

Automated PLC-Based Refrigerant Charging Machine for Automotive Air-Conditioning Systems

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Abstract – Manual refrigerant charging of automotive air-conditioning (A/C) systems is time-consuming and frequently results in overcharging, undercharging, and avoidable venting of refrigerant to the atmosphere. This paper presents the design and prototype implementation of an automated, Programmable Logic Controller (PLC) based refrigerant charging machine for vehicle A/C systems. The machine integrates pressure transducers, a load cell, and solenoid-actuated manifold valves under a single ladder-logic control program to perform refrigerant recovery, vacuum evacuation, leak verification, and metered charging in a fixed, repeatable sequence. A Human-Machine Interface (HMI) lets the operator set the target charge, select the operating mode, and observe live pressure and weight readings, while hardware interlocks—an emergency stop, motor thermal-overload trips, and a pressure-relief valve—protect the operator and the equipment. The prototype shows that the four-stage cycle can be executed automatically with the charge quantity governed by mass rather than operator judgement, reducing wastage and improving cycle-to-cycle consistency. Built from low-cost industrial components, the system suits small and medium automotive workshops and provides a foundation for future IoT-based monitoring and automatic leak detection.

Key Words: PLC automation, automotive air-conditioning, refrigerant charging, vacuum evacuation, human-machine interface, solenoid valve control.

I. INTRODUCTION

Air-conditioning is now a standard feature in passenger and commercial vehicles, and the cooling capacity of an A/C system depends strongly on its refrigerant charge. An undercharged system cools poorly and overworks the compressor, while an overcharged system raises discharge pressure, lowers the coefficient of performance (COP), and shortens compressor life. Correct charging—typically with R-

134a in current vehicles—is therefore a routine but critical servicing operation in workshops.

In most small workshops, charging is still performed manually using a gauge manifold, with the technician judging the quantity from pressure readings and experience. This practice is slow and inconsistent: it leads to over- and under-filling, allows moisture and non-condensable gases to remain in the circuit, and vents refrigerant to the atmosphere, which is both wasteful and environmentally harmful. The high-pressure refrigerant also poses a safety hazard to the operator.

Automation addresses these problems directly. A Programmable Logic Controller (PLC) can read pressure and weight in real time, sequence the recovery, evacuation, leak-test, and charging stages automatically, and cut off charging at a precise mass. The objectives of this work are: (i) to design a PLC-controlled machine that automates the A/C charging cycle; (ii) to integrate pressure and mass sensing for accurate, repeatable charging; (iii) to provide hardware and logic interlocks that protect the operator; and (iv) to present the operator with a simple HMI for set-point entry and live monitoring.

The remainder of the paper follows the IMRaD structure. Section II reviews related charging systems and studies. Section III describes the system architecture, process sequence, control logic, and power supply. Section IV reports the observed prototype operation, and Section V discusses the results, limitations, and comparison with prior work. Section VI concludes and outlines future scope.

II. LITERATURE REVIEW

Le Nguyen et al. [1] developed an automatic refrigerant charging unit for residential air conditioners using R410A, in which a LabVIEW interface, mass-flow sensors, solenoid valves, and a microcontroller achieved highly accurate, mass-based charging with real-time monitoring. The approach demonstrates the value of mass-based metering, but its reliance on mass-flow sensors and a licensed LabVIEW environment makes it costly for small workshops.

Shende et al. [2] reported a PLC-based A/C gas filling machine that automated a vacuum, leak-test, fill, and stop sequence using a vacuum pump, solenoid

valves, compressor control, and preset quantity selection through an HMI. Its industry-ready control logic and repeatability are directly relevant to the present design; the authors note, however, that the PLC raises cost and that on-board data logging is limited.

Li et al. [3] experimentally studied the effect of refrigerant charge on COP, operating pressures, and cooling capacity, establishing a clear correlation between charge level and system efficiency. This result motivates terminating the charge by measured mass rather than by operator judgement, which is the control strategy adopted here.

Broader studies of automotive A/C performance with R-134a [6], comprehensive modelling for design and control [7], and reviews of charging methods and their impact on system performance [8] reinforce the need for controlled, standardized charging, while SAE standard J2842 [9] defines safe service procedures for R-134a handling. Taken together, the literature points to a gap: an affordable PLC machine that combines mass-based metering, an explicit pressure-decay leak test, and robust safety interlocks for the small and medium workshop segment. The present work targets that gap.

III. METHODOLOGY

A. System Architecture

The machine is organized around a PLC operating on a 24 V DC control supply. Digital inputs read the start/stop and emergency-stop pushbuttons, the liquid/gas level indicator, a flow-meter “charge reached” contact, and the motor thermal-overload contacts. Analog inputs (4-20 mA) read a pressure transducer and the load-cell/flow-meter signal. Digital outputs drive—through contactors and relay/solenoid drivers—the transfer-pump (compressor) motor, the manifold solenoid valves, a vent/relief valve, and the alarm/HMI output. The overall signal and power flow is shown in Fig. 1, and the input/output assignment is summarized in Table I.

[Insert original high-resolution figure (min 300 DPI)]

Fig. 1. Block diagram of the PLC-based refrigerant charging machine.

TABLE I. PLC INPUT/OUTPUT ASSIGNMENT

Tag	Type	Function
X0	DI	Start / run command
X1	DI (NC)	Stop pushbutton
X2	DI (NC)	Emergency stop
X3	DI	Liquid / gas level indicator
X4	DI	Flow-meter OK / charge reached
X7	DI (NC)	Motor thermal-overload trip
AI1	AI	Pressure transducer (4-20 mA)
AI2	AI	Flow meter / load cell (4-20 mA)
Y0	DO	Compressor / transfer-pump contactor

Y1	DO	Manifold solenoid valve 1
Y2	DO	Manifold solenoid valve 2
Y3	DO	Vent / relief solenoid valve
Y4	DO	Alarm / HMI fault output

B. Process Sequence

After the charging adapter is connected to the vehicle service port and adequate compressed-air pressure is confirmed, the PLC executes four stages in sequence, as shown in the operational flow chart of Fig. 2. In the recovery stage, residual refrigerant is drawn from the A/C circuit into a storage cylinder through solenoid-controlled valves. In the evacuation stage, a vacuum pump removes air, moisture, and non-condensable gases until a target vacuum is reached. A leak test then isolates the sealed circuit and monitors it for a pressure rise; if a decay/rise indicates a leak, the cycle halts and an alarm is raised. If the circuit holds, metered charging begins: the transfer pump delivers refrigerant while the load cell measures dispensed mass, and the PLC closes the valves once the operator-set quantity is reached. A final pressure check confirms a stable, sealed system before the adapter is removed.

[Insert original high-resolution figure (min 300 DPI)]

Fig. 2. Operational flow chart of the charging cycle.

C. Control Logic and Safety Interlocks

Control is implemented in ladder logic. A seal-in (latching) rung holds the run state once the start pushbutton is pressed, provided the normally-closed emergency-stop and thermal-overload contacts are intact. The pump contactor is additionally interlocked with the flow-meter “charge reached” signal so that charging cannot continue past the set mass. Pressing the emergency stop, or any overload trip, de-energizes all critical outputs immediately. A mechanical pressure-relief valve provides a hardware safeguard independent of the program, and surge suppressors/snubbers protect the analog inputs and contactor coils. A representative ladder of the start/stop and interlock logic is shown in Fig. 3.

[Insert original high-resolution figure (min 300 DPI)]

Fig. 3. Simplified start/stop and interlock ladder logic.

D. Power Supply

Single-phase 230 V AC mains is fed through an isolator and MCB/fuses. A control transformer derives the 24 V DC control rail used by the PLC, sensors, and solenoid coils, while the pump and compressor motors are switched by contactors with integral thermal-overload relays. Where a low-cost variant of the controller is used in place of an industrial PLC, the same 24 V rail can be regulated down to 5 V and 3.3 V logic levels for the HMI and instrumentation, with appropriate heatsinking on the linear regulators. Key design values are listed in Table II.

TABLE II. SYSTEM DESIGN PARAMETERS

Parameter	Design value
Target refrigerant	R-134a
PLC control voltage	24 V DC
Mains supply	230 V AC, 50 Hz
Typical charge set-point	450 - 700 g
Charge termination	By mass (load cell)
Leak test	Pressure-decay, sealed
Safety interlocks	E-stop, overload, relief valve

IV. RESULTS

The assembled prototype executed the full four-stage cycle under PLC control. On start-up, the controller performed a check of the input states and would proceed only with the emergency stop released and the overload contacts healthy. During evacuation, the vacuum reading on the HMI fell steadily until the target was reached, after which the controller advanced automatically to the leak-test stage. When a sealed circuit was used, the isolated-pressure reading remained stable and the cycle continued; when a deliberate leak was introduced, the pressure change was detected and the controller stopped the cycle and asserted the alarm output, confirming the interlock behaviour.

In the charging stage, the transfer pump ran until the load cell registered the operator-set mass, at which point the PLC closed the manifold valves and stopped the pump—demonstrating mass-based, rather than judgement-based, termination. Throughout the cycle the HMI displayed live pressure and weight, and pressing the emergency stop at any stage de-energized the pump and solenoid outputs as designed. These observations provide a qualitative validation of the control sequence and the safety logic; quantitative characterization of charge accuracy and repeatability is identified as future work.

V. DISCUSSION

Governing the charge by measured mass removes the principal source of variability in manual servicing—operator judgement—and is consistent with the charge-versus-efficiency relationship reported by Li et al. [3]. Compared with the LabVIEW/mass-flow unit of Le Nguyen et al. [1], the present design avoids a licensed software environment by combining a PLC with a touchscreen HMI, lowering cost and simplifying maintenance. Relative to the PLC machine of Shende et al. [2], it adds an explicit pressure-decay leak test and a mass-based cut-off, tightening both safety and accuracy.

Several limitations remain. The industrial PLC, while robust, is the most expensive component; a microcontroller-based variant (for example, ESP32 or STM32) could reduce cost for price-sensitive

workshops at some loss of ruggedness. The current prototype lacks long-term data logging and has not yet been characterized quantitatively for charge accuracy across repeated cycles. Performance with newer low-GWP refrigerants such as R-1234yf has not been tested. From an environmental standpoint, automated recovery and metered charging reduce venting and wastage, supporting compliance with refrigerant-handling standards [9].

VI. CONCLUSION

This paper presented a PLC-based machine that automates the recovery, evacuation, leak-test, and metered-charging cycle for automotive A/C systems. The prototype demonstrated automatic stage sequencing, mass-based charge termination, live HMI monitoring, and functioning emergency-stop and overload interlocks, using low-cost industrial components suited to small and medium workshops. The main limitations are the cost of the PLC, the absence of quantitative accuracy testing, and untested operation with alternative refrigerants. Future work will add quantitative accuracy and repeatability characterization, IoT-based remote monitoring and data logging, automatic leak detection, smart refrigerant identification, and a microcontroller-based low-cost variant, advancing the system toward a smarter and more sustainable charging solution.

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