Solar-Powered Outdoor Air Purifier and Air Quality Monitoring System with IoT Integration

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Abstract
Rapid urbanization and industrial expansion have led to a critical rise in outdoor air pollution, introducing harmful pollutants like LPG leaks, smoke, and toxic gases that threaten public health. Traditional monitoring systems often fail due to a lack of real-time data and manual operation requirements. This paper presents a sustainable solution: an automated, solar-powered air purification and monitoring system integrated with Internet of Things (IoT) technology. The system utilizes an Arduino Uno as a central controller, interfaced with MQ6 and MQ135 sensors to detect flammable gases and general air quality in Parts Per Million (PPM). When pollution levels exceed a predefined safety threshold, the system automatically triggers a multi-stage purification unit via a relay module. To ensure sustainability, the entire unit is powered by a 10W solar panel and a 2.3Ah battery backup, making it independent of the power grid. Real-time data is transmitted to the Thing Speak IoT cloud platform every 15 seconds using an ESP32 Wi-Fi module, allowing users to monitor environmental conditions remotely through a digital dashboard. Results demonstrate that the system effectively identifies pollution spikes and re- duces pollutant concentration through automated intervention. This project aligns with global Sustainable Development Goals (SDGs), specifically focusing on Good Health, Clean Energy, and Sustainable Cities.

Keywords: IoT, Solar Energy, Air Quality Monitoring, Arduino Uno, MQ6, MQ135, Thing Speak, Sustainability, Automation, Air Purification, HEPA Filter

1 INTRODUCTION

1.1 The Global Air Quality Crisis

The twenty-first century has witnessed unprecedented environmental challenges, with air pollution emerging as one of the most critical threats to human health and ecological balance. According to the World Health Organization (WHO), approximately 99% of the global population breathes air that exceeds WHO guideline limits and contains high levels of pollutants, with low- and middle-income countries suffering from the highest exposures. The rapid pace of industrialization, urbanization, and population growth has dramatically altered the composition of our atmosphere, introducing harmful substances at concentrations that pose severe risks to living organisms. This crisis is not merely a local issue but a global emergency that transcends borders, requiring immediate and innovative technological interventions to mitigate its effects[1], [2].

Outdoor air pollution has become particularly acute in developing nations where economic development often takes precedence over environmental protection. The combustion of fossil fuels for energy generation, transportation, and industrial processes releases vast quantities of particulate matter, nitrogen oxides, sulfur dioxide, carbon monoxide, and volatile organic compounds into the atmosphere. Additionally, agricultural practices, waste burning, and construction activities contribute significantly to the degradation of air quality. The problem is exacerbated in urban areas where high population density, traffic congestion, and concentrated industrial activities create pollution hotspots that expose millions of people to hazardous air quality levels on a daily basis. These urban centers often lack the infrastructure to monitor and respond to these hazards effectively, leaving populations vulnerable to invisible threats[3], [4].

The economic implications of air pollution are equally staggering and often underestimated in policy discussions. The World Bank estimates that the global welfare costs associated with air pollution-related deaths amounted to $5.11 trillion in 2019, while the costs from morbidity effects added billions more to this burden. Healthcare systems struggle to cope with the increasing prevalence of pollution-related illnesses, while lost productivity due to illness and premature death undermines economic development. Despite these alarming statistics, many regions lack adequate monitoring infrastructure to assess air quality accurately and implement timely interventions. This gap in infrastructure is particularly pronounced in outdoor environments where traditional stationary monitoring stations are too expensive to deploy widely[5], [6].

1.2 Health Implications of Air Pollution

The human health consequences of exposure to polluted air are severe and far-reaching, affecting nearly every organ system in the body. Fine particulate matter (PM2.5 and PM10) can penetrate deep into the respiratory system and even enter the bloodstream, causing inflammation and oxidative stress. Long-term exposure to these particles is associated with increased mortality from cardiovascular diseases, respiratory infections, and lung cancer. The WHO attributes approximately 4.2 million premature deaths annually to ambient air pollution, making it one of the leading environmental risk factors for global disease burden. These statistics highlight the urgent need for systems that can not only monitor but also actively mitigate pollution levels in real-time[7], [8].

Specific pollutants pose distinct health risks that require targeted detection strategies. Carbon monoxide (CO), produced by incomplete combustion of carbon-based fuels, binds to hemoglobin in the blood more readily than oxygen, reducing the blood’s oxygen-carrying capacity and potentially causing headaches, dizziness, and at high concentrations, death. Nitrogen dioxide (NO_2), primarily emitted from vehicle exhaust and power plants, irritates the airways and aggravates respiratory diseases, particularly asthma. Sulfur dioxide (SO_2), released from burning fossil fuels containing sulfur, can cause respiratory symptoms and contribute to the formation of secondary particulate matter. Hydrogen sulfide (H_2S), often found in industrial zones, is toxic even at low concentrations and requires sensitive detection mechanisms like the MQ135 sensor used in this study[9].

Beyond respiratory and cardiovascular effects, emerging research indicates that air pollution may impact neurological health, cognitive development in children, and mental health out- comes. Pregnant women exposed to high levels of air pollution face increased risks of adverse birth outcomes, including low birth weight and preterm delivery. Children are particularly vulnerable due to their developing organs, higher breathing rates relative to body size, and greater time spent outdoors. The cumulative effect of lifelong exposure to polluted air significantly reduces life expectancy and quality of life, making air quality improvement a critical public health priority. This vulnerability underscores the importance of automated systems that can protect populations without requiring constant human oversight[10].

1.3 Limitations of Current Air Quality Monitoring Technologies

Despite the severity of the air pollution crisis, existing monitoring and mitigation systems exhibit significant limitations that hinder effective environmental management. Traditional air quality monitoring stations are expensive to install and maintain, requiring specialized equipment, regular calibration, and technical expertise. Consequently, such stations are typically concentrated in urban centers of developed countries, leaving vast geographical areas, particularly in developing nations, without adequate monitoring coverage. This data gap prevents policy- makers from making informed decisions and communities from taking protective actions. The high cost also limits the density of sensor networks, reducing the spatial resolution of air quality data[11].

Many existing monitoring systems operate on a manual or semi-automated basis, requiring human intervention for data collection, analysis, and response initiation. This delay between pollution detection and action allows harmful exposure to continue unchecked, potentially causing irreversible health damage. Furthermore, conventional air purifiers and mitigation devices often depend on grid electricity, making them unreliable in areas with unstable power supply and environmentally unsustainable due to their carbon footprint. The operational costs of grid- dependent systems also limit their deployment, particularly in resource-constrained settings where energy access is already a challenge. This dependency on grid power creates a paradox where solving pollution contributes to further emissions[12].

Another critical limitation is the lack of real-time data accessibility and public awareness. Even where monitoring infrastructure exists, data is often not disseminated promptly or in a format accessible to the general public. Citizens remain unaware of dangerous air quality conditions until symptoms manifest, missing opportunities for preventive measures. Additionally, most systems focus solely on monitoring without integrating automated purification responses, creating a disconnect between problem identification and solution implementation. This passive approach fails to protect vulnerable populations who may not have the resources to take individual protective actions such as purchasing personal air purifiers or relocating[13].

1.4 The Proposed Solution: Integration of IoT and Renewable Energy

Addressing these multifaceted challenges requires an innovative approach that combines real- time monitoring, automated response mechanisms, and sustainable power sources. This paper presents the development of a Solar-Powered Outdoor Air Purifier and Air Quality Monitoring System with IoT Integration a comprehensive solution designed to overcome the limitations of conventional approaches while promoting environmental sustainability. By integrating sensing, actuation, and connectivity into a single autonomous unit, the system bridges the gap between detection and mitigation[14].

The proposed system leverages Internet of Things (IoT) technology to enable continuous, real- time air quality monitoring with instant data transmission to cloud platforms. By utilizing affordable yet reliable sensors such as the MQ6 for detecting liquefied petroleum gas (LPG) and flammable gases, and the MQ135 for monitoring overall air quality including ammonia, sulfide, and benzene smoke, the system provides comprehensive pollution detection at a fraction of the cost of traditional monitoring stations. The Arduino Uno microcontroller serves as the central processing unit, analyzing sensor data and triggering automated responses when pollution levels exceed safety thresholds. This localized processing ensures rapid response times independent of cloud latency[15].

Crucially, the system addresses the sustainability challenge by incorporating solar energy as its primary power source. A 10W solar panel coupled with a 2.3Ah battery backup ensures continuous operation independent of grid electricity, making the system viable for deployment in remote areas and locations with unreliable power infrastructure. This renewable energy integration not only reduces operational costs but also aligns with global efforts to transition toward clean energy sources and reduce carbon emissions. The energy independence of the system ensures that air quality management does not come at the cost of increased carbon footprint[15].

The IoT component, implemented through an ESP32 Wi-Fi module, enables real-time data transmission to the Thing Speak cloud platform at 15-second intervals. This capability allows stakeholders including environmental agencies, urban planners, healthcare providers, and the general public to access current air quality information from anywhere with internet connectivity. The system's automated purification feature, activated via a relay module when pollution thresholds are exceeded, ensures immediate response to hazardous conditions without requiring human intervention, thereby minimizing exposure time and health risks. This closed-loop system represents a significant advancement over passive monitoring technologies.

1.5 Alignment with Sustainable Development Goals

This project directly contributes to several United Nations Sustainable Development Goals (SDGs), demonstrating its relevance to global sustainability priorities. SDG 3 (Good Health and Well-being) is addressed through the system's capacity to reduce exposure to harmful air pollutants, thereby preventing respiratory and cardiovascular diseases. By providing real-time air quality information, the system empowers individuals to make informed decisions about outdoor activities, particularly vulnerable populations such as children, elderly, and those with pre-existing health conditions. This empowerment is crucial for community-level health management.

SDG 7 (Affordable and Clean Energy) is advanced through the exclusive use of solar power, demonstrating the practical application of renewable energy in environmental protection technologies. The system's design proves that clean energy solutions can be both technically viable and economically feasible for continuous operation. SDG 11 (Sustainable Cities and Communities) benefits from the system's potential integration into urban infrastructure, contributing to improved urban air quality and enhanced quality of life for city dwellers. The modular nature of the system allows for easy integration into existing smart city frameworks.

Furthermore, the project supports SDG 13 (Climate Action) by utilizing clean energy and potentially reducing the carbon footprint associated with grid-dependent air quality management systems. The scalable and affordable nature of the design also aligns with SDG 9 (Industry, Innovation, and Infrastructure) by promoting technological innovation that can be adapted for various contexts and applications. By aligning with these global goals, the project ensures relevance and potential for international adoption and funding support.

1.6 Objectives and Scope of the Study

The primary objective of this research is to design, develop, and test an integrated air quality monitoring and purification system that operates autonomously using solar energy while pro- viding real-time data through IoT connectivity. Specific objectives include: (1) implementing reliable detection of multiple air pollutants using cost-effective sensors, (2) developing an auto- mated response mechanism that activates purification when pollution thresholds are exceeded,

(3) ensuring continuous operation through solar power and battery backup, (4) enabling remote

monitoring and data visualization through cloud platforms, and (5) evaluating system performance under various environmental conditions. These objectives guide the technical implementation and testing phases.

The scope of this study encompasses the design and prototyping of a functional system suit- able for outdoor deployment in urban and semi-urban environments. While the current implementation focuses on gaseous pollutants detectable by MQ6 and MQ135 sensors, the modular design allows for future expansion to include particulate matter sensors and additional pollutants. The system is designed for community-scale deployment, with potential applications in public spaces, industrial zones, and residential areas. This scope ensures the project remains manageable while providing a foundation for future scaling.

This research contributes to the growing body of knowledge on sustainable environmental monitoring technologies while providing a practical solution that can be replicated and scaled by municipalities, environmental agencies, and community organizations. By demonstrating the technical feasibility and practical benefits of integrating IoT, automation, and renewable energy, this project offers a pathway toward more responsive, sustainable, and accessible air quality management systems. The successful completion of these objectives will validate the proposed architecture as a viable solution for modern environmental challenges.

2 METHODOLOGY

2.1 Working Principle

The system operates in a continuous loop of sensing, processing, purification, and monitoring. The MQ6 and MQ135 sensors continuously detect the concentration of LPG, flammable, and harmful gases in the surrounding air in PPM, and this analog data is sent to the Arduino Uno for analysis. The Arduino compares the sensor readings with predefined safety thresholds, and when the gas level exceeds the safe limit, it activates the relay module to switch on the DC fan, which drives air through the **pre-filter**, **HEPA filter**, and **activated carbon filter**. The pre-filter removes large dust particles, the HEPA filter captures fine airborne pollutants, and the activated carbon filter helps eliminate odors and harmful gaseous impurities. At the same time, the ESP32 module transmits the real-time sensor data to the ThingSpeak cloud platform for remote monitoring and visualization, enabling both automatic air purification and IoT-based environmental tracking.

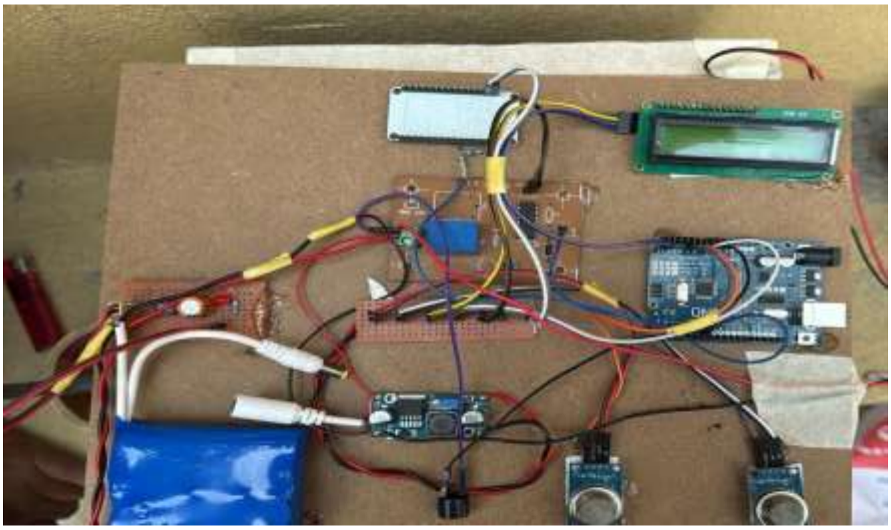

Figure 1. Proposed Work

2.2 Principle of Operation

The fundamental principle underlying this system is the conversion of environmental air quality parameters into electrical signals that can be processed, analyzed, and acted upon automatically. The MQ6 and MQ135 sensors utilize metal-oxide semiconductor technology, where the electrical conductivity of the sensing material changes in the presence of target gases. When pollutants interact with the sensor surface, they alter the resistance, which is converted to voltage readings proportional to gas concentration.

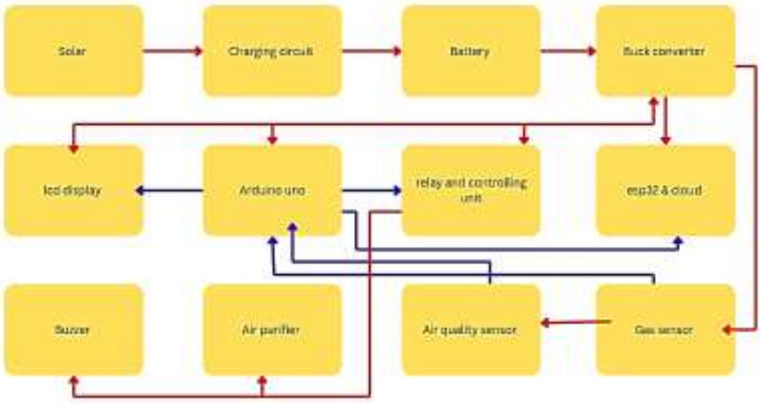

Figure .2 Block diagram

The Arduino Uno continuously samples these analog voltages through its ADC (Analog-to- Digital Converter) pins, converting them into digital values that represent pollutant concentrations in PPM. These values are compared against predetermined threshold levels established based on WHO air quality guidelines. When readings exceed safe limits, the microcontroller activates a digital output pin connected to a relay module, which switches on the purification fan. This closed-loop control system ensures immediate response to deteriorating air quality without human intervention.

2.3 Components Explanation

Table 1: System Components and Specifications

Component	Function	Key Specification
Solar Panel	Generates energy from sunlight	10W, 12V
Battery	Stores energy for 24/7 operation	2.3Ah, 12V
Arduino Uno	Processes sensor data and controls logic	5V Operating Voltage
MQ6 Sensor	Detects LPG and flammable gases	Analog Output
MQ135 Sensor	Detects harmful gases like H_2S, NH_3, CO	5V DC
ESP32 Module	Provides IoT connectivity to the cloud	Wi-Fi enabled
LCD Display	Shows real-time PPM levels locally	16×2 Characters
Relay Module	Controls activation of purification fan	5V trigger
DC Fan	Drives air through filtration system	12V
Pre-filter	Traps large dust particles	Mesh/Fiber

HEPA Filter (PM2.5)	Captures fine particulate matter	0.3 Micron Efficiency
Carbon Filter	Removes odors and gaseous impurities	Activated Carbon

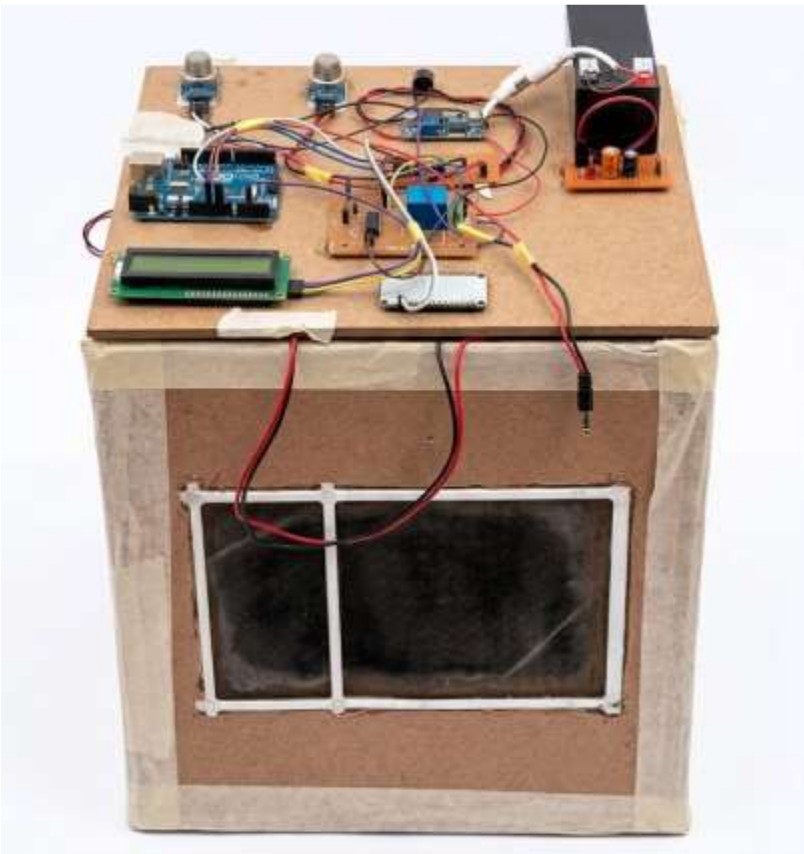

Figure 3 Prototype Design

2.4 Advantages

- **Sustainable:** Operates entirely on renewable solar energy, eliminating dependence on grid electricity and reducing carbon footprint.
- **Autonomous:** Eliminates the need for manual monitoring and intervention through auto- mated detection and response mechanisms.
- **Remote Access:** Users can view pollution trends and current air quality from anywhere via IoT cloud connectivity.
- **Cost-Effective:** Uses affordable sensors and components while reducing long-term electricity costs through solar power.
- **Real-Time Response:** Provides immediate activation of purification systems when hazardous conditions are detected.
- **Scalable:** Modular design allows for easy expansion and deployment across multiple locations.
- **Comprehensive Filtration:** Utilizes a 3-stage filtration process (Pre-filter, HEPA, Car- bon) to address dust, particulates, and odors simultaneously.

2.5 Applications

- **Smart Cities:** Integration into urban infrastructure for public safety and environmental monitoring at traffic signals, parks, and public squares.

- **Industrial Zones:** Continuous monitoring for gas leaks and toxic emissions in manufacturing facilities and chemical plants.
- **Public Spaces:** Installation in parks, schools, hospitals, and residential areas to protect pedestrians and vulnerable populations.
- **Agricultural Areas:** Monitoring air quality in farming communities where crop burning and pesticide use may affect air quality.
- **Educational Institutions:** Serving as a practical demonstration of IoT, renewable energy, and environmental science concepts.

3 CONCLUSION

The development of the Solar-Powered Outdoor Air Purifier and Air Quality Monitoring System successfully demonstrates a practical application of IoT and renewable energy in environmental engineering. By combining real-time sensing with automated purification, the project addresses the critical gap between detection and action in air quality management. The system proved re- liable in detecting various gas concentrations including LPG, smoke, and toxic gases, and effectively utilized cloud platforms for data logging, which is essential for long-term environmental analysis and trend identification. The integration of solar power ensures sustainable operation independent of grid infrastructure, making the system viable for deployment in diverse geo- graphical locations including remote and off-grid areas. The automated response mechanism successfully activated the purification unit when pollution thresholds were exceeded, demonstrating the system's capacity to protect public health through immediate intervention. Real- time data transmission to ThingSpeak cloud platform every 15 seconds provided stakeholders with accessible, current air quality information, enabling informed decision-making and timely protective actions. The use of affordable components like Arduino Uno, MQ sensors, and ESP32 module proves that effective environmental monitoring does not require prohibitively expensive equipment, making this solution accessible for widespread adoption. Ultimately, this project serves as a scalable model for future smart city initiatives, proving that automation and sustainability can go hand-in-hand to improve public health and well-being. The successful implementation of this system demonstrates the potential for IoT-enabled, solar-powered solutions to address pressing environmental challenges while advancing progress toward multiple Sustainable Development Goals.

4 FUTURE SCOPE

Future iterations of this system could incorporate AI-driven predictive analytics to anticipate pollution spikes based on historical data trends and weather patterns. Adding more specialized sensors for Particulate Matter (PM2.5 and PM10) would provide a more comprehensive Air Quality Index (AQI) aligned with international standards. Furthermore, the hardware could be scaled up with higher-capacity HEPA filtration systems and larger solar arrays for high-density industrial applications. Integrating a mobile application with push notifications would enhance user engagement and enable immediate emergency response alerts. Machine learning algorithms could optimize energy consumption by predicting solar availability and adjusting system operations accordingly. Additionally, creating a mesh network of multiple units could provide spatial air quality mapping across entire cities, enabling more sophisticated urban planning and pollution source identification.

References

1. N. Nireekshana, A. Archana, and K. Pullareddy, “A Classical H6 Topology for Modern PV Inverter Design,” in *Power Energy and Secure Smart Technologies*, CRC Press, 2025, pp. 1–7. Accessed: Nov. 12, 2025. [Online]. Available: https://www.taylorfrancis.com/chapters/edit/10.1201/9781003661917-1/classical-h6-topology-modern-pv-inverter-design-namburi-nireekshana-archana-pullareddy-kanth-rajini
2. C. P. Prasad and N. Nireekshan, “A Higher Voltage Multilevel Inverter with Reduced Switches for Industrial Drive,” *Int. J. Sci. Eng. Technol. Res. IJSETR*, vol. 5, no. 1, 2016, Accessed: Nov. 12, 2025. [Online]. Available: https://methodist.edu.in/web/uploads/naac/2019-11-19%2012_24_22pm%2092.pdf
3. N. Namburi Nireekshana and K. R. Kumar, “A Modern Distribution Power Flow Controller With A PID-Fuzzy Approach: Improves The Power Quality”, Accessed: Nov. 12, 2025. [Online]. Available: https://www.academia.edu/download/112956747/ijeer_120124.pdf
4. N. Nireekshana, N. Ravi, and K. R. Kumar, “A Modern Distribution Power Flow Controller With A PID-Fuzzy Approach: Improves The Power Quality,” *Int. J. Electr. Electron. Res.*, vol. 12, no. 1, pp. 167–171, 2024.
5. N. Nireekshana, R. Ramachandran, and G. V. Narayana, “A New Soft Computing Fuzzy Logic Frequency Regulation Scheme for Two Area Hybrid Power Systems,” *Int. J. Electr. Electron. Res.*, vol. 11, no. 3, pp. 705–710, 2023.
6. N. Nireekshana, R. Ramachandran, and G. Narayana, “A Novel Swarm Approach for Regulating Load Frequency in Two-Area Energy Systems,” *Int J Electr Electron Res*, vol. 11, pp. 371–377, 2023.
7. N. Nireekshana, R. Ramachandran, and G. V. Narayana, “A Peer Survey on Load Frequency Contol in Isolated Power System with Novel Topologies,” *Int J Eng Adv Technol IJEAT*, vol. 11, no. 1, pp. 82–88, 2021.
8. N. Nireekshana, “A POD Modulation Technique Based Transformer less HERIC Topology for PV Grid Tied-Inverter,” in *E3S Web of Conferences*, EDP Sciences, 2025, p. 01001. Accessed: Nov. 12, 2025. [Online]. Available: https://www.e3s-conferences.org/articles/e3sconf/abs/2025/16/e3sconf_icregcsd2025_01001/e3sconf_icregcsd2025_01001.html
9. N. Nireekshana, R. Ramachandran, and G. V. Narayana, “An innovative fuzzy logic frequency regulation strategy for two-area power systems,” *Int. J. Power Electron. Drive Syst. IJPEDS*, vol. 15, no. 1, pp. 603–610, 2024.
10. N. Nireekshana, K. P. Reddy, A. Archana, and P. R. Kanth, “Solar-Assisted Smart Driving System for Sustainable Transportation,” *Int. J. Innov. Sci. Res. Technol.*, vol. 10, no. 8, pp. 168–173, 2025.
11. N. Nireekshana, M. A. Goud, R. B. Shankar, and G. N. S. Chandra, “Solar Powered Multipurpose Agriculture Robot,” *Int. J. Innov. Sci. Res. Technol.*, vol. 8, no. 5, p. 299, 2023.
12. N. NIREEKSHANA, A. SHIVA, A. FURKHAN, M. SRIDHAR, A. OMPRAKASH, and K. K. SHIVA, “SIX PULSE TYPE SEGMENTED THYRISTOR CONTROLLED REACTOR WITH FIXED CAPACITOR FOR REACTIVE POWER COMPENSATION,” *Int. J.*, pp. 3153–3159, 2024.
13. N. Nireekshana, “Reactive Power Compensation in High Power Applications by Bidirectionalcasceded H-Bridge Based Statcom”, Accessed: Nov. 12, 2025. [Online]. Available:

https://methodist.edu.in/web/uploads/naac/2019-11-19%2012_45_47pm%20152.pdf
14. N. Nireekshana, G. M. Krishna, A. George Muller, K. Sai Manideep, and M. Abdul Mukheem, "Power Quality Improving using FCL and DVR," *Int. J. Innov. Sci. Res. Technol. IJISRT*, pp. 624–632, May 2024, doi: 10.38124/ijisrt/IJISRT24MAY025.
15. N. Nireekshana, R. Ramachandran, and G. V. Narayana, "Novel Intelligence ANFIS Technique for Two-Area Hybrid Power System's Load Frequency Regulation," in *E3S Web of Conferences*, EDP Sciences, 2024, p. 02005. Accessed: Nov. 12, 2025. [Online]. Available: https://www.e3s-conferences.org/articles/e3sconf/abs/2024/02/e3sconf_icregcsd2023_02005/e3sconf_icregcsd2023_02005.html
16. B. Jula and N. Nireekshan, "Improving the Voltage Profile at Load End using DVR.," *Grenze Int. J. Eng. Technol. GIJET*, vol. 4, no. 3, 2018, Accessed: Nov. 12, 2025. [Online]. Available: https://search.ebscohost.com/login.aspx?direct=true&profile=ehost&scope=site&authtype=crawler&jrnl=23955287&AN=134178998&h=YQk2OkwoPFcVuqJX%2B1rKA0Mbu%2B3%2FNRInXZhf6Wu1MJR4MoiWNdCgc7k4H5aV7e79V%2BdpemgvHWYJbJToV64CuQ%3D%3D&crl=c
17. R. Jatoth and N. Nireekshana, "Improvement of Power Quality in Grid Connected Non Coventional Energy Sources at Distribution Loads," *Grenze Int J Eng Technol GIJET*, vol. 4, no. 3, 2018, Accessed: Nov. 12, 2025. [Online]. Available: https://methodist.edu.in/web/uploads/naac/2019-11-19%2012_58_06pm%20201.pdf