasting importance of the PI-controlled DVR lies precisely in its ability to serve as a stable engineering core while the surrounding system becomes more complex.

Future research should therefore move toward adaptive yet interpretable PI tuning, renewable- and storage-aware voltage restoration strategies, secure supervisory communication architectures, and intelligent coordination mechanisms that preserve both technical performance and operational transparency. In that sense, the evolution of DVR research is not merely about improving a compensating device. It is about redefining power quality support as a resilient, integrated, and trustworthy function within modern electrical infrastructure. The supplied literature strongly supports this direction and makes clear that the DVR will remain a crucial technology in the ongoing development of secure and adaptive smart grids.

References

1. Ayyappa, G., Srikanth, D., Trivikram, K., Koteswararao, K. S., & Babu, K. N. (2025). Bi-directional DC/AC and DC/DC converter design and control for plug-in hybrid cars. Journal of Next Generation Technology, 5(1), 42–51. https://doi.org/10.5281/zenodo.15250278

2. Biyyapu, N., Veerapaneni, E. J., Surapaneni, P. P.,

Vellela, S. S., & Vatambeti, R. (2024). Designing a modified feature aggregation model with hybrid sampling techniques for network intrusion detection. Cluster Computing, 27(5), 5913–5931.

3. Chen, Y., & Li, Q. (2023). PI controller-based DVR for voltage regulation in distribution networks. Journal of Electrical Engineering & Technology, 18(2), 1200–1210.

4. Chen, Z., & Wang, P. (2023). Voltage sag compensation and power quality enhancement using DVR with PI controller. International Journal of Electrical Power & Energy Systems, 126, 106746.

5. Dalavai, L., Purimetla, N. M., Vellela, S. S., SyamsundaraRao, T., Vuyyuru, L. R., & Kumar, K. K. (2024). Improving deep learning-based image classification through noise reduction and feature enhancement. In Proceedings of ICAIQSA (pp. 1–7). IEEE.

6. Ganesh Kumari, M., Karthika, E., Sathiya Bharathi, B., & Swetha, V. (2022). Design and analysis of PV-based cascaded buck-boost converter for battery charging. Journal of Next Generation Technology, 2(1), 40–48.

7. Gavini, A., et al. (2025). Bi-directional DC/AC and DC/DC converter design and control for plug-in hybrid cars. Journal of Next Generation Technology, 5(1), 42–51.

8. Haritha, K., Vellela, S. S., Vuyyuru, L. R., Malathi, N., & Dalavai, L. (2024). Distributed blockchain-SDN models for robust data security in cloud-integrated IoT networks. In Proceedings of ICACRS (pp. 623–629). IEEE.

9. Hussain, M., & Qamar, M. (2023). Optimal DVR control strategy with PI controller for voltage sag compensation in industrial applications. IEEE Transactions on Industrial Electronics, 71(9), 2354–2361.

10. Jiang, Y., & Wu, Y. (2023). Application of PI controller-based DVR for voltage sag mitigation in industrial power grids. IEEE Transactions on Industrial Applications, 60(1), 365–372.

11. Katyal, P., Katyal, R., & Premkumar, K. (2024). Energy management approaches for enhanced performance in grid-linked solar PV system with battery storage. Journal of Next Generation Technology, 4(1), 1–16.

12. Khan, A., & Li, Y. (2023). Optimized PI controller for DVR in power quality improvement and voltage sag mitigation. Energy, 251, 123456.

13. Kumar, A., & Gupta, P. (2024). Design and optimization of DVR using PI controller for power system voltage regulation. Electric Power Systems Research, 212, 107717.

14. Li, M., & Zhao, F. (2022). Dynamic voltage restorer for voltage regulation using optimized PI controller in power distribution systems. Energy Reports, 8, 1005–1013.

15. Mandava, R., Vellela, S. S., Gorintla, S., Dalavai, L., Malathi, N., & Haritha, K. (2025). Evaluating the impact of explainable AI on user trust in financial decision-support systems. In Proceedings of ICCRTEE (pp. 1–6). IEEE.

16. Mandava, R., Vellela, S. S., Malathi, N., Haritha, K., Gorintla, S., & Dalavai, L. (2025). Exploring the role of XAI in enhancing predictive model transparency in healthcare risk assessment. In Proceedings of ICCRTEE (pp. 1–5). IEEE.

17. Mishra, S., & Gupta, R. (2022). PI controller-based dynamic voltage restorer for voltage sag and flicker mitigation in industrial systems. International Journal of Electrical Power & Energy Systems, 104, 372–380.

18. Patel, R., & Kumar, S. (2023). Enhanced voltage regulation using optimized DVR with PI controller. IEEE Transactions on Power Delivery, 38(5), 2341–2349.

19. Patel, S., & Mehta, R. (2022). Enhancement of voltage stability using optimized DVR with PI controller in smart grids. IEEE Access, 12, 3201–3209.

20. Rao, G., & Kumar, S. (2024). Optimal control of DVR using PI controller for enhancing voltage quality in distribution systems. IEEE Transactions on Energy Conversion, 39(2), 512–520.

21. Sarkar, A., & Sinha, N. (2024). Dynamic voltage restorer for voltage quality improvement using PI control in smart grids. Journal of Electrical Engineering, 80(1), 45–52.

22. Sharma, D., & Kumar, P. (2023). Optimization of DVR for voltage sag mitigation with PI control algorithm. IEEE Transactions on Smart Grid, 15(4), 1129–1138.

23. Singh, M., & Sharma, A. (2022). Optimization of dynamic voltage restorer with PI controller for power quality improvement. IEEE Transactions on Industrial Electronics, 69(7), 4102–4110.

24. Singh, N., & Bhargava, P. (2022). Optimized dynamic voltage restorer for power quality enhancement using PI controller. International Journal of Power Electronics and Drive Systems, 13(5), 1932–1939.

25. Soni, S., & Garg, N. (2024). Voltage regulation and power quality enhancement using optimized DVR with PI controller in smart grids. Journal of Power and Energy Engineering, 12(1), 29–36.

26. Swetha, M., Nageswari, S., & Maheshwari, A. (2021). Boost DC-DC converter based balancing system for lithium-ion battery pack in electric vehicle. Journal of Next Generation Technology, 1(1), 56–66.

27. Thangam, T., Muthuvel, K., & Eswaramoorthy, K. (2021). SEPIC converter with closed loop PI controller for grid utilized PV system. Journal of Next Generation Technology, 1(1).

28. Vellela, S. S., & Balamanigandan, R. (2023). An intelligent sleep-awake energy management system for wireless sensor network. Peer-to-Peer Networking and Applications, 16(6), 2714–2731.

29. Vellela, S. S., & Balamanigandan, R. (2024). An efficient attack detection and prevention approach for secure WSN mobile cloud environment. Soft Computing, 28(19), 11279–11293.

30. Wang, H., & Zhang, L. (2023). Optimization of DVR with PI controller for mitigating voltage sags. International Journal of Electrical Power & Energy Systems, 136, 107520.

31. Xu, L., & Liu, Q. (2023). PI-controlled DVR for voltage regulation and sag mitigation in industrial applications. Journal of Power Electronics, 34(3), 667–677.

32. Zhang, T., & Li, X. (2023). Voltage sag compensation using dynamic voltage restorer with PI control for improved power quality. IEEE Transactions on Power Electronics, 38(4), 1345–1354.

33. Zhao, H., & Yang, M. (2023). Enhanced voltage regulation using dynamic voltage restorer with PI controller in power distribution systems. Renewable and Sustainable Energy Reviews, 167, 112703.