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AUTOMATION OF TWO SUB-ASSEMBLIES IN 3-Φ LOW VOLTAGE CAPACITOR MANUFACTURING

[1]ROMIL D GANDHI, [2]AMUTHA PRABHA N.
[1]*School of Electrical Engineering, Vellore Institute of Technology University*
Vellore-632014, Tamil Nadu, India
[2] *School of Electrical Engineering, Vellore Institute of Technology University*
Vellore-632014, Tamil Nadu, India
E-mail: [1] romil_g12@yahoo.co.in, [2] amuthaprabha@vit.ac.in

ABSTRACT

In this paper, the aim is to automate two of the sub-assemblies involved in the manufacturing of 3-Φ low voltage capacitors. The vacuum heat treatment process and the reactor addition process while element testing are the sub-assemblies which are intended to be automated.

The vacuum heat treatment process is presently manual and when the unloading of elements is to be done is unknown. So, there is a need to automate this process in order to save precious time. Also, the automation of the element testing process is to be done in order to comply the element in accordance with the international standards in a faster and efficient way. Also during this process, the automatic addition and selection of the reactor for the power factor improvement of the element. Using Programmable Logic Controllers, the respective automations are achieved.

Keywords: *Automation, Programmable Logic Controller, Power Factor Correction, Low Voltage Capacitor Manufacturing, Ladder Logic*

1. INTRODUCTION

1.1 Automation

It is the delegation of human control functions to technical equipment aimed towards achieving higher productivity, superior quality, efficient usage of energy, improved safety in working conditions.

Automation or industrial automation or numerical control is the use of control systems such as computers to control industrial machinery and processes, reducing the need for human intervention [6]. In the scope of industrialization, automation is a step beyond mechanization. Whereas mechanization provided human operators with machinery to assist them with the physical requirements of work, automation greatly reduces the need for human sensory and mental requirements as well. Processes and systems can also be automated. Automation plays an increasingly important role in the global economy and in daily experience. Engineers strive to combine automated devices with mathematical and organizational tools to create complex systems for a rapidly expanding range of applications and human activities [3].

1.1.1 Advantages of automation

- As factory automation technology becomes more capable, more functional and ubiquitous, its meaning and purpose take on many interpretations.
- Factory automation delivers increased product and process information, and of course, improves product quality.
- Technology is used in so many ways and for so many different ends that it is almost impossible to have a single definition that includes all the solutions factory automation delivers.
- Its various data templates can be configured to address management and executive information needs.
- It presents real-time data that will help them to do something with the information and make an informed decision.
- System monitoring showed that unit costs varied by as much as 50 percent over the three daily shifts.

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- Providing proper training to the operators led to increased productivity and a more consistent unit cost.
- Factory automation's capabilities are multi-faceted and provide answers to the questions asked of it.

1.1.2 Programmable logic controller (PLC)

Before PLCs came into existence, sequencing, safety interlock logic for manufacturing, and other controls were accomplished using physical relays, timers, and dedicated closed-loop controllers.

But the control industries were looking forward to eliminate the high costs associated with inflexible, relay controlled systems. The specifications required a solid-state system with computer flexibility which must be able to survive in an industrial environment, be easily programmed and maintained by plant engineers and technicians, and be reusable.

Such a control system would reduce machine downtime and provide expandability for the future [3,5].

1.1.3 Ladder logic

For ease of programming the programmable controller was developed using existing relay ladder symbols and expressions to represent the program logic, needed to control the machine or process. The resulting programming language, which used these original basic relay ladder symbols, was given the name ladder language [5].

1.1.4 ADVANTAGES OF PLC

1. Flexible
2. Faster response time
3. Less and simpler wiring
4. Modular design- easy to repair and expand
5. Handles much more complicated systems
6. Sophisticated set of instruction set available
7. Easy to troubleshoot
8. Less expensive
9. Communication capability

1.2 Power factor and its correction

1.2.1 Power factor

Power Factor = Active Power (kW) / Apparent Power (kVA)

Power Factor can never be greater than 1.

Power Factor at best can be equal to 1. Practically the desired power factor is usually 0.93 – 0.96. Usually P.F is always “Lag” because of the presence of more Inductive loads. Sometimes the P.F can “Lead” if a capacitive load is present in the circuit [1,8].

1.2.2 Origin of low power factor

Electrical Equipment need reactive power. Inductive loads consume reactive power and capacitive loads generate reactive power. It is the phase difference between current & voltage [1,4].

1.2.2 Power factor correction

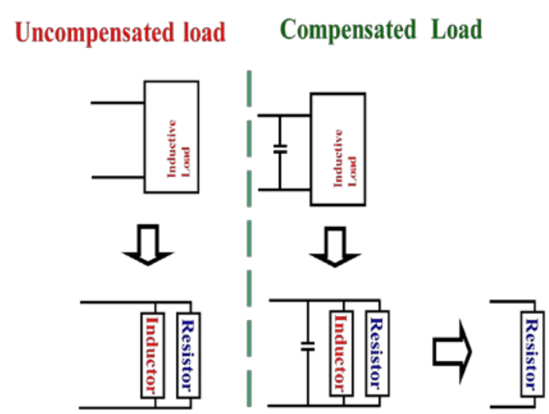

Figure 1.1: Power factor correction

If we make $|X_L|$ of Load = $|X_C|$ of capacitor at resonant frequency, then the PF will be unity due to Parallel resonance between capacitor & load inductor [7].

1.2.3 Advantages of power factor correction

- Reduction in KVA demand
- Reduction in transformer rating
- Reduction in line current and thus line loss
- Reduction in cable losses
- Reduction In switchgear rating [1].

2. LOW VOLTAGE CAPACITOR MANUFACTURING

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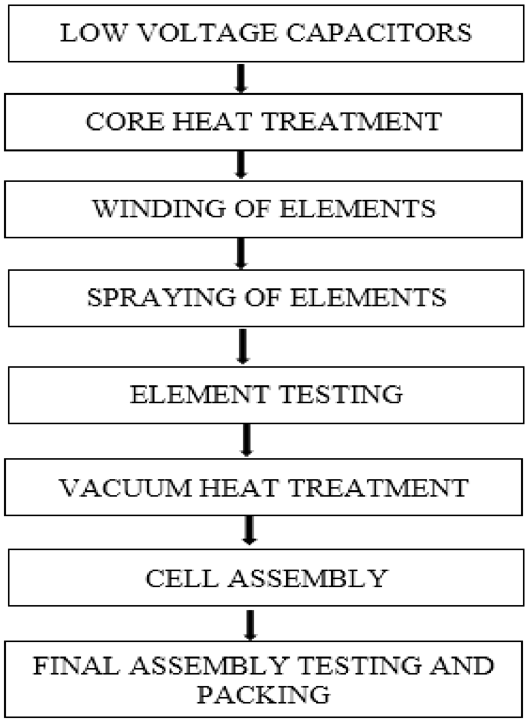
2.1 Process flow



3. EXISTING METHODOLOGY

3.1 Element testing

The elements after undergoing the spraying process are then taken into another area for testing. The elements are to be tested in order to comply it in accordance with the international standards. This process is completely manual.

Also, during this process, reactance is also added to capacitor element in order to optimize its own PF. Automation can be achieved with the help of a PLC by using and understanding the process flow of this process[2].

3.2 Vacuum Heat Treatment

The elements after testing are to be bought to another area for undergoing the vacuum heat treatment process. This process has to take place in order to remove the moisture content from the capacitors because moisture would have been absorbed by these elements while undergoing spraying and testing processes.

This process is manual but when the unloading has to take place is never known without continuous checking of the heat ovens. In this plant there are 14 of them and without automating it, every day, there is a high loss of precious time. Automation can be achieved with the help of a PLC by using and understanding the complete process[2].

4. PROPOSED METHODOLOGY

4.1 Element testing and Reactor addition

4.1.1Sequence of operations

- **Set the parameters:**

Select the CAT Reference in the HMI or PC, and parameters get selected automatically.

- **Element loading:**
Element is loaded manually.

- **Cycle starts:**
Press the Push button switch for cycle start.

- **AC Clearance test:**

After pressing the push button, jig and safety door close. Voltage of (60-100Volts AC) is applied to the element. Voltage is applied for 2 sec, then 2 sec OFF & again 2 sec ON.

- **Reactor addition**:

After completing the AC clearance test, high Voltage will be applied to the elements up to 10 sec. Reactor addition takes place during that time simultaneously with HV test.

- **Unloading**:

The element is unloaded manually after the testing and reactor addition is done.

4.1.2 Process flow

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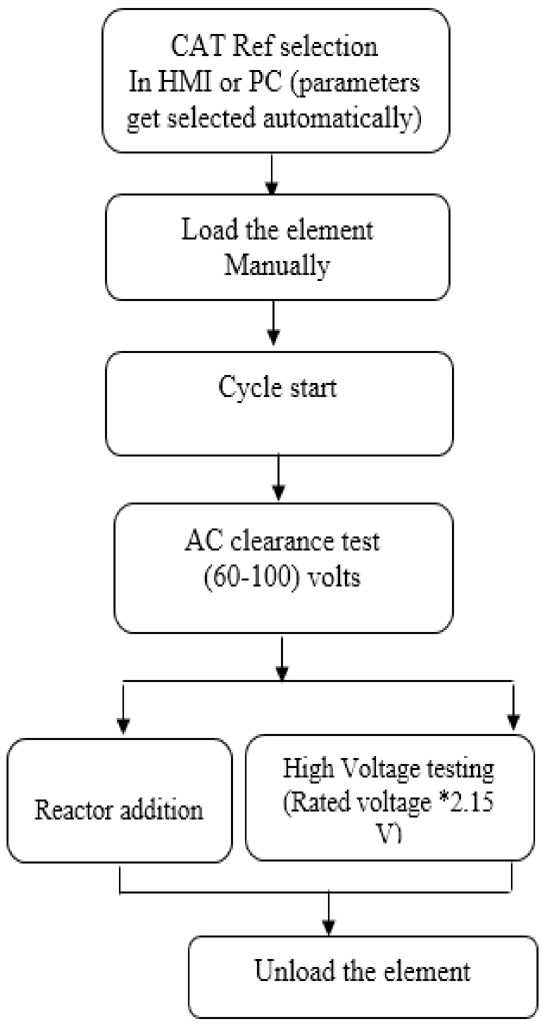

4.1.3 PLC used for reactor addition and element testing

Schneider Electric micro PLC – model-**SR3B261FU.** Software used for performing the simulation and making the ladder logic program is Zeliosoft 2, which is a ladder logic builder software by Schneider Electric.

4.1.4 Input – output allocation for the PLC

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reactor.zm2 - v0.0 Title

Physical inputs

No	Symbol	Function	Lock	Parameters	Location of (L/C)	Comment
I1		Discrete inputs	---	No parameters	(1/1) (2/4) (3/3) (4/3) (5/2) (6/4) (8/3) (10/3) (12/3) (15/2) (16/3) (47/3) (48/4) (50/1)	Bar code scanner
I2		Discrete inputs	---	No parameters	(3/2)	Loading complete
I3		Discrete inputs	---	No parameters	(3/1) (48/1)	Start PB
I4		Discrete inputs	---	No parameters	(1/3) (2/2) (3/4) (4/2) (5/3) (6/3) (8/2) (10/2) (12/2) (15/3) (16/2) (27/1) (47/2) (48/3) (49/1) (50/2)	Emergency PB
I5		Discrete inputs	---	No parameters	(27/2) (34/1) (48/5) (51/1)	All reset PB

Physical outputs

No	Symbol	Function	Latching	Location of (L/C)	Comment
Q1		Discrete outputs	No	(47/6)	Green LED for unloading
Q2		Discrete outputs	No	(48/6)	Orange LED for cycle in progress
Q3		Discrete outputs	No	(49/6)	Red LED for emergency
Q4		Discrete outputs	No	(50/6)	White LED for waiting of capcaitor element

Configurable functions

No	Symbol	Function	Lock	Latching	Parameters	Location of (L/C)	Comment
M1		Auxiliary relays	---	No	No parameters	(2/6) (20/6) (27/6) (34/6)	parameters select
M2		Auxiliary relays	---	No	No parameters	(3/6) (4/1) (19/6) (28/6) (35/6)	Jig close
M3		Auxiliary relays	---	Yes	No parameters	(4/6) (5/1) (6/1) (6/6) (8/6) (10/6) (29/6) (36/6)	(60-100) volts applied
M4		Auxiliary relays	---	No	No parameters	(13/6) (16/6) (30/6) (37/6)	(2.15 * Vr) volts applied
M5		Auxiliary relays	---	No	No parameters	(14/6) (15/1) (17/6) (31/6) (38/6)	Reac add para set
M6		Auxiliary relays	---	No	No parameters	(1/2) (2/3) (3/5) (4/4) (18/6) (39/6) (47/1) (48/2)	Unloading
M7		Auxiliary relays	---	No	No parameters	(15/6) (26/6) (33/6) (46/6)	Reactor corresponding to eler added
M8		Auxiliary relays	---	No	No parameters	(1/6) (2/1) (25/6) (32/6) (45/6)	Bar code read
T1		Timers	No	No	See details below	(5/6) (6/2) (21/6) (40/6)	Timer for 2 sec charging
T2		Timers	No	No	See details below	(7/6) (8/1) (22/6) (41/6)	Timer for 2 sec discharging
T3		Timers	No	No	See details below	(9/6) (10/1) (23/6) (42/6)	Timer for 2 sec 2nd charging
T4		Timers	No	No	See details below	(11/6) (12/1) (43/6)	timer for 2 sec delay
T5		Timers	No	No	See details below	(12/6) (16/1) (24/6) (44/6)	Timer for HV test and reacto...

4.2.1 Working

4.2 Vacuum heat treatment

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a) **Evacuation**: Vacuum pump is switched ON and after 10 min, the roots pump is switched ON. The duration of this process is ***2 hours.***

b) **N_2 feeding**: N_2 valve is opened with N_2 fed at 40 °C. The duration of this process is ***30 min.***

c) **Profile heating**: Heater is switched ON and also the oil circulation pump is switched ON. The duration of this process is ***36 hours.***

d) **Vacuum drying**: Once 105 °C is reached, the cycle is held, the vacuum pump is switched ON and 10 min later, the roots pump is switched ON. The duration of this process is ***8 hours.***

e) **Cooling**: The duration of this process is ***26 hours.*** The sub parts of this process are:-

i) Top cooling vacuum pump is switched ON and after 30 min, the vacuum pump and roots pump must be switched OFF.

ii) When temp reaches 70 °C, the heat exchanger valve is switched ON for further cooling.

iii) When temp reaches 60 °C, the top cooling vacuum pump is switched OFF along with the heat exchanger valve.

iv) N_2 at 40 °C is fed and oil circulation pump is switched OFF.

By following the cooling cycle, and by creating a ladder logic using this, oven indication after the vacuum heat treatment process can be established.

4.2.2 PLC used for vacuum heat treatment process:

Schneider Electric micro PLC – model- **SR3B261FU.**

4.2.3 Input – output allocation for the PLC

VH111_12 unloading updated.zm2 - v0.0 Idu

Physical inputs

No	Symbol	Function	Lock	Parameters	Location of (L/C)	Comment
I1		Discrete inputs	--	No parameters	(1/1) (2/2) (4/2)	Top cool vac pump on
I2		Discrete inputs	--	No parameters	(11/1)	All reset PB
I3		Discrete inputs	--	No parameters	(2/4)	Heat exc val ON chm 12
I4		Discrete inputs	--	No parameters	(2/3)	40 frm Ol chm 12
I5		Discrete inputs		No parameters	(3/4)	Oil pump ON_chm12
I6		Discrete inputs		No parameters	(10/1)	Emer PB
I7		Discrete inputs	--	No parameters	(6/3)	40 from DL chm 11
I8		Discrete inputs	--	No parameters	(3/4)	Heat ex val on Chm 11
I9		Discrete inputs	--	No parameters	(6/4)	Oil pump ON chm 11

Physical outputs

No	Symbol	Function	Latching	Location of (L/C)	Comment
Q1		Discrete outputs	No	(10/8)	Red
Q2		Discrete outputs	No	(7/4)	Orange (rdy unloading chm 12)
Q3		Discrete outputs	No	(9/8)	Green (cooling ON)
Q4		Discrete outputs	No	(6/4)	Blue (rdu unloading chm11)

Configurable functions

No	Symbol	Function	Lock	Latching	Parameters	Location of (L/C)	Comment
M1		Auxiliary relays	--	Yes	No parameters	(1/8) (2/1) (4/1) (3/1) (6/1) (8/1) (11/8)	Cool_Cyl_ON
M2		Auxiliary relays	--	Yes	No parameters	(2/6) (4/3) (12/8)	Reached 70 deg
M3		Auxiliary relays	--	Yes	No parameters	(4/8) (5/2) (8/2) (13/8)	Reached 60 deg
M4		Auxiliary relays	--	Yes	No parameters	(5/6) (7/1) (9/2) (14/8) (18/1)	Unloading rdy chm 12
M5		Auxiliary relays	--	Yes	No parameters	(8/6) (8/1) (9/3) (15/8) (17/1)	unlding rdy chm 11
T1		Timers	No	No	See details below	(7/2) (16/8)	Flasher chm12
T2		Timers	No	No	See details below	(8/7) (17/8)	Flasher chm 11

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5. SPECIFICATIONS FOR REACTOR ADDITION AND ELEMENT TESTING

The following in *Table 1* are the specifications and ranges for the hardware items installed for the element testing and reactor addition process.

Mentioned below are also the corresponding reactor values to be added for a given amount of capacitance. These reactors could be used together in order to get the capacitance values for those, which a single reactor cannot give.

Example: To add reactance for a 240µf capacitor, 21.170 mH and 42.21 mH reactors should be switched on.

6. SIMULATION RESULTS

6.1 Reactor addition and element testing

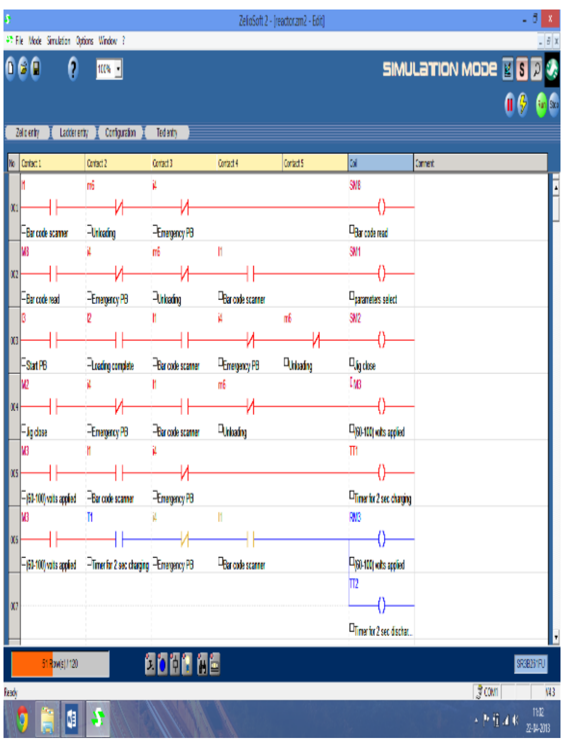

Figure 6.1: When Barcode Is Read, Loading Complete And Start PB Pressed

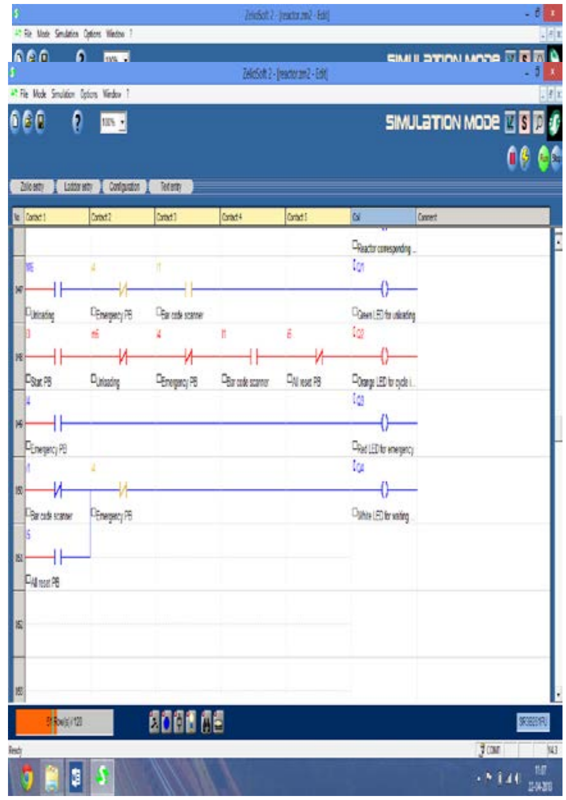

Figure 6.2: When Low Voltage Test Is Over And High Voltage Test And Reactor Addition Is About To Start

Figure 6.3: When Cycle In Progress, The Corresponding Orange LED

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Table 1: Specifications Of Reactor Addition And Element Testing

SL.NO	ITEM DESCRIPTION	RANGE/ SPECIFICATION/ DRAWINGS
1	MCCB 440V, 100A	100A, 440V, 3Ph
2	FUSE 150A	150 A
3	REACTOR	21.170mH = 160 µf
4	REACTOR	42.21mH = 80 µf
5	REACTOR	84.43mH = 40 µf
6	REACTOR	168.87mH = 20 µf
7	REACTOR	337.76mH = 10 µf
16	STEP UP TRF	I/P 440V 3 Ph , O/P 2300V,3 Ph,
8	CONTACTOR	50A,3Ph, 690V
9	CONTACTOR	25A,3Ph, 690V
10	CONTACTOR	10A,3Ph, 690V
11	CONTACTOR	10A,3Ph, 690V
12	CONTACTOR	100A,3Ph, 690V
13	DIMMER START	3Ph, 10kVA, 50 Hz dimmer stat, I/P 415V, O/P 440V ,Air cool motorized
14	DIMMER START	3Ph, 50kVA, 50 Hz dimmer stat, I/P 415V, O/P 480V , Oil cool motorized
15	RESISTOR	~
17	DIGITAL AMMETER	0 to 3000V AC
18	DIGITAL VOLTMETER	0 to 100A AC

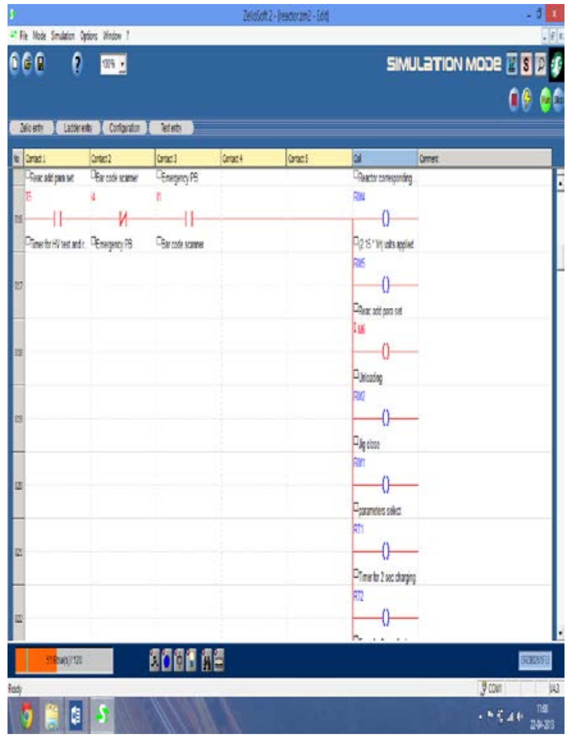

Figure 6.4: When The Process Is Completed And Ready For Unloading

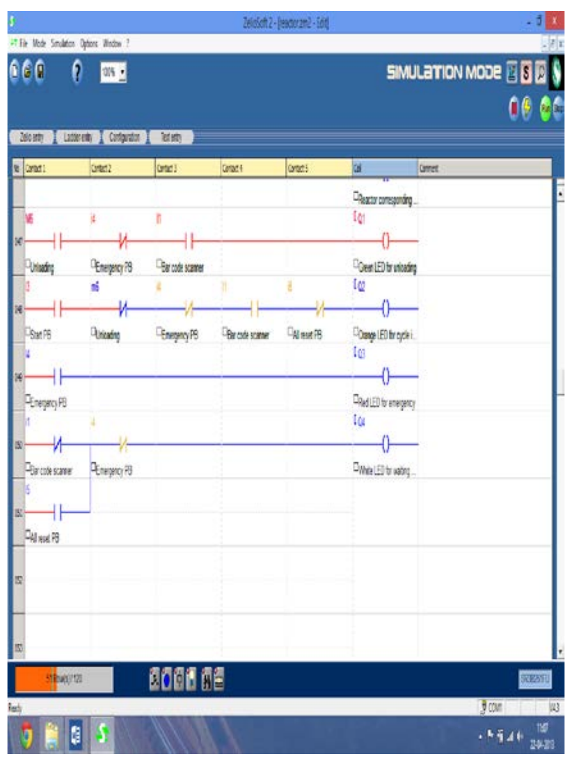

Figure 6.5: The Corresponding Green LED

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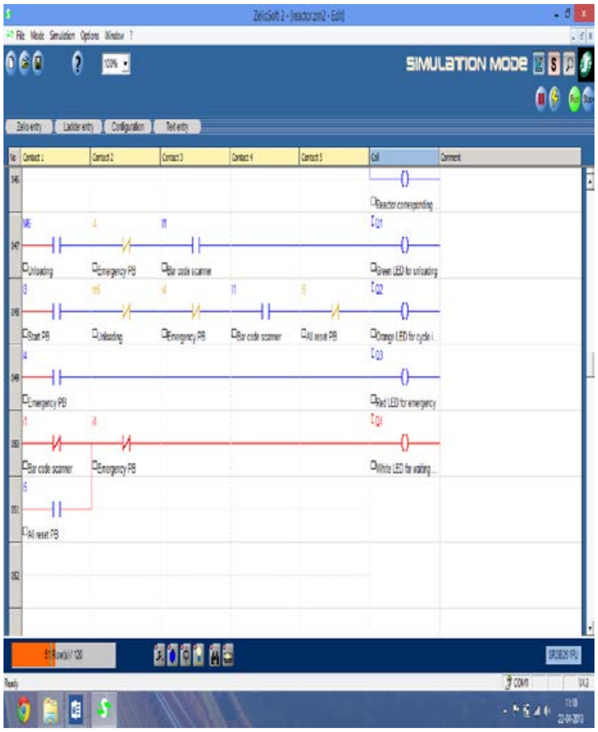

Figure 6.6: When Waiting For Capacitor Elements And Corresponding White LED Glowing

6.2 Vacuuum heat treatment process

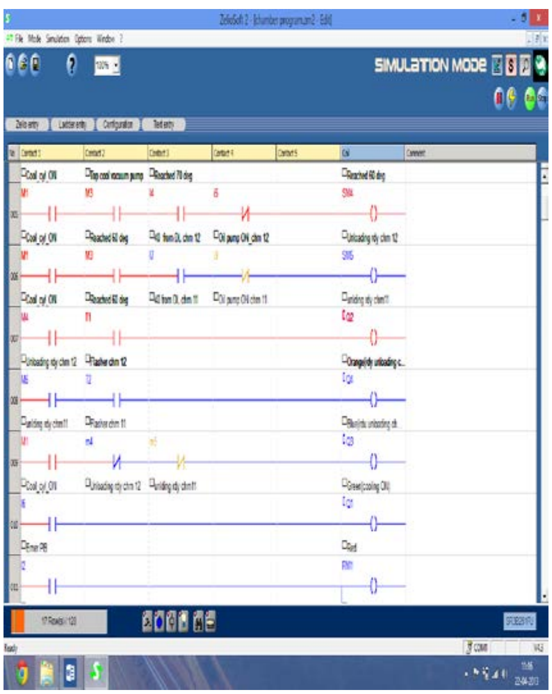

Figure 6.7: When Top Cool Vacuum Pump Is Pressed And Cooling Is On

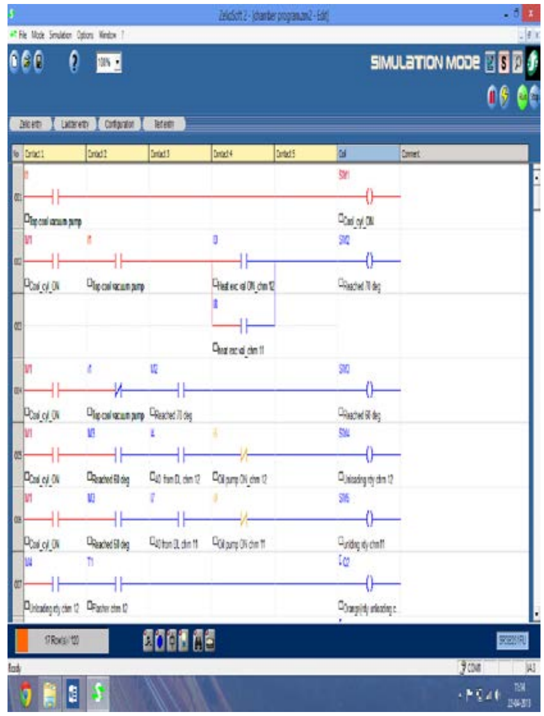

Figure 6.8: When Unloading Ready For Chamber 12 Along With Its Flashing Orange LED

7. CONCLUSION

Reactor addition and element testing is a manual process in existing technology. In the high voltage test, voltage has to be manually set as 2.15 * rated voltage. The reactor value to be added to the capacitor element, is manually been selected by pressing the push buttons corresponding to the reactor value required. Presently, the vacuum heat treatment is also a complete manual process. Temperature is manually read from the data logger which can ring an alarm for any one temperature. Operators have to come and check the readings every few hours.

The proposed technique in reactor addition and element testing becomes an automatic process except for the loading and unloading of the elements. The parameters get selected automatically corresponding to the capacitor element. The database provide those, corresponding to the CAT reference given to each element. The reactor values also been selected in the same way. We proposed a semi-automatic process for vacuum heat treatment. Indication of the unloading of elements is now known at the right time, by which time consumption is reduced and also the production per day increases by a large fold.

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In total, the production increases by a large margin and since the processes are automatic, human requirement is reduced to the maximum extent. Thus, the proposed technique advances more in all the aspects compared to the existing technique.

8. ACKNOWLEDGEMENT

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