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Secured Blockchain-Based Voting System Using ZKP, IPFS

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Abstract: In modern democracies, secure and transparent voting mechanisms are critical for ensuring public trust and electoral integrity. Traditional voting systems often face challenges such as tampering, identity fraud, and lack of transparency. This paper proposes a Blockchain-Based Voting System designed to address these issues by integrating advanced technologies including Zero-Knowledge Proofs (ZKP), InterPlanetary File System (IPFS), and the Polygon Proof-of-Stake (PoS) blockchain. The system incorporates Aadhaar-based identity verification with OTP authentication to ensure that only eligible citizens can vote, while preserving voter anonymity through the implementation of ZKP. All sensitive data, including votes and candidate information, are recorded on the decentralized Polygon network, ensuring immutability and transparency. IPFS is employed for storing large files such as candidate profiles and voting records in a secure and distributed manner. Smart contracts automate the core election functions such as vote casting, validation, and result declaration, thereby minimizing the risk of human error and manipulation. A modular user interface is provided for both voters and election administrators, facilitating real-time monitoring, seamless authentication, and secure participation. By leveraging blockchain's trustless architecture and privacy-preserving cryptographic protocols, the proposed system aims to modernize the electoral process, enhance voter confidence, and strengthen democratic institutions in the digital age.The architecture ensures end-to-end verifiability, making each vote independently auditable without compromising confidentiality. This integration of privacy, security, and scalability offers a robust foundation for next-generation electoral systems.

Keywords: Blockchain, Zero-Knowledge Proofs (ZKP), IPFS, Polygon PoS , Aadhaar Authentication, OTP Verification, Smart Contracts, Decentralized Voting, Voter Privacy, Electoral Transparency, Tamper-Proof Elections, Secure Voting System.

I. INTRODUCTION

In democratic societies, elections play a pivotal role in shaping governance and public policy. However, conventional voting systems continue to face significant challenges, including voter fraud, tampering of results, lack of transparency, and limited accessibility. Manual handling of votes and centralized databases are prone to errors and manipulation, which can erode public trust in the electoral process. Ensuring a secure, transparent, and verifiable voting system is therefore essential to uphold the integrity of democratic institutions.

Recent advancements in blockchain technology, cryptographic methods, and decentralized storage have opened new possibilities for building secure and tamper-proof digital voting systems. Blockchain provides a distributed and immutable ledger that can transparently record votes, while smart contracts enable the automation of election logic without human intervention. Zero-Knowledge Proofs (ZKP) enhance privacy by allowing identity verification without disclosing sensitive information, and IPFS supports decentralized storage of large, immutable data such as voter logs and candidate profiles.This paper presents a Blockchain-Based Voting System that leverages Aadhaar-linked OTP verification for voter authentication, ZKP for maintaining voter anonymity, and the Polygon PoS blockchain for secure and scalable transaction management. IPFS is utilized for storing non-transactional data in a distributed manner.

The system aims to minimize human intervention, eliminate election fraud, and provide real-time monitoring for administrators. By combining these technologies, the proposed platform addresses the limitations of traditional voting systems and offers a reliable, scalable, and privacy-preserving alternative for digital elections.

II. LITERATURE SURVEY

In [1], the authors proposed a blockchain-based electronic voting system utilizing Ethereum smart contracts to enhance vote security and transparency. The system recorded votes on-chain and enabled real-time result visibility. However, it lacked privacy measures, exposing voter identities and selections on the public ledger.

The study in [2] introduced an online voting platform using biometric authentication and a centralized server to store and verify votes. While the system improved user authentication accuracy, it was vulnerable to single-point failures and data breaches due to the centralized nature of storage and processing.

In [3], a decentralized voting model was developed using Hyperledger Fabric. This permissioned blockchain allowed only registered nodes to validate transactions, improving control but sacrificing the openness and decentralization offered by public blockchains like Polygon.

The research in [4] examined the use of IPFS for storing election data in combination with a blockchain ledger. Although this hybrid approach successfully offloaded large files from the chain, it did not integrate voter privacy mechanisms like Zero-Knowledge Proofs, leaving sensitive information partially exposed.

In [5], the integration of Zero-Knowledge Proofs into digital voting was explored for preserving voter anonymity. While the cryptographic framework ensured privacy, the implementation complexity and performance overhead were noted as potential barriers to adoption in large-scale elections.

The current project builds upon these previous works by combining the benefits of decentralized storage (IPFS), privacy-preserving cryptography (ZKP), and scalable blockchain infrastructure (Polygon PoS). It also introduces Aadhaar-based OTP verification to ensure voter eligibility while maintaining strict data privacy standards. The proposed system addresses the limitations of earlier models by offering a holistic, modular, and secure framework for conducting tamper-proof digital elections.

III. METHODOLOGY

The proposed Blockchain-Based Voting System is designed with a modular architecture to ensure scalability, security, and user-friendliness. It integrates blockchain smart contracts, decentralized storage, and identity authentication into a cohesive voting framework. The methodology is divided into the following core components:

A. *System Architecture*

The architecture consists of three main layers: the Frontend Interface, the Blockchain Backend, and the Distributed Storage Layer. The frontend is built using modern web technologies to provide interfaces for voters and administrators.

The backend comprises smart contracts deployed on the Polygon PoS network to manage the election logic, including voter registration, vote casting, and result computation. IPFS is used to store large and non-sensitive data like candidate profiles and voting logs in a decentralized manner.

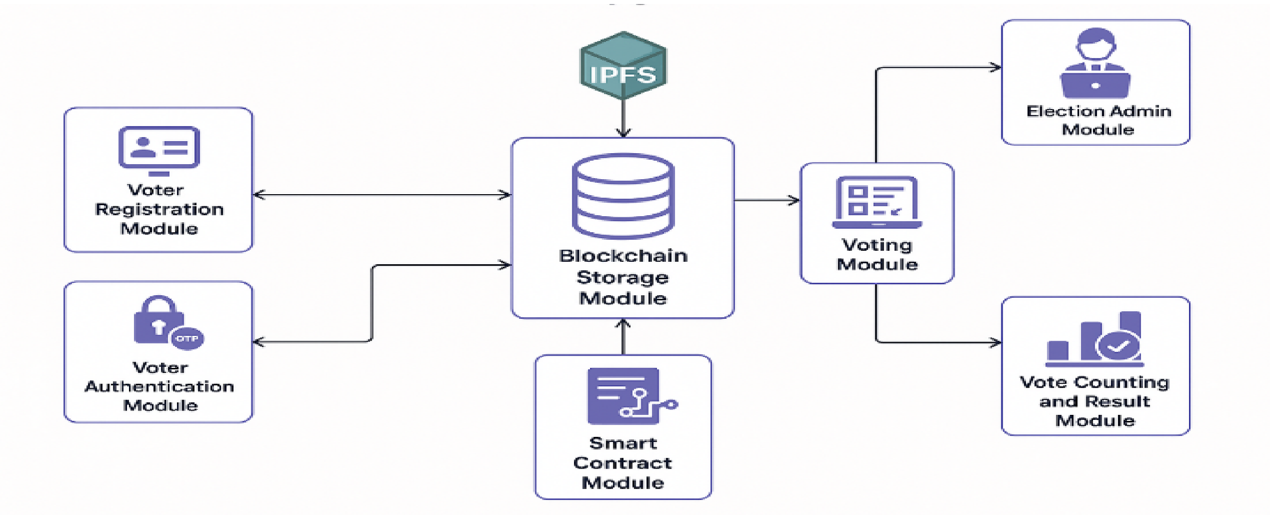

IPFS
Election Admin Module
Voter Registration Module
Blockchain Storage Module
Voting Module
Voter Authentication Module
OTP
Smart Contract Module
Vote Counting and Result Module

Fig. 1. Voting Architecture

B. *Voter Onboarding and Identity Verification*

Upon visiting the platform, voters undergo a secure onboarding process that begins with Aadhaar-linked OTP authentication. The user is prompted to enter their Aadhaar number, after which a one-time password (OTP) is sent to the registered mobile number. This step ensures that only eligible and verified individuals can proceed to vote. Upon successful verification, a unique voter ID is generated, and a Zero-Knowledge Proof (ZKP) is constructed to allow the system to authenticate the voter in subsequent actions without exposing their identity or personal data.

C. Vote Casting Using Smart Contracts

Once authenticated, users are directed to the voting interface where all available candidates are displayed. Upon selecting a candidate, the vote is encrypted and passed to a Solidity-based smart contract deployed on the Polygon blockchain. The contract validates that the voter hasn't already cast a vote and then records the encrypted vote immutably. This contract also manages real-time vote counts and ensures that voting logic is enforced without any human intervention. The use of ZKP ensures vote confidentiality, while the blockchain guarantees tamper-proof recording.

D. Decentralized Storage via IPFS

To reduce on-chain storage costs while maintaining transparency, the system utilizes the InterPlanetary File System (IPFS) for storing large and non-sensitive data. This includes candidate bios, voter turnout reports, and anonymized voting logs. Every file uploaded to IPFS returns a Content Identifier (CID), which is then stored on-chain. This approach ensures that election-related files are stored in a distributed and immutable format, yet easily retrievable for verification or auditing.

E. Election Monitoring and Admin Control Panel

Election administrators are provided with a dedicated dashboard where they can:

- Monitor live voting progress and turnout
- Add or remove candidate records
- Start and end the election process

All administrative actions are also logged on the blockchain, ensuring accountability and traceability. This interface enables real-time election governance while adhering to a role-based access model.

E. Privacy-Preserving and Verifiable Architecture

The entire architecture is built with a privacy-first approach. Voter identities are never stored on-chain, and voting selections are kept confidential via cryptographic commitments. The system ensures end-to-end verifiability, meaning any third party can independently verify that the recorded votes match the published results without compromising voter privacy. All data interactions are end-to-end encrypted and securely relayed through smart contracts.

IV. RESULTS AND ANALYSIS

The Blockchain-Based Voting System was evaluated through functional testing and scenario-based validation to assess its performance, accuracy, and robustness in a simulated election environment. A sample user base was created to simulate voter registration, authentication, vote casting, and result computation. The system was tested on its core modules including Aadhaar-based OTP verification, Zero-Knowledge Proof validation, smart contract interactions on the Polygon PoS network, and decentralized data storage via IPFS.

The results highlight the system's ability to provide a secure, transparent, and efficient digital voting experience. By simulating real-world election processes, the testing environment enabled performance benchmarking across multiple system features. The following are key outcomes observed during system evaluation:

1) *Accurate Voter Authentication*: The Aadhaar-linked OTP verification mechanism correctly authenticated all legitimate voters while blocking invalid attempts. The integration of ZKP ensured that user identities remained private throughout the process.
2) *Secure and Immutable Vote Recording*: Votes cast via the DApp were immutably recorded on the Polygon blockchain. Smart contracts successfully enforced the "one person, one vote" rule and automatically rejected duplicate vote attempts.
3) *Tamper-Proof Storage with IPFS:* Candidate profiles, voting logs, and election reports were uploaded to IPFS. The corresponding CIDs were reliably stored on-chain, ensuring data could be verified but not altered, providing full auditability.
4) *Real-Time Vote Tallying:* Smart contracts accurately tallied votes in real time and displayed the results on the admin dashboard without any delay or inconsistencies. The transparency of the process allowed observers to validate vote counts independently.
5) *Administrative Monitoring and Control:* Election administrators were able to seamlessly manage the election lifecycle, including adding candidates, initiating or ending the election, and accessing encrypted logs. The role-based dashboard ensured accountability for each administrative action.
6) *Scalability and Low Transaction Cost*: Leveraging the Polygon PoS network enabled high transaction throughput with minimal gas fees, making the solution scalable for institutional and governmental deployments.

These results confirm the system's effectiveness in delivering a highly secure, verifiable, and privacy-preserving digital voting process. The combination of blockchain immutability, cryptographic privacy, and decentralized storage positions this platform as a reliable alternative to traditional election systems

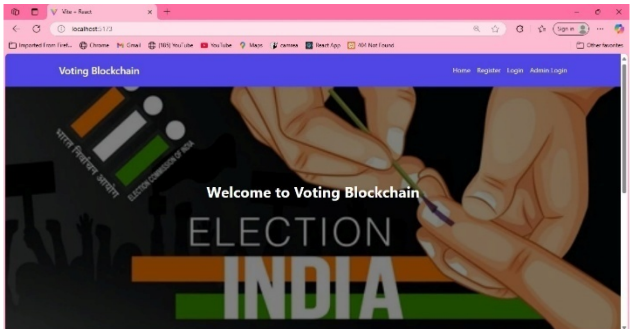
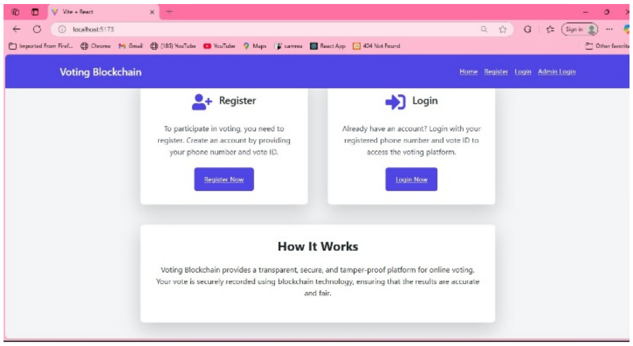


Fig. 2. Landing Page



To participate in voting, you need to register. Create an account by providing your phone number and vote ID.

Already have an account? Login with your registered phone number and vote ID to access the voting platform.

Voting Blockchain provides a transparent, secure, and tamper-proof platform for online voting. Your vote is securely recorded using blockchain technology, ensuring that the results are accurate and fair.

Fig. 3. Home Page

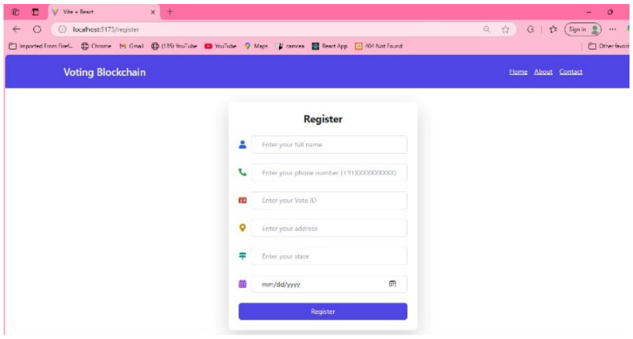


Fig. 4. User Registration Page

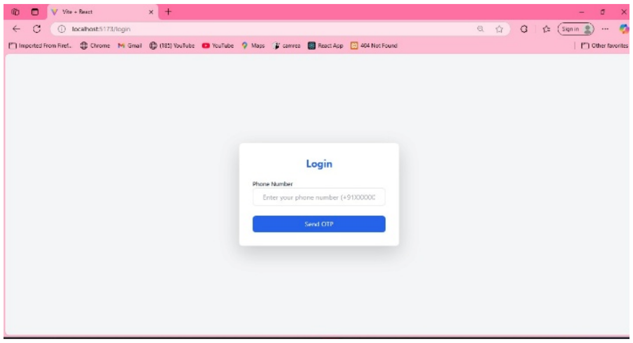
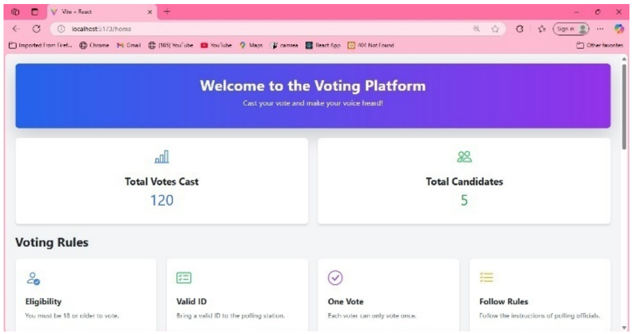


Fig. 5. Login Page



Welcome to the Voting Platform

Cast your vote and make your voice heard!

Total Votes Cast 120

Total Candidates 5

Voting Rules

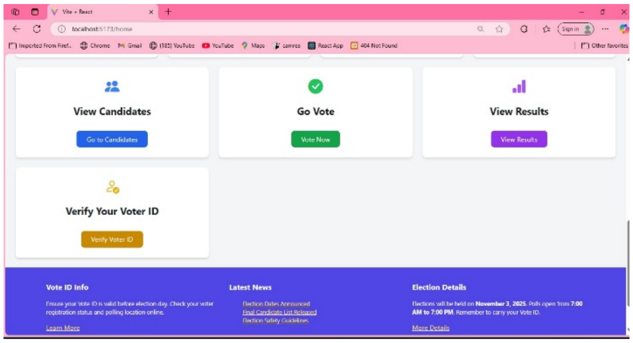
Eligibility: You must be 18 or older to vote.

Valid ID: Bring a valid ID to the polling station.

One Vote: Each voter can only vote once.

Follow Rules: Follow the instructions of polling officials.

Fig. 6. Welcome Page



Vote ID Info

Ensure your Vote ID is valid before election day. Check your voter registration status and polling location online.

Learn More

Latest News

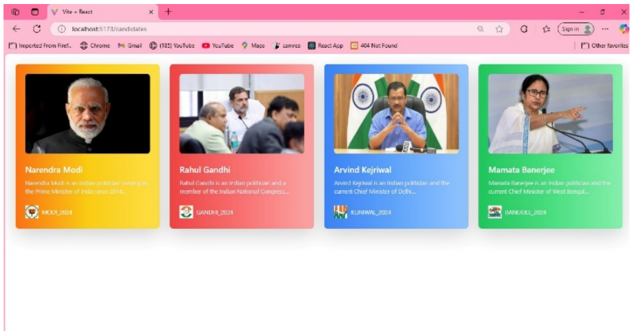
Election Dates Announced
Final Candidate List Released
Election Safety Guidelines

Election Details

Elections will be held on **November 3, 2025**. Polls open from **7:00 AM to 7:00 PM**. Remember to carry your Vote ID.

More Details

Fig. 7. Dashboard Page



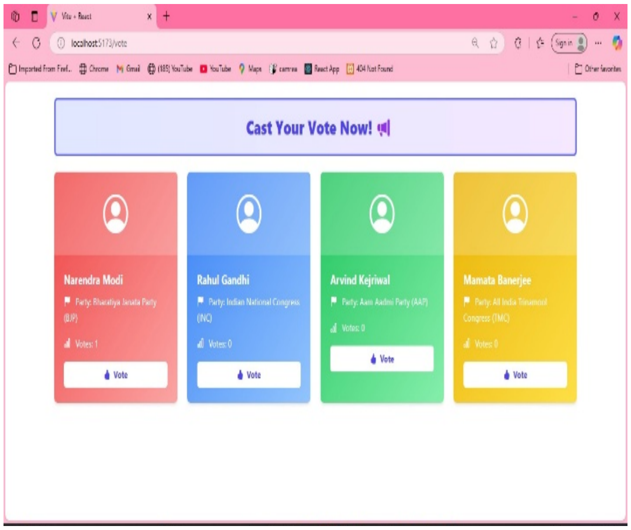
Narendra Modi: Narendra Modi is an Indian politician serving as the Prime Minister of India since 2014... MODI_2024

Rahul Gandhi: Rahul Gandhi is an Indian politician and a member of the Indian National Congress... GANDHI_2024

Arvind Kejriwal: Arvind Kejriwal is an Indian politician and the current Chief Minister of Delhi... KEJRIWAL_2024

Mamata Banerjee: Mamata Banerjee is an Indian politician and the current Chief Minister of West Bengal... BANERJEE_2024

Fig. 8. Candidate List Page



Cast Your Vote Now!

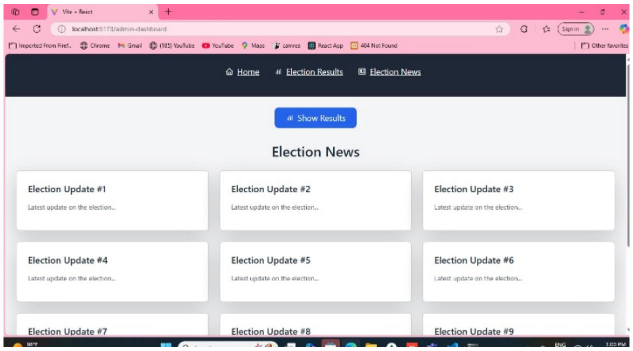
Narendra Modi: Party: Bharatiya Janata Party (BJP); Votes: 1

Rahul Gandhi: Party: Indian National Congress (INC); Votes: 0

Arvind Kejriwal: Party: Aam Aadmi Party (AAP); Votes: 0

Mamata Banerjee: Party: All India Trinamool Congress (TMC); Votes: 0

Fig. 9. Vote Casting Page



Home | Election Results | Election News

Show Results

Election News

Election Update #1
Latest update on the election...

Election Update #2
Latest update on the election...

Election Update #3
Latest update on the election...

Election Update #4
Latest update on the election...

Election Update #5
Latest update on the election...

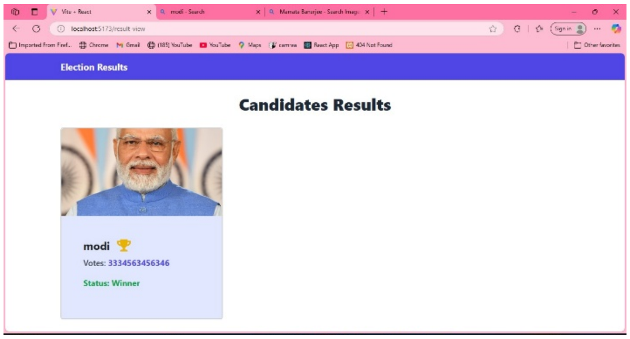
Election Update #6
Latest update on the election...

Election Update #7

Election Update #8

Election Update #9

Fig. 10. Admin page



Election Results

Candidates Results

modi 🏆
Votes: 3334563456346
Status: Winner

Fig. 11. Result Declaration Page

V. FUTURE WORK

To further enhance the performance, scalability, and real-world applicability of the proposed Blockchain-Based Voting System, the following improvements are envisioned:

1) *Biometric Integration for Voter Authentication:* Future versions will include biometric verification such as fingerprint or iris scans, enhancing voter identity validation and reducing the risk of impersonation or Aadhaar-based OTP misuse.
2) *Mobile Voting Application*: Developing a dedicated mobile application will increase accessibility for voters, particularly in rural or remote areas. The app will offer a streamlined interface for registration, voting, and result viewing while maintaining security and encryption standards.
3) *Multi-Language Interface*: To support electoral participation across diverse linguistic populations, the platform will be extended to support multiple regional languages. This includes both UI localization and voice-guided navigation for enhanced usability.
4) *Offline Voting Capability with Sync:* A hybrid offline-online model is proposed to allow vote casting in low-connectivity regions. Votes would be temporarily stored locally in encrypted form and synchronized to the blockchain once connectivity is restored.
5) *Integration with Government Electoral Databases*: For large-scale national deployment, the system will be integrated with official electoral rolls and verification databases. This will enable automatic eligibility validation and reduce administrative overhead during voter onboarding.
6) *ZKP Optimization for Scalability*: Further research will be conducted to reduce the computational complexity of Zero-Knowledge Proofs, enabling faster verification for large voter populations without compromising privacy or system throughput.

As digital governance and secure civic engagement gain prominence, these advancements will ensure the platform remains robust, inclusive, and aligned with evolving technological and democratic needs.

VI. CONCLUSIONS

The Blockchain-Based Voting System presented in this paper demonstrates the effectiveness of integrating decentralized technologies, cryptographic privacy, and Aadhaar-based authentication to modernize and secure the electoral process. Unlike traditional voting systems, this architecture ensures end-to-end transparency, immutability, and privacy through the use of Polygon PoS blockchain, Zero-Knowledge Proofs (ZKP), and IPFS-based decentralized storage.

It enables secure voter onboarding via OTP verification, verifiable and anonymous vote casting, and real-time result computation through smart contracts.

System evaluation showed high accuracy in vote handling, resistance to tampering, and seamless user interaction, indicating strong potential for scalability and public adoption. The modular architecture supports adaptability to both institutional and large-scale government elections, while cryptographic components preserve voter anonymity and data integrity. By eliminating manual intervention and central points of failure, the system enhances electoral trust, reduces fraud, and empowers democratic participation in the digital era. This work affirms blockchain's role in transforming voting infrastructure and lays the groundwork for future innovations in secure, transparent, and inclusive digital governance.

VII. ACKNOWLEDGEMENT

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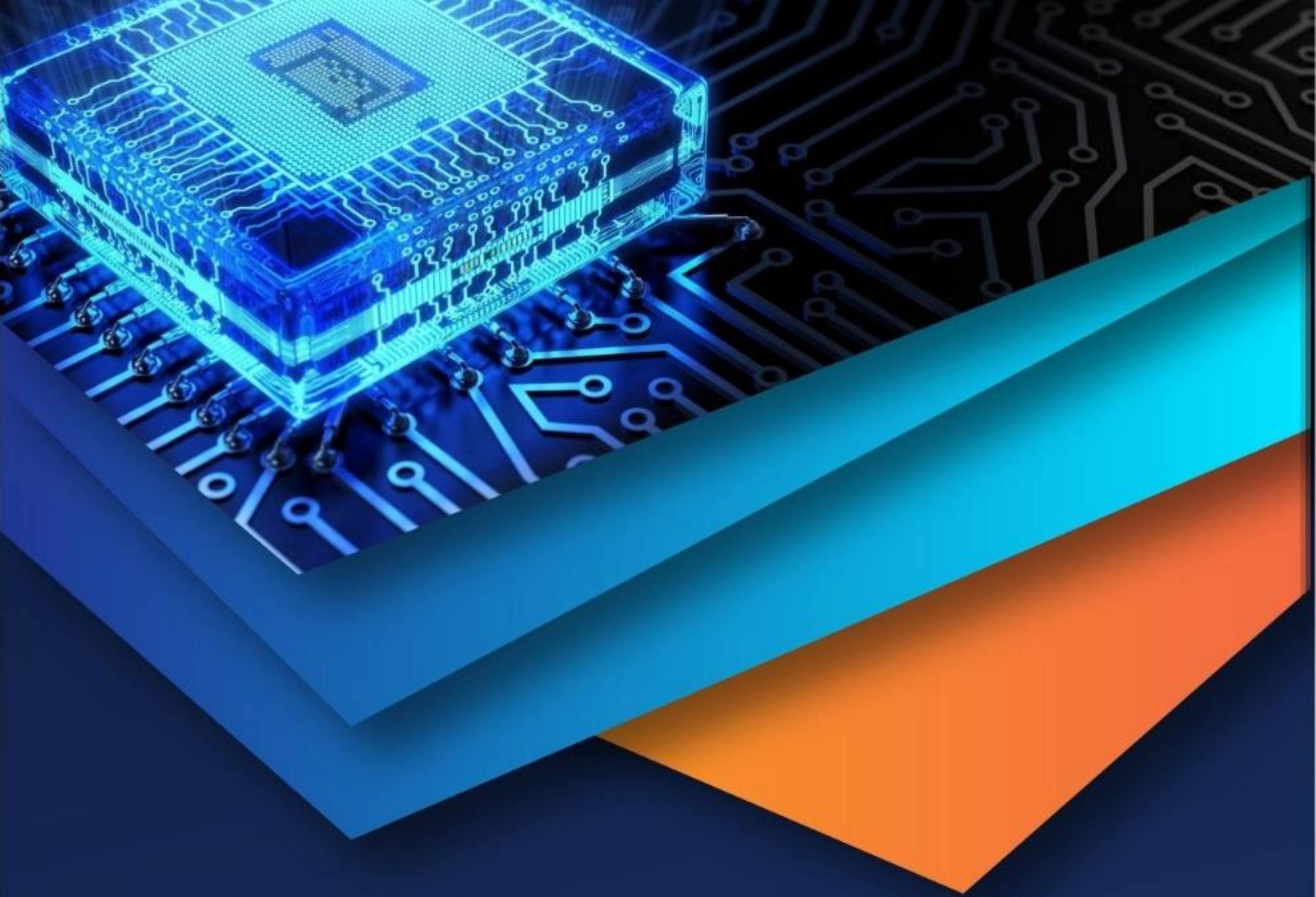

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