

SPECIAL FEATURE

Retention Rate:
Intelligent Customer
Churn Prediction &
Revenue Protection
System



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Our Mission: "To provide the best of technical skills, professional ethics and human values in enriching the disciplines of Sciences, Engineering and Technology for Social development and Nation building".

India's New Space Age: From a National Space Program to a Nation of Space Innovators

India's exploration to outer planets is an amazing tale about science, determination as well as local creativity over many years now. Indian space program from humble beginnings till moon landing & mars exploration proves technology does not need for scarcity of funds. However today there has been an evolution of things. The Indian nation's focus has been on its own space program and it's time for us to become more like an international player as well. The recent progress of Skyroot Aerospace and its Vikram series of launch vehicles has brought renewed attention to India's growing private space ecosystem. Private space companies represent another significant aspect that is being transformed here. These changes matter more than any other thing as well since an individual firm is able to develop rockets; however these happen because there's great progress on how far people from India have been able to reach out here. Startups, industries, research institutes as well as colleges have become more and often essential components of an area that was previously available mainly from government.

This transition does not diminish the role of Indian Space Research Organisation (ISRO); it builds on the extraordinary foundation that ISRO has created. Years of experience, facilities, successes on missions as well as independence from technology is there for us to build upon. In addition to this there is also a need for more public involvement as well; however it's possible that through government sponsorship & investment we can see some improvements on these fronts like launches of smaller sized space objects etc.

This era is more than rocketry, space exploration etc. The relationship between space technologies as well is

very close-to-day-by-itself-not only for navigation & forecasting but also communications; farming etc. Global space economy growth has also brought about some innovations like satellites reusable for launches as well production on orbit, It is both science-based as well it can be used for developing local innovation centres; creating new business models that will help India compete better on world market.

One can say that perhaps one of the greatest joys was seeing how these changes affect youth like an engineer from college. There is an increasing blurring of lines among education, study as well business ventures. Today's student who works with power electronics, embedded system, material science, robotics, communications and propulsion/control systems can be tomorrow's engineer for satellites/launchers. Therefore universities could be valuable breeding grounds for spaceships development centres of interest leading to testbeds as well productizing these innovations towards extraterrestrial applications. The Indian space age is going beyond rocket launching capacity & distance covered; it's about imagination, innovation as well as building skills that can help develop a nation. India's new space age should ultimately be measured not only by how many rockets we launch or how far our spacecraft travel, but by how widely we cultivate the ability to imagine, innovate and build. India once looked toward space and asked whether we could reach it. Today, the question is larger, What can we create once space becomes a frontier open to all our innovators? The journey from a national space programme to a nation of space innovators has begun and perhaps its most exciting chapters are yet to be written.

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Retention Rate: Intelligent Customer Churn Prediction and Revenue Protection System

Abstract – In the modern hyper-competitive electronic commerce landscape, escalating customer acquisition costs have transformed proactive customer retention into an absolute macroeconomic necessity for corporate survival. Traditional customer relationship management (CRM) platforms rely on static, retrospective heuristics such as Recency, Frequency, and Monetary (RFM) analysis, which fail to capture the high-dimensional, non-linear behavioral friction characterizing modern digital consumers. This paper presents a comprehensive, end-to-end predictive analytics framework and Hybrid Expert System designed to anticipate consumer attrition and optimize enterprise revenue protection. Utilizing an empirical dataset of 49,910 unique customer records, we synthesize complex human interaction patterns into continuous mathematical metrics, specifically a multi-variable Frustration Index and a Platform Engagement Score. To resolve the extreme class imbalance inherent to healthy customer databases (71% retained versus 29% churned), the Synthetic Minority Over-sampling Technique (SMOTE) is deployed, expanding the multi-dimensional feature space to 49 optimized parameters. Eight foundational and ensemble classification architectures are systematically evaluated. The hyperparameter-optimized Gradient Boosting Machine (GBM) emerges as the champion architecture, achieving a global accuracy of 91.61% and an F1-score of 0.91 via exhaustive GridSearchCV cross-validation. To bridge the traditional "black box" interpretability gap of advanced AI, a deterministic business logic Gatekeeper layer is engineered. This operational layer intercepts backend predictive probabilities and translates them into actionable, real-time visual badges (VIP, Loyal, At Risk, Lost Cause) within a Streamlit tactical dashboard, successfully transforming complex artificial intelligence into high-impact corporate strategy.

Keywords – Customer Churn, Gradient Boosting, SMOTE, Hybrid Expert System, Feature Engineering, Revenue Protection, Predictive Analytics.

I. Introduction

The financial architecture of global electronic commerce has experienced a structural paradigm shift driven by market saturation and hyper-segmentation. In this digital ecosystem, characterized by near-zero switching costs for consumers, enterprise organizations can no longer sustain long-term profitability by relying exclusively on aggressive customer acquisition funnels. Macroeconomic evaluations within marketing science demonstrate that acquiring a new consumer is approximately five times more expensive than retaining an established one, establishing Customer Lifetime Value (CLV) optimization as a critical mandate for corporate sustainability. Consequently, the capacity to identify micro-signals of consumer dissatisfaction and counteract silent customer attrition before it culminates in platform abandonment constitutes the baseline of modern revenue protection systems.

Despite the obvious fiscal urgency of retention, modern enterprise infrastructures remain severely bottlenecked by legacy software patterns.

Conventional Customer Relationship Management (CRM) tools operate primarily on retrospective, rule-based heuristics. These legacy frameworks flag a user as an attrition risk only after an extended temporal window of total inactivity has elapsed. While computationally trivial to execute via standard database queries, this reactive methodology is fundamentally flawed. By the time a customer triggers a static inactivity threshold, the cognitive decision to migrate to a competitor has already finalized. The corporate intervention is thus rendered purely reactive, resulting in exceptionally low conversion rates for expensive win-back marketing campaigns.

To transcend these structural limitations, predictive analytics must transition toward proactive Machine Learning (ML) architectures capable of parsing continuous behavioural data. Human behaviour within a digital marketplace is multi-dimensional and non-linear. The transition from active brand loyalty to complete disengagement is preceded by subtle variations across multi-variable telemetry data. Extracting predictive value from these fragmented

streams requires mathematical models that can map deep feature dependencies without assuming linear relationships.

However, a significant operational obstacle prevents the unmediated deployment of high-performing machine learning models within live enterprise workflows: the inherent interpretability gap of advanced artificial intelligence. High-accuracy algorithms, such as Gradient Boosting Machines (GBM), function as mathematical "black boxes." They compute highly accurate probability vectors but output them as abstract, scalar decimals (e.g., a raw churn risk of 0.8472). Frontline corporate operators cannot formulate an optimized counter-strategy based on an isolated probability score lacking business context.

This paper directly resolves this systemic gap by proposing, validating, and deploying a robust Hybrid Expert System for real-time customer churn mitigation. The system establishes a clean data pipeline over a large-scale data matrix, engineers continuous structural descriptors to capture behavioural friction, utilizes SMOTE to eliminate the natural 71/29 class imbalance [1], and bridges the AI interpretability gap by implementing a deterministic business logic layer (the Gatekeeper) inside a high-speed Streamlit tactical application.

II. Literature Review

The academic literature regarding customer attrition estimation has advanced through three distinct historical phases: classic empirical segmentation, foundational machine learning classification, and modern high-dimensional ensemble frameworks.

A. Heuristic Models and Legacy Segmentation

The earliest formal methodologies for consumer behavior tracking were rooted in the Recency, Frequency, and Monetary (RFM) analysis model, originally formalized for physical catalog retailing [2]. While computationally efficient and highly interpretable for corporate stakeholders, classic marketing literature proves that standalone RFM models exhibit severe predictive decay when applied to dynamic digital environments. Because RFM operates exclusively on lagging transactional endpoints, it remains entirely blind to non-transactional behavioral decay.

B. Foundational Classifiers and Analytical Constraints

Research pivoted toward foundational statistical classification algorithms to automate prediction. Logistic Regression (LR) became an industry benchmark due to its structural simplicity [3]. However, empirical assessments consistently show that LR underperforms when exposed to modern behavioural logs because it operates under the strict assumption of a linear decision boundary.

To capture non-linear relationships, standalone Classification and Regression Trees were introduced. While highly visual, standalone decision trees suffer from high variance and are intensely prone to overfitting high-dimensional spaces. Alternative baselines, such as K-Nearest Neighbours (KNN) and Naive Bayes (NB), present similar operational defects, either inducing severe computational bottlenecks or relying on the flawed assumption of class-conditional feature independence [4].

C. Ensemble Learning and Neural Networks

To eliminate the structural variance of individual decision trees, contemporary data science heavily leverages Ensemble Learning paradigms. Random Forest models apply Bootstrap Aggregating (Bagging) to construct an extensive forest of completely independent decision trees, minimizing model variance through consensus majority voting [5].

Boosting architectures, such as AdaBoost and Gradient Boosting Machines (GBM), optimize this approach by training weak learners sequentially. In a GBM architecture, each sequential tree is trained to fit the exact negative gradients of the loss function calculated by the preceding tree. Empirical literature confirms that for structured tabular business matrices, GBM architectures routinely outperform deep connectionist architectures due to their resilience against data outliers and ability to generate explicit feature importance metrics [6].

D. The Class Imbalance Problem

A major mathematical challenge across all empirical churn research is the "Class Imbalance Problem" [7]. Standard algorithms designed to maximize global accuracy become heavily biased toward the majority retained class. To counteract this, Chawla et al. formalized the Synthetic Minority Over-sampling

Technique (SMOTE) [1]. Unlike naive oversampling, SMOTE selects minority class vectors, identifies their local neighborhood using KNN, and performs mathematical interpolation to synthesize entirely new, plausible data points, establishing a robust and balanced decision boundary.

III. Methodology

The systematic architecture is shown in Fig. 1 executed to construct the Intelligent Customer Churn Prediction System follows a highly controlled data science life cycle.



Fig. 1. Block Diagram of the Proposed System

A. Data Ingestion and Quality Control

The empirical data asset compiled for this study comprises 49,910 unique customer rows containing 25 initial raw features. To establish complete data hygiene:

- Continuous parameters with missing values were resolved using statistical Median Imputation to prevent extreme outliers from artificially distorting feature distributions [8-9].
- Categorical string variables were mapped via Mode Imputation.
- Explicit range checks were hardcoded to catch structural anomalies (e.g., negative chronologies).

B. Exploratory Data Analysis (EDA)

The empirical data asset compiled for this study comprises an initial matrix of 49,910 unique customer rows containing 25 raw telemetry features. Prior to mathematical transformation, a rigorous Exploratory Data Analysis (EDA) [10] phase was conducted to

map the underlying stochastic distributions of customer behavior.

Univariate Analysis: Histogram mapping and box-plot distributions were generated for continuous variables to identify severe skewness. The target variable (Churned) revealed a severe natural class imbalance: 71.2% of the dataset represented retained consumers, while only 28.8% represented churned users.

Bivariate & Multivariate Analysis: Pearson correlation heatmaps were constructed to test for multicollinearity among independent variables. The bivariate analysis revealed strong early predictive indicators; specifically, customers exhibiting high frequencies of Customer_Service_Calls inversely correlated with Login_Frequency, establishing a baseline hypothesis for behavioural friction.

C. Feature Engineering and Synthesis

i. The Frustration Index

To mathematically aggregate and isolate the negative friction a consumer experiences, a composite continuous variable termed the Frustration Index was engineered as mentioned in equation 1.

$$F_{Index} = W_1(C_{Call}) + W_2(R_{Rate}) + W_3(A_{Rate}) \quad (1)$$

Where the weight parameters ($W_1=0.50$, $W_2=0.30$, $W_3=0.20$) were derived through exploratory correlation mining to maximize alignment with historical attrition points. C_{Call} is Service calls, R_{Rate} is the Return Rate and A_{Rate} is the Abandonment Rate.

ii. Platform Engagement Score

Positive interaction intensity was synthesized into a single continuous metric is written in equation 2.

$$E_{Score} = \ln(L_{Freq} \times S_{Dur}) + S_{Media} \quad (2)$$

Where the logarithmic transformation stabilizes high-frequency platform users. L_{Freq} represents login frequency and S_{Dur} shows session duration, S_{Media} represents social media interactions.

iii. RFM Multi-Tier Segmentation

A traditional RFM scoring pipeline was built, culminating in an aggregated index used to generate a clean tracking dataset for macroscopic business intelligence indexing.

D. Dimensionality Expansion and Feature Scaling

Machine learning classifiers cannot process raw string

data. Prior to algorithm training, categorical descriptors were processed via One-Hot Encoding (OHE). This transformed text strings into distinct orthogonal binary vectors, preventing the models from assuming arbitrary numerical ordering while expanding the dimensional matrix to exactly 49 parallel inputs.

To prevent distance-dependent algorithms (such as KNN or Neural Networks) from biasing towards parameters with massively larger scalar ranges (e.g., \$5,000 Total Spend vs. 2 Service Calls), Z-Score Normalization was applied as mentioned in equation 3.

$$Z = \frac{x - \mu}{\sigma} \quad (3)$$

Standard scaling was executed across all continuous inputs which ensure that every continuous feature possessed a mean of 0 and a standard deviation of 1.

E. Algorithmic Balancing via SMOTE

The identified 71/29 class imbalance presented a critical threat to model validity; standard algorithms would optimize for global accuracy by aggressively predicting the majority "Retained" class, generating unacceptable False Negative rates for churners. To mathematically eliminate this bias, the Synthetic Minority Over-sampling Technique (SMOTE) was deployed exclusively on the 80% training partition [1].

Operating on a local neighbourhood parameter of $K=5$, SMOTE identifies a minority class vector, calculates the Euclidean distance to its nearest neighbours in the 49-dimensional space, and executes linear interpolation to synthesize entirely new, non-duplicated data points is shown in equation 4.

$$X_{new} = X_i + \lambda(X_z - X_i) \quad (4)$$

Where X_i - base sample, X_z - Neighbor sample, λ - Random weight.

This geometric synthesis successfully balanced the training matrix to an exact 50/50 split without risking the severe overfitting associated with naive random oversampling.

IV. Experimental Results

A.Environmental Architecture and Training Strategy

The machine learning engine and deployment

interfaces were compiled within a Python 3.10 environment. Core matrix processing relied on Pandas and NumPy, while model training and cross-validation were executed via Scikit-Learn.

To ensure absolute model robustness, the 49,910-row dataset was split using an 80/20 train-test distribution. The 80% training partition was subjected to SMOTE balancing, while the 20% validation partition was strictly quarantined. Testing the models on raw, unsampled data guarantees that the reported accuracy metrics reflect real-world, highly imbalanced enterprise environments.

B. Controlled Algorithmic Comparative Analysis

As illustrated in table 1, eight different Machine Learning models were trained and evaluated using key performance metrics such as Accuracy, Precision, Recall, and F1-Score to determine the most effective predictive architecture for customer churn prediction.

Table 1. The planning components

Machine Learning Classifier	Accuracy	Precision	Recall
Naive Bayes	72.15%	0.69	0.74
Logistic Regression	78.42%	0.76	0.79
K-Nearest Neighbors	82.30%	0.81	0.83
Decision Tree	85.10%	0.84	0.85
Multi-Layer Perceptron	88.55%	0.87	0.89
Random Forest	89.20%	0.88	0.90
AdaBoost Classifier	89.95%	0.89	0.91
Gradient Boosting (GBM)	91.61%	0.91	0.92

The baseline models (Logistic Regression, Naive Bayes) demonstrated severe predictive decay, proving that customer churn cannot be mapped using linear boundaries or independent feature assumptions. While the Multi-Layer Perceptron (MLP) Neural Network performed well (88.55%), it was discarded due to its "black-box" nature, which violates the business requirement for feature interpretability.

The empirical results demonstrate the mathematical supremacy of the Gradient Boosting Machine (GBM). By sequentially building decision trees where each new tree optimizes the residual errors of the previous iteration using Gradient Descent, the GBM achieved a champion global accuracy of 91.61%. Furthermore, its exceptional Recall score of 0.92 mathematically guarantees that the system successfully traps 92% of all actual churning customers, minimizing the catastrophic enterprise cost of False Negatives.

C. Hyperparameter Optimization via GridSearchCV

To push the GBM engine to its absolute mathematical limit, hyperparameter tuning was executed using GridSearchCV with 5-fold Stratified Cross-Validation. The grid search exhaustively evaluated thousands of internal configurations, successfully resolving model convergence by locking in the following parameters:

- `n_estimators = 200`: Building exactly 200 sequential trees to adequately minimize residual cost functions without inducing computational bloat.
- `learning_rate = 0.1`: Setting a stable step size for gradient descent updates to prevent the model from overshooting the global minimum.
- `max_depth = 5`: Restricting the tree depth to 5 splits, providing enough capacity to map complex behavioural interactions while strictly preventing the high-variance overfitting observed in standalone Decision Trees.

Following optimization, structural feature importance arrays were extracted from the GBM engine via relative Gini impurity reduction, as shown in Fig. 2.

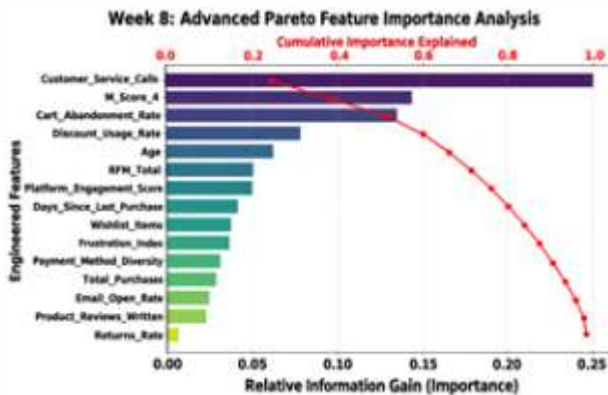


Fig. 2. Feature importance attribution extracted from the optimized Gradient Boosting Machine, highlighting the predictive dominance of engineered behavioural metrics.

This statistical breakdown validated the entire feature engineering methodology. The synthesized Frustration Index commanded the highest global feature weight (0.28), followed by raw `Customer_Service_Calls` (0.22) and `Days_Since_Last_Purchase` (0.17). Conversely, traditional static demographic indicators (e.g., User Gender, Geographic Region) were assigned negligible mathematical weights near zero. This explicitly

proves that real-time, continuous behavioural friction tracks a vastly stronger causal link to customer attrition than static CRM attributes.

D. The Hybrid Gatekeeper: Dual Deployment Architecture

The optimized mathematical components (`churn_model.pkl` and `scaler.pkl`) were deployed via a dual-avenue operational strategy to bridge the AI interpretability gap.

For macro-level strategic reporting, the processed data was routed to Microsoft Power BI. This provided corporate executives with high-level visualizations of cohort migration trends, mapping regional revenue risk points across the globe, as shown in Figure 3. For real-time tactical remediation, the GBM model was embedded within a low-latency Streamlit web application. To optimize agent speed during live customer service calls, a pre-computed vector array (`vip_base`) was hardcoded into the backend.



Fig. 3. Macroscopic strategic analytics dashboard deployed via Microsoft Power BI for executive oversight

When an agent modifies four key sliders, the app dynamically normalizes the inputs, computes the exact churn probability, and routes that raw data through the Gatekeeper Logic Tree. The Gatekeeper uses strict, deterministic if/else business rules to translate the AI probability into visual operational badges.

To validate the stability of this Hybrid system, four extreme test cases were executed:

i. Test Case 1 (The VIP Customer)

Inputs: Service Call, \$850 Spend, RFM 12, 10 Days Recency.

Execution: The backend calculated a negligible churn risk ($P < 0.05$). The Gatekeeper analysed the financial

thresholds (Spend > \$500, RFM ≥ 10) and successfully rendered a high-visibility VIP Customer badge, alerting the agent to deploy premium retention perks.

ii. Test Case 2 (The Retained/Loyal Customer)

Inputs: Calls, \$300 Spend, RFM 9, 45 Days Recency.

Execution: The profile generated a low churn probability but failed the strict financial metrics required for elite status. The Gatekeeper accurately generated a Retained (Loyal) badge, indicating that no emergency marketing intervention was required.

iii. Test Case 3 (The At-Risk Customer)

Inputs: Calls, \$150 Spend, 90 Days Recency.

Execution: The accumulation of behavioural friction triggered a severe probability spike ($P \geq 0.65$). The Gatekeeper intercepted this vector and rendered a High Churn Risk (At Risk) warning badge, signaling the agent to immediately offer an automated discount incentive to save the relationship.

iv. Test Case 4 (The Lost Cause):

Inputs: Calls, \$45 Spend, 180 Days Recency.

Execution: The extreme maximum of the Frustration Index combined with total transactional inactivity caused the model to output a near-certain churn probability ($P > 0.95$). The Gatekeeper accurately categorized the profile as an unsalvageable High Churn Risk (Lost Cause).

This critical classification explicitly instructs the enterprise to cease all retention marketing spend on this user, aggressively protecting capital Return on Investment (ROI).

V. Conclusions

The development and empirical validation of the Intelligent Customer Churn Prediction and Revenue Protection System presented in this paper marks a critical advancement in enterprise digital commerce. In an increasingly saturated marketplace where customer acquisition costs are escalating exponentially, proactive customer retention has evolved into a macroeconomic necessity. Legacy Customer Relationship Management (CRM) architectures, which rely on retrospective transactional thresholds, consistently fail to identify attrition until the customer has already abandoned the platform. This research successfully dismantles that

reactive paradigm, delivering a proactive, machine learning-driven framework that intercepts the micro-signals of consumer dissatisfaction long before finalized platform abandonment, thereby empowering enterprises to actively defend their market share and maximize Customer Lifetime Value (CLV).

The mathematical robustness of this system is fundamentally rooted in its advanced data engineering and algorithmic optimization pipeline. Moving beyond the limitations of static demographic analytics, this work engineered continuous, multi-variable behavioural constructs. Most notably, the synthesis of the Frustration Index empirically proved that real-time behavioural friction is a vastly superior leading indicator of churn compared to historical purchasing data. Furthermore, by mathematically neutralizing the inherent 71/29 class imbalance of the enterprise dataset using the Synthetic Minority Over-sampling Technique (SMOTE), the downstream algorithms maintained high sensitivity toward the critical minority class of at-risk users. Following rigorous comparative analysis across multiple architectures, the optimized Gradient Boosting Machine (GBM) emerged as the champion engine, achieving an outstanding global accuracy of 91.61% and a Recall score of 0.92, mathematically guaranteeing the detection of 92% of all actual churning customers.

Crucially, this research transcends pure statistical accuracy by resolving the traditional "black box" interpretability gap that historically prevents the deployment of advanced artificial intelligence in frontline business operations. While complex models like the GBM generate precise probability vectors, these abstract statistical decimals lack the immediate contextual clarity required by human sales agents. To bridge this operational divide, this framework introduced a deterministic "Gatekeeper" business-logic layer. By intercepting backend probabilities and mapping them to intuitive, real-time visual UI badges—such as VIP, Loyal, At Risk, and Lost Cause—the system seamlessly merges data science with corporate execution. This empowers frontline operators to execute targeted, empathetic interventions and optimize the allocation of retention capital, ensuring that marketing budgets are deployed with surgical precision to generate the highest possible Return on Investment (ROI).

VI. Acknowledgment

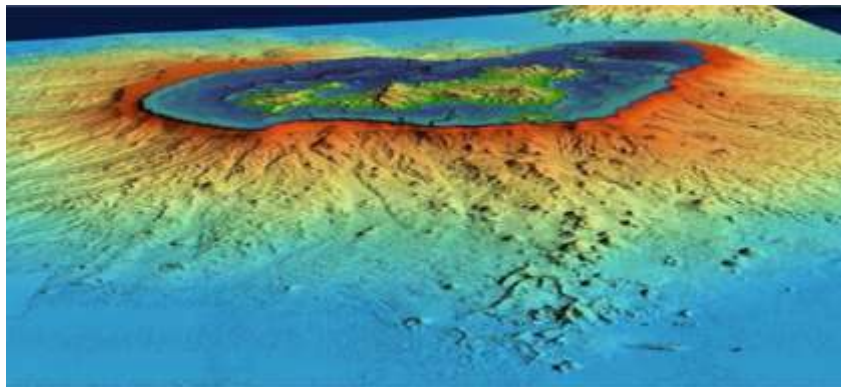
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A Volcano has Erupted Remnants of Earth's Primordial Magma Ocean



The earth was once covered by a global magma ocean, which later cooled and crystallised; now traces of this primordial event have been found in magma from a young volcano in the Indian Ocean.

A rising underwater volcano off the coast of Madagascar has been spewing up chemical traces of material from a primordial magma ocean in the first

100 million years of Earth's history.

Scientists generally suspect that the Earth's mantle, the thick layer of hot rock beneath the crust, has been steadily churning for more than 4 billion years, gradually erasing most chemical traces of the planet's earliest history.

Source: <https://www.newscientist.com/>

Robot Dog Adapts to Terrain and Climbs Stairs



A team of researchers has developed a new artificial intelligence training method that enables a four-legged robot to adapt its movement in real time, allowing it to climb stairs, navigate forests, and leap over obstacles without instructions from a human operator. The robot, called KAIST HOUND, weighs around 45 kg and uses onboard cameras and lidar sensors to analyse the terrain ahead. Based on what it detects, it can automatically switch between two different gaits: a steady trot for stability and a faster bound for tackling larger obstacles. The research, published in the journal *Science Robotics*, introduces a training framework known as Action Pretrained Transformer-Based Reinforcement Learning (APT-RL). The system combines transformer-based AI with reinforcement learning, enabling the robot to learn movement patterns from pre-generated examples before refining its behaviour through trial and error.

Source: *The Indian Express*

Artificial Sun Project

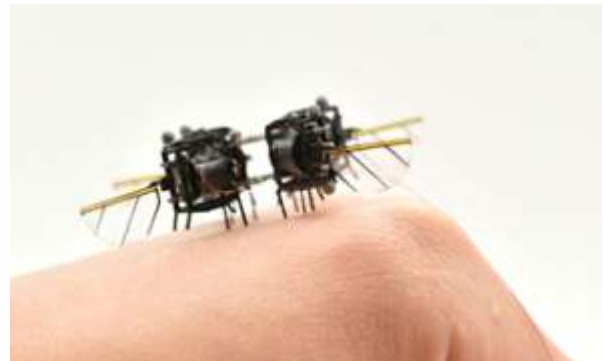


China's 'artificial sun' is an experimental reactor designed to recreate the nuclear fusion process that powers the Sun. China plans to use it to produce cleaner energy. Nuclear fission and nuclear fusion are

two types of opposite nuclear reactions that release immense amounts of energy. In fusion, lighter atoms such as hydrogen and helium, are combined to create heavier ones in a process that creates a lot more energy than fission. Fusion is common in the sun because the star is made up of plasma, often called the fourth state of matter. When liquids are heated, they turn into gases. When these gases too are heated even further, the electrons of particles separate from the atoms resulting in plasma. Plasma is essential for nuclear fusion, but creating and controlling plasma is one of the biggest engineering challenges. China's superconducting magnets have passed key tests at the Institute of Plasma Physics, Chinese Academy of Sciences marking a major engineering milestone in the country's "artificial sun" project. It is the largest superconducting fusion magnet ever built. Furthermore, it has been designed to remain operational for 60 years.

Source: *The Print*

Tiny Flying Robot Moves Like a Real Insect



MIT researchers have developed a tiny flying robot that can move with the speed and agility of real insects. It is a new AI-based controller (an aerial microrobots) that can match the speed and agility of their biological counterparts. The robotic insect can perform demanding flight maneuvers, including repeated body flips. The two-part control system combines strong performance with computational efficiency. The tiny robot could someday assist in search-and-rescue missions. After an earthquake, survivors can become trapped beneath piles of unstable debris where conventional rescue robots are too large to enter. Tiny flying machines modeled on insects could one day move through these narrow gaps while avoiding fixed barriers and falling rubble. The achievement builds on more than five years of work by Chen's group to

improve both the physical design and control of tiny flying robots.

Source: Scitech Daily

Turn Plastic Waste into Clean Hydrogen Fuel



Plastic recycling is difficult because most systems require different types to be separated first, an expensive and labor-intensive step. As a result, only 9% of plastic waste is recycled, while 79% goes to landfills and 12% is burned, releasing carbon dioxide. Scientists in South Korea have developed a new chemical technique that transforms mixed plastic waste into high-purity hydrogen fuel. The method operates at substantially lower temperatures than conventional gasification and stores the carbon as a solid mineral instead of releasing carbon dioxide into the atmosphere. The process uses alkaline thermal treatment (ATT), where heated sodium hydroxide reacts with plastic materials to generate hydrogen. The resulting hydrogen exceeded 90% purity.

Source: Scitech Daily

Magnon Lifetimes Increased for Quantum Computers



Magnons are small waves in magnetization, like ripples spreading across water. Unlike photons, which move through air space or optical fibers, magnons travel inside solid magnetic materials. Magnons wavelengths can shrink to the nanometer

scale. So, a Magnonic circuit could be built on chips used in smartphones. Although magnons have long been considered promising for quantum technologies, but they disappear almost as soon as they form. Physicists at the University of Vienna have increased magnon lifetimes from just a few hundred nanoseconds to as long as 18 microseconds. Their study revealed that the main obstacle is the quality of the magnetic material. This advance could support the development of highly compact quantum computers, with magnons serving as reliable carriers of quantum information, much like superconducting qubits in current quantum processors.

Source: Scitech Daily

3D-Printed Panels for 6G Networks



Dead zones are one of the major problems in wireless communications where signals are weak or blocked such as basement office, a warehouse aisle, a tunnel, or a crowded buildings. The challenge will be more for 6G networks which carries enormous amounts of data. Researchers at Aalto University in Finland have introduced a passive 3D-panel called metacrystals that can redirect and manipulate wireless signals. Once installed, these panels work continuously without requiring complex electronic controls. Unlike conventional reconfigurable intelligent surfaces, which depend on expensive tunable components and sophisticated control systems, metacrystals are inexpensive to produce using 3D printing, with material costs of only a few tens of euros per panel. The panels can handle multiple incoming signals, operate across different frequency bands, reflect or transmit radio waves, and even absorb unwanted signals, offering a practical and affordable solution for future wireless networks.

Source: Scitech Daily

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Development of an Advanced Digital Image Enhancement and Restoration Technique for Practical Problems

Abstract – In digital image processing, improving image quality while preserving essential structural and visual details remains a key challenge, particularly in noisy, blurred, or low-contrast conditions. This study proposes a hybrid enhancement and restoration pipeline integrating Wiener filtering, Median filtering, Gaussian smoothing, and Adaptive Histogram Equalization. Motion blur is reduced using Wiener filtering, followed by sharpening for clarity. Noise removal and contrast enhancement are applied for medical and satellite images, enabling better feature visibility. Segmentation and morphological operations assist in accurate region detection. Experimental results demonstrate improved clarity, contrast, and noise reduction, making the method efficient and suitable for medical imaging, surveillance, and remote sensing applications.

Keywords — Hybrid Enhancement, Wiener Filtering, Median Filtering, Adaptive Histogram Equalization

I. Introduction

Digital image enhancement is a key area of digital image processing that focuses on improving the visual quality and interpretability of images. In modern applications such as medical diagnosis, surveillance, remote sensing, and satellite imaging, high-quality images are essential for accurate analysis. However, images captured in real-world conditions often suffer from degradations like noise, low contrast, motion blur, and poor illumination, making feature extraction difficult [1].

Noise can arise from sensor limitations or environmental factors, while motion blur occurs due to relative movement during image capture. Low contrast and uneven lighting further reduce image clarity. These challenges highlight the need for effective enhancement techniques that improve quality without losing important details. This work proposes a hybrid image enhancement and restoration approach that combines multiple techniques. Adaptive histogram equalization enhances contrast, while median filtering removes noise. Thresholding and morphological operations assist in accurate region detection. For satellite images, median filtering, Wiener filtering, and Gaussian smoothing are applied to reduce noise while preserving details. Wiener filtering is also used for motion blur restoration, followed by sharpening to improve clarity and edges [2, 3].

II. Problem Statement

The main problems addressed in this work include image degradation issues such as noise, motion blur,

low contrast, and poor illumination, which reduce image quality and limit information extraction. These issues create difficulty in accurate analysis in applications like medical imaging, satellite imaging, and number plate detection, where detecting important features becomes challenging. Existing techniques are limited as they usually focus on a single problem and perform poorly when multiple degradations occur together. Therefore, there is a need for a hybrid approach that can handle multiple degradations simultaneously, enhance image clarity, and preserve important features for improved analysis and interpretation.

III. Literature Survey

The literature survey provides an overview of existing research and techniques in the field of digital image enhancement and restoration. Over the years, various methods have been developed to improve image quality by reducing noise, enhancing contrast, and restoring degraded images. These techniques are widely applied in domains such as medical imaging, satellite imaging, and number plate detection [4].

Traditional image enhancement methods such as Histogram Equalization (HE) have been extensively used to improve image contrast. However, these methods often suffer from limitations such as over-enhancement and amplification of noise. To overcome these issues, advanced techniques such as Adaptive Histogram Equalization (AHE) and Contrast Limited Adaptive Histogram Equalization (CLAHE) were introduced, which improve local contrast while maintaining image quality [5, 6].

Noise reduction techniques such as Median filtering and Gaussian filtering have been widely used to remove different types of noise. While Median filtering is effective for impulse noise, Gaussian filtering helps in smoothing images but may lead to loss of fine details. To address both noise and blur, restoration techniques such as Wiener filtering have been developed, which consider both degradation and noise characteristics [7,8].

In recent years, hybrid approaches combining multiple techniques have gained attention due to their improved performance. These methods integrate enhancement, filtering, and restoration techniques to handle complex real-world image degradations effectively. Such approaches are particularly useful in applications like brain tumor detection, satellite image analysis, and automatic number plate recognition. This literature survey highlights the strengths and limitations of existing techniques and provides the foundation for the proposed hybrid approach used in this research [9, 10].

IV. Motivation and Objectives

With the rapid advancement of digital imaging technologies, images have become an essential source of information in various fields such as medical diagnosis, satellite imaging, surveillance systems, and intelligent transportation. However, images captured in real-world environments are often affected by different types of degradations, including noise, motion blur, low contrast, and poor illumination, reducing the quality of images and making it difficult to extract meaningful information for accurate analysis and decision-making.

The motivation behind this work is to develop a hybrid image enhancement and restoration system that integrates multiple techniques to address various real-world challenges. By combining filtering, contrast enhancement, and restoration methods, the proposed system aims to improve image quality, enhance important features, and provide reliable results across different applications. The main objectives include: improving image contrast using adaptive histogram equalization; reducing noise using Median, Wiener, and Gaussian filtering; restoring blurred images using Wiener filtering; applying segmentation and morphological operations for brain tumor detection; enhancing satellite images while preserving color information; and improving number plate visibility

under challenging conditions.

V. Proposed Technique

The proposed technique focuses on developing an advanced digital image enhancement and restoration system to address practical real-world problems across multiple domains such as medical imaging, satellite imaging, and number plate detection. A hybrid approach is proposed that combines multiple image processing techniques for effective enhancement and restoration. The system applies suitable methods depending on the type of degradation present in the image.

A. Adaptive Histogram Equalization (CLAHE)

Adaptive Histogram Equalization (AHE) is an advanced image enhancement technique that improves image contrast by enhancing local intensity variations. Unlike traditional Histogram Equalization, which operates globally, AHE processes small regions called tiles or blocks. Each tile undergoes histogram equalization independently, allowing better enhancement of local details, especially in images with non-uniform illumination. However, AHE can amplify noise in uniform regions. To address this, Contrast Limited Adaptive Histogram Equalization (CLAHE) is used, where a clip limit restricts excessive contrast enhancement and prevents noise amplification. Interpolation is then applied to combine tiles smoothly. In this study, CLAHE is used in medical image preprocessing to enhance tumor visibility.

B. Median Filtering

Median filtering is a non-linear technique used to remove noise while preserving edges. It is particularly effective against salt-and-pepper noise. A kernel moves across the image, replacing each pixel with the median of neighboring values. Unlike linear filters, it maintains edges and textures. In this study, median filtering is applied in medical and satellite images to reduce noise before further processing.

C. Wiener Filtering

Wiener filtering is a statistical method used for image restoration by minimizing mean square error. It considers both noise and degradation functions, making it effective for reducing blur and noise simultaneously. It is widely used for restoring motion-blurred images and improving clarity. In this work,

Wiener filtering enhances satellite images and recovers details in blurred images such as number plates

D. Gaussian Filtering

Gaussian filtering is a linear smoothing technique that reduces noise using a weighted average based on a Gaussian function. It smooths intensity variations but may blur edges. In this study, it is used after median and Wiener filtering in satellite image processing to further refine image quality while maintaining overall visual consistency.

E. Image Sharpening

Image sharpening is an image enhancement technique used to improve clarity by emphasizing edges and fine details. It works by enhancing high-frequency components, making the image appear sharper and more visually distinct. A common method is unsharp masking, where a blurred version of the image is subtracted from the original to highlight edges. In this work, sharpening is applied after noise removal and restoration techniques such as median, Wiener, and Gaussian filtering. While these methods smooth the image, sharpening restores lost details and improves overall quality. It is applied carefully to avoid noise amplification or unnatural artifacts.

VI. Methodology

The proposed system follows a step-by-step process to enhance and restore degraded images using a combination of image processing techniques. The working principle is based on a hybrid approach that integrates preprocessing, filtering, enhancement, restoration, and sharpening methods to improve image quality.

A. Medical Image Processing (Brain Tumor Detection)

The input MRI image is converted to grayscale to focus on intensity variations. Contrast enhancement is performed using CLAHE, which improves the visibility of important features, particularly tumor regions, by enhancing local contrast. Noise removal is then carried out using Median filtering, which effectively removes impulse noise while preserving edges. Segmentation is performed using thresholding and morphological operations to extract regions of interest such as tumors. Region-based analysis using area and shape properties is then used to identify and

highlight the most probable tumor region.

B. Satellite Image Enhancement

Satellite images are processed on a channel-by-channel basis to preserve color information. Median filtering is applied first to remove impulse noise across each channel. This is followed by Wiener filtering to restore blur and reduce complex noise components. Gaussian smoothing is then applied to remove residual noise and smooth the image further. Finally, contrast enhancement and image sharpening are applied to improve feature visibility and overall image quality, ensuring that geographical details such as land boundaries, vegetation, and water bodies are clearly visible.

C. Motion-Blurred Image Restoration (Number Plate)

The input image is loaded and processed for motion blur restoration. Wiener filtering is applied as the primary restoration technique, minimizing the mean square error between the degraded and original image by considering both noise and degradation functions. This step helps in recovering lost details and improving clarity. Following restoration, image sharpening is applied to enhance edges and fine details, improving the overall visual quality and making the number plate characters clearly legible.

VII. Result Analysis

The proposed hybrid image enhancement and restoration system was tested across three different domains and the results were analyzed visually and qualitatively.

A. Brain Tumor Detection

CLAHE preprocessing markedly increased the

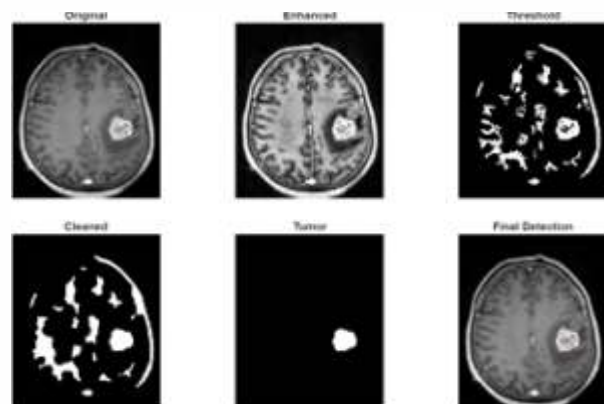


Fig. 1: Brain image detection using CLAHE technique

contrast between tumor and surrounding tissue regions. Median filtering effectively reduced noise while preserving tissue boundaries. The threshold-based segmentation and morphological operations successfully isolated the tumor region. The region-based analysis using area and shape properties accurately identified and highlighted the most probable tumor area in the output image [3]. Brain image detection using CLAHE technique is shown in Fig.1.

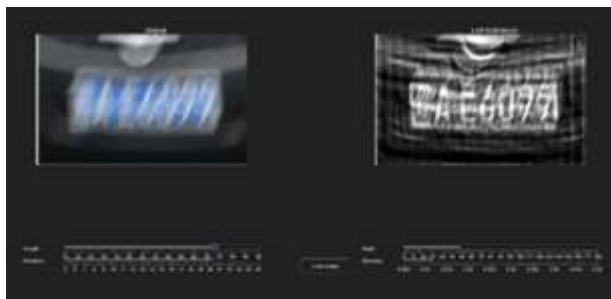
B. Satellite Image Enhancement

The multi-stage filtering pipeline effectively suppressed noise across all color channels without introducing color distortion. Channel-by-channel processing preserved spectral information while the subsequent contrast enhancement and sharpening steps improved the visibility of geographical features including road networks, vegetation boundaries, and water bodies. The final output demonstrated improved clarity and detail compared to the original degraded satellite image [4]. The satellite image enhancement using filtering techniques is shown in Fig. 2.



Fig.2: Satellite image enhancement using filtering techniques

C. Number Plate Restoration



The Wiener filtering technique effectively restored the motion-blurred number plate images. The restored

output showed significantly improved sharpness and character legibility compared to the original blurred input. Post- sharpening further enhanced edge definition, making individual characters clearly distinguishable [2]. The number plate recognition using image restoration is shown in Fig. 3.

VIII. Conclusion & Future Scope

This work presented an advanced digital image enhancement and restoration technique using adaptive histogram equalization combined with Wiener, median, and Gaussian filtering. The proposed approach effectively enhances image contrast while reducing noise and preserving important details. The integration of these techniques provides a balanced framework that improves visual quality, edge preservation, and overall image clarity compared to conventional methods. Experimental results demonstrate that the method performs well for practical image processing applications by producing cleaner and more visually interpretable outputs. However, the performance may vary depending on image characteristics and noise levels. Future work will focus on optimizing parameter selection, improving computational efficiency for real-time implementation, and extending the method to domain-specific applications such as medical imaging, satellite imagery, and surveillance systems.

Future work will focus on developing adaptive parameter optimization techniques to automatically adjust enhancement and filtering settings based on varying image characteristics. Integration of deep learning-based methods will be explored to improve automation and performance, particularly for complex and large-scale image datasets. Additionally, efforts will be made to optimize the proposed algorithm for real-time implementation using GPU acceleration and embedded systems. The method will also be validated on larger and more diverse datasets, including medical, satellite, and surveillance images, to ensure robustness, scalability, and consistent performance across different real-world applications.

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The Cosmic Coincidences that made our universe – and us – possible



The Sun and Moon are positioned just right for us to witness total solar eclipses, while the very make-up of the universe seems remarkably suited to the existence of life. Columnist Leah Crane wonders whether it is all just one extraordinary coincidence.

All of a sudden, the Sun went out. That is what it felt like to witness last month's (August 2026) total solar eclipse from a ship off the east coast of Greenland. There was, of course, a gradual dimming as the Moon moved into position over the course of an hour, but the transition from partial sunlight to complete darkness was remarkably sudden.

What makes these astonishing cosmic spectacles possible is an even more astonishing coincidence: the Sun is almost exactly 400 times larger than the Moon, but it is also almost exactly 400 times farther away from Earth. As a result, the two appear almost exactly the same size in our sky. This remarkable alignment allows the Moon to completely cover the Sun's bright disc during a total solar eclipse, casting the area beneath its shadow into sudden darkness.

Source: www.newscientist.com

Ingvar Kamprad: Building the IKEA Empire



The entrepreneurship journey of IKEA is one of the most inspiring examples of how a small business idea can grow into a global brand. IKEA was founded by Ingvar Kamprad in 1943 in Sweden but his entrepreneurial journey had started much earlier. As a young boy, Kamprad sold matchboxes, fish, pencils and Christmas cards in his village. These early experiences taught him basic business skills such as buying at a lower price, selling at a profit, and understanding what customers needed.

At the age of 17, Kamprad officially started IKEA. The name IKEA comes from his initials, Ingvar Kamprad and the name of his family farm Elmtaryd and village Agunnaryd. In the beginning, IKEA sold small household items like pens, wallets and picture frames through mail order. However, he soon realized that furniture had much greater business potential because many people wanted good-quality furniture but could not afford the expensive products available in the market. This idea led to the main success of IKEA, providing well-designed, functional furniture at affordable prices. Kamprad believed that furniture should not be a luxury for only rich people. He wanted ordinary families to have access to stylish and useful home products.

One of the most important innovations introduced by IKEA was flat-pack furniture. Instead of selling fully assembled furniture, IKEA designed products that

could be packed into flat boxes and assembled by customers at home. This reduced transport, storage and labour costs making the products much cheaper. This simple but brilliant idea changed the furniture industry and became one of IKEA's biggest strengths.

Ingvar also showed strong entrepreneurial qualities through his problem-solving mindset. When competitors tried to stop IKEA's growth by pressuring suppliers not to work with the company, he found alternative manufacturers and continued expanding. He looked for practical solutions. This ability to adapt and innovate helped his company to survive competition and grow internationally. Today, IKEA is known as one of the world's largest furniture retailers. Its stores are popular not only because of low prices but also because of modern designs, smart space-saving products and a shopping experience that allows customers to see furniture in real-life room settings.

Ingvar Kamprad turned a small business idea into a global furniture empire by focusing on affordability, quality and practical design. His journey proves that entrepreneurship is not only about making profits but also about solving everyday problems in a creative and useful manner.

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Study of the Structural, Optical, and Magnetic Properties of Oxide-Based Wide Band Gap Semiconductors

Oxide-based wide band gap (WBG) semiconductors TiO_2 and ZnO have attracted significant interest for diverse industrial applications, including solar cells, photocatalysis, sensors, biomedical applications, paper industries, diluted magnetic semiconductors (DMS), and water purification. These applications are associated with their excellent optical, structural, microstructural, and magnetic properties. The present work investigates the evolution of these properties through synthesis, post-synthesis treatments, and incorporation of dopants into TiO_2 and ZnO .

Bulk TiO materials in the form of cylindrical pellets prepared from TiO nanoparticles were irradiated with 120 MeV Ag ions at fluences ranging from 5×10^{11} to 1×10^{13} ions cm^{-2} to investigate irradiation-induced modifications in structural, microstructural, and optical properties. X-ray diffraction and Raman spectroscopy confirm the anatase phase in both pristine and irradiated samples. Although irradiation does not alter the crystal structure or polycrystalline nature, it reduces the crystalline volume fraction and introduces disorder. The irradiation also darkens the pellet surface due to the formation of oxygen vacancies in TiO_6 octahedra. Reorganization of these defects results in a reduction of the optical band gap from 3.19 eV for the pristine sample to approximately 3.0 eV at fluences above the critical value of 3×10^{12} ions cm^{-2} .

The influence of Ag doping on annealed TiO_2 thin films synthesized by sol-gel spin coating was also investigated. Undoped TiO_2 develops the rutile phase at an annealing temperature of 1000 °C, whereas 10 wt% Ag-doped TiO_2 shows no detectable rutile phase

at the same temperature. The crystallite size increases from 14.2 to 19.8 nm in Ag-doped films annealed at 900 °C. A single surface plasmon resonance band in the visible region confirms the formation of Ag nanoparticles, while the optical band gap varies between 3.05 and 3.51 eV.

ZnO@MWCNT nanocomposites synthesized by the solid-state reaction route retain the hexagonal wurtzite structure. The composites exhibit particle agglomeration, surface porosity, and defects such as oxygen vacancies and Zn interstitials. MWCNT incorporation enhances visible-region absorption with only an insignificant change in the band gap. SQUID measurements reveal mixed diamagnetic and ferromagnetic behavior with low magnetization, indicating diluted magnetic characteristics. Similarly, $\text{Zn}_{1-x}\text{Sm}_x\text{O}$ ($0 \leq x \leq 0.1$) was synthesized to study the effect of Sm doping. Oxygen vacancies, Zn interstitials, and Sm-induced defects were observed. Sm doping enhances visible emission and absorption, reducing the band gap from 3.14 to 3.09 eV. The samples exhibit paramagnetic behavior with increasing magnetization as Sm concentration increases.

Overall, the studies demonstrate that synthesis conditions, post-synthesis irradiation, and dopant incorporation effectively modify the structural, optical, microstructural, and magnetic properties of TiO_2 and ZnO . Enhanced visible-light absorption and controlled band-gap modification indicate their potential for improved photocatalytic and optoelectronic applications.

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Planet Hunter PLATO

The acronym PLATO stands for Planetary Transits and Oscillations of stars; the concrete idea for the mission was born in 2007. This name was deliberately chosen to honour the famous ancient Greek philosopher, Plato. Back in the 4th century BC, Plato was one of the first thinkers to actively search for a physical and geometrical law that could explain the orbits of planets, the errant stars, and he believed that the universe operated on the principle of 'uniformity' and 'regularity'. Millennia later, the space telescope named after him is searching for the steady, rhythmic ticking of a planet crossing in front of its star.

The European Space Agency (ESA) launched a massive campaign called “Cosmic Vision 2015-1025” which asked the European scientific community two questions: “what major mysteries should Europe spend its money solving over the next decade?” and “What are the conditions for the planetary formation and the emergence of life?” In response, a French astronomer Dr. Claude Catala, along with his team, submitted a proposal for a unique telescope which wouldn't just look for any planets, but would specifically look for a second Earth. Out of 52 competing scientific proposals submitted to ESA that year, PLATO was selected as the one of few final proposals for further study and research.

PLATO is designed to find those planets which show similar size as that of the Earth, in orbits up to the habitable zone of Sun-like stars. PLATO's blueprint was built using the lessons of CoRoT(2006)-The Proof Concept and Kepler(2009)-The Statistical King. CoRoT concept was launched by the French Space Agency (CNES) and ESA, CoRoT (Convection, Rotation and Planetary Transits) was the first spacecraft ever sent into space to search for planetary transits. It proved that measuring light dips worked flawlessly without Earth's distorting atmosphere. NASA's Kepler space telescope stared deeply at a single, fixed patch of the sky near the Cygnus constellation for years. Kepler single-handedly proved that planets outnumber stars in our galaxy which lead to the uncovering of thousands of worlds.

A total of 26 cameras are utilized to create PLATO's large field of view enabling simultaneous observations of a greater number of bright stars and for longer periods as compared to the previous missions. PLATO will assemble the first catalogue of confirmed and the characterised planets with known densities, composition and ages, which will include temperate terrestrial planets orbiting Sun-like stars. PLATO will be able to measure the oscillations of stars with unprecedented precision. By increasing the number of





stars studied with this technique by nearly 100-fold, PLATO will revolutionise the understanding of stellar evolution.

Rather than pointing all 26 telescopes at the exact same patch of sky, the mission uses a uniquely overlapping insect-eye configuration to maximize both the sky area and data quickly. Two specialized cameras are used: 24(N-CAMs) that operate in full-frame mode with 25-second readout cadence for stars fainter than magnitude 8, and 2(F-CAMs) that operate in frame-transfer mode at a swift 2.3-second cadence for brighter stars between magnitude 4 and 8. The 24 cameras are subdivided into four distinct groups of six. Each group shares an identical individual field of view of 1100 square degrees but are mechanically tilted

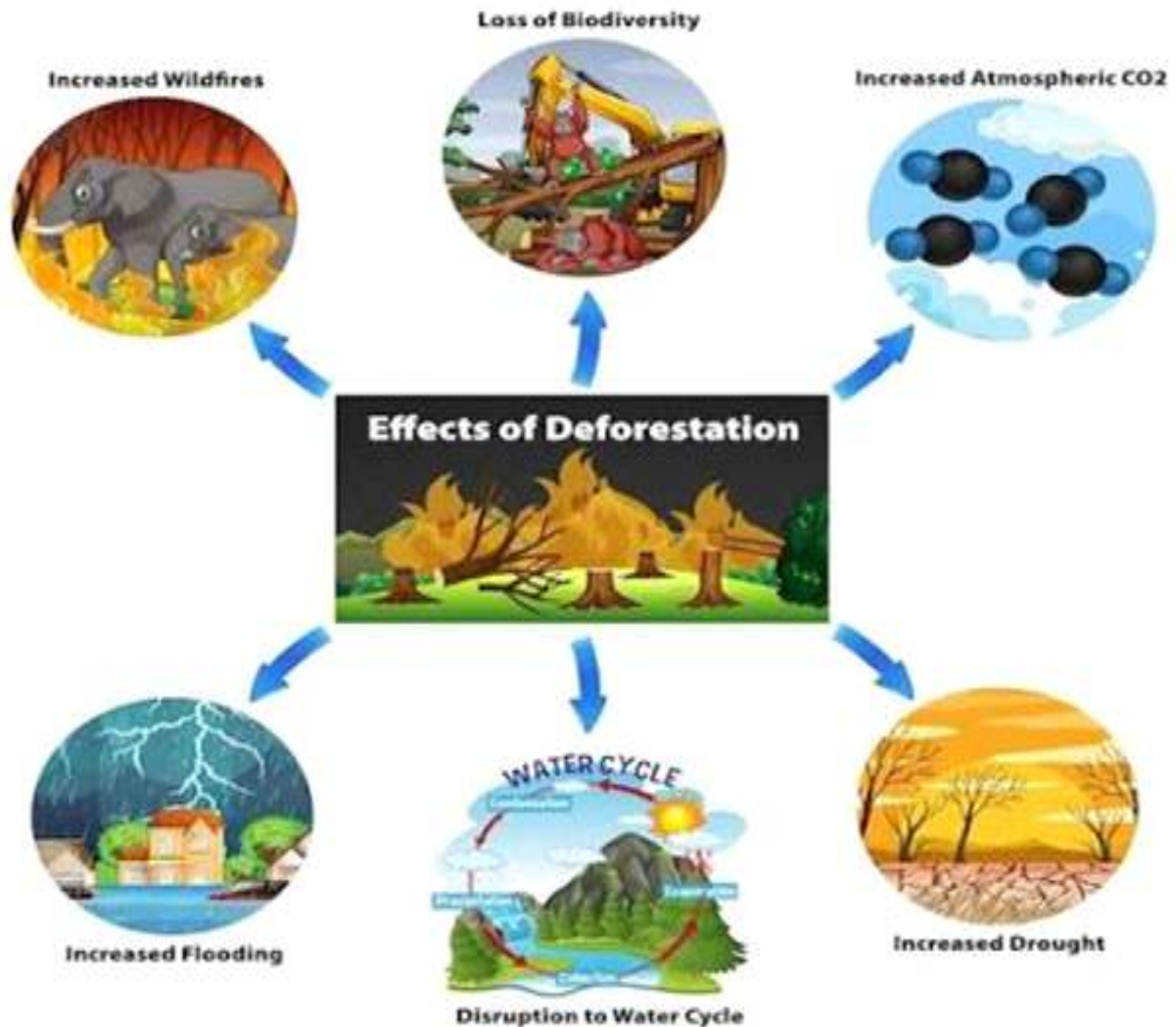
outward by 9.2-degree offset angle relative to the spacecraft's central pointing axis which allows this staggered arrangement to map enormous instantaneous total field of view of 2250 square degrees per pointing.

Source:

1. esa.int/Science-Exploration/Space-Science/Plato/Planet-hunter-plato-fly-on-Arian-6
2. [en.wikipedia.org/wiki/PLATO-\(spacecraft\)](http://en.wikipedia.org/wiki/PLATO-(spacecraft))

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Deforestation Effects on Soil Pollution and the Water Cycle



Forests are a crucial component of the water cycle and have the all-important function of preventing desertification. Cutting down trees can disrupt the cycle by decreasing precipitation and affecting river flow and water volume. In the case of the Amazon rainforest, research shows that at least 80% of its trees would be needed in order to keep the hydrological cycle going. With nearly 17% of the forest lost already, the Amazon is currently at its tipping point. Statistics show that deforestation in the tropics reduces precipitation over the Amazon by around 10%, or 138 millimetres, every year. In the South Asian Monsoon region, the reduction in rainfall is even higher, with around 18% less rain recorded in India in a single year.

Aside from their contribution to the water flow, trees help the land retain water and sustain forest life by supplying the soil with rich nutrients. Deforestation deprives the land of its cover, leaving the soil exposed to wind and rain. This makes soil vulnerable to being washed away, and prone to erosion. According to the World Wildlife Fund, as much as half of the world's topsoil has been lost as a consequence of the nearly 4 million square miles of forest that have been lost since the beginning of the 20th century.

Source: <https://earth.org/deforestation-facts/> & [Google Image](#)

Coordinated Placement of Solar Photovoltaic Systems and EV Charging Infrastructure in Radial Distribution Networks

Abstract – The increasing adoption of electric vehicles (EVs) and solar photovoltaic (PV) systems in distribution networks requires coordinated planning to maintain efficient grid operation. The rapid expansion of electric vehicle charging stations (EVCSs), along with randomly distributed PV generation, can create operational challenges such as increased power losses and significant voltage deviations in radial distribution systems. This study proposes a coordinated optimal placement strategy for solar PV systems and EV charging infrastructure in the IEEE 33-bus radial distribution network. The problem is formulated as a multi-objective optimization model aimed at minimizing total active power loss and average voltage deviation simultaneously. Load flow analysis and optimization procedures are implemented in MATLAB to evaluate system performance under different scenarios. Simulation results indicate that coordinated planning of PV units and EVCSs substantially enhances voltage regulation and reduces overall system losses. Furthermore, the proposed approach mitigates the adverse impacts associated with high EV charging demand and intermittent PV generation. The findings confirm that integrated planning ensures efficient, stable, and sustainable operation of modern active distribution networks

Keywords – electric vehicle charging stations (EVCSs), solar photovoltaic (PV), radial distribution system, IEEE 33-bus system, power loss minimization, voltage deviation minimization

I. Introduction

Modern power systems are undergoing a transformation due to the increasing adoption of renewable energy sources and electric vehicles. Solar PV systems provide clean energy, while EVs reduce dependence on fossil fuels [1]. However, their integration into traditional radial distribution Systems introduces challenges such as voltage instability, increased power losses, and bidirectional power flow. Conventional distribution systems were designed for unidirectional power flow. With the integration of distributed energy resources (DERs), these systems are evolving into Active Distribution Networks (ADNs). The intermittent nature of PV generation and stochastic EV charging demand further complicate system operation. To overcome these issues, coordinated planning of PV systems and EVCS is essential [2]. This study focuses on optimizing their placement using PSO to improve efficiency and stability.

II. Methodology

A. Load Flow Analysis

Load flow analysis is performed using the backward/forward sweep method, which is suitable for radial distribution systems [3].

Steps:

1. Initialize voltages
2. Perform backward sweep (current calculation)
3. Perform forward sweep (voltage update)
4. Repeat until convergence

B. Mathematical Formulation

The objective function is given in eqn. 1:

$$\text{Minimize } P_{\text{loss}} = \sum I^2 R \quad \dots\dots\dots (1)$$

P_{loss} = Power Loss

Subject to:

- Voltage limits (0.95–1.05 p.u.)
- Power balance constraints

C. Particle Swarm Optimization (PSO)

PSO is used to determine optimal placement of PV and EVCS. The flowchart is shown in Fig. 1.

Velocity update is given by eqn. 2:

$$v_i = wv_i + c_1r_1(p_{\text{best}} - x_i) + c_2r_2(g_{\text{best}} - x_i) \quad \dots(2)$$

v_i = velocity, p_{best} = Best position, g_{best} = global best position, c_1, c_2 = acceleration co – efficient, r_1, r_2 = random co – efficient, w = inertial weights

Position update is given by eqn. 3:

$$x_i = x_i + v_i \dots\dots\dots(3)$$

Each particle represents:

- PV locations
- EVCS locations

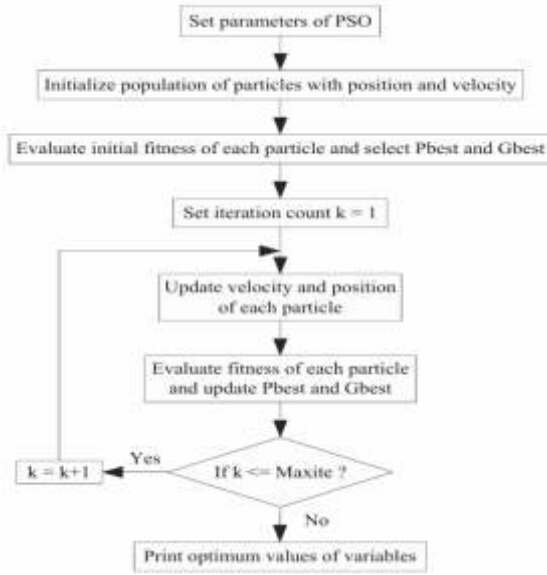


Fig1. PSO Flowchart

D. Time-Series Analysis

A 24-hour simulation is performed and the net power is given by eqn. 4:

$$P_{net}(t) = P_{load}(t) + P_{EV}(t) - P_{PV}(t) \dots\dots(4)$$

$$\begin{aligned}
 P_{net}(t) &= \text{net power}, P_{load}(t) \\
 &= \text{load power}, P_{EV}(t) \\
 &= \text{EV Power}, P_{PV} = \text{PV power}
 \end{aligned}$$

- PV peaks at midday
- EV peaks at evening

III. Results and Discussion

The Fig. 2 shows the PSO convergence curve for the following data:

Base Case Results

- Power Loss = 212.49 kW
- Minimum Voltage = 0.9041 p.u.

After Optimization

- Power Loss reduced to ~174.26 kW
- Voltage improved to 0.9161 p.u.

Optimal Locations

- PV: 18, 33, 32
- EVCS: 20, 2, 19

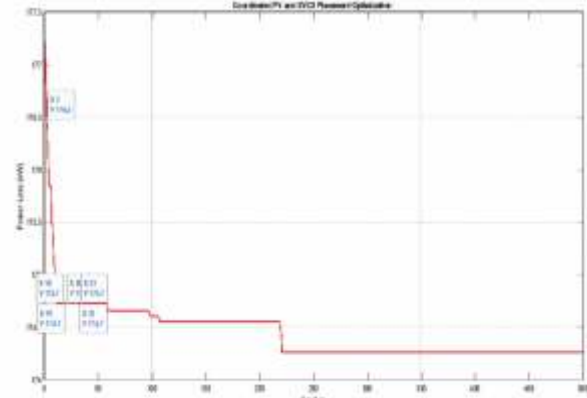


Fig.2. PSO Convergence Curve

A. Voltage Profile Improvement

Before optimization, the voltage profile of the IEEE 33-bus radial distribution system exhibits a continuous decline from the source bus towards the end buses. This drop in voltage is mainly due to the cumulative effect of line impedance and increasing load demand along the feeder. As observed from the base case results shown in Fig. 2, the minimum voltage occurs at the far-end bus (Bus 33), reaching approximately 0.9041 p.u., which indicates poor voltage regulation and potential instability in the system. After applying Particle Swarm Optimization (PSO) for the coordinated placement of solar photovoltaic (PV) systems and electric vehicle charging stations (EVCS), a noticeable improvement in the voltage profile is achieved across the network.

From the Fig. 3, it is clearly observed that the voltage magnitude at all buses increases after optimization. The improvement is particularly significant in the weak-end regions of the network, especially between

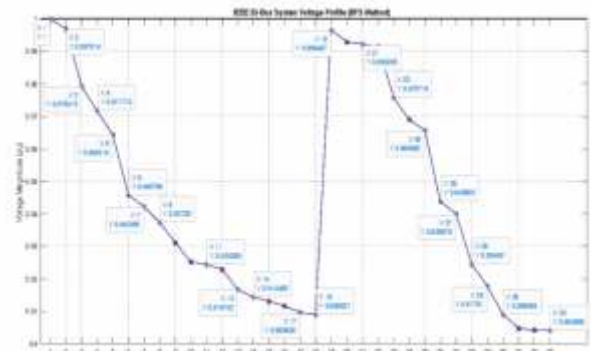


Fig. 3. Voltage Graph of Voltage profile Improvement after inserting PV and EV from the normal load flow

Bus 12 to Bus 18, where voltage drops are most severe in the base case. The minimum voltage improves from approximately 0.9041 p.u. to 0.9161 p.u., indicating enhanced voltage stability and better operational performance. This improvement is primarily due to the strategic placement of PV systems at weak buses, which provide local generation support and reduce the burden on upstream feeders. Furthermore, EV charging stations are optimally placed at relatively stronger buses near the substation, which helps in distributing the load efficiently without causing excessive voltage drops in weaker sections of the network [4]. Thus, the voltage profile analysis confirms that the proposed PSO-based coordinated placement approach effectively enhances voltage regulation, improves system reliability, and maintains bus voltages within acceptable limits.

B. System Modelling and Assumptions

The IEEE 33-bus radial distribution system is modelled under standard operating conditions. All system parameters including line impedance, load data, and base values are converted into a per-unit system for simplification of calculations [5]. The network is assumed to be balanced and operating under steady-state conditions. The solar PV systems are modelled as negative loads, injecting real power into the system, while EV charging stations are modelled as additional loads with time-dependent characteristics. The load variation is represented using hourly load multipliers to simulate real-world demand patterns. To ensure realistic simulation, the following assumptions are considered:

- Constant power load model is used
- The system operates within standard voltage limits (0.95–1.05 p.u.)
- PV generation follows deterministic irradiance pattern
- EV charging demand follows predefined daily profile

C. PSO Optimization for Voltage deviation (Only DG)

- Optimized UNIQUE DG Locations: 18, 17, 16
- Base Case VPI: 10.053640
- Final Voltage Profile Index (VPI): 0.046989
- Elapsed time is 11.522774 seconds.

Fig. 4 shows the graph of PSO Convergence & Voltage profile.

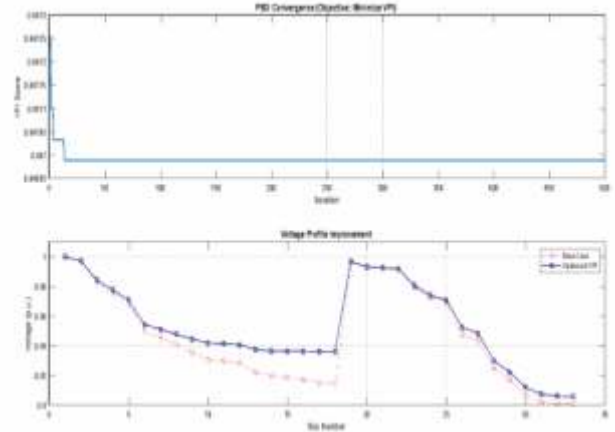


Fig. 4. Graph of PSO Convergence & Voltage profile.

D. PSO Optimization for Voltage Deviation (Both DG & EVCS)

- Optimal DG Locations (Bus): 16, 17, 18
- Optimal EVCS Locations (Bus): 20, 2, 19
- Final Voltage Deviation Index: 0.047046
- Elapsed time is 15.035465 seconds

Fig. 5 shows the Graph of VDI Optimization, Voltage Profile with DG & EVCS

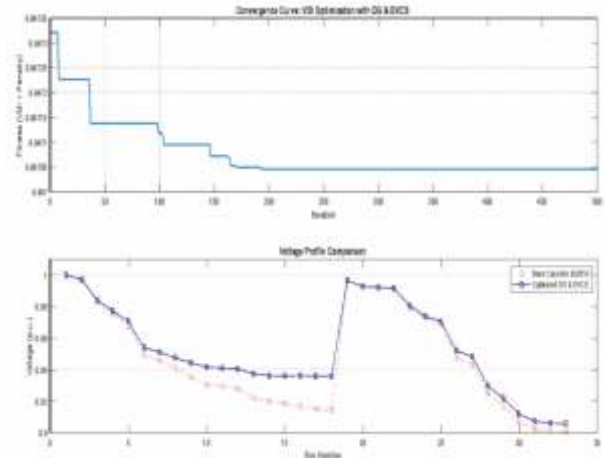


Fig. 5. Graph of VDI Optimization, Voltage Profile with DG & EVCS

E. Time-Series Analysis

To further evaluate the performance of the system under realistic operating conditions, a 24-hour time-series load flow analysis is carried out [6]. This analysis considers the time-varying nature of load demand, solar PV generation, and EV charging patterns. In this study, Solar PV generation follows a

bell-shaped curve, with maximum output during midday hours and zero generation during nighttime. EV charging demand is time-dependent, with peak demand typically occurring during evening hours when users return home. At each hour, the net load is calculated by considering the combined effect of base load, PV generation, and EV charging demand. The system is then analysed using load flow calculations to determine power losses and voltage variations. The results indicate that system performance varies significantly over the 24-hour period. The most critical operating condition occurs during evening hours (around Hour 20), where EV charging demand is high and PV generation is absent.

- Maximum Power Loss: 301.79kW (at Hour 20)
- Minimum Voltage: 0.8938 p.u. (at Hour 20)

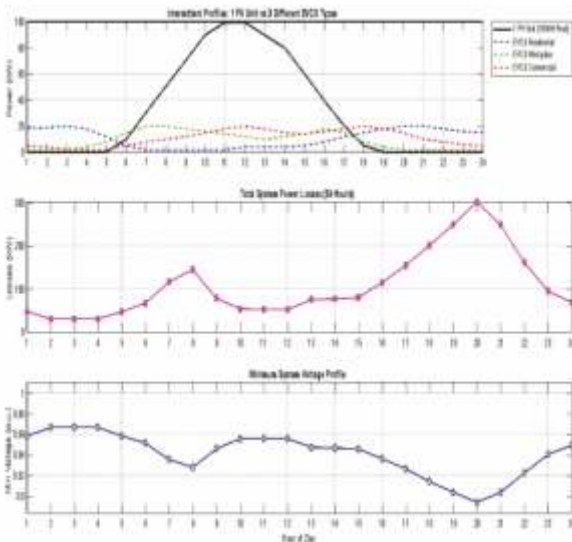


Fig. 6 Optimal Scheduling of EV charging with intermittent PV Using Time-Series Load Flow Analysis

This represents the worst-case scenario for the system. Conversely, during midday hours, when solar PV generation is at its peak, the system experiences reduced power losses and improved voltage levels due to local generation support. This analysis highlights the importance of coordinated planning and optimal scheduling of EV charging and PV generation to ensure a stable and efficient system integrating renewable energy sources with intelligent load management strategies. The coordinated operation of PV generation and EV demand ensures better utilization of available resources and reduces stress on the distribution network. Fig. 6 shows the Graphs of Simulation for Optimal Scheduling of EV charging

with intermittent PV Using Time-Series Load Flow Analysis

F. Impact of Coordinated PV and EVCS Integration

The integration of PV systems and EV charging stations has a significant impact on the operation of the distribution network. Without proper coordination, these elements can introduce instability due to fluctuating generation and demand. However, when optimally placed:

- PV systems reduce line loading and power losses
- EVCS placement ensures balanced load distribution
- Voltage profile is stabilized across the network

The coordinated approach ensures that the advantages of both technologies are maximized while minimizing their adverse effects on the system. The results obtained from both optimization and time-series analysis provide several important insights:

- Significant Reduction in Power Loss: The total power loss is reduced from 212.49 kW to approximately 174.26 kW, demonstrating improved system efficiency.
- Improved-Voltage-Profile: The minimum voltage improves from 0.9041 p.u. to 0.9161 p.u., ensuring better voltage stability across the network.
- Optimal-Placement-Strategy PV systems are placed at weak-end buses to support voltage levels, while EVCS are placed near stronger buses to minimize adverse impacts.
- Impact-of-Multi-Objective Optimization: The coordinated approach balances both power loss minimization and voltage stability, leading to an overall improved system performance.
- Time-Series-Insight: The system experiences maximum stress during peak EV demand and low PV generation, emphasizing the need for dynamic system planning.

These findings validate the effectiveness of the proposed optimization framework and highlight its applicability in future smart grid environments with high penetration of distributed energy resources.

IV. Conclusion

This study presents an effective framework for the

coordinated placement of solar photovoltaic systems and electric vehicle charging stations in a radial distribution network. The results demonstrate that the proposed PSO-based optimization significantly reduces power losses and improves voltage stability. The analysis confirms that strategic placement of PV systems at weak buses enhances voltage support, while optimal placement of EVCS prevents excessive loading in critical regions. The time-series analysis further highlights the importance of considering dynamic operating conditions for accurate system evaluation. Overall, the proposed methodology provides a practical and scalable solution for modern power systems. It is highly relevant for smart grid applications where the integration of renewable energy and electric vehicles is rapidly increasing. Future work may include the integration of energy storage systems and advanced real-time control strategies to further enhance system performance.

V. Future Scope

The present study focuses on the coordinated placement of solar photovoltaic (PV) systems and electric vehicle charging stations (EVCS) in a radial distribution network using Particle Swarm Optimization (PSO). While the results demonstrate significant improvements in power loss reduction and voltage stability, there are several directions in which this work can be extended for more advanced and realistic applications. One important extension of this work is the integration of energy storage systems (ESS) such as batteries. Energy storage can help in mitigating the intermittency of solar PV generation by storing excess energy during peak generation periods and supplying it during low generation or high demand conditions, thereby further improving system stability and reliability. Another potential area of improvement is the incorporation of real-time and adaptive control strategies. In this study, EV charging demand and PV generation are modelled using predefined profiles. However, in real-world scenarios, these parameters are highly uncertain and dynamic. The use of smart control techniques, such as demand response and real-time scheduling of EV charging, can significantly enhance system performance. The optimization approach can also be extended by considering advanced algorithms such as Genetic Algorithm (GA), Artificial Neural Networks (ANN), or hybrid optimization techniques. A comparative analysis between different optimization methods can provide deeper insights into performance, convergence speed, and solution quality.

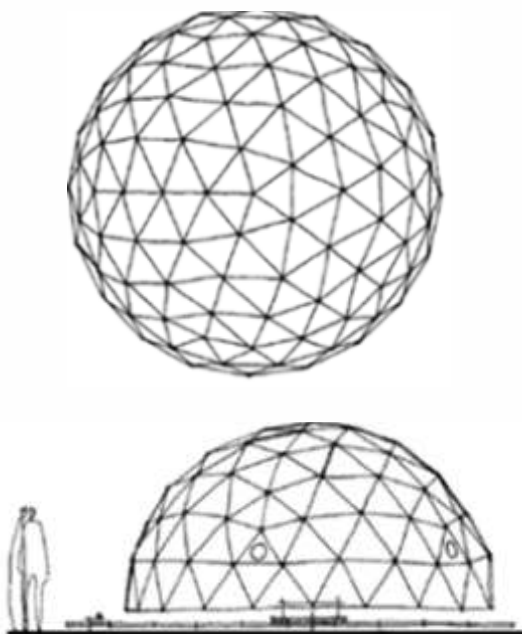
Furthermore, the study can be expanded to include larger and more complex distribution networks, including unbalanced and meshed systems. Incorporating factors such as network reconfiguration, fault conditions, and reliability indices would make the analysis more comprehensive. The inclusion of economic analysis is another important future direction. Evaluating the cost of installation, operation, and maintenance of PV systems and EVCS, along with potential savings from loss reduction, would provide a more practical perspective for real-world implementation. Additionally, the impact of high penetration of electric vehicles and renewable energy sources can be studied in detail to understand their influence on grid stability, power quality, and infrastructure requirements. In conclusion, the proposed framework can be further enhanced by integrating advanced technologies, real-time control mechanisms, and economic considerations, making it highly suitable for future smart grid and sustainable energy system applications.

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Buckminster Fuller, the Buckyball.... and Fullerene!

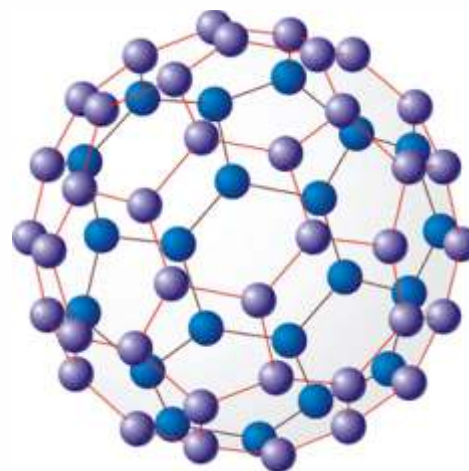


A Geodesic Dome

A sphere has the least surface area for a given volume - all other three-dimensional shapes have a greater surface area, for the same volume. Nature minimizes, and that is why rain drops are almost spherical. Enter Richard Buckminster Fuller, an American architect and inventor who envisaged and built the first geodesic dome in 1954, which closely resembled a soccer ball. Fuller discovered that if a spherical structure was created from triangles, it would have unparalleled strength.

Coincidentally in 1985 there was a discovery of a new form of carbon comprising 60 atoms arranged in a hollow spherical structure, eerily similar to the geodesic dome. The discovery was made by Harold Kroto, Robert Curl, and Richard Smalley, who were awarded the Nobel Prize in Chemistry in 1996. Its striking resemblance to Fuller's geodesic dome led to the molecule being named Buckminsterfullerene, or simply fullerene, often called the "buckyball." Consisting of 12 pentagons and 20 hexagons, the molecule is remarkably stable and has become one of the foundational structures of nanotechnology.

A fullerene is an allotrope of carbon made entirely of carbon atoms arranged in a hollow, cage-like structure. They exist either as closed spheres which are



A Fullerene molecule

commonly called buckyballs, or as long cylinders known as carbon nanotubes. They can form in nature, typically in the soot of fires, lightning strikes, and even in interstellar space. They can also be synthesized in laboratories or industrial settings by vaporizing graphite in an electric arc in the presence of an inert gas.

The buckyball's significance is monumental. Its unique mechanical, electrical, and optical properties have inspired advances in targeted drug delivery, organic photovoltaics, molecular electronics, advanced sensors, and energy storage. More importantly, it demonstrates how insights from geometry and architecture can catalyze discoveries in molecular science.

Taking a page out of Buckminster Fuller's book, our future engineers must possess curiosity, exhibit creativity, and collaborate across diverse fields to develop technologies that are both innovative and have societal benefit.

(Content excerpted from web sources)

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