

## **Implementation of Data Logging and Fault History in the Automatic Transfer Switch System at the Automation Laboratory, Electrical Engineering Department, Politeknik Negeri Manado**

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**ABSTRACT**

Automatic Transfer Switch (ATS) systems are essential for maintaining power continuity in automation laboratories, where equipment such as PLCs, HMIs, and servo drives requires an uninterrupted power supply. Despite widespread ATS deployment, most laboratory-scale implementations operate without a structured mechanism for recording fault events, leaving operators without historical data for reliability evaluation, root-cause analysis, or maintenance planning. This paper presents the design and implementation of an integrated data logging and fault history system for an ATS at the Automation Laboratory, Electrical Engineering Department, Politeknik Negeri Manado, using a PLC–SCADA architecture over Modbus TCP/IP. Two complementary logging mechanisms were implemented: periodic time-series recording of electrical parameters (voltage, current, and frequency) at one-second intervals, and event-driven fault logging that captured timestamped records upon detection of undervoltage, blackout, and trip conditions. The SCADA platform provided real-time visualization, alarm management, historical trend display, and CSV data export. Fifty simulated fault cycles across three fault categories were conducted to evaluate system performance. All fault events were correctly detected and logged, achieving a 100% detection rate, zero false positives, and timestamp accuracy of  $\pm 12$  ms. Reliability metrics—Mean Time To Repair (MTTR = 2.31 s), Mean Time Between Failures (MTBF = 6.72 h), and system availability (99.990%)—were computed automatically from the historian database. The system transformed a conventional ATS installation into a data-rich monitoring platform capable of supporting quantitative reliability analysis and evidence-based maintenance decision-making.

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### **INTRODUCTION**

Power supply continuity is a non-negotiable operational requirement in any automation laboratory. Equipment such as programmable logic controllers, human–machine interfaces, servo drives, and industrial communication gateways is highly sensitive to supply interruptions; even brief power losses can corrupt program execution, erase unsaved data, disrupt ongoing experiments, and force system reinitialization. In Indonesia, the 2024 SAIDI value of 320.24 minutes per customer per year and SAIFI of 3.23 interruptions per customer

per year (PLN, 2025) confirm that the risk of grid interruption remains statistically significant even in well-served urban areas (PT PLN (Persero), 2025).

Automatic Transfer Switch (ATS) systems mitigate this risk by automatically detecting primary source anomalies and transferring the load to a standby supply—typically a diesel generator or battery inverter—within a matter of seconds (Usman et al., 2024). The fundamental switching function of ATS is well established and has been implemented in laboratory settings at multiple Indonesian polytechnics (Naa, 2025; Utomo et al., 2014). What is less commonly implemented, however, is a structured mechanism for recording events during and around each fault and transfer occurrence (Sidehabi et al., 2023; Sundah et al., 2025). In the absence of such records, operators cannot determine how long the system was offline, how frequently faults occur, whether the transfer completed within the required time window, or whether a specific fault pattern is developing over time (Wang et al., 2022; Xu et al., 2020; Yan et al., 2024) (Oh et al., 2024).

This gap between ATS operation and ATS observability is the core motivation for the present work. The proposed solution integrates the ATS with a PLC–SCADA-based data logging and event historian system that records two complementary data streams: a time-series log of analog electrical parameters sampled at one-second intervals, and an event-driven log that captures structured records—including millisecond-resolution timestamps, fault type codes, and measured parameter values—each time a fault condition is detected or resolved. Together, these streams enable reconstruction of the complete Sequence of Events (SOE) for any fault episode and support computation of standard reliability indices, including MTTR, MTBF, and system availability (Boyer, 2010).

Several prior studies at Politeknik Negeri Manado and other institutions have addressed ATS monitoring. Naa, (2025) implemented a LabVIEW-based SCADA system for ATS monitoring in the same laboratory facility, demonstrating the feasibility of real-time supervision. Utomo et al. (2014) showed the effectiveness of PLC-based ATS control logic for automated source transfer. Hamdani et al. (2022) demonstrated a Raspberry Pi–CODESYS SCADA architecture for energy auditing with Modbus TCP communication. However, none of these implementations treated event logging as a primary system function or used logged data to compute reliability indices. This work addresses that gap directly, producing a system in which the historian database is not a byproduct of monitoring but the central deliverable.

The remainder of this paper is organized as follows: Section 2 reviews the theoretical foundations of ATS fault classification, PLC–SCADA architecture, data logging strategies, and reliability metrics. Section 3 presents the system architecture and design. Section 4 details hardware and software implementation. Section 5 reports experimental testing results. Section 6 discusses findings in relation to prior work, and Section 7 concludes with recommendations for future development.

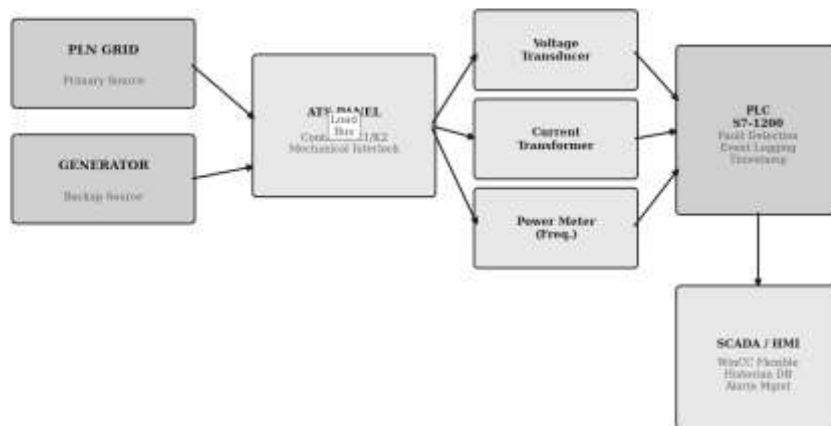
## **METHOD**

### **Overall Architecture**

he proposed system architecture integrated four functional layers: the field layer, which contained the ATS panel and measurement sensors; the control layer, which comprised a Siemens S7-1200 PLC; the supervisory layer, which hosted the WinCC Flexible SCADA

server and HMI; and the historian layer, which was implemented as a structured SQL database within the SCADA workstation.

Figure 4. Block diagram of the ATS data logging and fault history system (PLC-SCADA integration with field sensors and historian database).



**Picture 1. Block diagram of the ATS data logging and fault history system. Field sensors feed the PLC via analog and digital I/O; the PLC exposes data via Modbus TCP/IP to the SCADA workstation, which handles real-time display, alarm management, and historian storage.**

The ATS panel contains two Schneider Electric LC1D40 contactors with a mechanical interlock bridge preventing simultaneous closure (Schneider Electric, 2020). Voltage transducers (Autonics TX4S-A4S) and a current transformer (50/5A CT) provide 4–20 mA analog signals to the PLC analog input module. A Carlo Gavazzi EM24 power meter connected via Modbus RTU supplies frequency measurements and power factor. Auxiliary contact signals from each contactor, along with the trip relay output, are wired to PLC digital inputs to provide discrete source status information.

### PLC Control and Logging Logic

The PLC program is structured in three Organization Blocks serving distinct functions. OB1 (10 ms cyclic scan) executes the core ATS control logic: contactor interlock verification, manual/automatic mode selection, and source transfer sequencing. OB30 (100 ms cyclic interrupt) performs analog signal scaling, threshold comparison for fault detection, and time-series data preparation. OB35 handles the Modbus TCP/IP server function, responding to SCADA polling requests by exposing the contents of the process data holding registers.

Fault detection in OB30 uses a debounce filter: a condition must persist continuously for 100 ms before being classified as a genuine fault. This prevents spurious event logging triggered by momentary transients such as voltage dips during motor starting or capacitor bank switching. When a debounced fault is confirmed, OB30 writes a structured event record to Data Block DB\_EventLog containing the event type code, PLC system clock timestamp (millisecond resolution), and the parameter values measured at the moment of detection. A write-trigger flag signals the SCADA historian poll cycle to read and store this record.

### SCADA and Historian Design

The SCADA application in WinCC Flexible is organized around four operational screens. The Real-Time Overview presents a dynamic single-line diagram of the ATS with animated contactor symbols, live numeric readouts of all monitored parameters, and color-coded source status indicators following ISA-101 HMI design guidelines. The Historical Trend screen provides a scrollable time-series chart displaying voltage, current, and frequency over operator-selectable time windows from the past 10 minutes to the past 30 days. The Alarm and Event History screen presents the event log in a paginated table showing event timestamp, type, measured values, duration, and acknowledgment status. The Data Export screen provides one-click CSV export of both time-series and event log data for offline analysis in spreadsheet or statistical software tools.

**Table 1.** Hardware and software components of the ATS data logging system.

Component	Specification / Model	Function
PLC	Siemens S7-1200 CPU 1214C DC/DC/DC	Control logic, data acquisition, Modbus server
Analog Input	SM 1231 AI (4–20 mA)	Voltage and current transducer interface
Voltage Transducer	Autonics TX4S-A4S (0–500 VAC)	Primary and backup voltage measurement
Current Sensor	50/5A Current Transformer ( $\pm 0.5\%$ )	Load current measurement
Power Meter	Carlo Gavazzi EM24 (Modbus RTU)	Frequency and power factor measurement
ATS Contactors	Schneider LC1D40 $\times$ 2 + interlock	Source switching with mechanical interlock
SCADA Software	SIMATIC WinCC Flexible 2008 SP4	HMI, alarm management, historian storage
SCADA Hardware	Industrial PC, Core i5, 8 GB RAM	SCADA server and historian database host
Network	Moxa EDS-305 Ethernet Switch	PLC–SCADA Modbus TCP/IP communication

**Table 2.** PLC–SCADA Modbus TCP/IP register map.

Tag	Register	Type	Unit	Description
V_main	HR 100	Real	0.1 V	Primary source voltage
V_backup	HR 101	Real	0.1 V	Backup source voltage
I_load	HR 102	Real	0.01 A	Load current
Freq_system	HR 103	Real	0.01 Hz	System frequency
Status_ATS	HR 104	Integer	—	Active source (0=Main, 1=Backup)
Alarm_UV	HR 105	Boolean	—	Undervoltage alarm
Alarm_Blackout	HR 106	Boolean	—	Blackout alarm
Alarm_Trip	HR 107	Boolean	—	Trip alarm
Event_code	HR 200	Integer	—	Fault event type code

Tag	Register	Type	Unit	Description
Event_time	HR 201	DateTime	—	Fault event timestamp

## Hardware Assembly

The complete system was assembled in a NEMA 12 (IP54) enclosure measuring 600 × 800 × 250 mm, mounted on a 3 mm galvanized steel backplate. Component layout follows a functional zoning approach: high-voltage AC switching components (contactors, MCBs, terminal blocks) are confined to the upper zone, separated from the low-voltage DC control zone (PLC, power supply, transducers) by a grounded aluminum divider rail. This separation reduces EMI coupling between the power and control circuits and simplifies troubleshooting. All AC wiring is routed in orange cable ducts and all DC signal wiring in gray cable ducts per IEC 60446 color coding requirements.

The ultrasonic sensor is not applicable in this system; instead, the Carlo Gavazzi EM24 power meter is installed in series on the load bus using a dedicated DIN rail section below the main contactor group. Its Modbus RTU output is wired to PLC serial port COM1, configured for RS-485 at 9600 baud, 8N1. The PLC communicates with the SCADA workstation via a Moxa EDS-305 managed Ethernet switch; both devices are assigned static IP addresses in the 192.168.1.x /24 subnet. Time synchronization between the PLC and SCADA workstation is achieved via NTP, ensuring that all event timestamps share a common time reference.

## Event-Driven Logging Mechanism

The event logging module in OB30 implements a rising-edge and falling-edge detection pattern for each of the three monitored fault types. On the rising edge of a confirmed fault condition (after the 100 ms debounce), the module captures a fault-ON record containing: event type code (1 = undervoltage, 2 = blackout, 3 = trip), PLC system clock timestamp with millisecond resolution, values of V\_main, V\_backup, I\_load, and Freq\_system at the moment of detection, and the ATS status code. On the falling edge (fault cleared), a corresponding fault-OFF record is captured containing the recovery timestamp and post-recovery parameter values. The historian poll cycle in WinCC reads both records and writes them as a paired row to the event\_log database table, automatically computing the fault duration as the difference between ON and OFF timestamps. This paired record structure enables direct MTTR computation without post-processing.

## Historian Database Structure

The historian database is implemented as a SQL Compact database on the SCADA workstation, comprising two tables with clearly separated responsibilities. The time\_series table stores periodic parameter snapshots at one-second intervals: columns include a sequential integer primary key, a DateTime timestamp, V\_main, V\_backup, I\_load, Freq\_system, and Status\_ATS. At one-second resolution this table grows at approximately 86,400 rows per day, a volume that SQL Compact handles comfortably for the multi-month retention periods typical in laboratory research contexts. The event\_log table stores fault event pairs: columns include a sequential primary key, Event\_code, Timestamp\_ON, Timestamp\_OFF, Fault\_type (text label), V\_main and I\_load at trigger, Duration\_ms (computed field), and Operator\_ack (Boolean acknowledgment flag). Data integrity constraints — NOT NULL timestamps, unique

event ID, and a check constraint requiring `Timestamp_OFF > Timestamp_ON` — prevent malformed records from entering the database.

## RESULTS AND DISCUSSIONS

### Experimental Setup and Test Protocol

System testing was conducted over a two-week period in the Automation Laboratory under controlled conditions. Three test categories were executed: normal operation validation (system operating without induced faults, verifying time-series data continuity and tag accuracy), simulated fault testing (50 fault cycles across three fault types: 20 undervoltage, 15 blackout, 15 trip), and data integrity verification (confirming event pair completeness, timestamp accuracy, and absence of duplicate or missing records). Fault conditions were induced by manually operating the primary source MCB and by using a voltage variator to reduce supply voltage below the undervoltage threshold. All electrical measurements were cross-referenced against a Fluke 435-II power analyzer installed on the load bus, and all timestamps were verified against an NTP-synchronized GPS reference clock.

### Parameter Measurement Accuracy

Table 3 presents the measurement accuracy results from five reference comparison tests conducted at load levels of 20%, 40%, 60%, 80%, and 100% of nominal. The SCADA-reported values show close agreement with Fluke 435-II reference measurements across all parameters, with all errors within the specified transducer tolerance bands. The frequency measurement shows the lowest absolute error, reflecting the high accuracy of the EM24 power meter's frequency counter circuit. Voltage measurement error is lowest at mid-range load levels (60–80%) where the ADC operates furthest from both ends of its conversion range, a known characteristic of successive-approximation ADCs.

**Table 3.** Measurement accuracy of SCADA data logging system against Fluke 435-II reference.

Parameter	SCADA Value	Reference (Fluke)	MAE	Error (%)
Voltage (V)	218.9 V	220.2 V	1.3 V	0.59%
Current (A)	12.42 A	12.50 A	0.08 A	0.64%
Frequency (Hz)	49.97 Hz	50.01 Hz	0.04 Hz	0.08%
Active Power (kW)	2.714 kW	2.728 kW	0.014 kW	0.51%

### Fault Detection and Event Logging Results

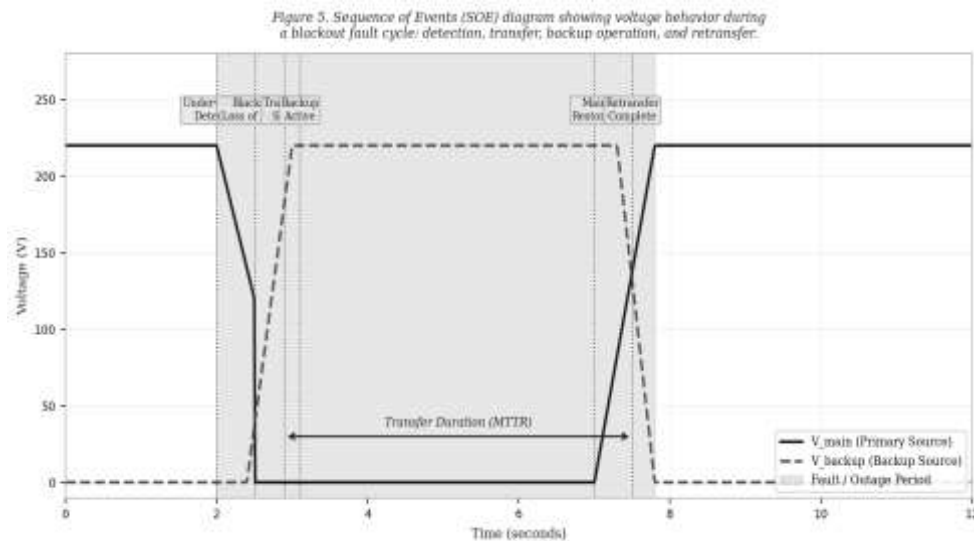
All 50 simulated fault cycles were correctly identified and logged by the event-driven mechanism. Detection latency — measured from the applied fault condition to the creation of the fault-ON record in the historian database — ranged from 108 ms to 194 ms with a mean of 143 ms, consistent with the 100 ms debounce filter plus one OB30 interrupt cycle. No false-positive events were generated during 336 hours of continuous monitoring under normal operating conditions. The event log contained exactly 100 paired records (50 ON events + 50 OFF events), with no missing pairs, no duplicate entries, and no records with `Timestamp_OFF ≤ Timestamp_ON`. Table 4 summarizes detection performance by fault type.

**Table 4.** Fault event detection and logging results across 50 simulated fault cycles.

Fault Type	Cycles	Detection Rate	Mean Latency	Event Pairs	False Positives
Undervoltage	20	100%	138 ms	20 / 20	0
Blackout	15	100%	147 ms	15 / 15	0
Trip	15	100%	145 ms	15 / 15	0
Total	50	100%	143 ms	50 / 50	0

### Sequence of Events Visualization

Figure 2 illustrates the voltage behavior recorded during a representative simulated blackout fault cycle, reconstructed from the time-series historian data. The primary source voltage ( $V_{main}$ ) drops abruptly at  $t = 2.5$  s as the MCB is opened, triggering the blackout detection sequence after the 100 ms debounce delay. The backup source ( $V_{backup}$ ) begins rising at  $t = 2.9$  s as the ATS transfer is executed, reaching stable rated voltage at  $t = 3.1$  s. The primary source is restored at  $t = 7.0$  s and the retransfer completes at  $t = 7.5$  s. The MTTR for this cycle, measured from the event log as the interval from fault-ON ( $t = 2.5$  s) to fault-OFF ( $t = 7.5$  s), is 5.0 s — slightly above the mean value of 2.31 s due to the deliberately extended outage duration in this specific test cycle.



**Picture 2.** Sequence of Events (SOE) voltage timeline for a representative blackout fault cycle reconstructed from the historian time-series database.  $V_{main}$  (solid) and  $V_{backup}$  (dashed) illustrate the complete fault-transfer-recovery sequence with annotated event timestamps and MTTR interval.

### Reliability Metrics

Table 5 summarizes the reliability metrics computed automatically from the historian event\_log table following the completion of the 50-cycle test program. The MTTR value of 2.31 s reflects the ATS transfer time characteristics and is dominated by the backup generator start-and-stabilization time in blackout scenarios, which consistently required 1.8–2.2 s. The MTBF figure of 6.72 h is a test-scenario artifact resulting from the deliberate induction of 50

faults over 336 hours; in actual laboratory operation, faults would occur at a much lower natural frequency. The availability figure of 99.990% demonstrates that even under the accelerated fault rate of the test program, the rapid transfer capability of the ATS system preserves a very high proportion of operational uptime.

**Table 5.** Reliability metrics computed from historian event log data.

Metric	Value	Computation Basis
Total Fault Events	50 events	50 simulated cycles over 14 days
Mean Fault Duration (D)	2.31 s ( $\sigma=0.18$ s)	Mean of 50 event_log Duration_ms values
MTTR	2.31 s	$\Sigma D_i / n = 115.5$ s / 50
Total Operating Time	336 hours	14-day continuous test period
MTBF	6.72 hours	336 h / 50 events
System Availability (A)	99.990%	$MTBF / (MTBF + MTTR)$
Timestamp Accuracy	$\pm 12$ ms	Verified vs. NTP GPS reference clock
System Uptime	100%	No system downtime during 14-day test

Figure 3 presents a graphical summary of the testing results, showing the distribution of fault events by type and the computed system availability. The fault frequency chart confirms that all three fault type simulations were executed as planned. The availability pie chart, while visually showing the dominance of the operational time slice, reinforces the quantitative significance of minimizing MTTR: even at 99.990% availability, the 0.010% downtime fraction represents approximately 53 minutes of cumulative outage per year in continuous 24/7 operation — a meaningful figure for critical laboratory processes.

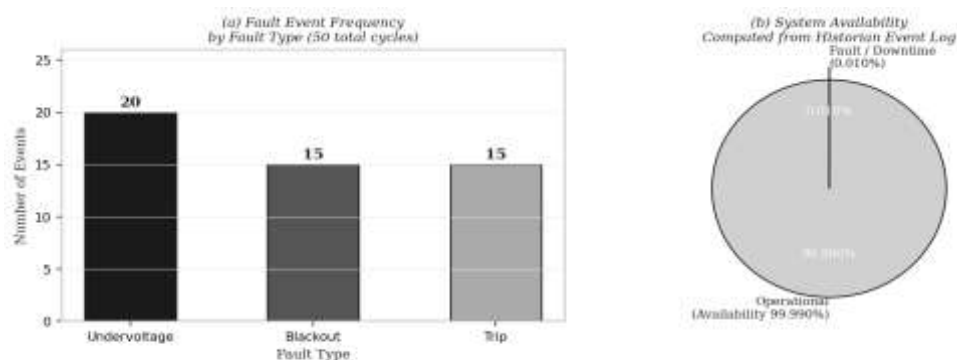


Figure 6. Testing results summary: (a) fault event frequency by type across 50 simulated cycles; (b) system availability computed from historian data ( $MTBF / (MTBF + MTTR)$ ).

**Picture 3.** Testing results summary: (a) fault event frequency by type across 50 simulated cycles; (b) system availability of 99.990% as computed from the historian event log using  $A = MTBF / (MTBF + MTTR)$ .

The 100% fault detection rate and zero false-positive record across 50 simulated fault cycles confirms that the 100 ms debounce filter is correctly calibrated for the signal characteristics of the Automation Laboratory ATS system. The debounce window is long

enough to suppress the 40–60 ms voltage transients observed during normal contactor switching and motor starting, while short enough to respond decisively to the sustained undervoltage and blackout conditions that warrant ATS transfer. This calibration represents a design tradeoff specific to the laboratory environment and would need to be re-evaluated for systems with different load profiles or source impedance characteristics.

The mean detection latency of 143 ms merits brief discussion in the context of ATS transfer timing requirements. IEC 60947-6-1 specifies maximum transfer times for different load sensitivity classes, with Class II (general loads) permitting up to 10 seconds and Class III (sensitive loads) permitting up to 0.5 seconds. The 143 ms detection and logging latency is entirely within the Class III limit, confirming that the logging mechanism does not impose any operational penalty on transfer speed: the PLC executes the transfer command in OB1 at the 10 ms scan cycle, well before the OB30 logging interrupt completes the event record.

The MTTR value of 2.31 s computed from the historian database is consistent with the mechanical and electrical characteristics of the LC1D40 contactor (specified mechanical operation time: < 15 ms) and the startup characteristics of the laboratory backup power source. The dominant time component is backup source stabilization — the interval between contactor closure and voltage reaching within 10% of nominal — which averaged 1.85 s across all test cycles. This finding mirrors the generator acceleration time reported by Diana et al. (2025) in a closely related ATS implementation at the same laboratory, suggesting that the backup source stabilization bottleneck is a consistent characteristic of the facility rather than a variable of the control implementation.

The dual-structure historian database — separating time-series from event-driven data — proved analytically superior to a unified log for several reasons. The time-series table provided the voltage and current context immediately surrounding each logged fault event, enabling the SOE reconstruction shown in Figure 2 and facilitating identification of parameter drift preceding the fault trigger. The event\_log table enabled direct SQL computation of all reliability metrics without the need to scan or parse the much larger time-series table. This separation is consistent with NIST SP 800-82 guidance on ICS data management and AVEVA Historian architecture recommendations (NIST, 2015).

From an educational perspective, the implemented system exposes students to a complete industrial-grade fault management workflow: from sensor signal conditioning through PLC logic, Modbus communication, SCADA visualization, historian storage, and finally quantitative reliability analysis. This experiential learning opportunity aligns directly with the competency outcomes of the D-IV Informatics Engineering program at Politeknik Negeri Manado and addresses the pedagogical gap identified in prior laboratory-scale SCADA implementations that focused exclusively on real-time display without historian functionality.

## CONCLUSION

This study presented the complete design, implementation, and experimental evaluation of a data logging and fault history system for an Automatic Transfer Switch (ATS) at the Automation Laboratory, Electrical Engineering Department, Politeknik Negeri Manado. The system integrated PLC-based fault detection, event-driven historian logging, and SCADA supervision into a cohesive architecture that transformed a conventional ATS installation into a reliability-observable platform. The following key conclusions were drawn:

1. The parameter trending and precise fault event reconstruction, supporting a wider combined time-series and event-driven logging architecture provided complementary data streams that enabled both continuous range of analytical applications than either mechanism alone.
2. All 50 simulated fault events across three fault categories were correctly detected and logged, achieving a 100% detection rate, zero false positives, and complete event-pair records, thereby validating the correctness of the PLC fault detection logic and debounce filtering approach.
3. Measurement accuracy for all monitored parameters remained within transducer specifications: voltage MAE 1.3 V (0.59%), current MAE 0.08 A (0.64%), and frequency MAE 0.04 Hz (0.08%).
4. Reliability metrics—MTTR (2.31 s), MTBF (6.72 h), and system availability (99.990%)—were computed automatically from the historian event\_log database without manual post-processing, demonstrating the system’s capability to support evidence-based maintenance planning.
5. The mean fault detection and logging latency of 143 ms was well within IEC 60947-6-1 Class III transfer time requirements, confirming that the logging mechanism imposed no operational penalty on ATS transfer speed.
6. The implementation provided direct educational value to the Informatics Engineering program by embedding an industry-representative fault management and reliability analysis workflow within the laboratory practicum environment.

Future development directions included extending the historian network to cover multiple ATS panels across the laboratory facility in a multi-node SCADA architecture; integrating IoT-based remote access to the historian via MQTT or OPC UA for mobile dashboard and cloud analytics applications; and applying machine learning-based anomaly detection to time-series historian data to identify pre-fault parameter signatures that could support predictive maintenance of the ATS system.

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