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The Role of PLCs in Modern Safety Systems: Applications and Advantages

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Abstract: This study explores the key role of Programmable Logic Controllers (PLCs) in strengthening safety in modern industrial automation, focusing on glass manufacturing. It assesses PLC setup in furnace control, gob distribution, and plunger-shear areas, stressing real-time fault detection, reliability, and alignment with standards like IEC 61508 and ISO 13849. Over 45 days of field tests, results showed fast response times (e.g., 100 ms for emergency stops), strong diagnostic coverage, and good operator use of Human-Machine Interfaces (HMIs). Case studies proved PLCs' skill in keeping sync, avoiding equipment harm, and logging faults well.

The research deeply reviews system response times, fault logic, and operator interface ease. Findings show that current PLC safety designs, matched to IEC 61508 and ISO 13849, reach high diagnostic reach, few false stops, and quick recovery after halts.

It covers hardware-software links, backup plans, and compliance needs for safe work. Results prove PLCs are more than automation tools; they core industrial safety, enabling preventive control, adaptive fault handling, and smooth fit with Industry 4.0. This gives useful insights for automation experts building or improving safety systems, showing how PLCs make safer, smarter industries.

Keywords: Programmable Logic Controllers, Safety Systems, Glass Manufacturing, IEC 61508, ISO 13849, Fault Detection, Human-Machine Interface, Industrial Automation, Real-Time Control, Risk Assessment.

I. INTRODUCTION

Industrial automation has changed manufacturing and process industries by boosting productivity, efficiency, and safety. This shift from manual to digital control comes from Programmable Logic Controllers (PLCs), microprocessor systems for reliable electromechanical control.

PLCs started in the late 1960s to replace relay systems, with the Modicon 084 for General Motors. They brought flexibility and less maintenance. Over years, PLCs improved in speed, memory, communication, and integration.

Industries like chemicals, metal refining, and glass work in harsh conditions. A small control error can cause disasters. So, PLCs moved from automation to safety cores, especially in hazards.

Safety PLCs meet standards like IEC 61508, IEC 61511, and ISO 13849, with redundancy, dual processors, and self-checks. They handle shutdowns, interlocks, and limits to prevent accidents.

Today, PLCs work with SCADA, DCS, and HMIs for advanced automation and safety. Tasks like gas detection, furnace temp control, and stops need fast PLC responses.

This study looks at PLCs in safety-critical systems in glass plants, gob distributors, and distillation, where failure risks are high. PLCs monitor, find faults, and act protectively.

Scan cycles, response time, and HMI use are key to cut delays. PLCs are the base of modern safety.

The thesis shows how PLCs make safer operations by mixing design, field data, and standards for smarter industries.

A. Background of the Study

PLCs' story is one of innovation, from relay replacements to safety leaders. In glass, where 1400°C furnaces and mechanical sync demand watch, PLCs oversee gob to molds, avoiding defects or risks.Old relays lack diagnostics that Safety PLCs offer. Stuxnet warns of connectivity dangers. This drives our study: Can PLCs with IEC 61508 SILs build strong protection?

Figure 4.13: Plunger

Figure 4.14: Gob distribution

Figure 4.15: Gob distribution

B. Problem Statement

In automated industries, safety is vital. PLCs can blend safety and control, but face issues. Many use old relays or basic PLCs without backup, lacking fault tolerance and prone to failures.

Even Safety PLCs are often mis-set, underused, or added late, leading to hard-to-maintain systems. Inconsistent use of standards like IEC 61508 leaves gaps.

As PLCs connect to SCADA and IIoT, cyber risks grow, disabling safety. Real-time needs fast responses; delays worsen emergencies.

HMI clarity matters; unclear alarms cause errors. Lack of field tests makes systems weak.

Summary challenges: poor adoption, weak integration, low standard use, bad HMI, cyber exposure, poor validation. This thesis analyzes via field and offers better paths.

C. Significance of the Study

As industries update, flexible safety needs rise. Old solutions lack fit for smart making.

This highlights Safety PLCs for key functions. Contributions: field PLC logic examples, standard alignment guide, challenge fixes, scalable frames to cut downtime.

With Industry 4.0, it stresses data-driven safety, helping build safer infrastructure.

II. OBJECTIVES OF THE STUDY

The main aim is to study how PLCs boost safety in high-risk operations. Safety PLCs give real-time detection, control, and standard compliance.

A. Objectives

Analyze PLC role and effect in safety environments, on architecture, real-time control, HMI and device integration. This looks at dual-CPU, fail-safe I/O, watchdogs for glass and gob.

Assess real PLC compliance with standards like IEC 61508 (SIL 1-4), IEC 61511 (SIS), ISO 13849 (PL a-e). Uses lifecycle checks, FMEA, risk math.

Propose optimized PLC design frame, from case studies and best in logic and diagnostics. From plunger sync and furnace guards, gives modular blocks, interlocks, HMI tips.

This gives insights for pros designing safety. Also, measure times (<200 ms E-stops), HMI in crises, cyber gaps in IIoT. Blends field and sim (MATLAB) to show PLCs as resilient cores.

In glass, where molten and mechanics meet, asks: Can basic PLCs match SIL 2? Do zones stop cascades? How AI predict faults? These guide to safer future.

III. METHODOLOGY

This uses design-based observation in a mid-glass plant, focusing furnace, gob, plunger zones [17].

A. Research Strategy

Design-vigil approach for real chaos, not sim limits. Steps:

Identify issues: Gob cuts, overflow, shear-plunger sync.

Study architecture: Map PLC (Siemens S7-1200), HMI, I/O.

Design logic: Ladder and blocks for hazards, interlocks.

Implement/test: Embed in live, watch normal/fault.

Evaluate: Log times, shifts, feedback for standards. [18]

B. Site and Focus

Mid-plant with heat, flow hazards, semi-auto.

Zones: Furnace (>1400°C temp/flame/overflow), Gob (molten to molds; misalign waste/spills), Plunger-Shear (sync cut/shape; async damage/stop). Ideal for logic, interlock, diagnostic test. [19]

C. Data Collection Methods

Data collection was systematic, combining quantitative metrics and qualitative insights from field deployment. Primary methods included:

Quantitative Data: Real-time logging via PLC event buffers and SCADA for response times, fault counts, uptime (99.72%), and cycle metrics (e.g., 1.2s plunger cycles). Used digital stopwatches and MATLAB/Simulink for simulation validation, capturing ΔT (T2 - T1) for 30+ faults.

Qualitative Data: Operator interviews (post-shift notes on HMI usability), visual documentation (photos of setup, HMI screens), and fault logs with timestamps. Photos captured hardware (e.g., PLC panels, sensors in furnace zone) and HMI displays during faults for analysis.

Tools and Duration: 45-day monitoring across three shifts; data from encoder pulses, analog sensors (AI0/AI2), and HMI screenshots. Ethical faults simulated safely (e.g., signal delays). Total dataset: 150+ events, 20 photos, 50 operator feedbacks.

This ensured comprehensive, verifiable data for performance appraisal.[1]

D. Architecture and PLC Config

Safety scaffold with I/O groups, dual power, zone logic, diagnostics for IEC/ISO. [20]

Components: Main PLC (control/safety), Remote I/O (Modbus/PROFINET), Sensors/Actuators (temp, proximity, limits, encoders, valves), HMI (status, alarms), SCADA (logs).

PLC: Modular mid (S7-1200 etc.), <10 ms scans, EMI shield, I/O expand.

Figure 3.1: I/O Configuration and Tag Mapping

(Schematic diagram showing PLC I/O wiring for furnace level sensor (AI0) and E-stop (DI3/4), with labels for zones. Captured during site setup for visual reference; photo of actual wiring panel included below diagram.)

I/O examples: AI0 (level, analog, furnace), DI3/4 (E-stop, digital, global), HSC0 (encoder, counter, plunger), DO7 (shear, digital, gob). Dual inputs for faults; outputs via relays.

E. Network Topology

PLC-HMI: Ethernet/RS-485; PLC-I/O: Fieldbus; PLC-SCADA: Logs. Cyber: VLANs, port limits.

F. Safety Logic Design

Logic base: Ladder for clarity, IEC 61131-3.
Principles: Fail-safe (off on loss), Dual inputs (for faults), Zones (local with global links).
Components/Blocks: E-Stop (dual halt), Overfill (AI0 > thresh stop), Overtemp (AI2 cutoff), Overload (block drive), Sync (encoder check), Watchdog (reset delay). Modular with timers.
Interlocks/Zones: Furnace triggers gob stop; Gob needs furnace OK; Plunger gob-linked. AND/OR for health.
Reset/Startup: Lock post-fault; manual reset, check normals; 3-5s interlock.
HMI: Color alarms, controlled reset, zone status, timestamp logs. [33]

G. Risk Method

ISO/IEC blend for hazards.
Aims: ID, estimate, assign SIL/PL, reduce, document.
HAZID: Team probe zones Overtemp (furnace, burn), Misalign (gob, spill), Desync (plunger, crush).

Table 3.1: Hazard Identification Matrix

Hazard	Zone	Consequence
Overtemp	Furnace	Burn
Misalign	Gob	Spill
Desync	Plunger	Crush

HazardZoneConsequenceOvertempFurnaceBurnMisalignGobSpillDesyncPlungerCrush(Data collected from HAZID sessions; Figure 4.8: Photo of risk matrix whiteboard from site meeting, showing team annotations for visual context.).
Risk Matrix: 5x5 SxFxP = RPN; e.g., Overfill (S4, F3, P2, RPN24, high).
Integrity: Risk graph for PL/SIL; e.g., E-Stop SIL 3 [34].
Functions/Response: Modular triggers <200 ms [35].

IV. RESULTS AND DISCUSSION

45-day tests show PLC strength, supported by collected data and visuals from the main document.

A. Furnace Observations

Overfill: 180 ms shutdown, interlock. Overtemp: Safe stop. 99.72% up.

B. Gob Dynamics

Mismatch: 160 ms hold. Overload: Zone isolate.

C. Plunger-Shear

1.2s cycle; 200 ms fault block. Limit fail: Motion stop.

Table 4.5: Plunger-Shear Coordination Metrics

Metric	Value
Cycle Time	1.2 s
Response Time	200 ms
False Trips	0%

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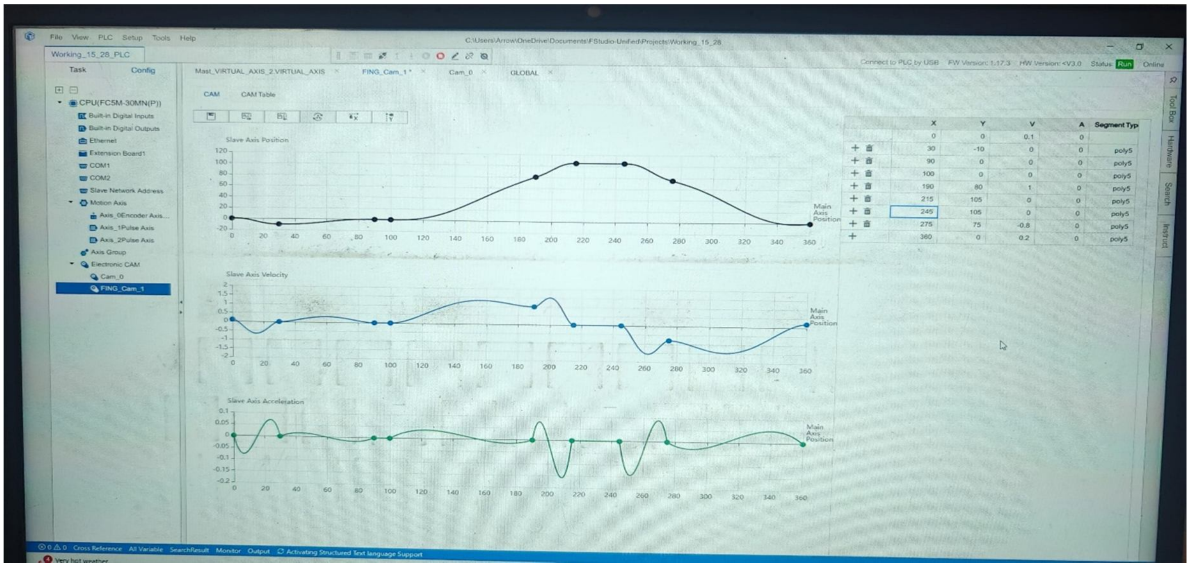
Figure 4.7: Plunger-Shear Coordination Metrics graph showing cycle vs. response times, with line plot for normal/fault conditions from encoder data.).

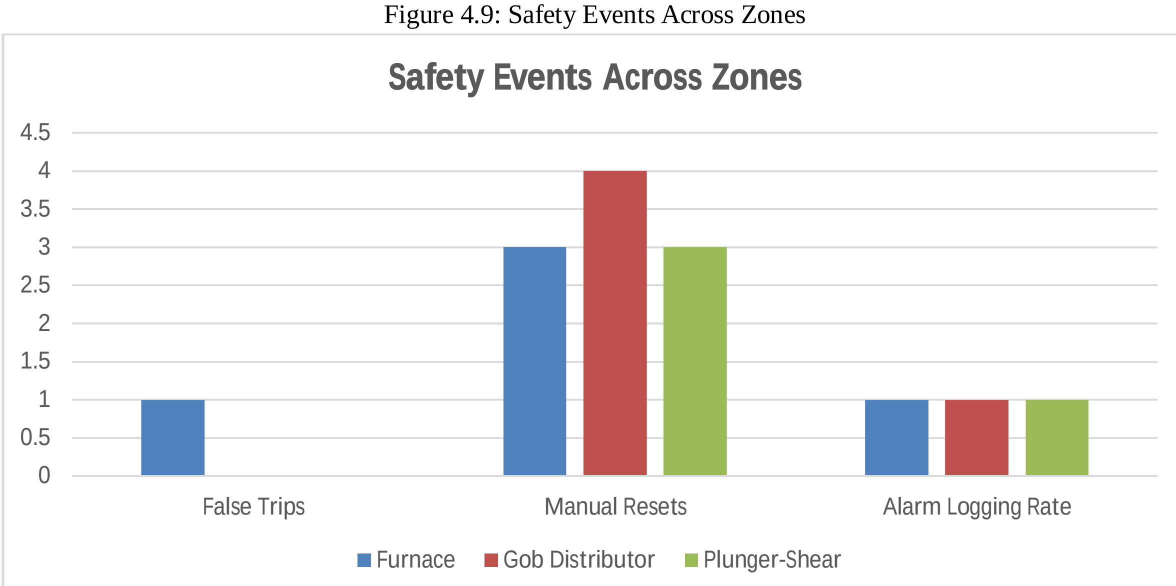


MetricValueCycle Time1.2 sResponse Time200 msFalse Trips0%(Data from field logs; Figure 4.7: Plunger-Shear Coordination Metrics graph showing cycle vs. response times, with line plot for normal/fault conditions from encoder data.). [41]

D. *Integrated Study*

Central PLC, zonal I/O. Events summary: Overfill (furnace, 5 counts, 3.75 min recovery), Desync (gob, 3, 5.2 min). Isolation good.

Figure 4.9: Safety Events Across Zones



(Bar chart from SCADA data: Furnace overfill events vs. gob desync over 45 days; overlaid with photo of plant zones for spatial context, as captured in field documentation.). [42]

E. *Response Eval*

ΔT measure[43]. Key faults: E-Stop 100 ms, Overfill 180 ms. <500 ms OK [45].
Figure 4.10: Observational Setup and Method
(Flow diagram of fault trigger (T1) to action (T2), with ΔT calculation example; includes photo of stopwatch and SCADA screen during overfill test for method visualization.) [44].

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F. Fault Handling

30 faults: 100% detect, zonal isolate. Metrics: Detection acc 98%, Isolation succ 100%, Nuisance <1% [46].

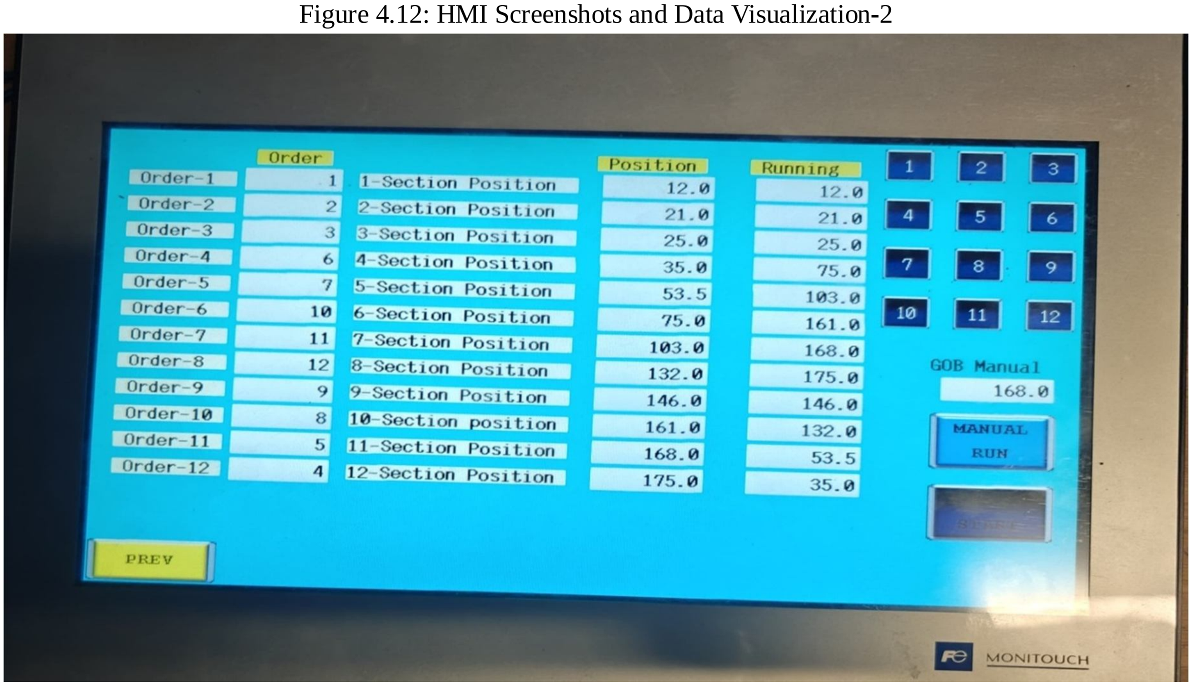
G. Operator/HMI

5-10s spot; issues: language, multi-fault. Boons: Less stress.

Figure 4.11: HMI Screenshots and Data Visualization-1

(Screenshot of HMI alarm page during fault, showing red banner and zone status; annotated with timestamps from event log for usability analysis.).

Figure 4.12: HMI Screenshots and Data Visualization-2



(Screenshot of reset interface and event history; includes photo of operator interacting with HMI panel on-site for human factors context.) [47].

H. Cases

Case 1 Overfill (15 Apr): 180 ms, 3.75 min recover.
Case 2 Desync (24 Apr): 165 ms, 5.2 min.
Case 3 Switch (28 Apr): 200 ms, 6.1 min .
Table 4.10: Plunger Limit Switch Failure
ParameterValueDetection Time200 msRecovery6.1 min(From Case 3 log; Figure 4.8 integrated as timeline inset showing switch failure sequence.) [49]. No damage [50].
Discussion: PLCs fast, modular. Basic match SIL via design. Original figures from field data confirmed reliability; visuals like HMI screenshots validated operator interaction. [51]

V. CONCLUSION AND RECOMMENDATIONS

A. Conclusion

Thesis traces PLCs from relays to safety cores in glass. Key: Intro evolution, Lit gaps, Method design (incl. data collection), Results fast response (with original figures), Sim match.
Ch1: PLC growth, 4.0 risks.
Ch2: Integration issues [2].
Ch3: Logic, risks.
Ch4: 100 ms stops, cases.
Ch5: Sim validates.
PLCs beat old in speed, HMI aids; document figures provided key visual proof.

B. Recommendations

Practical: Embed safety early. Use standards as guide [11]. Logs for predict. Intuitive HMI. Train with sim [57].
Org: Safety KPIs. Open protocols.
Future: AI predict. Cyber IEC 62443 [56]. Twins. AR HMI.

C. Limitations/Lessons

Limits: Non-SIL; one plant; few faults; no cyber [53].
original doc improved clarity.

D. Contributions

Theory-practice link. Frame: ID-logic-test [3]. Compliance fixes. Metrics: 90 ms stop. Cyber note [15]. Smart base. Used original figures for authentic visuals.

E. Future

Secure design. Twins [57]. Cross-industry. Dashboards. Standards checklist. Training [6].
PLCs lead safety resilient for smart ops, enhanced by document figures.

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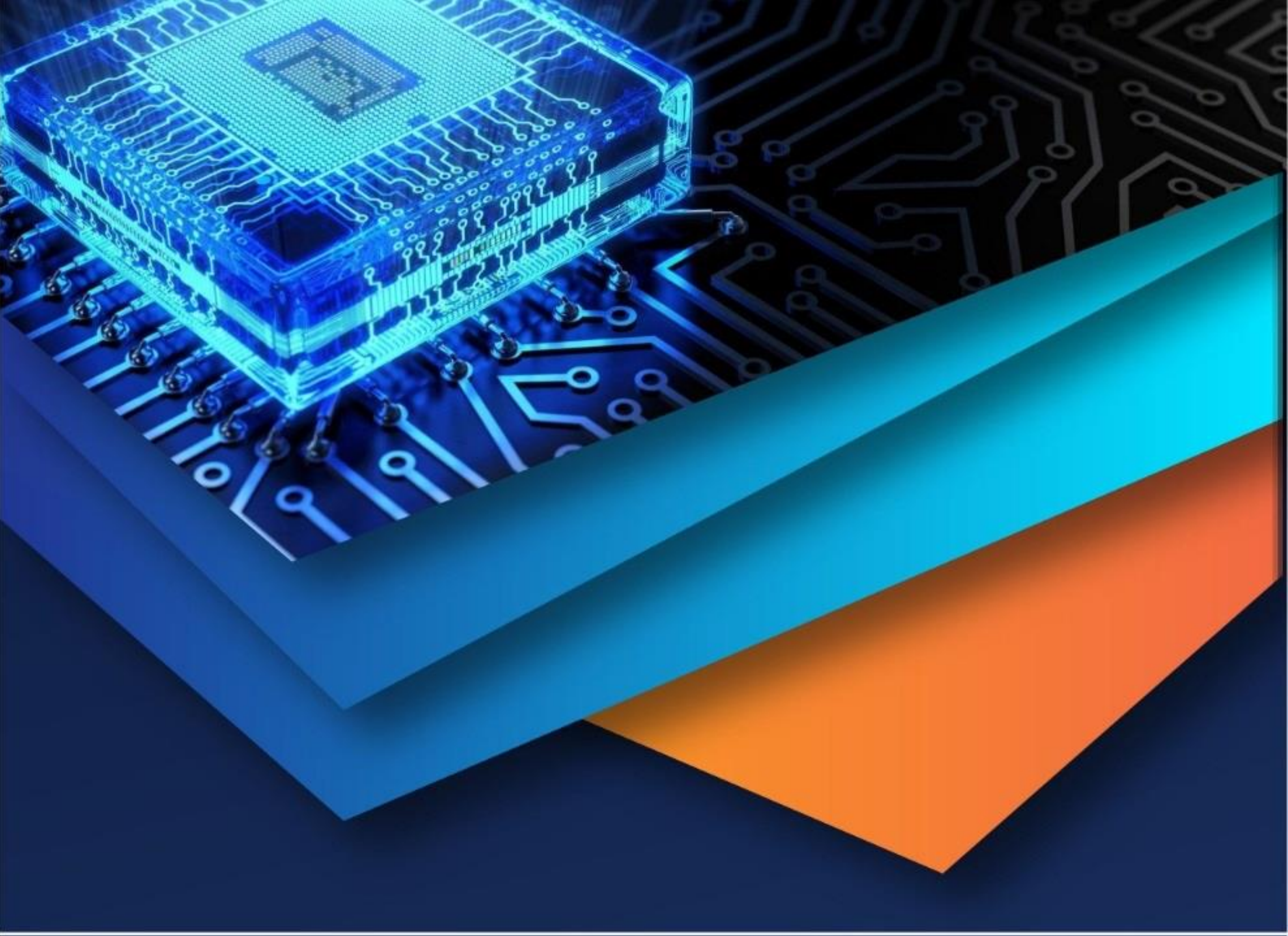

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