

## Implementation of an Electro-Pneumatic Prototype Elevator Controlled by PLC

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### Abstract:

The current paper presents a new simple and clear and implementation method for prototype Electro-pneumatic prototype elevator system. The controller used for the prototype was implemented in Ladder logic on a PLC. The PLC used for this work is (LS\GLOFA-G7M-DR20A) series with (8) input and (12) output. This elevator system can be used for learning the structure of the elevator as well as the control strategy involved in elevator system for educational purposes. The research work can serve in learning enhancement for the undergraduate's students in the Electromechanical Department in the University of Technology.

**Key word:** pneumatic, elevator, PLC

### انجاز نموذج مصعد كهرو هوائي مسيطر عليه بواسطة المسيطر القابل للبرمجة

#### الملخص:

البحث الحالي يمثل طريقة جديدة وواضحة لانجاز نموذج لمنظومة مصعد كهرو هوائي المسيطر المستخدم في هذا النموذج ينجز بواسطة منطق سلمي باستخدام المسيطر القابل للبرمجة. يمكن استخدام منظومة المصعد الحالية في تعليم بناء المصعد بالاضافة الى تقنية السيطرة المتضمنة في منظومة المصعد لاغراض تعليمية. حيث يمكن استخدام البحث الحالي في تعزيز العملية التعليمية لطلبة المراحل الاولى في قسم الهندسة الكهروميكانيكية في الجامعة التكنولوجية حيث ان نوع المسيطر المستخدم في العمل الحالي هو (LS/GLOFA-G7M-DR20A) والذي يحتوي على (8) مداخل و (12) مخرج

### INTRODUCTION:

For most people residing in cities, elevators have become an integral part of their daily life. Simply stated, an elevator is a hoisting or lowering mechanism, designed to carry passengers that typically moves in fixed guides and serves two or more landings [1]. Due to the cause of rapid population growth at the cities and multi-stored buildings, the need of elevators is being increased; with the rising life standards and attention to human and with the technologic developments,

elevator systems are getting better, more fast, stronger and better quality elevators are produced. Previously, most systems were focused on the mounting of elevators, especially after the 1980s the need for elevator maintenance and fault staff have been started to increase [2].

There are three commonly used elevators today: Hydraulic elevators, gearless traction elevators, and geared traction elevators. Traction elevators are pulled up and down with a rope connected to a motor with a counter-weight. Geared and gearless elevators work similarly, with the only difference being that a gearbox is built in between the motor and the sheave in a geared elevator. Hydraulic elevators are used today in both passenger and freight services in buildings from two to six stories high and has a speed from 0.125 to 1.0 mps (meters per second) [3].

Pneumatics is a subsection of an area known as fluid power; it uses air which is a colorless, odorless and tasteless gas consisting of approximately 78% Nitrogen and 20% Oxygen. The remaining 2% consists of about 1% Argon and a mixture of other trace elements such as Helium, Hydrogen and Neon [4]. The word 'Pneuma' means breath or air and pneumatics is application of compressed air in automation [5].

For home elevator specifically, one type of elevator used in dwelling of up to four floors is a pneumatic elevator, also called a vacuum elevator. This home elevator doesn't need a machine room, because it moves using a driving machine consisting of turbines that remove air from the top of the elevator car. Pneumatic elevator is the first residential elevator that runs merely by the atmospheric pressure.

The automation systems that use Electro-pneumatic technology are formed by mainly three kinds of elements: actuators or motors, sensors or buttons and control elements like valves [6]. Atypical pneumatic elevator is powered by a piston that travels inside a cylinder; a compressed air pumps air into the cylinder to move the piston. The piston smoothly lifts the elevator cab; electrical valves control the release of the air for a gentle descent.

A Programmable Logic Controller (PLC) or Programmable Controller is a digital computer used for automation of electromechanically processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. PLC has many advantages over other control systems. It is known for its flexibility, low cost, operational speed, reliability, ease of programming, security, and it is easy in implementing changes and correcting errors [7]

A PLC has many "input" terminals, through which, it interprets "high" and "low" logical states from sensors and switches. It also has many output terminals, through which it outputs "high" and "low" signals to power lights, solenoids, contactors, small motors, and other devices, lending themselves to on/off control [4].

There are many types of programming languages in PLC; languages are typically fixed to Ladder Logic

(LD), Sequential Function Block (SFC), Function Block Diagram (FBD) and Structure Text (ST).

The common program language of PLC is Ladder diagram [8]. Ladder diagram is an important concept not only at Electro-pneumatic systems, but also at PLC.

There is only few literatures are available close to current research:

Prěmysl Matous'ek [9] designed and constructed Electro - pneumatic model with the possibility of being controlled by a mobile phone; the model for remote control of PLC by means of Short Message System (SMS) was projected for the application

of Electro - pneumatic elevator. Sysala and Tomas [7] focused on description of laboratory models that were used in the process of education at their faculty. The models were connected to PLC and through these equipment, the models were controlled. The students had to connect the model to a PLC; with that, they had to make a program for model control and they must verify its functionality. Saru Sehga. J and Vikas Acharya [10] discussed the Ladder programming that used for PLC; it has very simple and handy programming, i.e., if we want to increase, decrease or skip any floor then program can change as per our requirements. Supervisory Control and Data Acquisition (SCADA) were also used to supervise and control the working of the elevator. If somehow any fault occurs, then, SCADA itself identifies the fault position and generates an alarm. The response on the fault could be taken within no time by interfacing PLC and SCADA with the elevator system. S.B. Ron Carter and A. Selvaraj [2] explained about an elevators operation which uses an AC motor to drive the elevator cabin. The elevator mentioned in this work was fully automated using PLC. Sandra Htay and SuSuYi Mon [1] focused on using PLC to control the circuit and building the elevator model. DC Motor was used to control the up and down movement of the elevator car. The elevator position was described by using the display unit. In this research work Auto Station Software Ladder logic program was used for four floors control system.

The current work, focuses on using pneumatic components and electrical components to build prototype model of an Electro-pneumatic elevator consisting of three stops (floors) in about (152 cm\*34 cm\*47 cm) and the travel length (126 cm) controlled by using PLC. The PLC is programmed with Ladder language. The PLC that used in the current research work is (LS\GLOFA-G7M-DR20A) series with (8) input and (12) output. It is programmed with a Ladder language (GMWIN 4.0), and during its construction, many theoretic knowledge from various fields were applied.

### **Model Construction:**

The elevator model is constructed to simulate an actual elevator in the real life. The Electro - pneumatic elevator is modeled as a laboratory model of elevator that combines the pneumatic and electronic components. This model is controlled by a PLC. The material and devices used to build the system of the elevator model were as follows: Air compressor – actuator - solenoids-relays-PLC-power supply – proximate switches –connector –wires and hoses –call switches and cabin switches – regulator – distributors –indictor connected directly to air compressor –special solenoid with an arm works as a brake in emergencies –guide to support the movement of the cabin in ascend and descend –pressure switch and tray. All the equipment specifications are listed in the Tables (A-1) and (A-2) in the Appendix.

### **The Structure of The Elevator:**

The aluminum was chosen to build the models' frame for being affordable and available in the market, as well as, its durability, possibility for reconstruction for different purposes. The aluminum frame is used in different lengths according to the model design as explained below:

The aluminum frame designed with (152 cm length – 34 cm width – 47 cm depth) and a travel length of (126 cm). The cylinder fixed on the frame, about (19 cm) far from the frame front and fixed on plastic card board as shown in Figure (1a).

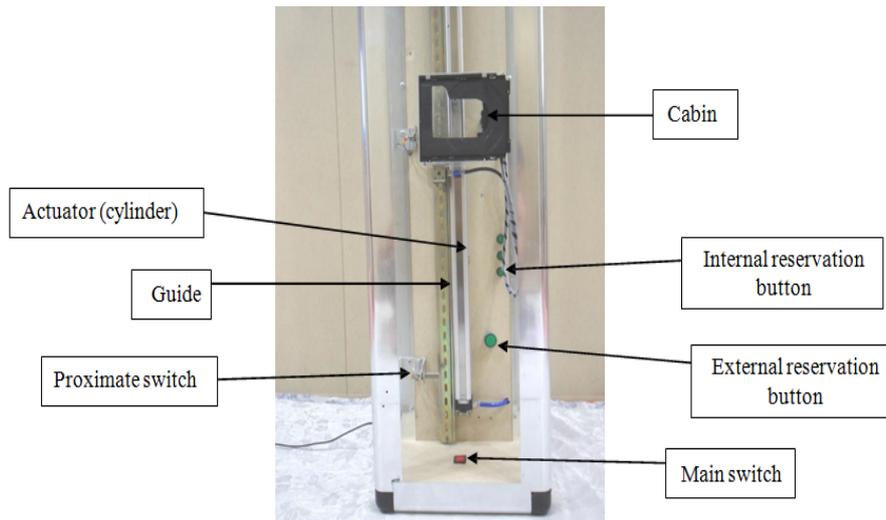


Figure (1-a): Front view of Elevator System

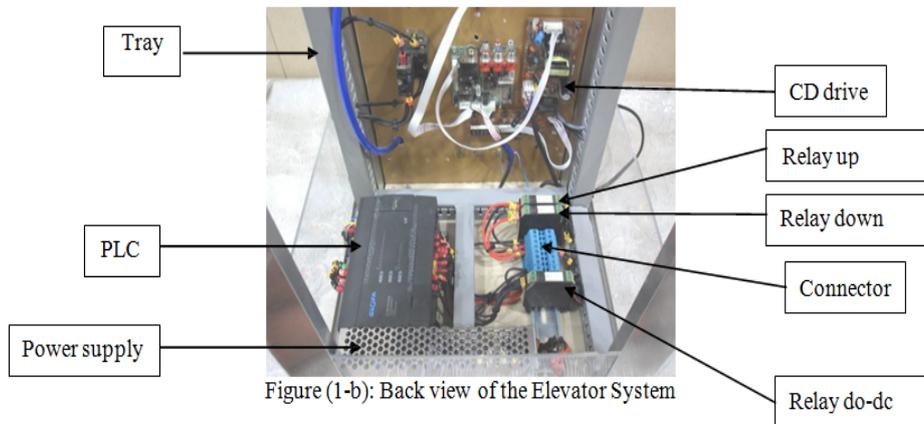


Figure (1-b): Back view of the Elevator System

#### The Construction of The Cabin:

Cabin is a travel room which transports the loads through the floors. The fiberglass was chosen to build the cabins' frame, in spite of being not available as other materials and the difficulty of dealing with it. Because of its hardness, the fiberglass has a high resistant of pressure and low breaking possibility compared to glass. As well as, the fiberglass is very suitable for educational purposes.

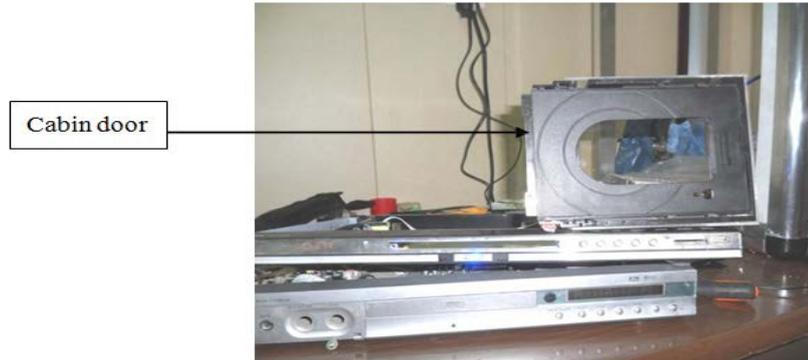
The embarkation cabin is designed with these dimensions: Length = 14 cm, Width = 15 cm, Depth = 8 cm

The fiberglass pieces is welded together with (liquid chlorine) to construct the cabin car.

#### The Cabin Door:

There are many research talks about cabin door design, therefore, the current paper proposed ready design to drive the door. The more suitable cabin door and its drive for the current research work is that CD drives (MARSHAL). It is very easy to

be controlled with the PLC. Figure (2) shows the cabin door drive:



**Figure (2) cabin door drive**

#### **Procedure of Elevator Model Implementation:**

In this paragraph, the steps are explained of assembling, the current prototype model for

Electro-pneumatic elevator and controlled by the PLC which is programmed with (Ladder GMWIN4.0) language. The model was assembled in a suitable way so as to simulate the real elevator as much as possible.

The pneumatic actuator (cylinder) shown in figure (1- a) was fixed on the aluminum frame with cardboard of plastic and located at (19 cm) far from the model front.

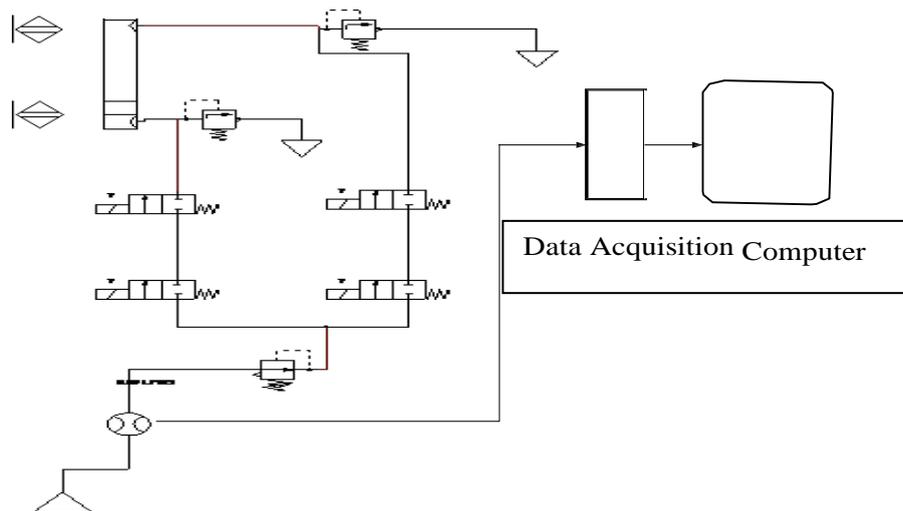
After that, the cylinder which is (126 cm) length was divided in to three equal sections. Each section represents a (42cm) story in the building model. The proximate switches were used to identify these stories limits for the cabin. The switches are fixed on aluminum (L) shaped supports on the edge of each floor.

The current model is constructed as a prototype system and can be used in the laboratory for educational purposes. This makes the wires and connections in the model in nearness to each other and risk of being entangled and undefined. This problem can be solved by a useful way named (numbering), where; a small letters and numbers in different colors with circular shapes were used. Different types of colored buttons were used. The green buttons fitted with LED. Each one of them is fixed in a different floor of the building model. These buttons are similar to the real buttons of the elevators. Every button in charge of calling the cabin to the floor by the passengers; the problem that may be faced in building the proposed prototype mode is that, there are another buttons which must be fixed inside the real elevator. These buttons work like that ones' outside the cabin in calling the cabin by the passengers. The priority in following command is for the buttons inside the cabin model which is small in size, there for, it was hard to attach the buttons inside the prototype elevator. To solve this problem, the buttons were fixed to the left of the cabin as small green buttons which were smaller than the floors' buttons and they are not fitted with (LED). A red switch fixed in the middle of the front base of the model is used to turn (on/off) the elevator. The PLC stores several commands during the

experiment. The red switch turns off the system allowing the user to cancel those commands. All the necessary buttons were fixed in the prototype as shown in figure (1-a).

**The Electrical Connection:**

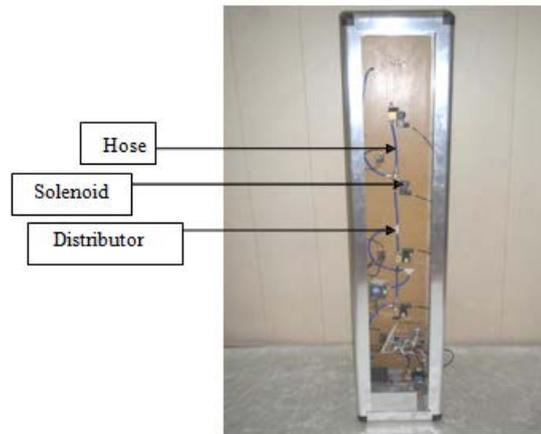
The electrical connection for the elevator parts is shown in the back side of the elevator prototype. All the components, used to build the elevator shown in figure (1-b) as much as Figure (3) shown schematic wiring:



**Figure (3): The Wiring Schematic Diagram**

**The Solenoids:**

The cylinder used in the elevator system has two openings; one is at the top and the other at bottom. The compressibility of air makes it difficult to stop the piston at a certain point. To solve this problem, two solenoids were used for each opening point desired. The elevator solenoids must be connected to the cylinder in such way, that allows for a sending and descending of the cabin and to achieve, this goal, a solenoid must be attached to the bottom opening and the compressor. On the other side, when the solenoid is provided with an air it pushes the piston upward which results in lifting the cabin in the same direction. Since, the air is highly compressible, another solenoid must be attached to the top opening for leaking the air above the piston. The descending is similar to the sending for the cabin. A solenoid is attached to the top opening of the cylinder and to the compressor from the other side. The piston is pushed down by the compressed air pulling the cabin down with it. Another solenoid is an attached to the bottom opening vent the air to ensure the descent. Four normally close solenoids were used; each two of them fixed to a distributor. As shown in Figure (3):



**Figure (4): solenoids connection**

#### **The Relays:**

Three relays were used in the elevator model they were and distributed as follows: The first relay is (relay up) named as (rlyup) in the PLC program. This relay is responsible for the cabin ascending for turning on both first solenoid and fourth solenoid (SV1 and SV4). The second relay is (relay down) named as (rlydown) in the PLC program. This relay is responsible for cabin descending to turn on both of second solenoid and third solenoid (SV2 and SV3).The last relay is the third relay, which responsible for opening and closing the cabins' door, which is named as (d-o and d-c) in the PLC program. The capital (d) refers to the word (door) while capitals (o and c) refer to the words (open and close), respectively.

#### **Connector:**

The connector is used for delivering the power received from the 220V AC voltage source to several terminals. The connector is used for delivering AC power to the relay up, relay down and the power supply.

#### **Power Supply:**

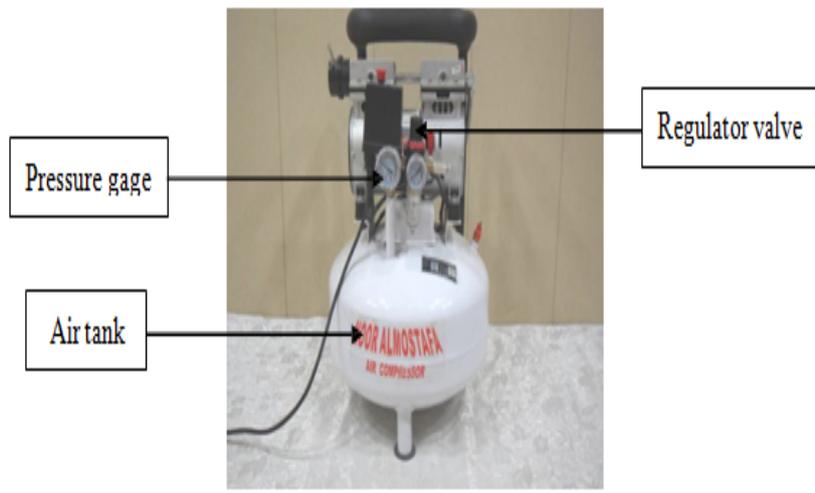
The electrical power supplied the elevator components with an AC and DC type. Some of these components work on AC power like (PLC-solenoid-the card of opening and closing the cabins' door-the main red switch-the light of the outside call buttons-contact of relay). Other components work on DC power like (coil of relay-PLC inputs-proximate switch-the outside and inside call buttons). The power supply used in the model can be shown in figure (1b).

#### **Programmable Logic Controller (PLC):**

The PLC is the systems' brain and the main controller of the elevator. The PLC is programmable device which can be connected to the PC (personal computer) and reprogrammed to fit the work requirements. The type of the PLC used in the current model was (LS\GLOFA-G7M-DR20A) series. Its' operator program is (GM WIN 4.0) in Ladder language.

**The Air Compressor:**

The air compressor is the systems' heart. The air compressor supplies the system with a compressed air. The suitable air compressor used must be with minimum size and lower noise and gives the suitable rated pressure required for the proposed elevator model. The used compressor gives a pressure range of (1-8 bar).



**Figure (5) the mute air compressor**

The force F can be calculated as:

$$F = P \times A$$

The piston area (A) can found from:

$$A = \frac{D^2 \pi}{4}$$

using  $D = 25 \text{ mm}$  (from the design specification of the cylinder)

where D is the diameter of the piston:

$$A = \frac{D^2 \pi}{4} = \frac{(25)^2 \times 3.14}{4} = 490.625 \text{ mm}^2$$

Since, the maximum pressure for the used compressor is 8 bar (1 bar equal to  $0.1 \frac{\text{N}}{\text{mm}^2}$ )

$$F = 0.8 \frac{\text{N}}{\text{mm}^2} \times 490.62 \text{ mm}^2 = 392.49 \text{ N}$$

The payload mass can be calculated as:

$$m = \frac{F}{g}$$

Where:

F: the force in Newton.

m: the mass of payload in kg.

g: the gravity (equal to 10 N/kg).

Therefore:

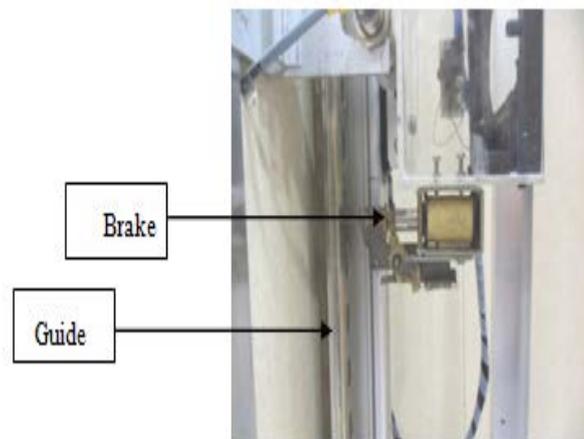
$m = 39.24$  kg for maximum pressure (8 bar)

### **Brakes and Guide:**

Many emergencies might happen during the elevator running, like:

- 1- Power outages.
- 2- A hole or a cut in the hoses connected to the solenoid.
- 3- A defect in the PLC.
- 4- The PLC stops.
- 5- Conflict in instructs and repetition in orders, etc.

There are different ways to make safety. In the current research, a special solenoid with an arm was used. This arm is fixed through guide. When a problem happens (this defect is sensed by a pressure switch, it senses the difference of air pressure from the preset pressure thus extending), the solenoid arm comes inside the solenoids' body through fixed guide, as a result, the brakes contained cabin in same place where the problem happen and prevent it from falling. Guide was fixed to the right of the cabin to maintain the cabin position and avoiding the sliding of the cabin. The guide also can be used to stop the cabin from falling in the emergencies.



**Figure (6) the brake**

After assembling all the previous components and over taking every ousted, we were left with wire entanglement in spit of numbering which helped us for naming the wire. Because of being with large number, it is favor to use it with tray. It saved too much time to use the tray and made it safe to deal with wires. These trays are fixed along the right and the left edges of the elevator model. As shown in Figure (1b).

**Software Process of The Elevator System:**

The software process first check the status of the floors the up and down movement, the opening and shutting of the door, by using sensors, and then the Ladder program is implemented in the system to control all the movements in time. The detailed system can be explained with the help of the process flowchart given in figure (7).

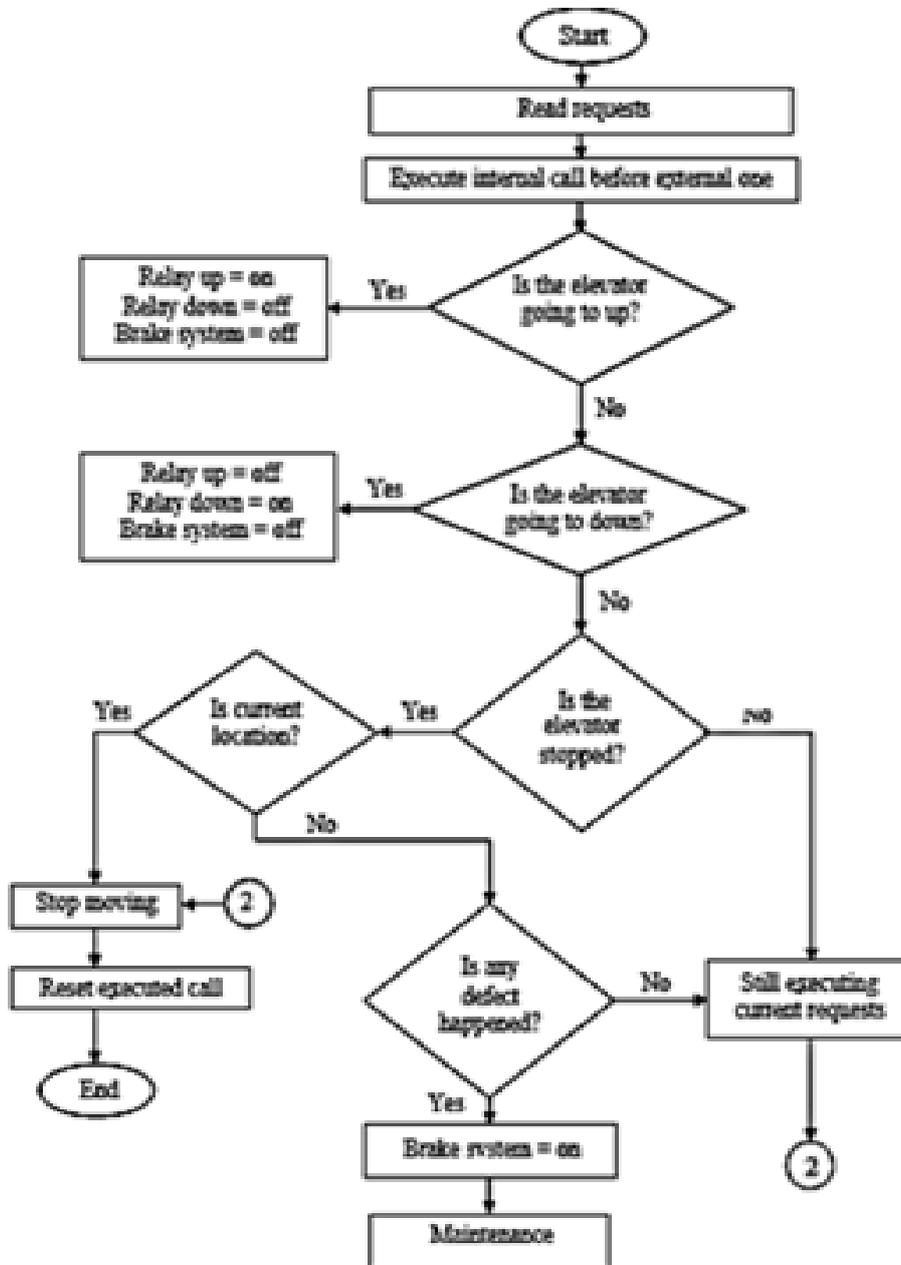


Figure (7): Elevator control algorithm flowchart

**Conclusions:**

- 1- The objective of this paper is to implement an Electro-pneumatic three level prototype elevator model system and create the Ladder programming of PLC control system.
- 2- The current PLC-based controlled model elevator allows the students to apply PLC operating skills to a real world. The current elevator is developed to demonstrate and simulate the operations of the elevators. Therefore, the over all prototype elevator system can be used for educational purposes.
- 3-The PLC problems which may happen can be solved by adding another same PLC to protect the system and programmed in the same way. When fault happens to the first PLC, the elevator takes orders from the second PLC. In design a real elevator, it is desirable to apply this. As a future work.

**Appendix**

Most of the Electro-Pneumatic components used in the current model were assembled from the FESTO Company, that, by it support, enabled the realization of this research work. Some other components were borrowed from the laboratories in the electromechanical engineering department. The specifications for all the used components are listed as in the Tables (A-1) (A-2) and (A-3) below:

**Table (A-1) Pneumatic components**

<b>Pneumatic Component</b>	<b>Name of company</b>	<b>Specifications</b>
Air compressor	ROLLS Company	Direct-driven air compressor with (1-8 bar)
Actuator	HOERBIGER\ORIG A Companies	126cm length has two opening with one piston (double ended piston rod cylinder) work in max 8 bar
Solenoids	HLPC company	Normally open AC 220V, 50HZ
Pressure switch	DUNGS company	LGW 10 A2 / Pmax = 500 mbar Luft

**Table (A-2) Electrical components**

<b>Electrical</b>	<b>Name of company</b>	<b>Specifications</b>
Relay	Murrelektronik	24 DC
PLC	LS\GLOFA-G7M-DR20A	12 inputs and 8 outputs Programmed in Ladder language (GMWIN 4.0)
Power supply	Anlixun company	s-120-24 I\P 110V AC 1.6A, 230V AC 0.8A50\60 HZ DC (5A)
Proximate switch	ABB Company	Inductive proximate switch
Electrical brake	FESTO company	Especial solenoid with arm, 220AC
Compressed Air Flow	T-CDI-5200-10S.	Input power: 250 mA at 24 Vdc, Output resistance: 600 Ohms max.

**Table (A-3) Mechanical Specification of the Elevator System**

Elevator Cabin		Elevator Frame	
Height	8cm	Length	152cm
Length	14cm	Width	34cm
Width	15cm	Depth	47cm
Cabin Material	Fiber glass	Travel Distance	126cm
Fiber glass Density	0.55 (lb/In <sup>3</sup> )	Frame Material	Aluminum
Cabin Weight	0.25 gm (approx)	Aluminum Density	2710 kg/m <sup>3</sup>
Load Wight	5 kg	Maximum Velocity	0.05 m/sec

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